CRANFIELD UNIVERSITY

CHIKA EDITH MGBEMENA

REAL-TIME EVALUATION AND FEEDBACK SYSTEM FOR ERGONOMICS ON THE SHOP FLOOR

SCHOOL OF AEROSPACE, TRANSPORT & MANUFACTURING
MANUFACTURING

PhD
Academic Year: 2014 – 2017

Supervisors: Prof Ashutosh Tiwari and Dr Yuchun Xu
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This thesis is submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy

ABSTRACT

Despite the greatly increased automation in manufacturing industries, manual operations still exist, and ergonomic risk factors that arise because of manual operations can lead to Work-Related Musculoskeletal Disorders (WMSDs). To mitigate the risk, manual operations should be assessed to identify if any risk, such as awkward posture, exist. Most assessments are carried out offline but this cannot alert and prevent operators from adopting awkward postures in time. Hence, due to the popularity of flexible manufacturing systems that require immediate response to changes, there is need for a real-time assessment.

Therefore, the aim of this research is to develop a real-time knowledge-based ergonomic assessment system for use in the real-time evaluation of work postures on the shop floor and provision of feedback to workers, using 3D motion sensors. The developed intelligent system utilizes the knowledge from health and safety (H&S) guidelines, set of rules and an inference engine, to automatically capture and assess worker's postures and provide real-time feedback to the worker through an easy-to-understand user interface.

The system has been validated using many case studies which include the posture assessment of: 6 operators assembling engine valve, 4 seated researchers conducting desk-based reading and 15 operators during lifting, assembly and hammering of IKEA table. The system when tested proved to achieve: real-time assessment, easy-to-understand feedback, reliable measurements with Cronbach's alpha of 0.978, p=0.045 and Kendall's coefficient of concordance of 0.634, p = 0.000.

The main contribution of this work lies in providing real-time feedback to workers. This contribution is in three sub-areas namely: i) Development of a real-time Kinect-based tool for H&S-compliant ergonomic assessment. ii) Development of a knowledge-based real-time feedback system for improved posture assessment. iii) Provision of real-time feedback to alert workers in time. The novelty of this research is in the development of a knowledge-based system for real-time ergonomic assessment and feedback to workers using 3D motion sensors.

Keywords:

Microsoft Kinect; Work-Related Musculoskeletal Disorders; Awkward postures; User Interface; Manual Handling.

LIST OF PUBLICATIONS

1. Mgbemena C.E., Tiwari A., Xu Y., Oyekan J., Hutabarat W. (2018) Ergonomic Assessment Tool for Real-Time Risk Assessment of Seated Work Postures. In: Arezes P. (eds) Advances in Safety Management and Human Factors. AHFE 2017. *Advances in Intelligent Systems and Computing*, vol. 604. Springer, Cham.
2. Mgbemena, C. E., Oyekan, J., Hutabarat, W., Fletcher, S., XU, Y., & Tiwari, A. (2017). Optimum Kinect Setup for Real-Time Ergonomic Risk Assessment on the Shop Floor. In J. Charles, Rebecca & Wilkinson (Ed.), *Contemporary Ergonomics and Human Factors 2017* (2017th ed., pp. 265–272). London, UK: Chartered Institute of Ergonomics and Human Factors.
3. Mgbemena, C. E., Oyekan, J., Tiwari, A., Xu, Y., Fletcher, S., Hutabarat, W., & Prabhu, V. (2016). Gesture Detection towards Real-Time Ergonomic Analysis for Intelligent Automation Assistance. In *Advances in Ergonomics of Manufacturing: Managing the Enterprise of the Future* (pp. 217-228). Springer International Publishing.
4. Mgbemena C.E., Tiwari, A, Xu, Y., Oyekan J., Windo H. Design and Implementation of Ergonomic Risk Assessment Feedback System for Improved Work Posture Assessment. *Theoretical Issues in Ergonomics Science* (Accepted for Publication).
5. Mgbemena C.E., Tiwari A., Xu, Y., Prabhu V., Hutabarat, W. Ergonomic Evaluation on the Manufacturing Shop Floor: A Review of Hardware and Software Technologies. *CIRP Journal of Manufacturing Science and Technology* (under review).
6. Mgbemena C.E., Xu, Y., Tiwari, A, Fletcher, S., Oyekan, J., Windo, H. A Real-Time Automatic Health and Safety Assessment of Human Work Postures for Production Operations. *Computers & Industrial Engineering* (Revision Under Review)
7. Mgbemena C.E., Tiwari, A, Xu, Y., Oyekan J., Windo H. Health and Safety Risk Assessment of Manual Handling Operations – A Review of

Guidelines and Requirement of Tools. *International Journal of Occupational Safety and Ergonomics* (Under Review).

EVENT ATTENDED.

1. Mgbemena, C. E. (2017). Real-Time Posture Assessment Tool for Ergonomic Risk Assessment of Shop Floor Activities. Presented at the *Human Factors in Future Manufacturing Event*. By the Chartered Institute of Ergonomics & Human Factors, at Advanced Manufacturing Research Centre (AMRC) “Factory 2050”, Sheffield University.

ACKNOWLEDGEMENTS

I am grateful to Almighty God who gave me the strength and grace to carry out this research. To Him alone be all the glory forever.

I would like to thank all the people who contributed towards the success of the thesis. I am grateful to my supervisor, Professor Ashutosh Tiwari, who accepted me into the manufacturing informatics centre and contributed immensely to my postgraduate experience by supporting my attendance at various conferences, events and workshops both locally and internationally. He engaged me in innovative ideas requiring a high-quality throughput and a cerebral approach to research which afforded me opportunity to learn new things. Thank you Prof.

In addition, I would like to thank Dr Yuchun Xu, my associate supervisor, for his guidance and constructive criticisms in our manuscripts.

Special thanks to my thesis committee members, Dr Qi Zhang and Dr Sarah Fletcher for their interest in my work and guidance which has helped to keep this research on the right track.

I am grateful to Dr John Oyekan and Mr. Windo Hutabarat whose insights I benefitted when faced with intractable difficulties during the PhD programme; and to Mr. David Onuoha who patiently taught me C# programming language as a beginner and was always willing to assist whenever I encounter difficulty.

I am grateful to the Petroleum Trust Development Fund (PTDF) Nigeria who funded my PhD studies in Cranfield University.

Finally, I would like to acknowledge friends and family who supported me during my studies here.

First I would like to thank my husband, Dr Chinedum and my son Zenith for their constant love and support all the way. My parents, Mr. and Mrs. Christian & Faustina Okafor, for their prayers and blessings. My siblings – Obi, ’Anyi, Chike, Uju and Ugoo for all their encouragement. My friends and colleagues, Shanika, Okey, the Aghanyas’, the Duabaris’, the Daniels’, the Obi’s, the Nnonyelus’ and the Obhuos’ made my time here at Cranfield a lot more fun. Thank you all.

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LIST OF EQUATIONS

LIST OF ABBREVIATIONS

WMSDs	Work-Related Musculoskeletal Disorders
3DSSPP	3D Static Strength Prediction Program™
ART	Assessment of Repetitive Tasks
DHM	Digital Human Modelling
H&S	Health and Safety
OWAS	Ovako Working Posture Assessment. System
RULA	Rapid Upper Limb Assessment
REBA	Rapid Entire Body Assessment
WMSDs	Work-Related Musculoskeletal Disorders
FMS	Flexible Manufacturing Systems
HSE	Health and Safety Executive
NIOSH	National Institute for Occupational Safety
BAuA	Federal Institute for Occupational Safety and Health (German: Bundesanstalt für Arbeitsschutz und Arbeitsmedizin, BAuA)
OSHA	Occupation Safety and Health Administration
FPS	Frame Per Second
RGB	Red, Green, Blue
IR	Infrared
SDK	Software Development Kit
CAD	Computer-Aided Design
KBS	Knowledge-based System
WSH	Workplace Safety and Health
FOV	Field of View
API	Application Programming Interface

1 INTRODUCTION

This chapter introduces the thesis document by presenting the following: i) the study background, ii) the research motivation which helps to establish the need for the research iii) the key terms used in the research, iv) the problem statement which helped to establish the need for the research and v) the thesis structure.

1.1 Background of the Study

Ergonomics is a science that focus its study on improved design as a remedial measure to fatigue and discomfort in humans (Openshaw and Taylor, 2006). Its objective is to optimize health, safety and productivity (HSE, 2002).

Despite high level of automation in the western world, many industries still depend on manual handling of some crucial tasks to reach their set target (Nguyen et al., 2013). Manual handling has been described as the transfer, carrying, pushing and pulling of loads by workers (EU-OSHA: E-fact 9, n.d.). Injuries associated with prolonged manual handling activities often affect the upper limbs, lower limbs and spine of the human body and leads to Work-Related Musculoskeletal Disorders (Choy et al., 2011; OSHA 3125, 2000).

During any manual handling operation on the shop floor (Shop Floor Data Capture for Manufacturing), the safety and comfort of the operators should be ensured and such factors like ergonomics, accessibility, reach, etc. should be considered. When ergonomic considerations are not given top priority during the initial design of workplaces, workers are likely to get injured during manufacturing operations. However, if human factor issues are well considered in the design of the shop floors, then such factors like accessibility and reach can be predicted (Caputo et al., 2006). These can help to ensure improved efficiency of any manufacturing process, increased human comfort and safety, increased productivity and reduced cost (Berlin and Kajaks, 2010; Karmakar, Sanjog and Patel, 2014; Mukhopadhyay, Das and Chakraborty, 2012; Rajput, Kalra and Singh, n.d.; Sanjog, 2012; Sanjog, Chowdhury and Karmakar, 2012).

Moreover, many manufacturing shop floors employ operators who are required to undertake manual handling activities such as lifting and carrying, which if not ergonomically executed, can result in risks that may lead to WMSDs and greatly limit worker's life and health (Savino, Mazza and Battini, 2016; Valentin et al., 2015).

WMSDs are injuries which affect the musculoskeletal system such as muscles and tendons (Luttmann et al., 2003). It is caused by ergonomic risk factors such as force, awkward postures, repetitive tasks, manual handling of heavy loads (Chander and Cavatorta, 2017; Tak et al., 2011), and by individual risk factors such as poor work habits (Klussmann et al., 2010; Middlesworth, n.d.; OSHA-ERGONOMICS, n.d.; Soe et al., 2015; WSH (Workplace Safety and Health) Council, 2014). The disorder is the major cause of about 90% of workplace injuries and absenteeism, and affects workers in many industrialised countries (BAuA, 2011; OSHA Technical Manual, n.d.). According to United Kingdom's Health and Safety Executive (HSE), WMSDs accounted for 41% of work-related illnesses in Great Britain between 2015 – 2016 thereby leading to 34% of lost working days (HSE, 2016). From 2009 – 2016, manual handling was rated as the highest cause of WMSDs among the other risk factors, accounting for up to 40% of the work-related upper limb disorders and 53% of the reported work-related low back disorders. This is followed by awkward postures and repetitive tasks (HSE, 2016). Interestingly, the industries with the highest rate of occurrence of this disease are industries where lifting, carrying and other manual handling activities are still in use despite the high level of automation in the country (HSE, 2016). Moreover, in the manufacturing sector of the United States of America where manual handling is prevalent, WMSDs accounted for 32% of the work-related illnesses reported in 2014 (NIOSH, 2016). Hence, operators on the shop floor involved in manual handling activities are at risk of developing the disorder. This is because critical postures that contribute to the development of WMSDs are usually adopted by operators while working (Johnson and Fletcher, 2014) and to minimise the rate of its occurrence, employers should provide adequate assessment tools that can identify and assess risks in workplaces.

WMSDs can be prevented by identifying, assessing and reducing the risks involved in any manual handling operation (Choy et al., 2011; Health and Safety

Executive, 2016), using adequate and effective intervention tools (NIOSH, 2016). To do this, a basic knowledge of the major issues that lead to the disorder is required as this helps to inform the personnel on the best preventive strategies (Anderson and Oakman, 2016). Again, the operator should be trained to have the basic knowledge of the manual handling guidelines such as safe lifting techniques that include bending the knees and keeping the spine straight while lifting (Grandjean and Hünting, 1977).

Moreover, different countries have established H&S regulatory bodies which are tasked with enforcing correct standards, and providing the risk assessment guidelines needed for identification and control of risks associated with manual handling operations in workplaces. These H&S professionals recommend initial risk assessment of workplaces using filters and worksheets, prior to detailed risk assessment (Darby, 2008). They recommend important proactive H&S practices aimed at preventing accidents and injuries in workplaces as against the traditional approach which addresses the problem after the injuries has been done to the worker (OSHA, n.d.)

Finally, since awkward postures are among the identified ergonomic risk factors resulting from manual handling and which can lead to WMSDs (Middlesworth, n.d.; Park, et. al., 2015), a simple, H&S-compliant, readily-available posture assessment tool that can reduce the rate of occurrence of this risk and consequently, the rate of occurrence of WMSDs, is required in workplaces.

1.2 **Research Motivation**

Companies with uncertain demand and high level of product customization are usually highly flexible (Zhao, Li and Huang, 2015) and competition can lead a manufacturing system to become more flexible (Torkul et. al., 2015).

In flexible manufacturing, there are several interacting parts (Suri and Hildebrant, 1984) all of which are involved in solving the production needs of the system, hence the flexibility built-in to take care of the sudden changes that may arise (ElMaraghy, 2005). The various classifications of a Flexible Manufacturing System (FMS) which include the machine flexibility, material handling flexibility, operation flexibility, process flexibility, routing flexibility (Joseph and Sridharan, 2011), product flexibility, volume flexibility, scheduling flexibility, flexibility in the design of bill of material (Torkul et al., 2015) etc., clearly shows that FMS involves every stage in the production planning and control process.

In a static manufacturing system, every task is pre-defined and processing times are known, hence the system's response is predictable on the condition that there is no system disturbance. In this case, fixed off-line production planning and control is possible. However, in FMS, there are many uncertainties and consequently, sudden changes which the system must respond to. Therefore, FMS require an immediate response to changes (Kim and Kim, 1994).

In this research, the motivation is to develop a system that can meet the challenges posed by awkward postures of workers on flexible manufacturing shop floors. Since immediate response is needed, the system should be such that can conduct a real-time automatic ergonomic posture assessment with real-time feedback to workers to help alert operators and prevent them from adopting awkward postures in time.

1.3 Terms of Reference

In this section, some of the terms used throughout the research are introduced and briefly discussed. These terms are the knowledge-based systems and the 3D motion sensors.

1.3.1 Knowledge-Based Systems

A knowledge-based system (KBS) is an intelligent system which utilizes the knowledge of a human expert as captured in the knowledge base, to solve specific problems that require human expertise (Jackson, 2011). Human experts have been described as specialists who identify specific problems and provide solutions to the problems while an intelligent system is a computer program that models the knowledge and inference methods of the human expert to solve specific problems. Hence, KBS uses the knowledge of specific topic from human experts to apply a set of rules using an algorithm, to provide information to users through a user interface. The benefits of a KBS include the provision of expert knowledge, provision of consistent result, increased efficiency and reduced costs. Its disadvantages include non-flexibility due to lack of human intuition as well as knowledge restrictions due to size of data.

1.3.1.1 Components of a KBS

KBS is made up of three parts namely:

- **Knowledge Base**

This consists of the knowledge in form of data which the expert supplies to the system

- **Inference Engine (Algorithms)**

This is a set of algorithms represented by the IF-THEN-construct

- **User Interface**

This component of the KBS enables the user to interact with the knowledge base.

A KBS usually have a set of rules that relates all the data together.

1.3.1.2 Applications of the KBS

- **Instruction**

KBS can be used to instruct, train and correct the performance of users.

- **Diagnosis**

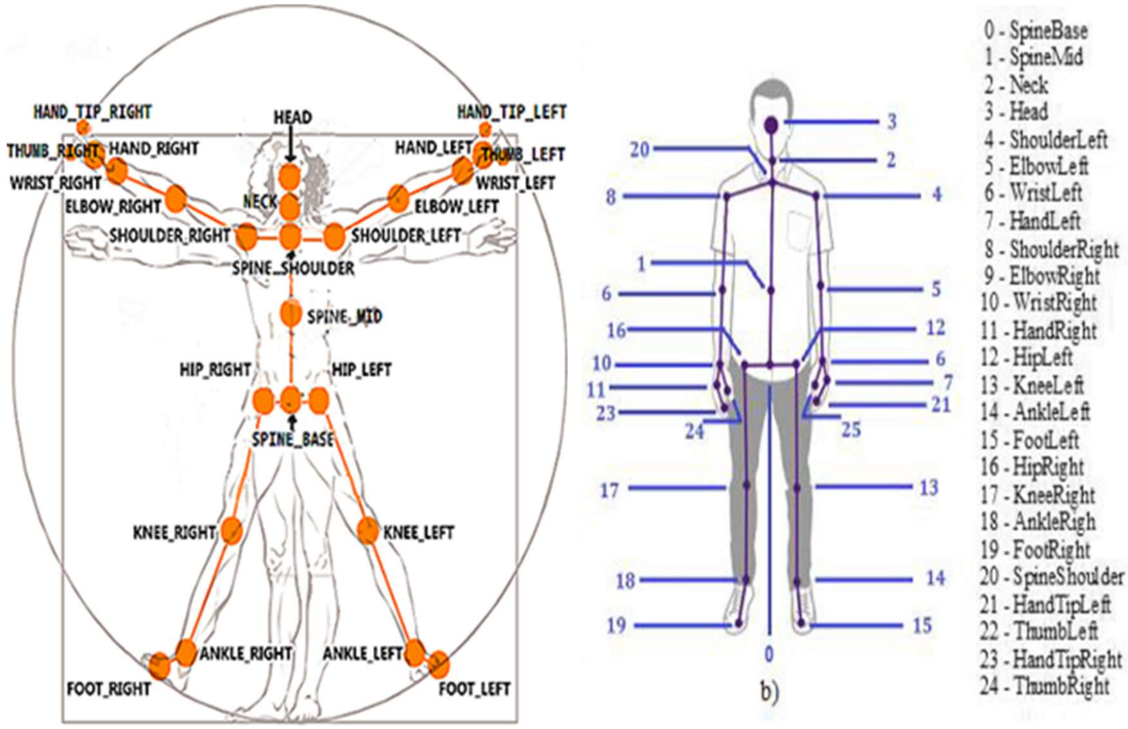
KBS finds wide application in the identification of given problems especially when the symptoms are supplied to the system.

- **Prediction**

KBS can predict future results based on the provided data.

1.3.2 The 3D Motion Sensor

The 3D motion sensor used in this study is the Microsoft Kinect^{TM} v2 sensor (hereafter called the Kinect). The Kinect is a low-cost, gaming, depth sensing device (Gholami et. al., 2016) utilized for human motion capture (Mgbemena et al., 2016). It is a product of Microsoft used in Microsoft windows computers and consists of a natural user interface that enables users to interact with their computers without using markers. The sensor has full HD color camera and an infrared technology at 30 frames per second (fps) and can track 25 skeletal joints of up to 6 people simultaneously at the range of 0.5m (near mode) to 4.5m (far mode) (Cai et. al., 2016; Mgbemena et al., 2016). Figure 1-1 presents the 25 skeletal joints tracked by the Kinect. Figure 1-1a shows the skeletal position relative to the human body (Microsoft, n.d.) while figure 1-1b represents the joint type members of a skeleton and their corresponding values in C# syntax (Manghisi et al., 2016; Microsoft, n.d.).



a) Skeletal position relative to the human body.

b) Joint type members of a skeleton and their corresponding values in C# syntax.

Figure 1-1 Skeletal joints of human as tracked by the Kinect.

Figure 1-2 shows the Kinect sensor and its various components (Lower, 2014a). The microphone array helps the sensor to pinpoint sounds for easier speech recognition while tracking. The power light is an indicator that tells when the sensor has power. The RGB camera is also known as the color camera. The Infrared emitters glows red when the sensor is switched on.

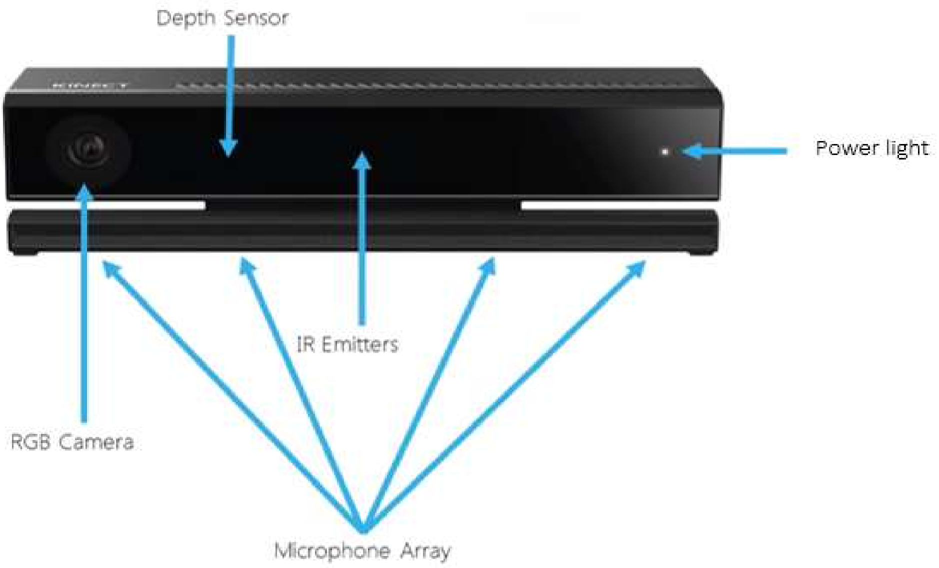


Figure 1-2 **The Kinect sensor and its components.**

The Kinect evolution consists of the Depth, Infrared, Color, Audio and Body as the platform data sources (Lower, 2014a).

- **The Depth Data**

The Kinect depth data generates pixels that produce detailed depth value whenever objects are tracked. These pixels are returned to the developer in millimetres (mm) and indicates the distance of the distance of each pixel from the sensor.

- **The Infrared Data**

This data helps to filter out unwanted lights from the room so that only the light from the infrared is put out by the Kinect.

- **The Color Image**

This produces raw color images at an increased stream resolution of 1920x1080.

- **The Audio View**

The Kinect can track sounds and indicate the direction of every sound in a room.

- **Body View**

The Kinect can track human skeleton and indicate the hand states adopted by the human. These hand states are represented by different colours which include the green, red and blue colours. The green colour indicates open hand state, the red colour shows closed hand state and the blue colour indicates a lasso hand state.

The sensor works with the software development kit (SDK) 2.0 which consists of drivers, APIs, tools, device interfaces and code samples.

1.4 Statement of the Problem and the Need for a Real-time Feedback System

As mentioned in section 1.1, WMSDs results in work-related illnesses and leads to lost working days (HSE, 2016). From 2009 – 2016, manual handling was rated as the highest cause of WMSDs among the other risk factors, accounting for up to 40% of the work-related upper limb disorders and 53% of the reported work-related low back disorders. This is followed by awkward work postures which accounted for up to 25% of the reported low back disorders and 14% of the reported work-related upper limb disorders in Great Britain (HSE, 2016). Moreover, awkward work postures, has been identified as an ergonomic risk factor resulting from manual handling (Valero et. al., 2016). Hence, to mitigate the risk posed by the adoption of awkward postures by operators during manual handling operations, adequate risk assessment has been recommended by H&S professionals to identify and assess awkward postures. However, such assessment is normally carried out by observing several operations and carrying out analysis afterwards. Although some improvements can be identified for the operations, this cannot alert operators and prevent them from adopting awkward postures in time. An intelligent system that not only observe the worker’s tasks, but also utilizes the knowledge base, the set of rules and the inference engine of a KBS supplied by a human expert, to automatically capture the worker’s joint data, process and convert this data into posture data, assess the posture and provide real-time feedback through an easy-to-understand user interface, is of great importance in a flexible system in which immediate response to changes are always required. Again, the human expert can supply the necessary knowledge from the health and safety recommendations on manual handling and these can form the knowledge base of the KBS.

Therefore, a real-time automatic H&S posture assessment feedback system which assesses worker's postures and prompts them to adjust any awkward posture that has been held over a period, is required.

1.5 Thesis Structure

This section summarises the chapters of the thesis aimed at helping the reader understand the thesis better.

Chapter 1 introduces the entire thesis. It starts with the description of the study background, followed by highlights on the need to reduce WMSDs in manufacturing systems that require immediate response to changes, which motivated this research work. After that, the terms used in the entire research which include the knowledge-based systems and 3D motion sensors, are introduced and briefly discussed. Then the problem statement is presented.

Chapter 2 presents the review of related literature on the ergonomic evaluation and posture assessment tools and methods available, with the establishment of the gaps in research.

Chapter 3 presents the research hypothesis, research aim, objectives and methodology employed in the research. The research methodology describes the stages and tasks required to accomplish the set objectives.

Chapter 4 presents details of the 3D motion sensor's development towards joint data tracking, detection of manual handling tasks and the determination of its optimum placement position for better data collection towards real-time ergonomic assessment.

Chapter 5 provides detailed health and safety studies and recommendations on manual handling. The chapter also describes the development of the knowledge base and inference engine of the proposed system as well as the further development of the 3D motion sensor initially developed in chapter 4, towards real-time data capture and automatic posture assessment in compliance with the health and safety guidelines.

Chapter 6 describes the detailed design, development and demonstration of a human-machine feedback interface for real-time motion data capture, work posture assessment and real-time feedback to workers. The chapter describes how the tool developed in chapter 5 is further developed into a simple, easy-to-understand feedback system.

Chapter 7 outlines and describes the various case studies used to validate the developed real-time health and safety-compliant posture assessment feedback system developed in chapters 5 and 6.

Chapter 8 discusses the research findings, contributions to knowledge, and the limitations of the study. The chapter also presents the conclusion of the work and the recommendations for future work.

The thesis structure is summarised in figure 1-3.

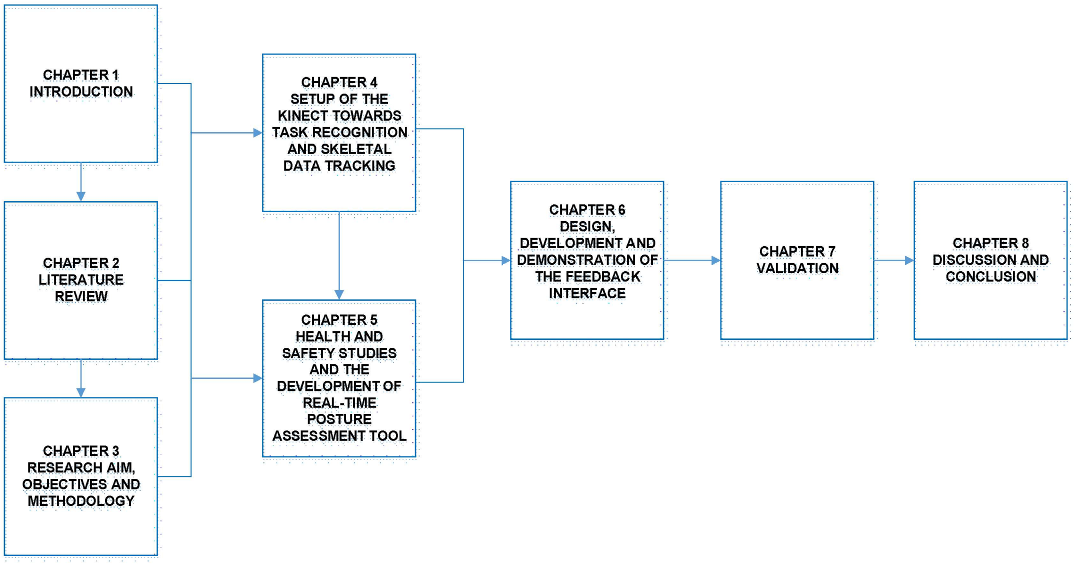


Figure 1-3 Thesis structure

1.6 **Chapter Summary**

This chapter introduces the thesis by providing the research overview, highlighting the research motivation which calls for systems that can meet the challenges posed by awkward postures in a flexible manufacturing shop floor where sudden system changes require immediate responses. The chapter explained the terms that will be used throughout the entire thesis and highlighted the need for an automatic intelligent feedback system that can automatically assess work postures and provide feedback to workers in real-time through an interface. The next chapter will review the various literatures and methods that exist for assessment of awkward postures to identify if better tools are available in literature.

2 LITERATURE REVIEW

The aim of this chapter is to review existing research conducted on the ergonomic risk assessment of manual handling operations on shop floors, with focus on the assessment tools developed for assessment of awkward work postures, which is a risk factor that can lead to WMSDs. The chapter reviews existing ergonomic assessment tools and evaluation methods. The gaps in the research are also highlighted and discussed in this chapter.

Figure 2-1 summarizes the approach adopted in the review, which is the thematic approach. The major research focus areas/themes reviewed in this chapter are categorized into three parts with literatures related to these parts studied and gaps highlighted.

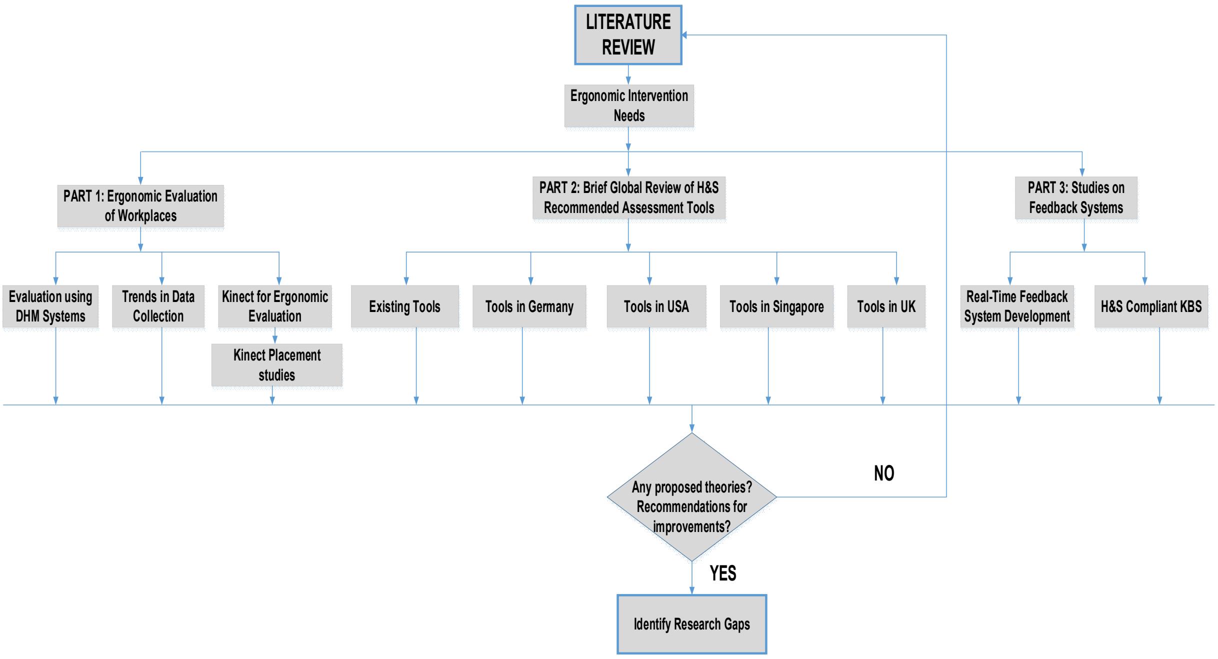


Figure 2-1 Literature Review Approach

2.1 Background

Ergonomic problems usually affect the efficiency and productivity of industries (Bossomaier et. al., 2010). Hence, ergonomics should not only be associated with the health and safety of workers but should also be integrated in organisation's planning strategies as timely ergonomic interventions. This does not only lead to worker's satisfaction but also leads to organisational economic and financial gains (Duarte-Dos Santos, Pereira-Moro and Ensslin, 2015). It is very important to understand the risks associated with manual handling and take appropriate measures to assess and ultimately reduce these risks, so that the likelihood of suffering from WMSDs such as back pain are reduced, hence the need for ergonomic Intervention and correct risk assessment using appropriate tools (Hermawati, Lawson and Sutarto, 2014; Hernan and Paola, 2013; Westgaard and Winkel, 2011; Wijk and Mathiassen, 2011).

WMSDs, which are caused by ergonomic risk factors are the most common cause of occupational ill health in workplaces resulting in 90% of workplace injuries and absenteeism in various countries (BAuA, 2011; OSHA Technical Manual, n.d.). HSE is concerned that as at 2016, there has been no improvement in the prevalence of this disorder as well as in the number of working days lost in Great Britain because of the disorder (HSE, 2016). WMSD is responsible for most of the reported work-related diseases in the world (De Magistris et al., 2013) and accounts for up to one-third of work injuries and worker's compensation costs with economic and social consequences (Chiasson, et. al., 2012; Delpresto et al., 2013). The disorder affects the muscles, joints, nerves, tendons and other parts of the musculoskeletal system (Delpresto et al., 2013; Douphrate et al., 2013; Erdinç and Yeow, 2011; Grosse et al., 2014; Halim et al., 2011; Ugbebor and Adaramola, 2012; Wijk and Mathiassen, 2011) especially the upper part of the body which include the upper limbs and the spine (De Magistris et al., 2013).

It is caused by ergonomic risk factors which include high task repetition (Berlin and Kajaks, 2010; Chiasson et al., 2012; Grosse et al., 2014; Ugbebor and Adaramola, 2012), awkward postures (Chiasson et al., 2012; Erdinç and Yeow, 2011; Ugbebor and Adaramola, 2012), forceful exertion (Chiasson et al., 2012),, vibration (Chiasson et al., 2012) and manual handling of heavy loads (Klussmann et al., 2010; OSHA-ERGONOMICS, n.d.; Soe et al., 2015; WSH (Workplace Safety and Health) Council, 2014). Activities that can result in these risks factors include prolonged standing on shop floor (Antle, Vézina and Côté, 2015; Halim et al., 2011; Messing, Tissot and Stock, 2008; Reid et al., 2010), prolonged sitting and improper sitting postures (Paliyawan, Nukoolkit and Mongkolnam, 2014;

Ugbebor and Adaramola, 2012), excessive bending, continued elbow or shoulder elevation, restrictive workstation, prolonged duration of activity (Choy et al., 2011; OSHA 3125, 2000), poor workstation design (Yeow and Nath Sen, 2003), and picking activities which involves a lot of repetitive tasks (Grosse et al., 2014). Furthermore, muscle reaction to dynamic load (Berlin and Kajaks, 2010), ill-structured jobs, poor human-machine system design among other factors, can also lead to WMSDs (Shikdar and Sawaqed, 2003).

Ergonomic intervention is the best preventive strategy to WMSDs as it helps to identify as well as reduce the risk of exposure of the workers to the disorders (Chiasson et al., 2012; Choy et al., 2011). Systematic and comprehensive ergonomic interventions on shop floors using appropriate assessment tools will not only reduce the risk of WMSDs but will also improve productivity, improve quality, reduce rejection costs as well as increase revenue (Duarte-Dos Santos, Pereira-Moro and Ensslin, 2015; Shikdar and Sawaqed, 2003, 2004; Yeow and Nath Sen, 2003).

Studies on existing ergonomic intervention tools are presented in parts 1 – 3 of this chapter.

2.2 **PART 1: ERGONOMIC EVALUATION OF WORKPLACES**

2.2.1 **Ergonomic Evaluation using DHM Systems**

Poor ergonomic evaluation of workplaces has been found to limit human worker's life and health (Savino, Mazza and Battini, 2016; Valentin et al., 2015) and the Digital Human modelling (DHM) is one technology that can be employed for ergonomic evaluation on the shop floor (Sekulova et al., 2015). The history of the development of DHM dates to the early 1960's with the emergence of the Computer Aided Design (CAD). The CAD development made the aerospace and automobile manufacturers see the need to convert their design processes into a virtual environment which led to the development of the first human ergonomic modelling tool known as the BOEMAN mannequin, followed by the computerized biomechanical man model called the COMBIMAN (Blanchonette, 2010; Bossomaier et al., 2010; Singh, Samuel and Solanki, 2014). Since then, DHMs has been developed for workplace ergonomic evaluations and finds wide application in the evaluation of workplaces during initial design and in the improvement of existing or proposed shop floors (Blanchonette, 2010; Rajput, et. al., 2013; Sanjog, 2012; Sekulova et al., 2015). It is applied in the evaluation of postures and in product design (Ha, Cao and Khasawneh, 2014; Qin, Panayiotou and Zhang, 2011; Sanjog, Chowdhury and Karmakar, 2012). Industries where DHM's are applied are depicted in figure 2-2 (Karmakar, Sanjog and Patel, 2014).

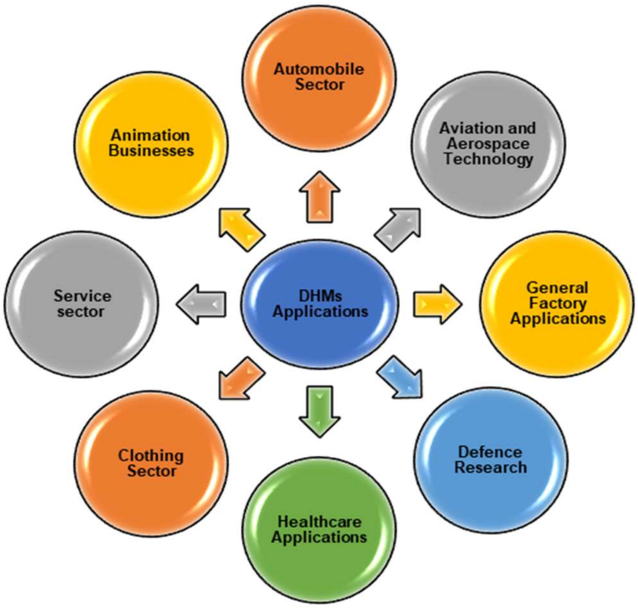


Figure 2-2 Industries where DHMs are applied.

There are several tools on which DHMs can be created. These include the SAFEWORKPRO, DELMIA Human, Jack, CATIA, RAMSIS, SAMMIE, ERGOSHAPE (Berlin and Kajaks, 2010; Blanchonette, 2010; Bossomaier et al., 2010; Deros et al., 2015; De Magistris et al., 2013; Mukhopadhyay, Das and Chakraborty, 2012; Singh, Samuel and Solanki, 2014). These tools are human simulation tools suitable for ergonomic assessment of manual handling operations at the design stage (SIEMENS, n.d.). The advantages of such tools for ergonomic evaluation of workplaces include lower occupational hazards, improved quality of products, increased productivity and greater efficiency (Berlin and Kajaks, 2010; Kaljun and Dolšak, 2012; Karmakar and Patel, 2014; Loczi, 2000; Mukhopadhyay, Das and Chakraborty, 2012). However, these ergonomic assessment technologies has been found to be time-consuming, require sufficient training before use (Daphalapurkar, 2012) and mostly suitable for use during the design stage. The identified limitations can be resolved by using low-cost, easy-to-use systems that are suitable for ergonomic assessment applications during both design and implementation stages.

2.2.2 Developmental Trends in Data Collection for Ergonomic Evaluations

Data collection methods for ergonomic risk assessment are divided into three categories namely: i) the judgement method, ii) the observation method and iii) the direct measurement methods (Chiasson et al., 2012; David, 2005; Manghisi et al., 2016).

The judgement method of data collection involves a subjective evaluation using self-reports such as interviews, surveys, checklists, and questionnaires (Bartnicka, 2015; Erdinç and Yeow, 2011; Manghisi et al., 2016; Plantard et al., 2015; Ugbebor and Adaramola, 2012). These has been successfully implemented on different shop floors to collect data for ergonomic assessment including the oil and gas facility where interviews have been used for critical task determination and questionnaires used to determine the rate of occurrence of risks factors, for onward analysis using the REBA and MAC tools (Hernan and Paola, 2013). In agriculture and healthcare, interviews and questionnaires has been implemented to collect data for posture assessment of operators involved in gardening and landscaping activities (Miskalo et al., 2017) as well as among caregivers (Moreira et al., 2012). The limitation of the method is that it depends on the subjective evaluation of the user and therefore not accurate (Manghisi et al., 2016)

The observational methods which are commonly used in industries involves the use of video-based capture systems and photographs to capture data for offline ergonomic assessment with such tools as the Rapid Upper Limb Assessment (RULA) (Bartnicka, 2015; Bossomaier et al., 2010; Deros et al., 2015; Erdinç and Yeow, 2011; Plantard et al., 2015; Ugbebor and Adaramola, 2012).

The method has been successfully implemented during variety of tasks on various shop floors. Photography was used to collect data from operators during a lifting and lowering task on auto parts shop floor for ergonomic evaluation using the Revised NIOSH Lifting Equation (Okimoto and Teixeira, 2009) and in the oil and gas facility, for data collection towards ergonomic analysis with REBA and MAC tools (Hernan and Paola, 2013). Even among maintenance operators, photography has been successfully implemented to collect data for ergonomic analysis (Mukhopadhyay, Jhodkar and Kumar, 2015). For upper limb posture assessment of farmer's awkward posture, video camera has been successfully implemented for data capture towards ergonomic assessment using RULA (Deros et al., 2015) and in the measurement of maintenance time of operators on railway maintenance shop floor towards ergonomic assessment using OWAS (Singh, Kumar and Kumar, 2015). In healthcare, video cameras has been successfully implemented among care home workers for data collection towards awkward posture assessment using the OWAS (Moreira et al., 2012). Observation method is often chosen by the practitioners because of its cost-effectiveness, flexibility and ease of use (Chiasson et al., 2012). However, both the observation and judgement methods which are easy to use, are not reliable (Plantard et al., 2015) and wastes time (Manghisi et al., 2016; Peppoloni et al., 2015). Again, the methods cannot capture the 3D joint information of operators which is required for more accurate posture assessment.

The direct measurement methods of data collection use such tools as 3D motion capture systems such as the Eagle Digital System (EDS) (Ma et al., 2011; Qin, Panayiotou and Zhang, 2011), and sensors attached to an operator's body, to capture data for ergonomic evaluations. Such sensors include goniometers, inclinometers, optical sensors, accelerometers and the gyroscope sensors. The goniometers are sensors designed for the measurement of Limb angular movement. They are attached across joints and connected to the biometric instruments which records data on human activity and also provide high accuracy for epidemiologic studies (Dai and Ning, 2013; Plantard et al., 2015). The inclinometers are high precision sensors which measures horizontal and vertical angular inclination at high resolutions (Dai and Ning, 2013). Optical sensors are used to detect motion as well as light. Accelerometers are electromechanical devices used to measure changes in velocity over time. They are used in fall and shock detection (Plantard et al., 2015). The Gyroscope sensor senses and measures the angular rate of an object under complex and severe operating conditions (Plantard et al., 2015).

The direct method has been found to be more reliable and more accurate than the observation and judgement methods (Chiasson et al., 2012). However, it is expensive and intrusive as the marker-based sensors worn directly on the operator's body during task-based activities on the shop floor can cause body discomfort to the operator (Manghisi et al., 2016). An example is the wireless wearable system developed by Peppoloni et al. (2015) to capture the upper limb motion data for onward assessment using Rapid Upper Limb Assessment (RULA).

The three methods and their examples are summarised in figure 2-4

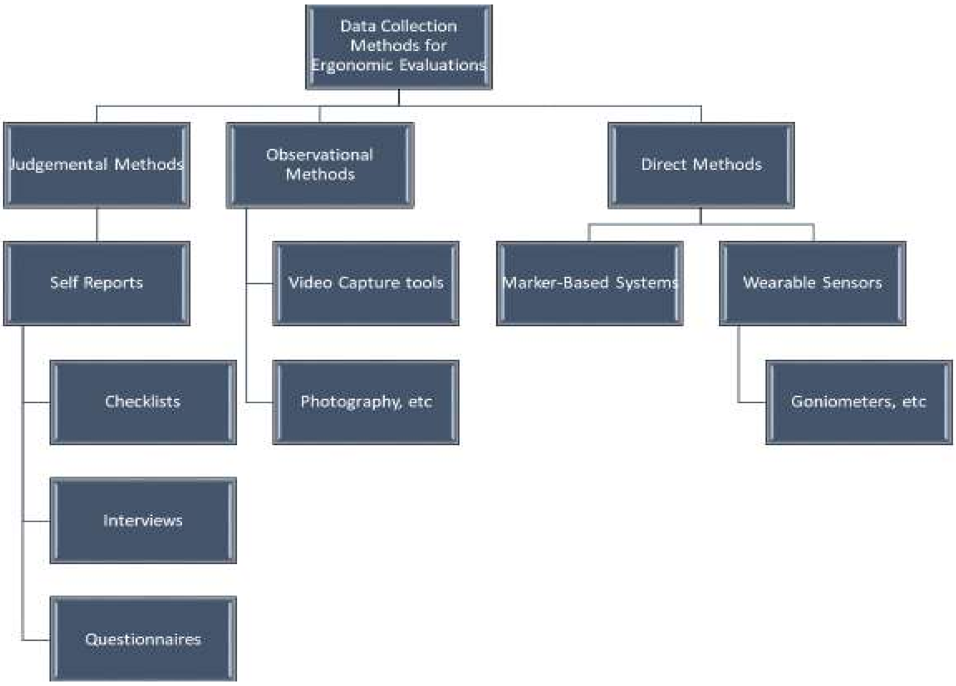


Figure 2-3 Three categories of data collection methods for ergonomic evaluations

To overcome the limitations posed by using marker-based sensors for data collection towards ergonomic evaluations, markerless sensors which provide an easy-to-use, non-intrusive and cheap alternative, can be used. An example is the Microsoft Kinect which can capture and analyse complex and dynamic human 3D motions in real workplaces (Thati and Mareedu, 2017). Researchers describe it as an imaging sensor capable of capturing the RGB and depth data of each image pixel and can also track objects, human body joints, human-object interaction, and operator's postures classifying the motion as either ergonomic or non-ergonomic (Dai and Ning, 2013; Diego-Mas and Alcaide-Marzal, 2014; Dutta, 2012; Plantard et al., 2015; Prabhu et al., 2014a, 2014b; Xu and McGorry, 2015). The sensor has been compared with the use observation methods for data collection towards ergonomic work posture assessment and graded as a better option due to its ease of use, reduced data processing, non-invasiveness and cost-effectiveness (Diego-Mas and Alcaide-Marzal, 2014). Hence, Plantard et al. (2015) has concluded that Kinect is a useful tool for motion capture towards ergonomic risk assessment involving operator's work postures (Clark et al., 2012). It has proved to be an effective tool for capturing the joint data of operators towards offline joint angle computation and ergonomic posture assessment with such tools as the RULA (Jiang et al., 2017).

2.2.3 **Microsoft Kinect for use in Ergonomic Assessment.**

Kinect has been proved to produce accurate kinematic information needed for ergonomic assessment and can generate joint angles that can be used as input data for RULA tool during ergonomic assessment (Plantard et al., 2015). It has been found to accurately measure human joint angles (Clark et al., 2012; Diego-Mas and Alcaide-Marzal, 2014; Fernández-Baena, et. al., 2012), when the joint angle computation output of the Kinect with another optical motion capture system were compared. The result showed the Kinect can be a very useful hardware for joint angle computation for purposes of posture evaluations and analysis (Diego-Mas and Alcaide-Marzal, 2014; Fernández-Baena, et. al., 2012) as well as in the assessment of 3D anatomical landmark positions (Clark et al., 2012).

The sensor has been implemented in real-time ergonomic assessment involving different manual handling tasks which include lifting tasks in which a system is developed using a static ergonomic model integrated with Kinect to measure the recommended weight limit (RWL) and strain on the operator’s body (Martin et al., 2012). Skeletal data from Kinect can be scaled into Jack human simulation system for real-time assessment of operators performing fastening operation on the shop floor for onward ergonomic evaluation using the RULA in Jack (Daphalapurkar, 2012). This involves the use of DHM in Jack for assessment. The sensor has been used to assess the posture variation of seated operators to detect any deviation from the neutral position for sitting which involves upright sitting with the head and neck vertically in line with the torso and the body facing forward (Paliyawan, Nukoolkit and Mongkolnam, 2014; Uribe-Quevedo, Perez-Gutierrez and Guerrero-Rincon, 2013). During a lifting operation, Delpresto et al. (2013) used the Kinect to monitor human operators by tracking in real-time, the body joint angles during the operation with the aim of recommending correct and safe lifting techniques.

Later on, Manghisi et al. (2016) developed a semi-automatic tool that utilizes Kinect for posture analysis based on the RULA tool. The developed tool can be used for both real-time and offline detection of awkward postures and is found to yield moderately accurate posture data.

The orientation of the person being tracked by the Kinect often affects the quality of data generated (Daphalapurkar, 2012). Hence, for a better posture measurement and assessment using Kinect, the user should face the sensor (Diego-Mas and Alcaide-Marzal, 2014). Originally, the Kinect, despite its advantages of portability, low cost, and convenience (marker less), also had its disadvantages of lower precision (Clark et al., 2012; Rosário, 2014), and its inability to assess the internal/external joint rotations of the peripheral limbs (Clark et al., 2012; Diego-Mas & Alcaide-Marzal, 2014), when compared with other 3D marker-based camera systems but these draw backs have been taken care of by the latest Kinect v2 which can measure joint rotations with more precision (Diego-Mas and Alcaide-Marzal, 2014). Again, its accuracy for use in awkward posture classification has been improved by Ho et al. (2016) through a framework that deals with any noisy posture data

The major problems identified with the use of Kinect for ergonomic assessment are the sensor placement issue and occlusion problems (Plantard, H. Shum and Multon, 2017), which can lead to inaccurate assessment results.

An extensive literature review has been completed on Kinect placement for more improved data capture as the accuracy of the data captured with the Kinect can be a function of its placement (Plantard, et. al., 2017). Inaccurate placement of the Kinect on the shop floor during data collection for ergonomic evaluation can lead to erroneous measurements. Accurate placement of the sensor helps to ensure decreased measurement errors (Banerjee et al., 2015). Khoshelham and Elberink (2012) recommends that the Kinect v1 (first version of Kinect), should be placed within 1m to 3m distance from the object as the quality of data is negatively affected by noise and low resolution of the depth measurement. This is because the random error of the depth measurement increases as the depth resolution decreases, when the distance of the object from the Kinect is increased up to 5m (Khoshelham and Elberink, 2012). Similarly, when Dutta (2012) placed the Kinect v1 at 1m to 3m distance from the operators at 54° and 39.1° horizontal and vertical field of views respectively, accurate data was captured for ergonomic evaluations. To establish if the distance between the Kinect and the operators on the shop floor affect the quality of data captured, Bonnechere et al. (2014) tested the sensor at different locations of 1.5m, 2.0m and 2.5m distances from the workers. The result showed an optimal Kinect v1 placement at 2.5m with better output. For skeletal data capture of seated workers using the Kinect v1, the sensor should be slanted to about 20° to 40° (Wiedemann, Planinc and Kampel, 2014).

Most researchers employ the trial and error methods to determine the Kinect placement locations during data collection. Again, existing studies that determined the placement locations for better depth measurement were conducted using the Kinect v1 sensor. There is therefore need for a study on the optimum placement of the Kinect v2 to determine the better placement location that can yield improved data for ergonomic analysis.

2.3 **PART 2: A Global Review of Health and Safety Recommended Assessment Tools**

While real-time evaluation and feedback system for ergonomics on the shop floor have been implemented using different schemes in many countries, its developmental trajectory has always pointed towards integrating the ergonomic risk assessments with relevant H & S guidelines across the globe. Punnett and Keyserling (1987) recommended the development of an information base which can help to ensure effective ergonomic intervention using standards on exposure limits and safe work practices. Presently, different countries have established H&S rules and guidelines that is targeted at providing safe work practices and helping employers to identify, assess and reduce the risk factors in workplaces. Researchers have even discovered that effective ergonomic assessment can be conducted by tracking and analysing the joint angles of operators on the shop floor in accordance with some approved standards such as the Occupational Repetitive Actions, OCRA index, the NF EN ISO 1005-1 to 5 Standard, etc. (Chiasson et al., 2012; De Magistris et al., 2013).

Risk management regulations requires every workplace to conduct risk assessments to address any possible risks and hazards that may lead to WMSDs. Different tools have been recommended, developed and adopted by health and safety professionals and some of these tools are presented in the proceeding sub-sections. To study and identify these tools, systematic search was conducted to identify the government approved H&S regulators of some selected countries. The review was limited to only four countries and on documents published only in English Language. The four countries were randomly chosen from different continents (North America, Europe, and Asia), with the United Kingdom included as the host country. These countries were selected as case studies because of their strong health and safety policies, to represent what is obtainable in other countries of the world and include the United States of America USA, Singapore, Germany and the United Kingdom UK. Only one government-approved H&S regulator is chosen for each country.

Again, the study was narrowed down to only one ergonomic risk factor which is the “Awkward Posture” because prolonged awkward work postures has been diagnosed as a major factor that leads to severe WMSDs among workers on the shop floor.

2.3.1 Overview of existing Ergonomic Risk Assessment Tools

As mentioned in section 2.1, ergonomic Intervention and correct risk assessment using appropriate tools is a good preventive strategy for Work-Related Musculoskeletal Disorders. Basic risk assessment is usually conducted using questionnaires, risk assessment filters, checklists and video analysis (De Magistris et al., 2013). Other tools include: the RULA (McAtamney and Nigel Corlett, 1993), Job Risk Classification Model (Mukhopadhyay et al., 2012), the Ovako Working posture Assessment System (OWAS) (Bartnicka, 2015), PATH (Posture, Activities, Tools, and Handling) (Sengupta Dasgupta et al., 2014), the Rapid Entire Body Assessment (REBA) (Chiasson et al., 2012; Löfqvist et al., 2015; Mork and Choi, 2015; Shah et al., 2016), the NIOSH Equation for lifting (Arjmand et al., 2015; Potvin, 2014; Waters, Baron and Kemmlert, 1998), the Manual handling assessment chart (MAC) tool (Hernan and Paola, 2013; Pinder, 2002) etc. These tools can assess the risks posed by manual handling on shop floors.

RULA is an ergonomic assessment tool used for detecting workplace injuries (McAtamney and Nigel Corlett, 1993) and for analysing the risks associated with Work-Related Upper Limb Disorders (Deros et al., 2015; Godilano et al., 2015). It finds wide application during the ergonomic assessment of worker’s postures on manufacturing shop floors (Shah, et. al., 2016) and in hospitals while lifting patients (Bartnicka, 2015; Ha et al, 2014). In agriculture, studies concerning oil palm harvests showed that of the six working postures analysed, all required immediate ergonomic intervention recommended (Deros et al., 2015). During bicycle repairing and fastening operations on the shop floor, RULA has been used to assess the risk of developing WMSDs (Daphalapurkar, 2012; Mukhopadhyay, Jhodkar and Kumar, 2015), etc. The advantages of the tool cannot be over-emphasised. It does not require special equipment for ergonomic risk assessment and considers biomechanical and postural load requirements of job tasks (Peppoloni et al., 2015). It is inexpensive, easy to use and hence do not require an ergonomist expert. It gives quick assessment of the postural loads on the neck, trunk, and upper limbs (Kee and Karwowski, 2007). The tool only focuses on the neck, trunk and upper limbs of humans but is very efficient when the risk assessment involves only the upper extremities of the body (Deros et al., 2015).

OWAS is an ergonomic risk assessment tool capable of estimating the postural load of an operator on a shop floor (Diego-Mas and Alcaide-Marzal, 2014). It rates work postures and classifies these postures according to the degree of their impact on the muscles of workers (Kee and Karwowski, 2007). The tool has been successfully implemented in the assessment of work postures such as seen when the tool assessed the work postures of operators as they changed brake shoes of freight wagons in a railway maintenance shop floor (Singh, Kumar and Kumar, 2015) and on bicycle maintenance shop floor (Mukhopadhyay, Jhodkar and Kumar, 2015). Results revealed high level of postural problems and consequently, great exposure to WMSDs among the operators and the bicycle repair workers, hence the need for immediate ergonomic intervention on the maintenance workplaces.

The REBA is a risk assessment tool which utilizes systematic approach to assess the risk of whole body exposure to WMSDs as well as risks associated with job tasks. It evaluates task-related factors such as whole body working postures, force, couplings, repetition, etc. and is inexpensive, easy to use and hence do not require an ergonomist expert. REBA has been employed for ergonomic posture assessment of numerous manufacturing shop floor operators. Recently, when workers in a garment manufacturing shop floor were assessed with this tool, the scores obtained suggested the need for immediate ergonomic intervention in the workplace (Shah et al., 2016).

There is no best ergonomic risk assessment tool rather every practitioner is expected to understand the variables that lead to risks in the workplace so as to choose appropriate tool to assess the risks (Chiasson et al., 2012).

Furthermore, awkward work postures resulting from manual handling, has been found to lead to WMSDs among workers (Phairah et al., 2016; Raffler et al., 2016; Valero et al., 2016), and researchers have recommended posture measurements and assessment as a remedial measure to minimise this threat (Dutta, 2012). Effective posture assessment is important in ensuring postural comfort (Naddeo et. al., 2015) and the methods for assessing this risk depends on the accuracy and precision of the data collection techniques employed (Diego-Mas and Alcaide-Marzal, 2014).

Generally, there are two methods by which human work postures are analysed on the shop floor – the observational technique and the instrument-based technique. The observational technique uses visual perception to evaluate the rate at which the body moves away from the neutral position. These include the OWAS, RULA, the Quick Exposure Check (QEC), and the REBA. (Diego-Mas and Alcaide-Marzal, 2014; McAtamney and Nigel Corlett, 1993; Mukhopadhyay, Jhodkar and Kumar, 2015; Park et al., 2015; Pinder, 2002; Sanjog et al., 2015). These tools, especially REBA, has been described as a suitable tool for posture assessment (Al Madani and Dababneh, 2016).

The instrument-based technique record work postures using instruments (Kee and Karwowski, 2007). These tools often require offline posture assessment using such tools as the force plate, photograph, video, goniometry, inclinometers and 3D analysis using markers (Åkesson, Balogh and Hansson, 2012; Clark et al., 2012; Diego-Mas and Alcaide-Marzal, 2014; Rosário, 2014), as well as active and passive video-based systems such as the NDI and the Vicon Motion capture systems which can pose great problems for use because they are complex and bulky. Photographs and videos often produce inaccurate measurement of joint angles as a result of distortions caused by camera placement issues (Diego-Mas and Alcaide-Marzal, 2014). Some of the existing 3D systems are either very expensive, require careful setup or need to be worn on the body of the worker which causes body discomfort. An example is the wearable Inertial measurement units which measures and analyse work postures in real-time with real-time feedback to the workers (Sessa et al., 2015; Yan et. al., 2017).

A 3D marker-based measurement system was used by Yang and Cho (2012) to measure the relative angles of the human body during a comparison of male and female posture control pattern among computer operators. It was found to yield accurate values of the head/neck flexion angles, shoulder and elbow flexion angles as well as the wrist deviation angles and can help in data collection and analysis (Clark et al., 2012). There was successful implementation of Inclinometers based on triaxial accelerometers to measure the flexion, extension and lateral extension angles of the human joints by Åkesson et. al. (2012).

A photogrammetric analysis method was used by (Naddeo, Cappetti and D'Oria, 2015) to measure joint angles of the Neck, shoulders, elbow and wrists for comfort evaluation of upper extremities of the human body.

Microsoft Kinect has been recommended as an alternative method for posture assessment because of its low cost and 3D motion capture capabilities (Diego-Mas & Alcaide-Marzal, 2014; Dutta, 2012; Rosário, 2014; Ho et al., 2016).

2.3.2 **Tools in the United Kingdom (HSE)**

The UK HSE has categorised its manual handling risk assessment tools into three phases which include assessment with risk filters, assessment with the Manual Handling Assessment Chart (MAC) tool, the Risk Assessment for Pushing and Pulling (RAPP) tool tools and the detailed assessment tools (Health and Safety Executive, 2016). HSE provides risk assessment filters for preliminary ergonomic assessment of workplaces. These are ergonomic assessment tools designed by the HSE to assess the risk of developing WMSDs in workplaces. The filters are used to identify possible risk factors to ascertain if detailed assessment is required. Details of these tools and how to use them are presented in literature (Graves et al., 2004; Health and Safety Executive, 2016).

However, after using the filters to identify risks, HSE recommends the use of the MAC and RAPP, the Assessment of the Repetitive Tasks of the Upper Limb (ART) tool, and the Variable MAC tool to assess the risks further. The MAC tool is a risk assessment tool developed by the HSE for initial screening of workplaces with the view to identify high-risk manual-handling activities (Hernan and Paola, 2013). it uses numerical and colour-coding scoring system to highlight the risks posed by lifting, carrying and team manual handling activities (HSE, 2014). It can be used on varieties of shop floors such as the construction industry, the manufacturing and retailing industries (Burciaga-Ortega and Santos-Reyes, 2010), etc. Its benefits includes improved workplace design, improved manual handling techniques, promotion of team work among employees, decreased WMSDs and increased worker's comfort (Mawle, 2005). The ART is a risk assessment tool designed by the HSE to assess the risk factors involved in repetitive work which can lead to the development of Upper Limb Disorders (ULDs). ART is suitable for repetitive tasks which involve actions of the upper limbs and occur at least 1-2 hours per day. It uses the numerical scoring and traffic light system to identify risk levels posed by such factors as the frequency, force, awkward postures etc. (HSE, n.d.; 2010).

For risk assessment of manual handling tasks, only the MAC and RAPP tools are recommended for further assessment (Health and Safety Executive, 2016). These tools do not fully assess the risks in the workplace so HSE also recommend the use of other ergonomic assessment tools to help the ergonomist conduct more detailed assessment of unusual manual handling activities. These tools include the NIOSH Lifting Equation, the RULA and REBA (Darby, 2008; Health and Safety Executive, n.d.; Leanne, 2007; Pinder, 2002). The three ergonomic risk assessment phases recommended by HSE for assessment of risks associated with manual handling activities are represented in figure 2-4.

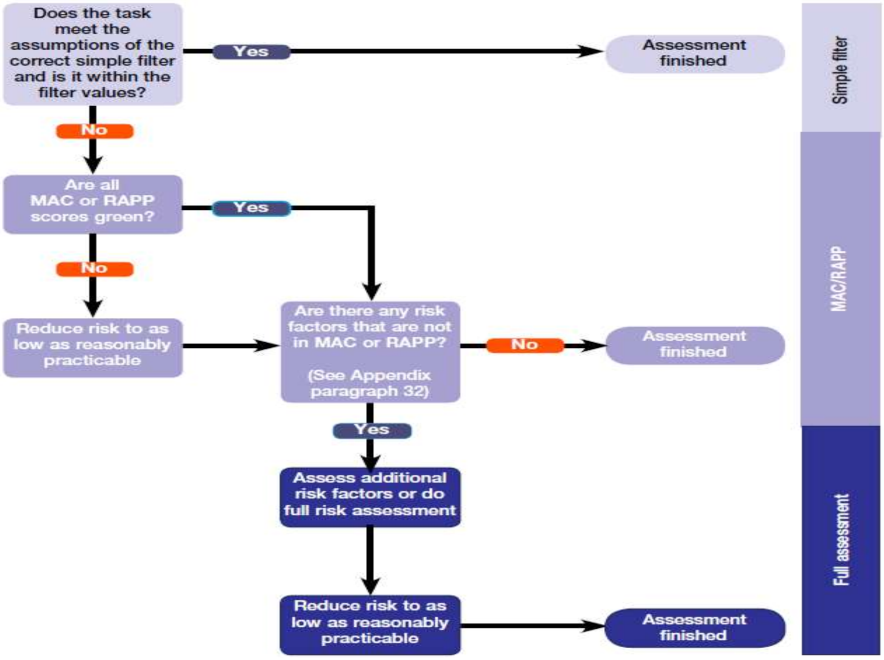


Figure 2-4 Phases of risk assessment of manual handling tasks by HSE (adopted from Health and Safety Executive, 2016).

One concern of HSE is that operators do not have access to posture measuring instruments that can measure and quantify their postures in degrees. That is why HSE's posture assessment is mainly based on descriptive criteria and not specific posture assessment quantified in degrees (Health and Safety Laboratory for the Health and Safety Executive, 2009). There is therefore, a need to solve this problem by developing a system that can quantitatively measure human work postures in degrees and assess the postures in compliance with HSE's recommended guidelines.

2.3.3 **Tools in Germany (BAuA)**

The German Federal Institute for Occupational Safety and Health (BAuA) in collaboration with the German Labour Inspectors has developed the Key Indicator Methods – KIM tools. These are semi-quantitative screening tools utilized for time-efficient risk assessment of physical workloads resulting from manual handling activities (Federal Institute for Occupational Safety and Health (BAuA), 2014; Steinberg, 2012). The tools consists of the KIM-LHC used for the risk assessment of lifting, holding and carrying tasks, the KIM-PP for risk assessment of pushing and pulling tasks and the KIM-MHO, for risk assessment of manual handling operations (Steinberg, 2012). The KIM tool functions by recognising and removing any deficits that may occur during job design stage. The methodology adopted for its development is in compliance-with the risk assessment of manual handling operations obtainable in German companies. The first KIM tool to be developed is the KIM-LHC, developed in 1996 as an additional method to bridge the gap created by the existing risk assessment methods in Germany which include unintelligible methods, possible application errors, unclear system descriptions, etc. (Steinberg, 2012). It was revised in 2000 and its key indicators include frequency or duration, mass of the load, working condition and posture. The second KIM tool is the KIM-PP, developed in 1998 for the risk assessment of loads manually handled by pulling or pushing. Its key indicators include the mass to be pulled/pushed, frequency/duration, vehicle transport, speed, posture as well as working condition. The first two KIMs use a numerical scoring system ranging from null to maximum to allocate scores to each of the key indicators after which the final risk score is computed and displayed in four risk point-ratings. The higher the rating point, the higher the risk which is classified as low risk, increased risk, highly increased risk, and highly increased risk with unavoidable workplace re-design, respectively (Steinberg, 2012).

However, despite the development of the first two KIM tools that evaluates the risk posed by manual handling of loads, there still exists gaps in the tools because of its inability to conduct risk assessment of the entire manual handling operation. Hence, in order to bridge this gap, the KIM-MHO was drafted in 2007 (Klussmann et al., 2010, 2012). The tool evaluates various key indicators such as duration, frequency, postures, work organisations, working conditions, and classifies these characteristics using scales with colour bands to indicate risk levels. Green colour indicates low risk of physical overload, Greenish yellow indicates increased risk, Yellow indicates highly increased risk, and red indicates highly increased risk with unavoidable workplace re-design (Klussmann et al., 2010).

Finally, BAuA advocates the development of tools/methods that can record and assess physical workloads in compliance to a unified assessment standard (Federal Institute for Occupational Safety and Health (BAuA), 2014).

2.3.4 **Tools in the United States of America (OSHA)**

USA OSHA recommends the use of assessment tools, screening tools, checklists, job analysis and observation methods for preliminary risk assessment of workplaces (NIOSH, 2007; OSHA Technical Manual, n.d.). An example is the National Institute of Occupational Safety and Health (NIOSH) hazard evaluation checklist for lifting, pushing and pulling. However, checklists are not good at detecting ergonomic hazards, hence, such tools as the NIOSH lifting equations, the Lumber Motion Monitor (LMM), the 3D Static Prediction Program (3DSSPP), the American Conference of Governmental Industrial Hygienists Threshold Limit Values (ACGIH TLVs), the Snook's Psychophysical Table, are recommended for detailed ergonomic assessment of manual handling tasks (NIOSH, 2007; Zarzar, 2006). These tools are classified as either qualitative, quantitative or semi-quantitative.

The NIOSH lifting equation is a quantitative ergonomic risk assessment tool developed in 1981 by NIOSH and revised in 1991. The equation consists of the recommended weight limit, (RWL) and the lifting index, (LI) and evaluates risks involved in manual Handling and lifting activities. The RWL is the maximum value of load a healthy worker can lift without developing lower back pain while LI is the weight of the lifted load (L) divided by the RWL for each task (Waters, Baron and Kemmlert, 1998). It integrates biomechanical, psychophysical, and physiological criteria while utilising Load Constants (LC) with Horizontal reach (H), Vertical height (V), and lifting Frequency (F) as inputs (Arjmand, Amini and Shirazi-Adl, 2015). M in equation 2-1 represents multiplier, D is distance of object, and C is the coupling/grip quality (Middlesworth, n.d.). The revised NIOSH Lifting equation can identify the risk factors that leads to lower back pain during asymmetric lifting operations on the shop floor (Chung and Kee, 2000). The RWL and LI are expressed using the following task variables (Waters, Baron and Kemmlert, 1998):

$$RWL = LC \times HM \times VM \times DM \times FM \times AM \times CM \qquad \textbf{2-1}$$

$$LI = {}^{L}/_{RWL} \qquad \textbf{2-2}$$

The methods for measuring the task variables are described in detail in (Middlesworth, n.d.; Okimoto and Teixeira, 2009). The limitations of this tool are numerous and include lower compression force as the lifting height increases, fluctuating lifting frequency with respect to the psychophysical and physiological criteria. The equation is generally unsuitable for the risk assessment of the following; seating/kneeling to lift, lifting unstable loads, lifting in constrained workplaces, one-handed lift, and assessment of other manual handling activities. Consequently, (Potvin, 2014), has alerted ergonomists on these limitations and recommends that more specific ergonomic tools be used when designing for biomechanical, psychophysical, and physiological criteria for lifting.

The Lumber Motion Monitor (LMM), developed by the Ohio State University quantifies the risk level exposure of the spine by monitoring the lower back while working (Risk Quantification | Spine Research Institute). LMM is a quantitative tool used for 3D risk assessment of operators while working. It is usually worn on the body of the operator and this poses a great limitation as it is not convenient.

The American Conference of Governmental Industrial Hygienists (ACGIH) provides guidelines for safe lifting through the development of Threshold Limit Values (TLVs) that provide upper and lower limit guidelines for safe lifting (NIOSH, 2007; Zarzar, 2006). They adopted the ACGIH TLVs for lifting, hand-arm vibration as well as hand activity level. One major limitation of these tools is that they do not assess risks posed by all manual handling operations.

The Snook's psychophysical table is a semi-quantitative tool developed in 1978 and revised in 1991, which utilizes psychophysical methodology to provide guidance for the ergonomic risk assessment of manual handling tasks involving posture, force, frequency, etc (SNOOK, 1978; Snook and Ciriello, 1991). It can be used by even novice operators as little or no training is required before use. However, it can only be used for only one task at a time.

The 3D Static Prediction Program (3DSSPP) developed at the University of Michigan is used to obtain the posture data of operators, analyse and display the outputs in compliance with the NIOSH guidelines (3DSSPP Software - Center for Ergonomics). The tool can predict such factors as push, pull, lifts, etc. and provide information about the posture, force and anthropometry data of the operator. It can perform the function of posture analysis and posture prediction and have the capability to visualise virtual humans in 3D (Ma et al., 2011). It can also evaluate trunk twists and bends as well as workplace design and re-design. (Ma et al, 2011) However, the program developers have proposed that it should not be used alone when predicting static strength and job design requirements. Again, the tool is difficult to use by novice operators as it requires sufficient training before use.

2.3.5 **Tools in Singapore (WSH Council)**

The recommended risk assessment tools listed by the Singaporean Workplace Safety and Health Council include (Liu, 2014; Peixin, 2010): i) the Liberty Mutual Psychophysical Table, Snook tables for the manual handling of pulling/pushing tasks. ii) the ACGIH TLVs for lifting, Liberty Mutual Psychophysical Table for manual handling of Lifting, Lowering and Carrying. iii) the ACGIH hand activity level, Moore’s strain index for assessment of hand-related manual handling tasks iv) REBA and RULA for whole body and upper body assessments respectively.

Other WSH Council’s recommended tools include the NIOSH lifting equation, the MAC, Quick Exposure Check (QEC), Manual Task Risk Analysis (ManTRA), LMM, etc. The WSH in collaboration with the Ministry of Manpower also recommends the use of Interviews, Checklists, etc. for preliminary risk assessment of workplaces. For awkward posture assessment of the upper body, RULA is recommended (Liu, 2014; Peixin, 2010).

Moreover, the WSH Council developed a tool known as the ‘Ergo’ which analyses work postures, identifies risk hazards as well as suggesting ways to reduce injuries in workplaces (WSH Institute, n.d.). One advantage of this tool is that it is easy to set up and available to everyone as an App. However, the tool is not convenient and wastes time as the operator must take a video of themselves and manually input the needed parameters. it also lacks the automatic assessment and real-time feedback posture assessment capabilities.

2.4 **PART 3: Studies on Feedback Systems**

Research has revealed that the CAD-based ergonomic tools and other existing tools can no longer meet the expectation of the users due to their inability to provide relevant expert advice to users (Kaljun and Dolšak, 2012). Ergonomists and risk assessors usually depend on their personal experience and knowledge when assessing risks with the existing assessment tools. This often leads to inaccurate ergonomic assessment results as vague and misleading decisions are often made. Employing an intelligent KBS which can give expert advice from a pre-defined knowledge base for improved assessment (Kaljun and Dolšak, 2012) and can also provide real-time feedback through its interface, can help to reduce this problem.

In this part of the review, relevant literature on real-time feedback and the existing KBS suitable for ergonomic risk assessment of manual handling tasks, are explored.

2.4.1 **Recent Studies in the Development of Real-Time Feedback Systems for Ergonomic Posture Assessment**

Designing a feedback user interface system is a loop between design choices and their evaluation in which the interface is modelled for specific use cases (Palmas et al., 2014). It is a significant aspect of the user experience and should indicate to users what they have done, where they have been, and where they currently are (Palmas et al., 2014). Attributes of good feedback systems include simplicity, legibility, transparency, and customizability (Claypoole, Schroeder and Mishler, 2016).

For the assessment of ergonomic risk factors on the shop floor, a natural and interactive interface that provides good feedback to the users, with screens that support flexible visualisation, enabling the user to define their own data for each case study are of utmost importance (Aromaa and Väänänen, 2016; Palmas et al., 2014). The design of this interface should capture the most important elements of the system ensuring that both expert and novice staff have a greater capacity to participate (Hoarau, Charron and Mars, 2014).

Feedback systems that provide real-time feedback to the worker concerning their current ergonomic behaviours thereby prompting them to adjust any possible awkward postures is highly beneficial and desirable. These systems when implemented, can lead to the best ergonomic workplace conditions as it is convenient and saves time (Johnson and Fletcher, 2014; Klippert, Gudehus and Zick, 2012).

Research has revealed that it is possible to develop a system that provide real-time feedback to the worker concerning their postures. Delpresto et al. (2013) developed a feedback system which utilizes the first-generation Kinect to capture worker's data, analyse it and display recommendations on safe lifting techniques. Even though real-time skeletal data was generated in their study, there was no specification on whether the feedback provided to the users was real-time or offline. The feedback was provided through visual display of the lifts with textual display of the recommendations to the users. Again, their tool is not a posture assessment tool and is only limited to training workers to adapt safe lifting techniques. The researchers concluded by recommending further work on feedback using audio feedback to users for better results (Delpresto et al., 2013). Vignais et al. (2013) developed an innovative system which utilizes visual and acoustic signals to send postural assessment feedback to the workers. Valentin et al. (2015) developed an ergonomic assistance system using wearable sensors with the production of real-time feedback to the workers and their managers. A system that combines the Microsoft Kinect and the Nintendo Wii balance board along with an established software to provide real-time visual feedback for correction of limb ligament and weight distribution disorders in a medical rehabilitation facility, was developed by Levinger et al. (2016).

Finally, research has been ongoing to develop simpler and more flexible real-time ergonomic posture assessment feedback systems, but no research has achieved the development of a cost-effective, easy-to-setup, easy-to-understand, H&S-compliant, real-time posture assessment feedback system.

2.4.2 Developments of Real-Time Health and Safety Knowledge-Based Systems for Ergonomic Risk Assessment.

A KBS is an intelligent system that utilises a knowledge base to solve problems (Aziz et al., 2017). The requirements of a KBS which include the hardware, the knowledge base and the user interface requirements are extensively described in Pavlovic-Veselinovic, et. al. (2016). Human knowledge on ergonomic risk assessment can be written in the form of rules and utilized in the knowledge base of an intelligent system to solve complex ergonomic problems (Aziz et al., 2017). KBS has been developed to solve ergonomic problems in various industries like healthcare where it is used to provide correct working conditions from a knowledge base built using ergonomic methods like OWAS (Bartnicka, 2015). In product design in which a knowledge base is built using data from expert knowledge on recommended design goals, and coded in the form of production rules into a KBS called OSCAR, to enable more improved ergonomic product design (Kaljun and Dolšak, 2012). In the automotive industry in which a knowledge base is built with occupational ergonomics data collected through interviews and questionnaires to provide decision makers with a framework that predicts ergonomic risk factors during product and process design in the automotive manufacturing shop floor (Aziz et al., 2017). These afore-mentioned are only prototypes and frameworks and are therefore incomplete systems.

Completely developed KBS has been implemented by different researchers over the years. A KBS known as LIFTAN was developed by Karwowski et al. (1986) for evaluating the risks posed by manual lifting tasks and analysis of work situations in the workplace as well as provide recommendations on preventive strategies. Its knowledge base was built with 159 rules extracted from a literature survey on risk assessment. In a bid to revise the LIFTAN KBS and provide modifications to the initial system, the M-LIFTAN was developed (Karwowski et al., 1987). The system evaluates manual lifting tasks and provides acceptable figures on load limit, weight, force as well as identify potential risk factors in the workplace. The system's knowledge base is built with rules extracted from health and safety commission, NIOSH and Snook on manual handling recommendations.

A KBS that evaluates risks posed by lifting task to provide recommendations on endurance time, energy expenditure and operator's heart rate was developed by Asfour and Genaidy (1987), with a knowledge base built with rules, and parameters such as task duration and frequency extracted from literature.

Kabuka, et. al. (1988) developed a KBS that evaluates repetitive manual handling tasks to recommend acceptable weight to workers. The system's knowledge base was built with rules and parameters extracted from literature. In the same year, a group of researchers developed a KBS known as EASY, for ergonomic assessment of manual handling activities (Chen, et. al., 1991). The knowledge base of this system was built with 45 production rules on job design, dynamic loading and biomechanical analysis extracted from literature.

In 1995, the ERGONOMIST V was developed to evaluate the risk from repetitive and forceful tasks while predicting risks of injuries (Moynihan et al., 1995). Its knowledge base was developed with rules extracted from literature.

Ergonomics Expert System (ERGOEX) was developed to evaluate workplace design dimensions and adjustments, lightening conditions and biomechanics. It has a knowledge base built with knowledge extracted from scientific literatures (Gilad and Karni, 1999).

To provide recommendations on the assessment of safety, environmental, ergonomics, health and general factors in a workplace, the HSEE was developed with a knowledge base built with rules extracted from oil and gas related national and international standards (Azadeh et al., 2008).

The FAST ERGO-X, developed by Nunes (2009), evaluates risk factors that can lead to WMSDs using a knowledge base built with knowledge extracted through subjective and objective means.

Even in video display terminal (VDT) workstation evaluation, KBS has been implemented to solve ergonomic problems. To provide recommendations to computer users on VDT workstation adjustment and computer accessories arrangement, EQ-DeX was developed (Rurkhamet and Nanthavanij, 2004). Its knowledge base was built with rules extracted from undefined ergonomic principles. Another KBS that evaluates the level of exposure of computer users to ergonomic hazards with a knowledge base built with information and rules extracted from OSHA standards on VDT for assessment of human body and Washington state ergonomics standards, for assessment of workstation design, has been developed and implemented (Shavarani and Korhan, 2015). The system provides information to users on any WMSDs hazard posed by their head, neck and trunk postures as well as workplace equipment, and recommends ways of eliminating such hazards. This evaluation and feedback to users occur after a 'few' minutes (Shavarani and Korhan, 2015). Hence, the system is not automatic. One major limitation of this system is that it requires manual input of the data by the user and uses a decision-making system that is stereotyped to either 'yes' or 'no' answers. This makes the output of the assessment unreliable as there is no flexibility in the assessment.

A more flexible KBS, known as SONEX, which allows the user to define their questions to the system, has been developed to identify risks that can lead to WMSDs among workers and recommend ways to avoid it. The system's knowledge base is built with data extracted both from literature review and from expert's experience of ergonomic issues (Pavlovic-Veselinovic, Hedge and Veselinovic, 2016). The system takes about 10 minutes to evaluate the risk of each worker and provide feedback and recommendation to the user (Pavlovic-Veselinovic, Hedge and Veselinovic, 2016). Again, the system depends on the data manually provided by the user as answers to its questions, to make its assessment.

These systems are expert systems that utilize some rules to build the knowledge base for ergonomic recommendations towards improved workplace assessment and consist of a knowledge base, an inference engine and a user interface. However, the limitations of the KBS tools include lack of automatic posture assessment and lack of effective real-time feedback to alert workers in time.

2.5 **Discussion**

Timely ergonomic interventions do not only lead to worker's satisfaction but also leads to improved productivity and reduced cost. It is the best preventive strategy to WMSDs as it helps to identify as well as reduce the risk of exposure of the workers to the disorders. High task repetition, awkward postures, forceful exertion, vibration and manual handling of heavy loads, if not identified and assessed, can lead to WMSDs in the workplace. For effective ergonomic interventions on shop floors, appropriate assessment tools are required to not only reduce the risk of WMSDs but to also improve productivity, improve quality, reduce rejection costs as well as increase revenue. Selecting the correct tool requires basic knowledge of the major issues that can lead to risks and injury.

While some researchers have identified the DHM as an effective ergonomic evaluation tool useful for visualising and assessing risk factors such as postures without using real humans, some other researchers have found limitations in its use for ergonomic evaluations of shop floors. These limitations include the inability of the model to consider task duration and repetition which are risk factors that can lead to WMSDs. Moreover, for work posture assessment using the DHM, human anthropometric data are often pre-recorded, scanned or manually imposed on the DHM (Qin, Panayiotou and Zhang, 2011), which often lead to errors, inaccuracies and waste time. Again, the systems are very expensive and require extensive training before use. They are most suitable for ergonomic assessment during product and workplace design. In a bid to get simpler, less complex tools for ergonomic analysis, researchers have been developing and implementing ergonomic risk assessment tools which can be used for either initial risk assessment or detailed risk assessment and evaluation.

Photographs and videos have limitations such as inaccurate measurement of joint angles because of distortions caused by camera placement issues. Other existing assessment tools are either very expensive, require careful setup or need to be worn on the body of the worker which often causes body discomfort. Many of the tools, especially the observation-based tools, are incomplete and therefore cannot capture data and assess it with the provision of automatic feedback to the users.

Different countries have established H&S regulatory bodies which are tasked with enforcing the correct standards, and providing the risk assessment guidelines and tools needed for identification and control of risks in workplaces. Most of the ergonomic posture assessment tools recommended by these H&S professionals and identified in this study has been found to yield appropriate posture assessment results. However, they have several limitations that call for the development of tools that are easier to use.

The BAuA’s KIM tools are only suitable for preliminary assessment and lack the real-time automatic feedback capabilities.

The OSHA’s 3DSSPP, which is a DHM-based system, is difficult to use, and requires manual inputs of needed parameters by experts. The Snook’s Psychophysical Table is most suitable for preliminary assessment. The NIOSH lifting equation is not versatile and therefore cannot assess varieties of tasks. The LMM is usually worn on the body of the operator and therefore causes body discomfort. These tools lack real-time automatic feedback capabilities

The WSH Council’s recommended tools, give quick assessment of the postural loads and can conduct preliminary assessment of worker’s postures. The tools however lack the real-time automatic feedback to the workers to enable them correct awkward postures while working. Again, apart from the Ergo tool, other tools such as the MAC tool, RULA and REBA are observation-based and therefore require offline data capture by additional tools such as the video camera.

The HSE’s recommended tools also have similar limitations as that of other countries. They generally lack the real-time automatic feedback capabilities and require additional tools for data collection.

To bridge the gap posed by these identified limitations, the German BAuA advocates the development of tools that can both record and assess physical workloads in compliance to a unified assessment standard and the UK HSE have called for posture measuring instruments that can measure and quantify their postures in degrees while working. In practice, most of the identified posture assessment tools are mainly based on descriptive criteria.

However, the Microsoft Kinect, which is a cheap, readily available, easy-to-set-up, markerless sensor with its easy-to-understand SDK, has been recommended as a useful posture monitoring tool with great potentials for reducing WMSDs because it supports non-invasive, real-time 3D posture analysis and provide real-time feedback to workers (Darby et al., 2016; Ho et al., 2016; Thati and Mareedu, 2017).

Literature survey by Aziz et al., (2017) have identified gaps in the development of knowledge based systems for effective ergonomic risk assessment. The KBS system developed by Bartnicka (2015) only contains the knowledge base with no defined inference and interface. The KBS by (Kaljun and Dolšak, 2012) has a knowledge base in which the knowledge on recommended design goals are built. It has an inference engine where the algorithms are defined but no interface. The KBS by Aziz et al. (2017) describe a framework that consists of a knowledge base without any defined inference and interface components.

The study has identified only two H&S compliant KBS whose knowledge base is developed with rules extracted from H&S standards and recommendations. However, these KBS are not suitable for ergonomic assessment of awkward work postures during varieties of manual handling tasks. This is because, while the OSHA-based KBS only assesses seated VDT users and workplace, the M-LIFTAN assesses only risks associated with lifting tasks. Moreover, the systems are not automatic and are not capable of providing real-time feedback to the workers on their awkward postures. The M-LIFTAN is outdated and may not run on modern computers and platforms.

Furthermore, postural assessment feedback system which utilizes the Kinect as its hardware component is needed to address the limitations of existing tools by providing the workplace with a system that: i) provides real-time automatic feedback to workers to enable them to adjust awkward postures in time. This will address the limitations of the existing tools which fail to inform workers about their ergonomic behaviours in real-time ii) is easy-to-use, with easy-to-understand feedback to overcome the limitation posed by tools that are difficult, and those that require experts and training iii) is non-intrusive and therefore more convenient as it does not interfere with work methods. iv) is portable, cost-effective and calibration-free. v) can integrate H&S rules and guidelines into a knowledge based intelligent system for more effective ergonomic posture assessment with provision of real-time feedback to its user. This can help to overcome the limitations of existing intelligent systems which fail to automatically assess work postures in real-time and are incapable of providing real-time feedback to users.

Finally, research has been ongoing to develop simpler and more flexible real-time ergonomic posture assessment feedback systems, but no research has achieved the development of a cost-effective, easy-to-setup, easy-to-understand, automatic real-time posture assessment H&S-compliant KBS system. This research therefore will explore the possibility of developing a KBS that integrates the knowledge extracted from H&S recommendations on awkward postures resulting from manual handling, an inference engine, and an easy to understand, interactive interface, using the Kinect as the hardware that captures data in real-time, automatically assess the postures and generate real-time feedback to the workers. This will inform operators when to adjust awkward postures that can be detrimental to their health and ensure timely ergonomic interventions even in flexible manufacturing systems.

2.6 **Research Gaps**

The literature studies have identified major research gaps in the real-time ergonomic evaluations and feedback systems on the shop floors.

GAP 1: There is no established feedback system that provides effective real-time feedback to shop floor workers during manual handling operation, using 3D motion sensors. In 2013, a team of researchers recommended the provision of audio feedback to users for better results during ergonomic assessment (Delpresto et al., 2013). At this point in time, no research has developed such real-time feedback system using 3D motion sensors, which can prompt operators to adjust awkward postures during flexible manufacturing operations.

GAP 2: There is no developed expert system that utilize H&S rules for manual handling to build a knowledge base for ergonomic assessment using 3D motion sensors. Research has been ongoing to develop a simpler, cost-effective, easy-to-setup, easy-to-understand, H&S-compliant ergonomic assessment knowledge-based system, but no such system has been reported in literature.

GAP 3: Research has identified gaps in the development of 3D motion sensors to record and assess physical workloads in compliance to a unified assessment standard. No research has developed the Kinect for use in automatic H&S compliant ergonomic risk assessment. This is necessary especially in an FMS where immediate response to system change is highly desirable. The health and safety guidelines will help to ensure adequate ergonomic assessment that conforms with approved standards but a compliant tool has not been developed by researchers using low-cost, easy-to-use 3D motion sensors.

GAP 4: None of the previous research that employed the Kinect sensor for data collection for ergonomic evaluations has considered training the sensor to detect manual handling tasks for reduced assessment errors but this will be addressed in the work of this thesis. Previously, researchers have used trial and error method to place the sensor on the shop floor during assessment but there is need to establish optimum locations to place the Kinect for better data capture towards real-time ergonomic assessment (Martin et al., 2012; Nguyen et al., 2013). This can be achieved by training the sensor to detect manual handling tasks. Detecting these tasks can help inform the user on the best location to place the sensor for reduced measurement errors.

2.7 **Chapter Summary**

This chapter presents the review of related literature and highlights existing tools currently used for ergonomic assessment of work postures. The chapter also highlights the limitations of the existing tools and identified the gaps in research. The next chapter will provide the research aim and objectives and discuss the methodology to address the identified gaps.

3 RESEARCH AIM, OBJECTIVES AND METHODOLOGY

This chapter outlines the research hypothesis which is based on the identified research gaps, the research aim and objectives which are derived from the hypothesis. The methodology followed to achieve the objectives is also presented.

3.1 **Research Hypothesis**

The hypothesis for this research is given thus;

“It is possible to provide real-time feedback to the workers on their work postures on the shop floor.”

With the aid of the proposed knowledge-based posture assessment feedback system, the research seeks to achieve;

- Real-time manual handling task recognition and feedback to workers.
- Real-time automatic posture assessment and feedback to the workers on the shop floor.
- Ergonomic improvement of worker’s postures using the developed tool.

3.2 **Research Aim**

The aim of this research is to develop a real-time knowledge-based ergonomic assessment system for use in the real-time evaluation of work postures on the shop floor and provision of feedback to workers, using 3D motion sensors.

3.3 **Research Objectives**

To achieve the aim, the following objectives which are based on the identified research gaps, are set as follows:

- To train an algorithm that enables the 3D motion sensor to track humans and detect manual handling tasks on the shop floor.
- To analyse the H&S recommendations, identify acceptable guidelines on manual handling and extract the relevant data to be supplied to the proposed system.

- To develop the rules and the inference engine of the system towards real-time ergonomic posture analysis based on H&S recommendations.
- To design and develop a real-time ergonomic posture assessment and feedback system.
- To test and validate the developed system with case studies.

The relationship between research objectives and the identified research gaps is represented in figure 3-1.

Figure 3-1 Relationship between research objectives and gaps.

3.4 **Research Focus**

Statistics in Great Britain show that there is a much higher prevalence in the rate of occurrence of WMSDs reported for the human's upper body (the spine, and upper limbs) when compared to the lower body. Between 2005 – 2016, a total of about 74% working days was lost because of Work-Related Upper Limb Disorders (WRULD) and back disorders, while only 26% lost work days was reported for Work-Related Lower Limb Disorders (WRLLD) (HSE, 2016). This data shows the great need for an intervention tool for the upper body assessment to reduce WMSDs. Therefore, this research work will focus on the design and development of a knowledge-based ergonomic posture assessment system for use in real-time ergonomic posture assessment of the back and upper limbs of the human body with real-time feedback to the operators, while undertaking manual handling tasks.

3.5 Research Approach

A research approach is the step by step plan and procedure on the assumptions and detailed methods involved in data collection, analysis and interpretation (Creswell, 2014; Grover, 2015). The approach chosen for any research depends on the type of the research problem that needs to be solved, the researcher's experience, and the type of audience involved.

3.5.1 Types of Research Approach

The various approaches to research are divided into three main types namely (Creswell, 2014; Grover, 2015):

3.5.1.1 The Qualitative Approach

Qualitative research approach involves the formulation and development of theories to explore and understand the phenomenon being investigated. Its data analysis method is inductive in nature which means that the researcher focuses on the methods of data collection taken at the researcher's location, from specific to general and is not concerned with the analytical techniques employed. The final report generated in this approach is usually flexible as the research process depends on emerging methods and procedures (Creswell, 2014; Grover, 2015).

3.5.1.2 The Quantitative Approach

Unlike the qualitative approach that uses word, this type of research approach uses numbers. It is a type of research approach that consists of hypotheses that needs to be tested, a clearly defined procedure for data collection and a well-structured statistical analysis approach. It uses instruments to measure variable and tests the relationship among the variables, with clear interpretation of the findings (Creswell, 2014; Grover, 2015). Hence its data analysis method is deductive in nature and the final report generated by this approach is usually well structured unlike the flexible report produced by the qualitative approach researcher (Creswell, 2014).

3.5.1.3 The Mixed Methods

Just as the name implies, the mixed method approach involves a mixture of the qualitative and quantitative approaches. It merges the data collection and data analysis approach of the first two approaches in a single research and gives a more complete understanding of a research problem compared to the other two alone (Creswell, 2003, 2014; Grover, 2015).

The quantitative research approach is used in this research to develop the knowledge-based posture assessment feedback system. The research involves the testing of hypothesis and statistical testing of variables to establish the relationship among the variables and evaluate the reproducibility and reliability of the data produced by the system. The data analysis approach used in this research is deductive in nature as experimentation helped to deduct the effect of variables on the system performance and the report-writing follows a well-structured method for clarity.

3.6 Research Methodology

This section outlines the specific methods to be followed to achieve the aim and objectives.

The research methodology systematically describes the methods involved in the design, development and testing of the knowledge-based posture assessment feedback.

There are five main stages of the research methodology as related to the five objectives of this work and these are:

3.6.1 Stage 1. Research problem identification

The first stage of this research is the recognition of the need for a more specific ergonomic assessment tool which can assess work postures in real-time and provide corresponding real-time feedback to the workers to reduce WMSDs and costs. This assessment can be achieved with total compliance to the health and safety recommendations.

At this stage, two main decisions were made namely:

- to develop a real-time ergonomic assessment and feedback system that can help mitigate the risk posed by the adoption of awkward postures by operators during manual handling operations. This decision was taken because of the identified need to meet the challenges posed by this ergonomic risk on flexible manufacturing shop floors on which immediate response to system change is urgently required.
- The system should be a knowledge-based system which utilizes the knowledge base, the set of rules and the inference engine of a KBS supplied by a human expert, to automatically capture the worker's joint data, process and convert this data into posture data, assess the posture and provide real-time feedback through an easy-to-understand user interface to workers in a flexible system. Again, this decision was taken because H&S have provided risk assessment guidelines needed for assessment of risks associated with manual handling operations in workplaces. These definitions need to be built into the knowledge base of the proposed system to develop a H&S compliance tool.

3.6.2 Stage 2. Review of related literature

After identifying the research problem that needs to be addressed, every paper that is related to the research topic and research area, is reviewed to identify existing tools and methods in use and establish the research gaps. The literature review starts with the review of all related published work on the general ergonomic evaluation methods and tools. The developmental trend in the method of data collection that led to the choice of the 3D motion sensor as a suitable sensor for data collection, is reviewed. Next, the ergonomic posture assessment tools and methods for assessing awkward postures are reviewed.

The review is conducted on several peer reviewed journal articles, conference papers, theses, etc., indexed in several databases especially in Scopus. The reviews led to the identification of gaps in the research.

This stage involves two tasks namely:

Task 1 Review of related literature

Task 2 Research gap identification

At this stage, some decisions were taken which include:

- To develop the health and safety compliance KBS system for real-time ergonomic assessment and feedback to workers using 3D motion sensors. This decision was taken to bridge the gaps in ergonomic work posture assessment identified from literature.
- To use the Microsoft Kinect sensor as the hardware component of the proposed KBS system, which was selected because it is cost-effective, non-intrusive, and can track the skeletal joints of human under motion. The sensor is also able to measure human joint data in degrees.

3.6.3 Stage 3. Identification of the Research Hypothesis, Research Aim, objectives and Research Methodology.

At this stage, the research hypothesis is formulated based on the research gaps identified in stage 2. The aim of the research, objectives with which to achieve the aim and the detailed methods by which the objectives will be accomplished, are presented.

The decision taken at this stage is to map out the methods that can ensure timely accomplishment of the research aim and objectives.

3.6.4 Stage 4. Train an algorithm that can enable the 3D motion sensor to track humans and detect manual handling tasks on the shop floor.

A major pre-requisite to this stage is the study and understanding of the capabilities as well as limitations of the hardware. The stage consists of the following tasks:

Task 1 The sensor is trained to detect various manual handling tasks on the shop floor.

Task 2 The sensor's optimum locations for more accurate data capture is determined.

Task 3 An algorithm is developed to track human skeletal data and compute joint angles using the 3D imaging sensor.

The main decision taken at this stage is how best to develop the 3D motion sensor for use in the real-time tracking of human joint data and real-time manual handling task recognition. This is because for the sensor to be a useful hardware for real-time ergonomic assessment of manual handling activities, it should be able to recognize such tasks and be programmed to track human joint data. This joint data will serve as the foundational part of the knowledge base developed in the next stage. Hence, the following decisions were taken:

- Correct programming language and Application Programming Interfaces (APIs) to code in. The C# programming language is chosen because it is fully supported by the Kinect SDK and is easy, fast and secure to use. The selected platform is the .NET 4.5 framework of the visual studio.
- Choice of the manual handling task to be trained for recognition. Most manual handling tasks undertaken on the shop floor involve constant lifting and lowering. Therefore, the lifting, lowering and the hammering gestures are chosen for the task recognition experiment.

3.6.5 **Stage 5. Analysis of the H&S recommendations, identification of acceptable guidelines on manual handling and extraction of the relevant data to be supplied to the system**

At this stage, the H&S recommendations on ergonomics evaluation of manual handling tasks and risk assessment of work postures are comprehensively studied with the aim of identifying the relevant and acceptable guidelines for manual handling and identifying specific posture assessment definitions. The identified definitions form the knowledge base of the developed knowledge-based system (KBS) which is used in the next stage to develop posture assessment tool.

The stage consists of the following tasks:

Task 1 Select the countries and their H&S professionals to be studied and the comprehensive study of the selected countries’ H&S guidelines on manual handling, posture assessment and recommended tools.

Task 2 Identify the relevant definitions for manual handling and posture assessment based on the H&S recommendations.

Task 3 Establish the posture assessment categories and scoring system.

Task 4 Build the knowledge base of the proposed KBS.

Here, decisions are taken on the following:

- Relevant H&S definitions that should be supplied to the proposed system, obtained from the H&S guidelines for manual handling. This is to form the major part of the knowledge base.
- Posture assessment categories that should be adopted. This can be obtained from the H&S guidelines. These categories are very important part of the assessment that establishes the scoring system.

3.6.6 Stage 6. Development of the rules and the inference engine of the system towards real-time ergonomic posture analysis based on the recommendations of the H&S professionals.

At this stage, the inference engine that constitutes the if-then-construct of the system, is developed. This is preceded by the establishment of the posture assessment categories and scoring Method which was part of task 3 in stage 5. Then the rules that relate all the data together are incorporated in the system. The resultant tool is tested on some case studies and statistically tested for reproducibility and reliability.

The tasks involved in this stage include:

Task 1 Development of the inference engine that constitutes the if-then-construct of the system

Task 2 Incorporate the rules that relates all the data together and develop the assessment tool.

Task 3 Test the developed posture assessment tool through case studies.

Task 4 Statistically analyse the developed tool for consistency in generating reliable and reproducible data.

The following decisions were taken at this stage of the research:

- Choice of correct algorithms. If the wrong algorithms are used, then the developed system will generate erroneous data.
- Choice of case studies that depict previous H&S tested tasks. This decision is taken because a comparison is needed to test if the resultant tool is in-compliance-with the H&S assessments.

- Choice of suitable statistical tool to be used in the data analysis. This requires a tool that best represents the type of variables to be tested.

3.6.7 **Stage 7. Design and develop the real-time ergonomic posture assessment human-machine interface feedback system.**

At this stage, a human-machine interface that enables users to interact with the system and display the posture assessment updates to the user, is designed and developed. The user interface employs the tool developed in stage 6 to capture worker's postures and assess it in real-time with real-time feedback to workers. Again, the stage consists of the following tasks:

Task 1 Comprehensive study of system requirements.

Task 2 Modelling and design of the interface feedback system

Task 3 Development of the interface feedback system

Task 4 Implementation of the developed interface system by testing with case studies.

Decisions taken at this stage include:

- Suitable system requirements which describes what the system is required to accomplish after its design.
- Choice of adequate modelling tools to use.
- Critical decisions on how the screens of each user will appear. There should be considerations on who the external users of the proposed system are.

3.6.8 **Stage 8. Validation of Results**

The functionalities of the developed feedback system are tested through experimentations using selected case studies. The following tasks are involved at this stage:

Task 1 Choosing and designing the case studies.

Task 2 Testing the developed system with the manual handling activity involving lifting, lowering and carrying tasks.

Task 3 Testing the developed system with an assembly task.

Task 4 Testing the developed system with a hammering task.

Decisions are made on the choice of manual handling tasks that depicts what is obtainable on the shop floor. The tasks are selected from the library of shop floor tasks that can force operators to adopt awkward postures.

3.6.9 Stage 9. Discussion and Conclusion

This part of the research presents the comprehensive discussion of the findings and outlines the conclusions. At this stage of the research, the detailed contributions of the research to knowledge are provided and the study limitations are identified. Further work is proposed.

Finally, the intelligent system, whose method for conception, design and development is described in this methodology, employs a set of rules established in stage 6 to bind the knowledge base developed in stage 5, the inference engine built in stage 6, the skeletal tracking data developed in stage 4, together with the user interface developed in stage 7. This forms the complete real-time automatic posture assessment feedback system developed in this research. The system architecture is represented in figure 3-2.

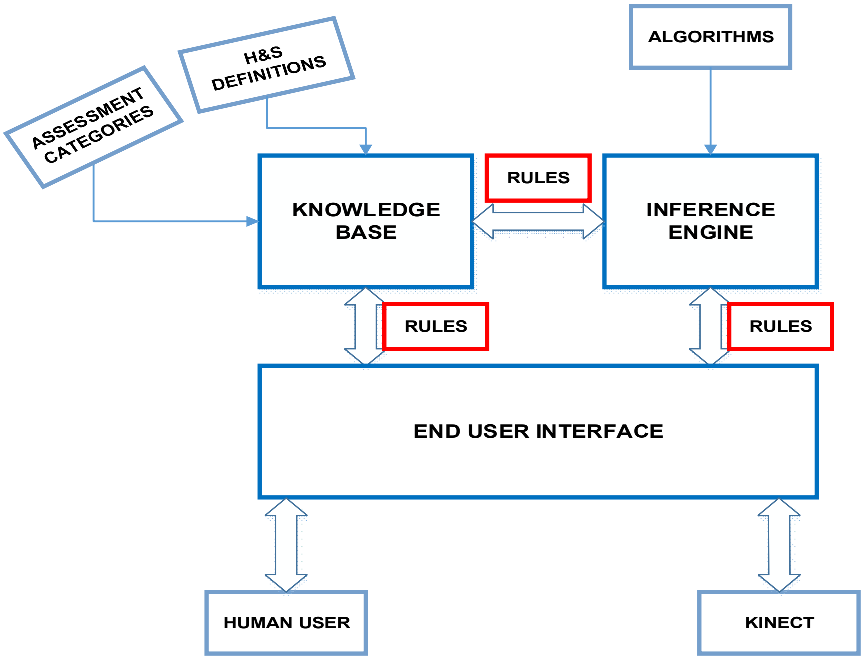


Figure 3-2 The Posture assessment feedback system architecture.

The mapping of the methodology and its relationship with the thesis chapters is presented in figure 3-3.

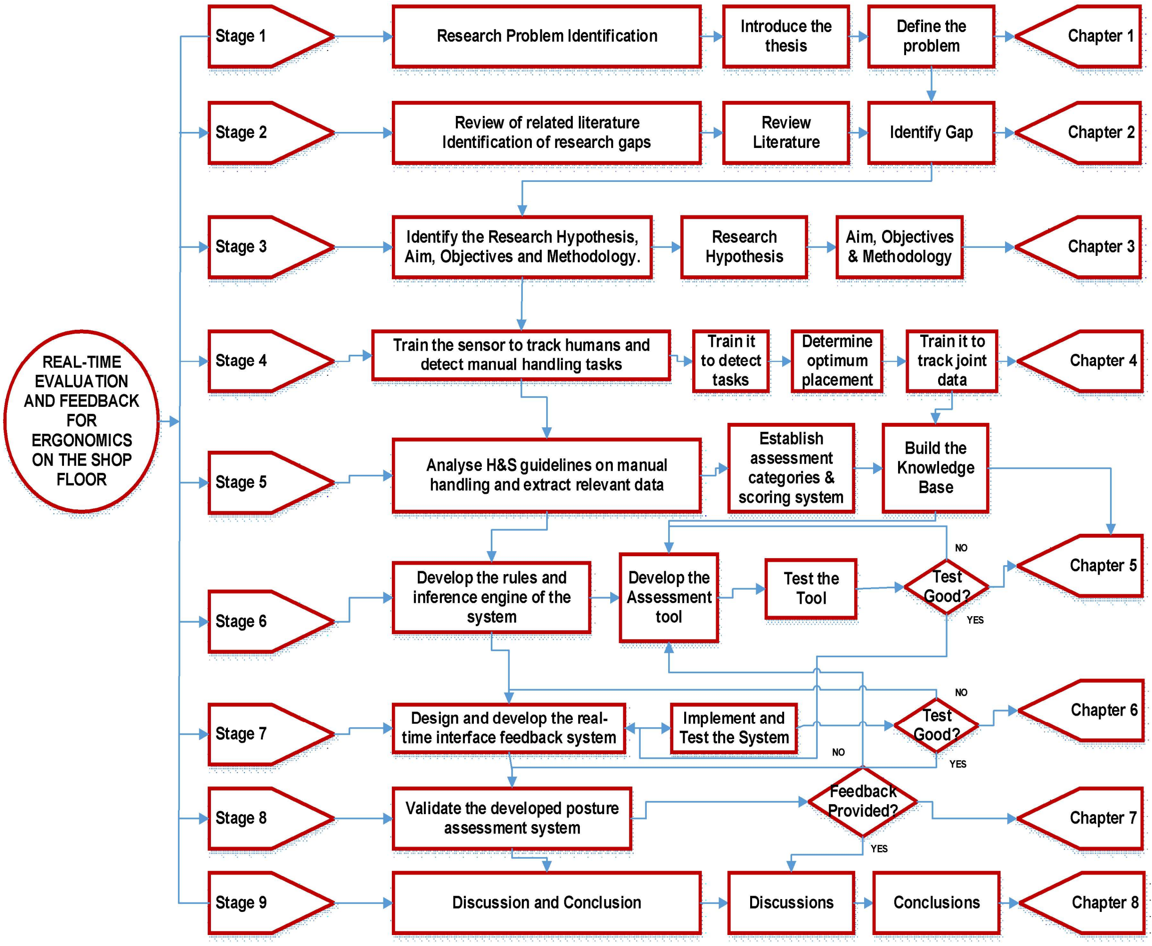


Figure 3-3 A map of the Research Methodology and the relationship with the thesis chapters.

3.7 Chapter Summary

This chapter presents the research hypothesis which highlights the main research statement addressed throughout the research. The chapter also highlights the research aim, objectives and provide the detailed methodology to be employed in undertaking the research. The next chapter will discuss the details of the tasks identified in stage 4 of the chapter, which is the initial technical development of the 3D motion sensor for use in the real-time ergonomic assessment of awkward postures.

4 SETUP OF THE KINECT TOWARDS TASK RECOGNITION AND SKELETAL DATA TRACKING

Manual handling activities which involve lifting, lowering, pulling, pushing, carrying or moving, are carried out daily by workers on manufacturing shop floors (Batish and Singh, 2008; Burciaga-Ortega and Santos-Reyes, 2010). Industries whose workers undertake tasks involving such activities have recorded cases of WMSDs and therefore requires adequate risk assessment. To apply ergonomic assessment tools correctly, there is need for an adequate data collection approach (Diego-Mas and Alcaide-Marzal, 2014; Okimoto and Teixeira, 2009) and the use of Kinect in workplaces can enable ergonomists to analyse motions with real-time feedbacks (Plantard et. al., 2015). However, to employ Kinect for real-time ergonomic evaluation on the shop floor, there are some preliminary issues that need to be resolved. These include preparing the sensor towards manual handling task recognition to help operators to determine the correct location for sensor placement, and preparing the sensor towards skeletal tracking of humans while performing manual handling activities. Task detection and correct placement is required at the data collection stage as it helps to ensure that human motion data is captured without measurement errors while tracking of skeletal data is required to trigger the ergonomic analysis as it serves as the foundation upon which the knowledge base is built.

Therefore, this chapter aims at resolving the issues raised by describing how the Kinect is prepared towards detecting manual handling tasks and to track the skeletal data of workers for ergonomic evaluations, when placed at pre-determined locations in the workplace.

The focus of the chapter is three-fold and includes:

i. To detect and track gestures associated with manual handling activities using the Visual Gesture Builder (VGB) and the Discrete Gesture Basics (DGB) of the Kinect for Windows SDK 2.0.
ii. To establish the optimum locations where the Kinect can be placed during data capture for ergonomic analysis on the shop floor.

iii. To utilize the motion sensing technique of the Kinect to track the skeletal data especially the joint angles of human operators while performing any manual handling task on the shop floor.

The above was developed using the Natural User Interface (NUI), and the Application Programming Interface (API) of the Kinect for Windows SDK 2.0 with the aim of providing the data for ergonomic risk assessment on the shop floor.

4.1 Detecting Manual Handling Tasks on Shop Floors

In this work, gestures associated with manual handling activities such as lifting, lowering and hammering, are trained. VGB and DGB are used because its gesture detection outputs are probability numbers which are useful for determining proper sensor placement and/or proper skeleton detection.

In this section, an experiment is conducted whose aim is to create gestures as seen in a typical manufacturing environment such as lifting and lowering gestures, using the VGB and DGB.

4.1.1 Background

Basically, there are two main approaches to gesture detection using Kinect. These are the heuristic or traditional approach and the Machine Learning (ML) approach which involves data sources and recording of clips using the Kinect studio and then training the gestures using the VGB.

A summary of the features of both approaches is presented on table 4-1 (Lower, 2014b):

Table 4-1 Features of the Heuristic approach and the ML approach with VGB.

S/N	HEURISTIC APPROACH	MACHINE LEARNING APPROACH
1	The programmer oversees the coding of gestures	Kinect Studio records the data and the VGB builds the gestures.
2	Gesture is a coding problem	Gesture is a data problem

Some of the limitations of the heuristic approach include:

- Its task is time-consuming and basically requires an engineer or a programmer because of the many lines of codes involved.
- The Kinect data is complex—for example, twenty-five 3D joint positions.
- Determining the best detection thresholds can be difficult.

However, the advantage of the ML approach using VGB is that its task is mainly based on content creation instead of code writing as seen in the heuristic approach. As such, even non-engineers such as the animators, designers and technicians can perform the task of gesture detection in VGB.

Hence, manual handling gestures will be trained in this work using VGB to enable easy detection of manual handling tasks during ergonomic assessment of shop floor operators performing such tasks. This is because VGB can facilitate machine learning techniques for the capture of user's gestures using recorded and tagged data (Lower, 2014b).

4.1.2 Methods of Creating Gestures Towards Manual Handling Task Recognition

This section discusses the methods on how the Kinect can be trained to detect manual handling tasks using the tools in the Kinect for windows SDK 2.0. This is achieved by training the gestures associated with the tasks such as the lifting and lowering gestures to help trigger data recording for ergonomic analysis. ML was used for training the gestures.

The method begins with recording data in clips using the Kinect Studio. The Kinect Studio is a tool in the Kinect for windows SDK 2.0 which enables developers to record clips that are utilized by the VGB as the input data. VGB uses the skeletal data tracked to train and analyse the gestures. These skeletal data are monitored and recorded by the Kinect Studio and then imported into the VGB solution as input data, for proper training and testing of the gestures.

4.1.2.1 Experimental Setup

The components used in this experiment include:

- The hardware component which is the Kinect sensor.
- A Laptop/PC.

- The software component which is the Kinect Studio, the VGB, and the Discrete Gesture Basics (DGB), all found in the Kinect for Windows SDK 2.0.
- Tables
- Load

The gestures were trained at a measured location in the laboratory (P_5) and tested on different locations as represented in figure 4-1. The test locations, denoted by P_1 to P_9, are defined further on table 4-2.

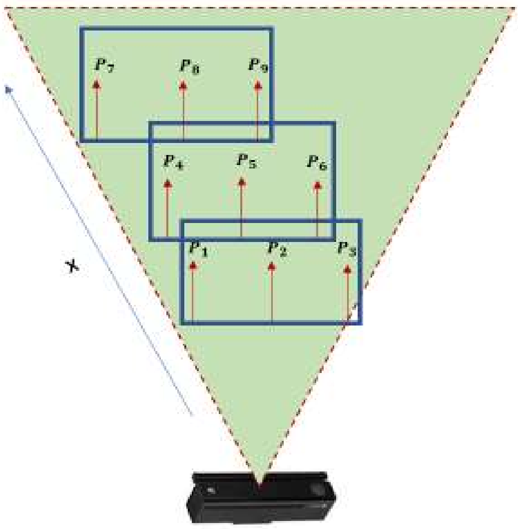


Figure 4-1 Locations for training and testing the gestures

Table 4-2 Definition of the locations for training and testing the gestures

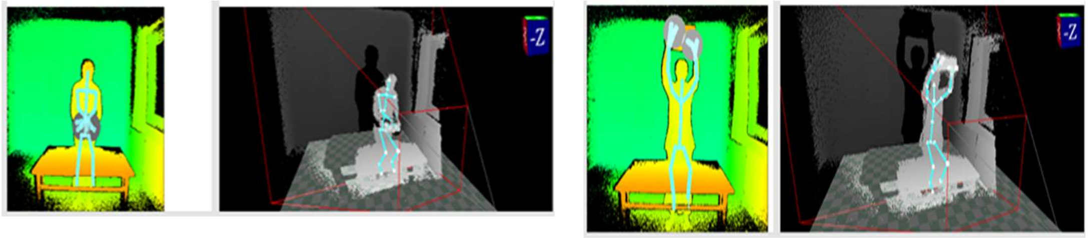
Angle (°)	Distance from the Kinect		
	1 meter	2 meters	3 meters
60	P_1	P_4	P_7
90	P_2	P_5	P_8
120	P_3	P_6	P_9

P_5 for instance, represents a 2m-perpendicular distance from the Kinect. The height of the sensor is maintained at 1.2m from the floor throughout the experiment.

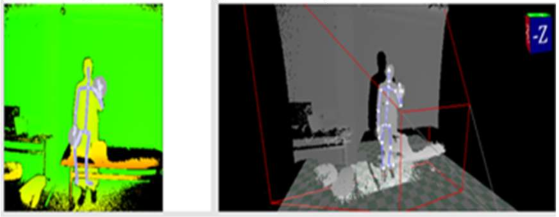
4.1.2.2 Experimental Procedure

The procedure taken to create, train and analyse the gestures include:

- Record the skeletal data of the trainer with the Kinect Studio while performing the desired task as shown on figure 4-2. The recorded data are recorded in clips. This task is repeated continuously until the desired number of clips are recorded. Figure 4-2a shows how the Kinect Studio records the skeletal data of the trainer while performing a lowering activity. Similarly, figures 4-2b and c depicts the screenshots of the recording of the trainer by the Kinect Studio during the lifting and hammering activities.



a) Skeletal data recording during a Lowering task **b) Skeletal data recording during a Lifting task**



c) Skeletal data recording during a Hammering task

Figure 4-2 2D and 3D views of the skeletal data of the trainer as recorded by the Kinect studio

- Import the processed .xef extension files which are in clips into the VGB by creating new solutions in VGB in which the clips are added to projects. The project, when created in the new solution, automatically splits into two, one for the building/training data and the other for the testing/analysis data as shown in the structure of figure 4-3. Figure 4-4 shows the screenshot of the trainer during the training of the lowering gesture. The figure shows the main project, the training and testing projects as well as the training and testing clips.

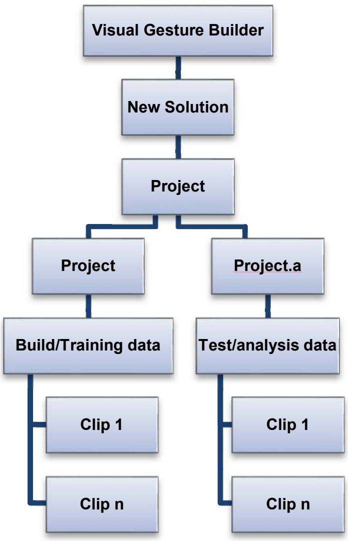


Figure 4-3 Solution Structure of the VGB

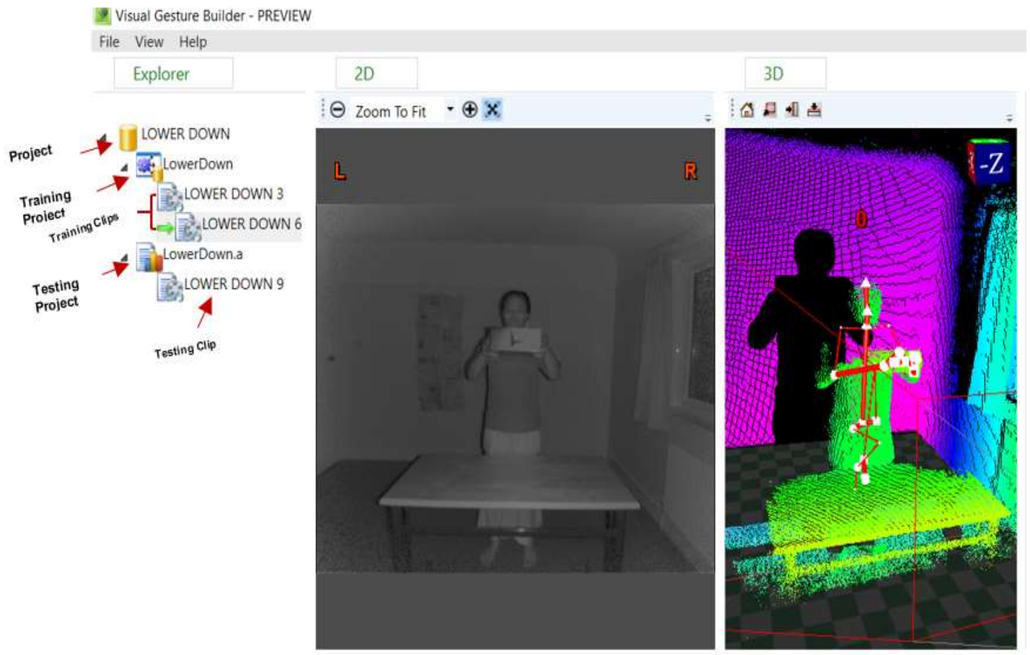


Figure 4-4 Screenshot of the VGB structure for training lowering gesture

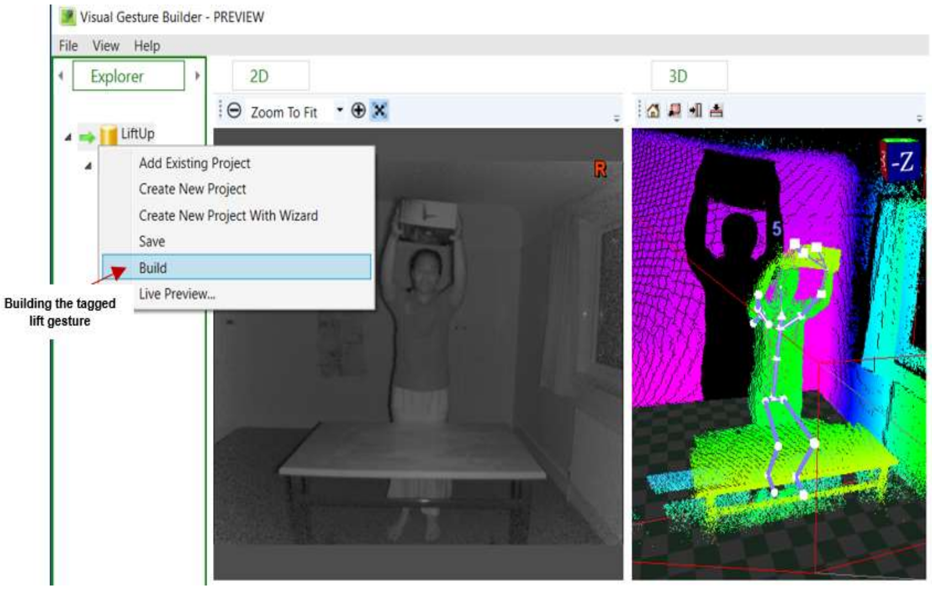
- The gestures are trained by tagging the recorded data in VGB. Figure 4-5 shows the training of the lift gesture by tagging. The blue horizontal lines depict the beginning to end of each lift. This means that the start of each blue line signifies the start of each lift and vice versa.

Name	Value	Type
LiftUp	True	BOOL

Blue horizontal lines show tagging of data

Figure 4-5 Training of the lifting gesture by tagging

- The next step is to build and analyse the trained gestures. This is achieved by right-clicking on the main project and selecting the 'build' menu button, as represented in figure 4-6.



Building the tagged lift gesture

Figure 4-6 The lift gesture is built in VGB

- The trained gestures' file generated after the build, is extracted and used to write appropriate codes in the DGB.
- The gestures are tested. The test is achieved by performing the specific task in front of the Kinect using the live preview tool of the VGB. The

live preview can be found by right-clicking the main project file in VGB as shown on figure 4-7, or by running the VGB-Viewer-Preview found in the Kinect for Windows SDK 2.0.

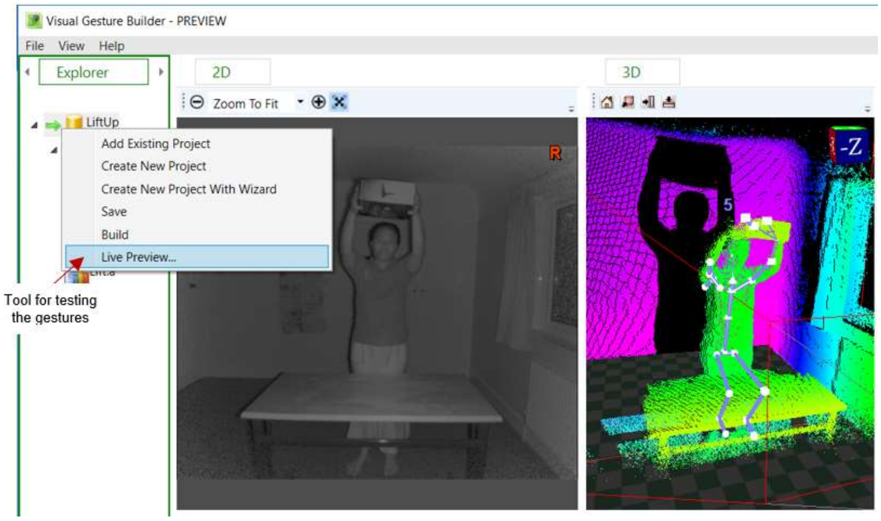


Figure 4-7 Live Preview button for testing the trained gestures

The experimental procedure described in this sub-section is summarised in figure 4-8.

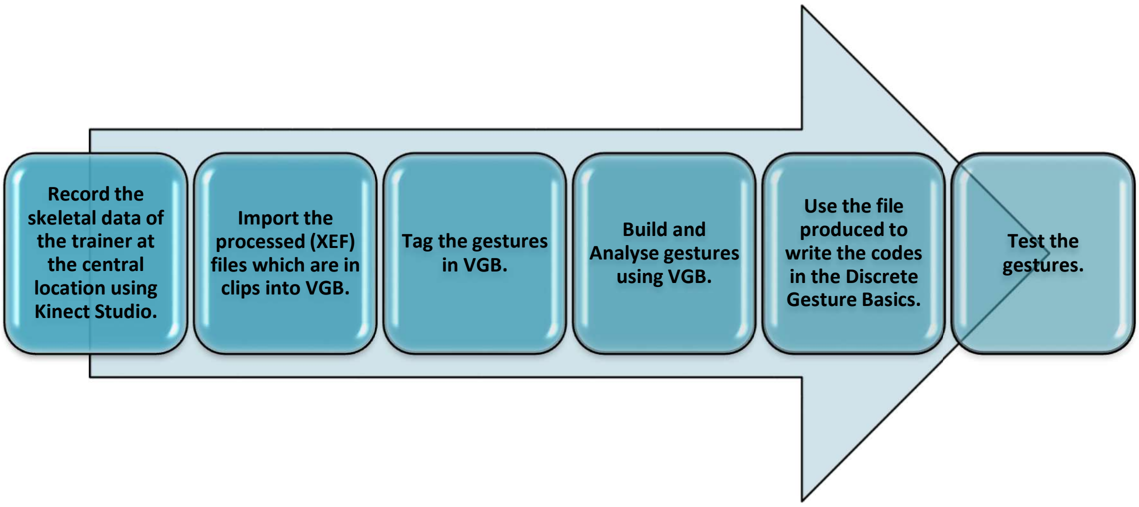


Figure 4-8 Steps by step method involved in the creation of manual handling gestures.

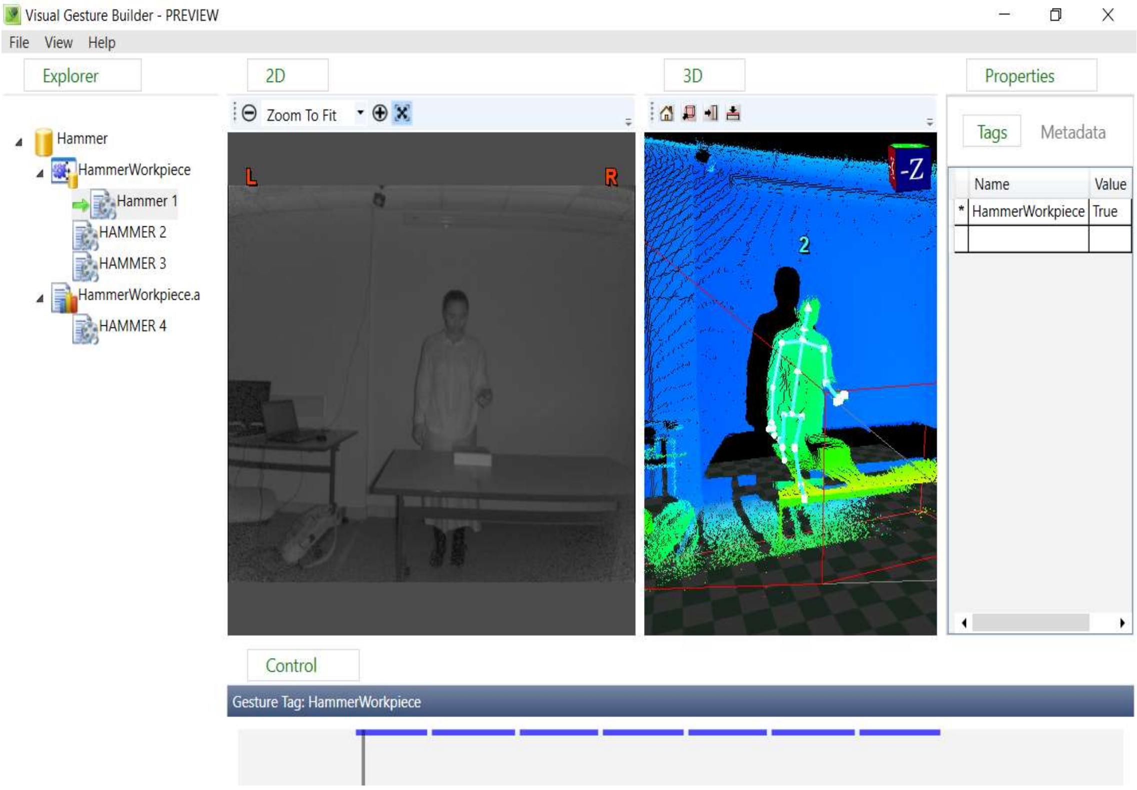
4.1.3 **Results of the Task Detection Experiment**

The results of training the lifting, lowering and hammering tasks are summarised in table 4-3.

Table 4-3 Summary of the training results for the three trained gestures

Gestures Description	Lifting Gesture	Lowering Gesture	Hammering Gesture
Total number of Gestures	32	30	40
Accuracy of True Positives per Frame and per Gesture (%)	100	100	100
Error of False Positives per Frame and per Gesture (%)	0	0	0

For instance, column four of table 4-3 depicts the summary of training results for the hammering gesture whose training and analysis clips, tagged gestures and screenshot of the trainer are presented in figure 4-9. This means that during the training of the hammering gesture as depicted in figure 4-90, a total of 40 hammering gestures were trained with a 100% true positive per frame and per gesture and a 0% false value.



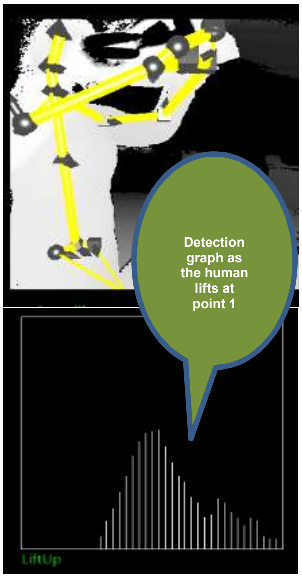
Name	Value
HammerWorkpiece	True

Gesture Tag: HammerWorkpiece

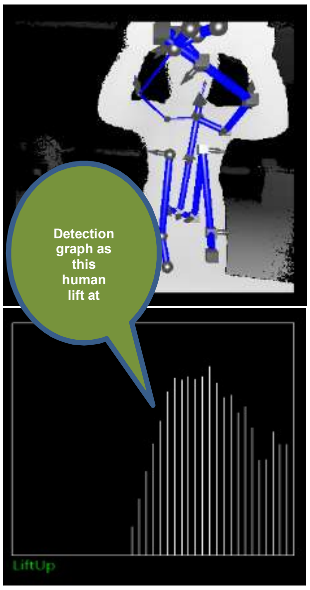
Figure 4-9 Training and analysis clips of the hammer gesture

The right-hand side of figure 4-9 shows a ‘true’ value when the operator begins to hammer and a false value as she stops hammering. This is the first indication that a hammering gesture has been trained.

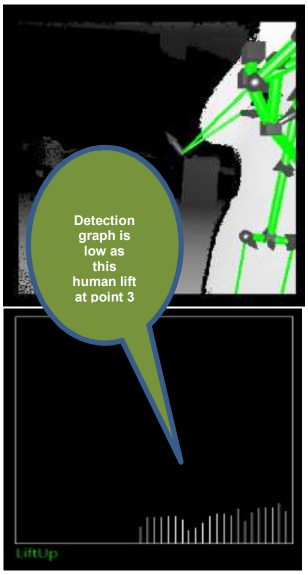
The gestures are first tested with the live preview tool after which they are coded in the DGB if the developer is satisfied with the detection results. The result of testing the gestures are represented by the lift gesture test result of figure 4-10.



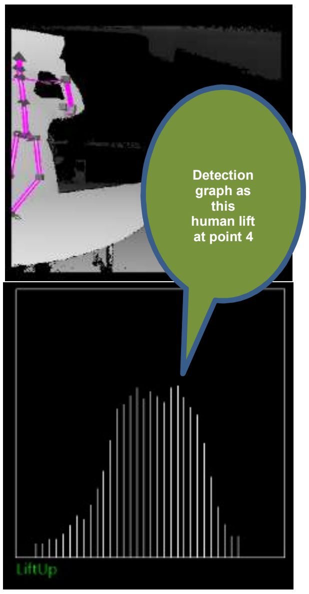
P_1



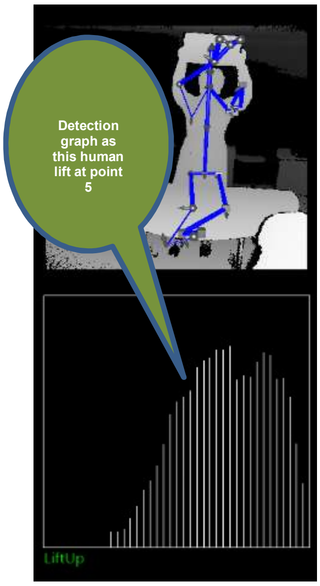
P_2



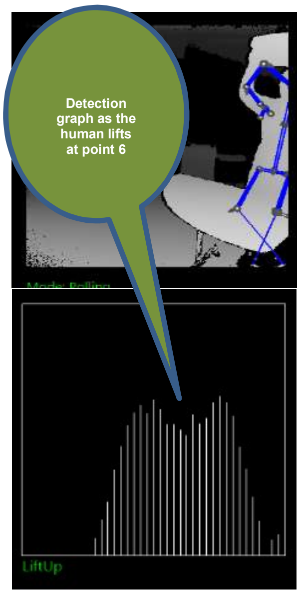
P_3



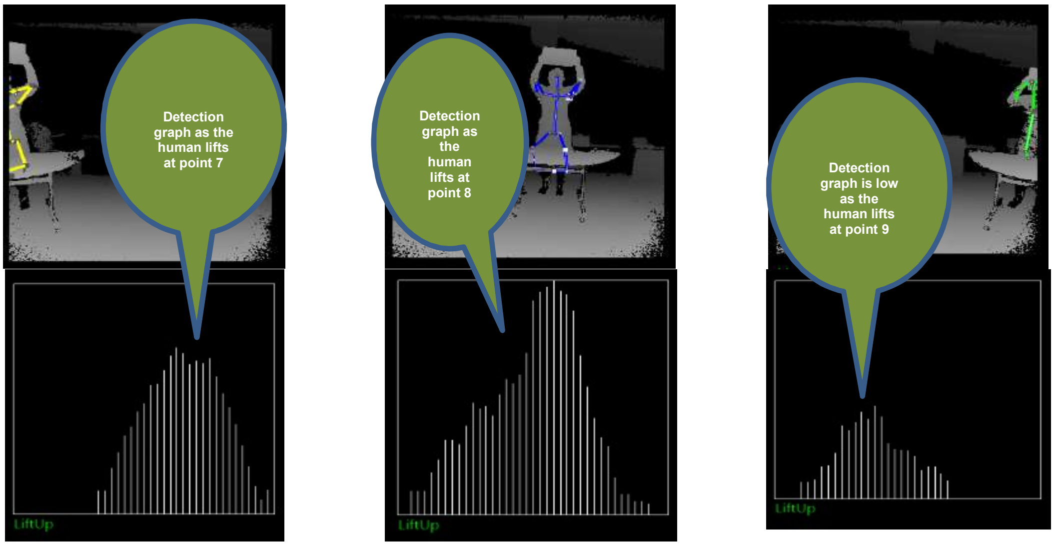
P_4



P_5



P_6



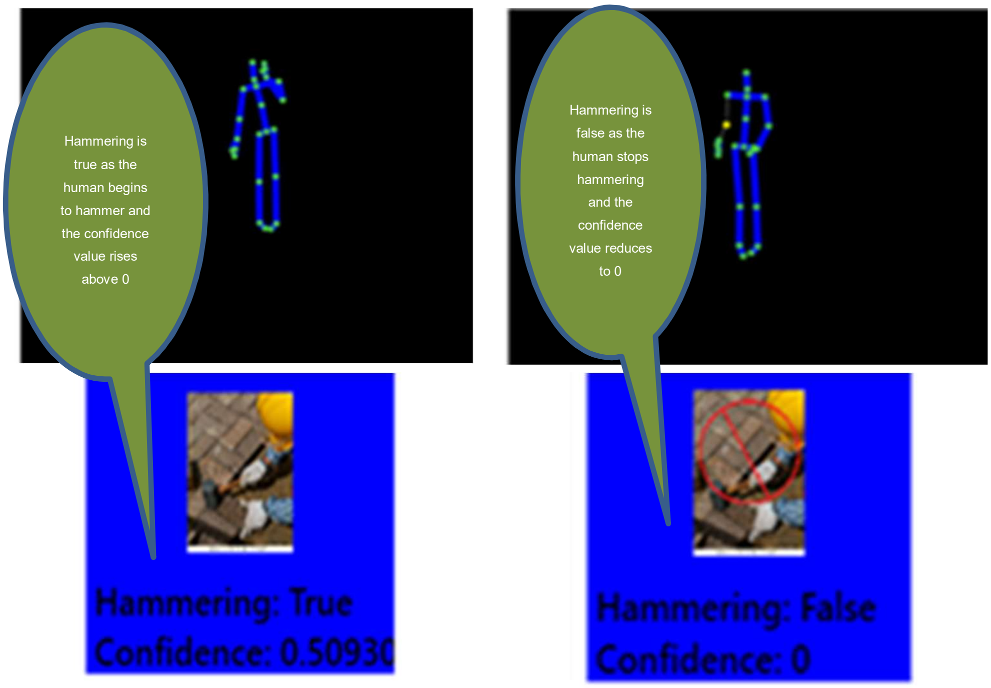
P_7 P_8 P_9

Figure 4-10 Live Preview result when the lift gesture is tested

The figure represents the capture of the lift-load live preview at the various locations as seen on table 4-2. We can deduce that a lift gesture is detected as indicated by the detection curves drawn as a human lifts load. The detection curves signify the confidence of gesture detection. At P_3 and P_9 for instance, the confidence of the Kinect at detecting gestures was very low and could suggest that Kinect placement in the environment might affect the accuracy of the data generated for real-time ergonomic assessment.

Furthermore, the file produced after the training is used to write appropriate lines of code in the DGB. Figure 4-11 shows the DGB result when an operator was tracked during a hammering task.

As soon as the operator begins to hammer, the hammering icon displays a 'True' value with the hammering confidence increasing from 0 to 1 (figure 4-11a), but if the operator stops hammering or starts another task, the value becomes 'False' for hammering and the hammering confidence reduces to zero. This shows a hammering gesture has been trained successfully and the Kinect has been made to recognise the hammering task on the shop floor.



a) **Hammering task**

b) Non-hammering task

Figure 4-11 Testing of the hammering gesture after coding in the DGB

Finally, the results obtained from training the gestures show that the Kinect, which is the hardware utilized for real-time ergonomic assessment in this research, can be made to detect manual handling tasks. The aim being to enable the user to determine the best locations where the Kinect can be placed during data collection for real-time ergonomic assessment.

4.2 Establishing the Best Setup for Kinect for accurate data collection on the Shop floor.

4.2.1 Overview

When using low-cost sensors such as the Microsoft Kinect for data collection towards yielding the much needed 3D human motion data for ergonomic evaluations, a good approach is recommended (Diego-Mas and Alcaide-Marzal, 2014; Okimoto and Teixeira, 2009). This is because incorrect placement of the Kinect on the shop floor can lead to inaccurate data due to measurement errors.

In time past, researchers who used the Kinect as a data collection tool used trial and error methods to establish the correct locations to place the sensor. This led to increased depth measurement errors and decreased depth resolutions as inaccurate placement of the sensor negatively affects the output. However, if the Kinect is well placed at a suitable position, data collection will be easier and more accurate. During real-time data collection, the sensor is placed at a location P_n. If $P_n$is a correct location, then the sensor will track the operator and capture his data which is fed into an ergonomic evaluation tool for onward ergonomic assessment. However, if $P_n$is incorrect, the operator may be partially tracked or may not be tracked and this means the sensor must be re-adjusted until the correct position of P_n is reached. This trial and error method wastes time and is highly unreliable as the likelihood of obtaining inaccurate skeletal data is increased.

Furthermore, the need to determine the best locations where the Kinect can be placed during data collection for real-time ergonomic assessment was established during the testing of the trained manual handling gestures using the Live Preview. It was discovered that at some locations within the sensor's horizontal FOV, the operator's gestures were not well tracked which led to low detection confidence. Therefore, this section presents the optimum location for Kinect placement setup for improved data capture in real-time ergonomic evaluations involving manual handling operations on the shop floor.

The gesture detection application developed in section 4.1, will be utilized in this study to track human skeletal data at different locations, at varied distances and heights, to establish the best locations for placing the hardware for better data capture towards real-time ergonomic evaluation.

4.2.2 **Methods**

To determine the optimum location for placing the Kinect for accurate data capture towards real-time ergonomic evaluation, three parameters were tested. These include the distance, height and horizontal field of view (FOV). Measuring points, each of which is defined by the three parameters, were set up. At each point, an operator lifts load at certain measured distance from the Kinect (from 2m to 4m), at an angle which is maintained within the FOV of the Kinect, that is 70° to the horizontal (i.e. between 55° to 125°), and the heights of the sensor varied between 1.2m, 1.7m and 2.2m. The points are described on table 4-4.

Table 4-4 Experimental setup showing the various points of placement

Points / Parameters	P_1	P_2	P_3	P_4	P_5
D_1 (m)	2.0	2.0	2.0	2.0	2.0
D_2 (m)	3.0	3.0	3.0	3.0	3.0
D_3 (m)	4.0	4.0	4.0	4.0	4.0
θ(°)	55	70	90	110	125

The angles are measured with a protractor with the measured points represented on the protractor as depicted in figure 4-12.

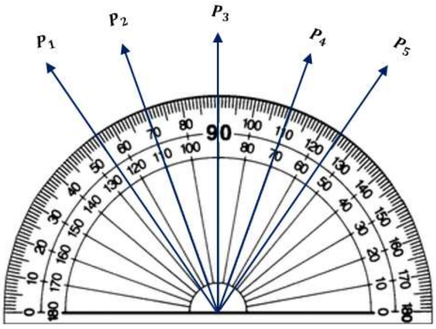


Figure 4-12 Measured points and angles on a protractor

At points 1-5, the Kinect is positioned at specified distances which range from 2m to 4m, and angles ranging from 55° to 125°, as seen on table 4-4. The height of the Kinect is also varied as represented in figure 4-13. At each distance, and for each specified angle placement and height of Kinect, an operator carries out a handling activity. This activity is captured using the developed application in DGB.

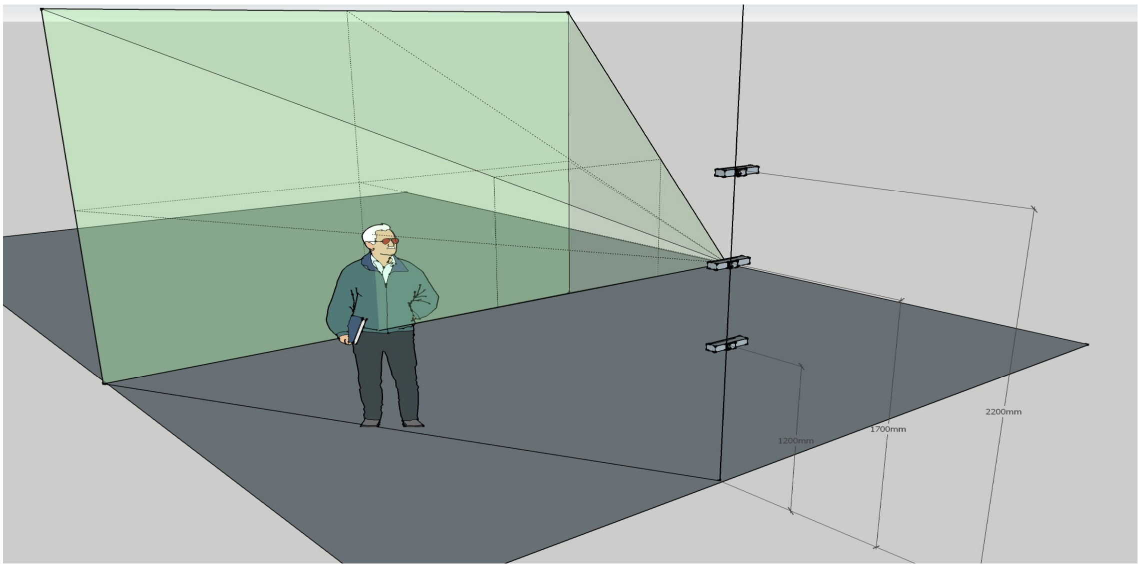


Figure 4-13 Experimental setup showing the various heights for Kinect placement

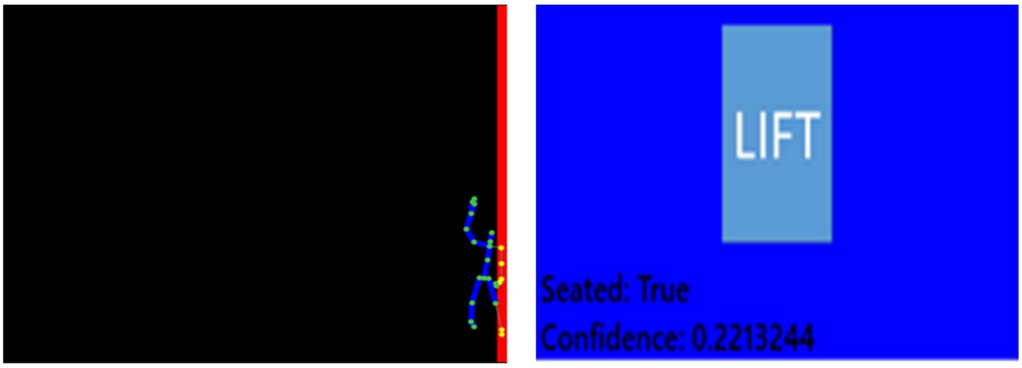
4.2.3 Experimental Results

Figure 4-14 shows an operator lifting a load at 3m distance and at 70° from the Kinect which is 1.2m high from the floor level while figure 4-15 represents an operator lifting at 4m distance, 125° angle and 2.2m height of Kinect. Other distances, angles and heights of the Kinect are described by table 4-4 and figures 4-12 and 4-13.

Seated: True

Confidence: 1

Figure 4-14 Load-lift at P_2,D_2, H_1 as represented by the Discrete Gesture Basics.



Seated: True

Confidence: 0.2213244

Figure 4-15 Load-lift at P_5, D_3, H_3 as represented by the Discrete Gesture Basics.

Tables 4-5 to 4-7 show the maximum confidence obtained at each of the location points for distances of 2m, 3m, and 4m respectively, as well as the computed area of the confidences. The computed area of confidence was calculated by taking an integral of the confidence values under the confidence curve during a load lift operation. The higher the confidence value at any point, the more the likelihood of the Kinect to track the operator at that point

Table 4-5 Results at a 2m distance for different heights.

Location Points	H (m)	θ (°)	Maximum Confidence	Confidence Area
P_1	1.2	55	0.53	41.07
P_1	1.7	55	0.62	40.54
P_1	2.2	55	0.51	37.64
P_2	1.2	70	1.00	88.03
P_2	1.7	70	1.00	86.51
P_2	2.2	70	0.87	72.06
P_3	1.2	90	1	99.27
P_3	1.7	90	1	98.27
P_3	2.2	90	1	89.81
P_4	1.2	110	0.97	84.48
P_4	1.7	110	1	107.59
P_4	2.2	110	0.99	76.79
P_5	1.2	125	0	0
P_5	1.7	125	0.36	26.31

P_5	2.2	125	0	0

Table 4-6 Results at a 3m distance for different heights.

Location Points	H (m)	θ (°)	Maximum Confidence	Confidence Area
P_1	1.2	55	0.34	17.35
P_1	1.7	55	0.56	27.94
P_1	2.2	55	0.29	18.66
P_2	1.2	70	1	78.14
P_2	1.7	70	1	83.52
P_2	2.2	70	1	84.08
P_3	1.2	90	1	117.65
P_3	1.7	90	1	88.25
P_3	2.2	90	1	93.07
P_4	1.2	110	1	87.98
P_4	1.7	110	1	73.27
P_4	2.2	110	1	88.91
P_5	1.2	125	0	0
P_5	1.7	125	0.30	12.64
P_5	2.2	125	0.45	25.74

Table 4-7 Results at a 4m distance for different heights.

Location Points	H (m)	θ (°)	Maximum Confidence	Confidence Area
P_1	1.2	55	0.37	19.02
P_1	1.7	55	0.4	26.38
P_1	2.2	55	0.34	20.80
P_2	1.2	70	1	81.76
P_2	1.7	70	1	70
P_2	2.2	70	1	74.64
P_3	1.2	90	1	80.78
P_3	1.7	90	1	78.26

P_3	**2.2**	**90**	**1**	**89.34**
P_4	**1.2**	**110**	**1**	**79.29**
P_4	**1.7**	**110**	**1**	**83.41**
P_4	**2.2**	**110**	**1**	**72.98**
P_5	**1.2**	**125**	**0**	**0**
P_5	**1.7**	**125**	**0.31**	**16.78**
P_5	**2.2**	**125**	**0.22**	**28.92**

Table 4-8 summarises the result of the Kinect placement experiment and shows using ‘YES’, ‘NO’ or ‘PARTIALLY’, whether the sensor can track an operator or not at each of the locations specified by points, distances, heights and angles.

‘YES’ means that the sensor can perfectly track and give correct data of the operator at the given location. ‘NO’ means that the sensor cannot track or ‘see’ the operator at that location. ‘PARTIALLY’ means that the sensor can track some of the operator’s skeleton but not all.

Table 4-8 Summary of the Experimental Results.

POINTS **PARAMETERS**	P_1	P_2	P_3	P_4	P_5
D_1, H_1	Partially	Yes	Yes	Yes	No
D_2, H_1	Partially	Yes	Yes	Yes	No
D_3, H_1	Partially	Yes	Yes	Yes	No
D_1, H_2	Partially	Yes	Yes	Yes	Partially
D_2, H_2	Partially	Yes	Yes	Yes	Partially
D_3, H_2	Partially	Yes	Yes	Yes	Partially
D_1, H_3	Partially	Yes	Yes	Yes	No
D_2, H_3	Partially	Yes	Yes	Yes	Partially
D_3, H_3	Partially	Yes	Yes	Yes	Partially

Figures 4-16 and 4-17 show the data in Tables 4-5 to 4-7 visually. The legends in the two figures represent the heights.

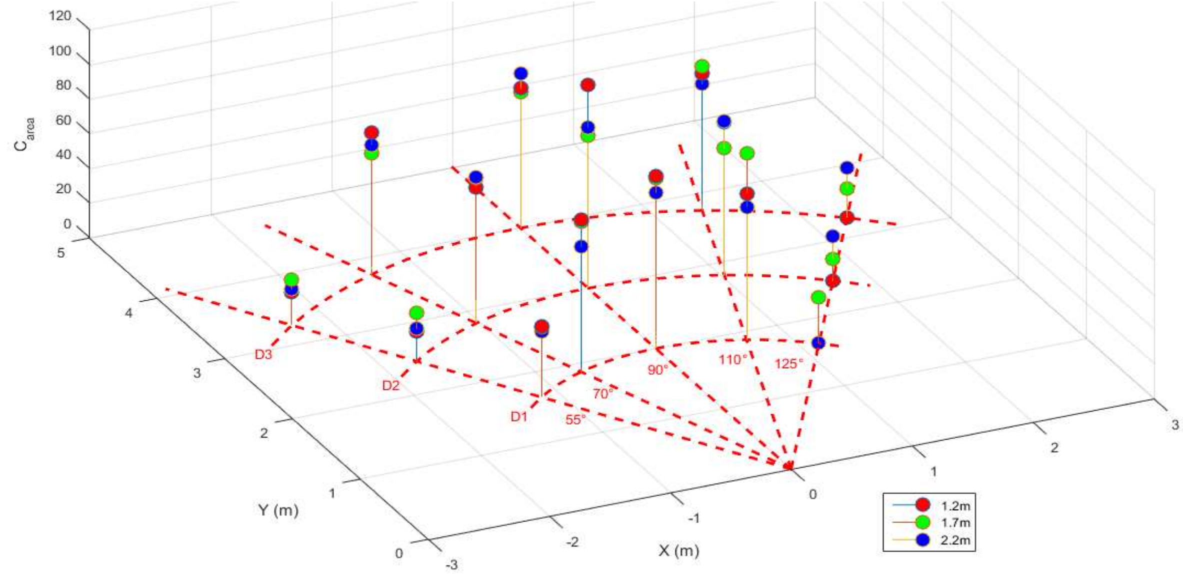


Figure 4-16 Computed confidence area (C_{Area}) under the confidence curve within a time frame of 10 seconds.

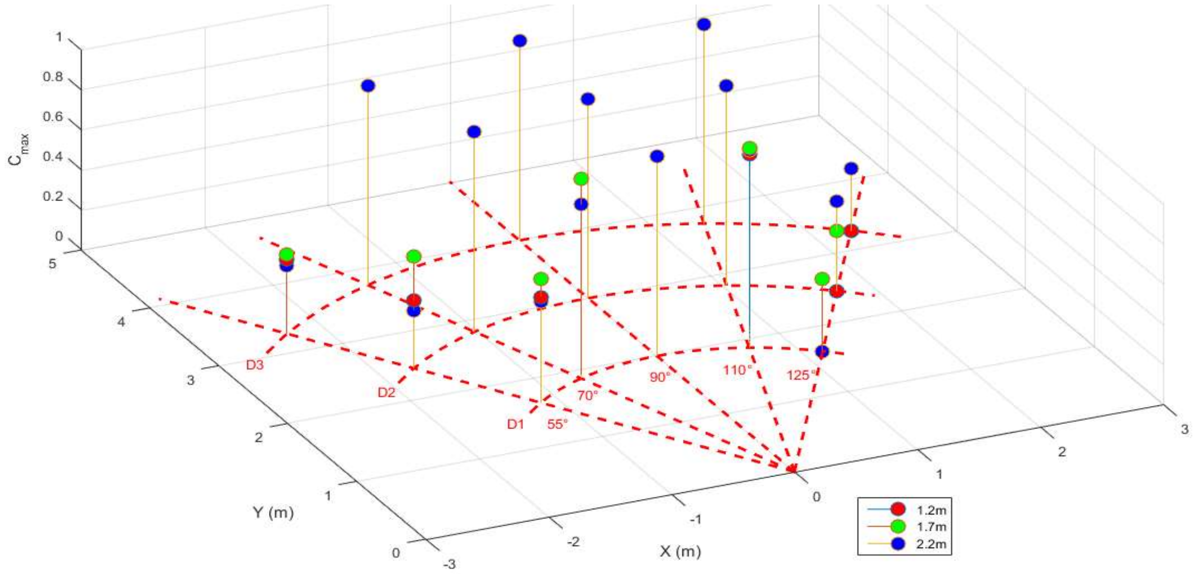


Figure 4-17 Maximum confidence C_{max} of the confidence curve within a time frame of 10 seconds

Finally, the DGB code was utilized to obtain the optimum position where the Kinect can be placed, to trigger accurate data capture at minimised measurement error.

Looking at figure 4-14, we see that the sensor can track all the skeletal joints of the operator and consequently display measurement results, hence the high confidence value of 1. However, a closer look at figure 4-15 shows that only some parts of the operator's skeletal data is tracked, hence the low confidence value of approximately 0.2.

Furthermore, table 4-8 shows that at the two extremes of the field of view (that is at 55° and 125°), the Kinect can only partially track humans as some of the skeletal information cannot be tracked. However, above 55° and below 125°, the Kinect can perfectly track and generate accurate joint information of the operator. Again, when the Kinect is maintained at 1.2m height and the operator is at distances between 2m to 4m, at angle 125° (+35°) from it, the sensor cannot see or track anything. Hence it is recommended that the Kinect should not be placed at these locations under any circumstance.

Therefore, it is recommended that during data collection for ergonomic evaluation on the shop floor using Kinect, the sensor should be placed at points $\boldsymbol{P_2}$, $\boldsymbol{P}_3$, $\boldsymbol{P}_4$, at distances between 2m to 4m, and heights of 1.2m, 1.7m and 2.2m as specified on table 4-8 to ensure better skeletal tracking and consequently, a robust output.

One limitation of this study is that the vertical field of view was not considered. To account for this however, the Kinect was constrained by placing it horizontally without tilting while other parameters were varied.

4.3 Skeletal Data Tracking and Computation of the Joint Angles of Humans

The accuracy of the Kinect to compute joint angles has been ascertained by Fernández-Baena, et. al. (2012) when the joint angles generated by the Kinect was compared with another optical motion capture system. The result showed the Kinect can be a very useful hardware for joint angle computation.

In this work, a data-retrieval program is developed which comprises of a set of written codes in C# programming language. It is developed using the APIs provided by the Kinect for Windows SDK 2.0 and the Windows Presentation Foundation (WPF) application of the .NET Framework 4.5 in Visual Studio 2013. It can track, measure and record the angle of the joints of any human and the 3D skeletal joint positions (x, y, and z) in millimetres. It is used on the shop floor to track and measure the joint angles of the operators, as they perform any manufacturing operation, for ergonomic evaluations, in conjunction with the Kinect sensor.

This section therefore describes in detail how the Kinect is programmed to track human skeletal data and compute joint angles which are needed for effective ergonomic assessment of shop floor operators.

4.3.1 Methods for Developing the Data-Retrieval Program

4.3.1.1 Initial Coding of the Sensor to Track Human Skeletal Data and Compute 3D Joint Positions.

The coding of the Kinect towards tracking skeletal joint data follows some important stages which are described in this sub-section.

- First the developer opens a new project which is a WPF application in the .NET framework 4.5 of the visual C# template. This displays the main window.
- From the solution explorer, right-click on the reference icon and select suitable references in the assembly extension. This includes the Microsoft·Kinect.
- Start adding the appropriate codes. First, rename the namespace accordingly, get the sensor, create the multi frame source reader, which grants access to all the streams. Create the comma-separated values (CSV) file and the database using the csv file writer and the SQL connection code respectively. The CSV file writer and SQL connection codes are meant to store the data generated using the application in specified databases.
- Initialise the sensor and define the 3D points joint position world space for each of the joints in x, y, z coordinates. Initialise the multi frame source reader for color, infrared, depth and body streams and check for null values.

The ‘null’ values are used throughout the code to crosscheck if there is any missing value.

- Call the body frame reference. This is used to track the skeletal data. Check for null body frames and initialise the body stream using appropriate code. The code enables the sensor to track the bodies within its field of view. This includes codes that enable the sensor to track the 3D joint positions for all the 25 joints in millimetre.
- Map the coordinates. To successfully draw the skeleton, the 3D point joint positions in world space will be mapped into the color 2D spaces. The joint position color space represents the location of each pixel of the color image in 2D.
- Draw the skeleton.
- Store the skeletal data.

The next step is to calculate the 3D vectors for each joint position and compute the joint angles. This is fully described in the next sub-section.

4.3.1.2 Calculation of Joint Vectors and Joint Angles

The vectors are calculated based on the MSDN's skeleton's position in relation to the human body. Recall that from figure 1-1b, each of the 25 joints are numbered from 0 to 24. For instance, 0 represents the spine base, 1 represents spine mid while 3 equals head.

The vectors are of utmost importance for each of the joint as they are used to compute the joint angles of each joint. To get the vectors, the 3D skeletal positions in world space, which outlines the values of joint types in a skeleton, is utilized.

To get the joint angles for each joint, the dot product of vectors is introduced as depicted in the following expression:

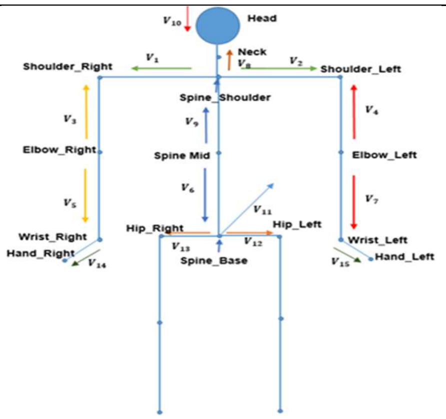
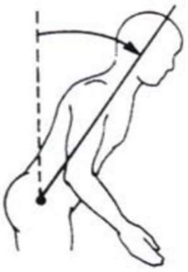
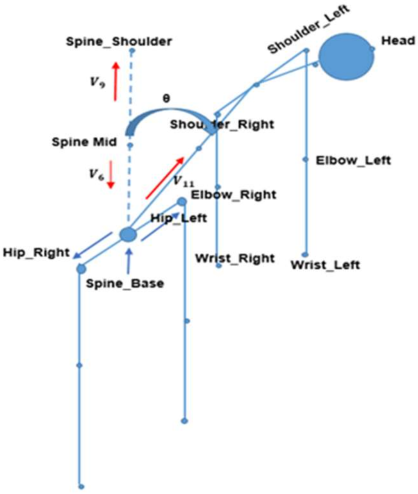
$$\boldsymbol{A}.\boldsymbol{B} = |\boldsymbol{A}||\boldsymbol{B}|\boldsymbol{cos\theta} \qquad 4\text{-}1$$

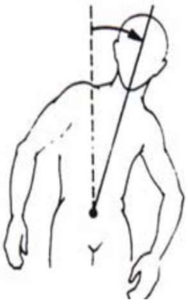
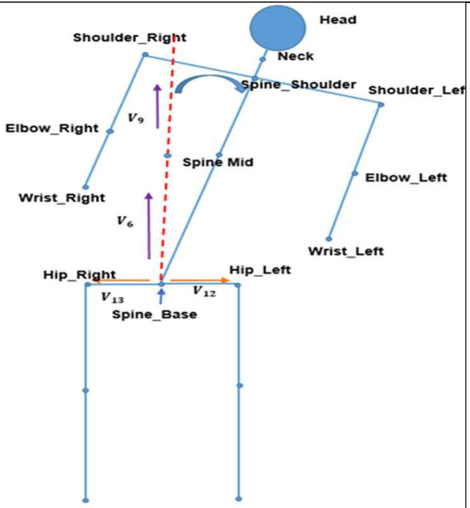
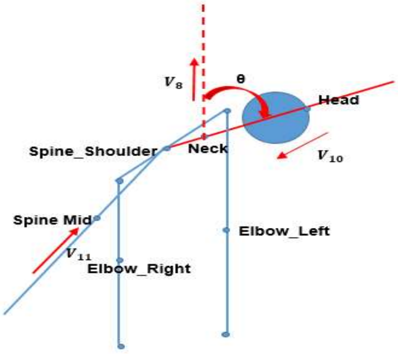
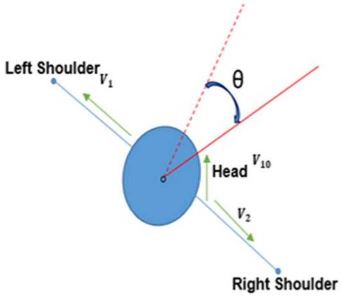
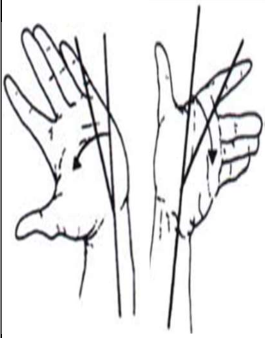
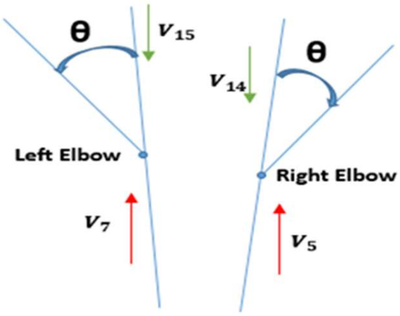
Where $\boldsymbol{\theta}$ is the joint angle, A and B are joint vectors.

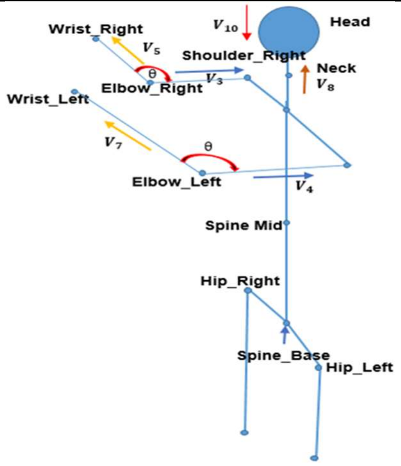
This is coded for each joint using appropriate lines of code. Only joints of the upper body are coded in this work.

The table below describes dummies of various postures and that of human body on which the vectors are represented and show the relationship between these vectors and the joint angles of humans for specific postures. For instance, the angle between vectors V_9 and V_{11} yields the flexion/extension data of the Trunk/Spine (also known as back). This is because the back/truck/spine vector has been defined as the vector connecting the spine base to the spine shoulder (Manghisi et al., 2016). Hence, the back is represented by the 'spine base'. Again, the lateral bending of Trunk/Spine/back to the left is defined by the angle between vectors V_6 and V_{12} while bending the back to the right is computed as the angle between vectors V_6 and V_{13}. Details of some joint angle computation and their corresponding vectors are found on table 4-9.

Table 4-9 Vector Computation table

S/N	**Posture**	**Posture Representation**	**Dummies showing Relevant Vectors**	**Angle Computation with the Vectors**	
				Angle Between	
1	**Neutral**			-	-
2	**Flexion / Extension of Trunk / Spine**			V_9	V_{11}

3	**Lateral Bending of Trunk/Spine** **1. Leaning to the left** **2. Leaning to the right**			1. V_9 2. V_9	1. V_{12} 2. V_{13}
4	**Flexion and Extension of Neck**			V_8	V_{10}
5	**Twisting of Neck**			1. V_{10} 2. V_{10}	1. V_2 2. V_1
6	**Side by Side Hand movement**			1. V_5 2. V_7	1. V_{14} 2. V_{15}

7	**Arm Movement (Elbow)**			**1.** V_4 **2.** V_3	**1.** V_7 **2.** V_5

The steps followed to develop the application are summarised in the flowchart of figure 4-18.

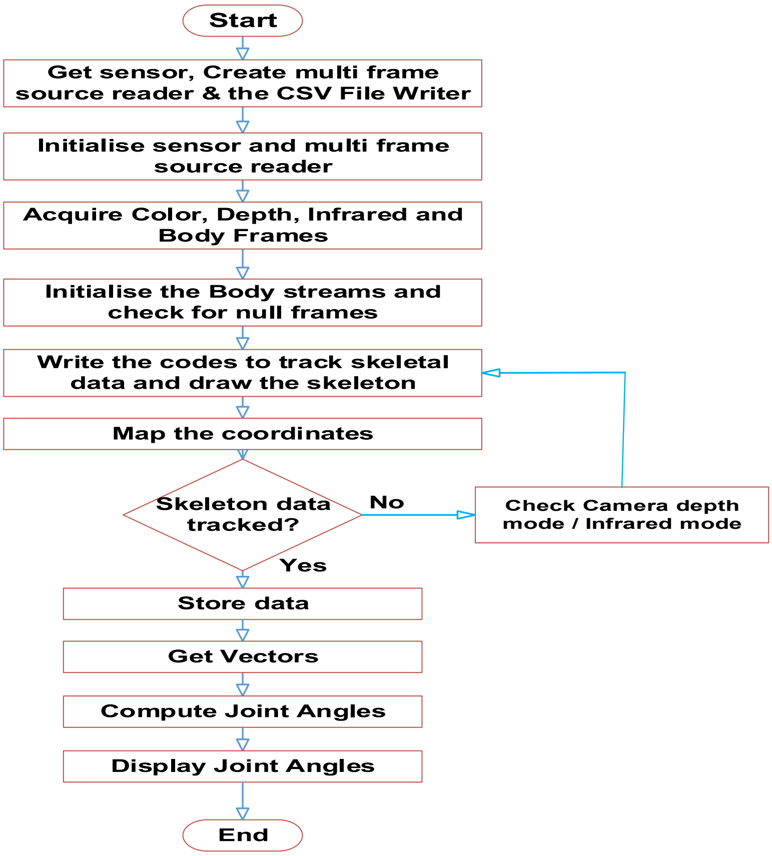


Figure 4-18 Program flow chart

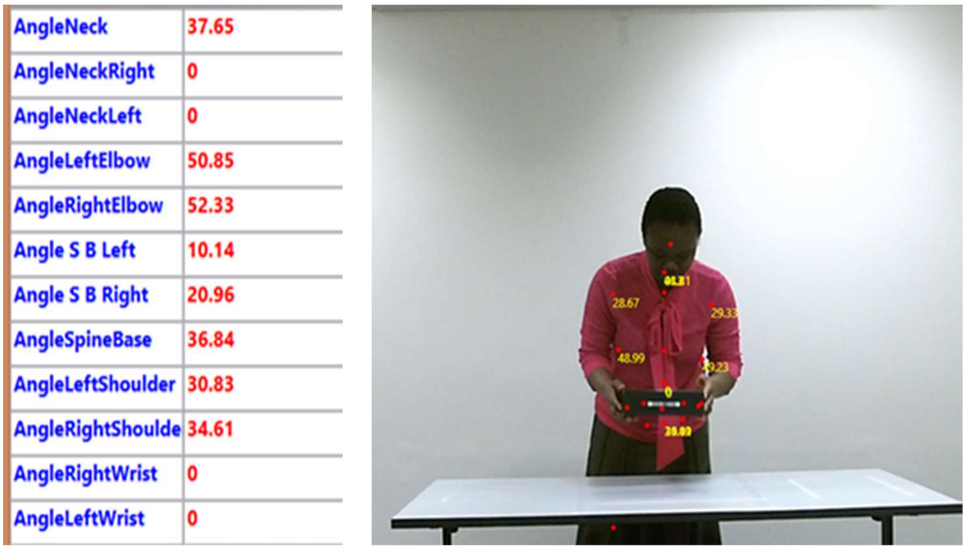
The pseudo code of the developed algorithm is written thus:

- Open a new Main Window from a WPF application in the .NET framework 4.5 of the visual C# template.

- Add relevant references to the project.
- In the Main Window
    - Call the sensor
    - Create the multi frame source reader.
    - Create the comma-separated values (CSV) file.
    - Create the database using the csv file writer and the SQL connection
    - Open the sensor
    - Initialise the multi frame source reader for color, infrared, depth and body streams
        - Call the body frame reference.
        - check for null values.
    - Map the coordinates.
    - Draw the skeleton.
    - Store the skeletal data.
    - Get the Vectors.
    - Compute the joint angles.
    - Display the joint angles

4.3.2 **Result of Testing the Program**

After coding the joint angles, various humans are tested to ascertain if the program can track their skeletal joint data. Figure 4-19 shows a human tracked by the application while bending to carry a parcel. The joint angles are tracked and displayed on the screen in real-time. This data can be viewed by even the human. The 3D joint position in millimetres are stored in the created csv file and can be generated offline.



AngleNeck	37.65
AngleNeckRight	0
AngleNeckLeft	0
AngleLeftElbow	50.85
AngleRightElbow	52.33
Angle S B Left	10.14
Angle S B Right	20.96
AngleSpineBase	36.84
AngleLeftShoulder	30.83
AngleRightShoulde	34.61
AngleRightWrist	0
AngleLeftWrist	0

Figure 4-19 Tracking of human while working

The displayed joint angles are made to display at intervals as determined by the user, using some lines of code. The displayed data can be interpreted thus: At the time of capture, the neck is flexed by 37.65° without any form of twisting to the right or left, the left and right elbows are bent upward 50.85° and 52.33° respectively, the trunk is moved 10.14° to the left, 20.96° to the right, and 36.84° forward, the left and right shoulders are moved 30.83° and 34.61° away from the body respectively while the wrists are not deviated or bent.

For best results while using the developed program, the user should face the sensor (Diego-Mas and Alcaide-Marzal, 2014), as the orientation of the person been tracked by the Kinect often affects the quality of data generated (Daphalapurkar, 2012).

4.4 Chapter Summary

For real-time motion data capture and ergonomic evaluations on the shop floor using the Kinect, the sensor has been prepared to detect manual handling tasks on the shop floor. This is because for the Kinect to be made to collect motion data effectively during any manual handling task, it must be trained to detect these tasks. The result of this study is very important as it provides a guide for ergonomists and other researchers as to the correct locations for Kinect placement during data capture on the shop floor. The application is to be used by an operator to verify skeletal data during data collection towards ergonomic analysis. It can help to inform a user if measurement errors exist. It is also useful in the determination of the correct location for sensor placement during real-time data capture and ergonomic assessment. The best positions for Kinect placement are found within some boundaries which include the horizontal field of view of the Kinect which is 70°. Distances of the operators from the sensor as well as the heights of the Kinect, within which the sensor yields good results, are also recommended. However, at the two extremes of the field of view, the Kinect can either partially track humans or not track at all.

The program which is utilized for task detection and helpful in determining best placement location, is mostly required during the data collection stage. However, for ergonomic evaluation using the Kinect, the skeletal data of the operators are required. Hence, a program is written, which tracks the skeletal data of the human operators, measures and displays the joint angles of the operators as they perform their tasks. The application, when tested, proved to yield good joint data which is displayed in real-time to the operator.

Finally, the application developed from the VGB experiment is intended to be integrated with the skeletal data retrieval program for effective ergonomic evaluation. The framework of figure 4-20 shows a proposal on how the Kinect can utilize these developed applications to effectively extract the motion data of human operators for ergonomic evaluations on the manufacturing shop floor.

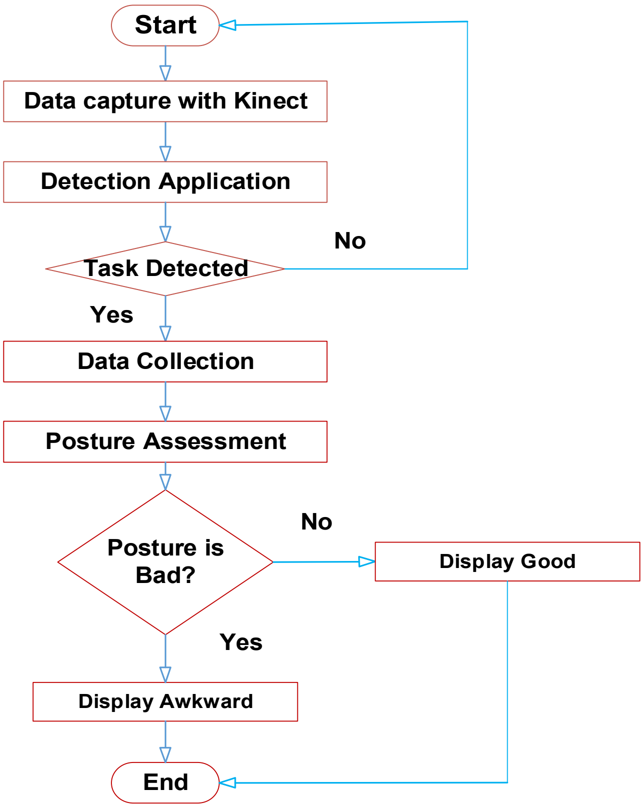


Figure 4-20 A framework for real-time ergonomic evaluation using Kinect.

The next chapter will describe how the ergonomic H&S compliance assessment tool is developed from a knowledge base integrated with the applications developed in this chapter.

5 HEALTH AND SAFETY STUDIES AND THE DEVELOPMENT OF REAL-TIME POSTURE ASSESSMENT EXPERT SYSTEM

H&S professionals of different countries provide guidelines and tools to assess worker's safety and identify awkward postures that can lead to WMSDs during manual handling activities on the shop floor. Research has revealed the existence of ergonomic tools for posture analysis using 3D motion sensors. However, none of this research focuses on real-time H&S compliance assessment concerning the worker's awkward postures (see chapter 2).

This chapter therefore presents a knowledge-based ergonomic assessment tool that can capture, analyse and assess the postures of workers in real-time, with total compliance to the H&S guidelines. In this chapter, the H&S recommendations on ergonomic evaluation of manual handling tasks and risk assessment of work postures are comprehensively studied with the aim of identifying the relevant and acceptable guidelines for manual handling and identifying specific posture assessment definitions. The identified definitions form the knowledge base of the proposed knowledge-based system. Apart from the knowledge base, posture assessment categories and scoring system, the inference engine, which constitutes the if-then-construct of the system are all developed in this chapter. The resultant tool for posture assessment is tested on some case studies and statistically tested for reproducibility and reliability

The chapter's focus is three-fold and includes:

- Development of the knowledge base of the proposed system. To successfully develop the knowledge base, the H&S guidelines on manual handling and posture assessment of some selected countries are studied, with the relevant definitions for posture assessment of manual handling tasks extracted. Again, the posture assessment categories and scoring system are established.
- Development of the inference engine that constitutes the if-then-construct of the system.

- Testing the developed posture assessment tool on some case studies. This also involves statistical analysis of the developed tool for consistency in generating reliable and reproducible joint data.

5.1 H&S Guidelines on Manual Handling and Posture Assessment

As highlighted in section 2.3, the government approved H&S regulators of four countries with strong health and safety policies, were chosen from different continents (North America, Europe, and Asia), with the United Kingdom included as the host country. The countries are the United States of America, Singapore, Germany and the United Kingdom. The selected regulators from these countries are defined on table 5-1 (BAuA, n.d.; HSE, n.d.; OSHA, n.d.; WSH Council, 2017).

Table 5-1 H&S Regulators of the Selected Countries

SINGAPORE (WSH Council)	USA (OSHA)	Germany (BAuA)	United Kingdom (HSE)
The Workplace Safety and Health (WSH) Council, which was established in 2008, is a major H&S Regulator in the country. It works in collaboration with the countries' Ministry of Manpower, and other government agencies as well as industries, with focus on improving the workplace safety and health in the country by implementing acceptable H&S practices.	The Occupational Safety and Health Administration (OSHA), a part of the US Department of Labor, was created by the US Congress in 1970, to regulate H&S, enforce standards, train and assist the workforce in the country.	In Germany, the federal government and the state enforces the H&S regulations while the accident insurance institutions ensure accident prevention. Hence the Joint German Health and Safety Strategy (GDA), which serves as interface between the two, was developed. The GDA, which is developed and controlled by the National Occupational Safety and health Conference, is tasked with improving the H&S of workers. The Federal Institute for Occupational Safety and Health (BAuA) is a body under the GDA.	The Health and Safety Executive (HSE), approved over 40 years ago, regulates the health and safety of workplaces in the Great Britain. Its mission is to prevent injuries, ill-health and death in UK workplaces.

5.1.1 UK HSE's Guidelines on Manual Handling and Posture Assessment

HSE identifies manual handling of heavy loads and awkward postures as risk factors that can lead to WMSDs. It uses ergonomic approach to assess manual handling activities by considering the load, task, individual capability and the environment (Health and Safety Executive, 2016 - http://www.hse.gov.uk/pubns/priced/l23.pdf).

HSE has recommended guidelines and strategies for minimising the rate of occurrence of awkward postures during manual handling operation (HSE - ART tool: Posture - http://www.hse.gov.uk/msd/uld/art/posture.htm).

5.1.1.1 Guidelines for manual handling of loads

Generally, before starting the manual handling activity, HSE recommends that the operator should first think and plan how to undertake the specific handling task. The following guidelines for handling in workplaces are also recommended by HSE (Health and Safety Executive, 2012, 2016):

- Adopt a stable position with feet apart, before lifting as shown in figure 5-1a. Hug the load close to the body and to the waist, with the feet moved (see figure 5-1b).

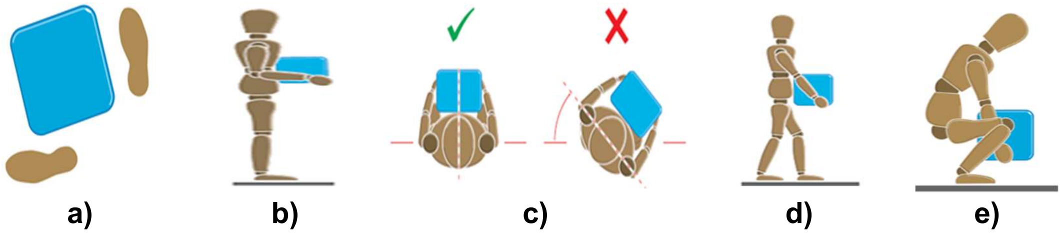


Figure 5-1 Recommended position while handling a) Feet apart b) Load hugged close c) Turning and twisting while handling d) Head held straight e) bending the knees to avoid deep squatting and stooping

- Avoid turning, twisting the trunk and leaning sideways while handling. Full risk assessment should be undertaken if the handling involved both turning and twisting as shown in figure 5-1c.
- Straighten the head, move smoothly and do not jerk the load, during handling (see figure 5-1d).

- Avoid lifting from floor level or above shoulder height.
- Do not stoop or squat, instead, bend the back, hips and knees moderately (see figure 5-1e).
- Keep frequently used items at about 450mm from the Operator to avoid excessive reaching.
- Modify hand tools to enable straight wrists.
- The carrying distance should not exceed 10m at a time. Otherwise, carry the load on the shoulder.
- Pulling/pushing force required to move the load through a flat or level surface is 2% of the weight of the load while 10% is needed for soft and uneven surfaces.
- Training should be provided for all staff

Guidance for Weight during Handling

The recommended weights while handling, are represented in figure 5-2. The boxes in figure 5-2 represent different zones through which the hand passes during handling. If it passes more than one box at a time, then the lowest weight applies. Intermediate weight is chosen if the hands are on the boundary of two boxes (Health and Safety Executive, 2016 - http://www.hse.gov.uk/pubns/priced/l23.pdf) .

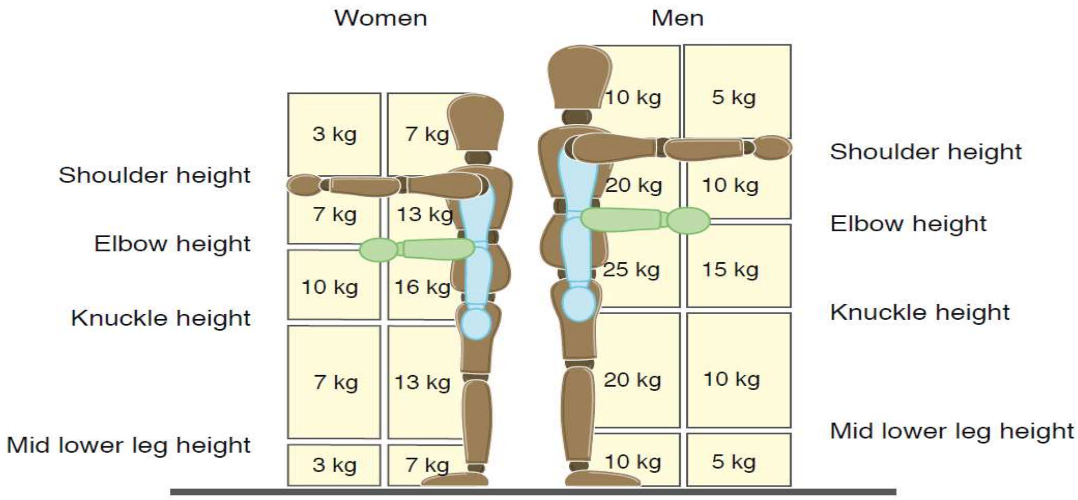


Figure 5-2 Recommended weight during handling

The weight decreases as the arm is extended during handling. Detailed assessment should be done if the manual handling activity exceeds the weights represented in the boxes above for infrequent operations of about 30 operations/hr or 1 lift/2min (Health and Safety Executive, 2016 - http://www.hse.gov.uk/pubns/priced/l23.pdf).

Acceptable Load Weight at Different Frequencies of operation

The various weights of load at different frequencies of operation as recommended by HSE is presented on table 5-2 (Health and Safety Executive, 2016). The table shows acceptable load weights when handling at waist height, knee height and at floor level.

Table 5-2 Acceptable weight for load carried at different body heights and frequencies of operation.

FREQUENCY	WEIGHT OF LOAD FOR MALE (kg)	WEIGHT OF LOAD FOR FEMALE (kg)
Waist height		
30 operations per hour	≤ 25	≤ 16
1 or 2 per minute	≤ 18	≤ 11
5 to 8 times per minute	≤ 13	≤ 8
More than 12 times per minute	≤ 5	≤ 3
Knee height		
30 operations per hour	≤ 20	≤ 13
1 or 2 per minute	≤ 14	≤ 9
5 to 8 times per minute	≤ 10	≤ 7
More than 12 times per minute	≤ 4	≤ 3
Floor level		
30 operations per hour	≤ 10	≤ 7
1 or 2 per minute	≤ 7	≤ 5
5 to 8 times per minute	≤ 5	≤ 4
More than 12 times per minute	≤ 2	≤ 1

5.1.1.2 Guidelines for Sitting to Handle

Unsuitable seating causes workers to adopt awkward postures. Therefore, one of HSE's legal requirements for employers is to provide safe and suitable seating for their workers (Health and Safety Executive, 2011 - http://www.hse.gov.uk/pUbns/priced/hsg57.pdf).

Seats should be designed to be adjustable, with back rests, which give firm support to the spine. Arm rests, footrests and mobile (swivel) chairs should be provided whenever needed so as to reduce the rate of occurrence of awkward postures and WMSDs (Health and Safety Executive, 2011 - http://www.hse.gov.uk/pUbns/priced/hsg57.pdf).

Again, frequently used workpieces and equipment should be kept within close reach of the operators to avoid awkward twisting and stretching that can strain the back (Health and Safety Executive, 2011 - http://www.hse.gov.uk/pUbns/priced/hsg57.pdf).

Guidelines for safe manual handling of seated workers include:

- The weight of load for both men and women while seated should not exceed 5kg and 3kg respectively.
- Avoid awkward stretching and twisting by placing objects within the reach distance of -0.6m to +0.6m along the horizontal plane
- Ensure the workplace is well lighted to avoid adoption of awkward postures by the workers.
- Adjust the seat to enable you sit comfortably depending on the task.
- Avoid sitting to lift because it strains the back. If not, keep the object to be lifted close to the body.
- Work surface thickness of about 0.03m should not be exceeded.
- Avoid bending and twisting while sitting to handle rather place the load/materials at waist height on a rack.
- Avoid sitting to handle heavy loads.

The following seat dimensions should be ensured;

- Adjustable seat height of 0.38m to 0.56m.
- Well-padded sitting surface of about 0.4m.
- Backrests with adjustable tilt angle of +5° to -5° and 90° to 110° angle with the sitting surface at adjustable height of between 0.17m to 0.3m.

- Adjustable armrests of 0.2m to 0.25m if needed (some jobs may not require armrests).
- Footrests for workers who need them.
- Chairs should pass the test stipulated in BS 5459 to be suitable for use.

5.1.1.3 UK HSE’s definitions for posture assessment of manual handling tasks

According to HSE, an awkward posture occurs when a part of the body deviates from its neutral position (Health and Safety Executive HSE Books, 2002). “A neutral position occurs when the trunk and head are upright, with the arms by the side, and forearms hanging straight or at a right angle to the upper arm, while the hand is in the handshake position” (HSE - ART tool: Risk factors - http://www.hse.gov.uk/msd/uld/art/riskfactors.htm).

Awkward postures, whose examples are depicted in figure 5-3 (Health and Safety Authority, 2005), occur when:

- A worker handles a load below mid-thigh thereby forcing him to bend his back.
- Loads are handled above shoulder height.
- Trunks are twisted during handling.
- A worker bends below mid-thigh.
- The wrists are bent or deviated
- A worker reaches behind or across the body with the shoulder, etc.

a) **Awkward bending**

b) **Lifting above the shoulder height**

c) **Awkward bending and twisting of the back**

Figure 5-3 Awkward postures

Awkward postures can be reduced by simply reducing the rate of holding the postures when performing a task (HSE - ART tool: Posture http://www.hse.gov.uk/msd/uld/art/posture.htm). HSE recommends the use of the RULA or REBA scores for assessment of work postures as they provide a scoring system for the assessment of both static and dynamic work postures (Darby, 2008; Health and Safety Executive, 2009).

Head/Neck Posture

The neck is classified as bent when there is an apparent angle between the neck and back during handling (HSE - Awkward Postures, 2015). Figure 5-4 describes awkward neck/head with respect to its repetitiveness as defined by the HSE ART tool (Health and Safety Laboratory & for the Health and Safety Executive, 2009; HSE - ART tool: Awkward postures - http://www.hse.gov.uk/msd/uld/art/awkpostures.htm).

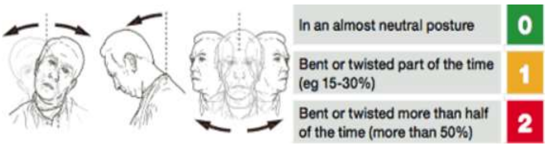


Figure 5-4 Straight neck, bent or twisted neck in awkward position

The green colour indicates neutral position, amber colour indicates awkward posture held for 15-30% of the task duration while the red colour shows an awkward posture held more than 50% of the task duration.

Back Posture

The back posture is classified as awkward when the back is bent or twisted more than 20° as depicted in figure 5-5 (Health and Safety Laboratory & for the Health and Safety Executive, 2009; HSE - ART tool: Awkward postures - http://www.hse.gov.uk/msd/uld/art/awkpostures.htm).

Figure 5-5 Back bent about 20° forward

Arm Postures

According to HSE, “Reaching upwards places additional stress on the arms and back. Control of the load becomes more difficult and, because the arms are extended, they are more likely to be injured”, (Health and Safety Executive, 2016 - http://www.hse.gov.uk/pubns/priced/l23.pdf). Hence, the arm posture is classified as awkward when the elbow is raised to around chest height and the arm is unsupported as represented in figure 5-6 (Health and Safety Laboratory & for the Health and Safety Executive, 2009; HSE - ART tool: Awkward postures - http://www.hse.gov.uk/msd/uld/art/awkpostures.htm).

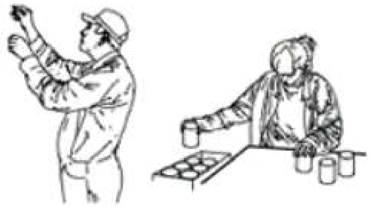


Figure 5-6 Raised and unsupported arms

Wrist Posture

The wrist is classified as bent or deviated if there is a noticeable angle on the wrist as in figure 5-7 (Health and Safety Laboratory & for the Health and Safety Executive, 2009; HSE - ART tool: Awkward postures - http://www.hse.gov.uk/msd/uld/art/awkpostures.htm).

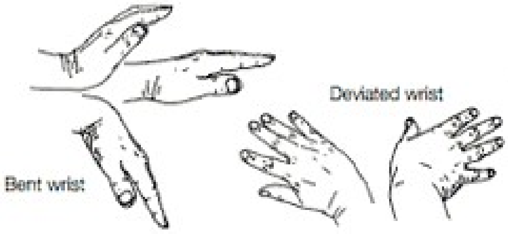


Figure 5-7 Bent and Deviated Wrists

5.1.2 US, Singapore and Germany’s Guidelines on Manual Handling and Posture Assessment

5.1.2.1 Guidelines for manual handling of loads

Table 5-3 summarises the recommended guidelines for safe manual handling by the OSHA, the WSH Council and the BAuA (BAuA, 2012; Federal Institute for Occupational Safety and Health (BAuA), 2015; Occupational Safety and Health Administration, 2004; OSHA-Heavy Lifting, n.d.; OSHA, 2004; OSHA 2236, 2002; OSHA Technical Manual, n.d.; Steinberg, 2012; WSH (Workplace Safety and Health) Council, 2014). Proactive H&S practices aimed at preventing accidents and injuries in workplaces are recommended against the traditional approach which addresses the problem after the injuries has been done to the worker (OSHA, n.d.). These proactive practices are presented on table 5-3.

Table 5-3 Guidance for Safe Manual Handling in Different Countries

UNITED STATES OF AMERICA (OSHA)	GERMANY (BAuA)	SINGAPORE (WSH Council)
• Ensure stability before lifting. • Keep the elbows close to the body with the legs moving while lifting • Avoid excessive bending or twisting, rather turn by moving the feet. • Vertical lift distance should not exceed mid-thigh and shoulder height. • Do not start a lift below the knee and do not end a lift above shoulder height. • Maintain a neutral/straight spine alignment.	• Hold the load close to the body with the feet moving • Avoid twisting and Bending the body • Ensure handling height is between the shoulder and waist to avoid awkward postures. Avoid handling above shoulder height or overhead. • Keep the back straightened with the arms straightened downwards. • Modify hand tools to enable straight wrists • Ensure hard, even and clean floors. • Lean forward when pushing and backward when pulling. • Move the feet while handling.	• A foot should be placed on one side with the other foot behind the load. • The load should be hugged close to the body • Avoid Twisting or side bending of the body. • Avoid handling heavy loads below the waist height or above the shoulder • Keep the back straight and bend the knees during a lift • Keep frequently used items close to avoid excessive reaching. • Modify hand tools to enable straight wrists and avoid awkward postures • Avoid jerking the object

• Avoid reaching while handling as this strain the shoulders and causes back disorders • Modify hand tools to enable straight wrists • Avoid pulling loads as pulling strains the muscles. Push the load instead. • Keep the hands straight and in-line with forearms • Do not carry load on one part of the body rather place the load at the power zone height defined as the mid-thigh, mid-chest. Or at the best/preferred zone • The back should be kept straight with the knees bent when lifting from floor level. • Train and educate every staff member.	• Avoid frequent kneeling and squatting while handling instead use special equipment. • Do not bend-over while working • Avoid handling heavy loads. • Avoid working overhead • Avoid prolonged standing and sitting while working • Pushing /pulling over a distance of 5m at a time should not exceed 10 • The Pushing /pulling distance should be <300m • Weight of load to be rolled and slide should not exceed 100kg and 10kg respectively. • Training should be provided for all staff	• Avoid frequent and repetitive activities and forceful gripping. • Store frequently handled heavy loads on shelves at waist level • Use mechanical aids and team handling where necessary • As much as possible, avoid carrying heavy loads, instead slide, roll or push them. • Provide clean handholds and ensure the hand fits well on it during handling. • Training should be provided for all staff • Provide conducive working environment of appropriate temperature and lighting devoid of noise and vibration.

Furthermore, these regulators also provide guideline weights for manual handling tasks. The guidelines can be accessed from relevant websites (EU-OSHA:Factsheet 73, n.d.; Health and Safety Executive, 2012, 2016; Occupational Safety and Health Administration, 2004; OSHA-Heavy Lifting, n.d.; WSH (Workplace Safety and Health) Council, 2014; Zarzar, 2006).

5.1.2.2 Guidelines for safe manual handling of seated workers

United States of America's Occupational Safety and Health Administration

The United States of America's Occupational Safety and Health Administration recommends the following guidelines for seated operators (OSHA-Chairs, n.d.; OSHA-eTools, n.d.; OSHA-General Solutions, n.d.; OSHA - Hazard Index, n.d.; OSHA 3125, 2000).

- Operators should avoid sitting to lift
- Avoid bending while seating in a static position.
- Avoid excessive reaching while seated.
- Height adjustable chairs or stools with adjustable lumber supports should be provided
- Footrests should be provided when needed or the feet should rest flat on the floor.
- Backrests, which support the natural curvature of the spine should be provided.
- Armrests must be soft and should enable the elbows to stay close to the body.
- Operators should be trained on the ergonomically correct handling practices, proper use of all equipment, safety precautions and recognition of hazards
- Use ergonomically designed hand tools that enables straight wrists.
- Ensure the elbows are held close to the body while handling.
- Avoid tilting the head rather use tilt work stations
- Do not bend the neck instead use height-adjustable workstations.
- Take frequent breaks

- Ensure the back is always supported
- When seated to handle, the knees must be about the same height as the hips
- The hips and thighs should be supported by a well-padded seat and parallel to the floor.
- Employers should provide highly adjustable chairs for multiple users.
- The chairs must have a five-leg base with casters for adequate support.

Germany's Federal Institute for Occupational Safety and Health (BAuA) (BAuA:Guidance, n.d.)

- Chairs should be height and depth-adjustable with minimum depth of 0.38mm as recommended by EN 1335.
- Movable armrests of at least 0.2m length, 0.04m width and 0.2 to 0.25m height should be provided.
- Backrests should have at least 0.36m wide and 15° backward inclination reaching the shoulder.
- Adjustable neck support should be provided.
- Sitting surface should be inclined forward with the front edge radius ≤ 0,06m.
- Adjustable seat heights that makes room for at least 90° angle between the thighs and the calves should be provided.
- Footrests of at least 0.45m wide and 0.35m depth is required for short workers.

Singapore's Workplace Safety and Health Council (Peixin, 2010; WSH (Workplace Safety and Health) Council, 2014)

- When seated to work, the feet should be flat on the floor or supported by a footrest to reduce pressure on the thighs.
- The chair should be adjustable, stable and fitted with removable armrests and footrests.
- Backrests of 100 to 120° height/tilt should be provided.
- Adjustable work surface should be provided in such a way as to suit the needs of every worker.

- The recommended height of the chair should be between 0.35m to 0.5m while the width should be the dimension of the worker's hip + 0.5m which is approximately 4.6m in women. The depth should be between 0.38m to 0.43m.
- Hand tools should be ergonomically designed to minimize workers adopting awkward hand and arm postures.
- The physical environment, which include temperature, lighting and noise, should be conducive.
- To avoid excessive reaching and overstretching, more frequently used objects should be placed within the primary reach zone while less frequently used items are placed within the secondary reach zone.
- Sufficient room should be provided under the worktable for easy movement of the knees and legs.
- Do not handle heavy loads while seated.
- Group all the items that are frequently used together on the workplace.
- Avoid prolonged sitting. Always change postures.

5.1.2.3 US, Singapore and Germany's definitions for posture assessment of manual handling tasks

The H&S regulators of the above-named countries have defined awkward postures and identified some activities that can result to the risk, as outlined on table 5-4 (HSE, n.d.; HSE - Awkward Postures, 2015; Occupational Safety and Health Administration, n.d.; OSHA-Heavy Lifting, n.d.; OSHA - Hazard Index, n.d.; Steinberg, 2012; WSH (Workplace Safety and Health) Council, 2014).

Table 5-4 Awkward Postures

UNITED STATES OF AMERICA (OSHA)	GERMANY (BAuA)	SINGAPORE (WSH Council)
Definition of Awkward Postures by the three countries' H&S		
Awkward posture occurs when the different parts of the body are flexed, extended or bent away from its neutral position. The neutral position is a well aligned and balanced standing or sitting position in which the head and torso are upright with the natural curves of the spine maintained and the arms at the side of the body with elbows close to the body. The wrists and forearms are in line and not bent or deviated.	Awkward postures occur when the upper body is not held upright	Awkward posture occurs when some or all parts of the body are not in its natural relaxed position. It often stresses the muscles, tendons and leads to pains and aches.
The following can result in awkward postures and consequently, WMSDs and injuries		
• Reaching in front, to the side or behind the body. • Lateral bending or flexion of the back/neck	•Bending over while working •Slight bend or twisting of the trunk with the manual handling done at medium level away from the body.	• Flexion or lateral bending of the back or neck • Twisting about the waist • Lifting of shoulders and arms

• Twisting and turning while handling • Bending to lift and handle heavy loads • Poor workplace arrangement • Handling in one shoulder, under the arm or in one hand • Prolonged standing, looking down or sideways. • Elbow bent above 90°. • Squatting or kneeling to handle • Working with bent wrists (wrists should be kept straight and neutral) • Handling beyond the 'power zone' which is mid-thigh to mid-chest etc.	•Low bending with twisting at the same time •Holding the load far from the body •Handling loads above shoulder height. •Far forward bending with twisting of the trunk and load held far from the body. •Kneeling or crouching. •Wrists are bent •Squatting etc.	• Bending the wrists • Working below the waist height or above the elbow height etc.

5.2 **Posture Assessment Categories and Scoring Method**

Different posture assessment tools assess postures using different assessment categories. Some researchers believe that errors generated during posture assessment is a function of the number of assessment categories used and have optimised the effectiveness of users choosing the assessment categories themselves as they visualise the postures. This of course is affected by camera placement and therefore inaccurate (NIOSH, 2014).

Assessment categories for the upper body postures of four of the posture assessment tools studied in chapter 2, are presented on table 5-5 (Hignett and McAtamney, 2000; Karhu et al., 1981; McAtamney and Nigel Corlett, 1993; NIOSH, 2014).

Table 5-5 Assessment categories of some posture assessment tools

No of Categories							
Methods	**Spine**		**Shoulders**	**Elbows**	**Wrists**	**Neck**
	Flexion	**Lateral Bend**	**Flexion/ extension**	**Flexion**	**Flexion/ extension**	**Flexion/ extension**
Rapid Upper Limb Assessment (RULA)	4	-	4	2	3	4
Rapid Entire Body Assessment (REBA)	4	2	4	2	2	2
Ovako Working Posture Assessment (OWAS)	4	-	3	-	-	-
National Institute for Occupational Safety and Health (NIOSH)	4	3	5	4	-	-

The assessment categories used in the methods from the above table is suitable for observation-based assessment of work postures where offline feedback is generated for the users.

However, for real-time assessment involving flexible manufacturing systems where immediate response to posture changes is required, having several categories of postures may confuse the workers. Therefore, from the H&S definition of awkward postures which considers only the neutral and awkward posture, two categories of postures will be utilized in this research for the tool's development. That is the 'Good' and the 'Awkward' categories.

'Good' assessment category implies the postures at the neutral position range, equivalent to the existing neutral to mild category or the green colour band for posture classifications using colour bands.

'Awkward' category implies the postures beyond the neutral position range, equivalent to the existing moderate and severe categories and corresponding to the amber to red colour categories.

Moreover, H&S professionals recommend the RULA observation tool as an effective assessment tool for ergonomic assessments involving joint angles (Darby, 2008; IFA-MSD, n.d.; Liu, 2014; OSHA, n.d.; Peixin, 2010). Hence, some of the assessment limits are established using the RULA scores. RULA classifies each joint into three or more categories, but the developed tool will classify the joints in two categories of either 'Good' or 'Awkward'.

5.3 **Development of the Proposed Tool's Knowledge Base**

Having studied the H&S guidance for posture assessment during manual handling operations and having established the posture assessment categories, the next step is to extract the relevant definitions that will form the knowledge base of the proposed system.

The proposed posture assessment system should have a knowledge base from which the posture analysis rules are extracted. Its knowledge base is the posture assessment definitions extracted from the OSHA, WSH Council, HSE and BAuA recommendations. These definitions are the posture assessment reference point, defined as the neutral position limits beyond which the posture is classified as 'awkward'. The acceptable limits are all extracted and used to build the knowledge base of the system. Hence, the knowledge base consists of the H&S definitions expressed with respect to the assessment categories.

5.3.1 Extracting the Neutral Position Definition

The neutral position as defined by the H&S professionals, is when the joints are naturally aligned with the trunk and head upright, the arms by the side, and forearms hanging straight or at right angle to the upper arm, while the hand is in handshake position with the wrists not bent or deviated (Contractors et al., 2016; EU-OSHA: E-Fact 45, n.d.; HSE, 2002; "HSE - ART tool: Risk factors," n.d.; OSHA - Hazard Index, n.d.; Steinberg, 2012a). The neutral figures denote the reference point for each joint and therefore is represented by the 'zero' score. Therefore, each of the joints of the upper body is set at zero and the definition is programmed for each joint such that any deviation from it beyond the recommended limits results in awkward posture.

5.3.2 Extracting the Assessment Definitions for each Joint

For ergonomic assessment involving joint angles of the upper body, H&S regulators of the four countries under study recommend the RULA observation tool as an effective assessment tool (Darby, 2008; IFA-MSD, n.d.; Liu, 2014; OSHA, n.d.; Peixin, 2010). Hence, the assessment limits are established using the RULA scores for some joints and the H&S specified scores.

5.3.2.1 The Spine/Trunk/Back Posture Assessment Definitions

The *Back* posture is scored based on the definition extracted from the UK HSE, that the back posture is classified as awkward when the back is bent or twisted more than 20° (HSE - Awkward Postures, 2015), and the US OSHA, that the torso is not bent more than 10° - 20° from the neutral position (OSHA:Supplemental Information, n.d.; OSHA - Hazard Index, n.d.)

The scores are:

Good = 0° – 20°

Awkward = >20°

5.3.2.2 The Neck Posture Assessment Definitions

The *Neck* posture is scored based on the four countries' RULA recommendation (McAtamney and Nigel Corlett, 1993), and the UK HSE guideline that the neck should be assessed as awkward if an obvious angle is observed (HSE - Awkward Postures, 2015).

The scores are:

Good = 0° – 10°

Awkward = >10°

5.3.2.3 The Elbow Posture Assessment Definitions

The *Elbow* posture is scored based on the four country's definitions which include:

UK HSE - the elbows become awkward when held above chest height but neutral when hanging straight by the side or in handshake position (that is 0° and 90°) (HSE - Awkward Postures, 2015).

US OSHA – elbows are awkward when bent more than 90° (OSHA:Supplemental Information, n.d.).

WSH Council – handling above shoulder heights results in awkward elbow (WSH (Workplace Safety and Health) Council, 2014).

BAuA - postures are classified as awkward when loads are handled above shoulder height (Steinberg, 2012).

Therefore, based on these definitions, the scores extracted for elbow posture assessment are:

Good = 0° – 90°

Awkward = >90°

5.3.2.4 The Shoulder Posture Assessment Definitions

The *Shoulder* posture is scored based on the four countries' RULA recommendation (McAtamney and Nigel Corlett, 1993)

The scores are:

Good = 0° – 20°

Awkward = >20°

5.3.2.5 The Wrist Posture Assessment Definitions

The *Wrist* posture is scored based on three countries' definitions which include:

UK HSE - the wrists should be assessed as awkward if an obvious angle is observed (HSE - Awkward Postures, 2015)

US OSHA's - the wrists should be maintained at straight or neutral position while working as bent wrists leads to severe injuries (OSHA - Hazard Index, n.d.)

WSH Council - the wrists are awkward when bent (WSH (Workplace Safety and Health) Council, 2014).

The scores extracted from these definitions, which is also in agreement with the RULA scores for the wrist posture, are:

Good = 0°

Awkward = >0°

These definitions all form the knowledge base of the proposed tool and are written using appropriate lines of codes.

5.4 Development of the Inference Engine of the Proposed Tool

The inference engine is the reasoning structure of the KBS that provides the methodology which reasons about the knowledge and draws conclusion. It is the IF-THEN part of the KBS in which the 'IF' part sets the condition, which when satisfied, is concluded by the 'THEN' part (Rdotexe, 2013).

Rules for Assessing the Neutral Position

The IF-THEN construct was employed to code the neutral position. The default angles displayed by Kinect when human stands or sits at neutral position was found not to be zero for all humans. A default angle value of zero is required to fully define the reference point. Hence, every tracking must start from the reference point with all the angles displaying as zero.

Therefore, the if-then algorithm will infer that IF an angle is measured as zero by the hardware, THEN, the corresponding posture should be assessed as GOOD. For instance, IF the Angle Spine Base is tracked as zero, THEN Spine Base is assessed as Good.

In this construct, the condition that the angle must be zero is set, then the conclusion is expressed by the THEN statement which infers that whenever such condition is satisfied, the system should assess the posture as Good. This is represented in the engine using appropriate lines of codes.

Rules for Assessing the Postures

The IF-THEN construct is again used to reason the assessment of the postures as the body part deviates from the neutral position, to the limits and beyond. An alternative statement known as the ELSE statement is introduced when the condition set by the IF statement is not satisfied.

For instance, IF the joint angle is less than or equal to the H&S limits and the posture is greater than or equal to the neutral position, THEN assess the posture as GOOD. ELSE, assess it as AWKWARD.

Appropriate lines of codes are used to represent this construct in the engine.

Rules for Displaying the Assessed Results

The IF-THEN construct is utilized in the engine for the display of the posture assessment results to the operators. The awkward postures become a threat to the worker if held for prolonged periods (HSE - Awkward Postures, 2015; OSHA - Hazard Index, n.d.). Hence, IF the assessed posture is held awkward for several frames at a time, THEN display ‘Awkward’ and enable the voice alert, ELSE continue tracking.

5.5 Development of the Posture Assessment Tool

The knowledge base, built with the knowledge derived from the H&S database, and the inference engine, are merged together with the data-retrieval algorithm that computes joint angle developed in the previous chapter. This is achieved using appropriate lines of codes written in C# programming language. The resultant program retrieves skeletal data from the upper joints of the human body using the data-retrieval algorithm and uses the H&S definitions stored in the knowledge base, with the reasoning provided by the inference engine, to assess the retrieved data. The developed tool is therefore an automatic H&S compliance posture assessment tool which captures the worker’s joint data, automatically converts it to posture data and assess the postures using the knowledge from the knowledge base.

The pseudo code of the developed tool is written thus:

```
• Open the sensor.
• In the Main Window.
    • Get skeletal data.
    • Get joint vectors.
    • Get joint angles.
    • Read the joint position for each tracked joint.
    • From the joint position.
        • If the value of the joint position is within the limit, then:
            ▪ Check the display interval.
            ▪ Display ‘Good’.
        • If the value of the joint position exceeds the limit, then:
            ▪ Check the display interval.
            ▪ Display ‘Awkward’.
```

5.6 Testing the Developed Posture Assessment Tool

Three different tests were carried out on the new tool to determine its effectiveness and reliability. The first two tests are targeted at testing the level of consistency of the data measured by the tool to evaluate the repeatability and reproducibility of each of the measured joint data and consequently, the tool's reliability. The last test is conducted to ascertain if the tool can assess postures in compliance with the H&S regulations of the four countries studied in this work.

5.6.1 Methods

Data collection involved capturing the posture assessment data of several operators, computing and statistically evaluating the closeness of agreement in the tool's measured joint data, assessing the postures and comparing the posture assessment results with existing H&S definitions. The human participants are volunteers some of whom are employed as cleaners in various companies in the United Kingdom, and some are PhD students. These participants were recruited by the researcher through contacts with friends and colleagues. Before the experiment, the operators were briefly trained on the tasks they were to perform.

Several tests were conducted with the Kinect setup at 1.2m height and 2m object distance from the sensor. This location, which is found to enable better tracking, is chosen from the optimum Kinect setup determined in the previous chapter.

For the joint data, repeatability and reproducibility tests were carried out to determine the closeness of agreement in measurements made on same operator wearing same clothing, performing same task in the same workstation, and on different operators, performing different tasks in different workstations, wearing different clothing.

5.6.1.1 Reliability Test

Internal consistency reliability test was carried out on a sole participant to determine the level of consistency of the data measured by the posture assessment tool. The purpose of the test was to evaluate the repeatability of the measured joint data and consequently, the tool's reliability as the posture of an operator is assessed while wearing same clothing to perform same task with same load, lifted at same the workstation.

This study involves the use of the developed tool to capture the joint data of an operator that lifts a load of 0.5kg above the shoulder height. The data was captured for 30 lifts under controlled reliability conditions which include same workplace location and condition, same load of 0.5kg, as represented by the screenshot of figure 5-8.

The data collected was analyzed in SPSS to assess the level of agreement and consistency in the data captured by the tool, computed using the Cronbach's alpha denoted with the system α.

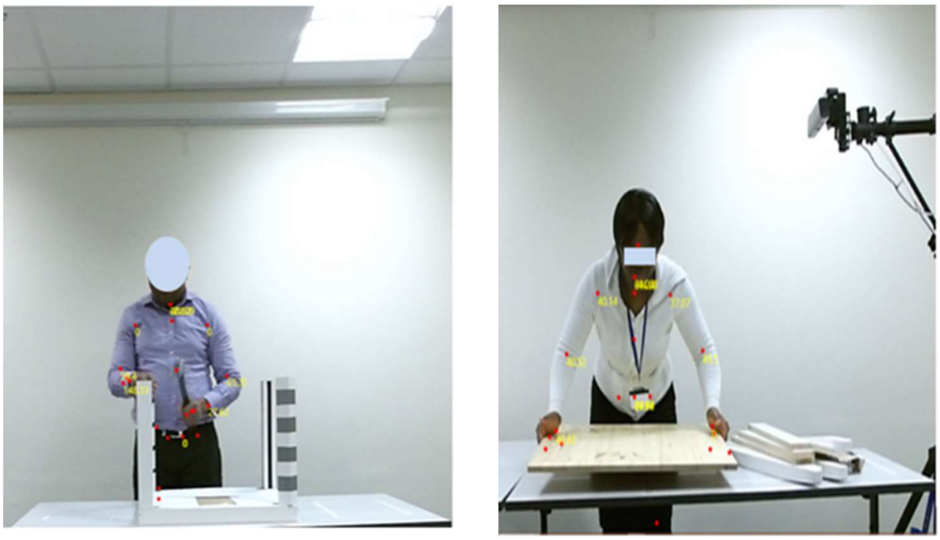
Another internal consistency measure used to interpret the results is the average inter-item correlation.

The null hypothesis is that **'there is no internal consistency in the measured data'**.

Figure 5-8 Screenshot of operator during the test for reliability.

5.6.1.2 Reproducibility Tests

To evaluate the performance of the posture assessment tool, reproducibility test was conducted on sixteen different operators under varying conditions which include different workplace locations while carrying out different varieties of tasks with different loads and wearing different clothes. Some of the tasks undertaken include lifting, hammering, sitting to handle, assembly tasks, carrying load, some of which are shown in the screen shots of figure 5-9.



a. **Hammering task**

b. **Carrying task**

Figure 5-9 Screenshots of operators during the test for reproducibility.

The Kendall's coefficient of concordance was calculated using statistical tools in SPSS software and this was interpreted to establish if the system produces accurate or erroneous measurements.

5.6.1.3 Further System Tests on Selected Case Studies

Further experiments were conducted on selected case studies including operations: bending to lift and lifting above shoulder height, to test if the system can effectively assess the work postures of the upper human body in compliance with the recommended H&S guidelines.

5.6.2 Results and Discussion

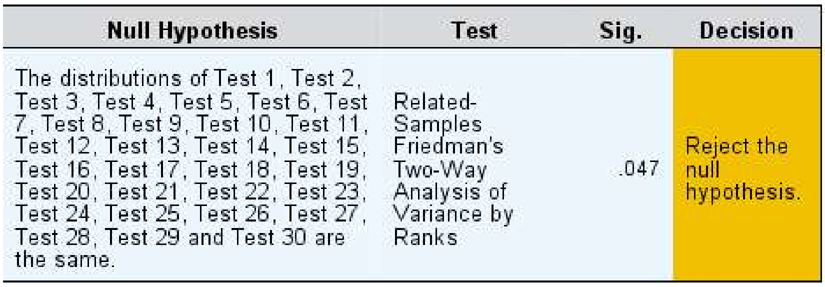
5.6.2.1 Results of the Reliability Test

Repeated joint angle measurement of an operator was captured 30 different times during a lifting task and statistically analysed to ascertain the tool's reliability. (See Appendix A for details of the data captured from a single operator under reliability conditions).

The null hypothesis is that **“there is NO consistency in the data generated by the developed tool”.**

An SPSS nonparametric test of the data to check if the samples are related using the Friedman’s two-way analysis of variance, yielded a significant level of 0.047 ($p<0.05$), with a decision to reject the null hypothesis, as depicted on table 5-6. This means that there is no chance of type 1 error when the null hypothesis is rejected. We therefore conclude that there may be consistency in the data generated by the tool and the samples might be related.

Table 5-6 Null hypothesis test results showing p=0.047



Null Hypothesis	Test	Sig.	Decision
The distributions of Test 1, Test 2, Test 3, Test 4, Test 5, Test 6, Test 7, Test 8, Test 9, Test 10, Test 11, Test 12, Test 13, Test 14, Test 15, Test 16, Test 17, Test 18, Test 19, Test 20, Test 21, Test 22, Test 23, Test 24, Test 25, Test 26, Test 27, Test 28, Test 29 and Test 30 are the same.	Related-Samples Friedman's Two-Way Analysis of Variance by Ranks	.047	Reject the null hypothesis.

Further statistical analysis of the data yielded a Cronbach’s Alpha of 0.978. This means that 97.8% of the variance in the joint angle data captured by the tool is reliable, with 2.2% of error variance. The average inter-item correlation value is 0.614, indicating moderately good consistency in the data generated by the sensor.

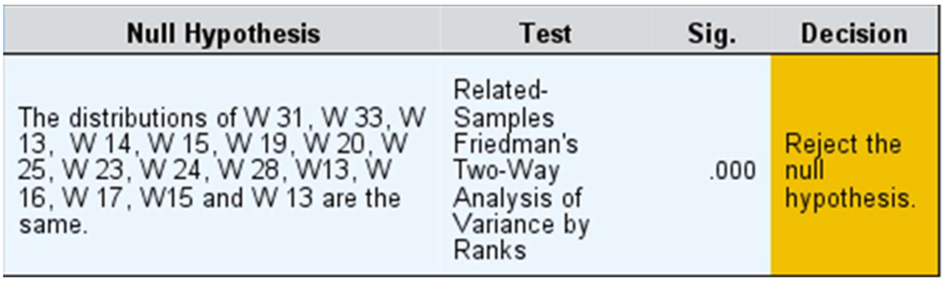
Hence, results of the reliability test show that the developed tool appear to be consistent in its measurement and therefore reliable for use in the assessment of work posture in the workplace. This is because the higher the reliability, the lower the measurement errors obtained (Bartlett and Frost, 2008).

5.6.2.2 Results of the Reproducibility Test

Again, further tests were conducted on the data captured from different operators under varying conditions, known as the reproducibility conditions (see Appendix A for details). The null hypothesis is that **“there is no level of agreement in the data generated at different workstations by different operators handling different loads”.**

Conducting the nonparametric test to test if the data is related yielded a no significance value of 0.000 ($p<0.05$), with a decision to reject the hypothesis as shown on table 5-7.

Table 5-7 Null hypothesis test results showing p=0.000



Null Hypothesis	Test	Sig.	Decision
The distributions of W 31 , W 33, W 13, W 14, W 15, W 19, W 20, W 25, W 23, W 24, W 28, W13, W 16, W 17, W15 and W 13 are the same.	Related-Samples Friedman's Two-Way Analysis of Variance by Ranks	.000	Reject the null hypothesis.

This indicates that there may be some level of agreement in the data generated by the tool under reproducibility conditions.

Further data analysis produced a Kendall's coefficient of concordance, w = 0.634. This means moderate association between the data.

Hence, we again conclude that there is considerable closeness of agreement in the data measured with the tool indicating that it is precise and reliable.

5.6.2.3 Posture Assessment Results

Having established that the developed H&S compliance tool is reliable, further tests are conducted, to ascertain if the tool can assess postures and generate results that agree with H&S regulations.

First, the neutral positions of the participants were tracked, with all the joints classified by the tool as 'Good' and the joint angles displaying '0' values, as shown in figure 5-10. In the figure, LElbow means the Left Elbow joint, RElbow = Right Elbow; Neck RTL = Neck Relative to Left which means bending of neck in the right direction; Neck RTR = Neck Relative to Right; LShoulder = Left Shoulder; RShoulder = Right Shoulder; SpineB RTR = Spine Base Relative to Right (for assessing bending of the back to the right, which is hereafter called back right); SpineB RTL = Spine Base Relative to Left (for assessing bending of the back to the left, which is hereafter called back left).

AngleNeck	0
AngleNeckRight	0
AngleNeckLeft	0
AngleLeftElbow	0
AngleRightElbow	0
Angle S B Left	0
Angle S B Right	0
AngleSpineBase	0
AngleLeftShoulder	0
AngleRightShoulde	0
AngleRightWrist	0
AngleLeftWrist	0

LElbow Good	RElbow Good
Neck RTL Good	Neck RTR Good
NECK Good	SpineBase Good
LShoulder Good	RShoulder Good
RightWrist Good	LeftWrist Good
SpineB RTR Good	SpineB RTL Good

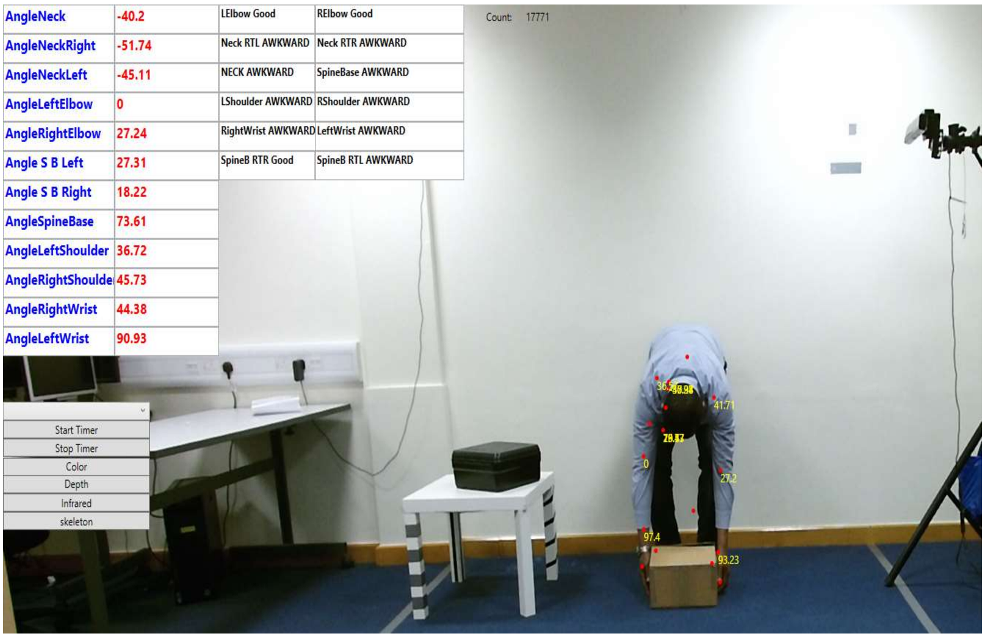
Figure 5-10 A participant at neutral position.

However, as soon as the worker's posture changes and exceeds the set limit as derived from the database, the tool classifies the motion as 'Awkward'. The results of the tests conducted on the case studies to determine the effectiveness of the developed tool to assess postures is presented.

Case 1: Bending to lift from floor level

According to the four countries' guidelines, objects should be placed at waist height or 'power zone' to avoid over stretching the back (Health and Safety Executive, 2016; OSHA-Supplemental Information, n.d.; WSH Council 2014). The Singapore Code of Practice opines that reducing the height differences reduces the need to bend the back (Singapore Standard, 2002), hence objects should be placed on shelves, tables, etc. (OSHA-Heavy Lifting). Again, operators should avoid lifting from floor level (Health and Safety Executive, 2016; NIOSH, 2007) as this moves the back and shoulders far away from the neutral position.

Figure 5-11 shows the posture assessment of an operator who bends to lift from floor level. The posture assessment tool is found to display the result of the assessment which reveals awkward back and arm postures. This display, which is pre-set to show at intervals depending on the task duration, informs the operator to change the identified awkward postures. This posture assessment result when compared to the guidelines from the four countries' H&S Regulators showed good agreement as they also defined lifting at floor level as highly awkward. The HSE's red colour of figure 5-11b means that the posture is highly risky and requires immediate ergonomic intervention.



AngleNeck	-40.2	LElbow Good	RElbow Good
AngleNeckRight	-51.74	Neck RTL AWKWARD	Neck RTR AWKWARD
AngleNeckLeft	-45.11	NECK AWKWARD	SpineBase AWKWARD
AngleLeftElbow	0	LShoulder AWKWARD	RShoulder AWKWARD
AngleRightElbow	27.24	RightWrist AWKWARD	LeftWrist AWKWARD
Angle S B Left	27.31	SpineB RTR Good	SpineB RTL AWKWARD
Angle S B Right	18.22		
AngleSpineBase	73.61		
AngleLeftShoulder	36.72		
AngleRightShoulde	45.73		
AngleRightWrist	44.38		
AngleLeftWrist	90.93		

Count: 17771

a) **developed tool assessing an operator as he bends to lift at Floor level.**

b) HSE (Health and Safety Laboratory for the Health and Safety Executive, 2009)

c) BAuA (Steinberg, 2012) **d) OSHA (OSHA-Heavy Lifting, n.d.)**

d) OSHA (OSHA-Heavy Lifting, n.d.)

e) WSH (WSH (Workplace Safety and Health) Council, 2014)

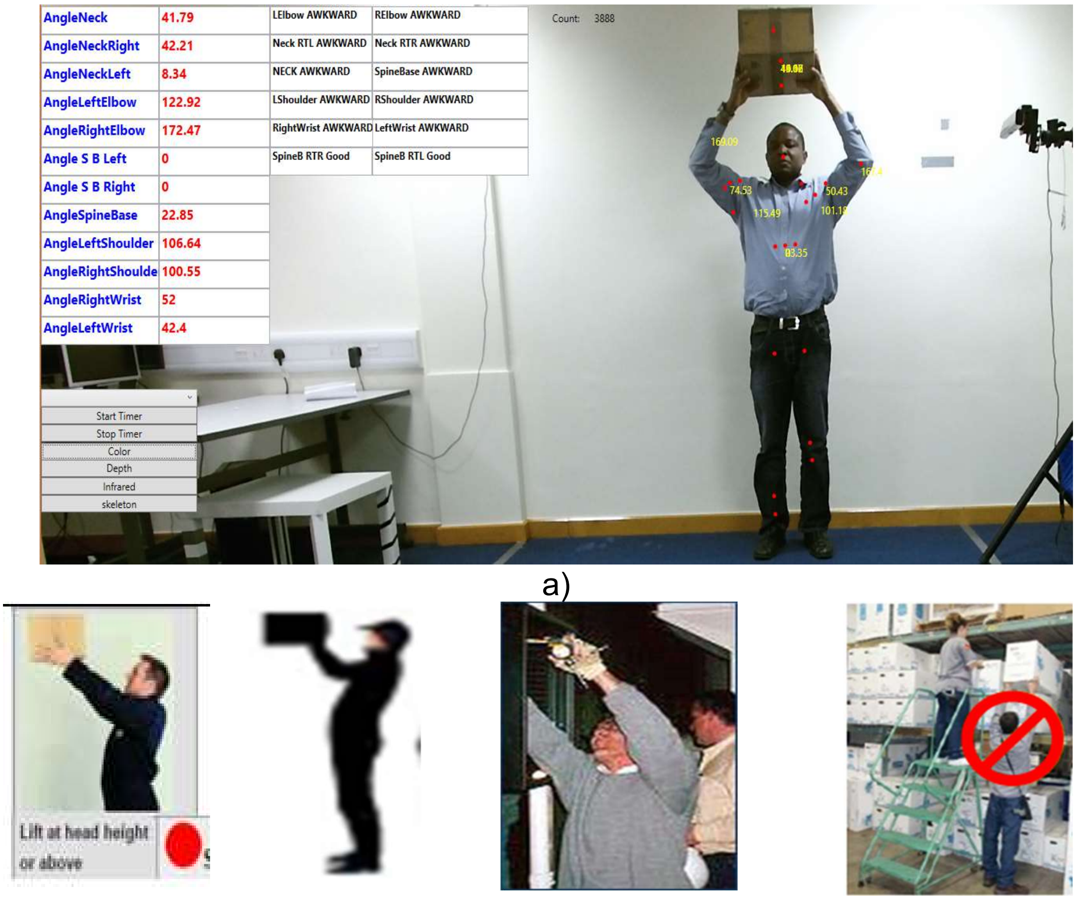
Figure 5-11 Handling from floor level

The four countries' guidelines establish that lifting at floor level greatly stresses the back and shoulders which results in the adoption of awkward postures by the workers. A closer look at figure 5-11a shows a back-flexion angle of 73.61°, accessed as "SpineBase Awkward" and a left and right shoulder angles of 36.72° and 42.73°, assessed as "LShoulder Awkward" and "RShoulder Awkward" respectively. These joints are awkward because they exceeded the neutral limits of 20° for back and shoulder posture assessment.

Case 2: Lifting above shoulder height

Performing overhead work moves the elbows further away from the torso and results in awkward postures (OSHA - Hazard Index). Hence, operators should avoid handling loads above shoulder height (Singapore Standard, 2002) as this stresses the arms (Health and Safety Executive, 2016). The Elbows become awkward when raised above chest height (HSE - Awkward Postures, 2015)

In figure 5-12, the arms are extended and the tool assessed as awkward, the left and right elbow angles with values 122.92° and 172.47° respectively and the left and right shoulder angles of values 100.64° and 100.55°. There is great correlation when this is compared to that of the four countries.



AngleNeck	41.79
AngleNeckRight	42.21
AngleNeckLeft	8.34
AngleLeftElbow	122.92
AngleRightElbow	172.47
Angle S B Left	0
Angle S B Right	0
AngleSpineBase	22.85
AngleLeftShoulder	106.64
AngleRightShoulde	100.55
AngleRightWrist	52
AngleLeftWrist	42.4

LElbow AWKWARD	RElbow AWKWARD
Neck RTL AWKWARD	Neck RTR AWKWARD
NECK AWKWARD	SpineBase AWKWARD
LShoulder AWKWARD	RShoulder AWKWARD
RightWrist AWKWARD	LeftWrist AWKWARD
SpineB RTR Good	SpineB RTL Good

Count: 3888

a)

b) c) d) e)

Figure 5-12 Awkward lifting above the shoulder a) Interface with displayed info by Kinect when operator is lifting above the shoulder. b) HSE (MAC Tool - Assesment 1). c) BAuA (Steinberg, 2012) **d) OSHA (Hazard Index) e) WSH (WSH Council, 2015)**.

Finally, the experimental results from these case studies have shown that the developed posture assessment tool can assess worker's posture. Comparing the H&S posture assessment figures with that generated by the tool as represented in figure 5-12, there is great correlation.

The advantages of the developed posture assessment tool cannot be overemphasised. The tool is affordable and readily available, highly convenient and does not need to be worn on the operator's body during assessment. Again, the tool is in-compliance with international H&S guidelines on manual handling.

5.7 **Chapter Summary**

This chapter describes the guidelines for manual handling and awkward posture assessment as stipulated by the selected countries with strong H&S policies and approved regulators. These are the UK HSE, the US OSHA, the Singaporean WSH Council and the German BAuA. The study helped to establish the relevant definitions from where data is derived to build the knowledge base of the proposed assessment tool. The developed knowledge base and inference engine are incorporated with the data-retrieval algorithm using appropriate rules, to form a posture assessment tool which captures human motion data in real-time and automatically assesses the data based on the H&S definitions provided in the knowledge base.

When tested under reliability and reproducibility conditions, the tool was found to yield reliable and consistent joint data with a Cronbach's alpha value of 0.978, p=0.045 (p<0.05) and a Kendall's coefficient of concordance of 0.634, p =0.000 (p<0.05). This shows that the developed tool is considerably reliable and consistent in its measurement.

Further tests also demonstrate that an effective H&S-compliant real-time posture assessment tool has been developed for the assessment of worker's postures during manual handling activities. 'Good' was displayed when the postures were complying with the H&S acceptable limit and 'Awkward' was displayed when the postures have gone beyond the recommended limit as specified by the H&S

regulators. This display is to alert the worker to adjust any awkward posture that has been held over a period.

The benefit of the tool is its usefulness in the automatic real-time detection and assessment of work postures thereby reducing the rate of occurrence of awkward postures, and consequently reducing the risk of WMSDs among workers in the workplace.

The next chapter will focus on the design and development of the user interface of the KBS to enable better user interaction with the system as well as effective real-time feedback of posture assessment results to the operators.

6 DESIGN, DEVELOPMENT AND DEMONSTRATION OF THE FEEDBACK INTERFACE

Having developed the knowledge base and the inference engine of the proposed KBS in the previous chapter, the next stage is to develop the user interface of the system through which the user interacts for effective feedback of the worker's posture assessment updates.

Good feedback systems should be simple and interactive in use. An effective posture assessment KBS, which is suitable for use even in a flexible manufacturing system, should provide real-time feedback to the worker concerning his current ergonomic behaviours on the shop floor. The KBS developed in this research is not complete without the user interface through which the user interacts with the system and which also enables real-time feedback to workers concerning their posture assessment reports. The user Interface design (UI) is aimed at maximizing the user experience by making the user's interaction as simple and efficient as possible. The design process must balance technical functionality and visual elements so as to generate a system that is both operational, usable and adaptable to changing user needs (Galitz, 2007).

Figure 6-1 shows the flow of data in the proposed interface in which data is supplied to the system through an input device. The data is stored in the database as well as assessed by the posture assessment tool developed in the previous chapter, and then displayed as output. The displayed posture quality output is communicated as feedback to the user who reacts by taking appropriate action. The user acts based on the feedback he receives. The area in the diagram, represented by the green dotted lines, is the focus of this chapter.

The chapter therefore presents the design, development and demonstration of a human-machine interface of the posture assessment feedback system. The proposed system is targeted at providing a shop floor with a simple, cost-effective and automatic tool for real-time display of worker's postures.

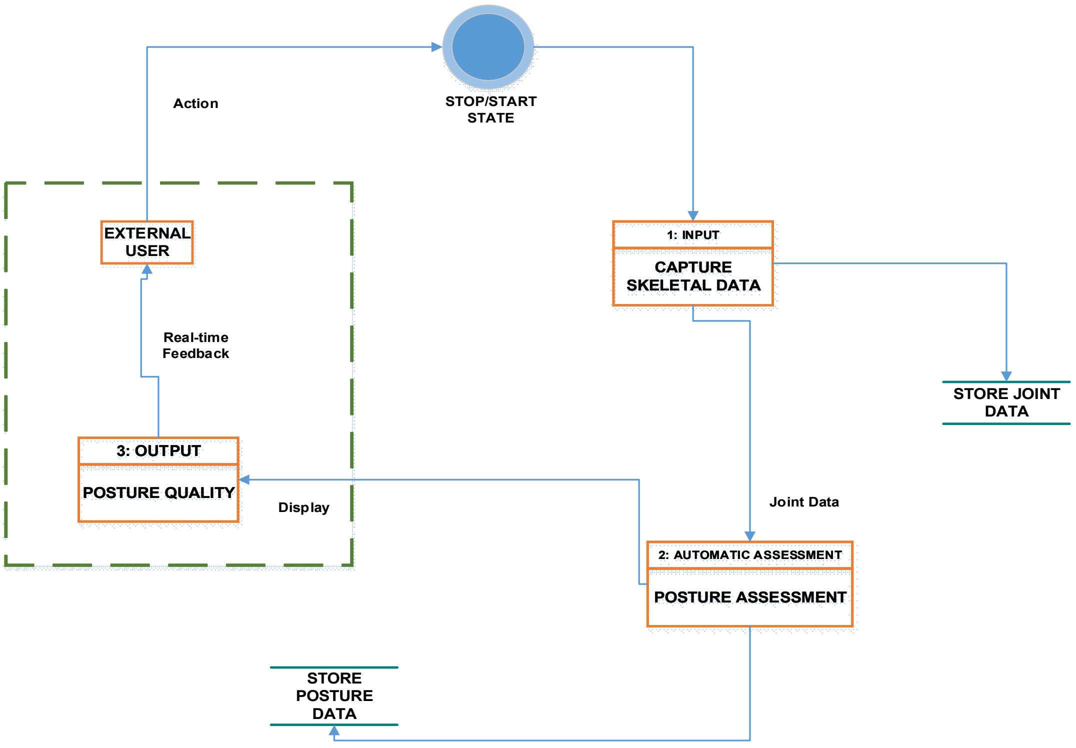


Figure 6-1 Data Flow Diagram of the Proposed Interface

The focus of the chapter is three-fold and includes:

- Design of the posture assessment feedback user interface.
- Development of the designed interface.
- Demonstration of the developed system.

6.1 Research Methods

Literature survey as presented in chapter 2 has helped to establish research gaps about real-time data capture and feedback of ergonomic assessment outputs to workers. This helped to determine the need for the design.

The step by step methods adopted for the design, development and implementation of the proposed interface include;

I. Establishment of the design requirements of the proposed system which provides the functional requirements on what the system is expected to accomplish after its design. This is presented in the next section.

II. Detailed System Design. This involves the following; a) identification of the system's external users. b) Modelling the usage requirements, set of actions and performance of the external users using the UML use case diagram. c) modelling the flow and format for information among the external users within the system. d) development of a model for the logic captured by the use case model using the UML activity diagrams and e) developing the model for the system's widgets using the user interface flow diagram/storyboards. This is modelled with the information provided by the UML Activity diagram models and shows at a glance, the various widgets of the designed system and depict the final design of the feedback system.

The step also involves the development of the designed system widgets. These widgets are developed using C# programming language in the WPF application of the .NET Framework 4.5 of Microsoft visual studio.

III. System demonstration using real-life examples. This involves testing the developed system on some participants to test the system functionalities.

6.2 Design of the Feedback Interface

This section explains the processes and methods adopted to design the ergonomic assessment feedback interface. In the design, the proposed system's functional requirements are identified and some basic questions which could help to collect relevant information for the design of the proposed posture assessment feedback system, were established and answered. The questions are: who are the external users? what information does the external user need to give or receive? what format is the information provided in?

The feedback interface was iteratively designed to resolve the complexities associated with user difficulties such as ease of use, ease of understanding and aesthetics. Several versions of the interface were evaluated by users and the user's recommendations were implemented in the subsequent versions until the final version of the design was achieved.

6.2.1 Description of the Proposed System Requirements

The first step to system design is to identify the system's functional requirements which describes what the system is required to accomplish after its design and are captured in the use case model. The next step is to develop a detailed design which satisfies the identified requirements (O 'hara and Higgins, 2010). The requirement includes a system that; a) Supports new staff registration, captured in the 'staff accounts' use case, b) Provides and retains staff details, which also reflects in the 'staff accounts' use case, c) Reflects workplace information, captured in the 'workplace reports' use case d) Displays joint information of staff, which reflects in the 'Display joint' use case e) Retains information on the load, captured in the 'Load attribute' use case f) Supports viewing, searching and editing of required manual handling tasks, captured in the 'Select task' and 'Select task order' use cases g) Alerts the worker whenever the motion becomes awkward, reflected in the 'Prompt staff' use case h) updates the posture assessment information of all operators, which is captured by the 'Display posture' use case and updated in the system database i) Allows the worker to view previous posture assessment results. This is captured by the 'Display posture' use case j) Supports change from one task to another, captured by the 'Select task order' use case and k) Allows update of worker's activities on the shop floor, captured by the 'workplace reports' use case and updated in the system database.

6.2.2 Basic Questions

6.2.2.1 Question One: Who are the External Users?

This section will answer the question on who the external users of the system are. The UK HSE recommends the personnel to involve in risk assessment and these include employees, supervisor, H&S representatives (hereafter called the HSE Rep.), ergonomist, manager, and the industrial engineer (Health and Safety Executive, 2016). These recommended requirements on personnel to involve in risk assessment was used to identify the various users of the proposed system, also known as the system actors as illustrated in the figure below:

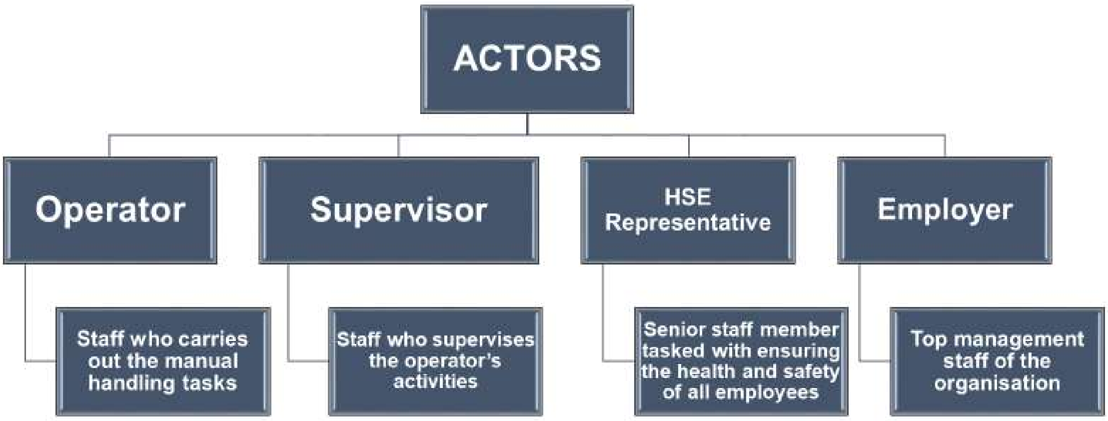


Figure 6-2 System Actors/External users

6.2.2.2 Question Two: What information does the external user need to give or receive?

To answer the second basic question on what information the user need to give or receive, the knowledge of the user's functions in the system and their interaction with each function, is paramount.

The user's functions and interactions are modelled to establish the workflows and interrelationship among the users in the system.

Guidelines for Developing the Feedback System's UI Models.

The processes adopted to develop the models of the proposed feedback system for users include (Galitz, 2002, 2007):

- Basic understanding of the user's mental models such as the user's needs, user's profile, user's task analysis. The user's task analysis is the description of all user tasks and interactions which provides information on workflows and interrelationship between people, objects and users.
- Development of the system models. This is discussed fully in subsequent sub sections These models should have the following features:
- Make the invisible parts and processes of the system become visible.
- Provide correct feedback.
- Avoid unnecessary items.
- Ensure consistency in design.
- Ensure easy-to-understand models for both the novice and expert.

Modelling the UI of the Proposed Feedback System

The model-based user interface design is adopted in the design of the proposed system's interface. An advantage of this type of design is that it helps to reduce the developer's efforts and capture user requirements while ensuring quality and eliminating confusions (Meixner et. al., 2013). The Unified Modelling Language (UML) and the User Interface Flow Diagram (storyboards), are employed in the modelling of the proposed system.

The Unified Modelling Language, UML

UML comprises of languages used to generate process and workflow diagrams (Motive Glossary, 2004). It provides diagrams suitable for the following modelling techniques (Traetteberg, 2002);

- Domain modelling provided by the class and object diagrams
- Functional requirements provided by the use case diagram, the sequence and the activity diagrams
- System behaviour provided by the sequence diagram, collaboration diagram, state and activity diagrams
- Deployment provided by the component diagram.

UML helps to identify the essential properties of a system during the design stage (Hilken et. al., 2014) and its models can detect initial modelling mistakes (Balsamo and Marzolla, n.d.).

In this chapter, the UML Use Case Diagram and Activity Diagram are used to model the proposed system. This is because the UML use case has the capability to model the set of actions that one external user or actor can perform with other users. The diagram provides the graphic summary of the system users, the functions performed by each user and the description of the interactions among the actors and functions. The activity diagram depicts the graphical representation of the workflows of the different components of the system.

In the development of these models, the Assessor (Kinect) is regarded as an actor because of its role in the system as some of the user's tasks have relationships with that of the assessor.

The UML Use Case Diagram

The UML Use Case diagram is used to identify the usage requirements of the system, the set of actions on the system, as well as the performance of the external users of the system. Hence it models the interaction between the system users and the functions they perform which in this case are modelled as use cases.

Assessor: The assessor level use case includes: Read and display joint, receive selected task and task order, analyse and display postures, detect task and display detected task.

Operator: The operator level use case includes; Receive display joint, select task and task order, check posture feedback/prompts, detected task, feedback, error messages, report awkward tasks, request assistance, receive training, report workplace issues, receive load with attributes.

Supervisor: The supervisor level use case includes: receive workplace report, provide feedback, prompt staff, error message, posture updates, remedial measures, receive awkward task report, training.

HSE Representative: The HSE Rep. use case include: Posture updates, reports, remedial measures, Training, Load, Defects, New developments.

Employer: Training, posture master, remedial measures, defects, reports, New developments

The use case diagram, along with the user-interaction diagrams are presented in figures 6-3 to 6-8.

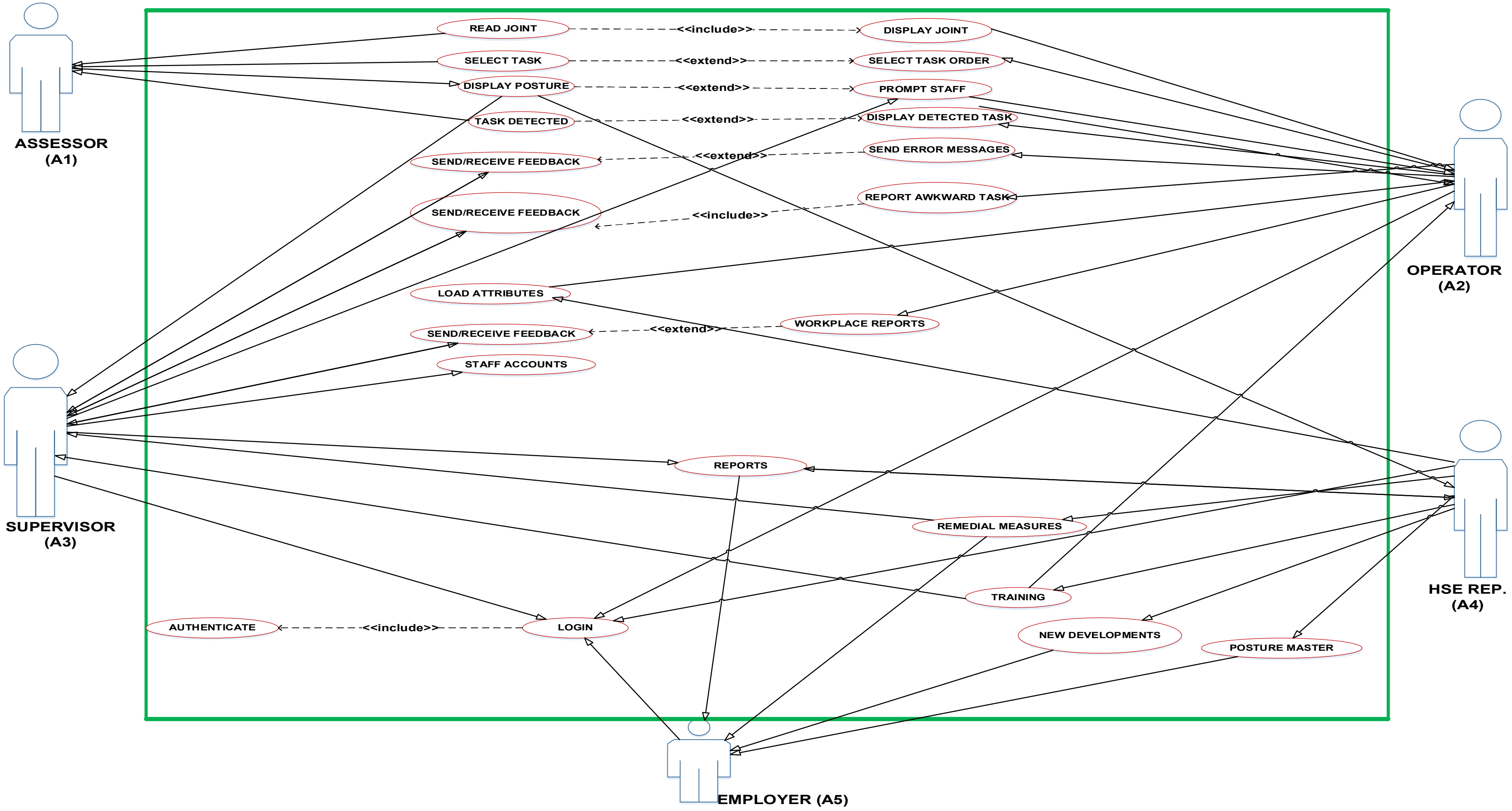


Figure 6-3 Model of the System using the UML Use Case Diagram

Figures 6-4 to 6-8 show how information is intended to flow from one user to another within the system. The arrows indicate whether the information is given or received by the Actor. These diagrams are employed to further explain the use cases highlighted in figure 6-3. The boxes represent the actors while the arrows show the direction of flow for each use case.

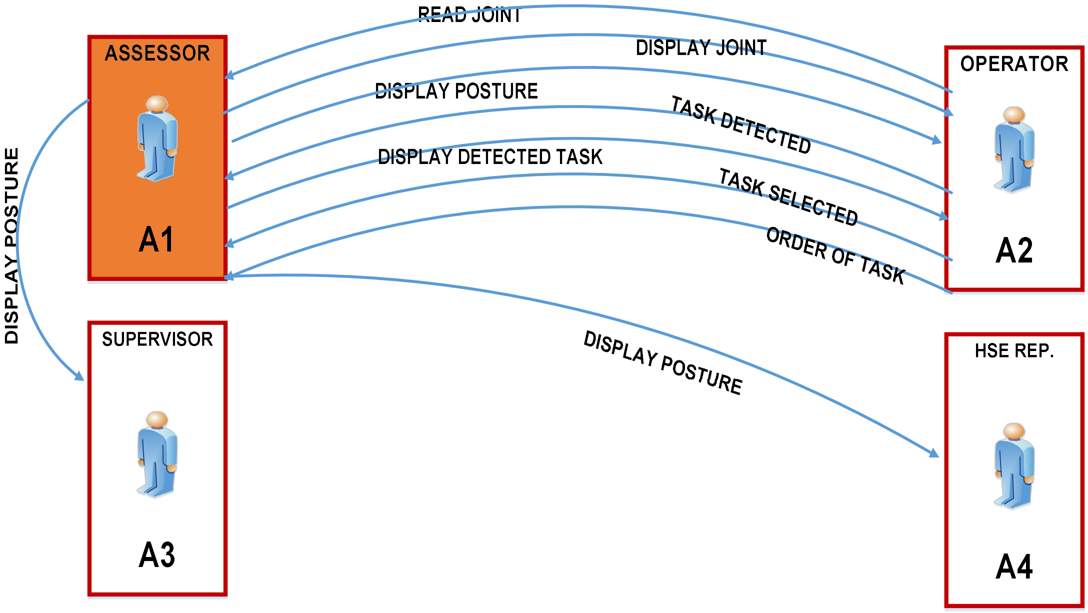


Figure 6-4 Assessor's interaction with other actors

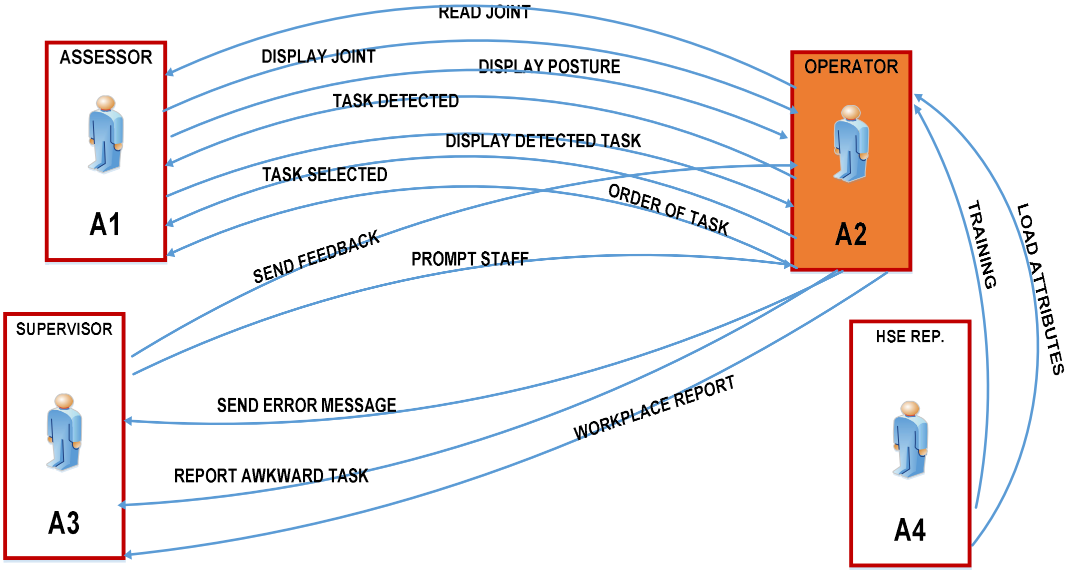


Figure 6-5 Operator's interaction with other actors

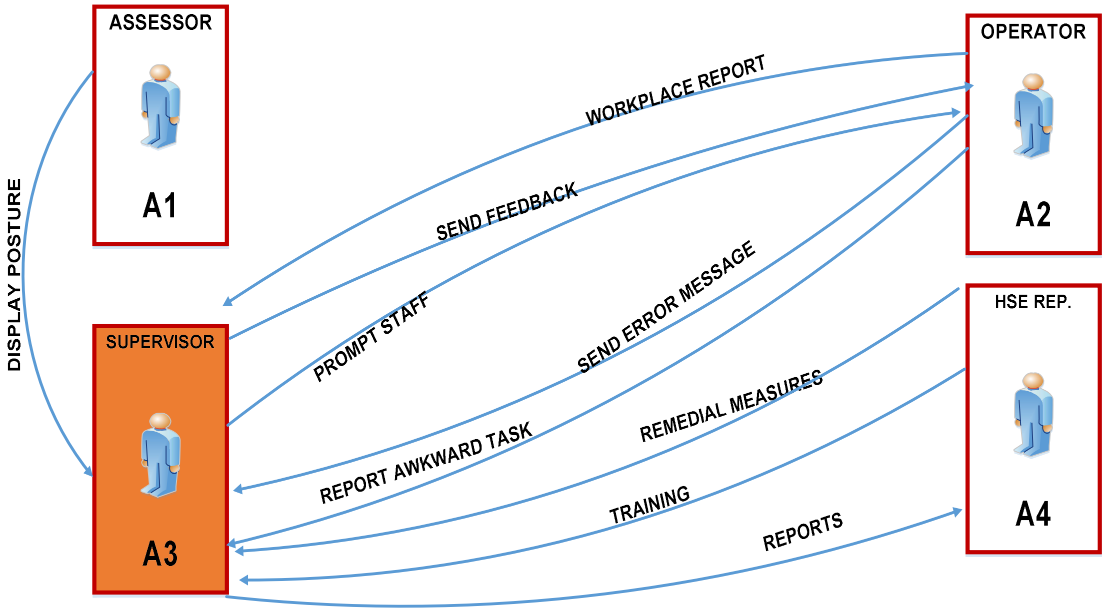


Figure 6-6 Supervisor Interaction with other actors

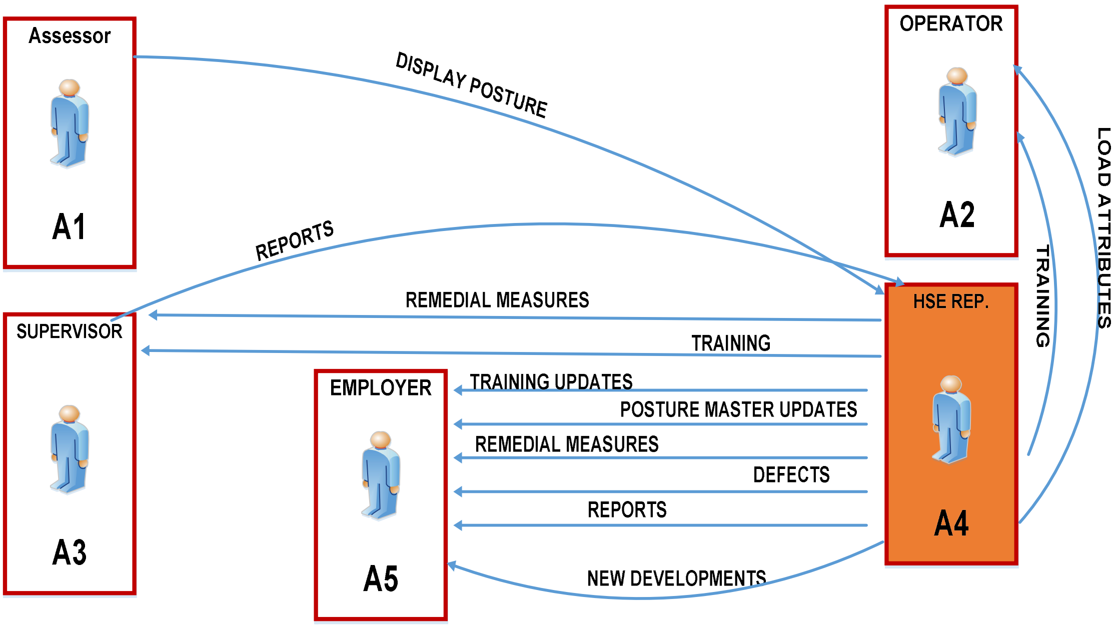


Figure 6-7 HSE Rep. interaction with other actors

Figure 6-8 Employer Interaction with other actors

In figure 6-4 for instance, the ‘Read Joint’ use case flows from the operator to the Assessor (Kinect). This means that though the assessor extracts the joint data from the operator, the flows from the operator to the assessor who assesses the data and displays the joint results to the workers as represented by the ‘Display Joint’ use case.

6.2.2.3 Question Three: What format is the information provided?

The format with which the information flow from one actor to another is delivered to the end user is presented in the tables below. For instance, row 2 of table 6-1 shows how the posture status of the operators is to be displayed by the assessor in real-time both by display on the screen and by voice alert from the system. The supervisors and HSE Rep. in addition to the prompting by the assessor, could also prompt the worker to adjust awkward postures by using the chat screen.

Table 6-1 **Information flow and format of Information for Actor 1 (A1)**

Information	Description of Information	Nature of Information	Flow	Format
Joint Information	a) The assessor receives information on the joints of a worker within its field of view. b) It processes the data and display output	a) Real time b) Real time	a) A2 – A1 b) A1 – A2	Tracked body joints displayed as numerical values.
Posture Status	The assessor displays the posture output to staff.	Real time	A1 – A2	Display of posture updates on screen and voice alert
Gesture detection	a) The operator checks if task is detected by the assessor. b) The assessor responds.	a) Real time b) Real time	a) A2 – A1 b) A1 – A2	a) Press the 'run detection' button. b) Displays the detection window
Task Selected	The assessor receives information from the operator on the choice of task.	Real time	A2 – A1	Choice of task from a list of tasks through a drop-down menu.

Table 6-2 Information flow for Actor 2 (A2 - Operator)

Information	Description of Information	Nature of Information	Flow	Format
Login	Login with assigned Username and Password.	Real time	-	Text input
Joint Information	Receives information from the assessor on his joint data.	Real time	A1 – A2	Display of joint angles
Task	(a) Sends information to the supervisor requesting help with awkward tasks (b) He informs the system on his choice of task.	a) Real time b) Real time	(a) A2 – A3 (b) A2 – A1	a) Message to signal awkward task. b) Choice of task from a library of task
Posture	Receives feedback of his posture assessment results from the assessor.	Real time / offline	A1 – A2	Display of Posture updates on screen and voice alert.
Workplace	(a) Should notify the supervisor if the workplace has any ergonomically unacceptable issues such as poor lighting which can affect the posture assessment. b) He receives feedback from the supervisor.	a) Either real time or offline b) Either real time or offline	(a) A2 – A3 (b) A3 – A2	a) Text entry in chat describing the issue. b) Text response via chat.
Load	Receives load marked by the HSE Rep and inputs this information to the system.	Offline	A4 – A2	Marks on the loads showing the load

				attributes/ Text entry of the attributes.
Error Message	Notifies the supervisor when the sensor starts generating erroneous feedback			
Training	Receives training on the use of the system.	Offline	A4 – A2	Choice of suitable training from library of training log

Table 6-3 Information flow for Actor 3 (A3 - Supervisor)

Information	Description of Information	Nature of Information	Flow	Format
Login	Login with assigned Username and Password.	a) Real time	-	Text input
Staff Account	a) Registers new User and updates existing users.	a) Offline.	-	a) Text entry
Task	a) Receives awkward task information from the operator. b) Deploys help to the operator.	a) Real time b) Real time	a) A2 – A3 b)A3 – A2	a) Message via chat b) Text response via chat
Workplace	a) Receives information from the operator. b) Sends feedback to the operator.	a) Either real time or offline b) Either real time or offline	a) A2 – A3 b) A3 – A2	a) Text entry in chat describing the issue. b) Text response via chat.

Error Reports	a) Receives information when the assessor generates erroneous feedback. b) Sends feedback to the operator.	a) Real time b) Either real time or offline	a) A2 – A3 b) A3 – A2	a) Text entry in chat describing the issue. b) Text entry via chat.
Postures	a) Receives updates concerning the operator's postures. b) Prompts operators to adjust risky postures	a) Offline b) Real time/ offline	a) A1 – A3 b) A3 – A2	a) Choice of posture update from database. b) Text entry via chat.
Reports	Generates and sends report to the HSE representative	Offline	A3 – A4	Text entry via chat or by paperwork.
Archive	Can assess the past posture updates of Operators any time.	Offline	-	Choice of posture output from the database
Training	Receives training on the use of the system.	Offline	A4 – A3	Choice of suitable training from library of training log.

Table 6-4 Information flow for Actor 4 (A4 - HSE REP.)

Information	Description of Information	Nature of Information	Flow	Format
Login	Login with assigned Username and Password.	Real time	-	Text input
Reports	Receives reports from the supervisor	Offline	A3 – A4	Display on chat.
Posture	Receives updates concerning the operator's postures.	Offline	A1 – A4	Choice of posture update from database.
Load	Marks the Loads to indicate its weight, heaviest side, etc.	Offline	A4 – A2	Marking of Load
Training	Organizes training for the all staff	a)Offline	a) A4 – A2	-

Table 6-5 Information flow for Actor 5 (A5 - Employer)

Information	Description of Information	Nature of Information	Flow	Format
Posture Master	Receives feedback from the HSE Rep., on the efficiency and effectiveness of the system to prevent risks in the workplace. a) He receives information on the upgrade of the system.	Offline	a) A4 – A5 b) A4 – A5	c) Text entry via chat or by paperwork d) Text message receipt or paperwork
Reports	Receives comprehensive reports.	Offline	A4 – A5	Paperwork

6.2.3 **System Architecture Diagrams**

6.2.3.1 Models of the Internal Logic of the Complex Operations in the System using the UML Activity Diagrams

To design a feedback system that meets the proposed system requirements, the logic captured by the use case model is further modelled using the UML activity diagram and the results are represented for each actor in the figures below. The UML activity diagrams aims to model the internal logic of the complex operations involved in the proposed feedback system

UML activity diagrams of figures 6-9 to 6-13 shows how the activities of each of the users were modelled using the UML activity diagrams which show at a glance, the modelled internal logic of the complex operations involved in the design of the system and provides the possible navigation paths and connections to other key data elements necessary for state changes. The models clearly communicate the system functionality, processing and user interface flows for each external user, including the assessor.

While the use case model shows why and when the users should follow particular paths in the system, the activity diagrams models the roadmap of the user functionality which shows the paths followed by the users (Lieberman, 2004).

The assessor’s activity diagram describes how the Kinect receives information and display results. The assessor receives the choice of task and task order from only the operator, reads his joint information, analyses his posture and detects his task when prompted. It displays the posture assessment and task detection results to the operator.

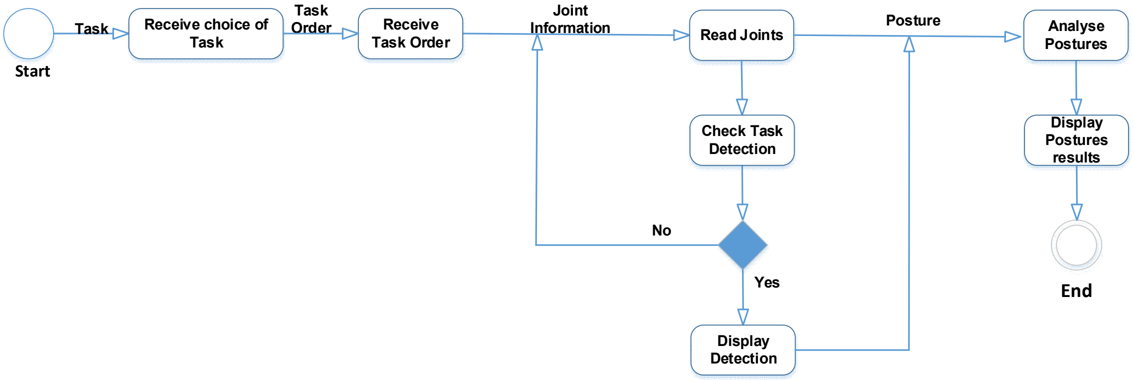


Figure 6-9 Assessor's Activity Diagram

The operator's activity diagram explains the operator's activities from when he logs in to when he completes his task. The operator first signs into the system and when authenticated, views task, selects appropriate task and before running the task, checks if the task is awkward (handling heavy loads etc.). if so, requests for assistance and waits. if not, run the task and check to see if task is detected. If not detected, reports the error but if task is detected, the operator continues the task and checks for feedback while adjusting their postures until their task is completed.

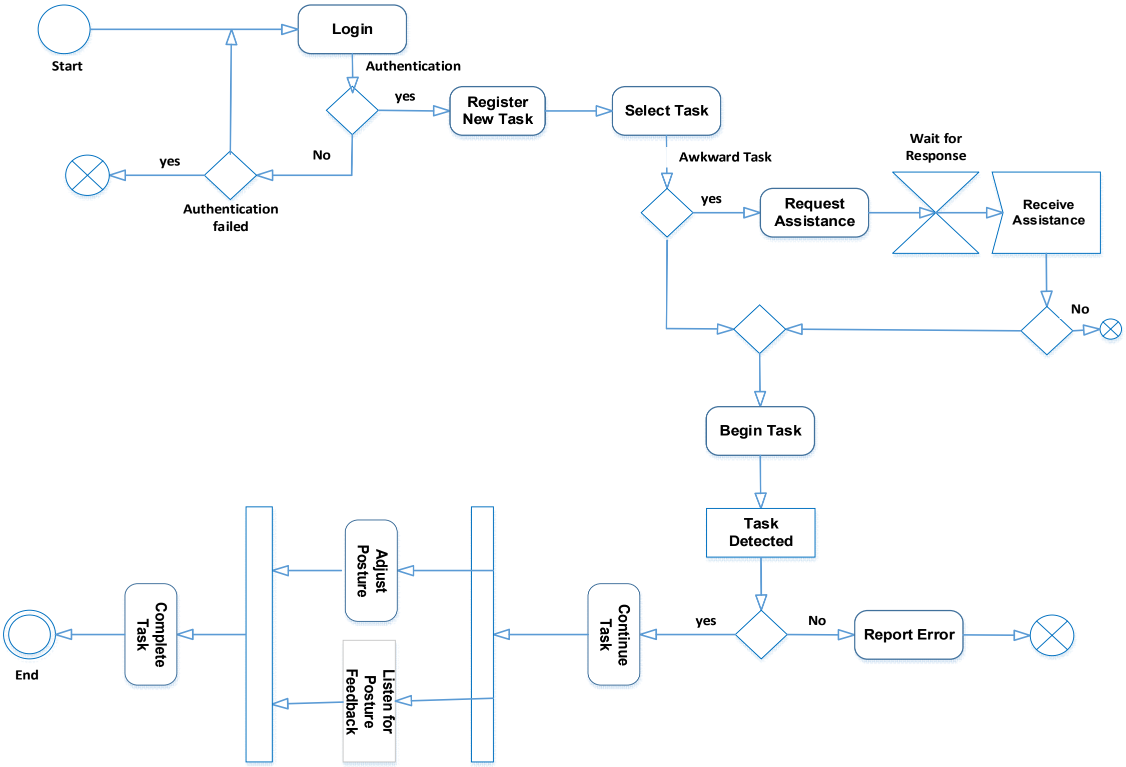


Figure 6-10 Operator's Activity Diagram

In the supervisor's activity diagram, the supervisor gains access to the system using the login button. The supervisor then chooses either to go to the user accounts and register new staff/update existing staff, or to check the workplace reports and monitor operators for awkward posture updates and feedback.

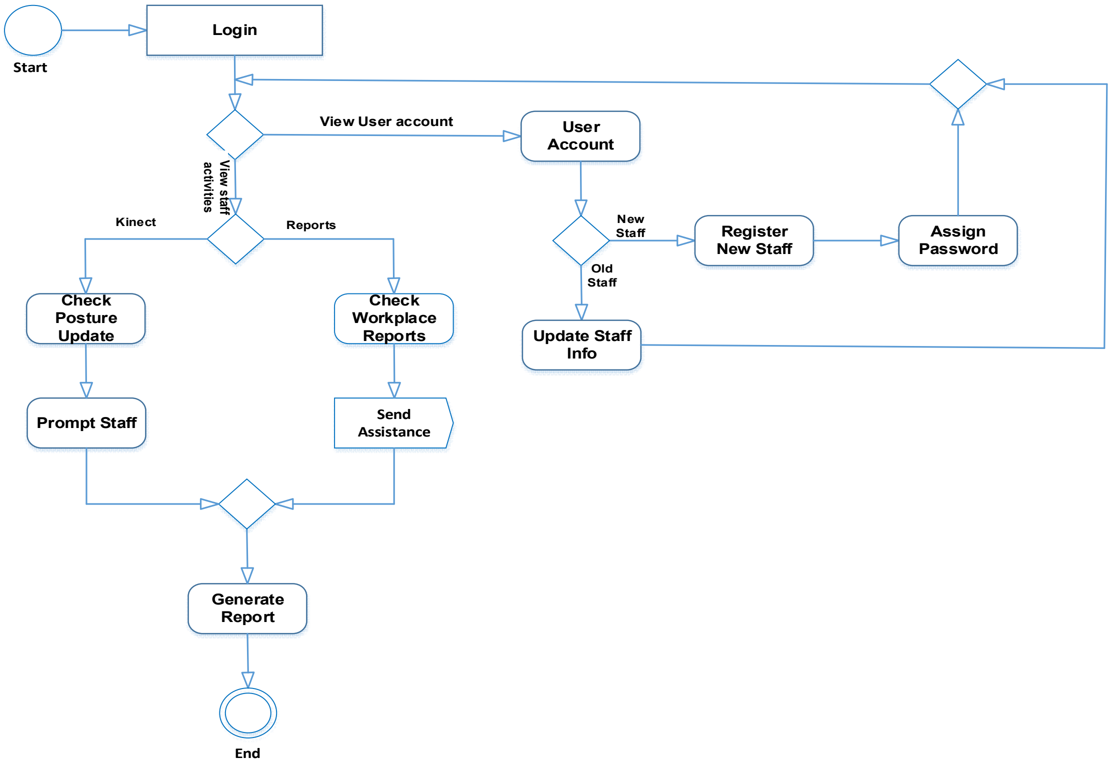


Figure 6-11 Supervisor's Activity Diagram

The HSE Rep.'s activity diagram depicts the activities of the HSE Rep. at the operator's desk, supervisor's desk and at employer's desk.

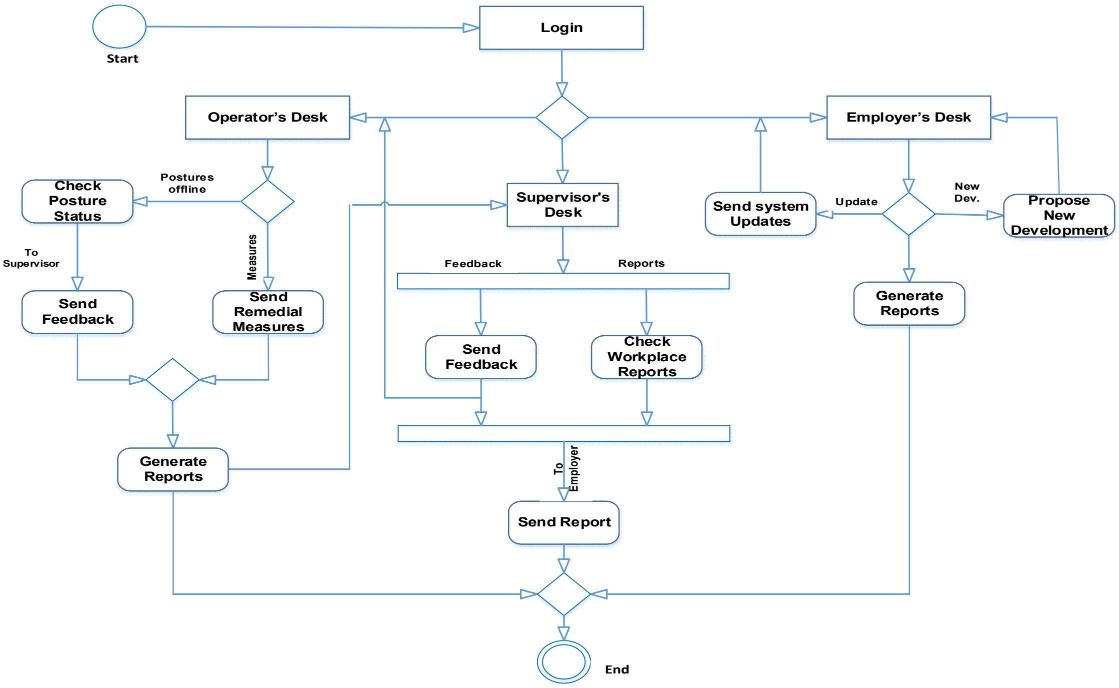


Figure 6-12 HSE Rep's Activity

The employer's activity diagram shows the employer activities.

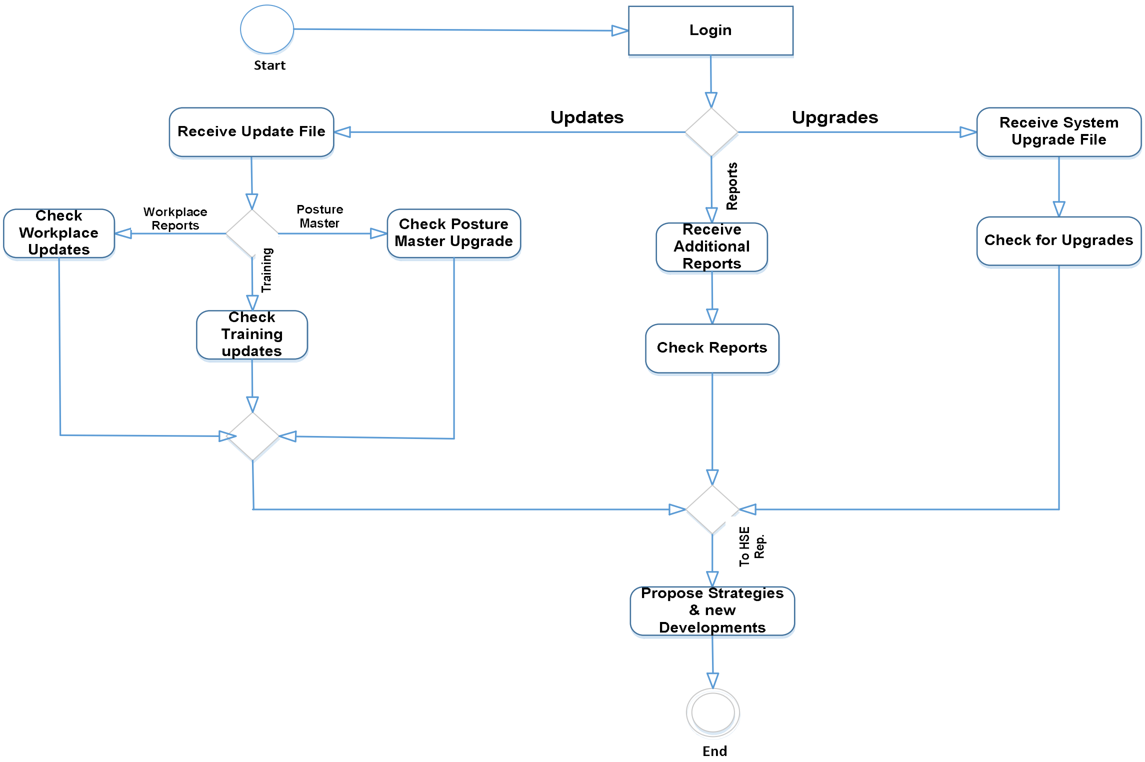


Figure 6-13 Employer's Activity Diagram

6.2.3.2 Model of the architectural view of the system using the User Interface Flow Diagram

The User Interface Flow Diagram of figure 6-14, also known as the Storyboard, employed to model the high-level relationships between the major user interface elements, shows a high-level overview of the feedback system design and is the architectural view of the system as it represents the complete interface system along with its controls. The final design of the feedback system as modelled by the User Interface Flow Diagram of the system is presented.

Furthermore, the system’s site map of figure 6-15 describes the system’s screens and sub screens and summarises the user interface flow diagram.

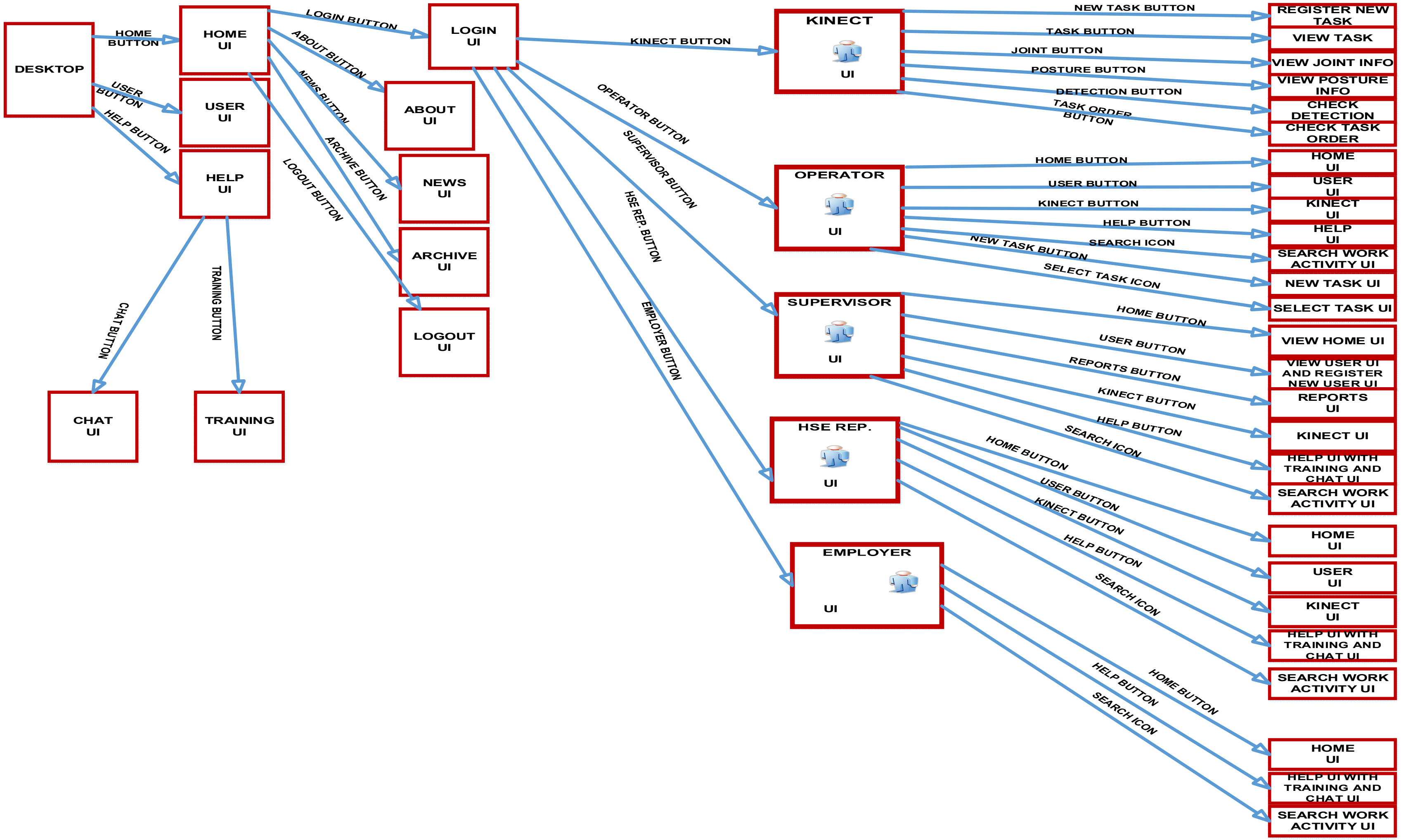


Figure 6-14 User Interface Flow Diagram (Storyboards) of the proposed Feedback System.

The site map of the proposed system, which gives a visual understanding of the system development represented as a ‘tree’, is illustrated thus.

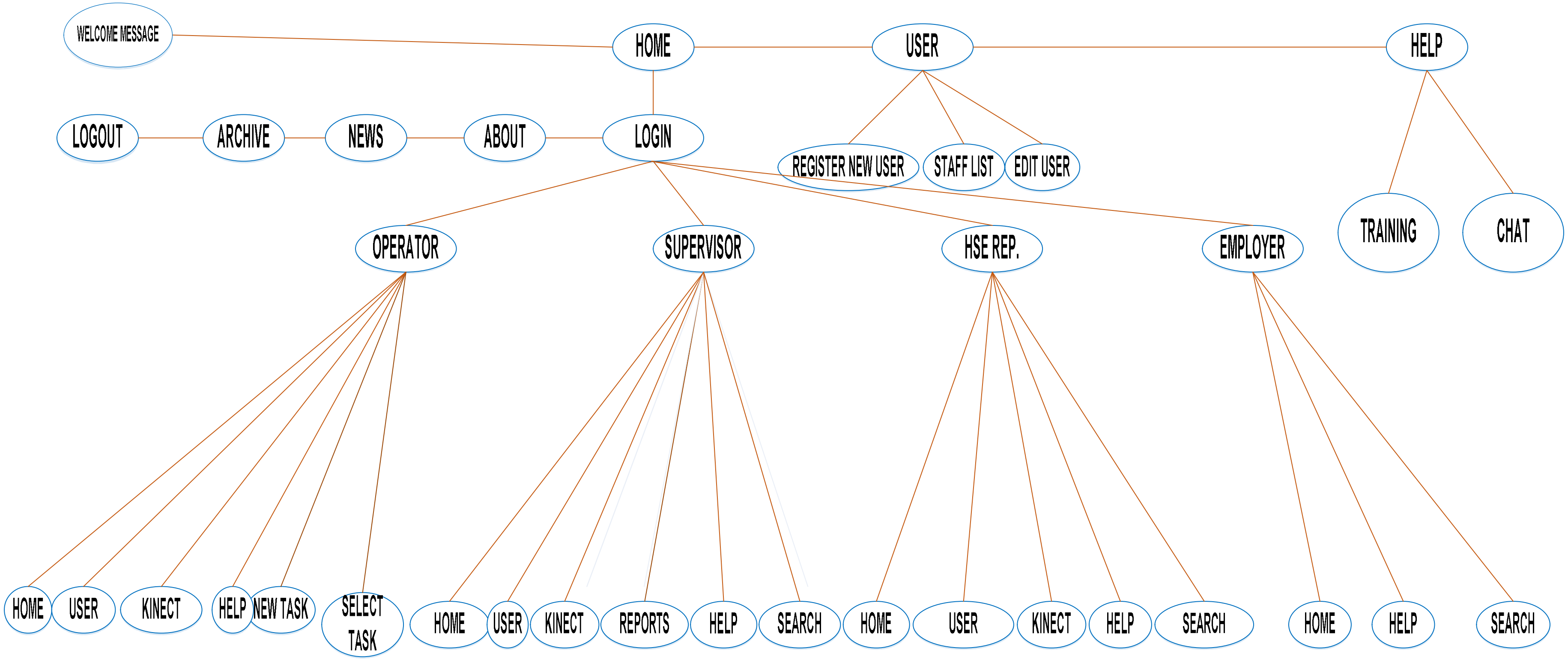


Figure 6-15 The site map of the proposed system

6.3 **Feedback Interface Development**

After designing the interface, it is further developed, with some of the screens presented in this section.

The first level screens the user is expected to see after launching the system is the ‘Home Screen’ which contains the ‘Home Menu’, ‘User Menu’ and the ‘Help Menu’ buttons as shown in figure 6-16. These menus consist of sub-menus which the user accesses by pressing buttons with pointers such as keyboard or mouse. The ‘Login Menu’ when clicked with a pointer, displays the login window to all users, the ‘About Menu’ displays the about window with information about the system, the ‘News Menu’ for display of current news to the users, the ‘Archive Menu’ for accessing database updates and the ‘Logout Menu’ for signing out of the system.

On the right side of each window is a welcome message that displays the name and role of the user that is currently signed into the system.

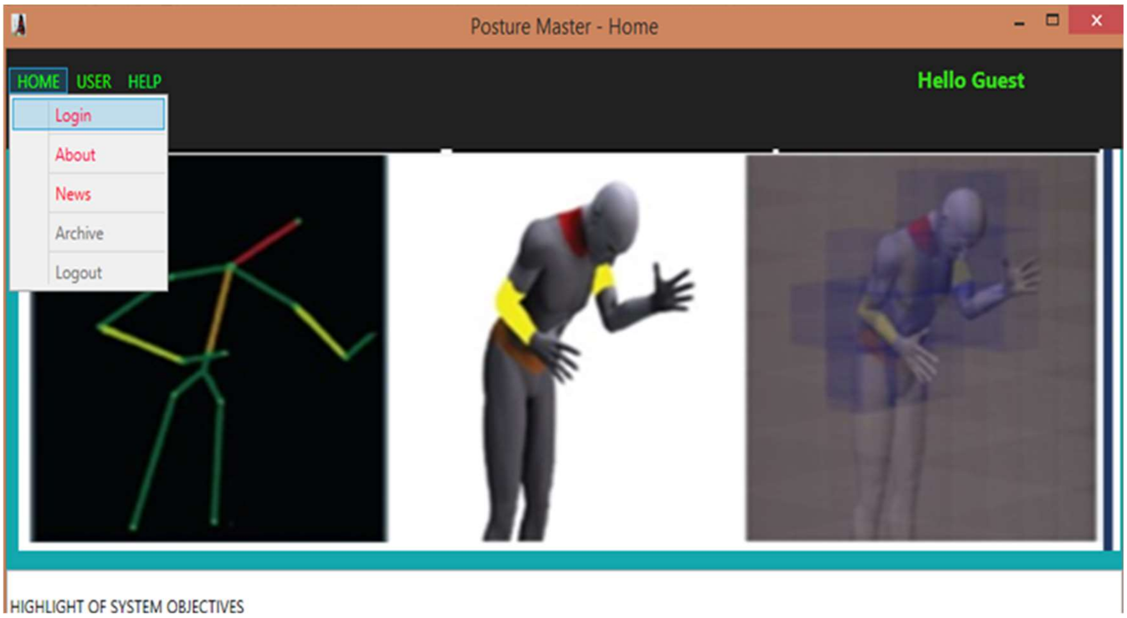


Figure 6-16 Home window displaying the ‘Home Menu’ and sub-menus

The Login window of figure 6-17 is used by all users to sign into the system using assigned username or password. Forgotten passwords can also be reset and the user can go back to the home window using the ‘home menu’.

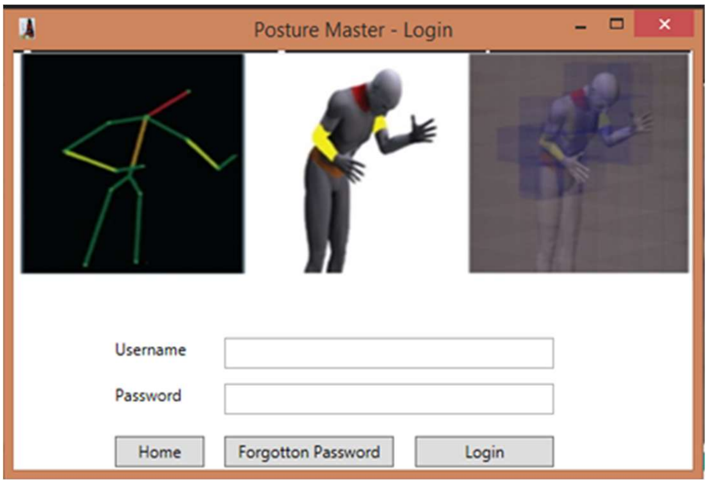
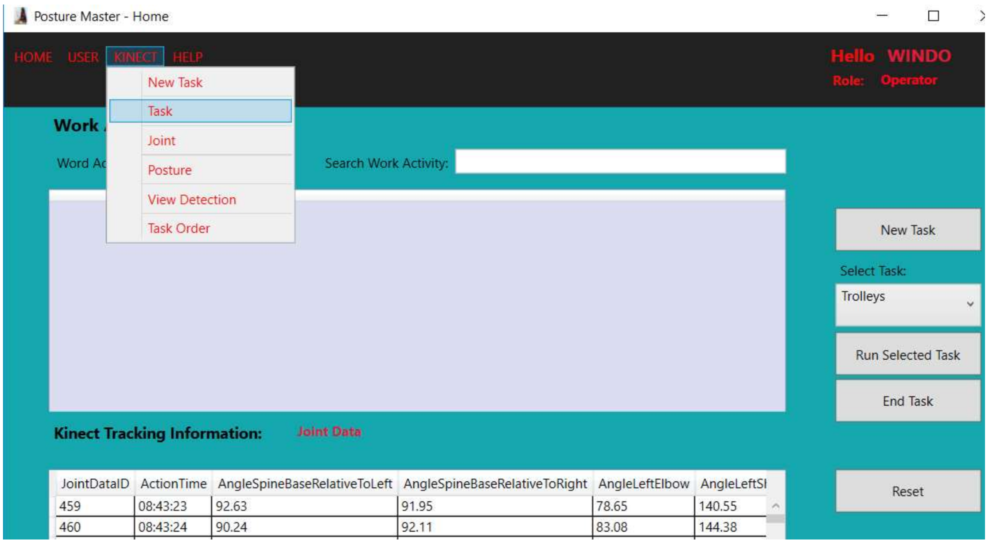


Figure 6-17 Login Screen

The operator’s window of figure 6-18 shows on the left-hand side, the home menu, user menu, Kinect menu and help menu with sub-menus. The Kinect menu contains the ‘New Task sub-menu’ with which the operator registers new tasks, the ‘Tasks Menu’ of figure 6-18 which when clicked displays all previous and current assessed task and posture updates of the operator. Information displayed includes weight of the load, duration of task, task start time and stop time.

The Kinect menu also consists of the ‘Joint sub-menu’ which displays the current and previous joint information of the operator for each joint, the ‘Posture Sub-menu’ which displays the posture assessment results, the ‘View Detection Sub-menu’ which opens the detection window for viewing the task detection updates and the ‘Task Order Sub-menu’ that displays the task in the order with which it was performed.

On the right-hand side of the operator’s window is the ‘Select Task drop-down-menu’ with which registered task are selected, the ‘Run selected task menu’ which opens the Kinect window when clicked (figure 6-20), the ‘End Task button’ and the ‘Reset’ button.



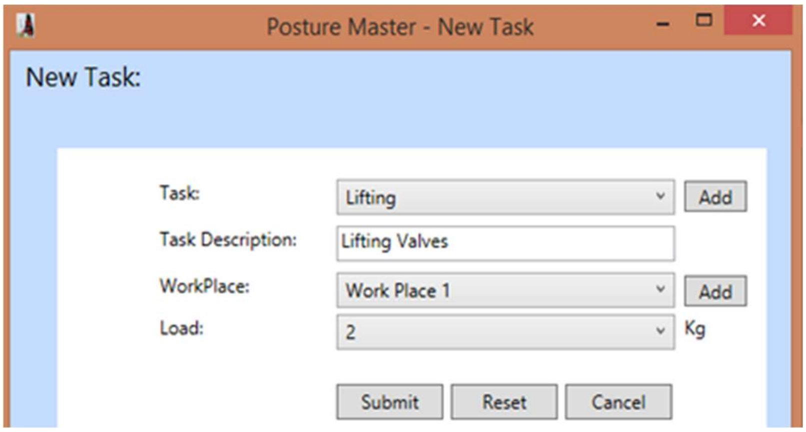
Hello WINDO
Role: Operator

Select Task: Trolleys

JointDataID	ActionTime	AngleSpineBaseRelativeToLeft	AngleSpineBaseRelativeToRight	AngleLeftElbow	AngleLeftSl
459	08:43:23	92.63	91.95	78.65	140.55
460	08:43:24	90.24	92.11	83.08	144.38

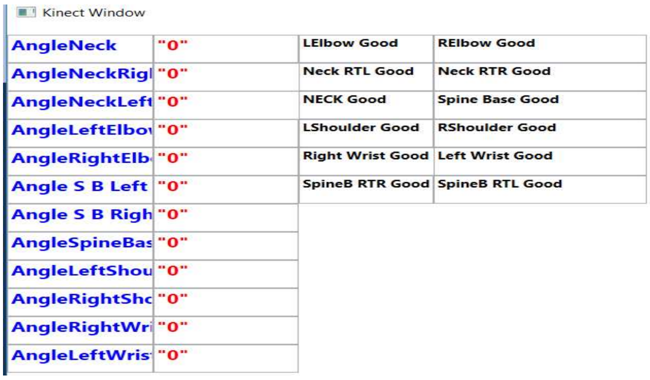
Figure 6-18 Operator’s Screen showing ‘Kinect Menu’ and sub-menus.

New task screen showing where the operator registers new tasks. This usually takes less than 15 seconds to complete and submit.



Task: Lifting
Task Description: Lifting Valves
WorkPlace: Work Place 1
Load: 2 Kg

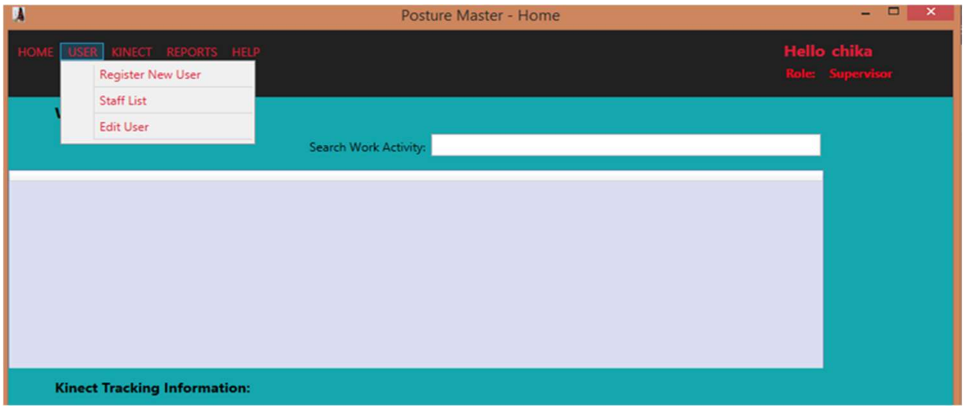
Figure 6-19 Operator’s New Task Screen



AngleNeck	"0"	LElbow Good	RElbow Good
AngleNeckRigl	"0"	Neck RTL Good	Neck RTR Good
AngleNeckLeft	"0"	NECK Good	Spine Base Good
AngleLeftElbo	"0"	LShoulder Good	RShoulder Good
AngleRightElb	"0"	Right Wrist Good	Left Wrist Good
Angle S B Left	"0"	SpineB RTR Good	SpineB RTL Good
Angle S B Righ	"0"		
AngleSpineBas	"0"		
AngleLeftShou	"0"		
AngleRightShc	"0"		
AngleRightWri	"0"		
AngleLeftWris	"0"		

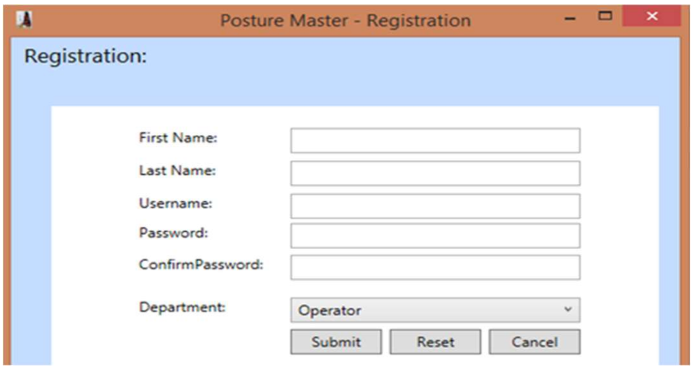
Figure 6-20 **The Kinect window**

The supervisor's window showing all the menus especially the user sub-menus, is presented in figure 6-21. The user menu contains the 'Register New User sub-menu' which when pressed, opens the registration window as shown in figure 6-22. It also consists of the staff list sub-menu and the edit user sub-menu used to view or edit the registered staff details. The registration page of figure 6-22 is used by the system admin to register new users.



Hello chika
Role: Supervisor

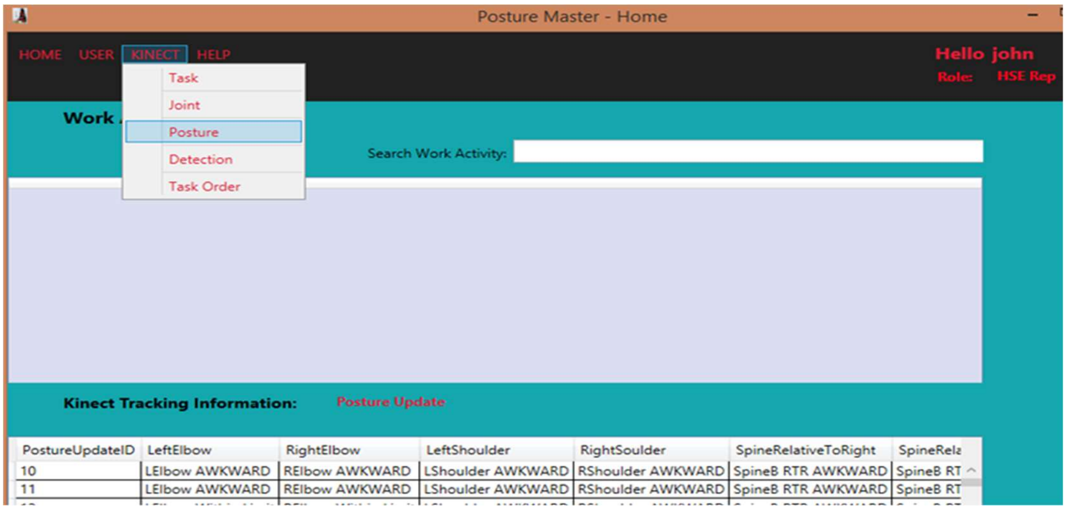
Figure 6-21 Supervisor's Screen showing the User Menu and sub-menus.



Department: Operator

Figure 6-22 System's Registration Screen

Figure 6-23 shows the HSE Rep's window with its associated menus and sub-menus. The Kinect task menu, like that of the supervisor, shows how staff call previous posture updates of operators from the database.



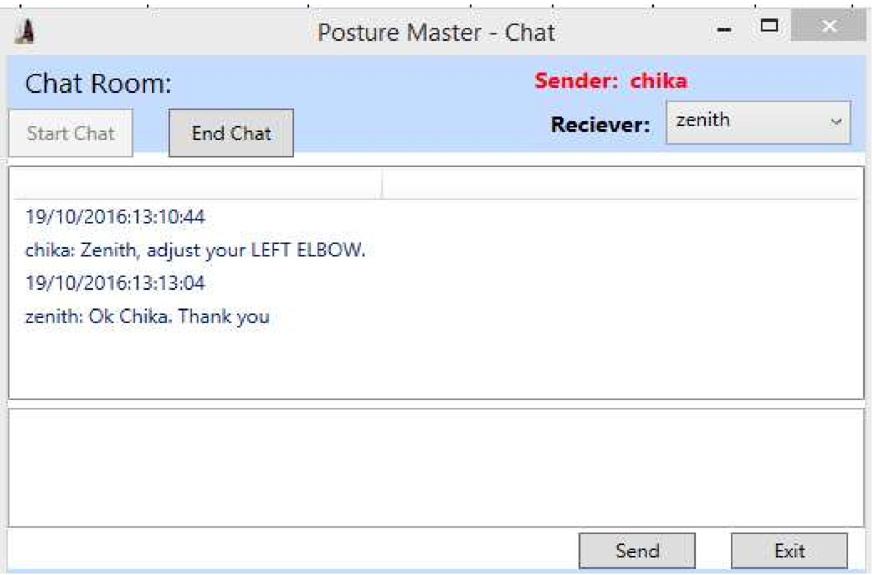
Hello john
Role: HSE Rep

Kinect Tracking Information:

PostureUpdateID	LeftElbow	RightElbow	LeftShoulder	RightSoulder	SpineRelativeToRight	SpineRela
10	LElbow AWKWARD	RElbow AWKWARD	LShoulder AWKWARD	RShoulder AWKWARD	SpineB RTR AWKWARD	SpineB RT
11	LElbow AWKWARD	RElbow AWKWARD	LShoulder AWKWARD	RShoulder AWKWARD	SpineB RTR AWKWARD	SpineB RT

Figure 6-23 HSE Rep.'s Screen showing the 'Kinect Posture' button functionality

The chat window of figure 6-24 shows how the users can send and receive information through chat, and can be opened by clicking the 'Help menu' button.



Sender: chika

Reciever: zenith

19/10/2016:13:10:44
chika: Zenith, adjust your LEFT ELBOW.
19/10/2016:13:13:04
zenith: Ok Chika. Thank you

Figure 6-24 Chat window

Developed system's Architecture

The resulting posture assessment KBS is a multi-tier architectural system which consist of the Interface (presentation tier), the inference engine (the logic tier) and the knowledge base (the data tier). This is represented in figure 6-25.

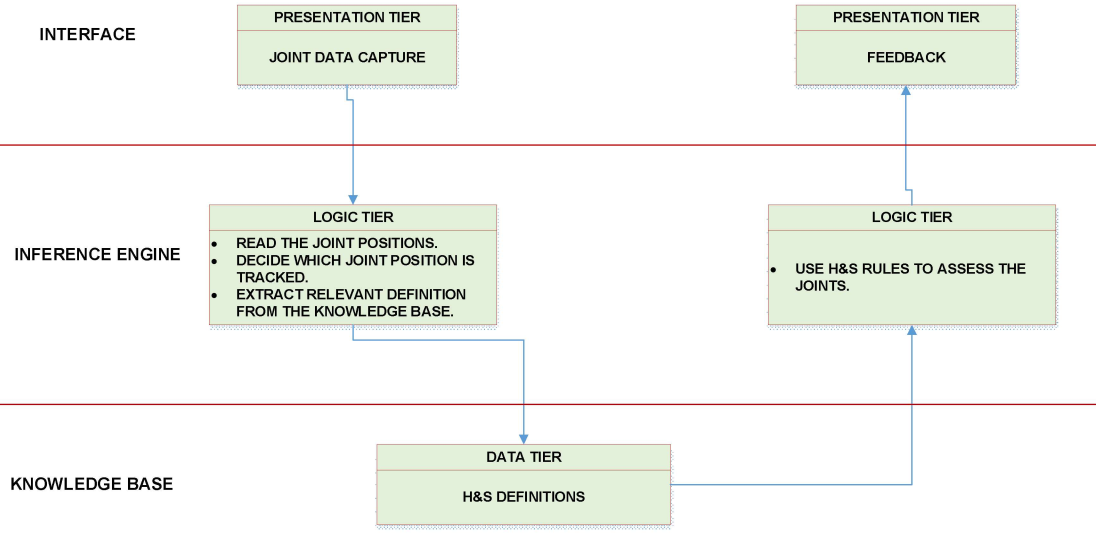


Figure 6-25 Developed KBS Multi-Tier Architectural Diagram

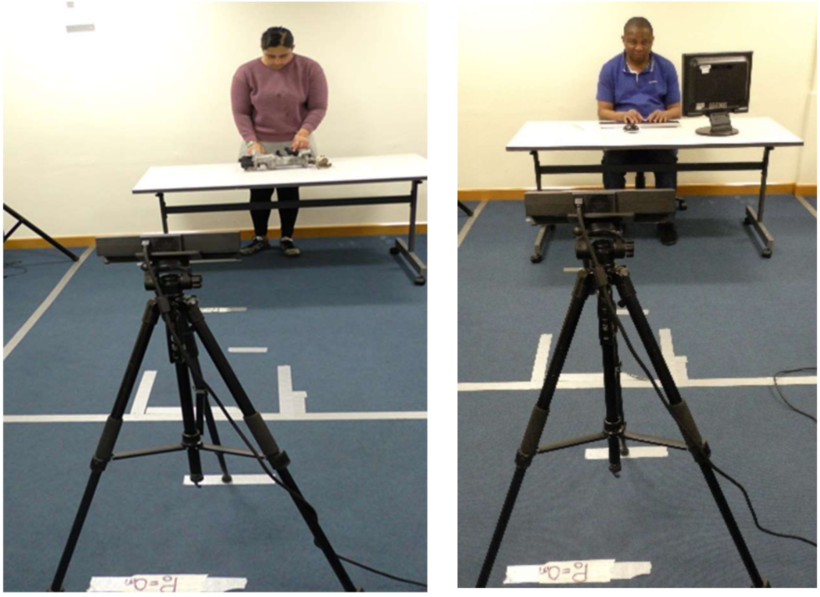
6.4 **System Demonstration**

Having developed the designed feedback interface, the resulting system is tested on selected case studies.

6.4.1 **Experimental Setup for testing the developed System.**

To test the functionalities of the developed system, experiments were conducted on two case studies. These are the manual assembly of Valve of a diesel engine by six operators and the posture assessment of four PhD researchers while studying. A total of 10 participants aged between 25 to 40 years, participated in the study. The system's assessor, which is the Kinect, costs approximately £90/$112 and is readily available in the market. The developed system requires very little set up time as it only requires the user to place the sensor within the sensor's field of view and to start the system by pressing the start button. The sensor is programmed to simply inform the operator when the posture is good or awkward. This is done by real-time display on the screen and speech communication to the operator on the postures that have been held over prolonged periods. The system is easy-to-implement because the screens are designed in a simple and interactive way.

For this experiment, the sensor is placed at 1.2m Height and 3m object distance from the sensor, as established in chapter 4, and shown in figure 6-26.



a. Operator assembling engine valve b. Researcher studying

Figure 6-26 Experimental Setup for testing the developed system.

6.4.2 Experimental Procedure

The participants were asked to setup the system, login and register their various tasks, while the setup times for each participant were recorded. Then the postures of their upper body (spine and upper limbs), were captured and assessed by the system while executing the tasks. Each participant was asked to complete an assessment form to evaluate the system using the following criteria; i) ease of use ii) ease of understanding iii) ability to provide real-time feedback and iv) convenience. By convenience, we meant to assess if the participants were comfortable and satisfied with the feedback provided by the system.

Case 1: Posture Assessment of operators Assembling Jaguar Engine Valve.

According to the UK HSE's definitions 'The back posture is considered awkward if more than 20° of twisting or bending is observed' ('HSE - ART tool: Awkward postures,' n.d.). In this study, we aim to assess the system's capability to assess back postures in compliance with HSE guidelines and provide feedback, as six of the participant's upper body postures were captured and assessed with the developed feedback system, during the assembly of the valve engine component.

These volunteer operators, who are employed as cleaners in different workplaces in the United Kingdom, were briefly trained on how to assemble the engine valve and the experiment was carried out under controlled laboratory condition. Each operator assembled the valve component while the system captures his motion data, assesses his posture and provides feedback to the operator while working. The assembly task is performed once while the system captures the operator’s posture data and records the task completion time.

Case 2: Posture Assessment of Seated Researchers

Again, according to the UK HSE, ‘The arm is considered to adopt an awkward posture if the elbow is raised around chest height’ (‘HSE - ART tool: Awkward postures,’ n.d.). Hence, the system’s capability to assess arm postures in compliance with HSE guidelines and provide feedback to the participants, was assessed as four of the participant’s upper body postures were captured and assessed while studying.

The PhD researchers who participated in the experiment are students of Cranfield University, United Kingdom, whose posture data was assessed by the system as they were studying. This case study was selected to test the generality of the developed system for use in other workplaces involving non-manual handling tasks.

6.4.3 Experimental Results and Discussion

In this section, the results obtained from testing the developed feedback system are presented.

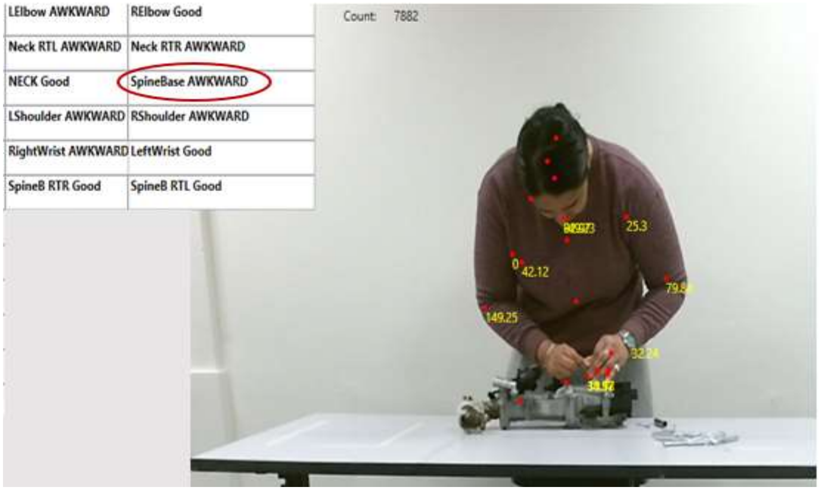
In figure 6-27, the result of the posture assessment update of one of the operators while assembling the valve engine component, is presented. This data is retrieved from the system database and plotted in SPSS software to analyse the frequency of the back-posture quality. Frequency is computed as the rate at which the joint is held either awkward or good states at a time.

The operator in figure 6-27 had her back posture assessed as ‘Awkward’ at the time of capture, as depicted in 6-27a and represented by ‘SpineBase Awkward’ displayed to the operator on the Kinect window at the time of capture. This result was displayed as real-time feedback to the operator who is expected to act by adjusting her awkward back posture.

In figure 6-27b, the back posture of the operator is seen to be held awkward for up to 8 frames or more at a time. Figure 6-27b shows how the operator views his posture update and task information, stored in the database, using the Kinect task menu button. Pressing the Kinect task menu button displays the task display window and the posture update window. The task display window displays information on all the tasks carried out in the past by the operator, which includes the task name, task description, weight of load handled, task duration, as well as task start time and stop time. All information on their posture update while performing these tasks are displayed on the posture update window and this is accessed by clicking either the Kinect menu task button or the Kinect menu posture button. Pressing the Kinect joint button displays the angular joint data for each of the joints. Availability of this database information via the stored database may help inform workers to retrieve all their past posture assessment updates for future ergonomic interventions and actions. In figure 6-27b, the information displayed on the task display window indicate that the operator at workplace number 3, was performing an assembly task on a 5.5kg valve and cooler engine. The task duration is also provided in the database information.

The analysis of the back-posture quality data in accordance with its frequency of occurrence during the entire task duration, is presented in figure 6-27c. The blue horizontal lines represent the rate of occurrence of awkward postures while the green horizontal lines depict the rate of occurrence of good postures. The back posture seems to have been held awkward for prolonged period at a time because the ‘SpineBase Awkward’ has the highest frequency of occurrence whereas the ‘SpineBase Good’ was held for shorter period as represented in figure 6-27c. In the Figure, the assessment started with the back posture held awkward for many frames at different times, after which it switched from awkward to good and vice versa at different times and went back to being held awkward till the end of the task. This analysis has helped to establish that during the assembly task by the operator, the back postures were held in a highly risky position over 78% of the task duration.

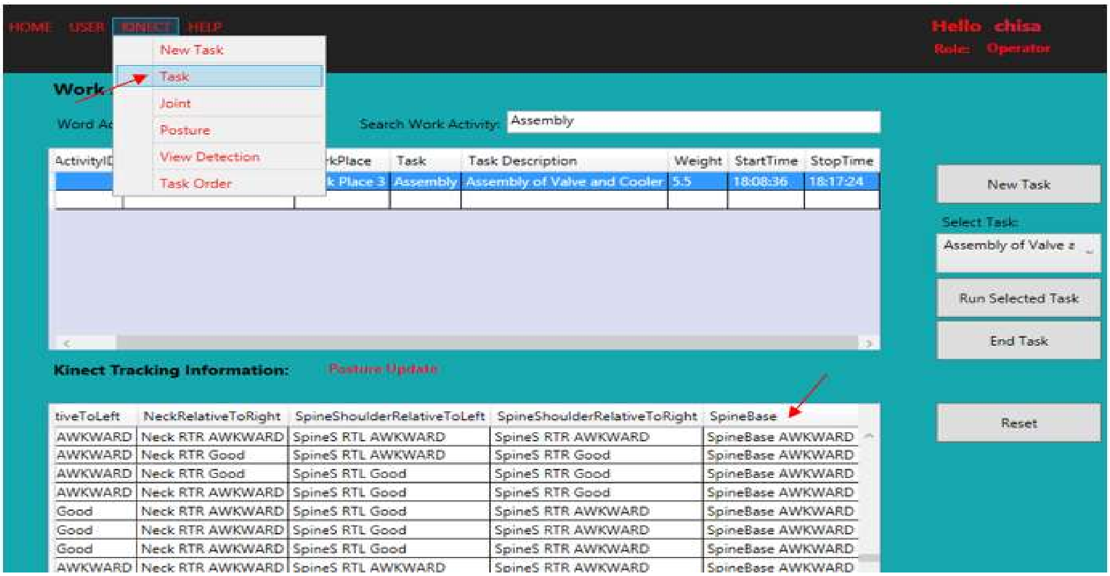
This result in an actual work environment would indicate the need for immediate ergonomic interventions and possible workplace re-design and training.



LElbow AWKWARD	RElbow Good
Neck RTL AWKWARD	Neck RTR AWKWARD
NECK Good	SpineBase AWKWARD
LShoulder AWKWARD	RShoulder AWKWARD
RightWrist AWKWARD	LeftWrist Good
SpineB RTR Good	SpineB RTL Good

Count: 7882

a. Real-Time tracking/feedback to an Operator showing awkward back posture assessment during assembly task



Hello chisa
Role: Operator

Search Work Activity: Assembly

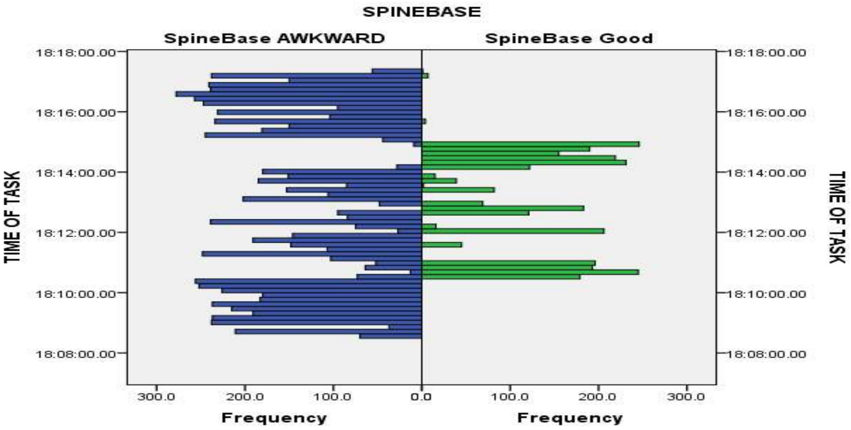
ActivityI	rkPlace	Task	Task Description	Weight	StartTime	StopTime
	k Place 3	Assembly	Assembly of Valve and Cooler	5.5	18:08:36	18:17:24

Select Task: Assembly of Valve a

Kinect Tracking Information: Posture Update

tiveToLeft	NeckRelativeToRight	SpineShoulderRelativeToLeft	SpineShoulderRelativeToRight	SpineBase
AWKWARD	Neck RTR AWKWARD	SpineS RTL AWKWARD	SpineS RTR AWKWARD	SpineBase AWKWARD
AWKWARD	Neck RTR Good	SpineS RTL AWKWARD	SpineS RTR Good	SpineBase AWKWARD
AWKWARD	Neck RTR Good	SpineS RTL Good	SpineS RTR Good	SpineBase AWKWARD
AWKWARD	Neck RTR AWKWARD	SpineS RTL Good	SpineS RTR Good	SpineBase AWKWARD
Good	Neck RTR AWKWARD	SpineS RTL Good	SpineS RTR AWKWARD	SpineBase AWKWARD
Good	Neck RTR AWKWARD	SpineS RTL Good	SpineS RTR AWKWARD	SpineBase AWKWARD
Good	Neck RTR AWKWARD	SpineS RTL Good	SpineS RTR AWKWARD	SpineBase AWKWARD
AWKWARD	Neck RTR AWKWARD	SpineS RTL AWKWARD	SpineS RTR AWKWARD	SpineBase AWKWARD

b. Back posture updates of the Operator from the database



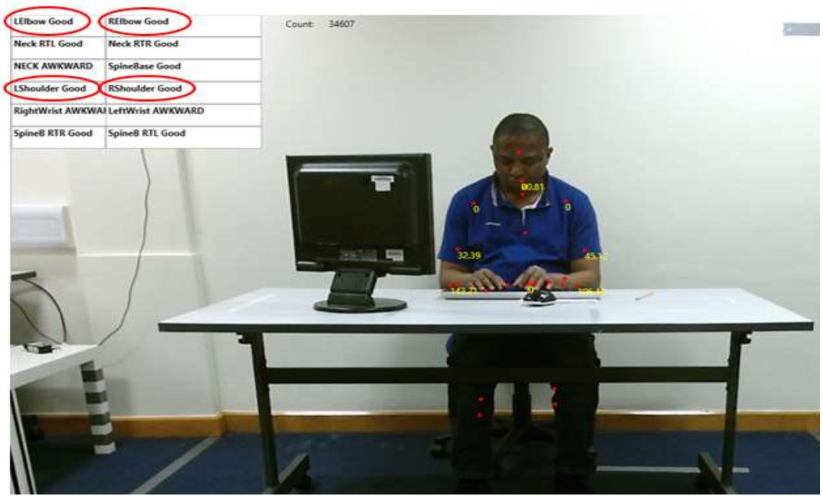
c. Back Posture Quality vs frequency for Assembly Task

Figure 6-27 Feedback System Implementation on Assembly Task Operator

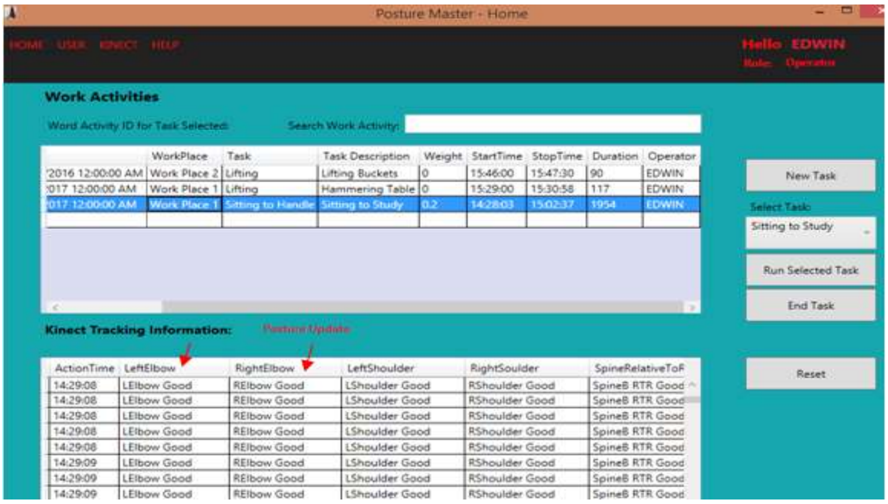
Similarly, in figure 6-28, the elbow postures update of a researcher, assessed by the system, is presented.

Both the right and left elbows were displayed as ‘Good’ in 6-28a and held for a long time as ‘Good’ in figure 6-28b when viewed offline by the researcher. In figure 6-28b, the information displayed on the task display window indicate that the researcher at workplace number 1, was sitting to study for up to a duration of 1954 seconds. During the duration of the study, the lower arm postures of the researcher was captured and assessed by the system. The posture update window displays the results of the right and left elbow posture assessment of the researcher. The developed system assessed the left and right elbows of the researcher for prolonged periods as seen on the posture update window of figure 6-28b. Other joints were also assessed but our focus in this study is the elbow postures.

Figure 6-28c show the right elbow being held as ‘Good’ for longer periods of up to 80% of the task duration. This is seen by the green bars of figure 6-28c, occurring at higher frequencies as compared to the blue bar that represent the rate of occurrence of awkward postures. Moreover, in figure 6-28d, the left elbow was held as ‘Good’ for longer periods of up to 91% of the task duration, as indicated by the higher frequency of the green bars, compared to the blue bars. This result indicates that the researcher does not require any immediate ergonomic intervention.



a. Real-Time tracking/feedback to Researcher showing good arm posture assessment



Work Activities

Word Activity ID for Task Selected:

Search Work Activity:

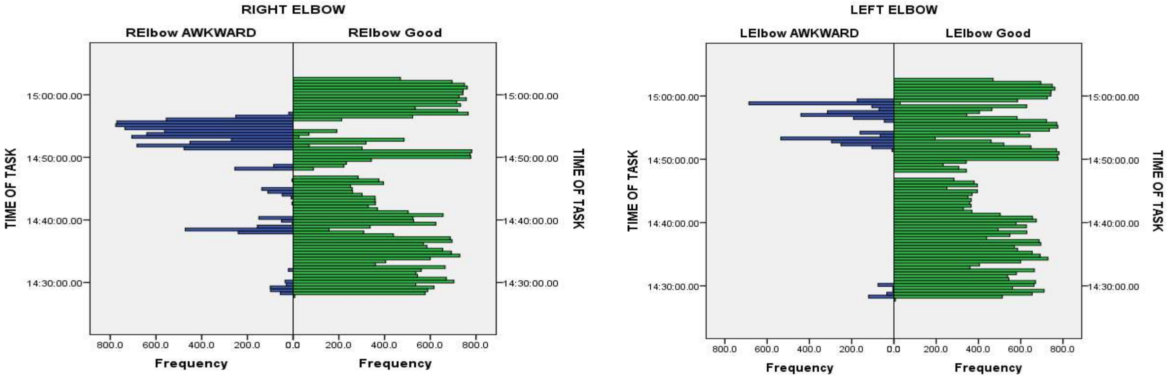
	WorkPlace	Task	Task Description	Weight	StartTime	StopTime	Duration	Operator
'2016 12:00:00 AM	Work Place 2	Lifting	Lifting Buckets	0	15:46:00	15:47:30	90	EDWIN
017 12:00:00 AM	Work Place 1	Lifting	Hammering Table	0	15:29:00	15:30:58	117	EDWIN
017 12:00:00 AM	Work Place 1	Sitting to Handle	Sitting to Study	0.2	14:28:03	15:02:37	1954	EDWIN

Select Task: Sitting to Study

Kinect Tracking Information:

ActionTime	LeftElbow	RightElbow	LeftShoulder	RightSoulder	SpineRelativeToF
14:29:08	LElbow Good	RElbow Good	LShoulder Good	RShoulder Good	SpineB RTR Good
14:29:08	LElbow Good	RElbow Good	LShoulder Good	RShoulder Good	SpineB RTR Good
14:29:08	LElbow Good	RElbow Good	LShoulder Good	RShoulder Good	SpineB RTR Good
14:29:08	LElbow Good	RElbow Good	LShoulder Good	RShoulder Good	SpineB RTR Good
14:29:08	LElbow Good	RElbow Good	LShoulder Good	RShoulder Good	SpineB RTR Good
14:29:09	LElbow Good	RElbow Good	LShoulder Good	RShoulder Good	SpineB RTR Good
14:29:09	LElbow Good	RElbow Good	LShoulder Good	RShoulder Good	SpineB RTR Good
14:29:09	LElbow Good	RElbow Good	LShoulder Good	RShoulder Good	SpineB RTR Good

b. Researcher's posture update showing the elbow postures



c. Right Elbow posture quality vs frequency for Researcher 3

d. Left elbow posture quality vs frequency for Researcher 3

Figure 6-28 Feedback System Implementation on Seated Researcher

The assessment form completed by the participants revealed that eight of the ten participants rated the system as convenient to use, the remaining two do not seem to agree. six participants found the system very easy to use, two found it easy while one rated it as a difficult system. Eight participants found the feedback from the system very easy to understand while two rated it as easy. All the participants agreed that the system provided real-time feedback by both voice alert and display on the screen. When asked why they think the feedback is easy to understand, the participants stated that the voice alert that enables the system to communicate verbally to them concerning their posture, is very simple and very easy to understand. The operator who found the system difficult to use said that she is not used to being monitored while working and does not like to be distracted. Operator 4 and researcher 1, who rated the system as not convenient, said the prompting by the system made them lose concentration. Hence, since up to 70% of the participants rated the feedback system as convenient, easy-to-use, with easy-to-understand real-time feedback, we conclude that an easy-to-use, simple and convenient real-time posture assessment feedback system has been successfully designed and developed in this work. The average setup time used by all participants, which includes the time used to start the system and register new task is 33.6 seconds. Hence, the developed system requires very little set up time as it only needs the user to place the hardware at the recommended optimum position and to start the system by pressing the start button.

Details of the participant’s response can be found in Appendix B.

6.5 **Chapter Summary**

This chapter describes the design, development and implementation of a human-machine interface feedback system that displays the real-time ergonomic posture assessment results to a worker. It also provides a manufacturing shop floor with a simple, low-cost, easy-to-implement, feedback mechanism for correct display of a worker's posture assessment outputs.

The system design was initiated by the establishment of some basic questions which helped to establish the external users of the system, the information flow from one user to another as well the format the information is delivered to the end user. The UK HSE's recommended requirements on personnel to involve in risk assessment was used to identify the external users of the system.

The UML Use Case diagram was used to model the usage requirements, set of actions and performance of the external users of the system. The activities of each of the users were modelled using the UML activity diagrams which show at a glance, the modelled internal logic of the complex operations involved in the design of the system and provide the possible navigation paths followed by the users in the system. While the use case model shows why and when the users should follow particular paths in the system, the activity diagrams models the roadmap of the user functionality which shows the paths followed by the users (Lieberman, 2004).

Similarly, the User Interface Flow Diagram, also known as the Storyboard was employed to model the high-level relationships between the major user interface elements and show the architectural view of the system as it represents the complete interface system along with its controls.

The designed system was successfully developed and implemented through case studies which include the back-posture assessment of operators during the assembly of an engine part and the lower arm posture assessment of seated researchers. In both cases, there was real-time feedback to the participants. The feedback from the participants rated the feedback system as convenient, easy-to-use, with easy-to-understand real-time feedback. The system is easy-to-implement because the screens are designed in a simple and interactive way.

The experimental results show that the developed system can help to identify risky postures and their frequency of occurrence for informed ergonomic intervention purposes. This information is useful to both the safety representatives and the workers as it enables prompt and timely ergonomic interventions.

Further tests are required to establish the system's capability to improve worker's ergonomics through provision of real-time feedback. This will be addressed in the next chapter.

7 VALIDATION

This chapter presents 3 case studies which test the performance of the real-time posture assessment knowledge-based system for use in the evaluation of work postures on the shop floor and feedback to workers. The case studies are designed to test some functionalities of the feedback system to ascertain its usefulness and practicality in fulfilling the purpose for which it is designed. The system is developed using a cost-effective, automatic-detection motion sensor. The ability of the system to assess ergonomic work postures with real-time feedback to the workers will be tested using real-life situations.

The focus of the chapter is four-fold and includes:

- Introduction of the case studies.
- Description of the system implementation for each case study.
- Evaluation of the system performance with respect to the research hypothesis.
- Discussion of results.

7.1 **Overview**

A fast detection system which detects ergonomic criticalities for immediate intervention purposes is highly desirable for human work posture assessment so as to minimize scientifically inaccurate outputs (Rosário, 2014; Savino, Mazza and Battini, 2016). The developed knowledge-based feedback system is an automatic fast-detection posture assessment system designed to detect ergonomic criticalities in worker’s postures as well as provide immediate intervention to help the worker adjust any awkward posture that can lead to WMSDs. These functionalities will be tested in this chapter using some case studies, to determine the system’s effectiveness. Case studies are investigations meant to address the research concerns highlighted by the hypothesis.

An important aspect considered in the design of these case studies is to ensure a focused and concise design as well as collect only relevant data (Case Study Research Design - How to conduct a Case Study).

To design the case studies, the following steps were taken:

i) Select the topic to study. In this study, the topic chosen is **'Provision of real-time feedback to work postures'.**

ii) Select the audience. Here the audience are the shop floor workers.

iii) Choose the questions that the study would address and answer. The questions include:

- Is it possible to provide real-time feedback of manual handling task detection and posture assessment to workers using the system?
- Can real-time posture assessment feedback to the workers on the shop floor be achieved with the system?
- Is there effective ergonomic improvement of worker's ergonomics using the developed system?
- What type of feedback is more effective? Voice alert or screen display?
- Is the feedback effective at different time intervals?
- Can this feedback be effective when different tasks and different subjects are involved?

iv) Choose appropriate research methods

The case study selection also considered the following factors:

1. The case studies must involve humans to test the effectiveness of the feedback system to capture and monitor human work postures.
2. The case studies must involve a variety of tasks, to test the effectiveness of using the feedback system to analyse and display posture assessment output to humans while performing different tasks.
3. The tasks chosen must be simple and must involve manual handling tasks which can be detected by the system thereby informing the operators if the task was completed correctly.

Three cases to be investigated are selected, as tabulated on table 7-1. These cases are chosen to help prove the research hypothesis.

Table 7-1 Description of Case Studies

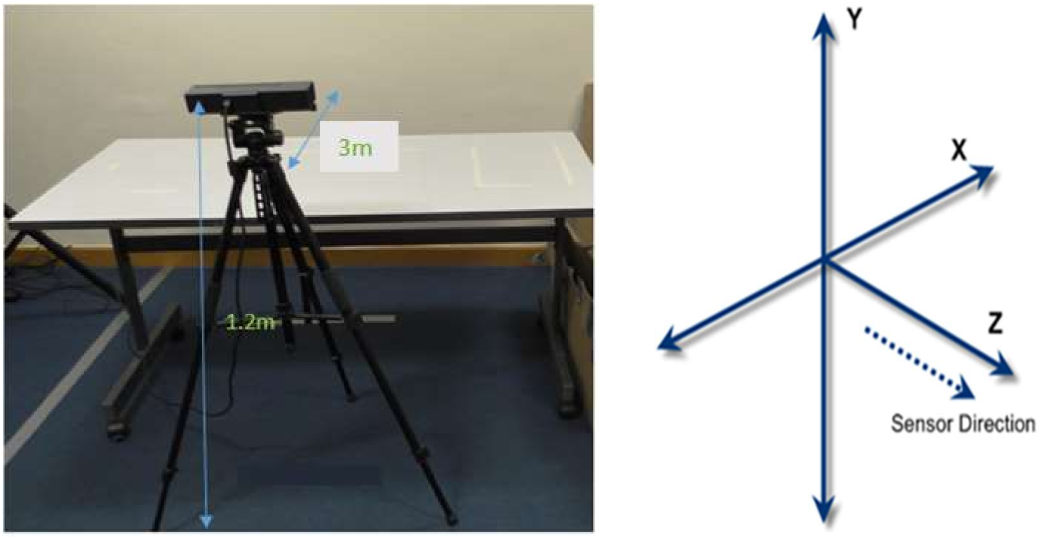
S/N	CASE STUDY	FEATURES	KEY CHALLENGE(S)
1	CASE 1: Lifting, lowering and carrying of IKEA table components. Here, the effectiveness of the system to provide real-time feedback of work posture assessment to the workers while undertaking manual lifting, lowering and carrying, is tested	Series of experiments are carried out to determine if the system can provide real-time feedback to the worker while undertaking lifting, lowering and carrying task. The feature tested is: To check if the system can assess the work postures of operators and provide real-time feedback to them on their postures during different manual handling tasks, executed simultaneously. Results are compared for both real-time and without real-time feedback to the workers.	Setup delays may arise due to variety of tasks.
2	CASE 2: Assembly of IKEA table components. In this study, the effectiveness of the developed tool to achieve ergonomic improvement of worker's	Experiments are undertaken to determine if the developed system can improve the ergonomics of the operators during the assembly of IKEA table components, based on the following features: i. Possibility of providing real-time feedback on highly repetitive task.	The feedback system may be faced with many uncertainties and setup delays.

	postures is tested.	ii. Effective type of feedback. iii. Effective feedback display interval. • These are assessed based on if the feedback provided to the worker is either of the following; a. With real-time feedback b. Without real-time feedback	
3	CASE 3: Hammering of IKEA table components. The capability of the developed tool to detect manual handling tasks and simultaneously assess the worker's posture and provide real-time feedback to the worker, will be tested in this case study.	Different experiments are carried out to determine the following: i. If the system can detect manual handling tasks and give real-time feedback to the operator on the task detection. ii. If the system can assess work postures and provide real-time feedback to workers simultaneously with task detection. Here, the upper arm posture is studied and comparison made for when; a. The hammer is held away from the body b. Close to the body	Setup delays may arise. Again, participants may be reluctant to carry out a hammering task.

		Is there any link between task detection and posture assessment?	

7.2 Experimental Setup

The experimental setup for all the cases is represented in figure 7-1.



a) Experimental setup **b) Positive x, y, z coordinates**

Figure 7-1 Experimental Setup

In figure 7-1a, the arrow represented by 1.2m is the height of the Kinect from the floor while the 3m arrow represents the depth z distance to the operators as depicted by figure 7-1b. Figure 7-1b represents the Kinect positive coordinates facing the direction of the Kinect (MSDN, 2016), in which z is equal to 3m, with the x and y coordinates representing the value and location of a pixel in the color and depth frame.

A large table is used as the workstation. The IKEA table components are lifted, carried and lowered to the large table from their original position. It is then assembled on the workstation. During the assembly, the part that required hammering is hammered using a hammer. Kinect, placed at a 3m distance from the operators and mounted on a tripod stand of height 1.2m as recommended in chapter 4, is used to capture the skeletal data of each of the operators, convert to posture data and assess the postures and display the results in real-time to the operators.

A total of fifteen operators, seven males and eight females, participated in each of the tasks. They are aged between 23-41 years, all right-handed and with heights ranging from 1.5m to 1.92m. The operators are all volunteers who were briefly trained on the tasks before performing the experiments.

Figure 7-2 shows the age distribution of the participants.

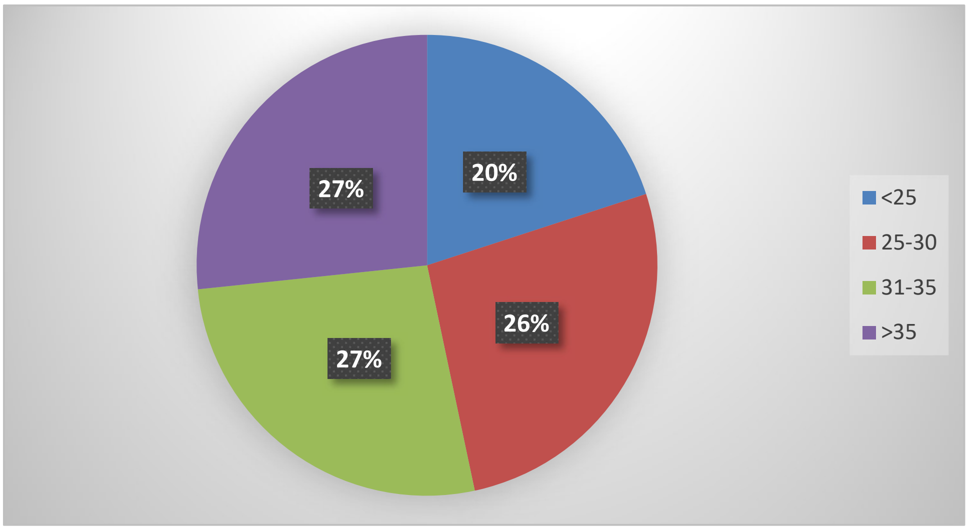
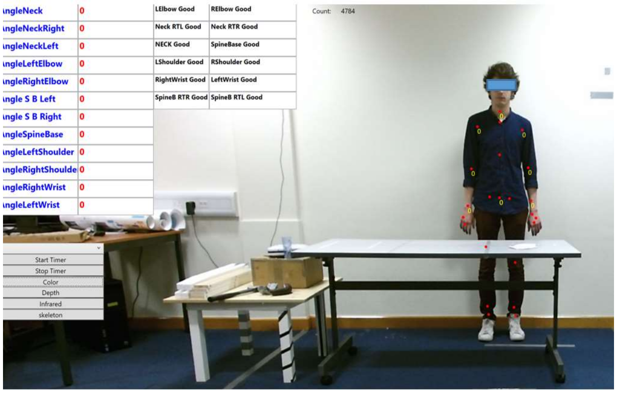


Figure 7-2 Age distribution of participants.

The neutral positions of the participants were first tracked before starting the experiments. Figure 7-3 shows participants 11 and 13 tracked at their neutral positions before the commencement of the experiments.

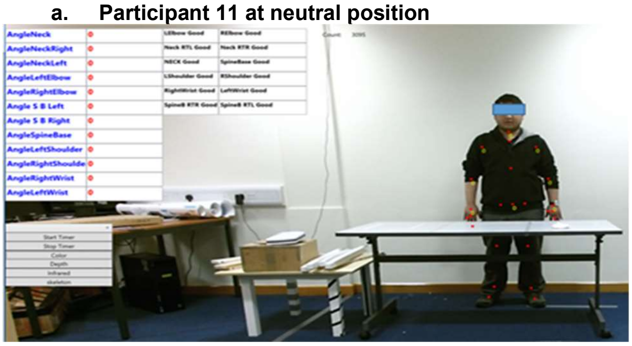


ngleNeck 0
ngleNeckRight 0
ngleNeckLeft 0
ngleLeftElbow 0
ngleRightElbow 0
ngle S B Left 0
ngle S B Right 0
ngleSpineBase 0
ngleLeftShoulder 0
ngleRightShoulde 0
ngleRightWrist 0
ngleLeftWrist 0

LElbow Good	RElbow Good
Neck RTL Good	Neck RTR Good
NECK Good	SpineBase Good
LShoulder Good	RShoulder Good
RightWrist Good	LeftWrist Good
SpineB RTR Good	SpineB RTL Good

Count: 4784

a. Participant 11 at neutral position



AngleNeck 0
AngleNeckRight 0
AngleNeckLeft 0
AngleLeftElbow 0
AngleRightElbow 0
Angle S B Left 0
Angle S B Right 0
AngleSpineBase 0
AngleLeftShoulder 0
AngleRightShoulde 0
AngleRightWrist 0
AngleLeftWrist 0

LElbow Good	RElbow Good
Neck RTL Good	Neck RTR Good
NECK Good	SpineBase Good
LShoulder Good	RShoulder Good
RightWrist Good	LeftWrist Good
SpineB RTR Good	SpineB RTL Good

Count: 3095

b. Participant 13 at neutral position

Figure 7-3 Participants tracked at Neutral Positions

7.2.1 Setup Precautions

During the initial setup, the following precautions were taken;

- The sensor was placed and maintained within the recommended position in the field of view for the duration of the case study to avoid depth measurement errors.
- The operators ensured they avoided errors due to self-occlusion and obstacles.

7.2.2 General Task Rules

There are some rules which the operators were acquainted with while performing the tasks in the three case studies. These rules include:

- The tasks must be performed in such a way as to depict what is obtainable among operators performing same tasks on the shop floor.
- The operators are required to face the sensor while performing the tasks. This helps to reduce measurement errors and occlusions.

7.3 Case Study 1: Lifting, Lowering and Carrying of IKEA Table Components.

The task chosen for this study is manual handling involving lifting, lowering and carrying of IKEA table components. In the study, the ability of the Knowledge based feedback system to provide feedback to operators on the shop floor is tested as they lift, lower and carry the IKEA table components prior to assembly.

The case study differs from the other case studies in the following areas:

- The study involves more than one manual handling task.
- Tests the feedback capabilities of the system when different subjects are assessed.

The task was carried out in a laboratory under controlled conditions.

7.3.1 Choice of Task

The Health and Safety Executive (HSE) defines manual handling as the lifting, lowering and carrying of load by hand, and recommends that hazardous manual handling tasks should be avoided or assessed to reduce injuries and WMSDs (Health and Safety Executive, 2016). Hence, lifting, lowering and carrying of the table components prior to assembly, is chosen for the following reasons:

- The chosen task enables a switch from one manual handling task to another.
- It represents a typical manual handling task performed on the shop floor on daily basis.
- Assessment of such a task is highly recommended as it can help to establish if the system can effectively provide real-time feedback on the shop floor.

7.3.2 **Task Description**

The task involves the lifting, lowering and carrying of table components by fifteen operators wearing different clothing, while the developed system assesses their work postures and provide feedback to the workers. Only the assessment of the joints of the upper arm (shoulders), lower arm (elbows) and spine (back flexion and sideways movement) will be of interest in the study.

The task involves the following steps:

- Lift each of the table components from its original position
- Carry the components to the assembly floor.
- Lower the components at the correct position for assembly.

7.3.3 **Task setup**

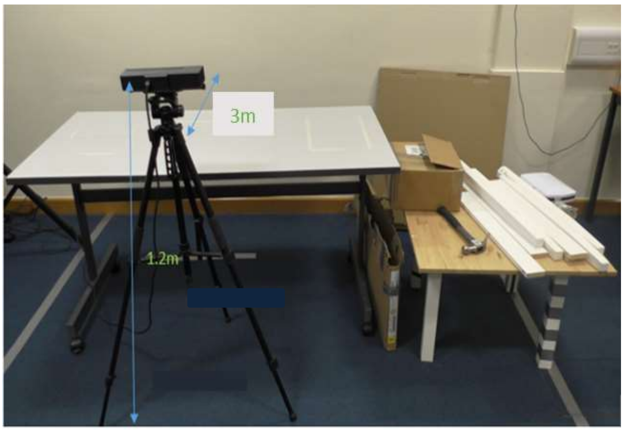
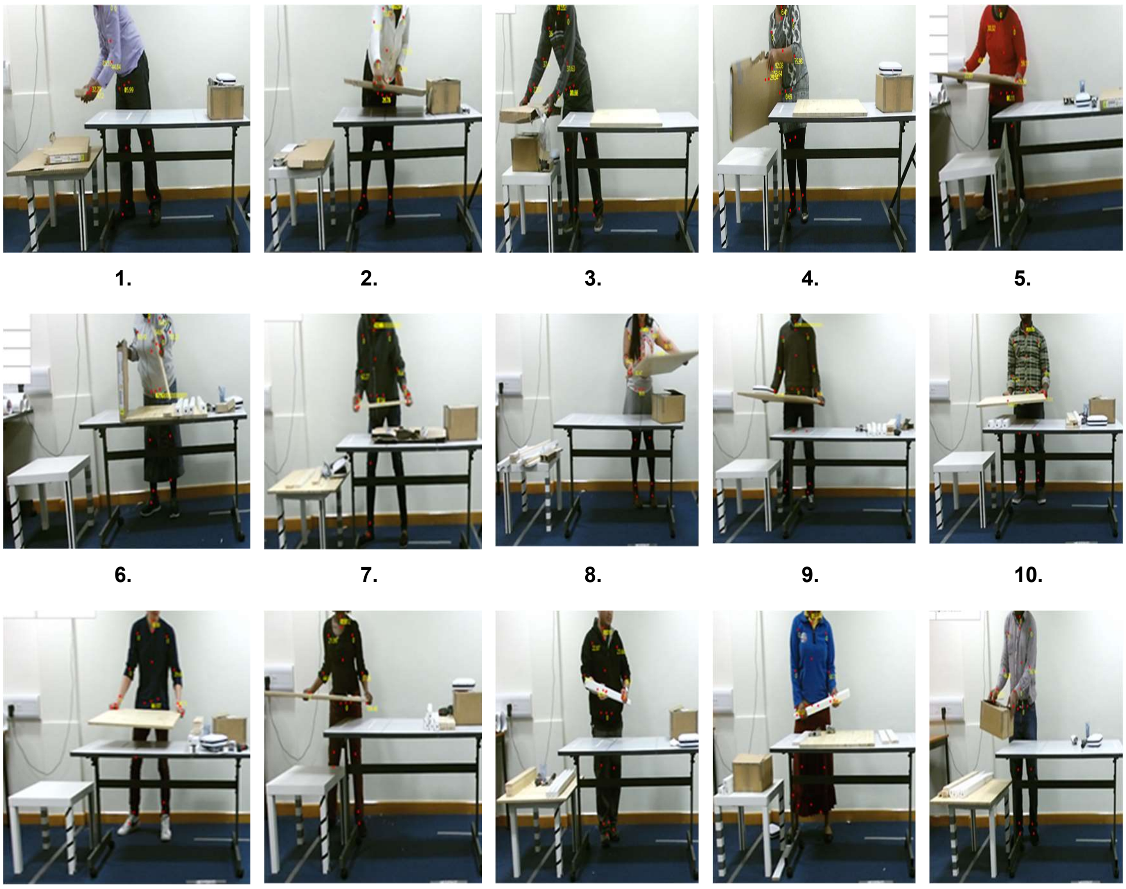


Figure 7-4 Experimental setup for lifting, lowering and carrying the table components.

The IKEA table components are stored in a storage area beside the workstation. The operators are required to lift each table component from the storage area, carry it to the workstation and then lower it on to the workstation. The three manual handling tasks are performed simultaneously by each of the operators and repeated twice. The first time is without real-time feedback to the operators while the second time is when the task is performed with real-time feedback to the operators.

Figure 7-5 shows the screenshots of the fifteen operators while performing the lifting, lowering and carrying tasks. For purposes of identity protection, the head of the operators were edited out of the screenshots.


1. 2. 3. 4. 5.

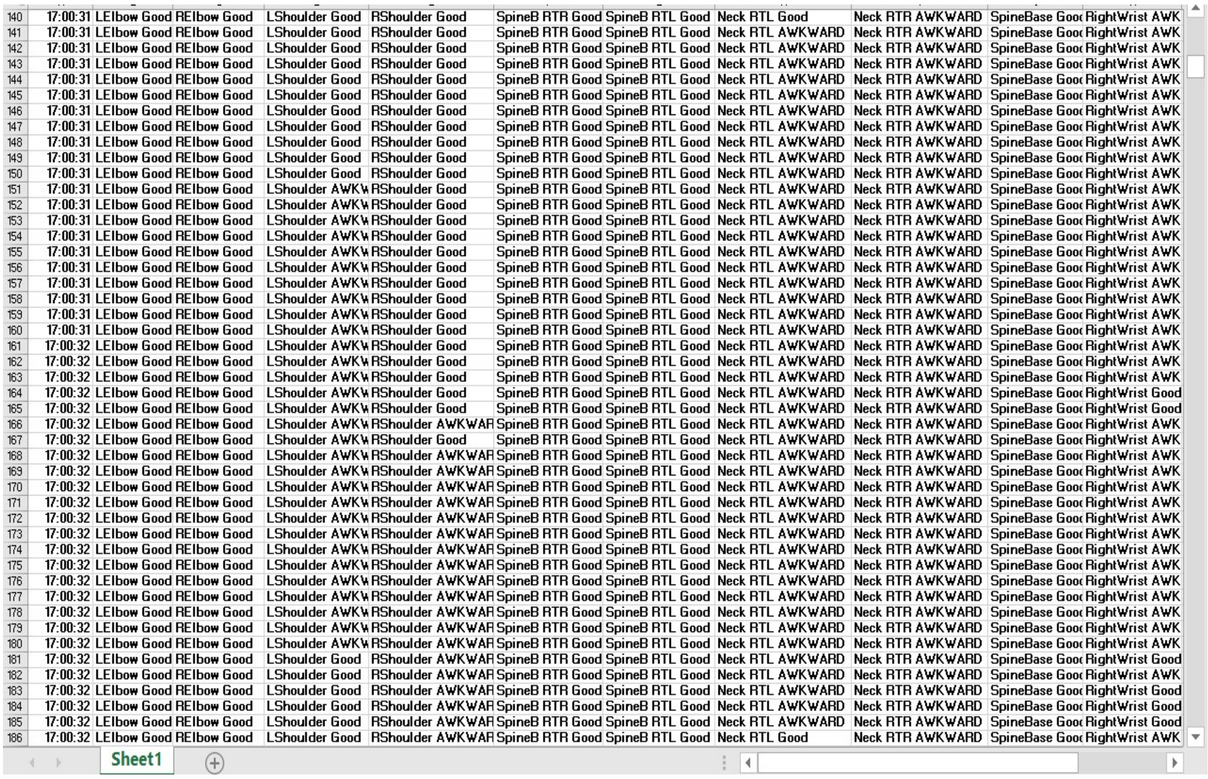
6. 7. 8. 9. 10.

11. 12. 13. 14. 15.

Figure 7-5 Lifting, Lowering and Carrying of Table components

7.3.4 **Results and Discussion**

The posture assessment outputs are stored in the system's database and retrieved using the SQL query button on the database. The retrieved data is then imported into the excel spreadsheet as represented in figure 7-6, and analysed using the SPSS software.



140	17:00:31	LElbow Good	RElbow Good	LShoulder Good	RShoulder Good	SpineB RTR Good	SpineB RTL Good	Neck RTL Good	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
141	17:00:31	LElbow Good	RElbow Good	LShoulder Good	RShoulder Good	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
142	17:00:31	LElbow Good	RElbow Good	LShoulder Good	RShoulder Good	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
143	17:00:31	LElbow Good	RElbow Good	LShoulder Good	RShoulder Good	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
144	17:00:31	LElbow Good	RElbow Good	LShoulder Good	RShoulder Good	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
145	17:00:31	LElbow Good	RElbow Good	LShoulder Good	RShoulder Good	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
146	17:00:31	LElbow Good	RElbow Good	LShoulder Good	RShoulder Good	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
147	17:00:31	LElbow Good	RElbow Good	LShoulder Good	RShoulder Good	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
148	17:00:31	LElbow Good	RElbow Good	LShoulder Good	RShoulder Good	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
149	17:00:31	LElbow Good	RElbow Good	LShoulder Good	RShoulder Good	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
150	17:00:31	LElbow Good	RElbow Good	LShoulder Good	RShoulder Good	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
151	17:00:31	LElbow Good	RElbow Good	LShoulder AWK	RShoulder Good	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
152	17:00:31	LElbow Good	RElbow Good	LShoulder AWK	RShoulder Good	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
153	17:00:31	LElbow Good	RElbow Good	LShoulder AWK	RShoulder Good	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
154	17:00:31	LElbow Good	RElbow Good	LShoulder AWK	RShoulder Good	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
155	17:00:31	LElbow Good	RElbow Good	LShoulder AWK	RShoulder Good	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
156	17:00:31	LElbow Good	RElbow Good	LShoulder AWK	RShoulder Good	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
157	17:00:31	LElbow Good	RElbow Good	LShoulder AWK	RShoulder Good	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
158	17:00:31	LElbow Good	RElbow Good	LShoulder AWK	RShoulder Good	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
159	17:00:31	LElbow Good	RElbow Good	LShoulder AWK	RShoulder Good	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
160	17:00:31	LElbow Good	RElbow Good	LShoulder AWK	RShoulder Good	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
161	17:00:32	LElbow Good	RElbow Good	LShoulder AWK	RShoulder Good	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
162	17:00:32	LElbow Good	RElbow Good	LShoulder AWK	RShoulder Good	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
163	17:00:32	LElbow Good	RElbow Good	LShoulder AWK	RShoulder Good	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
164	17:00:32	LElbow Good	RElbow Good	LShoulder AWK	RShoulder Good	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist Good
165	17:00:32	LElbow Good	RElbow Good	LShoulder AWK	RShoulder Good	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist Good
166	17:00:32	LElbow Good	RElbow Good	LShoulder AWK	RShoulder AWKWAR	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
167	17:00:32	LElbow Good	RElbow Good	LShoulder AWK	RShoulder Good	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
168	17:00:32	LElbow Good	RElbow Good	LShoulder AWK	RShoulder AWKWAR	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
169	17:00:32	LElbow Good	RElbow Good	LShoulder AWK	RShoulder AWKWAR	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
170	17:00:32	LElbow Good	RElbow Good	LShoulder AWK	RShoulder AWKWAR	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
171	17:00:32	LElbow Good	RElbow Good	LShoulder AWK	RShoulder AWKWAR	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
172	17:00:32	LElbow Good	RElbow Good	LShoulder AWK	RShoulder AWKWAR	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
173	17:00:32	LElbow Good	RElbow Good	LShoulder AWK	RShoulder AWKWAR	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
174	17:00:32	LElbow Good	RElbow Good	LShoulder AWK	RShoulder AWKWAR	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
175	17:00:32	LElbow Good	RElbow Good	LShoulder AWK	RShoulder AWKWAR	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
176	17:00:32	LElbow Good	RElbow Good	LShoulder AWK	RShoulder AWKWAR	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
177	17:00:32	LElbow Good	RElbow Good	LShoulder AWK	RShoulder AWKWAR	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
178	17:00:32	LElbow Good	RElbow Good	LShoulder AWK	RShoulder AWKWAR	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
179	17:00:32	LElbow Good	RElbow Good	LShoulder AWK	RShoulder AWKWAR	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
180	17:00:32	LElbow Good	RElbow Good	LShoulder AWK	RShoulder AWKWAR	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
181	17:00:32	LElbow Good	RElbow Good	LShoulder Good	RShoulder AWKWAR	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist Good
182	17:00:32	LElbow Good	RElbow Good	LShoulder Good	RShoulder AWKWAR	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK
183	17:00:32	LElbow Good	RElbow Good	LShoulder Good	RShoulder AWKWAR	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist Good
184	17:00:32	LElbow Good	RElbow Good	LShoulder Good	RShoulder AWKWAR	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist Good
185	17:00:32	LElbow Good	RElbow Good	LShoulder Good	RShoulder AWKWAR	SpineB RTR Good	SpineB RTL Good	Neck RTL AWKWARD	Neck RTR AWKWARD	SpineBase Goo	RightWrist Good
186	17:00:32	LElbow Good	RElbow Good	LShoulder Good	RShoulder AWKWAR	SpineB RTR Good	SpineB RTL Good	Neck RTL Good	Neck RTR AWKWARD	SpineBase Goo	RightWrist AWK

Figure 7-6 Screenshot of the manual handling data for participant 1

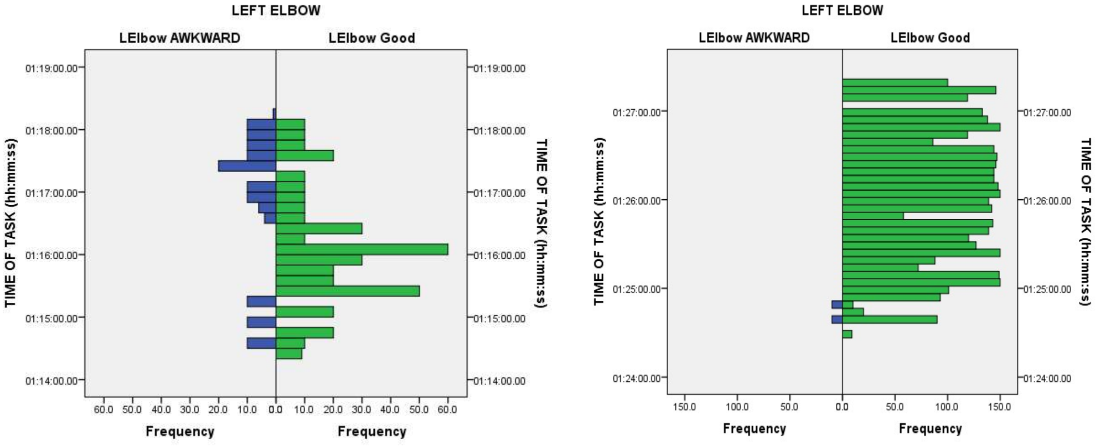
After the experiment, the participants were asked to fill a form to ascertain if real-time feedback was provided to them during the manual handling activities. Table 7-2 presents the participant's responses. Details of the participant's responses to questions concerning the system is on Appendix C.

Table 7-2 Operator's responses on whether real-time feedback was provided to them during the lifting, lowering and carrying tasks.

Participants (P)	Back	Left Elbow	Right Elbow	Left Shoulder	Right Shoulder
P1	Yes	Yes	Yes	Yes	Yes
P2	Yes	Yes	Yes	Yes	Yes
P3	Yes	Yes	Yes	Yes	Yes
P4	Yes	Yes	Yes	Yes	Yes

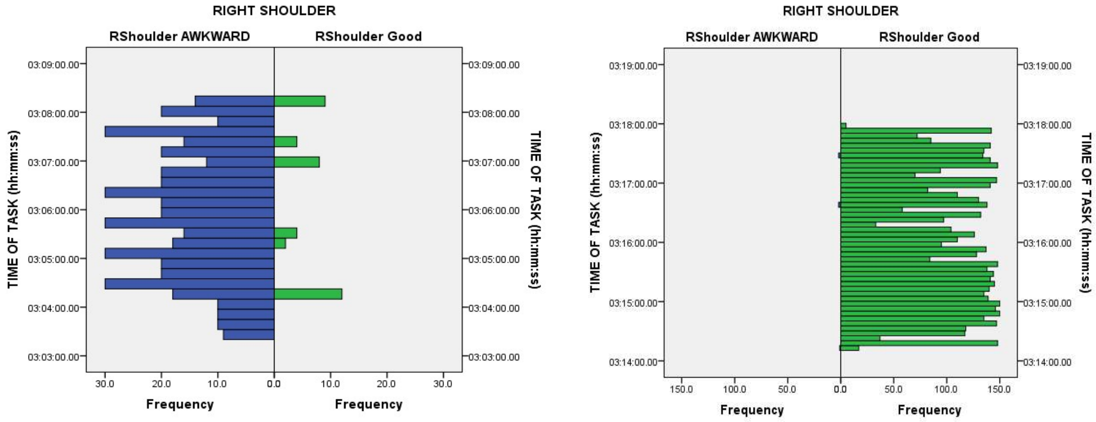
P5	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
P6	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
P7	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
P8	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
P9	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
P10	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
P11	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
P12	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
P13	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
P14	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
P15	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**

Results are compared for both real-time and without real-time feedback to the workers and presented in figures 7-7 to 7-13. Each figure represents each of the upper joints of some of the participants. In the figures, the blue lines represent the frequency of the awkward postures while the green lines represent the frequency of the good postures. By frequency we mean the rate of occurrence of each posture at a time.



a. Without Real-time Feedback **b. With Real-time Feedback**

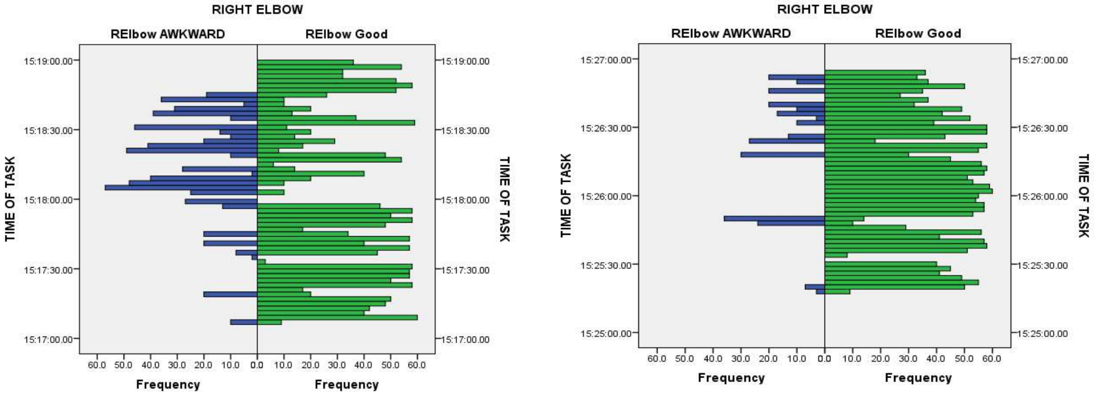
Figure 7-7 Results of posture assessment feedback to participant 15 during lifting, lowering and carrying task.



a. **Without Real-time Feedback**

b. **With Real-time Feedback**

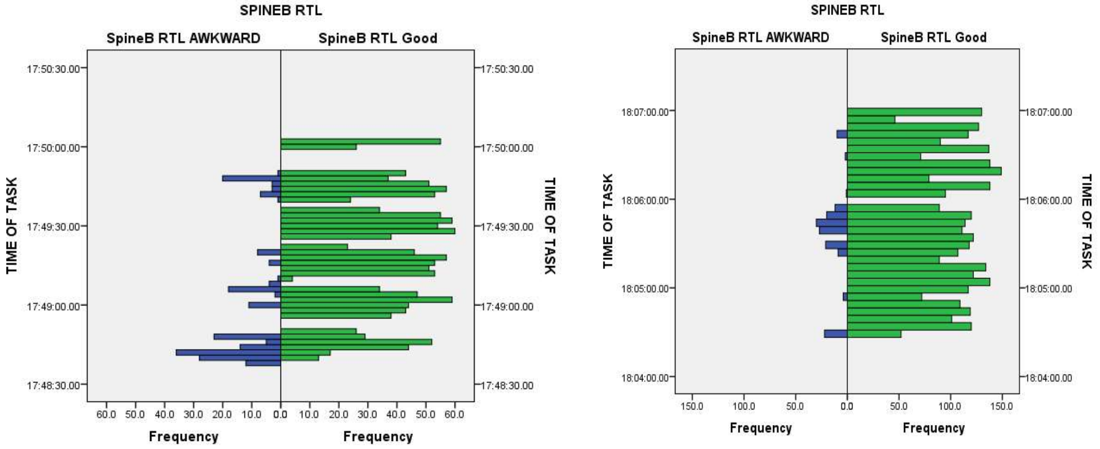
Figure 7-8 Results of posture assessment feedback to participant 14 during lifting, lowering and carrying task.



a. **Without Real-time Feedback**

b. **With Real-time Feedback**

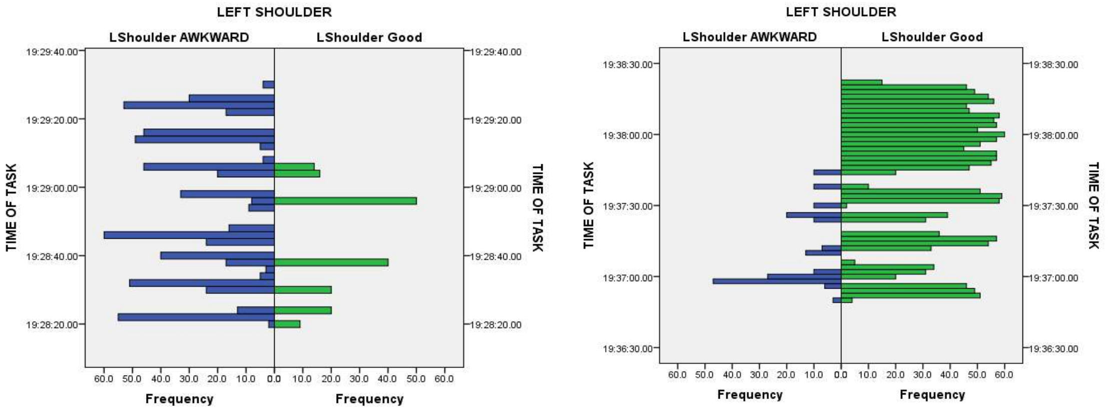
Figure 7-9 Results of posture assessment feedback to participant 3 during lifting, lowering and carrying task.



a. **Without Real-time Feedback**

b. **With Real-time Feedback**

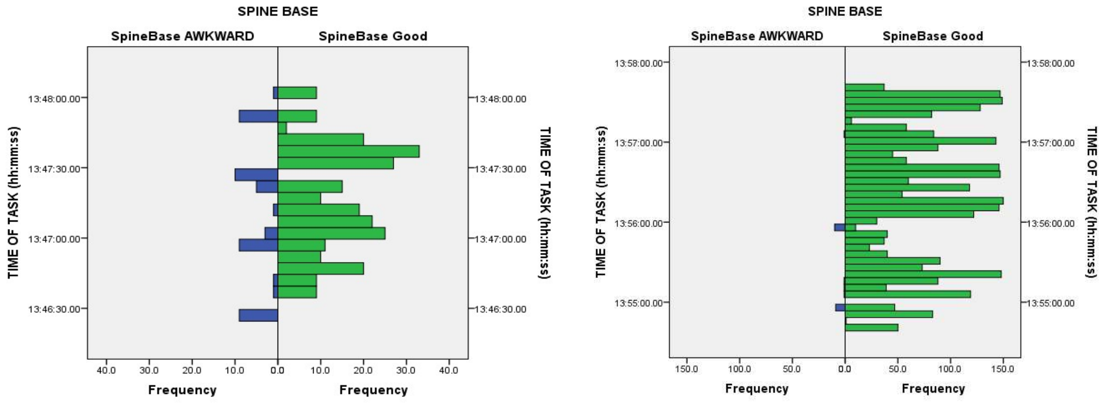
Figure 7-10 Results of posture assessment feedback to participant 4 during lifting, lowering and carrying task.



a. **Without Real-time Feedback**

b. **With Real-time Feedback**

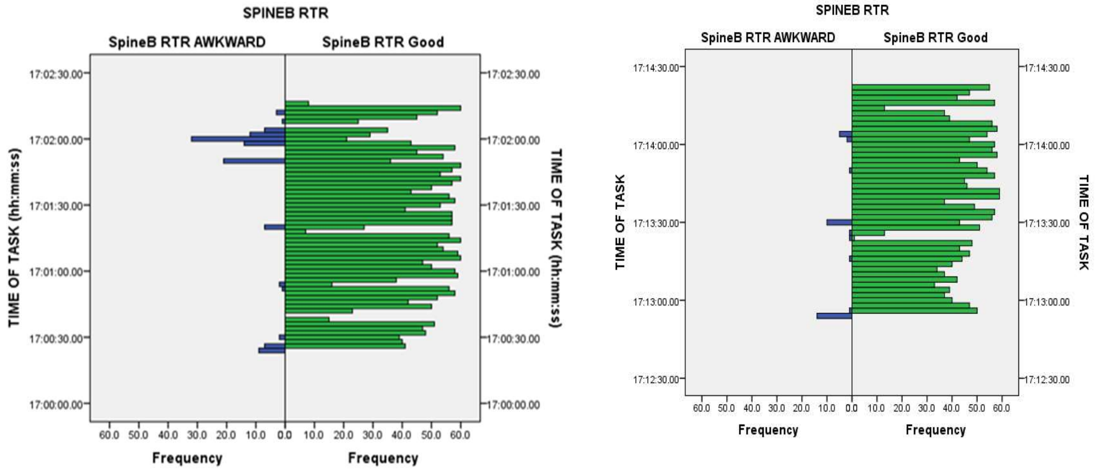
Figure 7-11 Results of posture assessment feedback to participant 6 during lifting, lowering and carrying task.



a. **Without Real-time Feedback**

b. **With Real-time Feedback**

Figure 7-12 Results of posture assessment feedback to participant 9 during lifting, lowering and carrying task.



a. **Without Real-time Feedback**

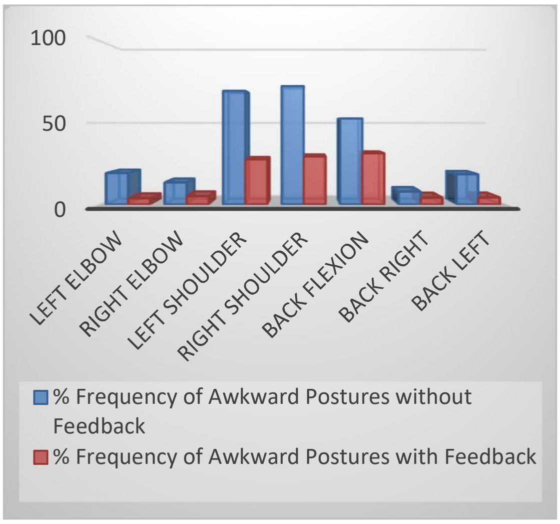
b. **With Real-time Feedback**

Figure 7-13 Results of posture assessment feedback to participant 1 during lifting, lowering and carrying task.

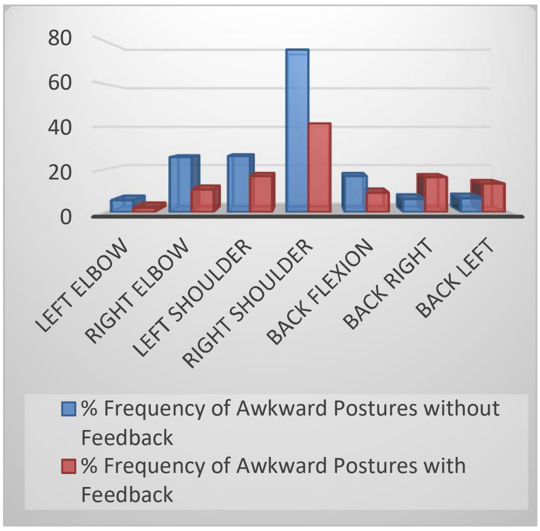
For participant 15, the left elbow assessment is presented for both real-time and without real-time feedback. For participants 14, 3, 4, 6, 9 and 1, the right shoulder, right elbow, back right, left shoulder, spine base, and back left assessments are presented.

The left-hand column of each of the figures depict the posture assessment without real-time feedback to the worker while that of the right-hand column shows the assessment results when real-time feedback was introduced. The results clearly show a reduction in the frequency of awkward postures when real-time feedback was introduced, as compared to the result obtained when the postures were assessed without real-time feedback. This is because the left column is the result of posture assessment in which no feedback was provided to the operators, but when feedback was provided the rate of occurrence of awkward postures became significantly reduced.

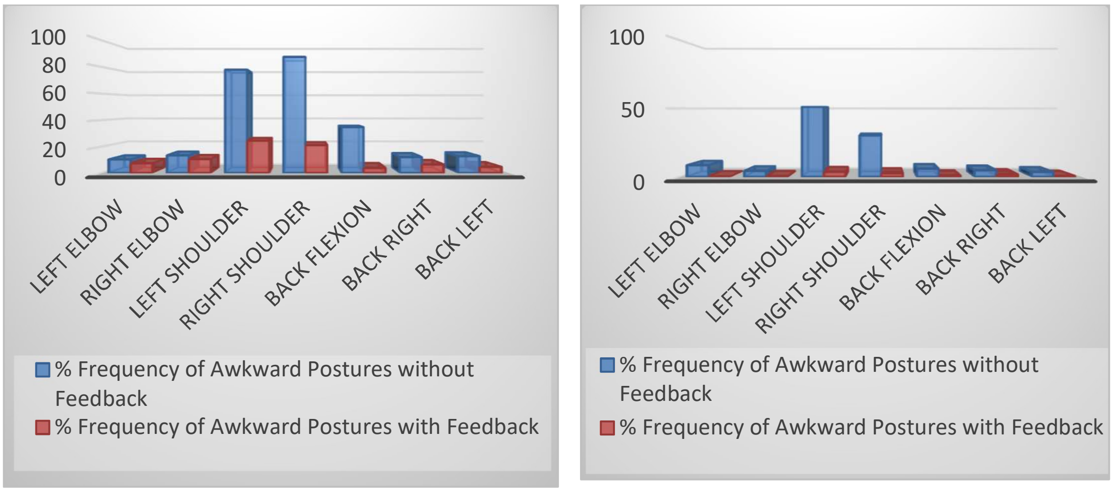
The decrease in the rate of occurrence of awkward postures when real-time feedback was introduced is further investigated by conducting a descriptive statistical analysis of the results for the participants as presented in figure 7-14 (See also Appendix D for the tabular representation of the data).



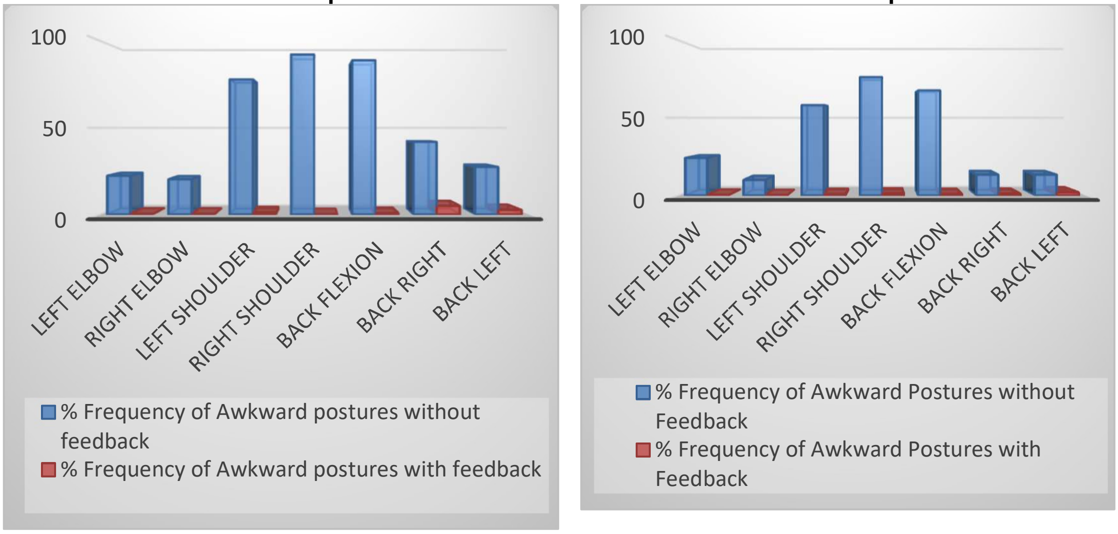
a. Participant 2



b. Participant 3



c. Participant 4 **d. Participant 13**



e. **Participant 14** f. **Participant 15**

Figure 7-14 Descriptive statistical analysis of the results for lifting, Lowering and Carrying tasks

For the participants, there was significant reduction in the rate of occurrence of awkward postures during the task duration as real-time feedback was introduced.

In figure 7-14e for instance, the rate of occurrence of awkward left elbow was reduced from 22.4% to 0.4% for the entire task duration when real-time feedback was introduced, that of the right elbow reduced from both 20.3% to 0.4%, the left shoulder from 77.8% to 1.3%, right shoulder from 92.1% to 0.1%. The back posture was found to be reduced from 88.8% to 0.8% and from 41.9% to 5% for back right, 27.4% to 2.7% for back left.

Similar reduction is noticed for all other participants when real-time feedback was introduced to the participants. An exception is noticed from the result of the lateral back movement of participant 3 in which the rate of occurrence of awkward postures became increased as real-time feedback was introduced. This, being an exception, may be because of non-adherence to the feedback by the participant.

The results obtained from this study seem to agree with the participant's response of table 7-2 that real-time feedback was provided to them while working.

Finally, we can infer from this case study that the developed knowledge-based feedback system can provide real-time feedback to the worker during lifting, carrying and lowering activities.

7.4 **Case Study 2: Assembly operation on the Shop floor**

The choice of task for this study involves assembly of IKEA table components. Assembly task is characterised by lots of awkward postures but ergonomic guidelines, when correctly applied in an assembly task, can help to reduce the rate of occurrence of awkward postures and WMSDs (Kulwong, 2010; Miguez et al., 2016). Hence, this case study is on ergonomic posture assessment and real-time feedback of the back and arm postures of operators during an assembly of IKEA table components on the shop floor.

The case study differs from the other case studies in the following areas:

1. The study involves only assembly task.
2. Tests if real-time feedback is provided when a highly repetitive task such as assembly task is performed
3. Tests the most effective type of feedback.
4. Tests the most effective feedback display interval.

The study involves the following steps:

Step 1: Capture of the operator's postures as they execute the assembly task.

Step 2: Ergonomic assessment of worker's postures without real-time feedback to the operators.

Step 3: Ergonomic assessment of worker’s postures with real-time feedback to the operators.

Step 4: The results are compared to establish the most effective type of feedback and the effective feedback display interval that best improves worker’s posture.

The task was carried out in a laboratory under controlled conditions.

7.4.1 **Choice of Task**

The Health and Safety Executive (HSE) have identified assembly as a set of tasks that involve high level of repetition, require repetitive upper limb movement and consequently, require constant assessment (HSE, 2010). Hence, since the developed system is focused only on the posture assessment of the upper limbs of the human body, assembly task is chosen to test certain functionalities of the system that have not been tested.

7.4.2 **Task Description**

The task involves the assembly of IKEA table by fifteen operators with the upper body postures captured, assessed and displayed to the operator both in real-time and offline. However, the real-time feedback is achieved in two ways – by on-screen display and by voice alert. The ability of the system to achieve effective real-time feedback to the operators are the functionalities to be tested in this study.

The task involves the following steps:

1. Pick each of the table components from its original position on the assembly floor.
2. Find the correct part for assembly and place them together.
3. Pick the matching bolts and screws with the screw driver and matching spanner and tighten the parts
4. Follow steps 1-3 until the assembly is completed.

7.4.3 **Task setup**

The IKEA table components already at the workstation, are assembled as presented in figure 7-15. The assembly task is performed by each of the operators and repeated twice. The first time is without real-time feedback to the operators while the second time is when the task is performed with real-time display to the operators. All the joints of the upper body are assessed in this study with real-time feedback of screen display provided for all joints. Voice alert feedback system is however provided for only the back and arm joints. The purpose of varying the type of feedback to the workers is to establish the most effective type among the two provided.

Furthermore, seven of the operators were assessed with the voice alert feedback programmed for awkward postures held for 100 frames at a time while the remaining eight operators had the voice alert programmed for awkward postures held for 10 frames at a time. The purpose of varying the feedback display interval is to establish the most effective real-time display interval.

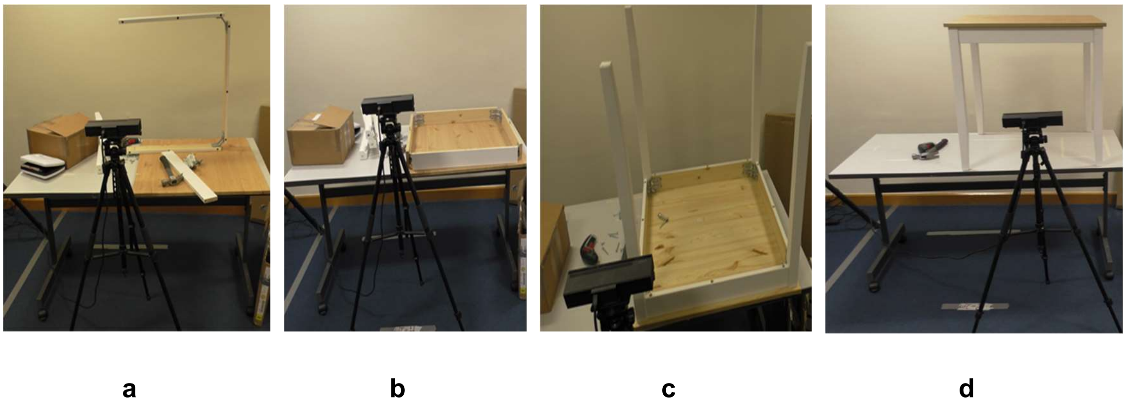


Figure 7-15 Assembly of the IKEA table

Figure 7-16 shows the screenshots of the fifteen participants during the assembly task. For purposes of identity protection, the faces of the participants were edited out of the screenshots.

1. 2. 3. 4. 5. 6. 7. 8. 9. 10. 11. 12. 13. 14. 15.

Figure 7-16 Screenshots of the fifteen participants during the assembly task

7.4.4 Results and Discussion

Having completed the assembly process by all the operators, the posture assessment results stored in the system's database are retrieved using the SQL query on the database. The retrieved data is then imported into excel spreadsheet and analysed using the SPSS software.

7.4.4.1 Case Study 2, Feature i: Provision of Real-time feedback when a highly repetitive task is performed

Again, the operators were asked to fill a form on whether real-time feedback was provided to them by the system during the assembly task and their responses are presented on table 7-3.

Table 7-3 **Operator's responses on whether real-time feedback was provided to them during the assembly task.**

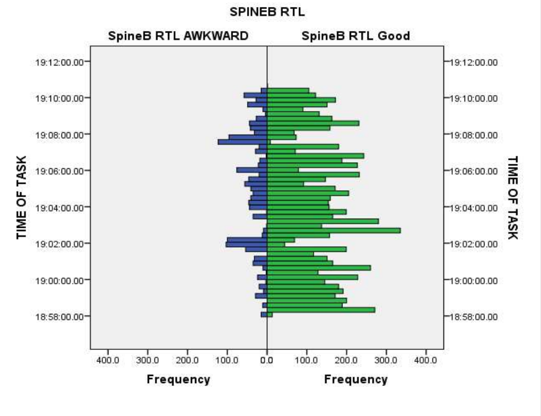
Participants (P)	**Back (Flexion and side movements)**	**Left Elbow**	**Right Elbow**	**Left Shoulder**	**Right Shoulder**	**Neck (Flexion & side movement)**	**Wrists (Left and Right)**
1	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
2	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
3	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
4	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
5	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
6	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
7	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
8	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
9	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
10	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
11	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
12	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
13	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
14	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
15	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**

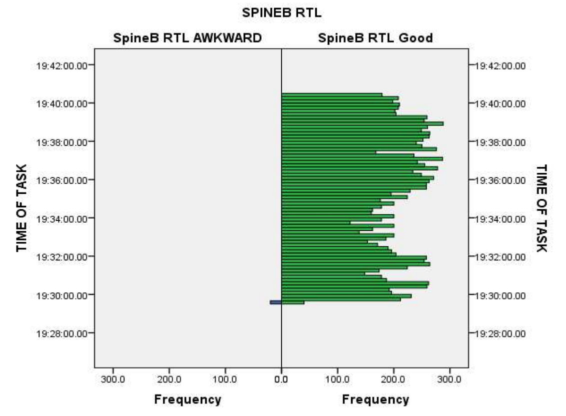
The posture assessment results of the participants are presented on tables 7-4 to 7-8. The blue lines represent the frequency of the awkward postures while the green lines represent the frequency of the good postures.

A comparison of the posture assessment results from the real-time and without real-time feedback shows great agreement with the participant's responses. There is considerable improvement in the posture quality of the operators when real-time feedback is introduced to the system.

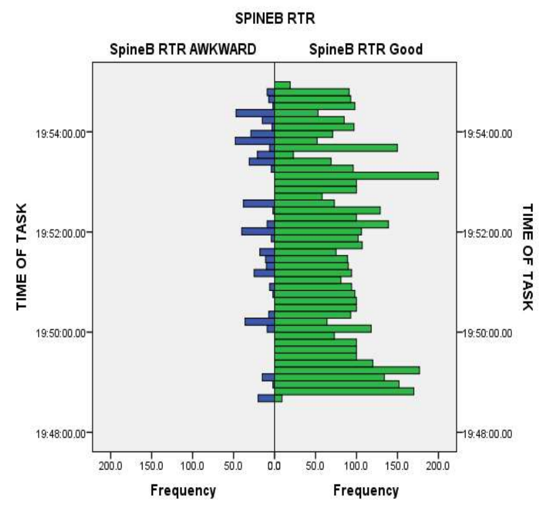
Table 7-4 Results of back posture assessment feedback to participants during assembly task.

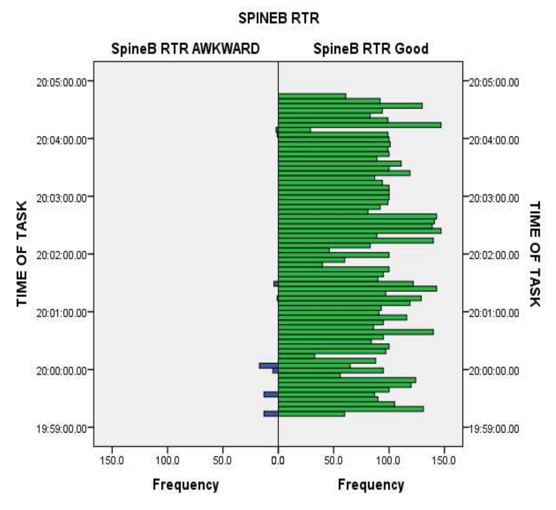
WITHOUT REAL-TIME FEEDBACK	**WITH REAL-TIME FEEDBACK**
Participant 7 (Lateral bending of back to the Left)	



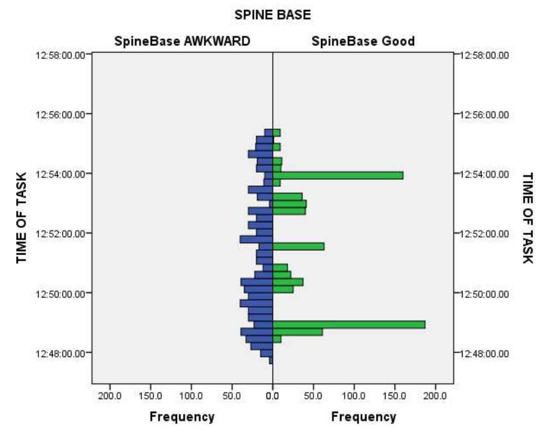


Participant 6 (Lateral bending of back to the right)





Participant 11 (Back flexion)



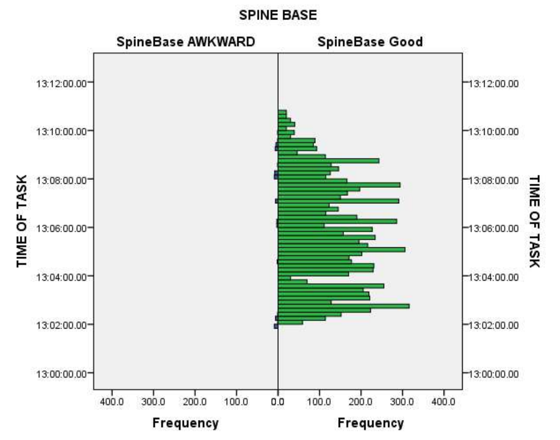


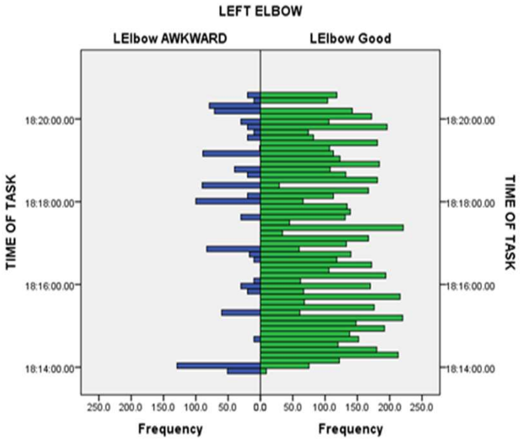
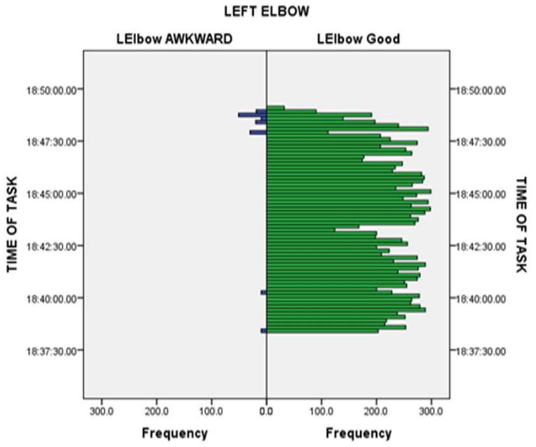
Table 7-4 shows the back-posture assessment of 3 participants during the assembly of the IKEA table. The result is compared for real-time and without real-time feedback. For participant 7, statistical analysis shows that the lateral posture of the spine to the left was held awkward for up to 16.4% of the task duration during the assembly task without real-time feedback. The same posture was held for 0.1% of the task duration for the same task, with the same participant, when real-time feedback was introduced.

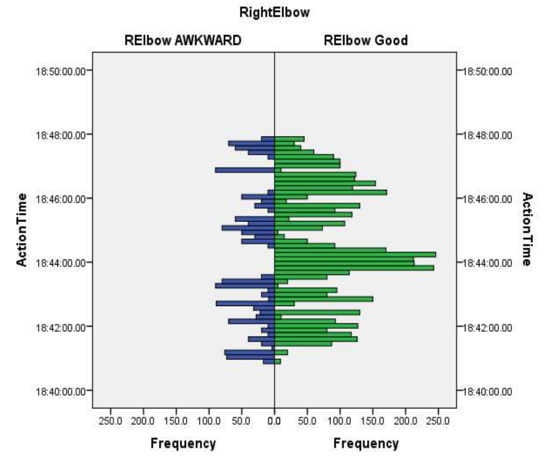
Similarly, participant 6 had her lateral back-bend to the right posture reduced from 9.7% to 0.8% of the task duration as real-time feedback was introduced.

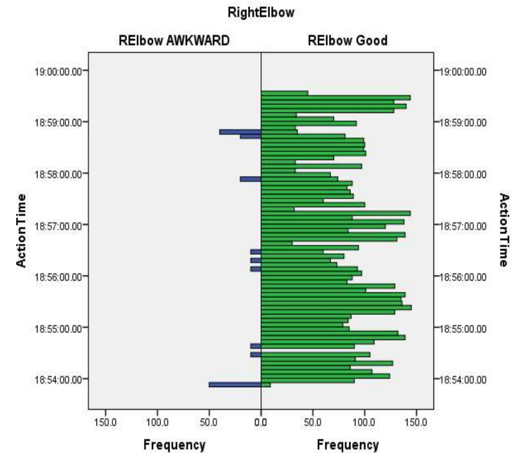
The back-flexion posture of participant 11 was held awkward for 50.7% of the assembly task duration when no real-time feedback was provided to him. This was reduced to 0.8% as real-time feedback was provided to him.

Hence, real-time feedback was provided to the participants on their back postures as proved by the reduced frequency of awkward back posture of these participants.

Table 7-5 Results of the lower arm (Elbows) posture assessment feedback to participants during assembly task.

<table>
<tr><th>WITHOUT REAL-TIME FEEDBACK</th><th>WITH REAL-TIME FEEDBACK</th></tr>
<tr><td colspan="2">Participant 4 (Left elbow)</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td colspan="2">Participant 5 (Right elbow)</td></tr>
</table>





In table 7-5, the left elbow posture of participant 4 was held awkward for 13.8% of the task duration when there was no real-time feedback but as real-time feedback was introduced, the frequency of the awkward left elbow was reduced to 1%. Similarly, the frequency of the right elbow posture of participant 5 was reduced from 25.1% to 2.8% when real-time feedback was introduced.

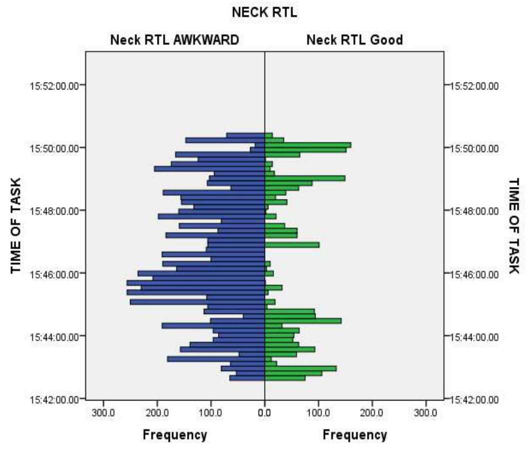
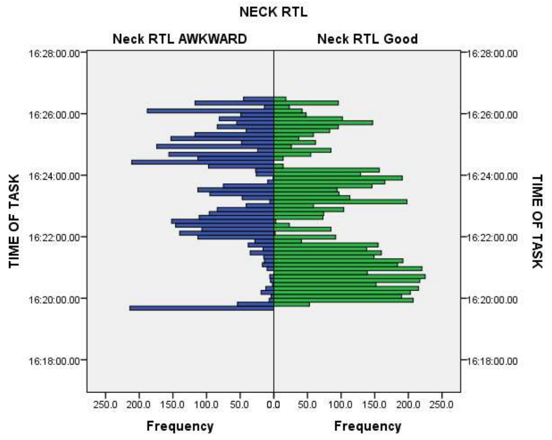
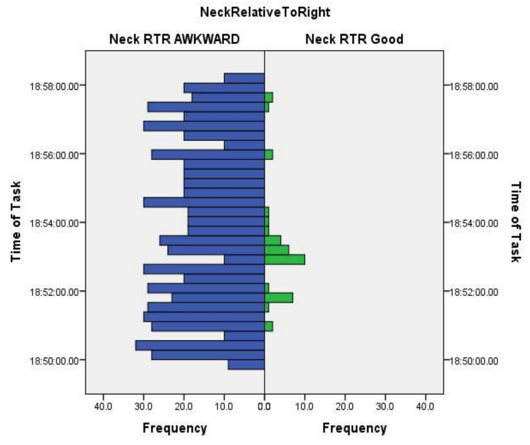
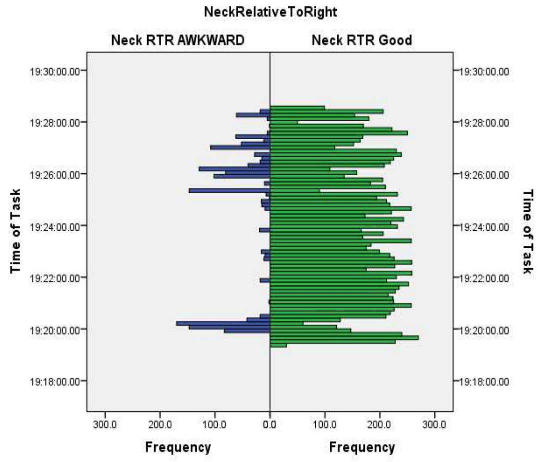
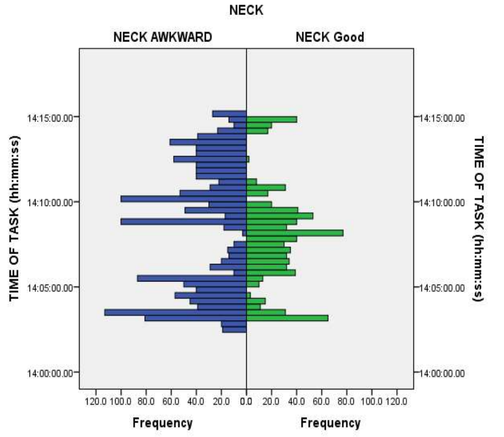
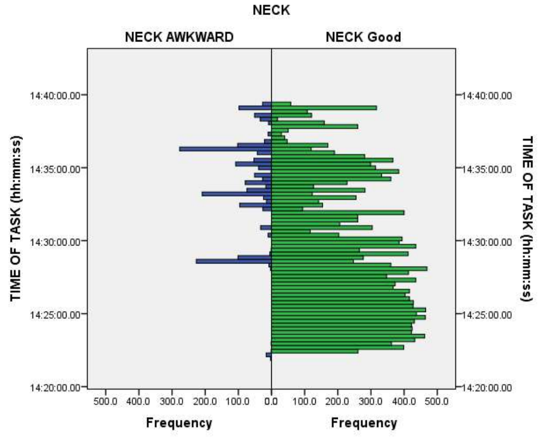
These results show that real-time feedback was provided to the participants on their elbow postures, as proved by the reduced awkward elbow posture of the participants.

Furthermore, table 7-6 shows the neck posture assessment of three of the participants when real-time feedback was not provided, compared to when it was provided.

For participant 3, the neck was bent laterally to the left and held awkward up to 74.8% of the task duration when real-time feedback was not provided. However, when real-time feedback was provided through screen display to the participant, the awkward posture of the neck bent to the left was held for 39.3% of the task duration.

Similarly, the neck of participant 10 was awkwardly bent laterally to the right and held awkward for up to 94.6% of the task duration when no feedback was provided to the participant, but as real-time feedback was provided, the neck was bent awkwardly and held awkward for only 10.2% of the task duration.

Table 7-6 Results of the Neck posture assessment feedback to participants during assembly task.

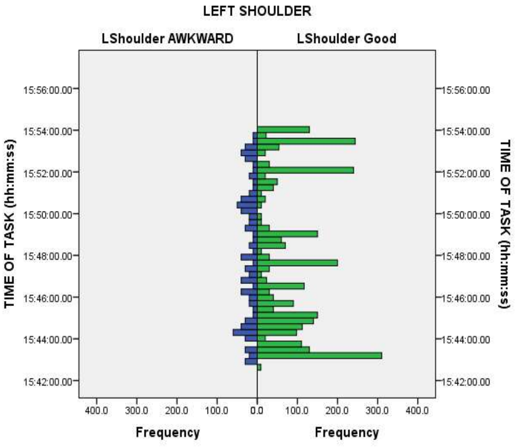
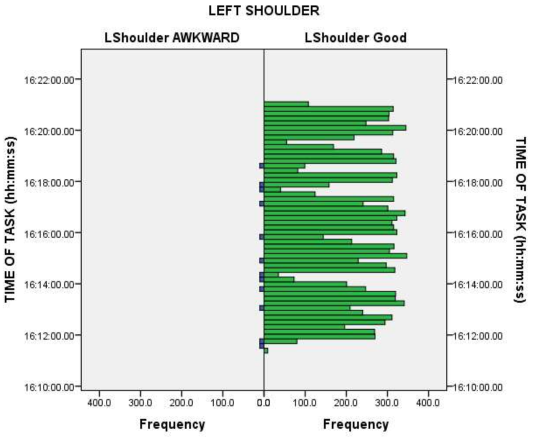
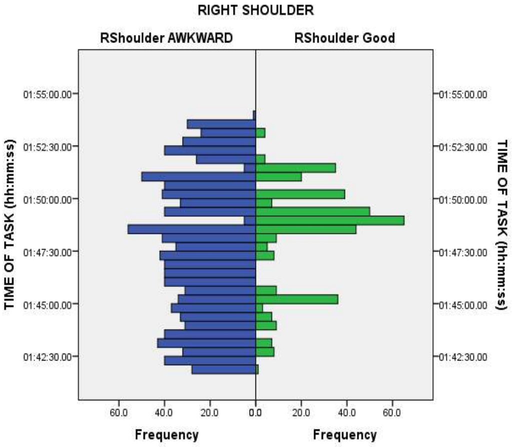
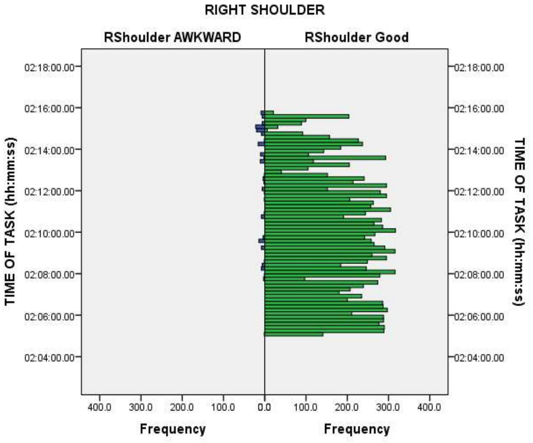
WITHOUT REAL-TIME FEEDBACK	WITH REAL-TIME FEEDBACK
Participant 3 (Neck Left)	
	
Participant 10 (Neck Right)	
	
Participant 12 (Neck)	
	

Participant 12 has her neck posture awkwardly bent forward and held awkward for up to 65.6% of the task duration when there was no feedback provided to her.

However, when real-time feedback was provided, the neck posture was held awkward for only 8.9% of the task duration.

The results show some considerable decrease in the frequency of the neck posture as real-time feedback was introduced during the assembly task.

Table 7-7 Results of the upper arm (Shoulders) posture assessment feedback to participants during assembly task.

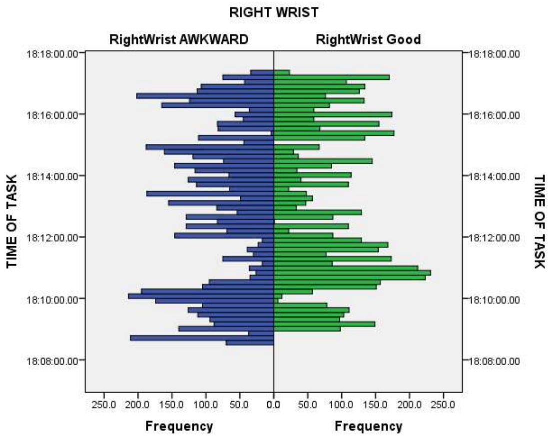
WITHOUT REAL-TIME FEEDBACK	WITH REAL-TIME FEEDBACK
Participant 13 (Left Shoulder)	
	
Participant 15 (Right Shoulder)	
	

In table 7-7 in which the upper arm (Shoulders) posture assessment of 2 participants are presented, participant 13 had his left shoulder moved awkwardly away from his body and held awkward for up to 24.4% of the task duration when there was no provision of real-time feedback. However, this same posture was held for only 1% of the task duration as real-time feedback was provided to the participant.

Similarly, participant 15 had his right shoulder held awkward for up to a concerning level of 73.2% of the task duration when no feedback was provided but as real-time feedback was provided relating to his upper arm postures, the right shoulder was held awkward for only 1.3% of the task duration.

Therefore, the statistical analysis of the upper arm posture assessment for two of the participants reveal a considerable decrease in the rate of occurrence of awkward shoulder postures as real-time feedback was introduced during the assembly task.

Table 7-8 Results of wrist posture assessment feedback to participants during assembly task.

<table>
<tr><th>WITHOUT REAL-TIME FEEDBACK</th><th>WITH REAL-TIME FEEDBACK</th></tr>
<tr><td colspan="2">Participant 1 (Right Wrist)</td></tr>
<tr><td>


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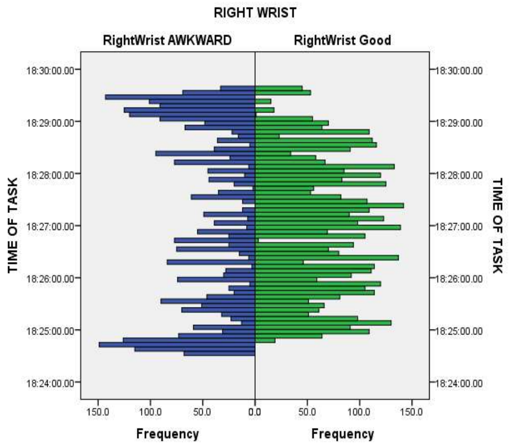
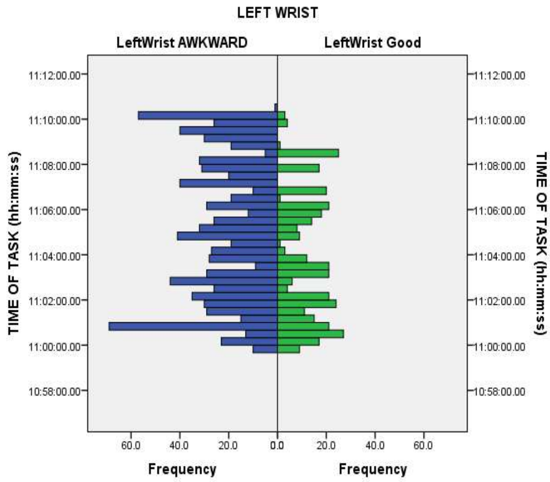
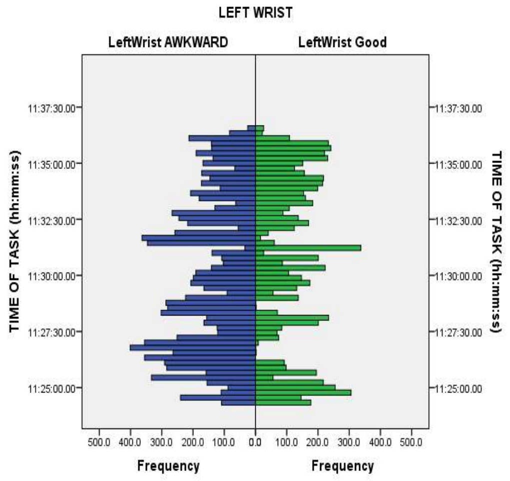


</td></tr>
<tr><td colspan="2">Participant 8 (Left Wrist)</td></tr>
<tr><td>


</td><td>


</td></tr>
</table>

For wrist assessment as presented on table 7-8, participant 1 had his right wrist held awkward for up to 50.9% of the task duration when there was no provision of real-time feedback. However, when real-time feedback was provided in form of screen display, the frequency of awkward right wrist posture was decreased to 39.7%.

Similarly, participant 8 had her left wrist held awkward for up to 71.2% of the task duration when no feedback was provided on her posture status, but when real-time feedback was provided in the form of on-screen display, the left wrist was held awkward for 59% of the task duration.

For all the operators and all joints, depending on the type of feedback provided, there is reduction in the frequency of awkward posture when real-time feedback is introduced. This is evaluated using the SPSS descriptive statistics analyser. Figures 7-17 and 7-18 show the graphical comparison of a participant's postures when held awkward during the task duration. The comparison is made for real-time and without real-time feedback to the participant.

Figure 7-17 shows slightly reduced awkward postures when the postures are assessed with real-time feedback provided to the participant, with elevated level of awkwardness when there is no feedback provided to the participant. This is further validated by the elevated 'Good' posture quality obtained in figure 7-18, when the joints were held in 'Good' posture for prolonged periods as real-time feedback was provided to the participant.

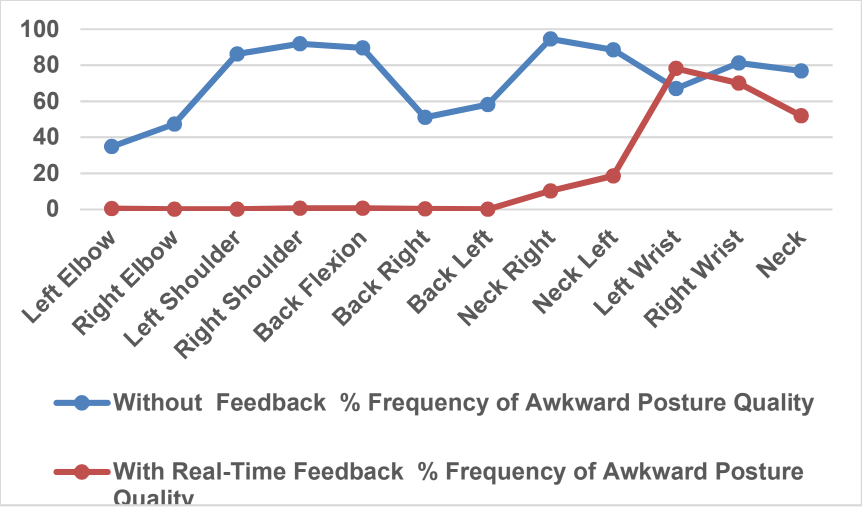


Figure 7-17 Graphical comparison of a participant's postures when held 'Awkward' during the task duration

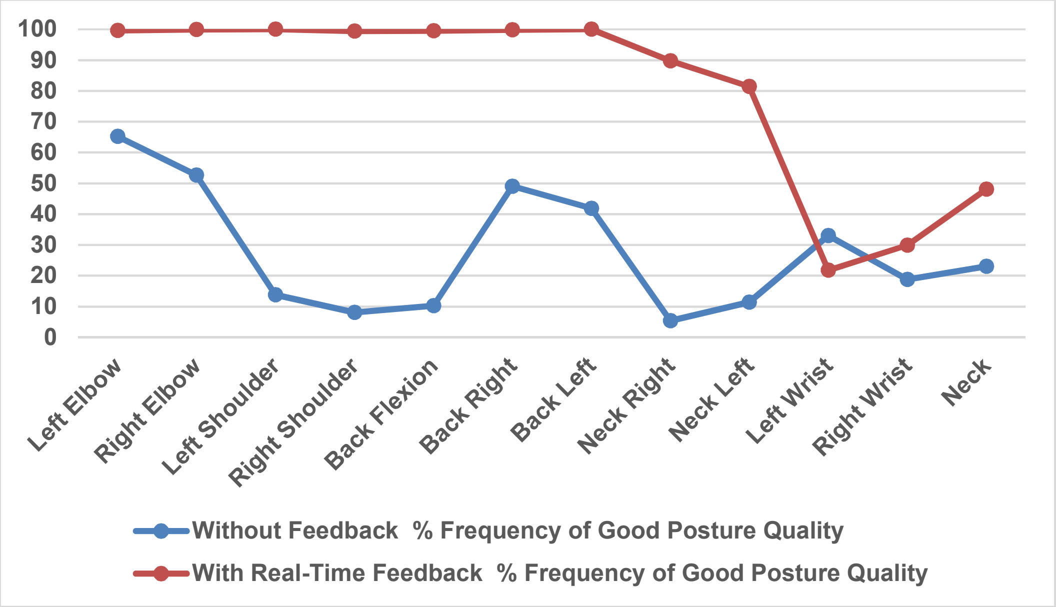


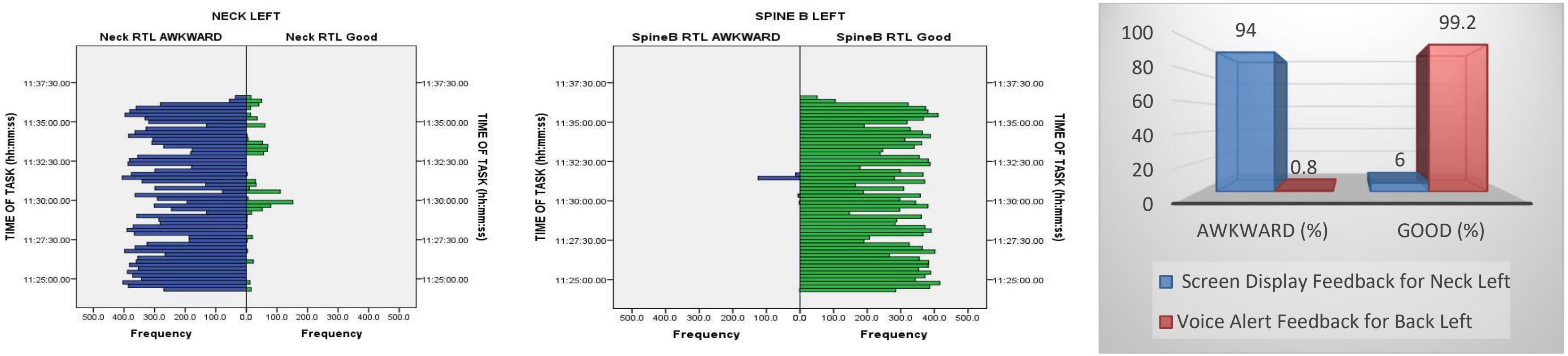
Figure 7-18 Graphical comparison of a participant's postures when held 'Good' during the assembly task duration

The result, classified as either real-time feedback or without real-time feedback, clearly shows that as real-time feedback is introduced, there is some reduction in the rate of occurrence of awkward postures.

Finally, we conclude that even for highly repetitive tasks such as assembly task, the system can also provide real-time feedback to the operators concerning their postures.

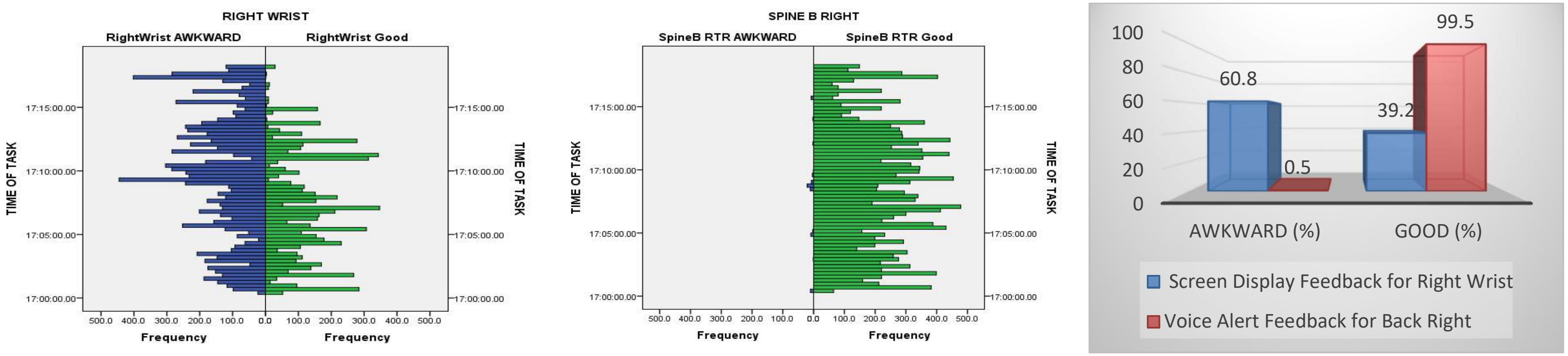
7.4.4.2 Case Study 2, Feature ii: Testing for the most effective type of feedback

As mentioned earlier, two types of real-time feedback are provided which include the screen display and voice alert feedback. The back and arm postures are assessed with the voice alert feedback while the screen display type was used to assess the neck and wrist postures. The table below shows the result of real-time posture assessment of the participants for all joints during the assembly task. A comparison of the real-time feedback provided for the screen display type of feedback and the voice alert feedback system, is presented on figures 7-19 to 7-23.



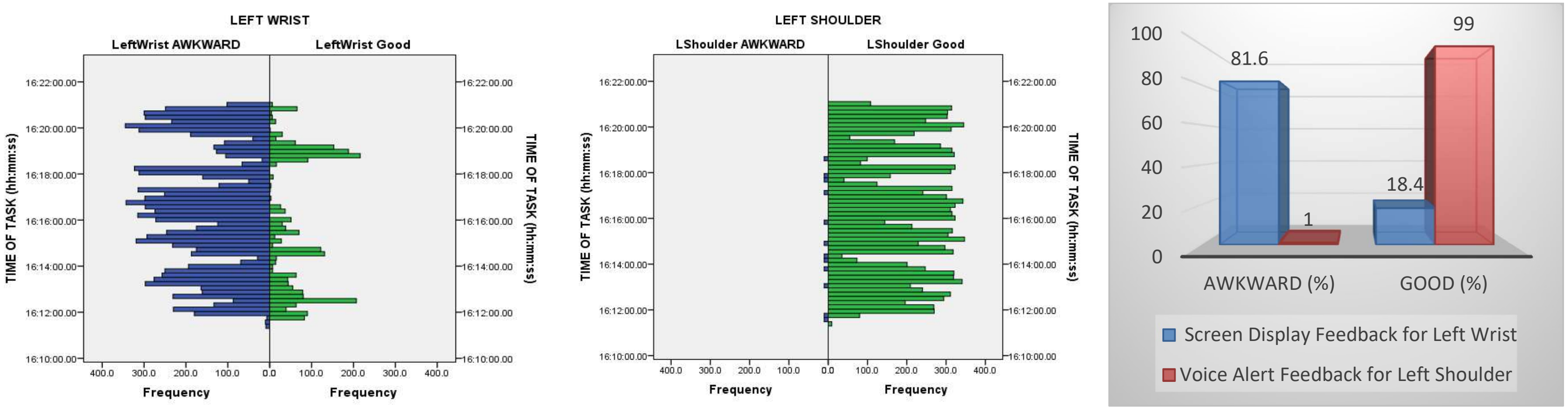
a. Screen Display feedback for Neck Left **b. Voice alert feedback of Back Left** **c. Statistical comparison of results**

Figure 7-19 Comparing the screen display feedback to voice alert feedback for Participant 8



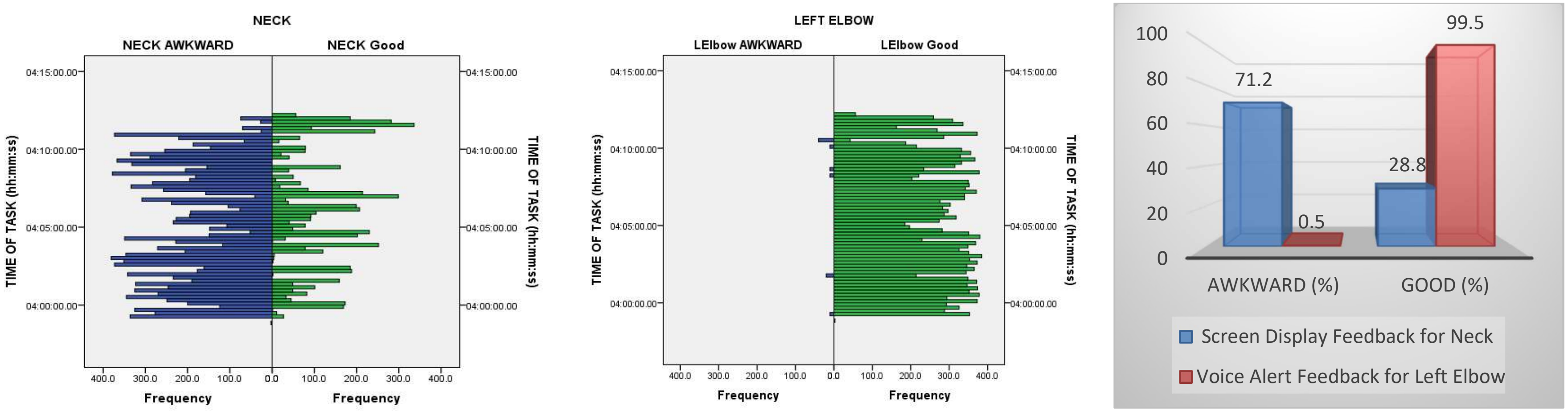
a. Screen Display feedback of right wrist **b. Voice alert feedback of back right** **c. Statistical comparison of results**

Figure 7-20 Comparing the screen display feedback to voice alert feedback for Participant 9



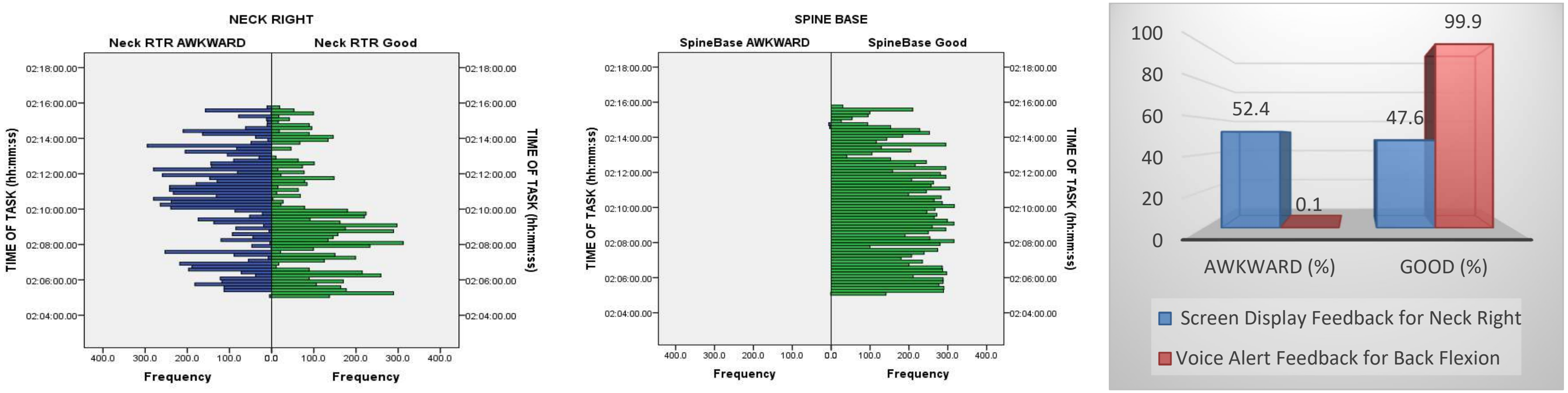
a. **Screen Display feedback of left wrist** b. **Voice alert feedback of left shoulder** c. **Statistical comparison of results**

Figure 7-21 Comparing the screen display feedback to voice alert feedback for Participant 13



a. **Screen Display feedback for Neck** b. **Voice alert feedback for Left Elbow** c. **Statistical comparison of results**

Figure 7-22 Comparing the screen display feedback to voice alert feedback for Participant 14



a. Screen Display feedback for Neck Right b. Voice alert feedback for Back flexion c. Statistical comparison of results

Figure 7-23 Comparing the screen display feedback to voice alert feedback for Participant 15

The frequencies of the awkward postures are apparently greater when screen display feedback was used as compared to the voice alert feedback (compare figures 7-19a to 7-23a with 7-19b to 7-23b). This is probably because the participants were too engrossed in the task that they forgot to check for their posture updates on the screen.

This comparison is studied further with a statistical analysis of the screen display feedback results and voice alert results. In figure 7-19c, the side-neck posture of participant 8 was held awkward for up to 94% of the task duration with only 6% of the posture held as ‘Good’, when the screen display feedback was used. However, same participant’s side-back posture was held good for 99.2% of the task duration and awkward for only 0.8% of the task duration, as the voice alert feedback was used.

In figure 7-20c, participant 9 had his right wrist held for up to 60.8% of the task duration with screen display type of feedback while his spine right was held awkward for only 0.5% of the task duration when the voice alert feedback was used. Participant 13 of figure 7-21c had his left wrist held awkward for over 81.6% of the task duration with screen display type of feedback while his left shoulder was held awkward for only 1% of the task duration as the voice alert feedback was used. Similarly, participants 14, and 15 had their neck and neck right held awkward for 71.2%, and 52.4% of the task duration with screen display type of feedback while their left elbow and back flexion postures were held awkward for only 0.5%, 0.1% respectively during the entire task duration as the voice alert feedback was used. Similar result was obtained for all participants indicating that the voice alert is more effective in communicating the feedback to the participants.

A participant response/questionnaire form filled by the participants on the feedback they feel is more effective showed that all the participants picked the voice alert feedback as the most effective in communicating the real-time feedback of their work postures. Details of their response is on the questionnaire in Appendix C.

Finally, since the results of the assembly task posture assessment showed considerable reduction in the rate of occurrence of awkward posture for the joints on which the voice alert feedback is used, with the joints on which the screen display feedback was provided showing little or no reduction in frequency of awkward postures, we therefore infer that the voice alert feedback system is more effective than the screen display and should always be used. This is because the operators hardly looked at the screen as they were working as they were all busy with the task.

7.4.4.3 Feature iii:Testing for the most effective feedback display interval

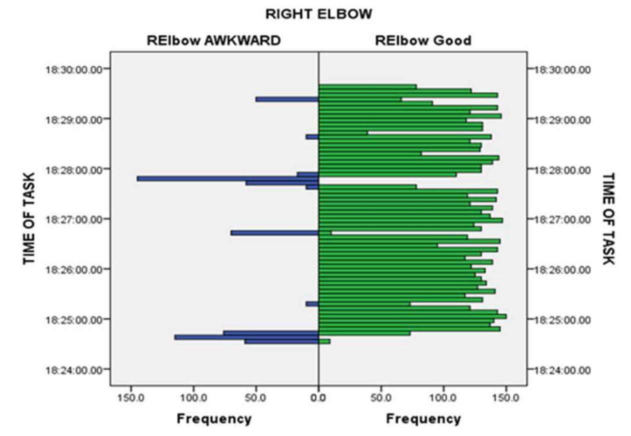
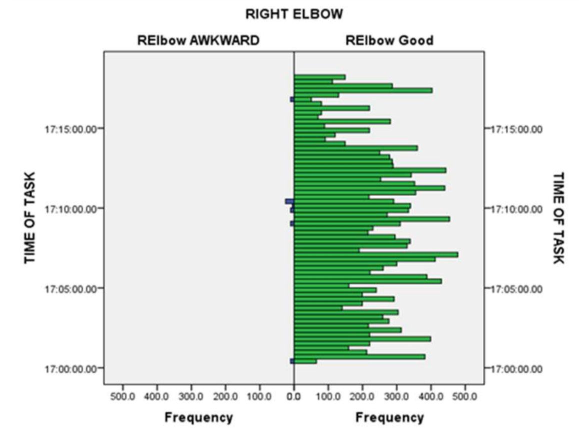
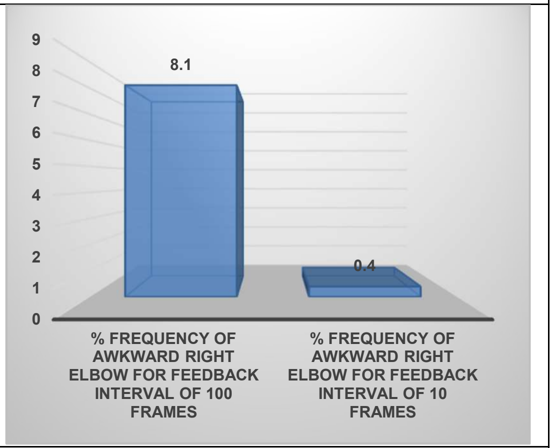
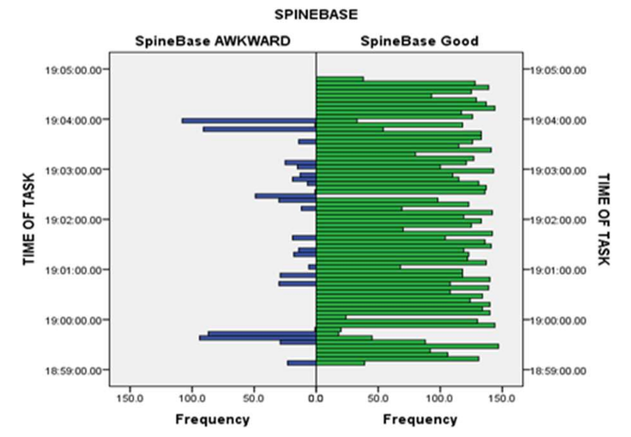
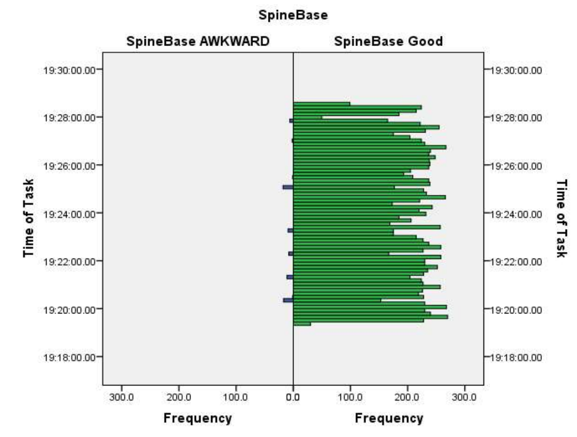
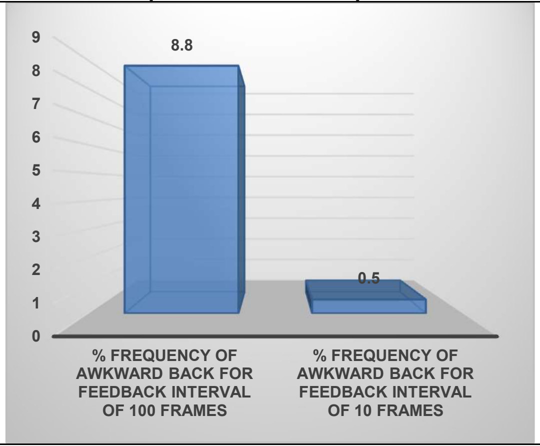
Having established that the voice alert feedback is more effective than the screen display, the purpose of the study presented in this section is to test the effective interval with which the voice alert should be programmed. As mentioned earlier, seven of the operators were assessed with the voice alert feedback programmed for awkward postures held for 100 frames at a time while the remaining eight operators had the voice alert programmed for awkward postures held for 10 frames at a time to prove the most effective real-time feedback interval that best reduces awkward postures. For the feedback interval of 100 frames, the system was meant to prompt the worker when the posture has been held awkward for prolonged period of up to 100 frames while the feedback interval of 10 frames prompts the operator as soon as 10 frames of awkward posture has been held.

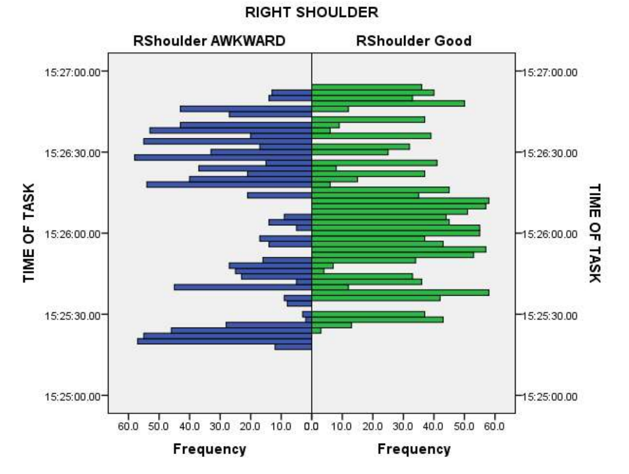
A comparison of the results obtained for the two intervals is presented on table 7-9. Participants 1, 2, 3, 5 and participant 6 had the assessed postures held for 8.1%, 8.8%, 18.1%, 24.2% and 19% respectively, of the task duration when the feedback was programmed to prompt the participant at 100 frames feedback interval. However, for participants 9, 10, 13, 14 and 12, the assessed postures were held for 0.4%, 0.5%, 1%, 0.2%, and 2.4% respectively, of the task duration as the feedback was programmed to prompt the participants at 10 frames feedback interval

From the results obtained, even with the real-time voice alert feedback to the operators, we can deduct that the rate of occurrence of awkward postures improved when the voice alert is programmed to prompt the operator at smaller frame interval than at higher frame intervals.

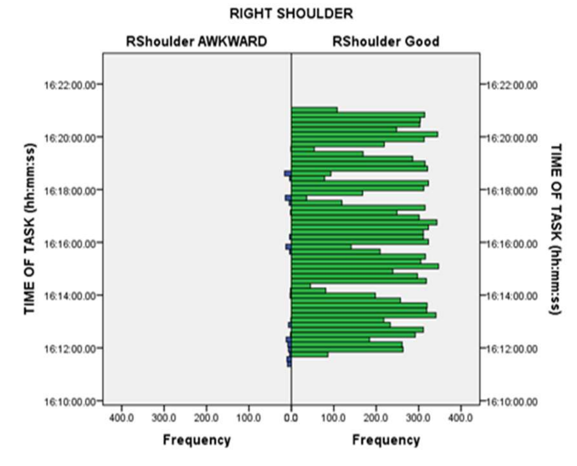
We therefore recommend the voice alert feedback system programmed at a shorter frame interval for more effective real-time feedback to the operators.

Table 7-9 Comparison of the results of posture assessment voice alert feedback for different display intervals

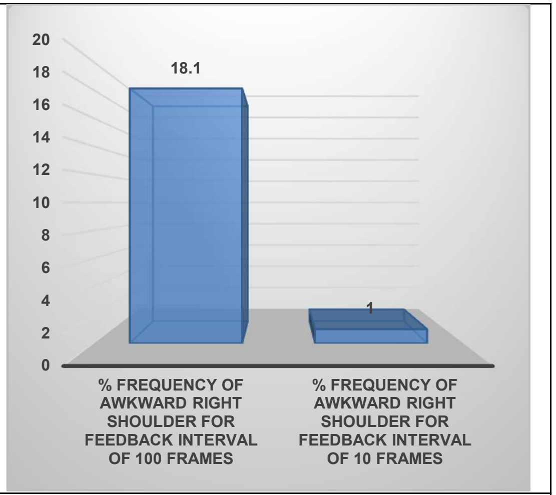
VOICE ALERT INTERVAL OF 100 FRAMES	VOICE ALERT INTERVAL OF 10 FRAMES	COMPARISON OF % FREQUENCIES
		
Participant 1	Participant 9	Comparison of the % frequencies
		
a. Participant 2	b. Participant 10	c. Comparison of the % frequencies



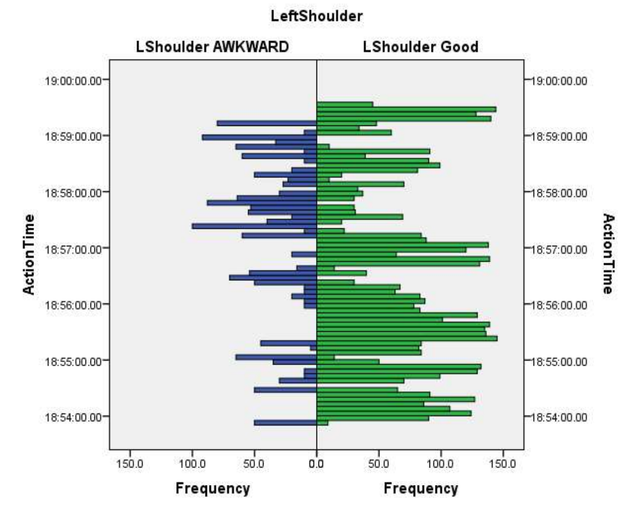
d. Participant 3



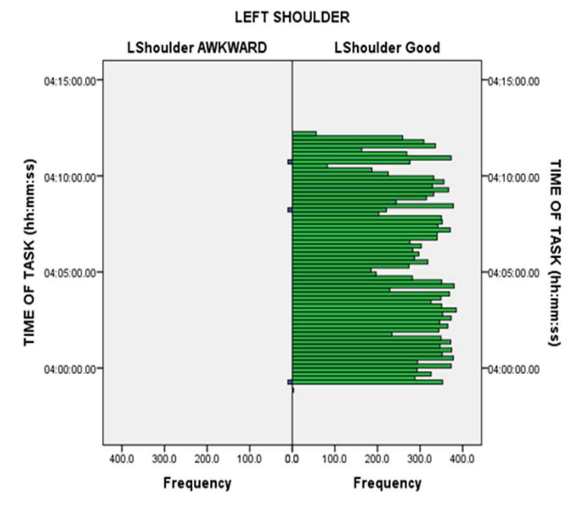
e. Participant 13



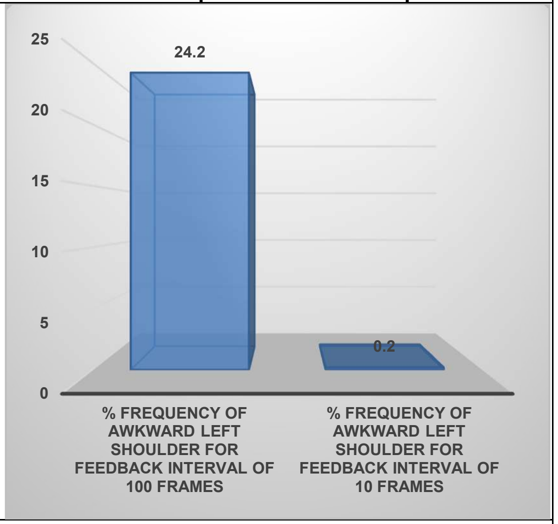
f. Comparison of the % frequencies



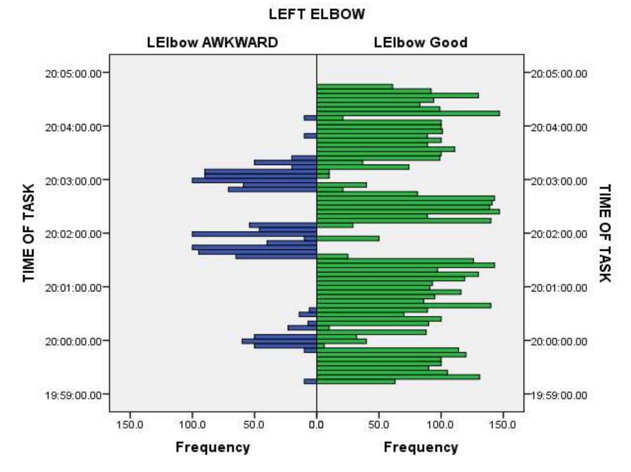
g. Participant 5



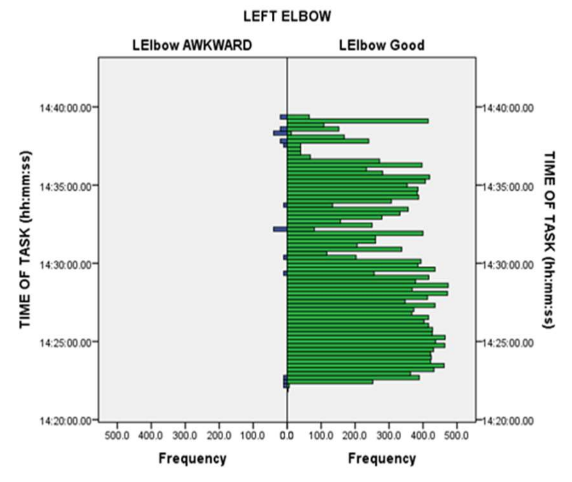
h. Participant 14



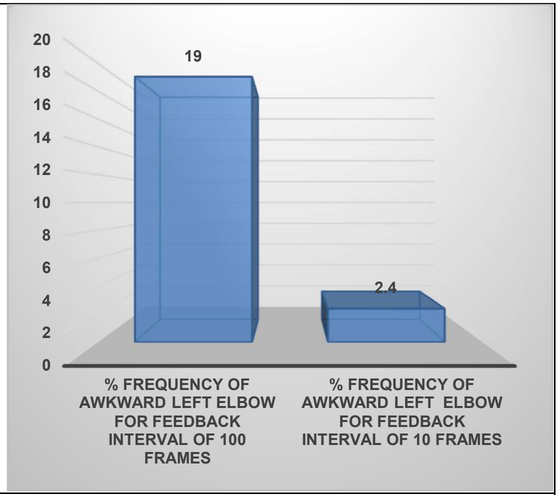
i. Comparison of the % frequencies



j. Participant 6



k. Participant 12



l. Comparison of the % frequencies

7.5 Case Study 3: Hammering of IKEA Table Components.

The task chosen for this study is the hammering of the IKEA table components. In the study, the ability of the feedback system to provide real-time feedback of both the task detection and posture assessment to the operators is tested as they hammer the IKEA table components.

The case study differs from the other case studies in the following areas:

1. The study involves a hammering task.
2. Investigates the possibility of detecting manual handling tasks using the system.
3. Investigates any possible relationship between task detection and awkward postures.

The task was carried out in the laboratory under controlled conditions.

7.5.1 Choice of Task

In this study, the ability of the system to achieve real-time manual handling task detection will be tested during a hammering task on the IKEA table assembling floor. Hammering task was chosen because the task has been identified as a high-risk task that usually leads to WMSDs if not properly assessed (Cheng et al., 2013; Karhu et al., 1981; Karhu, Kansi and Kuorinka, 1977; Lee and Han, 2013; Li and Lee, 1999; Mattila, Karwowski and Vilkki, 1993; Valero et al., 2016). Again, incorrect use as well as repetative use of the hammer can lead to muscle and tendon injuries on the hand (Buchanan et al., 2016).

7.5.2 Task Description

The task requires an operator to hammer table components while the sensor captures his body, his upper arm posture and possibly detect the task. The detection is necessary to enable the operator ascertain if the tracking of his joint data is progressing satisfactorily and if the task is to be completed correctly. Hence, the operator checks if the task is detected by the system even while adjusting his posture.

The steps involved in the study include:

Step 1: Assessment of the operator’s upper arm postures during a hammering activity.

Step 2: The operator checks to see if the task is detected by the system

Step 3: Feedback from the system on the task detection status

Step 4: A check to ascertain whether the task detection capability can help to detect awkward postures.

For each operator, the hammering task was captured twice. One is when the hammer was held close to the operator’s body and the second capture is with the hammer held away from the body.

7.5.3 Task setup

The hammering task is performed during the assembly of the table. Hence, the setup is the same as that of the assembly task setup. The hammering task is performed by each of the participants and repeated twice. The first time is with the upper arm held away from the body while the second time is with the upper arm held close to the body.

To check for task detection, the operator while selecting the color button in the KBS, is given an option through a dialogue box, whether to run detection or not. Selecting the run detection button opens the detection window on which the detection results are displayed.

7.5.4 Result and Discussion

The result of the real-time task detection with feedback, and the corresponding posture assessment to the participants are presented in this section.

7.5.4.1 Case 3, Feature i: If the system can detect manual handling tasks and give real-time feedback to the operator on the task detection.

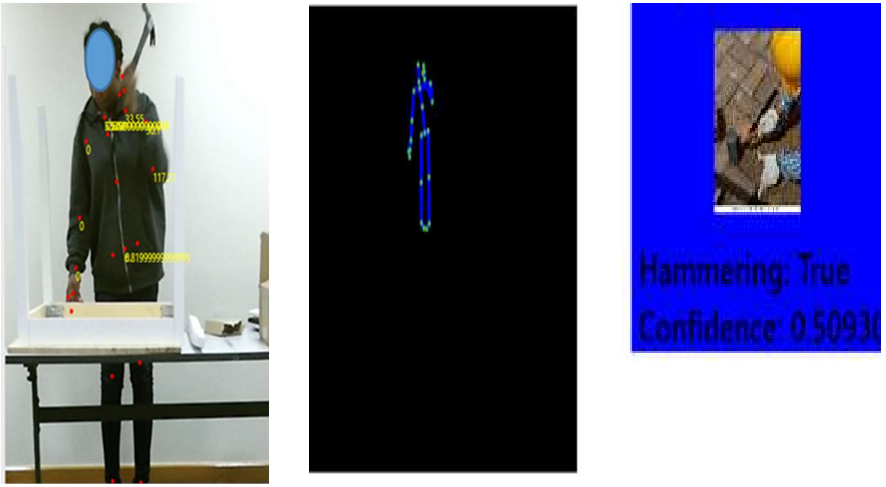
There was successful task detection when the operators checked for task detection during the hammering activity as presented in figure 7-24.

In the figure, the participant’s tasks are displayed in real-time. For participant 7, the hammering task was detected as confirmed by the ‘True’ value displayed for hammering, with a detection confidence of 0.5 at the time of capture (figure 7-24a). Figure 7-24b depicts the detection confidence rate of participant 7 during the entire task duration.

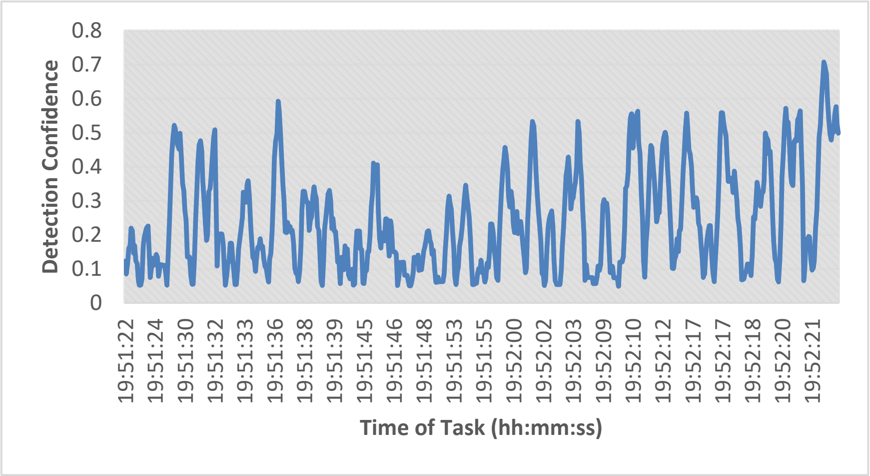
Similarly, a true value was displayed for hammering when participants 9, 11 and 13 were detected with detection confidences of approximately 0.4, 0.5 and 0.7 respectively at the time of capture. This indicates that the system detects the tasks performed by the participants and successfully displays the detected task result to them in real-time. A plot of the confidence rates for these participants is presented on figure 7-24d, f and h.

The participant’s response on whether real-time feedback was provided to them concerning their tasks, which agree with the results of figure 7-24, is presented on table 7-10.

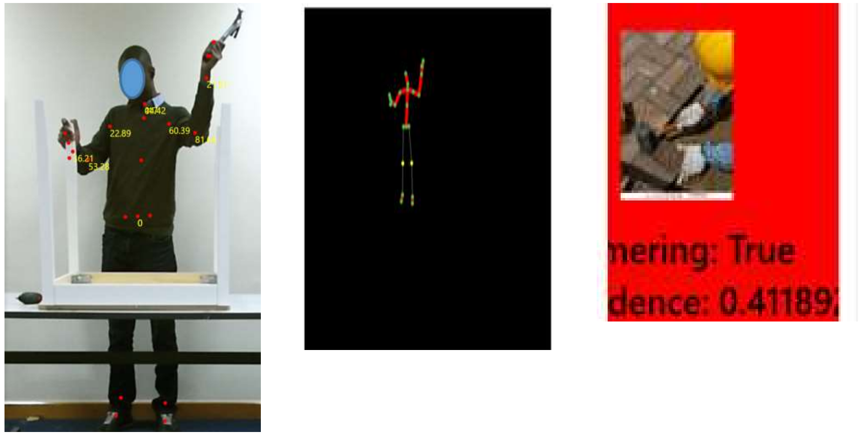
We can therefore infer that the developed KBS can also provide real-time feedback of task detection to the operators to help in the reduction of measurement errors.



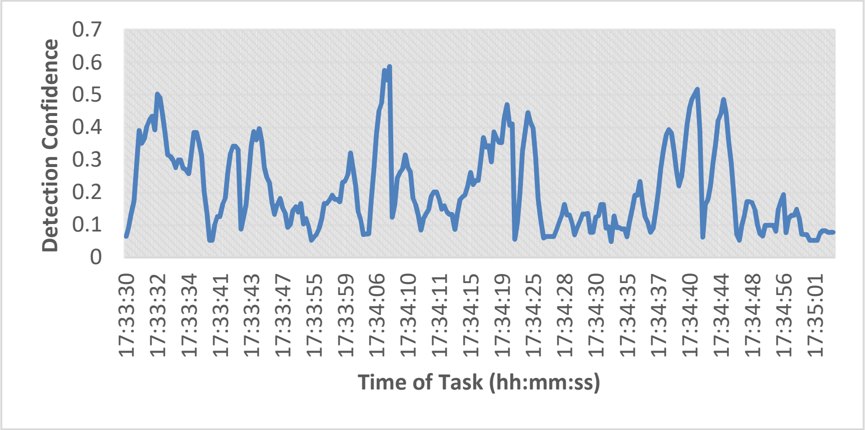
a. Real-Time Task detection display to participant 7



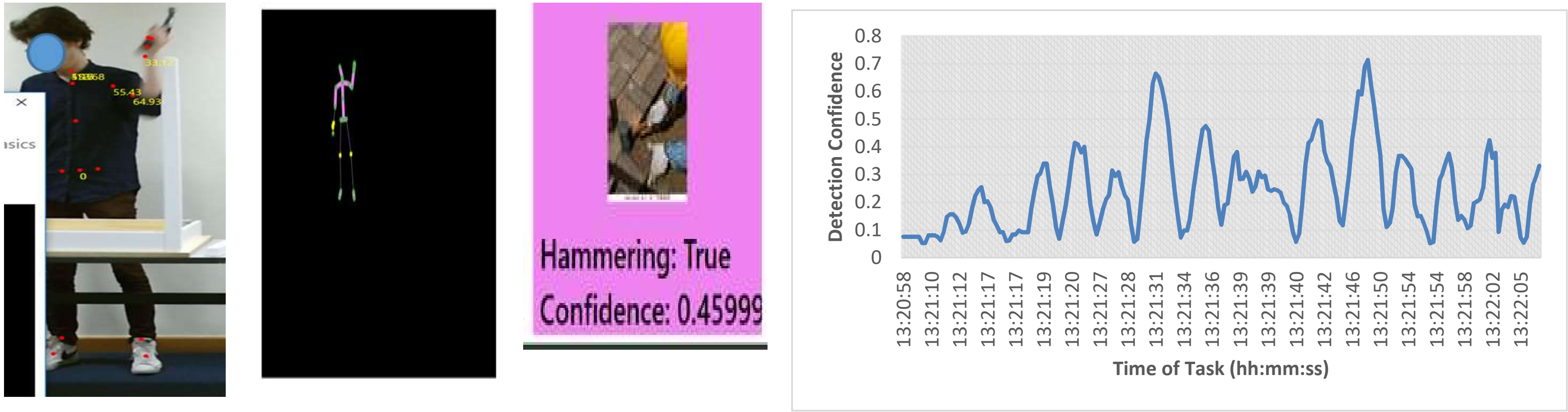
b. Detection Confidence rate for participant 7



c. Real-Time Task detection display to participant 9

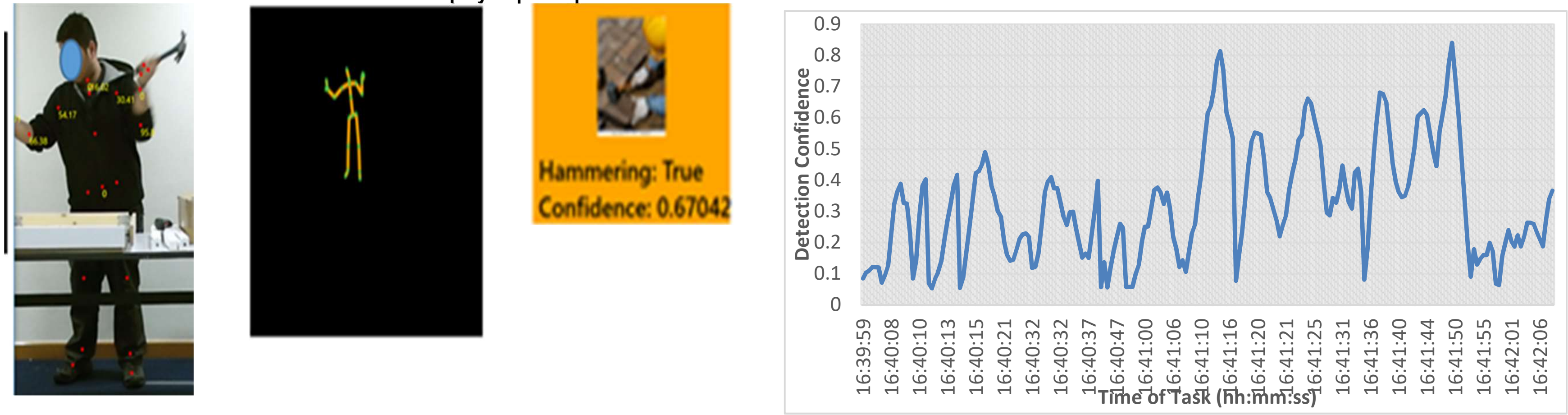


d. Detection Confidence rate for participant 9



e. Real-Time Task detection display to participant 11

f. Detection Confidence rate for participant 11



g. Real-Time Task detection display to participant 13

h. Detection Confidence rate for participant 13

Figure 7-24 Real-Time Task Detection by the Participants

7.5.4.2 Case 3, Feature ii: If the system can assess work postures and provide real-time feedback to workers simultaneously with task detection.

The upper arm posture of the participants was assessed as they performed hammering operation on the IKEA table. Results obtained revealed that real-time feedback of the posture assessment was provided simultaneously with the real-time task detection results, as presented in figure 7-25. Because all the participants are right-handed, only the right shoulder assessment result is of interest in this study.

Hammering: True
Confidence: 0.43954

AngleNeckLeft	30.27	NECK AWKWARD	SpineBase Good
AngleLeftElbow	120.19	LShoulder AWKWARD	RShoulder Good
AngleRightElbow	99.11	RightWrist AWKWARD	LeftWrist Good
Angle S B Left	0	SpineB RTR Good	SpineB RTL Good

a. Task detection and posture assessment feedback to participant 2

Hammering: True
Confidence: 0.30609

AngleNeckLeft	0	NECK Good	SpineBase Good
AngleLeftElbow	30.54	LShoulder AWKWARD	RShoulder AWKWARD
AngleRightElbow	85.49	RightWrist AWKWARD	LeftWrist AWKWARD
Angle S B Left	0	SpineB RTR Good	SpineB RTL Good
Angle S B Right	0		
AngleSpineBase	0		
AngleLeftShoulder	33		
AngleRightShoulde	62.28		

b. Task detection and posture assessment feedback to participant 10

Figure 7-25 Simultaneous Task Detection and Posture Assessment Feedback to the Participants

Participant's response on whether there was real-time feedback of the upper arm posture assessment and task detection results is also presented in table 7-10. Therefore, results reveal that the system can assess work postures and provide real-time feedback to workers simultaneously with task detection.

Table 7-10 Operator's response on real-time feedback of task detection and posture assessment results

Participants	Hammering Task Detected?	Real-Time Feedback Provided for Task Detection?	Shoulder Posture Assessed?	Simultaneous Real-Time Feedback provided for Posture Assessment and Task Detection?
1	Yes	Yes	Yes	Yes
2	Yes	Yes	Yes	Yes
3	Yes	Yes	Yes	Yes
4	Yes	Yes	Yes	Yes
5	Yes	Yes	Yes	Yes
6	Yes	Yes	Yes	Yes
7	Yes	Yes	Yes	Yes
8	Yes	Yes	Yes	Yes
9	Yes	Yes	Yes	Yes
10	Yes	Yes	Yes	Yes
11	Yes	Yes	Yes	Yes
12	Yes	Yes	Yes	Yes
13	Yes	Yes	Yes	Yes
14	Yes	Yes	Yes	Yes
15	Yes	Yes	Yes	Yes

To ascertain whether task detection can help to detect awkward postures, the hammering task was carried out in two ways i.e. the close-body hammering and hammering with arms away from the body.

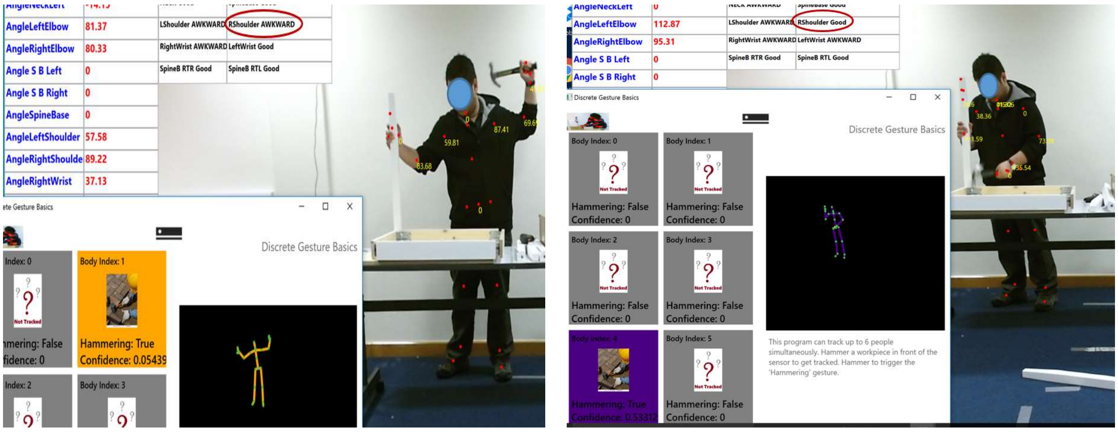
Figure 7-26a shows participant 13 hammering with arms away from the body while 7-26b shows the same participant hammering with arm close to the body. At the time of capture, the right shoulder was assessed as 'Awkward' when the hammering task was performed with arms away from the body, and assessed as 'Good' as the arm was held close to the body in 7-26 a & b. Statistical analysis of the data in figures 7-26 e & f revealed that the right shoulder of the participant was held 'Awkward' for up to 66.1% of the task duration, when the arm was held away from the body, but was held 'Good' for up to 92.8% of the task duration as the arm was held close to the body. This agrees with the H&S guideline that the arm should be held close to the body during manual handling tasks to reduce awkward postures. An analysis of the task detection confidence rate revealed some differences in the rate of task detection for both cases.

It seems some task detection data points were not captured by the system when the arm was held away from the body as depicted in figure 7-26c, as compared to 7-26d of close-body hammering.

Similar result as that of figure 7-26 was obtained when participant 9 performed the hammering task. In 7-27a, the participant’s arm was captured as ‘Awkward, and held awkward for up to 37.9% of the task duration as he performed the task with his arm held away from his body. However, it was captured as ‘Good’ and held good for up to 96.4% of the task duration as he was performing the task with arms close to his body (figure 7-27b). This again agrees with the H&S guidelines for manual handling.

Curiously, it again seems some task detection data points were not captured by the system when the arm was held away from the body as depicted in figure 7-27c, as compared to 7-27d of close-body hammering.

Hence, figures 7-26 and 7-27 have revealed that as the operator is working with arms away from the body, the posture assessment indicates it is highly awkward and even risky and the task detection indicates some lost data because of undetected frames. However, when the arm is held close to the body, the posture is assessed as good and more of the task frames seem to be detected. This calls for further investigation as there is indication that may be some relation or link between posture assessment and task detection which can enable the use of task detection for detection of awkward postures.



AngleLeftElbow 81.37
AngleRightElbow 80.33
Angle S B Left 0
Angle S B Right 0
AngleSpineBase 0
AngleLeftShoulder 57.58
AngleRightShoulde 89.22
AngleRightWrist 37.13

LShoulder AWKWARD RShoulder AWKWARD
RightWrist AWKWARD LeftWrist Good
SpineB RTR Good SpineB RTL Good

Discrete Gesture Basics
Body Index: 1
Hammering: True
Confidence: 0.05439

AngleLeftElbow 112.87
AngleRightElbow 95.31
Angle S B Left 0
Angle S B Right 0

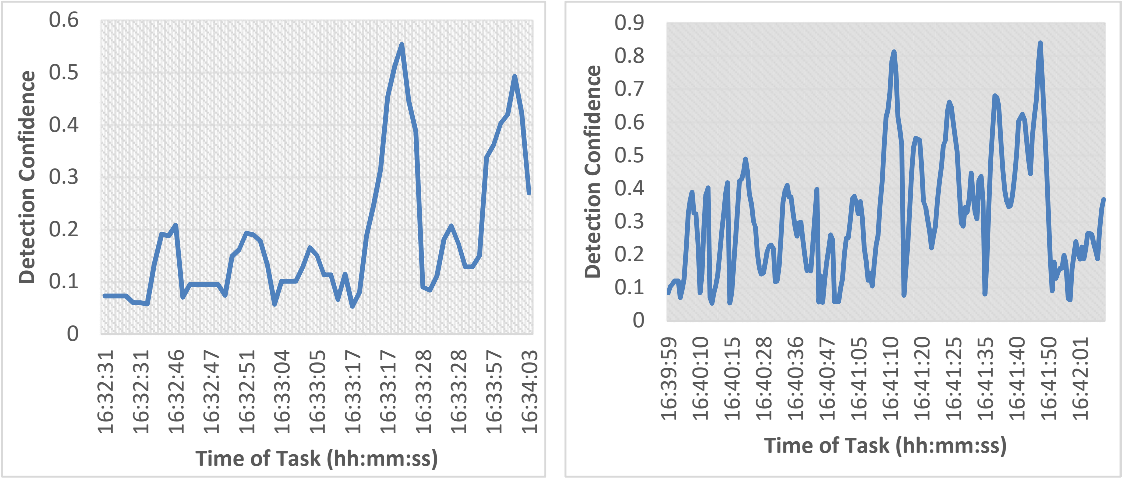
LShoulder AWKWARD RShoulder Good
RightWrist AWKWARD LeftWrist AWKWARD
SpineB RTR Good SpineB RTL Good

Discrete Gesture Basics
Body Index: 0 Hammering: False Confidence: 0
Body Index: 1 Hammering: False Confidence: 0
Body Index: 2 Hammering: False Confidence: 0
Body Index: 3 Hammering: False Confidence: 0
Body Index: 4 Hammering: True Confidence: 0.5331
Body Index: 5 Hammering: False Confidence: 0

This program can track up to 6 people simultaneously. Hammer a workpiece in front of the sensor to get tracked. Hammer to trigger the 'Hammering' gesture.

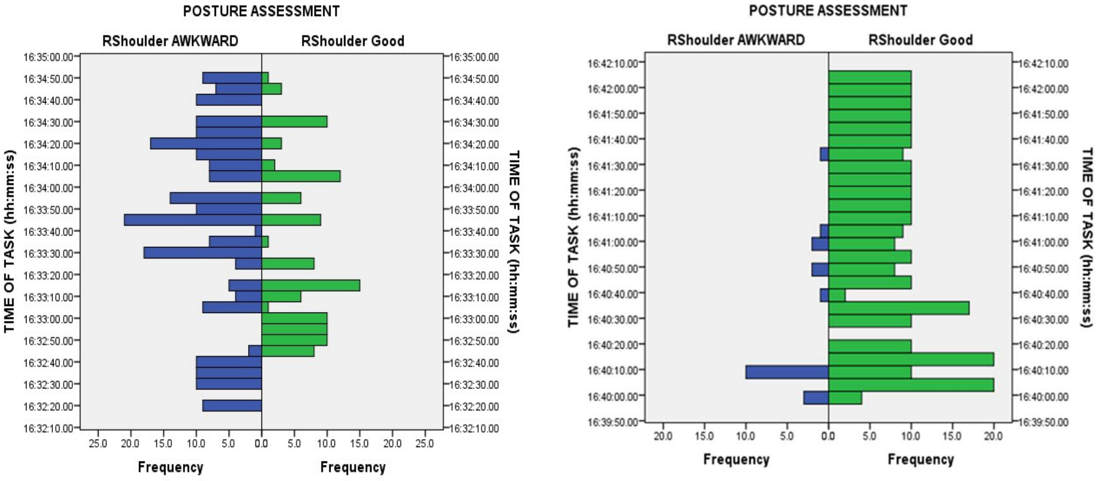
a. **Hammering with arms away from the body**

b. **Close-body hammering**



c. **Confidence rate when arm is away from body**

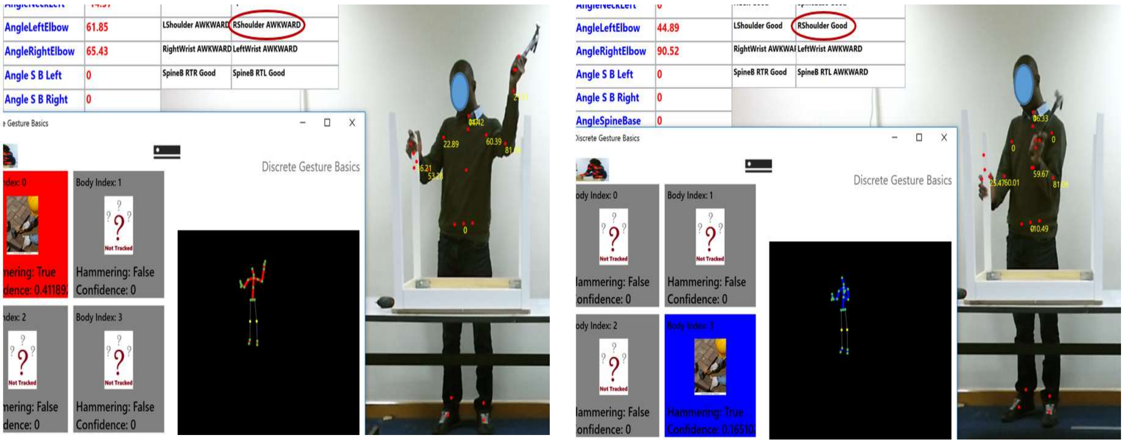
d. **Confidence rate for close-body hammering**



e. **Posture assessment for arm away from body**

f. **Posture assessment for close-body hammering**

Figure 7-26 Task detection versus posture assessment for participant 13



AngleLeftElbow 61.85 | LShoulder AWKWARD | RShoulder AWKWARD
AngleRightElbow 65.43 | RightWrist AWKWARD | LeftWrist AWKWARD
Angle S B Left 0 | SpineB RTR Good | SpineB RTL Good
Angle S B Right 0

Discrete Gesture Basics

Body Index: 1 Hammering: False Confidence: 0
Body Index: 3 Hammering: False Confidence: 0

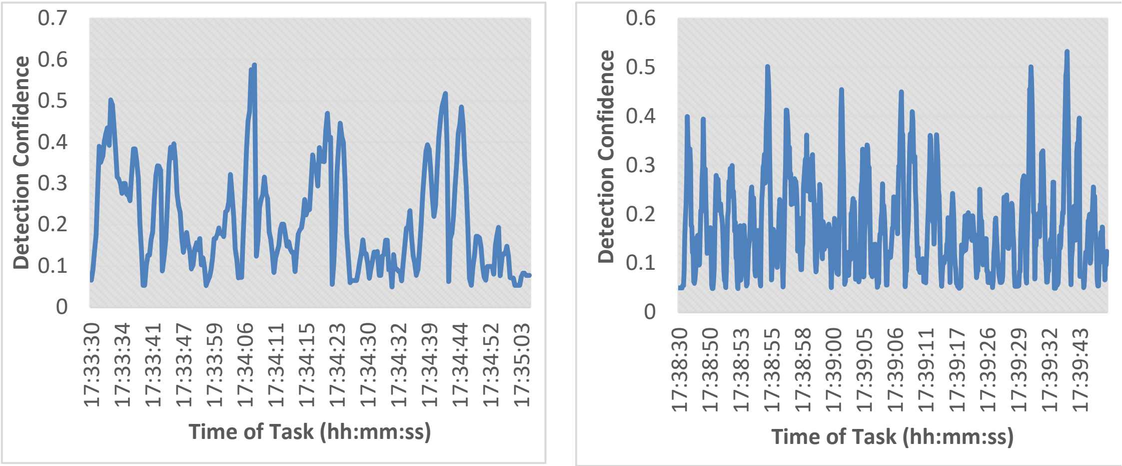
a. Hammering with arms away from the body

AngleLeftElbow 44.89 | LShoulder Good | RShoulder Good
AngleRightElbow 90.52 | RightWrist AWKWAI | LeftWrist AWKWARD
Angle S B Left 0 | SpineB RTR Good | SpineB RTL AWKWARD
Angle S B Right 0
AngleSpineBase 0

Discrete Gesture Basics

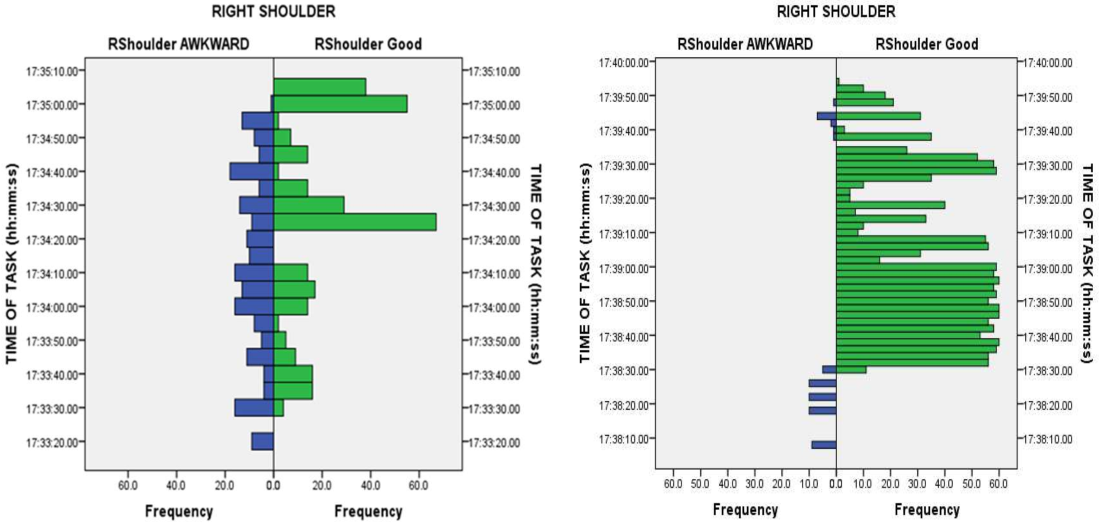
Body Index: 1 Hammering: False Confidence: 0

b. Close-body hammering



c. Confidence rate when arm is away from body

d. Confidence rate for close-body hammering



e. Posture assessment for arm away from body

f. Posture assessment for close-body hammering

Figure 7-27 Task detection versus posture assessment for participant 9

7.6 **Chapter Summary**

This chapter presents the validation of the developed real-time knowledge-based ergonomic evaluation and feedback system using 3 case studies. The case studies include a manual handling task involving a lifting, lowering and carrying task, a highly repetitive assembly task and a hammering task. The study was conducted to ascertain if the developed feedback can provide real-time feedback to operators concerning their ergonomic behaviour in terms of postural loading. Results of the study have proved that the developed system can provide real-time posture assessment feedback and effectively reduce the awkward work postures of operators by prompting them to adjust any awkward postures that can be detrimental to their health. The study has also highlighted some of the limitations of the system details of which will be discussed in the next chapter.

8 DISCUSSION AND CONCLUSION

This chapter presents the discussion of the major findings of this research and outlines the research outcomes and conclusions. The contributions of the research to knowledge are also provided and the study limitations are identified. Further work is proposed.

The focus of the chapter includes:

- Presentation of the research achievements.
- Description of the research contributions to knowledge.
- Discussion of the developed system's limitations.
- Presentation of future work.
- Conclusion.

8.1 Research Achievements

This research presents an ergonomic assessment system, which utilizes the knowledge extracted from the H&S definitions for awkward posture assessment, to develop a H&S-compliance system for real-time ergonomic assessment and feedback of worker's postures. By employing this system, human motion data is tracked by a 3D motion sensor, converted to posture data and assessed in real-time, with real-time feedback provided to the user, alerting him/her to adjust any awkward postures that can result in injuries.

The comprehensive review of related literature helped to identify research gaps which led to the formulation of research hypothesis and research objectives. To achieve these set objectives, relevant methodologies were adopted. The following summarises the achievement of each of the objectives:

- **Objective 1:** Data-retrieval and task-detection algorithms were successfully developed, as presented in chapter 4. These algorithms can enable the 3D sensor to track human skeletal data and detect manual handling tasks on the shop floor. Experiments to test the developed task detection algorithm, as presented in section 4.1.3, revealed successful manual handling task detection. The resulting application was successfully employed in section 4.2, to establish the best setup of the hardware for accurate data collection during real-time ergonomic evaluations. This helps to reduce measurement errors. Furthermore, the Kinect was successfully programmed in section 4.3 to track the human joint angles with real-time display in degrees. Experiment was conducted to test the capability of the developed program to track the joint positions of humans while working and to convert the same to joint angle data. The results, presented in section 4.3.2, shows that the developed data retrieval program can track joint angles of humans while working. This served as the preliminary algorithm on which the ergonomic assessment tool was built.

- **Objective 2:** The H&S recommendations on ergonomic evaluation of manual handling tasks and risk assessment of work postures are comprehensively studied in chapter 5, and the acceptable guidelines for manual handling and posture assessment were successfully extracted as presented in section 5.1. The identified definitions were successfully implemented in the development of the knowledge base of the proposed knowledge-based system as presented in section 5.3.
- **Objective 3:** The inference engine that constitutes the if-then-construct of the system, and form the reasoning structure of the KBS, was successfully developed in chapter 5. This engine provides the methodology which reasons about the knowledge in the knowledge base, and draws conclusion. Rules were used to incorporate the knowledge base and the engine to form a posture assessment tool of section 5.5. The tool, when tested on many volunteer participants, was found to be reliable and can automatically assess worker's postures in real-time, in compliance to the H&S definitions.
- **Objective 4:** The user interface of the system through which the user interacts with the system for effective real-time feedback of worker's posture assessment results was successfully designed and developed in chapter 6. The developed interface, achieved after several iterations, forms the final stage in the design of the KBS. The design started with the identification of the feedback interface's functional requirements as well as

the establishment of the system's external users using the HSE's recommendations. The detailed design, presented in section 6.2, was successfully achieved by modelling the usage requirements and the performance of the external users using the UML use case diagram, and the logic captured by the use case models using the UML activity diagrams. The system's widgets, successfully modelled with the information provided by the UML activity diagrams, was designed using the user interface flow diagram/storyboards. The development of the feedback interface was successfully achieved with the C# programming language. In the study, alternate feedback/display methods were explored with the voice alert feedback method recommended. There was successful demonstration of the developed feedback interface in section 6.3, on two case studies involving ten volunteer participants. The result of the system demonstration and participant's response is that an easy-to-use, easy-to-understand feedback system has been successfully developed.

- **Objective 5:** The developed KBS was successfully validated as fifteen volunteer participants tested the research hypothesis as presented in chapter 7. Results obtained from the experiment validates the hypothesis and shows that effective real-time feedback can be provided to workers using 3D imaging sensors. This feedback was found to effectively reduce the frequency of awkward postures adopted by the participants.

Finally, the aim of this research which is to develop a real-time knowledge-based ergonomic assessment system for use in the real-time evaluation of work postures on the shop floor and for provision of feedback to workers, using 3D motion sensors, has been achieved. Each of the research objectives were also successfully achieved in the work. These achievements will be further analysed based on the quality of the research work, generality and applicability of the developed system.

8.2 **Quality of Research**

To develop good quality feedback system that can assess worker's postures in real-time at reduced errors and increased efficiency, the system was developed in compliance with approved H&S guidelines. Hence, the knowledge base of the system was built with the data extracted from the H&S definitions and guidelines.

During the study, high quality of the research process was ensured by conducting tests at each stage of the research work and by carrying out full validation at the end.

8.2.1 **Ensuring the Quality of Research through Reduced Measurement Errors**

The research conducted in this thesis was motivated by the need to provide a real-time ergonomic assessment system which can assess worker's postures in such manufacturing systems as the FMS where immediate response to changes are highly beneficial. Such an assessment system should be easy-to-use, cost-effective and readily available. These requirements among other factors led to the choice of Kinect as the hardware component of the system. In the developed KBS, the hardware performs the function of data collection as well as posture assessment – all in real-time. This means that any measurement error will affect the quality of the posture assessment and consequently, the feedback. Hence, to ensure a high quality of measured data and effective posture assessment and feedback, the hardware component of the KBS is tested in several locations within its horizontal field of view to choose the best locations to place the sensor during real-time assessment. These locations, as presented in chapter 4, were implemented in all the case studies and demonstrations in this research, with the results showing quality data capture as reflected in the feedback to the operators.

8.2.2 **Assessment of the Quality of Research through Validation of the Developed System**

The developed real-time feedback system was initially demonstrated using two case studies, as presented in chapter 6, before the final validation. Three major case studies were implemented to validate the research which is the final stage in the achievement of the research objective. These cases, presented in chapter 7, tested the research hypothesis to ascertain if the developed system can provide real-time feedback of manual handling activities.

During the system demonstration and validation, the volunteer participants were asked to assess the quality of the developed system based on the following criteria; convenience, ease of use, ease of understanding of feedback, and the ability to provide real-time feedback. The human participant's assessment report of table 8-1, whose details are presented in Appendix C, shows that an average of 78% of the users found the system to be convenient and easy to use while 100% of the users found it to be sensitive to posture changes, thereby providing real-time feedback that effectively reduced awkward posture occurrence by either voice alert alone or a combination of voice alert and screen display. All the users assessed the feedback as easy to understand.

Table 8-1 Summary of participant's assessment report

S/N	Participant's Assessment Report (%)			
	System Capability	**System validation report (%)**	**System Demonstration (%)**	**Average (%)**
1	Convenience	87	70	78
2	Provision of real-time feedback	100	100	100
3	Effective awkward posture reduction	100	-	100
4	Easy to understand feedback	100	100	100
5	Voice alert feedback as the preferred format	100	-	100
6	Combined voice alert and screen display as the preferred feedback format	-	100	100
7	Easy to use	67	90	78

		(for scores of up to 4 & 5 in a 5-scale scoring system)	(for responses from easy to very easy)	
8	Sensitivity to posture changes	Very high (50), High (40)	-	100

Finally, based on the user's responses and on the fact that an average of at least 75% of users gave positive reports on each of the criteria, the author concludes that the developed system is convenient, sensitive, easy-to-use, with real-time easy to understand feedback which can effectively reduce awkward postures.

8.2.3 Generality of the Developed Posture Assessment Feedback System

In this section, we assess the generality of the research findings to applied settings. The methodology adopted in the research focuses on the development of a real-time ergonomic assessment feedback system for assessment of worker's postures during manual handling activities on the manufacturing shop floor. The findings show that the developed posture assessment KBS can assess the postures of workers and provide effective real-time feedback that can reduce the rate of occurrence of awkward postures.

The scope of this research focuses on shop floors that have the characteristics outlined in figure 8-1. Hence, the author strongly believes that the developed knowledge-based feedback is applicable in several industries such as manufacturing shop floors, medical field, agricultural sector, construction industries, sports fitness/training facilities and every other workplace where humans perform tasks. This claim is supported by the fact that the system has been successfully demonstrated on a study involving non-manual handling tasks when desk-based seated researchers were tested. The system was found to provide real-time feedback to the researchers. In the medical field, the developed system can be employed to assess the work postures of staff while performing tasks such as the lifting of patients. It can also be employed in the evaluation of patient's postures in real-time during physical activities in rehabilitation facilities (Dahmen et al., 2017). In agricultural sector, the system can be applied in the posture assessment of farmers.in construction industries where workers perform varieties of manual handling tasks, the system can find wide application in the assessment of worker's postures. In sports fitness/training facilities, the system can be applied on weightlifters as well as humans involved in health and fitness-related activities (Fritz et al., 2014), to enable them to correct awkward postures that can lead to injuries.

Again, there has been successful implementation of the Kinect by researchers for use in several workplaces which include the medical field (Alabbasi et al., 2016; Dave, Obeid and Tucker, 2014; Metzler, Kroschel and Willersinn, 2017; Noonan et al., 2016), aerospace sector (Daphalapurkar, 2012), industries and factories (Haggag et al., 2013; Martin et al., 2012), in the field (Dutta, 2012), agricultural sector (Marinello et al., 2015), and in construction industries (Khazaeli, Javadpour and Knapp, 2013).

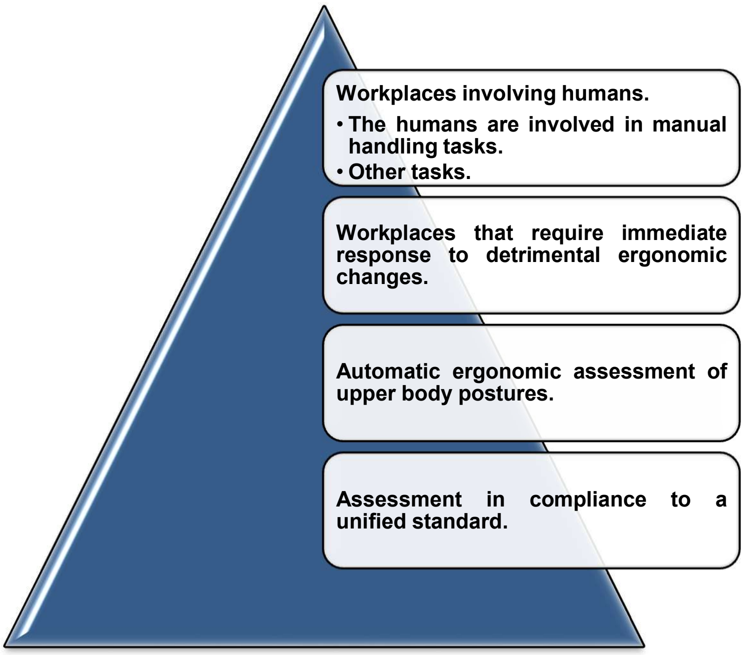


Figure 8-1 Focus of the research scope

Finally, this research has provided several workplaces with an effective and cost-effective ergonomic assessment feedback system. The author however, recommends further work to prove the successful implementation of the system in these workplaces.

8.2.4 Applications of the Developed Posture Assessment Feedback System

The knowledge-based feedback system developed in this research consists of a hardware component which is portable, cost-effective, readily-available and simple to use. It has the capability to effectively capture human motion data, automatically assess the postures and provide real-time feedback that can prompt workers to adjust awkward postures. Its users have described the system as easy-to-use, highly sensitive to posture changes, with feedback that is very easy to understand. The real-time feedback raises alarm whenever workers adopt critical postures that can lead to injuries.

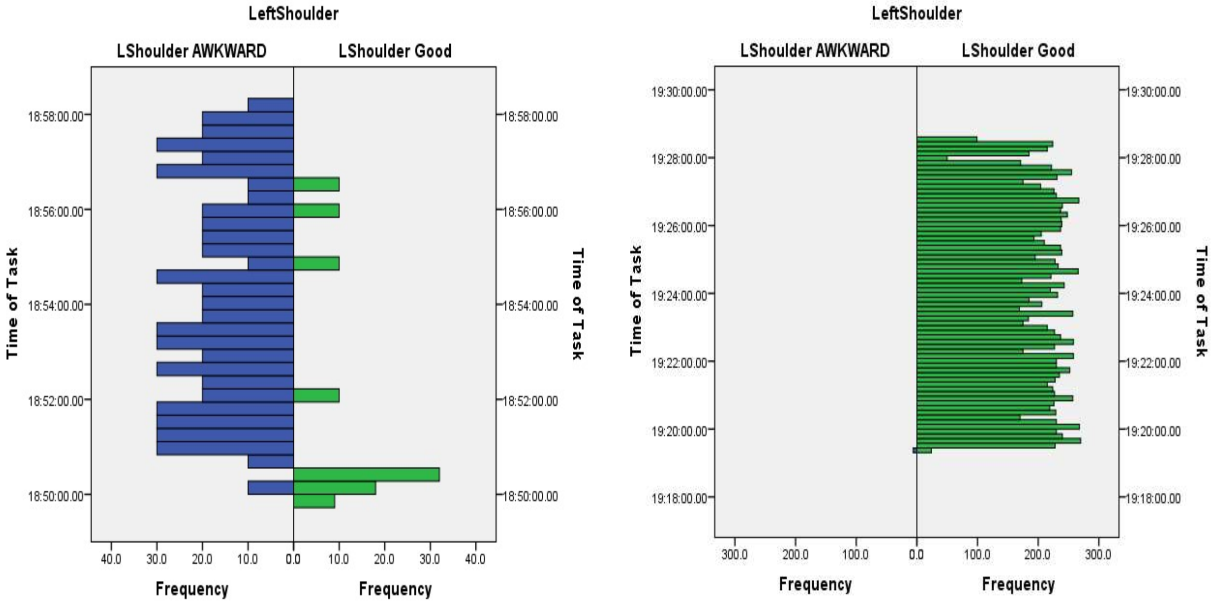
The applications of the system are briefly outlined thus:

- **Correction of Worker's Postures in Workplaces.**

The system is useful as it overcomes the currently and widely used observation methods in which data is captured with video-based systems and assessed afterwards.

This system, which can alert workers to adjust awkward postures in real-time, can be applied in any workplace where humans perform tasks that can force them to adopt awkward postures. The voice alert as well as the screen display feedback is developed such that even novice operators can understand it.

Figure 8-2 depicts the result of the left shoulder posture assessment of an operator, during an assembly task. In the figure, frequency represents the rate of occurrence of postures while the time of task is the time the task is performed corresponding to the time of capture. Figure 8-2a shows the result obtained as the operator performed the task without feedback while figure 8-2b portrays the assessment as real-time feedback was provided. In 8-2b, we see how the worker's posture was corrected by the alarm raised at the beginning of the task. This prompt made the operator to adjust to good posture and consciously maintain the good posture for almost 100% of the task duration. However, in 8-2a, the operator started with good posture but adjusted to awkward postures and held the awkward postures for long period of up to 86% of the task duration. This is because no feedback was provided to correct this worker's posture and this can lead to muscles strains and consequently, WMSDs.



a. Without Feedback

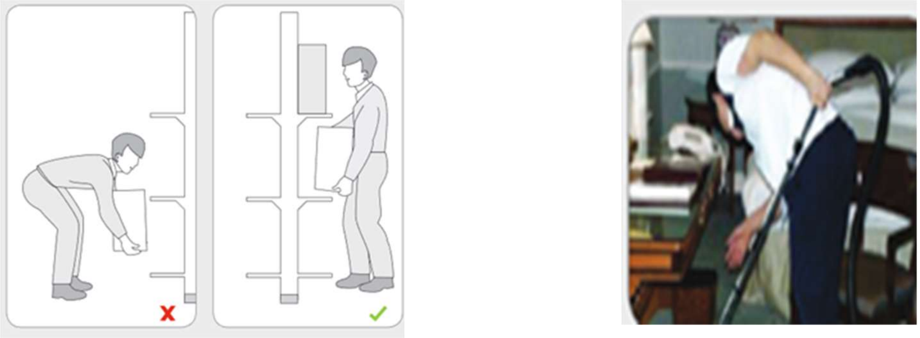
b. With Real-time Feedback

c. Participant performing assembly task

Figure 8-2 Corrected Left Shoulder Posture of an Operator

- **Re-Design of Workplaces.**

One of the capabilities of the developed feedback interface of the system is to report any ergonomically unacceptable issues that may arise in workplaces. This is achieved by using the Help menu button or the Reports menu button. These unacceptable issues, as identified by the international H&S regulators, include workspace constraints and unsuitable shelving (Health and Safety Executive, 2016; WSH (Workplace Safety and Health) Council, 2014). They are presented in figure 8-3.



a. Acceptable and unacceptable shelving (adopted from WSH Council, 2014)

b. Constrained workspace (adopted from WSH Council, 2014)

Figure 8-3 Workplace ergonomic issues

Constrained workspace makes it difficult for operators to manoeuvre loads while executing tasks and may force them to adopt awkward postures as seen in figure 8-3b. Unsuitable shelving often forces the workers to either bend their backs or overstretch their arms inappropriately thereby adopting awkward postures as shown in 8-3a. A study of the causes of these awkward postures, as alerted by the system, can inform the management to re-design the workplace to minimise the rate of occurrence of awkward postures.

- **New product Design.**

Hand tools if not ergonomically designed, can force the user to adopt awkward postures of the arm and wrists as shown in figure 8-4.

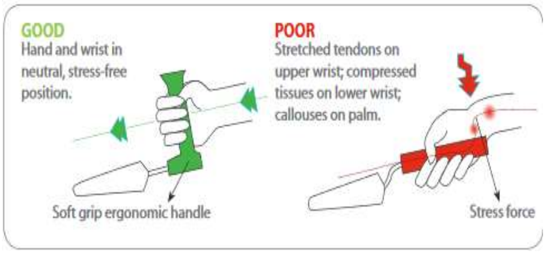


Figure 8-4 Acceptable and unacceptable hand tools (adopted from WSH Council, 2014)

The developed system can detect these awkward postures and provide real-time feedback to the user on the postures. This information can be useful during the design stage of a new tool and can inform designers on the best design specifications that produce ergonomic tools.

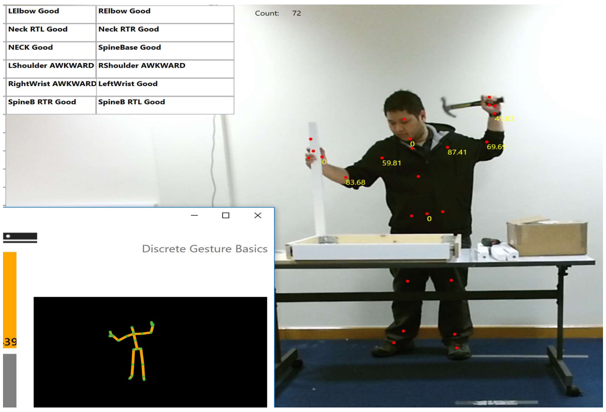
- **Accident Prevention.**

H&S regulators recommend ergonomic intervention as the best preventive strategy to injuries among workers in wrokplaces as it helps to identify and reduce the risk of exposure of the workers. The developed system is suitable for effective ergonomic interventions as it will help the workers and their employers detect awkward postures in time thereby preventing possible accidents and injuries in the workplace.

Finally, the developed system has demonstrated its ability to automatically assess work postures and provide real-time feedback to its users during the execution of varieties of tasks, as demonstrated in chapters 6 and 7. This shows great pottentials for industries and can serve as suitable replacement to the current widely used observation method which is time-consuming with offline feedback that is provided after the injuries have occurred.

8.3 Contribution of the Study to Knowledge

This research focuses on the provision of real-time feedback to workers. In the work, Kinect is made to detect tasks for use in real-time ergonomic assessment purposes. Task detection is significant as it serves as control mechanism to help the user of the system to ascertain if his/her task will be completed correctly as well as inform him/her on the best location to place the sensor for reduced measurement errors. Figure 8-5 depicts a user whose task is detected in real-time with feedback provided.



LElbow Good	RElbow Good
Neck RTL Good	Neck RTR Good
NECK Good	SpineBase Good
LShoulder AWKWARD	RShoulder AWKWARD
RightWrist AWKWARD	LeftWrist Good
SpineB RTR Good	SpineB RTL Good

Count: 72

Figure 8-5 Task detection by the developed system

The contributions of the research are in three sub-areas and include:

i. **Development of a real-time tool for H&S compliant assessment using motion sensors.**

This research presents the development of a Kinect-based expert system that extracts data from a knowledge built with rules collected from H&S database. This ensures more accurate ergonomic work posture assessment in accordance with acceptable H&S guidelines. For the first time, an expert system, which utilizes H&S rules to build a knowledge base for real-time ergonomic assessment using 3D motion sensors, is developed.

ii. **Development of a knowledge-based real-time feedback system for improved assessment.**

In the research, a knowledge-based system with knowledge extracted from H&S database, inference engine which reasons on the knowledge and draws conclusion, interface through which the user interacts with the system, and a hardware based on Kinect, was successfully developed and implemented. This is the first of its kind.

iii. **Provision of real-time feedback to alert workers in time.**

The KBS developed in this research assesses work postures and provides real-time feedback that alerts the workers to adjust awkward postures in time. These awkward postures if held for prolonged periods, can result in injuries and losses. Consequently, a system that can assess worker's postures in real-time and provide real-time feedback to prompt the workers to adjust awkward postures that may be detrimental to their health is highly beneficial in workplaces. Such system, as developed in this research, can help to reduce costs and increase efficiency and productivity in workplaces.

8.4 **Novelty of Research**

The novelty of this research is in the development of a knowledge-based system for real-time ergonomic assessment and feedback to workers using 3D motion sensors. The research provides workplaces with the following:

- An effective real-time feedback system that can prompt operators to adjust awkward postures during flexible manufacturing operations (Gap 1).
- An expert system that utilizes H&S rules to build a knowledge base for ergonomic assessment. Hence, a H&S-compliant ergonomic assessment knowledge-based system has been developed for immediate correction of awkward work postures (Gap 2).
- A cost-effective, easy-to-use and affordable system for automatic H&S compliance assessment of postures using 3D motion sensors (Gap 3).
- An ergonomic assessment tool that can detect manual handling tasks for reduced assessment errors during real-time assessment (Gap 4).

The research outcome has revealed that the gaps identified from comprehensive literature review are successfully bridged by the developed real-time feedback system.

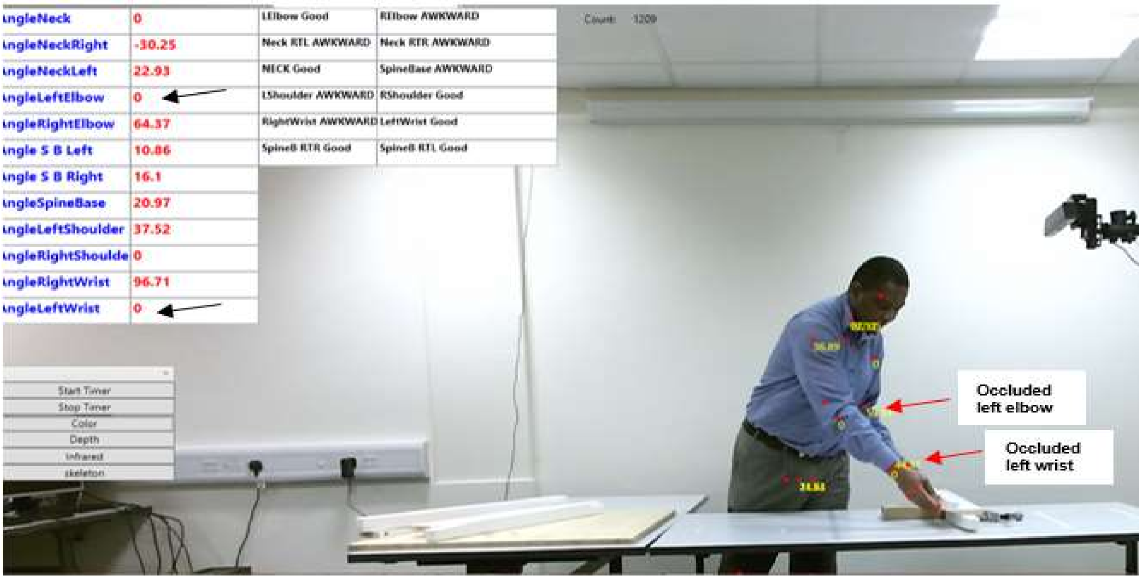
8.5 **Study Limitations**

In this section, the limitations of the developed system are presented. The main limitations of the system developed in this research lies in the hardware component which is Kinect-based and in the scope of the study which is limited to the ergonomic assessment of only the back and upper limbs of the human body.

8.5.1 **Limitations Posed by the Hardware**

- **Occlusions**

Occlusion occurs when a part of the body is covered making it difficult for the sensor to track it as the Kinect usually cannot track any part of the body that is covered. Generally, the Microsoft Kinect can only track humans who are within the field of view, facing the sensor. The load handled as well as the worker's body can cause occlusion during real-time ergonomic assessment using the system. The effect of occlusion is tested on two participants while performing two different tasks. The operator shown in figure 8-6 is seen lifting and carrying some load while twisting his body. Because of the twist, the left wrist and elbow, which were obviously bent but covered from the sensor by the right side of the body, are found to display '0' angle values and consequently, 'Good' posture update. This means that any occlusion will affect the accuracy of the posture assessment.



ngleNeck	0
ngleNeckRight	-30.25
ngleNeckLeft	22.93
ngleLeftElbow	0
ngleRightElbow	64.37
ngle S B Left	10.86
ngle S B Right	16.1
ngleSpineBase	20.97
ngleLeftShoulder	37.52
ngleRightShoulde	0
ngleRightWrist	96.71
ngleLeftWrist	0

LElbow Good	RElbow AWKWARD
Neck RTL AWKWARD	Neck RTR AWKWARD
NECK Good	SpineBase AWKWARD
LShoulder AWKWARD	RShoulder Good
RightWrist AWKWARD	LeftWrist Good
SpineB RTR Good	SpineB RTL Good

Count: 1209

Occluded left elbow

Occluded left wrist

Figure 8-6 Occlusion because of blockade by part of operator's body.

Similarly, the operator represented in figure 8-7 had part of his arm covered by the load he was handling which in this case is the table. The effect of the occluded arm when viewed from the task detection application, showed the body part that is covered by the table.

a. Operator hammering a table

b. Detection application showing occluded arm

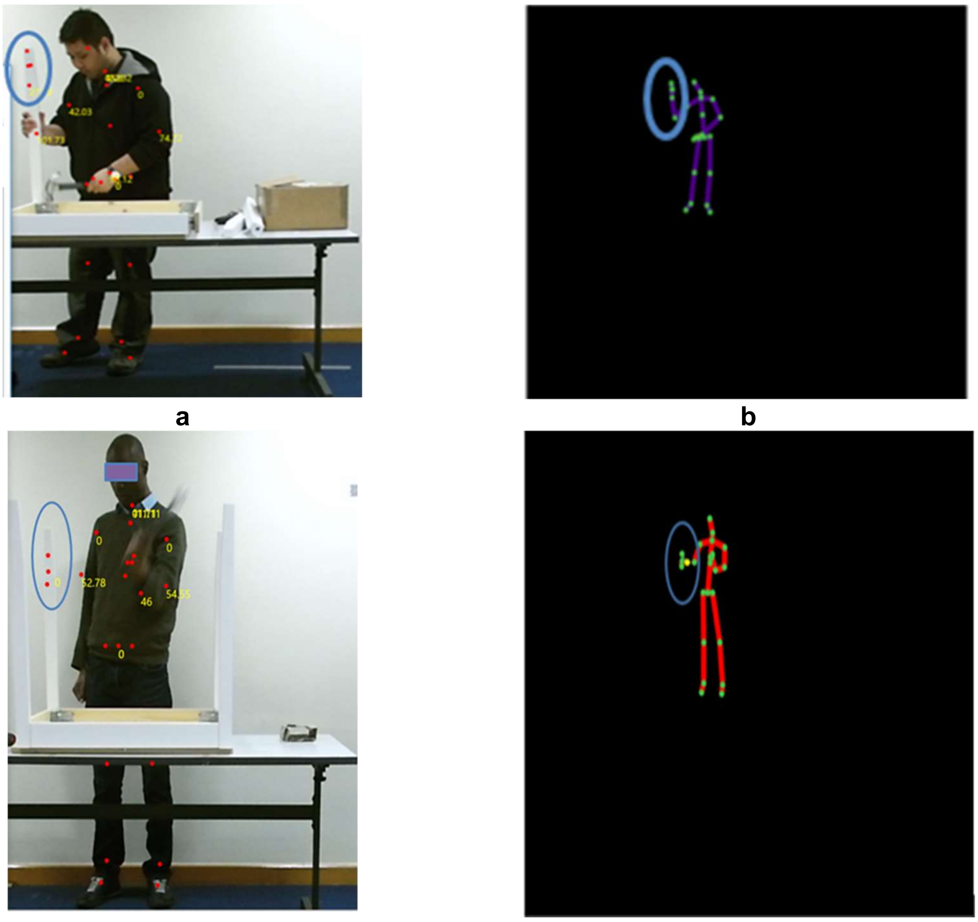
Figure 8-7 Occlusion caused by load.

These results show that any occlusion will affect the accuracy of the posture assessment. Hence, for better posture assessment using the tool, the workplace should be free of any occlusion and the operators should ensure that no part of their body is covered. The use of multiple sensors in the workplace is also recommended but care should be taken to avoid interferences from the infrared.

- **Misclassification of Human Joints**

Kinect sometimes misclassifies human joint data in a behaviour that may generate inaccurate data for real-time ergonomic assessment. Examples of such miscalculations are represented in figures 8-8 and 8-9 in which 3 different operators performing manual handling tasks, are shown.

In figure 8-8a, the operator initially had his hand on the upper part of the table leg, but later moved the hand to the middle. However, the sensor continued to track the original position of his hand as depicted by the detection application of 8-8b. Similar result was obtained from the operator on 8-8c, whose hand was by his side but the sensor still tracked his initial hand position as shown in 8-8d.

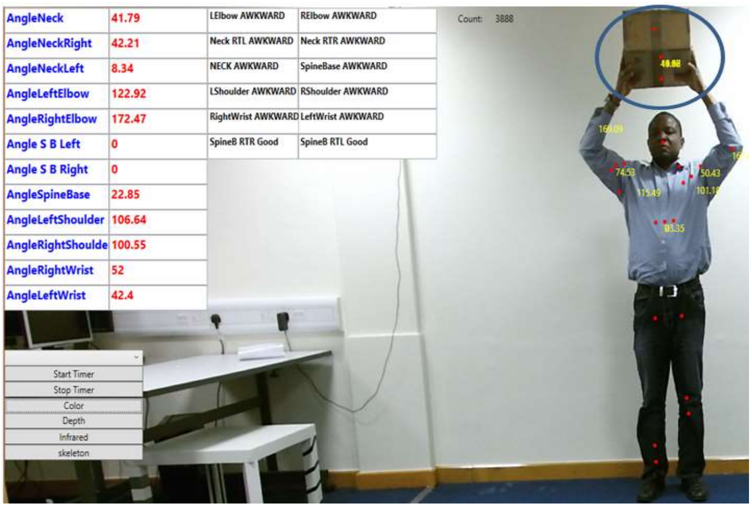


a b

c d

Figure 8-8 Misclassification by Kinect during a hammering task

The misclassification was also observed in scenario where the operator’s hand was not originally placed. Figure 8-9 shows an operator lifting a load above shoulder height. In the captured frame, we see that Kinect was tracking the load and confusing it to be the operator’s head and neck.



AngleNeck	41.79
AngleNeckRight	42.21
AngleNeckLeft	8.34
AngleLeftElbow	122.92
AngleRightElbow	172.47
Angle S B Left	0
Angle S B Right	0
AngleSpineBase	22.85
AngleLeftShoulder	106.64
AngleRightShoulde	100.55
AngleRightWrist	52
AngleLeftWrist	42.4

LElbow AWKWARD	RElbow AWKWARD
Neck RTL AWKWARD	Neck RTR AWKWARD
NECK AWKWARD	SpineBase AWKWARD
LShoulder AWKWARD	RShoulder AWKWARD
RightWrist AWKWARD	LeftWrist AWKWARD
SpineB RTR Good	SpineB RTL Good

Count: 3888

Figure 8-9 Misclassification by Kinect during a lifting task

This behaviour is clearly a hardware limitation which can produce inaccurate joint data and consequently, wrong posture assessment feedback.

- **Narrow Field of View for Wider Applications**

Another limitation of the Kinect is its narrow horizontal field of view of 70° and vertical field of view of 60°, with the maximum depth distance of 4.5m. This field of view is narrow and may hinder posture assessment in large workplaces as it is likely to restrict operator's movement and task execution. Further research aimed at studying a cost-effective way of increasing the sensor's field of view without affecting the quality of posture assessment, is recommended.

8.5.2 Limitations Posed by the Scope of the Research

The following are the limitations of the system based on the scope of the research.

- The scope of the research is limited to only the joints of the upper human body. This means that the lower limb joints are not assessed by the developed system.
- The study is limited to manual handling activities such as lifting, lowering, carrying and assembly, with the knowledge base built with data extracted from manual handling definitions.
- There is lack of industrial deployment of the system as all the tests and validation studies carried out on the developed system has been done in a controlled laboratory environment. Hence, system implementation is limited to laboratory and not industrial environment.
- Again, the scope of this study is limited to only the assessment of awkward postures as an ergonomic risk factor. Other risk factors such as high-task repetition and forceful exertion, are not assessed by the developed system.

Finally, despite these limitations posed by the hardware component of the KBS as well as the research scope, the system is affordable, readily available, highly convenient, very sensitive to posture changes and simple. The claim is supported by the participant's responses after they used the system. Again, the system is in-compliance with international H&S guidelines on manual handling.

8.6 **Future Work**

Further work is recommended on the developed feedback system to make it more robust and suitable for use in wider range of scope.

- **Increase the hardware's field of view**

One major limitation of the Kinect sensor that can make it difficult for the developed system to be employed in engineering applications, is its narrow field of view. The author therefore recommends further research on possible ways of increasing the sensor's field of view to allow for wider applications of the posture assessment system.

- **Use multiple Kinect sensors during real-time assessment**

Future work should consider using multiple Kinect sensors to reduce the effects of occlusion as well as increase the field of view during real-time assessment in workplaces. However, this is greatly plagued by possible overlapping of the field of views as well as interference from the infrared emitters of the different sensors which can greatly affect the quality of the posture assessment. This therefore calls for more research.

- **Application in real workplaces**

Several cases were employed to test the capabilities of the developed system. These cases are such that are seen in a typical shop floor and workplaces. However, the experimentation was conducted in controlled environment and not in real workplaces. The author therefore recommends further testing and validation of the system in real workplaces.

- **Address more ergonomic risk factors**

The feedback system is developed to assess work posture which is only one of the many ergonomic risk factors that can lead to WMSDs. Since, the system has been developed to detect manual handling tasks in real-time, the author recommends further work to develop the system to assess risks posed by high task repetition.

- **Address the assessment of awkward postures of the lower limb**

Future work is recommended for the system to be developed further to assess work postures of the lower limb of users. This is important because the lower limb postures, if held awkward for prolonged periods, can lead to injuries and WMSDs.

- **Autonomous system**

Future studies should consider converting the developed KBS into a web-based autonomous system within an organisation. This will enable the employers and H&S representatives to effectively manage risks in the workplace.

8.7 Conclusion

Competition and uncertain demand has led many industries to adapt high flexibility in all stages of its production planning and control. Such industries require built-in flexibility to take care of the sudden changes that may arise. These industries, which still depend on manual handling of some crucial tasks to reach their set target despite the high level of automation, are obliged to prevent ergonomic risks that may arise in the workplace by identifying, assessing and reducing the risks involved in any manual handling operation, using adequate and effective ergonomic intervention tools. This is because injuries associated with prolonged manual handling activities often affect the upper limbs, lower limbs and spine of the human body and leads to WMSDs which negatively impact on the efficiency and productivity of any workplace. This disorder, which affect the musculoskeletal system such as muscles and tendons and greatly limits the worker’s health, is caused by ergonomic risk factors such as awkward postures.

Presently, awkward posture assessment in workplaces are normally carried out by observing several operations and carrying out analysis afterwards. Although some improvements have been identified for the operations, such assessment cannot alert operators and prevent them from adopting awkward postures in time.

Hence, a system that can meet the challenges posed by awkward postures of workers on shop floors where immediate response to system change is needed is the interest of this research. The system should be such that can conduct a real-time automatic ergonomic posture assessment with real-time feedback to workers to help alert them to adjust awkward postures in time

The aim of this research is to develop a real-time knowledge-based ergonomic assessment system for use in the real-time evaluation of work postures on the shop floor and for provision of feedback to workers, using 3D motion sensors. The research achieves the development of the H&S-compliant system by extracting the relevant manual handling guidelines from H&S database to build the knowledge base of the KBS. The system can track humans, capture the motion data, convert it to posture data and assess this data using the knowledge in the knowledge base and the reasoning from the inference engine. The developed system can also provide effective real-time feedback that can inform workers when to adjust awkward postures. The feedback is provided to users through a well-developed, flexible and interactive user interface through which the users interacts with the system. In addition to the awkward posture assessment, the developed system can also detect manual handling tasks which can help to reduce measurement errors as well as indicate possible occlusions that may affect posture assessment. The tool's ability to capture data consistently, has been proved through a reliability and reproducibility assessment.

The developed feedback system was successfully demonstrated during assembly tasks as well as desk-based reading by some volunteer participants. It was also successfully validated on three case studies with different manual tasks. The findings from these studies reveal that an automatic, easy to use and convenient ergonomic posture assessment system, which can assess worker's postures in real-time and provide real-time feedback to them, has been successfully developed.

The research contributes to knowledge by providing real-time feedback to workers to help them reduce the rate of occurrence of awkward postures while working. This contribution is in three sub-areas namely: i) development of a real-time tool for H&S compliant assessment. ii) development of a knowledge-based real-time feedback system for improved work posture assessment. iii) provision of real-time feedback to alert workers in time.

The novelty of this research is in the development of a knowledge-based system for real-time ergonomic assessment and provision of feedback to workers using 3D motion sensors. No previous research has developed a Kinect-based intelligent system for real-time H&S-compliance assessment of work postures with real-time feedback that can prompt workers to adjust awkward postures in time. This was addressed in this research.

This real-time feedback is beneficial in industries where immediate change to awkward postures are required so as reduce the rate of occurrence of injuries and increase workplace efficiency and productivity.

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Appendix A : Consistency of the Results generated by the System

After the development the posture assessment tool, two types of tests were conducted to evaluate the quality of the developed tool for consistency in measurement. Hence, reliability and reproducibility tests were employed for the evaluation.

Reliability Tests

Reliability test is a measure of the degree to which the data measured with an instrument yields the same result on repeated trials (Carmines and Zeller, 1979).

There are different approaches to reliability estimation. These include (https://web.cs.dal.ca/~anwar/ds/Lec3.pdf):

- Test-Retest reliability which involve repeating a test over two points of time with the same instrument.
- Equivalent-form reliability which involves using two forms of results from the same instrument.
- Internal consistency reliability which involve testing the degree of consistency in the data measured by an instrument. It considers neither time nor form.

In this research, the internal consistency reliability was employed to test the consistency of data measured by the developed tool. This was evaluated using the Cronbach's alpha, denoted by the symbol α. The Cronbach's alpha, which is a measure of internal consistency of measured data, was selected for this statistical analysis because it has been proved to be more versatile and suitable for testing the closeness of association among data measured by instruments under reliability conditions (Carmines and Zeller, 1979; Padilha, Gallani and Colombo, 2004). The Cronbach's alpha scores ranges from 0 to 1 with values closer to one signifying higher internal consistency and values closer to zero indicating lower internal consistency (Brckalorenz et al., 2013). Hence, $\alpha \geq 0.9$ signifies excellent internal consistency, $0.9 > \alpha \geq 0.8$ shows good internal consistency, 0.8 > α ≥ 0.7 indicates acceptable internal consistency, 0.7 > α ≥ 0.6 indicates questionable internal consistency, 0.6 > α ≥ 0.5 signifies poor and 0.5 > α indicates unacceptable internal consistency.

An internal consistency test conducted on the data measured with the developed tool on the same volunteer participant during a lifting task involving the same load, performed in the same workplace, and repeated 30 times, yielded a Cronbach’s alpha of 0.978. This indicates that there is excellent internal consistency among the data generated by the developed tool. The data is represented on table A-1.

Table A-1 Data captured from a single operator under reliability conditions

Right Wrist	Right Shoulder	Left Shoulder	Spine Base	Spine Base	Spine Base	Right Elbow	Left Elbow	Neck Left	Neck Right	Neck
0	123.31	120.8	0	0	0	62.14	64.78	0	-7.7	0
0	81	50.04	25.92	11.56	0	90.99	59.46	0	9.91	38.11
27.83	87.78	43.25	16.22	-10.32	15.12	73.12	78.4	0	34.26	49.69
145.28	95.23	95.98	0	0	0	83.94	171.3	0	-6.13	28.52
46.8	101.22	107.22	0	0	0	66.75	166.69	0	-7.34	0
52	100.55	106.64	22.85	0	0	172.47	122.92	8.34	42.21	41.79
0	80.62	85.05	0	0	0	72.58	67.73	-22.85	0	-18.16
28.16	104.82	107.18	0	0	0	154.61	55.58	0	-4.17	0
0	96.69	96.29	0	0	0	78.41	58.72	-31.12	-19.43	48.14
49.74	97.62	104.06	0	0	0	64.73	55.79	-22.38	-11.28	24.42
20.52	60.4	66.35	23.05	0	0	91.24	80.92	-31.33	16.38	37.78
78.31	104.12	101.49	0	0	0	59.73	46.25	0	-4.29	-12.02
42.53	100.94	106.3	0	0	0	170.4	57.59	0	-8.92	0
0	79.02	46.36	14.73	0	0	83.05	63.02	-48.83	-9.38	45.15
0	50.07	32.5	21.48	0	11.4	30.33	0	0	6.93	51.81
0	104.53	106.58	22.27	0	0	55.25	57.03	25.52	32.07	25.53
0	104.53	106.58	22.27	0	0	55.25	57.03	25.52	32.07	25.53
55.34	26.95	35.78	20.9	0	0	39.91	0	-39.86	-34.3	41.05
44.76	32.79	91.46	24.78	0	0	40.39	151.04	18.12	0	26.29
64.71	34.07	113.53	26.38	15.36	0	35.4	157.56	4.78	0	12.53
121.8	121.06	45.25	19.68	0	0	157.22	31.34	-37	29.9	54.24
42.54	44.91	112.24	22.96	0	0	62.7	133.36	0	0	48.18
30.04	126.6	148.52	24.5	0	0	161.16	142.84	22.59	11.07	54.19
34.25	29.2	92.01	19.05	0	0	58.34	73.57	5.76	12.59	46.46
63.14	31.31	31.85	24.73	0	0	39.42	47.25	0	0	56.48
75.4	41.24	122.1	22.9	0	0	40.78	139.88	30.55	5.93	39.73
33.18	38.56	126.77	21.64	0	0	61.7	144.87	6.49	-4.32	40.6
22.27	45.76	111.49	21.15	0	12.7	70.28	161.89	6.57	20.47	30.41
97.61	31.45	116.52	13.99	0	0	30.86	74.31	8.42	-30.96	51.83
42.67	50.97	54.72	24.11	0	-17.38	64.62	61.11	-62.96	6.3	49.62

Tests Joints	Left Wrist
Test 1	0
Test 2	53.38
Test 3	21.39
Test 4	45.15
Test 5	43.44
Test 6	42.4
Test 7	63.16
Test 8	41.83
Test 9	156.47
Test 10	156.79
Test 11	58.45
Test 12	152.75
Test 13	43.66
Test 14	0
Test 15	0
Test 16	47.58
Test 17	47.58
Test 18	42.78
Test 19	0
Test 20	41.77
Test 21	137.45
Test 22	0
Test 23	66.53
Test 24	63.75
Test 25	54.51
Test 26	49.38
Test 27	78.08
Test 28	0
Test 29	22.16
Test 30	32.63

Reproducibility Tests

Reproducibility test is a measure of the closeness of association between the data measured with the instrument, under different conditions (Taylor and Kuyatt, 1994). To evaluate the performance of the tool, reproducibility tests were carried out to ascertain if there is agreement in the data measured by the instrument when different volunteer participants wearing different clothes perform different tasks on different workstations. The measured data, captured from 16 different operators on different workplaces (W), is tested for closeness of association using the SPSS Friedman Chi-square estimator. This gave a Kendall’s coefficient of concordance value of 0.634, indicating moderate closeness of association between the measured data.

The outcome of these tests indicates some level of agreement in the data measured by the tool. Therefore, we conclude that the tool is consistent in its measurement. Table A-2 shows the data employed for the reproducibility assessment.

Table A-2 Data captured from sixteen different operators under reproducibility conditions.

TIME STAMP	ACTIVITY	WORKPLACE ID	NECK	RIGHT WRIST	LEFT WRIST	SPINE BASE	RIGHT ELBOW	RIGHT SHOULDER	NECK RIGHT	NECK LEFT	LEFT SHOULDER	LEFT ELBOW	S B RIGHT	S B LEFT
17:47:35	Lifting & lowering	Workplace 31	33.83	0	31.36	55.56	48.57	39.38	-14.96	0	42.47	39.93	18.63	21.43
13:33:45	Lifting product	Workplace 33	20.31	43.42	148.32	0	64.9	0	0	-21.57	0	60.82	0	0
13:54:13	Carrying load	Workplace 13	98.63	168.35	155.2	85.85	163.99	119.83	134.2	116.12	115.79	159.72	86.17	91.18
15:44:37	Sitting to pick	Workplace 14	0	11.17	18.49	3.58	97.31	9.63	0	9.71	37.49	88.62	12.05	8.11
00:16:52	Carrying towels	Workplace 15	109.86	10.3	91.31	114.16	47.34	132.39	126.34	94.79	110.68	91.78	74.2	70.2
14:25:26	Sitting to handle	Workplace 19	94.05	156.65	168.06	85.74	117.35	129.54	118.53	119.59	140.4	163.94	90.62	90.83
14:16:47	Assembly of valves	Workplace 20	141.98	172.15	152.21	126.95	147.82	79.1	118.48	116.65	106.97	137.35	73.88	76.86
14:43:05	Sitting to lift	Workplace 25	32.92	70.14	86.64	57.95	146.22	0	21.12	0	12.55	16.07	16.49	18.09
15:17:44	Assembly of valves	Workplace 23	114.06	80.38	112.24	83.94	28.14	114	91.92	127.71	157.56	25.12	90.44	96.98
15:07:06	Sitting to lift	Workplace 24	84.18	0	86.16	79.01	116.43	123.45	122.46	130.53	113.34	50.23	96.01	88.46
16:29:40	Lifting & lowering	Workplace 28	11.45	0	65.08	-12.44	31.32	0	-15.12	0	0	59.79	0	0
13:48:45	Carrying load	Workplace13	54.22	40.22	77.93	58.13	35.99	7.84	-15.55	-90.36	14.56	42.07	23.01	34.63
15:47:11	Pushing trolleys	Workplace 16	21.57	27.21	57.04	0	19.35	44.7	57.98	58.8	50.59	0	0	0
14:19:19	Pushing trolleys	Workplace 17	96.92	173.57	153.94	84.43	161.64	119.97	144.9	100.05	114.91	89.86	86.94	89.89
12:15:29	Carrying towels	Workplace 15	13.13	27.84	56.72	0	74.89	27.63	-9.82	-14.82	5.58	75.94	11.18	0
15:01:47	Carrying load	Workplace 13	13.19	49.06	62.14	19.63	65.49	30.07	7.81	-26.79	0	49.03	11.2	13.59

Appendix B Initial demonstration of the Feedback System

A human-machine feedback interface whose function is to display the assessed postures of workers in real time, was designed and implemented in chapter 6 of this thesis. The developed interface completes the posture assessment KBS, and with the aid of the Kinect sensor, the resulting KBS enables ergonomic posture analysis of the operator with real-time display which prompts its users to adjust any awkward posture that may occur while working.

The developed feedback interface of chapter 6 was incorporated with the posture assessment tool of chapter 5 using appropriate rules in form of codes, to produce the KBS. The developed KBS was demonstrated on ten (10) participants and results obtained showed real-time posture analysis and feedback to workers. The generality of the system for use in other workplaces involving non-manual handling tasks, was tested on desk-based seated researchers. The system also provided real-time feedback to the researchers, showing that it can find wide application in varieties of industries.

The volunteer participants were given a participant's response form to fill and their responses are summarised on tables B-1 and B-2.

Table B-1 Researcher's Responses to the feedback system's performance

PARAMETER	**RESEARCHER 1 (MALE)**	**RESEARCHER 2 (MALE)**	**RESEARCHER 3 (MALE)**	**RESEARCHER 4 (FEMALE)**
Age	30	34	35	25
Set-up Time including new task registration time (s)	32	30	37	39
Is the system convenient to use?	Yes [✓ No] Maybe	[✓ Yes] No Maybe	[✓ Yes] No Maybe	[✓ Yes] No Maybe

Ease of Use	[✓ Very Easy] Easy Difficult	[✓ Very Easy] Easy Difficult	Very Easy [✓ Easy] Difficult	Very Easy [✓ Easy] Difficult
Is the system easy understand?	[✓ Very Easy] Easy Difficult	[✓ Very Easy] Easy Difficult	[✓ Very Easy] Easy Difficult	[✓ Very Easy] Easy Difficult
Was real-time feedback provided concerning awkward postures?	[✓ Yes] No Maybe	[✓ Yes] No Maybe	[✓ Yes] No Maybe	[✓ Yes] No Maybe
Which feedback format did you find easier to understand?	Voice Alert only Screen display only [✓ Both by voice alert and screen display]	Voice Alert only Screen display only [✓ Both by voice alert and screen display]	Voice Alert only Screen display only [✓ Both by voice alert and screen display]	Voice Alert only Screen display only [✓ Both by voice alert and screen display]

Table B-2 Operator's responses to the feedback system's performance

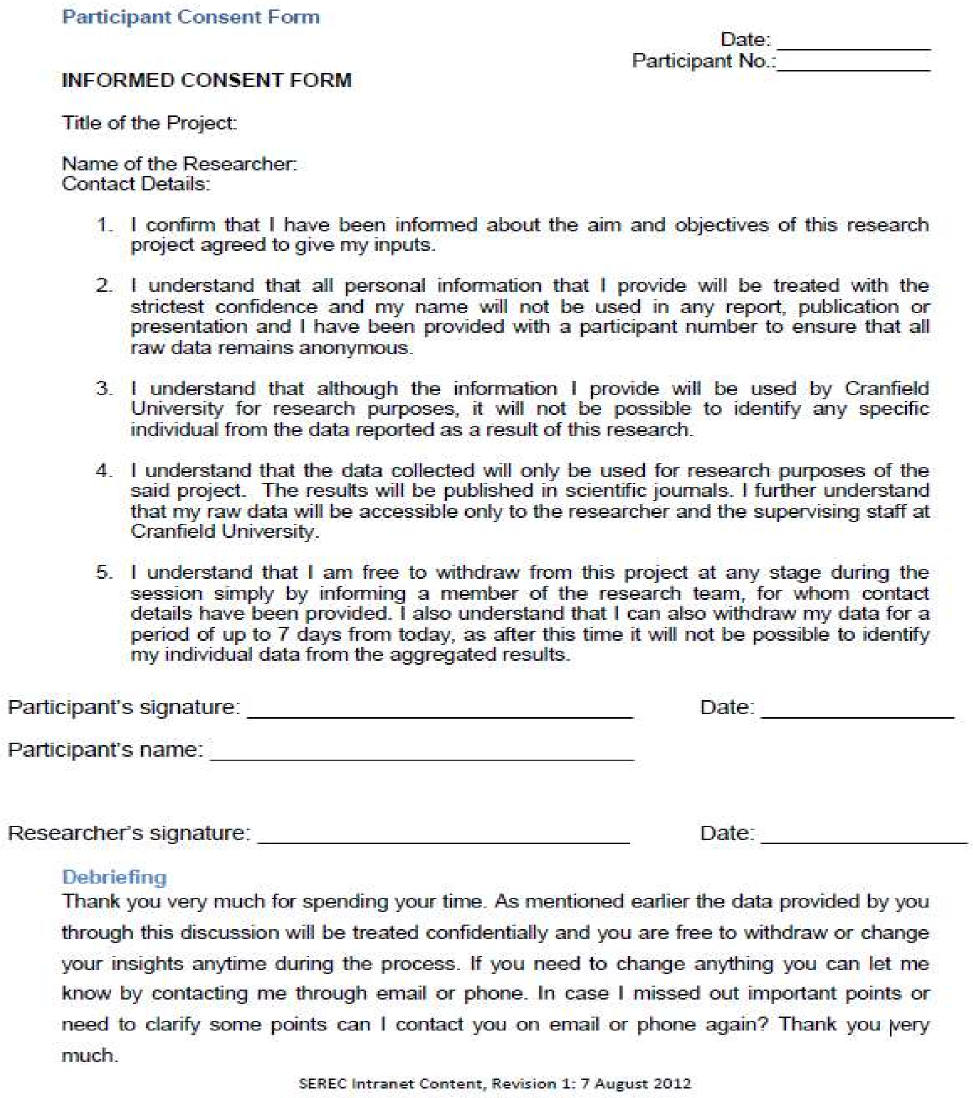
PARAMETER	OPERATOR 1 (FEMALE)	OPERATOR 2 (MALE)	OPERATOR 3 (FEMALE)	OPERATOR 4 (MALE)	OPERATOR 5 (MALE)	OPERATOR 6 (FEMALE)
Age	28	35	29	30	40	55
Set-up Time	38	30	31	32	30	37
Is the system convenient to use?	[✓ Yes] No Maybe	[✓ Yes] No Maybe	[✓ Yes] No Maybe	Yes [✓ No] Maybe	[✓ Yes] No Maybe	Yes No [✓ Maybe]
Ease of Use	[✓ Very Easy] Easy Difficult	[✓ Very Easy] Easy Difficult	[✓ Very Easy] Easy Difficult	Very Easy [✓ Easy] Difficult	[✓ Very Easy] Easy Difficult	Very Easy Easy [✓ Difficult]
Is the feedback from the system easy to understand?	[✓ Very Easy] Easy Difficult	[✓ Very Easy] Easy Difficult	[✓ Very Easy] Easy Difficult	Very Easy [✓ Easy] Difficult	[✓ Very Easy] Easy Difficult	Very Easy [✓ Easy] Difficult
Was real-time feedback provided concerning awkward postures?	[✓ Yes] No Maybe	[✓ Yes] No Maybe	[✓ Yes] No Maybe	[✓ Yes] No Maybe	[✓ Yes] No Maybe	[✓ Yes] No Maybe
Which feedback format did you	Voice Alert only	Voice Alert only	Voice Alert only	Voice Alert only	Voice Alert only	Voice Alert only

find easier to understand?	Screen display only [✓ Both by voice alert and screen display]	Screen display only [✓ Both by voice alert and screen display]	Screen display only [✓ Both by voice alert and screen display]	Screen display only [✓ Both by voice alert and screen display]	Screen display only [✓ Both by voice alert and screen display]	Screen display only [✓ Both by voice alert and screen display]

From these responses, we conclude that in addition to its cost-effectiveness, the developed system is also convenient, easy to use, and can provide easy-to-understand real-time feedback to its users.

Appendix C : Participant's Responses During the Validation Study

In this research, the validity of the developed ergonomic assessment KBS for use in the real-time capture, assessment and feedback of work postures to human users, was tested on fifteen (15) participants using three (3) case studies. These participants were requested to study and sign a participant consent form before starting the experiment. This consent form is depicted in the screenshot of figure C-1. The participant's perception of the new system was assessed using a questionnaire as represented in the screenshot of figure C-2.



Participant Consent Form

Date: ____________
Participant No.:____________

INFORMED CONSENT FORM

Title of the Project:

Name of the Researcher:
Contact Details:

1. I confirm that I have been informed about the aim and objectives of this research project agreed to give my inputs.
2. I understand that all personal information that I provide will be treated with the strictest confidence and my name will not be used in any report, publication or presentation and I have been provided with a participant number to ensure that all raw data remains anonymous.
3. I understand that although the information I provide will be used by Cranfield University for research purposes, it will not be possible to identify any specific individual from the data reported as a result of this research.
4. I understand that the data collected will only be used for research purposes of the said project. The results will be published in scientific journals. I further understand that my raw data will be accessible only to the researcher and the supervising staff at Cranfield University.
5. I understand that I am free to withdraw from this project at any stage during the session simply by informing a member of the research team, for whom contact details have been provided. I also understand that I can also withdraw my data for a period of up to 7 days from today, as after this time it will not be possible to identify my individual data from the aggregated results.

Participant's signature: ______________________________ Date: _______________

Participant's name: ________________________________

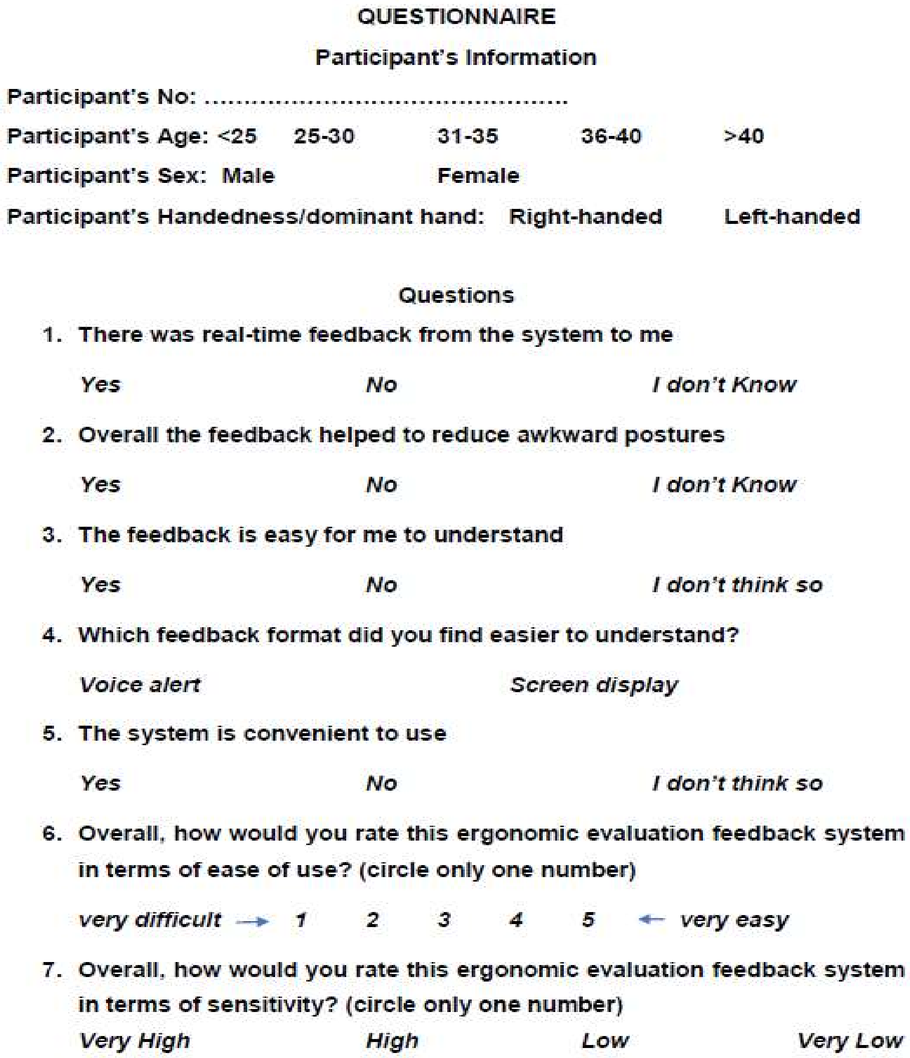
Researcher's signature: ______________________________ Date: ________________

Debriefing

Thank you very much for spending your time. As mentioned earlier the data provided by you through this discussion will be treated confidentially and you are free to withdraw or change your insights anytime during the process. If you need to change anything you can let me know by contacting me through email or phone. In case I missed out important points or need to clarify some points can I contact you on email or phone again? Thank you very much.

SEREC Intranet Content, Revision 1: 7 August 2012

Figure C-1 Participant's consent form



QUESTIONNAIRE

Participant's Information

Participant's No: ....

Participant's Age: <25 25-30 31-35 36-40 >40

Participant's Sex: Male Female

Participant's Handedness/dominant hand: Right-handed Left-handed

Questions

1. There was real-time feedback from the system to me

   Yes *No* *I don't Know*

2. Overall the feedback helped to reduce awkward postures

   Yes *No* *I don't Know*

3. The feedback is easy for me to understand

   Yes *No* *I don't think so*

4. Which feedback format did you find easier to understand?

   Voice alert *Screen display*

5. The system is convenient to use

   Yes *No* *I don't think so*

6. Overall, how would you rate this ergonomic evaluation feedback system in terms of ease of use? (circle only one number)

   very difficult → 1 2 3 4 5 ← *very easy*

7. Overall, how would you rate this ergonomic evaluation feedback system in terms of sensitivity? (circle only one number)

   Very High *High* *Low* *Very Low*

Figure C-2 Questionnaire for assessing the participant's perception of the developed system

Their responses are summarised on table C-1. From the table, we see that real-time easy-to-understand feedback, provided to all the participants, helped them to reduce the rate of occurrence of awkward postures while working. To these participants, the voice alert feedback is preferable to the screen display feedback. They all rated the system as being sensitive to posture changes and moderately easy to use, while 13 of the 15 participants found the system convenient. The author therefore conclude that the developed system is an easy-to-use, convenient, real-time ergonomic work posture assessment system, which can provide an easy-to-understand feedback to its user

Table C-1 Questionnaire/Participant’s response to the performance of the KBS

PARTICIPANTS QUESTIONS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	PARTICIPANT’S RESPONSES														
There was real-time feedback from the system to me	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Overall the feedback helped to reduce awkward postures	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
The feedback is easy for me to understand	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Which feedback format did you find easier to understand?	Voice Alert	Voice Alert	Voice Alert	Voice Alert	Voice Alert	Voice Alert	Voice Alert	Voice Alert	Voice Alert	Voice Alert	Voice Alert	Voice Alert	Voice Alert	Voice Alert	Voice Alert
The system is convenient to use	YES	YES	YES	YES	I don’t think so	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES
Overall, how would you rate this ergonomic evaluation feedback system in terms of ease of use (from 1-5)?	4	5	4	3	3	3	5	5	5	4	3	4	4	4	3
Overall, how would you rate this ergonomic evaluation feedback system in terms of sensitivity (from very high to very low)?	HIGH	VERY HIGH	HIGH	HIGH	VERY HIGH	VERY HIGH	HIGH	VERY HIGH	HIGH	HIGH	HIGH	HIGH	VERY HIGH	HIGH	VERY HIGH

Appendix D : Real-Time Feedback vs No Feedback

Tables D-1 to D-6 is the tabular representation of the data obtained from the descriptive statistical analysis of participants presented in figure 7-14. From these analyses, it is evident that there is decrease in the rate of occurrence of awkward postures when real-time feedback was introduced on almost all the participants.

Table D-1 Descriptive statistical analysis of the results of participant 2

Joints	Posture Quality	Without Real-Time Feedback		With Real-Time Feedback	
		Frequency	% Frequency	Frequency	% Frequency
Left Elbow	Awkward	265	19.3	30	3.8
	Good	1109	80.7	757	96.2
Right Elbow	Awkward	185	13.5	40	5.1
	Good	1189	86.5	747	94.9
Left Shoulder	Awkward	955	69.5	218	27.7
	Good	419	30.5	569	72.3
Right Shoulder	Awkward	993	72.3	231	29.4
	Good	381	27.7	556	70.6
Back flexion	Awkward	724	52.7	247	31.4
	Good	650	47.3	540	68.6
Back Right	Awkward	109	7.9	33	4.2
	Good	1265	92.1	754	95.8
Back Left	Awkward	254	18.5	34	4.3
	Good	1120	81.5	753	95.7

Table D-2 Descriptive statistical analysis of the results of participant 3 for lifting, lowering and carrying tasks

Joints	Posture Quality	Without Real-Time Feedback		With Real-Time Feedback	
		Frequency	% Frequency	Frequency	% Frequency
Left Elbow	Awkward	142	5.6	50	2.1
	Good	2379	94.4	2317	97.9
Right Elbow	Awkward	650	25.8	250	10.6
	Good	1871	74.2	2117	89.4
Left Shoulder	Awkward	662	26.3	400	16.9
	Good	1859	73.7	1967	83.1

Right Shoulder	**Awkward**	**1913**	**75.9**	**984**	**41.6**
	Good	**608**	**24.1**	**1383**	**58.4**
Back flexion	**Awkward**	**427**	**16.9**	**216**	**9.1**
	Good	**2094**	**83.1**	**2151**	**90.9**
Back Right	**Awkward**	**156**	**6.2**	**389**	**16.4**
	Good	**2365**	**93.8**	**1978**	**83.6**
Back Left	**Awkward**	**164**	**6.5**	**316**	**13.4**
	Good	**2357**	**93.5**	**2051**	**86.6**

Table D-3 Descriptive statistical analysis of the results of participant 4 for the lifting, lowering and carrying tasks

Joints	**Posture Quality**	**Without Real-Time Feedback**		**With Real-Time Feedback**	
		Frequency	**% Frequency**	**Frequency**	**% Frequency**
Left Elbow	**Awkward**	**161**	**10.2**	**250**	**7.3**
	Good	**1419**	**89.8**	**3179**	**92.7**
Right Elbow	**Awkward**	**210**	**13.3**	**360**	**10.5**
	Good	**1370**	**86.7**	**3069**	**89.5**
Left Shoulder	**Awkward**	**1231**	**77.9**	**840**	**24.5**
	Good	**349**	**22.1**	**2589**	**75.5**
Right Shoulder	**Awkward**	**1382**	**87.5**	**719**	**21.0**
	Good	**198**	**12.5**	**2710**	**79.0**
Back flexion	**Awkward**	**547**	**34.6**	**131**	**3.8**
	Good	**1033**	**65.4**	**3298**	**96.2**
Back Right	**Awkward**	**189**	**12.0**	**221**	**6.4**
	Good	**1391**	**88.0**	**3208**	**93.6**
Back Left	**Awkward**	**201**	**12.7**	**158**	**4.6**
	Good	**1379**	**87.3**	**3271**	**95.4**

Table D-4 Descriptive statistical analysis of the results of participant 13

Joints	**Posture Quality**	**Without Real-Time Feedback**		**With Real-Time Feedback**	
		Frequency	**% Frequency**	**Frequency**	**% Frequency**
Left Elbow	**Awkward**	**40**	**8.5**	**10**	**0.3**
	Good	**430**	**91.5**	**3780**	**99.7**
Right Elbow	**Awkward**	**20**	**4.3**	**20**	**0.5**
	Good	**450**	**95.7**	**3770**	**99.5**
Left Shoulder	**Awkward**	**240**	**51.1**	**140**	**3.7**
	Good	**230**	**48.9**	**3650**	**96.3**

Right Shoulder	**Awkward**	**142**	**30.2**	**104**	**2.7**
	Good	**328**	**69.8**	**3686**	**97.3**
Back flexion	**Awkward**	**28**	**6.0**	**42**	**1.1**
	Good	**442**	**94.0**	**3748**	**98.9**
Back Right	**Awkward**	**23**	**4.9**	**72**	**1.9**
	Good	**447**	**95.1**	**3718**	**98.1**
Back Left	**Awkward**	**17**	**3.6**	**26**	**0.7**
	Good	**453**	**96.4**	**3764**	**99.3**

Table D-5 Descriptive statistical analysis of the results of participant 14 for the lifting, lowering and carrying tasks

Joints	**Posture Quality**	**Without Real-Time Feedback**		**With Real-Time Feedback**	
		Frequency	**% Frequency**	**Frequency**	**% Frequency**
Left Elbow	**Awkward**	**110**	**22.4**	**20**	**0.4**
	Good	**382**	**77.6**	**5299**	**99.6**
Right Elbow	**Awkward**	**100**	**20.3**	**20**	**0.4**
	Good	**392**	**79.7**	**5299**	**99.6**
Left Shoulder	**Awkward**	**383**	**77.8**	**70**	**1.3**
	Good	**109**	**22.2**	**5249**	**98.7**
Right Shoulder	**Awkward**	**453**	**92.1**	**5**	**0.1**
	Good	**39**	**7.9**	**5314**	**99.9**
Back flexion	**Awkward**	**437**	**88.8**	**42**	**0.8**
	Good	**55**	**11.2**	**5277**	**99.2**
Back Right	**Awkward**	**206**	**41.9**	**268**	**5.0**
	Good	**286**	**58.1**	**5051**	**95.0**
Back Left	**Awkward**	**135**	**27.4**	**144**	**2.7**
	Good	**357**	**72.6**	**5175**	**97.3**

Table D-6 Descriptive statistical analysis of the results of participant 15.

Joints	**Posture Quality**	**Without Real-Time Feedback**		**With Real-Time Feedback**	
		Frequency	**% Frequency**	**Frequency**	**% Frequency**
Left Elbow	**Awkward**	**121**	**24.2**	**20**	**0.5**
	Good	**379**	**75.8**	**3814**	**99.5**
Right Elbow	**Awkward**	**50**	**10.0**	**10**	**0.3**
	Good	**450**	**90.0**	**3824**	**99.7**
Left Shoulder	**Awkward**	**291**	**58.2**	**40**	**1.0**
	Good	**209**	**41.8**	**3794**	**99.0**
Right Shoulder	**Awkward**	**381**	**76.2**	**52**	**1.4**

	Good	**119**	**23.8**	**3782**	**98.6**
Back flexion	**Awkward**	**338**	**67.6**	**42**	**1.1**
	Good	**162**	**32.4**	**3792**	**98.9**
Back Right	**Awkward**	**67**	**13.4**	**46**	**1.2**
	Good	**433**	**86.6**	**3788**	**98.8**
Back Left	**Awkward**	**67**	**13.4**	**82**	**2.1**
	Good	**433**	**86.6**	**3752**	**97.9**