CRANFIELD UNIVERSITY

Peng Ou

Maintenance Applications of Augmented Reality for The Chinese Aerospace Industry

SCHOOL OF APPLIED SCIENCE

MSc by Research Thesis
Academic Year: 2011 - 2012

Supervisors: Prof. Ashutosh Tiwari
Dr. Paul Baguley

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ABSTRACT

Since augmented reality has not reached full maturity in use, it is not widely adopted within the aerospace industry. According to the literature review, minimal research efforts have been conducted to assess the cost-benefit or cost- effectiveness of augmented reality so far. Moreover, to the best of researcher's knowledge, no research has been carried out to develop a systematic process for selecting and implementing augmented reality within the Chinese aerospace industry. This research will therefore aim to bridge the gaps.

The primary aim of this research is to develop a process for selecting and implementing augmented reality to support maintenance within an aerospace company. The following objectives will be fulfilled in this research: 1) Identify different types of AR technologies and their strengths and weaknesses for maintenance; 2) Perform cost-benefit analysis for augmented reality within the maintenance industry; 3) Develop a process for selecting and implementing augmented reality in a range of activities. Data analysis and a questionnaire were employed to achieve these objectives.

In the proposed cost benefits analysis framework, the costs of implementing an augmented reality system, both direct and indirect benefits, and the costs incurred by risks have been introduced. A proposed equation on the basis of above variables has been adopted to determine the feasibility of implementing an augmented reality system in terms of money.

The proposed implementation framework has introduced a process which can be followed to develop a new augmented reality system. A set of criteria have been established for selecting augmented reality technologies.

The two frameworks have been applied to a developed scenario and validated by experts from Cranfield University, as well as engineers from an aerospace company. Keywords:

Augmented reality, Maintenance, Cost benefit analysis, Chinese aerospace industry.

ACKNOWLEDGEMENTS

Firstly, may I take this opportunity to express my thanks to my company-COMAC to support my studies.

I also express my thanks to my father and mother whose love encourages me to overcome difficulties.

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ACRONYMS

AIPC: Aircraft Illustrated Parts Catalogue

AMM: Aircraft Maintenance Manual

AR: Augmented Reality

CAD: Computer Aided Design

CAI: Computer Assisted Instruction

CDMA: Code-Division Multiple Access

COMAC: Commercial Aircraft Corporation of China

DART: Designer's Augmented Reality Toolkit

DWARF: Distributed Wearable Augmented Reality Framework

EICAS: Engine Indication and Crew Alerting System

GSM: Global System for Mobile Communications

GPS: Global Positioning System

HMD: Head Mounted Display

NASA: National Aeronautics and Space Administration

PDA: Personal Digital Assistant

VR: Virtual Reality

WLAN: Wireless Local Area Network

WPAN: Wireless Personal Area Network

WWAN: Wireless Wide Area Network

1 INTRODUCTION

This chapter gives the reader an overview of this research. The research background, the Chinese aerospace industry and motivation will be presented in the first place, followed by a brief introduction in section 1.5 of Commercial Aircraft Corporation of China (COMAC), of whom the research aims and objectives are based. Section 1.6 will detail the research aim and objectives with the structure of the thesis covered in section 1.7.

1.1 Research Background

Augmented Reality (AR) is a new approach which enables users to see the images of real world through displays with virtual objects superimposed on, so that the virtual objects and real world images appear to exist at the same time in the same place (Azuma et al., 2001). Caudell, a Boeing employee, introduced the concept of Augmented Reality (AR) in 1990 (Carmigniani et al., 2011). Since then numerous related researches have been carried out worldwide and much progress has been made. Augmented reality aims to convey useful virtual information, generated by computers, to enhance an individuals' perception of reality. Promising prototypes have been developed in various areas such as the medical profession, manufacturing, the entertainment industry, and advertising.

The aerospace industries, both military and civil, have been aware of the potential of augmented reality. Many novel concepts to aid aircraft design and maintenance have been introduced and some of them have successfully turned into applications. Gautier et al. (2007) proposed a collaborative workspace for aircraft maintenance. Regenbrencht et al. (2005) have implemented augmented reality for airplane cabin design and cockpit layout.

1.2 Chinese Aerospace Industry

With higher expected air traffic and freight growth rates than world average level the next 20 years, China is playing an increasingly important role in the global aerospace industry. According to an estimation from AeroStrategy (Stewart, 2010), the fleet of China will triple and 13% of total aircraft manufacturing will be delivered to China over the next 20 years.

In spite of the most promising market, the Chinese aerospace industry still faces great challenges. Currently most airplanes are purchased from Boeing and Airbus. The whole industry has not mastered core technologies of aircraft design and manufacture. Meanwhile, Boeing and Airbus are expected to bring the updated B737 and A320, the most popular single-aisle airplanes around the world, to the market over the next few years.

Commercial Aircraft Corporation of China (COMAC) was founded in 2008 aiming to address the issues. In order to compete with major aircraft manufacturers such as Boeing and Airbus, COMAC has to take advantage of novel technologies to outstand. Augmented reality, having great potential for all stages of aircraft design, manufacturing and maintenance, therefore serves as an optimal solution. And it may benefit the Chinese aerospace industry significantly.

1.3 Research Motivation

Aircraft maintenance refers to the overhaul, repair, inspection, replacement, modification, or defect rectification of an aircraft or component (EASA, 2010). It is information intensive and time consuming.

Reinhart and Patron (2003) pointed out that augmented reality can be more employed in maintenance. Wang et al. (2011) argued that augmented reality is a useful solution for complex equipment maintenance. Kleiber and Alexander (2011) presented an augmented reality approach for collaborative maintenance. All these are growing evidence in support of augmented reality for aircraft maintenance.

Besides, as a newcomer to the aerospace industry, it is imperative for COMAC to adopt novel technologies like augmented reality to become competitive in world markets.

This research will therefore focus on augmented reality for aircraft maintenance for the Chinese aerospace industry.

1.4 Research Problem Statement

Since augmented reality has not reached full maturity in use, it is not widely adopted within the aerospace industry. This research has been undertaken in order to understand augmented reality and how to apply augmented reality to a new Chinese aerospace company. In particular, the technologies and applications of augmented reality will be reviewed. In terms of implementation, the potential costs and benefits of employing augmented reality should be identified in the first place to determine whether this technology is economically viable and the criteria or requirements for selecting augmented reality should then be established. This research will mark the decision to apply augmented reality systematically.

1.5 Sponsor Company

The Commercial Aircraft Corporation of China Ltd. (COMAC) is a state-run aircraft design and manufacturing company with a registered capital of 19 billion CNY (1.8 billion GBP). It was founded in 2008 and is located in Shanghai, China. The company is jointly invested by State-owned Assets Supervision and Administration Commission (SASAC) of the State Council, the Aviation Industry Corporation of China (AVIC). COMAC is engaged in developing large single-aisle commercial aircraft in the hope of reducing dependence on Boeing and Airbus. Also, the company wishes to enter the world market and become a world-class enterprise. The company has designed and manufactured an advanced regional jet (ARJ21) with capacity of 70-90 seats. And the new model, C919 with capacity of 150 seats, is now under development. COMAC has yet to build up a reputation in the aerospace industry. Therefore, there is a significant drive towards state of the art technology to compete internationally.

1.6 Aim and Objectives

1.6.1 Aim

The primary aim of this research is to develop frameworks for selecting and implementing augmented reality to support maintenance within the Chinese aerospace industry.

1.6.2 Objectives

1. Identify different types of AR technologies and their strengths and weaknesses for maintenance.

2. Develop a framework for performing cost-benefit analysis for augmented reality within the maintenance industry.

3. Develop a framework for selecting and implementing augmented reality in activities and validate the frameworks.

1.7 Thesis Structure

The thesis structure is demonstrated in the following Figure 1-1:

Chapter 1: INTRODUCTION

This chapter introduces the research background, motivation, sponsoring company, research problem statement, as well as the research aim and objectives and thesis structure.

Chapter 2: LITERATURE REVIEW

The state of the art of augmented reality will be presented in this chapter. Different types of augmented reality technologies and the strengths and weaknesses will be identified. And different augmented reality applications will be introduced, along with the research gaps and future trends.

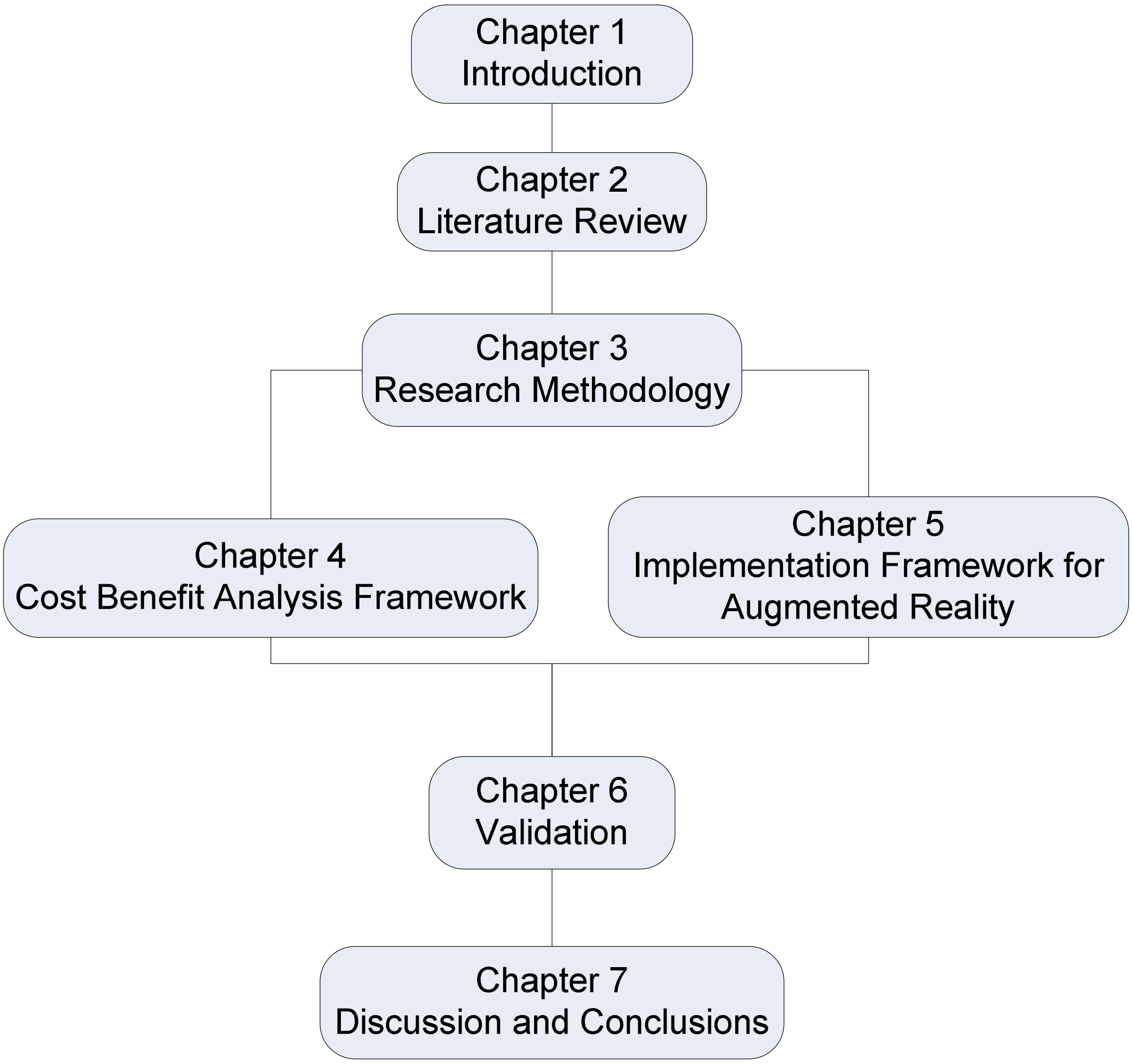

Figure 1-1 Thesis Structure

Chapter 3: RESEARCH METHODOLOGY

In this chapter, the research methodologies used to achieve the aims and objectives will be described. Moreover, the methodology for the development of cost benefit analysis framework and implementation framework will be introduced considering the specific features of the Chinese aerospace industry.

Chapter 4: COST BENEFIT ANALYSIS

The aim of this chapter is to present a framework which enables the aerospace industry to perform an overall evaluation of costs and benefits associated with augmented reality, in order to determine its economic and technical feasibility. This chapter will also introduce a scenario to investigate the feasibility and applicability of this framework. Finally, the results of this framework will be analysed.

Chapter 5: IMPLEMENTATION FRAMEWORK

This chapter will establish a framework for selecting and implementing augmented reality within the Chinese aerospace industry. Firstly, the aim for developing this framework will be introduced. The following section will present details of this framework. Finally, the validation of this framework will be given.

Chapter 6: VALIDATION

This chapter will introduce the methodology for validation. The validation results by university experts and company engineers will be presented. Finally, the summary of validation will be given.

Chapter 7: DISCUSSION AND CONCLUSIONS

This chapter will discuss the experience gained during the research. Future work and conclusions will be presented.

2 LITERATURE REVIEW

2.1 Introduction

Figure 2-1 is the overview of the literature review. This chapter aims to study the state of the art, and identify the strengths and weaknesses of augmented reality technologies. Augmented reality applications to manufacturing and maintenance, as well as other fields will be introduced in section 2.4. The future trends and current research gaps will be discussed in section 2.5. Section 2.6 will make a summary of the literature review.

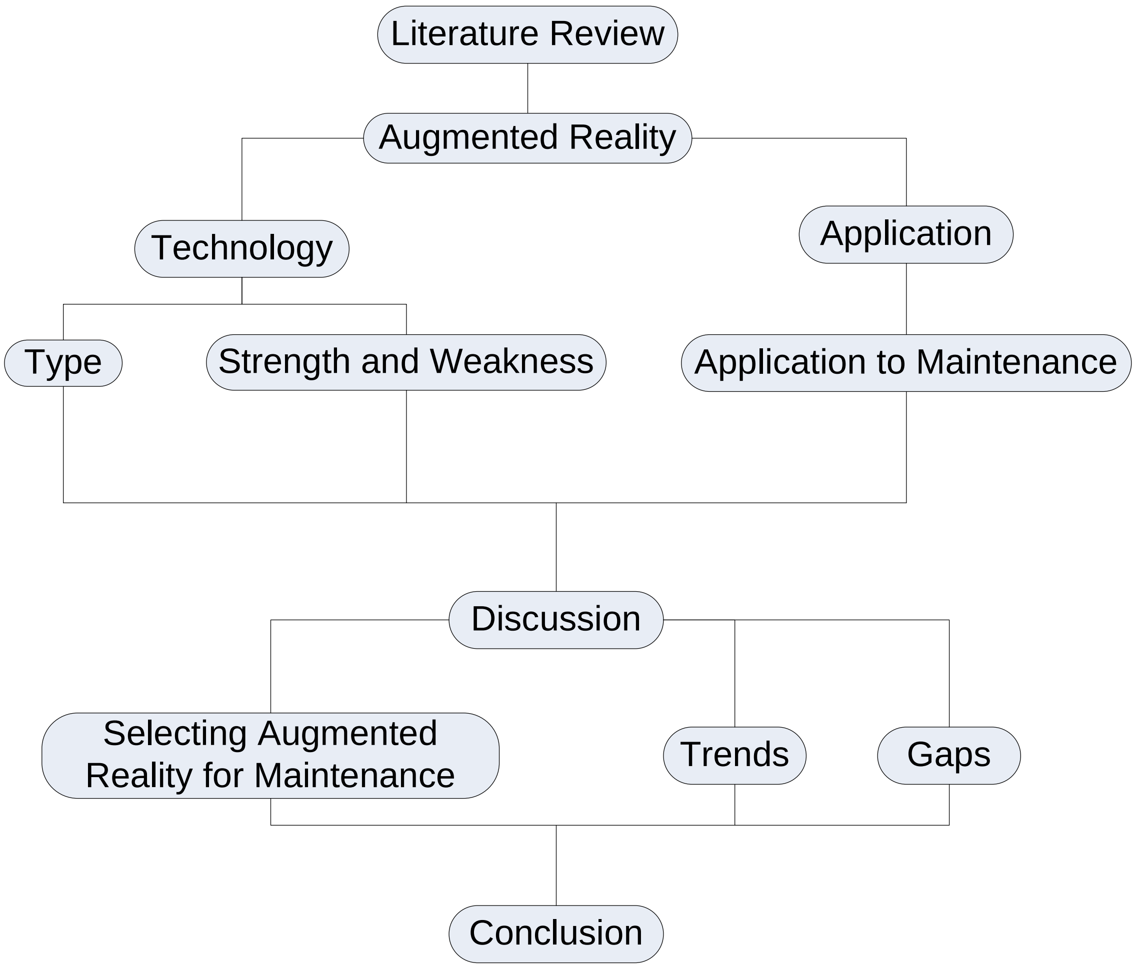

Figure 2-1 Literature Review Structure

2.2 Augmented Reality

2.2.1 Definition and Characteristics

Augmented Reality (AR) is a new approach which is different from Virtual Reality (VR) that presents users with a completely synthetic environment. It enables users to see the images of the real world through displays upon which virtual objects are superimposed, so that the virtual objects and real world images appear to exist at the same time in the same place (Azuma et al., 2001). Instead of replacing the real world, augmented reality aims to supplement it with computer-generated virtual elements to provide relevant and useful information to enhance an individuals' perception of reality. Milgram's Reality-Virtual Continuum (Milgram and Kishino, 1994) in Figure 2-2 clearly illustrates the location of augmented reality.

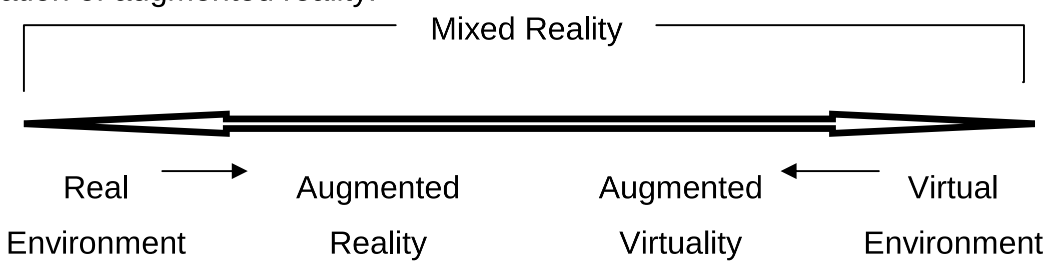

Figure 2-2 Milgram's Reality-Virtual Continuum

(Milgram and Kishino, 1994)

A definition of augmented reality from Azuma (1997) is widely accepted: 1) combine virtual and real views, 2) provide real time interactions between real and virtual objects, 3) virtual objects are registered in three dimensions.

2.2.2 Hardware and Software in Augmented Reality

Applications of augmented reality make much use of hardware and software and commercial hardware and software are able to be obtained in many places (Ong et al., 2008). Augmented reality benefits considerably from both the hardware and software advances.

Minolta clipon displays (Kasai et al., 2000) is a very light wearable display which is a well known optical see-through display. Retina display (Lewis, 2004) is well suited for a mobile outdoor augmented reality system. Tinmith (Piekarsiki, 2006) provides an efficient user interface for interaction. Augmented reality platforms such as Designer’s Augmented Reality Toolkit (DART) (Blair et al., 2003) and Studierstube (Reitmayr and Schmalstieg, 2001) have been developed to help researchers with application implementation. The details of augmented reality technologies will be given in section 2.3.

2.3 Augmented Reality Technology

Augmented reality technology can be divided into two main categories: hardware and software (See Figure 2-3). The major hardware components consist of those used for various functions like display, interaction, tracking and processing, while the software contains the different well-known software packages and tools, including basic algorithms, built by researchers for further development of AR applications.

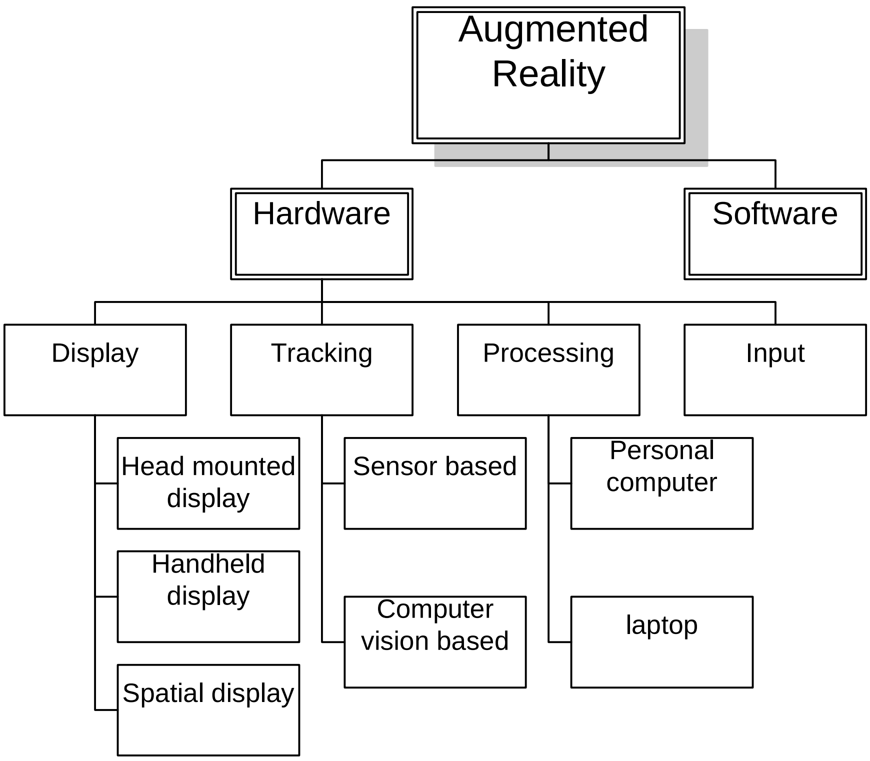

Figure 2-3 General Diagram of Augmented Reality

2.3.1 Display

Displays play a key role in combining the real and virtual world. The displays are the means through which users are able to see images of the real world with essential computer generated virtual images and annotations overlaid. There are mainly three types of displays in use for augmented reality: head-mounted display (HMD), handheld display and spatial display. Head-mounted display can be further divided into video see-through and optical see through. Figure 2-4 illustrates different display techniques and their locations with respect to the real object (Bimber et al., 2007).

Optical see-through display (Figure 2-5) takes advantage of partially transmissive and reflective optical combiners, through which the users are able to directly observe the real world and scene generator generated graphic images from head-mounted monitors. Video see-through display (Figure 2-6) makes use of combining head-mounted video cameras. The view of the real world captured by video cameras mixed with the virtual images generated by computer is delivered to the monitor in front of the user (Azuma, 1997).

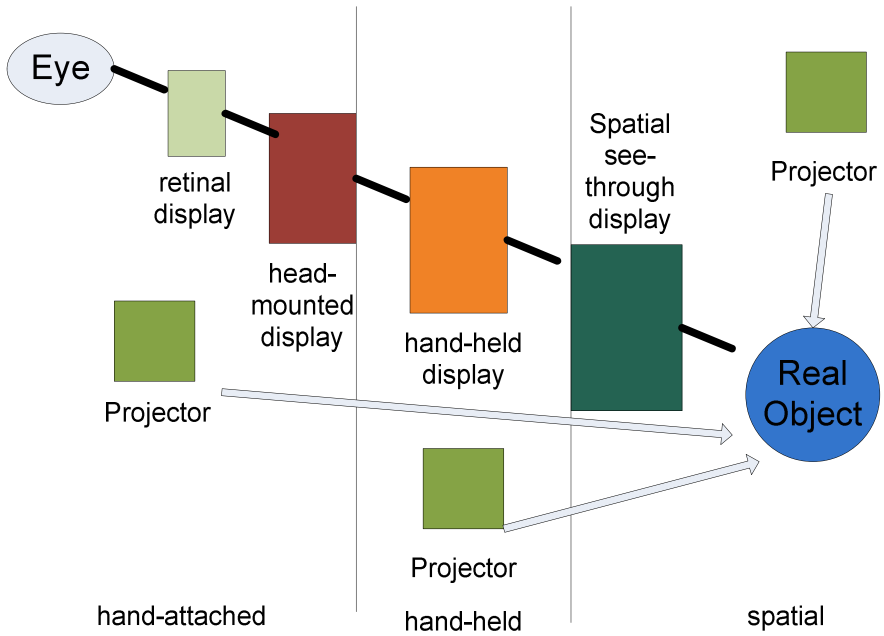

Figure 2-4 Display Techniques and Positioning

(Bimber et al., 2007)

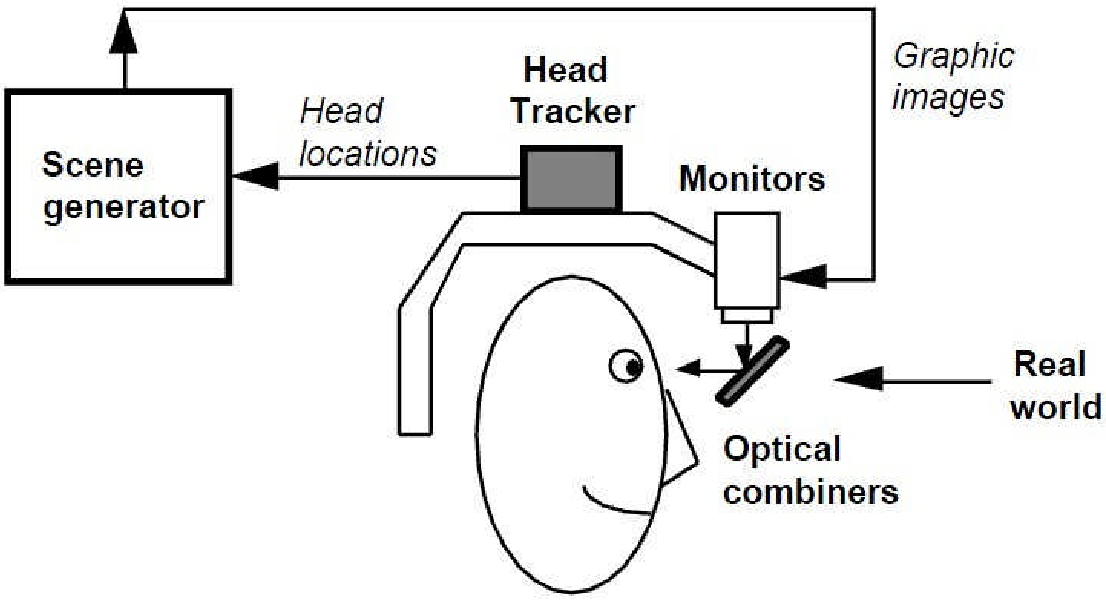

Figure 2-5 Optical See-Through Display

(Azuma, 1997)

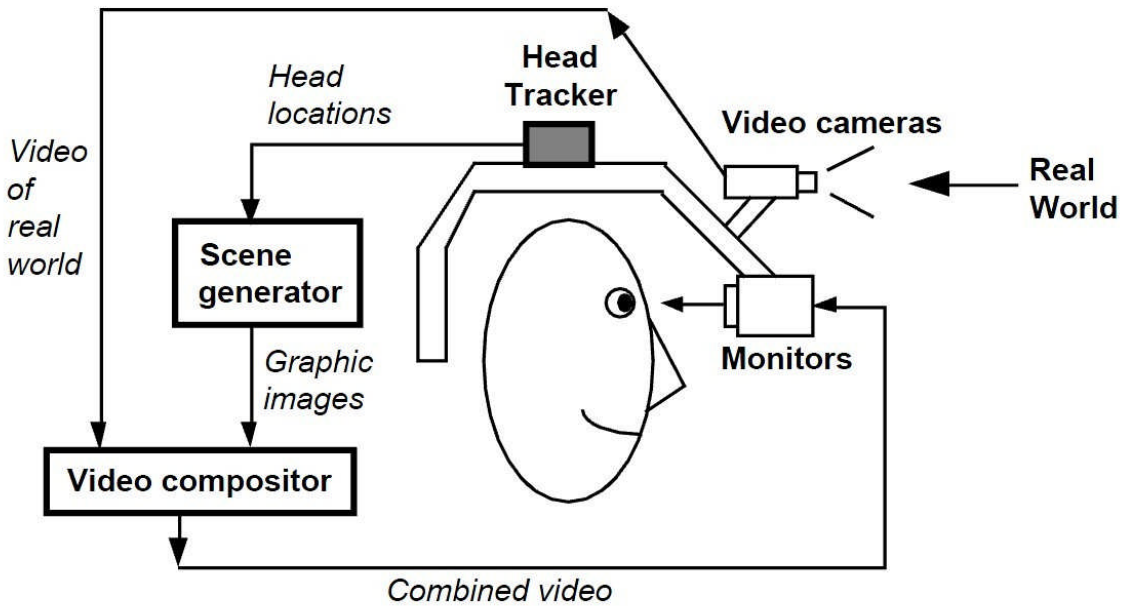

Figure 2-6 Video See-Through Display

(Azuma, 1997)

In the case of a handheld display, a user carries a small handheld device which suits his/her hand well instead of wearing the head-mounted displays. With the advance of technology, a wide range of handheld displays is available for augmented reality, ranging from a Personal Digital Assistant (PDA), Smartphone, and Tablet Personal Computer to a handheld projector (Schmalstieg and Wagner, 2007), as shown in Figure 2-7.

Figure 2-7 Handheld Displays Used in AR Projects

(Schmalstieg and Wagner, 2007)

Spatial augmented reality (Figure 2-8) employs a digital projector to display information onto the real world. It supplies users with 3D images without the need to wear or hold the display. And it eliminates the need of sensors for tracking (Olwal et al., 2008). As this display is disconnected from users, spatial augmented reality scales up to group users, which make collaboration between users available.

2.3.2 Tracker

The user's location and orientation with reference to the surroundings must be accurately tracked in order to display virtual objects into the real environment in the correct way. A wide range of trackers, including mechanical, ultrasonic, magnetic, inertial, optical, electromagnetic, are in use today. Welch and Foxlin (2002) carried out a thorough examination of motion tracking and identified the respective strengths and weaknesses of different trackers. Table 2-1 provides the types of trackers and basic working principles:

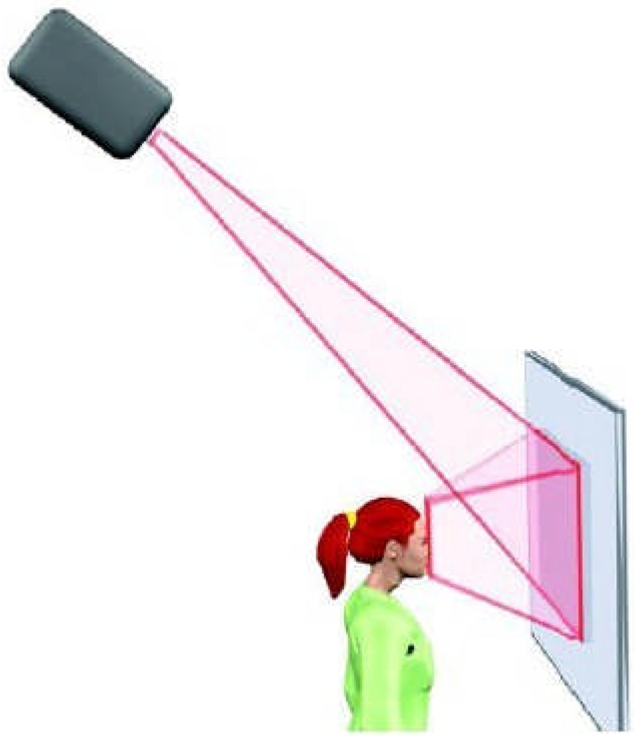

Figure 2-8 Spatial Display

(Olwal et al., 2008)

Table 2-1 Types of Augmented Reality Trackers

	Working principle
Mechanical	Mechanical tracker involves a direct mechanical linkage, string pulley for instance, between the target and environment, and the movement of forward and inverse could be used to estimate the pose and direction of the user with respect to the environment (Welch and Foxlin, 2002).
Ultrasonic	It uses devices to receive and send ultrasonic chirps and determine the position of user (Tamura, 2002).
Magnetic	Magnetic tracker employs magnetic sensors to identify the magnetic field vector to indicate the orientation.
Inertial	Inertial tracking makes use of rate gyroscopes and accelerometers fixed on a rigid body. The initial velocity, position, and orientation are already obtained and the rate gyroscopes compute the angular velocities, on the basis of which the angular displacements or orientation of the rigid body can be calculated (Ong et al., 2008).
Optical	Optical tracker relies on one or more cameras to identify objects in the scenes and calculate the position and orientation of user (Welch and Foxlin, 2002).

Electromagnetic	Electromagnetic tracking system takes advantage of waves, such as infrared waves and radio waves. And there are two types available: outside-looking-in and inside-looking-out. For the former, emitters mounted on the user are tracked by the sensors placed in the environment, which is more used for motion capture cases. In contrast the latter, where emitters are placed in the environment, is typically adopted in mobile applications (Welch and Foxlin, 2002).

2.3.3 Input (Interaction) and Processing

The traditional input devices, like mouse and keyboard, are widely used for AR input. However, as augmented information provided by the system is 3D in most cases, the input (interaction) devices are supposed to be designed to support more complex interactions. Wayne Piekarski and Ross Smith from Tinmith (2006) developed novel menu-based user interface gloves for interaction (Figure 2-9). Other interaction devices like joysticks, speech input, Personal Digital Assistant (PDA) and Smartphones are also in use for various augmented reality applications.

Figure 2-9 Tinmith Glove

(Tinmith, 2006)

(Top right: PCB of the glove; Bottom: User demonstration)

Processing devices are essential to build an augmented reality system. All the data gathered, sensed visual data for example, are combined and augmentation is positioned through them. Typical processing devices are PC, workstation and laptop. With the advance of technology, Smartphones with dual-core chip and late-model tablet PCs are able to cope with heavy graphics and computational work.

2.3.4 Software

An increasing number of augmented reality software is available. Users with limited augmented reality knowledge or a thorough understanding of augmented reality will find it a handy tool to develop various projects. Besides, with the development of these AR platforms, different components can be integrated into a whole AR system.

Software is developed for a specific operating system, such as Windows, MacOS, Linux and mobile operating systems like iOS and Andoird. Table 2-2 introduces several platforms that are frequently mentioned in papers and journals for augmented reality.

2.3.5 Strengths and Weaknesses

A wide range of augmented reality technologies have been introduced in the previous section. Each of them has respective advantages and disadvantages which should be carefully studied for the sake of a thorough understanding and better application. Table 2-3, Table 2-4 and Table 2-5 further discuss the different AR technologies.

Table 2-2 Augmented Reality Software

	Introduction
ARToolkit	ARToolkit is a popular tool famed for its widespread availability and applications. It is an open-source platform that can be downloaded from internet for free. ARToolkit is able to track markers that have been previously designed to detect various targets so as to superimpose the augmentations on (Kato and Billinghurst, 1999).
ARToolkit Professional	Since 2007 there is no further update for free version of ARToolkit. ARToolkit professional is a commercial paid version which might be the most generally used marker-based platform (Siltanen et al., 2007). It allows developing stand alone, web based and mobile AR applications and has been incorporated into a growing range of other software development tools (ARToolkit).
Studierstube	Studierstube supports a multitude of software and hardware, embracing various HMDs and trackers which enable researchers doing rapid prototyping of augmented reality applications (Mendez et al., 2006). Studierstube provides an individual interaction panel which is user-friendly to communicate with the augmented reality system, as well as a management system that is applicable to produce 3D user interface in complex AR applications (Schmalstieg et al., 2002).
Designer's Augmented Reality Toolkit (DART)	DART is a multimedia based platform. It eliminates the obstacles of a large amount of programming and virtual objects generation. It also removes the need of technical knowledge of cameras and trackers. A user is able to create complex augmented reality applications and get low-level assistance for the tracker, sensor, and camera management (Blair et al., 2003).
Distributed Wearable Augmented Reality Framework (DWARF)	DWARF is a component-based approach to build augmented reality system. It consists of reusable services such as existing components and modules existing on computer providing certain functionality (Bauer et al., 2001).

Table 2-3 Comparison of Augmented Reality Displays

<table>
<tr><td rowspan="4">Optical See-through</td><td>Advantages</td></tr>
<tr><td>1. Simpler and cheaper over video see-through counterpart;

2. Time delay is generally a few nanoseconds which is negligible (Azuma et al., 1997);

3. As real world is directly seen by the users, it only deals with graphic image stream (Azuma et al., 1997);

4. It has little distortion of the real world view;

5. The real world resolution is not constrained by the display;

6. It has no eye-offset (Azuma et al., 1997).</td></tr>
<tr><td>Disadvantages</td></tr>
<tr><td>1. Prices vary significantly among various models depending on the resolution and field of view;

2. It requires users to wear equipment or carry device over the eyes which causes fatigue;

3. It could interfere with other equipments or tools when being used in cramped conditions (Moss and Muth, 2011).</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td rowspan="4">Video See-through</td><td>Advantages</td></tr>
<tr><td>1. It has more flexibility in terms of composition and registration;

2. It has wide field of view (Moss and Muth, 2011);

3.Delay of virtual and real objects are matched;

4. Brightness of real world and virtual images is much easier to be matched (Azuma et al., 1997).</td></tr>
<tr><td>Disadvantages</td></tr>
<tr><td>Similar to optical see-through head mounted displays.</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td rowspan="2">Handheld</td><td>Advantages</td></tr>
<tr><td>1. It is portable;

2. It has ubiquitous nature of Smartphone with camera;

3. High resolution digital cameras, high performance processor, and global positioning system (GPS) are combined with Smartphone which promise the success of handheld augmented reality (Feiner, 2011).</td></tr>
</table>

Handheld	**Disadvantages**
	1. Users have to hold the device all the time. One hand or even both hands are occupied; 2. Typical cameras integrated in Smartphone suffer from distorting effect in contrast with the real images as captured by eyes (Feiner, 2011).
Spatial	**Advantages**
	1. Users are free from carrying any display equipment; 2. It is not constrained by display area which means a group of people are able to use one system at the same time, supporting collaborative tasks (Von Itzstein et al., 2011).
	Disadvantages
	1. It is affected by the sunlight and a surface is needed in the real world on which to display the virtual images (Von Itzstein et al., 2011); 2. It has limited interaction.

Table 2-4 Comparison of Augmented Reality Trackers

Mechanical	**Advantages**
	1. It is the simplest method for sensing (Welch and Foxlin, 2002); 2. It is able to provide high accuracy and precision pose estimation (Welch and Foxlin, 2002); 3. It is adept at tracking single object with relatively small range of movement and incorporating force feedback.
	Disadvantages
	1. It has short range (Welch and Foxlin, 2002); 2. It is difficult to move or carry.
Inertial	**Advantages**
	1. It is a promising technology that is applicable to most cases; 2. It is self-contained so it does not require line-of-sight, has no need to install the emitters, and is not affected by interference from magnetic fields or noise (Welch and Foxlin, 2002); 3. Latency is very low.
	Disadvantages
	1. Inertial tracker has the problem of drift and has only three degrees of freedom; 2. It is not accurate when motion change of is slow (Rolland et al., 2001).
Ultrasonic	**Advantages**
	1. It is lightweight (Ong et al., 2008); 2. It is inexpensive.
	Disadvantages
	1. It suffers from latency (Rolland et al., 2001); 2. It is sensitive to noise, wind speed and temperature (Rolland et al., 2001).

Electromagnetic	**Advantages**	
	1. It is lightweight (Ong et al., 2008); 2. It is cheap.	
	Disadvantages	
	1. It requires line of sight without any obstructions or unwanted objects (Welch and Foxlin, 2002); 2. It is complex; 3. It is sensitive to adverse environment.	
Optical	**Advantages**	
	1. It has high accuracy, flexibility, high availability and low latency (Rolland et al., 2001); 2. It is free of electric and magnetic interference (Rolland et al., 2001).	
	Disadvantages	
	1. It has low mobility and is expensive 2. It is dependence on line of sight; 3. It requires calibration.	
Magnetic	**Advantages**	
	1. Location and orientation are determined by magnetic field and magnetic waves. It therefore works without any line of sight problem (Welch and Foxlin, 2002); 2. It has high accuracy.	
	Disadvantages	
	1. It is subject to mobility; 2. It is sensitive to interference from metal objects.	

Table 2-5 Comparison of Augmented Reality Input Devices

Traditional (Keyboard and Mouse)	**Advantages**
	1. It is cheap; 2. It is widely available; 3. It conforms to users' habit; 4. It is employed in most cases.
	Disadvantages
	1. It is unable to deal with more complex operations since augmented reality information is virtually 3D; 2. It lacks mobility due to cables or range of emitter.
Personal Digital Assistant (PDA)	**Advantages**
	1. It is small and light weight; 2. It is inexpensive.
	Disadvantages
	1. It has two-dimensionality; 2. It has not enough computational ability; 3. It has physical constraint; 4. It is out of date.
Smartphone	**Advantages**
	1. It is lightweight; 2. It is ubiquitous; 3. Tracking and processing devices are included.
	Disadvantages
	1. It has physical constraint; 2. It suffers from short battery life.

Tablet Personal Computer	**Advantages** 1. It has high performance; 2. It has larger screen size compared with Smartphone; **Disadvantages** 1. It is expensive 2. It sometimes require both hands; 3. It has limited availability.
Novel Device (Tinmith Glove)	**Advantages** 1. It supports complex operations; 2. Direct manipulation within real and virtual environments; 3. Most of them are wireless, which results in less interference with operations (Piekarski and Thomas, 2003). **Disadvantages** 1. It is normally more expensive than standard input devices; 2. It takes time for user to familiarise with them.

The processing devices employed in augmented reality, such as workstation, PC, and laptop, are common devices available in most cases. The strengths and weaknesses of each type are well understood by most users. This research will not cover this topic.

As stated in the previous section, augmented reality software is designed for specific operating system and particular purpose. It is difficult to make a comparison with each other by advantages and disadvantages. The following Table 2-6 highlights the distinct characteristics of several augmented reality software in terms of function and supporting system.

Table 2-6 Comparison of Augmented Reality Software

	Characteristics
ARToolkit	1. It is maintained as an open source project; 2. It is a widely used AR tracking library with over 460,000 downloads since 2004 (ARToolKit download statistics, 2011); 3. It supports most existing operating systems: Microsoft Windows, Mac OS X and Linux; 4. It also supports the Symbian, iPhone, and Android operating systems which means the support for mobile AR applications is available; 5. Saqoosha (2009) developed ARToolkit that is able to support Adobe Flash within which. And thus the augmented reality can be used in the web browser.
Studierstube	1. It is a modular augmented reality framework within which new elements can be integrated.(Bauer et al., 2003); 2. It allows rapid prototyping of new applications and enables convenient scripting; 3. It supports distributed execution of applications.
DART	1. The Designer’s Augmented Reality Toolkit (DART) facilitates the whole process of new application design and development, from concept at the very beginning through virtual augmentation testing to final product (Blair et al., 2003); 2. It emphasises quick generation of virtual objects and early experience testing, allowing iteration in the design process; 3. It is useful for rapid prototyping and exploration; 4. It is applicable to most users ranging from experienced designers to novice researchers who are willing to develop augmented reality applications (Blair et al., 2004).
DWARF	1. New components can be integrated in the modular framework (Bauer et al., 2001); 2. It is easily understandable to the user (Bauer et al., 2001); 3. It supports the flexible applications development.

2.4 Augmented Reality Applications

For virtual reality, users have to spend much time on familiarising the details of real environment before they are going to simulate. Besides, it is expensive and difficult to build virtual counterparts for some complex objects. An aircraft containing tens of thousands of parts, serves as a good example.

Since useful information can be conveyed by virtual objects without changing the environment, augmented reality helps users perform a task better in the real world. It has considerable potential in a wide range of fields, such as advertisement, manufacturing and repairing, product design and assembly. Many studies have been or are being conducted on augmented reality over the past few years and top researchers in the manufacturing industries, academic institutes and universities have done significant work. The following Table 2-7 introduces generic applications of augmented reality.

Table 2-7 General Augmented Reality Applications

Researchers /Groups	Area of Work	Applications
Nissan (2008)	Advertising	In Los Angeles auto show, Nissan company demonstrated a new concept vehicle called Cube in 2008. The visitors were given a small book. If they hold it in front of a webcam, alternate versions of the vehicle will be shown.
Lieberman et al. (2009)	Art	Augmented reality has found its application in art. It can be used to assist disabled people in painting and drawing. Zachary and some other members developed an augmented reality application Eyewriter in 2009, aiming to help a paralysed graffiti artist to draw again.
Quest Visual (2010)	Translation	Word Lens is an iphone augmented reality application which overlays captions into the targeted language in video. It also immediately translates words in the books from one language to another with the assistance of video camera.

Fermoso (2008)	Education	Interactive 3D book is an augmented reality scenario that may alter the traditional method to read books for children. 3D virtual contents (for example the UFOs and Aliens) are projected onto the real world by specific designed software, which is obtained from websites once a user bought the book. All user needs is a webcam on a computer with windows operating system.
Wearable Computer Lab (2006)	Entertainment	ARQuake is the first outdoor game employing augmented reality technology developed by a labouratory located in Australia. It enables user to explore the real world while engaging in a virtual shooting game with the first-person view. The system makes use of hybrid tracking method which consists of GPS, magnetic and inertial trackers. A gun controller is offered and the user wears laptop on the back for processing.
Dähne et al. (2002)	Sightseeing	Information about the places or objects visiting will be provided to the tourists in the form of texts or labels with augmented reality. Moreover, tourists can build ruins, relics again as they used to be.

Table 2-8 focuses on augmented reality applications that have been developed for manufacturing.

Table 2-8 Augmented Reality Applications in Manufacturing

Researchers /Groups	Area of Work	Applications
Yuan et al. (2004)	Assembly	Yuan et al. (2004) developed an augmented reality system to guide the assembly. The assembly sequences or assembly plans are given to users by an interactive panel. In addition, it eliminates the need for any sensors or markers.
Jurgen et al. (2004)	Product development	Jurgen et al. (2004) designed a collaborative augmented reality system to assist new car design. Users are allowed to pick up virtual components and apply them onto a car in real world.

Zhang et al (2006)	Numerical Control(NC) machining	Augmented reality has been employed by Zhang et al. (2006) in the examination of machining processes in computer numerical control machining The users can input existing numerical control codes through an interaction panel to carry out simulation and observe cutting forces. Once they change the codes, the new results are given immediately so as to save iterative and monotonous testing.
Dangelmaier et al. (2005)	Manufacturing layout	Dangelmaier et al. (2005) have developed an augmented reality system that helps users with model simulation and validation, as well as the optimisation of the production system.
Robertson et al. (2004)	Assembly	Robertson et al. (2004) used the conceptual framework of communicative intent as the basis for providing semantic knowledge of the graphics generated by AR systems, and implemented two visualisation techniques, namely general virtual text in the real world and detailed relationship between a virtual object and other objects in the real world, as well as four demonstration prototypes to create an intent-based augmentation system for maintenance tasks such as assembly and repair.
Rolland et al. (2004)	Distributed manufacturing	Based on teleportal head-mounted projection display (T-HMPD), Rolland et al. (2004) designed a teleportal augmented reality system, which includes the creation of AR tool spaces around the body of a mobile user, a face to face collaboration tool, and an integration of the teleportal AR technologies within the Artificial Reality Centre (ARC) work room, for distributed collaborative work and visualisation of 3D models in interactive design to enable either a local or remote collaboration.

2.4.1 Augmented Reality Applications in Maintenance

Reinhart and Patron (2003) argued that augmented reality can be more employed in maintenance. As this research will focus on a maintenance application for the aerospace industry, this section will discuss the applications of augmented reality to maintenance in order to find out what has been done or is being done, and identify the research gaps within the maintenance field.

Application 1:

Haritos et al. (2005) argued that traditional training methods in aviation maintenance may not meet the needs for future trends. They presented an augmented reality system to train the novice maintenance aircraft technicians.

This application is a mobile system which makes use of optical trackers to identify the markers that are attached on the components of an aircraft. The virtual texts of identified system functions, combined with real world images are displayed to the users. The maintenance procedures and inspection criterion are also accessible to the users.

They carried out an experiment of an inspection task associated with parts on a Cessna 172S airplane such as mounting bolts and safety wire to determine the effectiveness of augmented reality compared with traditional training paradigms.

Figure 2-10 illustrates a mobile augmented reality application at Embry-Riddle Aeronautical University presented in Haritos' paper.

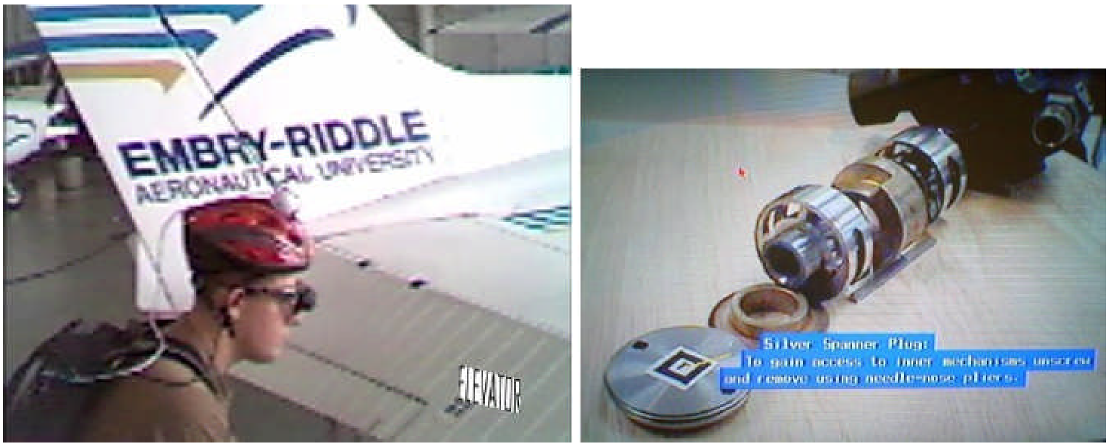

Figure 2-10 Mobile Augmented Reality Training Paradigm from Haritos

(Haritos et al., 2005)

(Left: User demonstration; Right: Screenshot of user display)

Application 2:

Gautier et al. (2007) argued that current technologies used in the maintenance process are insufficient to support communication and decision making. Therefore, they proposed a scenario in which augmented reality is employed to support collaborative unplanned maintenance involving remote experts, as shown in Figure 2-11.

A wearable computer connected to a light weight head mounted display was used. They also suggested the CoSpace platform supporting collaboration between engineers and experts, and Morgan supporting various tracking system and distributed render scene graph as the basic framework. The information gathered by the maintenance technicians at the scene would be shared with the experts and other collaborators through an augmented reality system, in order to help identifying the faults on the aircraft.

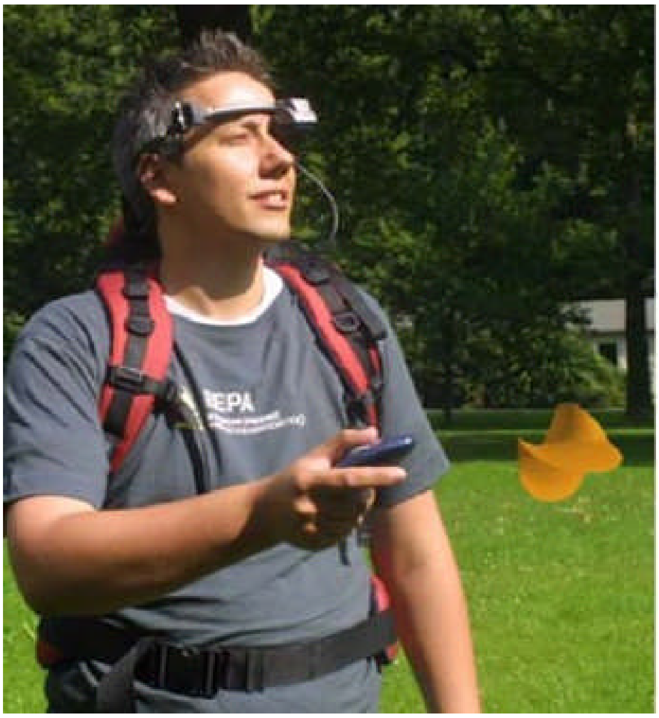

Figure 2-11 Settings of Proposed Application from Gautier

(Gautier et al., 2007)

However, this application is an ambitious scenario. And the outcome of this application needs further evaluation.

Application 3:

Assistant professor Crescenzio, researcher Fantini and Professor Persiani (2011) from the University of Bologna carried out research on augmented reality to support aircraft maintenance training and operations. They believe aircraft maintenance engineers who are mostly under tremendous pressure should be trained and supported by advanced technologies like augmented reality to reduce errors.

They selected the oil-check task of daily inspection on a Cessna C.172P airplane as a case study. Due to the limitation of placing markers on an aircraft, this head mounted application employs computer vision based tracking which makes use of naturally existing visual features in the environment. They exploited available CAD component models as well as graphic symbols such as arrows and pointers to guide maintenance technicians through the task.

Figure 2-12 shows the prototype of their application.

Figure 2-12 Prototype from Crescenzio for Aircraft Maintenance Training (Crescenzio et al., 2011)

However, they suffered latency, the dynamic errors due to system delay in the tracking (Ong, 2004) and the loss of accuracy during position estimation.

Application 4:

Henderson and Feiner (2007) from Columbia University argued that augmented reality can be used in the maintenance, repair and training domain to improve productivity and accuracy. They therefore developed an augmented reality prototype to assist maintenance and repair jobs.

With this prototype, users are provided with related information such as maintenance procedures, safety warnings, and diagnostic data. The information can be shared with remote experts so that collaborative maintenance is available.

Figure 2-13 shows a screenshot of their prototype:

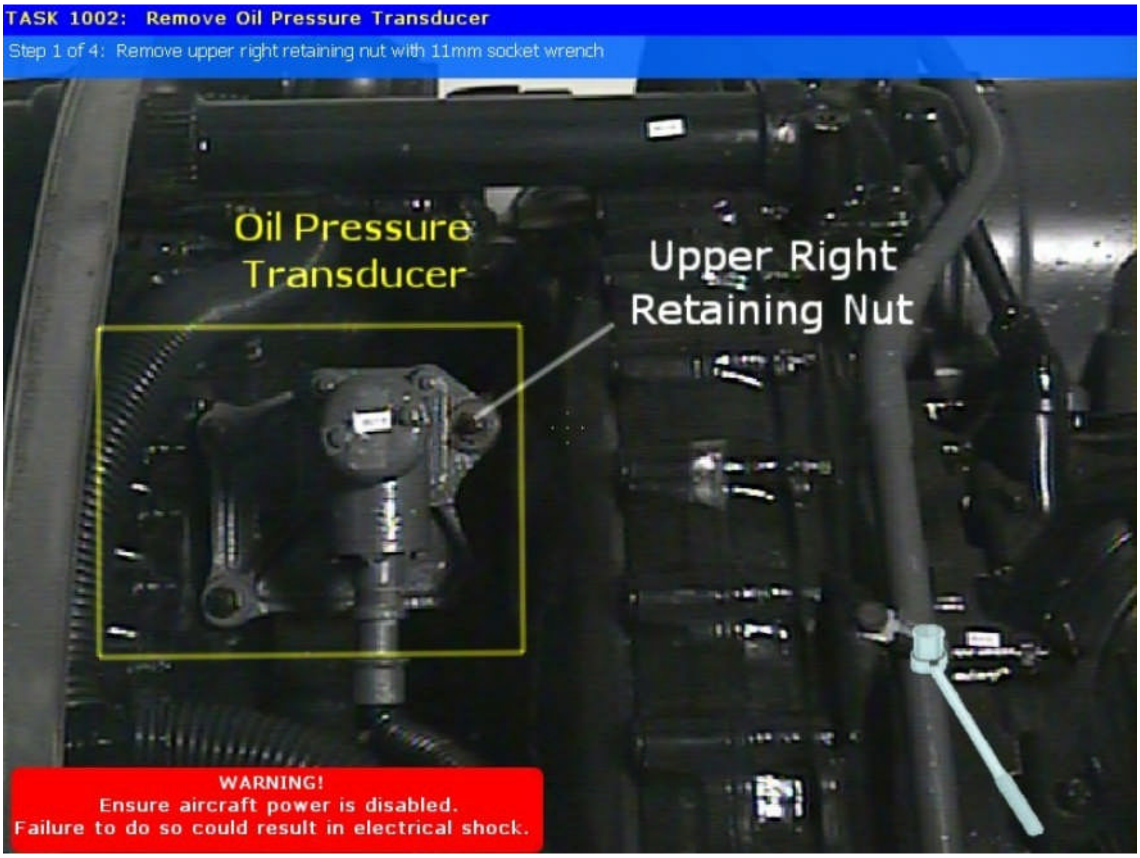

Figure 2-13 Screenshot of Prototype from Henderson and Feiner (Henderson and Feiner, 2007)

According to the above analysis, although researchers are aware of the great potential of augmented reality for aircraft maintenance, only a few works have been done in the aircraft maintenance area in recent years. Besides, most applications are a testing prototype or a proposed concept. And the effectiveness of augmented reality has not been systematically evaluated.

2.5 Discussion

2.5.1 Selecting Augmented Reality for Maintenance

All the current augmented reality technologies could be employed for maintenance. The great challenge lies in establishing a set of criteria for selecting specific AR technologies to meet the needs for certain maintenance tasks based on factors ranging from the financial, political and ergonomical sides to feasibility, availability and reliability issues. However, there are some basic rules that should be followed.

With aircraft maintenance for instance, interior maintenance tasks are normally carried out in cramped conditions and an optical see-through head mounted display is better than a video see-through counterpart due to safety concerns. A video see- through head mounted display can assist exterior checks. A handheld display is well suited for tasks requiring more interaction with an input device but with less demand for hands. Faults diagnosis is a good case in point. Users could perform the tasks guided by mediums like touch screen step by step and send the observation values back for identification in real time. Spatial displays are applicable to group training or collaborative work involving many people where the room is spacious, capable of accommodating a large area of projection surface. Spatial augmented reality is particularly suitable for the maintenance engineers' training workshop and seminar.

Because of the direct a mechanical linkage, mechanical tracker is not ideal for interior inspections. It might cause damage to delicate avionics. A magnetic tracker cannot be used for electronic and electrical equipment, a navigation system for example, due to the magnetic field interference. An inertial tracker is not a robust solution for aircraft maintenance as maintenance technicians keep still or are in slow motion most of the time. An ultrasonic tracker is sensitive to ambient noise, wind speed and temperature. It cannot be employed for engine related tasks. An optical tracker has the requirement of line of sight. It is therefore more applicable to exterior tasks.

For tasks containing simple actions of locating a specific object or moving it from one place to another, traditional input devices like mouse and keyboard offer a good solution. Otherwise, advanced input tools such as Smartphone or Tinmith glove aforementioned should be employed for complex interactions and data exchange. Hence, mouse and keyboard can be used as augmented reality input devices to assist the parts replacement or visual inspections while the advanced counterparts are optimal for fault identification or isolation.

The above discussion is an overview of technologies' selection for augmented reality. Details will be discussed in a later chapter.

2.5.2 Trends

A head mounted display is still widely adopted for augmented reality applications. And with the integration of a global positioning system, high performance processor and high resolution screen, Smartphone is increasingly popular as a handheld display. Future augmented reality displays are supposed to be sufficiently lightweight, smaller with a higher resolution with a larger field of view as well as reasonable price. High quality and attractive looks also should be taken into account. Augmented reality contact lenses, even the implanted augmented reality in head, have been coined by Feiner (2011).

As markers are not always allowed to be attached to objects in the surrounding environment, especially on aerospace products due to safety concerns, markerless tracking may be more applicable in future. Besides, markerless tracking is well suited for mobile applications. In addition, by reviewing papers in the past years, computer vision based tracking is more active than sensor based tracking. Hybrid tracking which combines several tracking technologies provides more robustness and accuracy compared with single tracking methods (Zhou et al., 2008). For instance, Klein and Drummond have demonstrated a hybrid tracking system in 2003 combining model-based tracking technology with inertial trackers. Foxlin et al. (2004) employed optical and inertial tracker systems for cockpit helmet tracking. Bleser et al. (2006) developed a model based hybrid tracking to explore unknown parts of the scene.

The user interface needs to be further improved to be more convenient and efficient for users to operate. Not only the visual cues, but also the haptic (Anabuki and Ishii, 2007) and audio (Higa et al., 2007) methods can be taken advantage of to enhance user experience. Moreover, multimedia guidance information such as voice messages and video clips can be added since they will be more informative rather than simple textual annotation.

Augmented reality systems, taking advantage of internet and computer developments, are becoming faster and more reliable to better support distributed and collaborative work, which meet the increasing competitive business and industry environment. Furthermore, with the prevalence of the wireless network, mobile augmented reality will play a more important role in the future, as will be discussed in chapter 5.

2.5.3 Gaps

It can be argued that one of the main goals for an enterprise is to investigate a potential novel technology in the hope of generating more potential profit in future. However, little research has been conducted to assess the cost-benefit or cost-effectiveness of augmented reality so far (Dias et al., 2007). Moreover, to the best of the researcher's knowledge, there is no research that has been carried out to develop a systematic process for selecting and implementing augmented reality within a new aerospace industry such as the Chinese aerospace industry, although work from Gautier et al. (2007) is an example that developed a similar systematic process for an augmented reality application in the aerospace industry, which means that there are few people from the aerospace industry in China understanding augmented reality in this way and there are few chances for them to be involved in the implementation of this technology. This research will therefore aim to bridge these gaps in chapter 4 and chapter 5.

2.6 Summary

This literature chapter introduced the novel concept of augmented reality and reviewed the individual technologies currently employed for augmented reality, ranging from display, tracker, input device, processing device to software platform. A comparison was made to determine the relative advantages and disadvantages of each technology. Also, applications of augmented reality to different areas were introduced and applications to aircraft maintenance were highlighted. Finally, the future trends of augmented reality were defined and research gaps were found based on the above literature review. The whole research therefore aims to address the cost benefit analysis and implementation issues that are currently not available to the Chinese aerospace industry.

3 RESEARCH METHODOLOGY

3.1 Introduction

In this chapter the research methodology will be introduced. The research methodology is divided into three parts: state of the art, development and validation. Specific features of the Chinese aerospace industry were taken into account to make suggestions for the development.

3.2 Methodology

Since the information of the topic studied is comprehensive, Data analysis is the most important tool for this research to achieve the aim and objectives. It analyses different perspectives and summarises them into useful information. Data analysis can be used in the development phase. Questionnaire (Oppenheim, 2005) is another useful tool for this research. It helps the researcher to gather information and opinions from respondents. Questionnaire was used in the validation phase. The aim of questionnaires designed in this research (Appendix A and Appendix B) is to investigate the completeness and usability of cost benefit analysis framework and implementation framework, as well as collect feedback from correspondents. Face to face and telephone interview were adopted. The research methodology is mainly divided into three parts, as illustrated in Figure 3-1.

3.2.1 State of the Art of Augmented Reality Technologies

In this part, the researcher focused on the understanding of the project at this stage. Comprehensive literature with reference to the research area, such as journal papers, conference proceedings, related theses and books were reviewed to gather sufficient information on this project. It is helpful to the following phases. The primary aim of this phase is to find out the state of the art of augmented reality technologies and their strengths and weaknesses, as well as related applications and researches, especially those for the aerospace industry, and thus identify the research gaps. The aim and objectives of this research will therefore be derived from the research gaps.

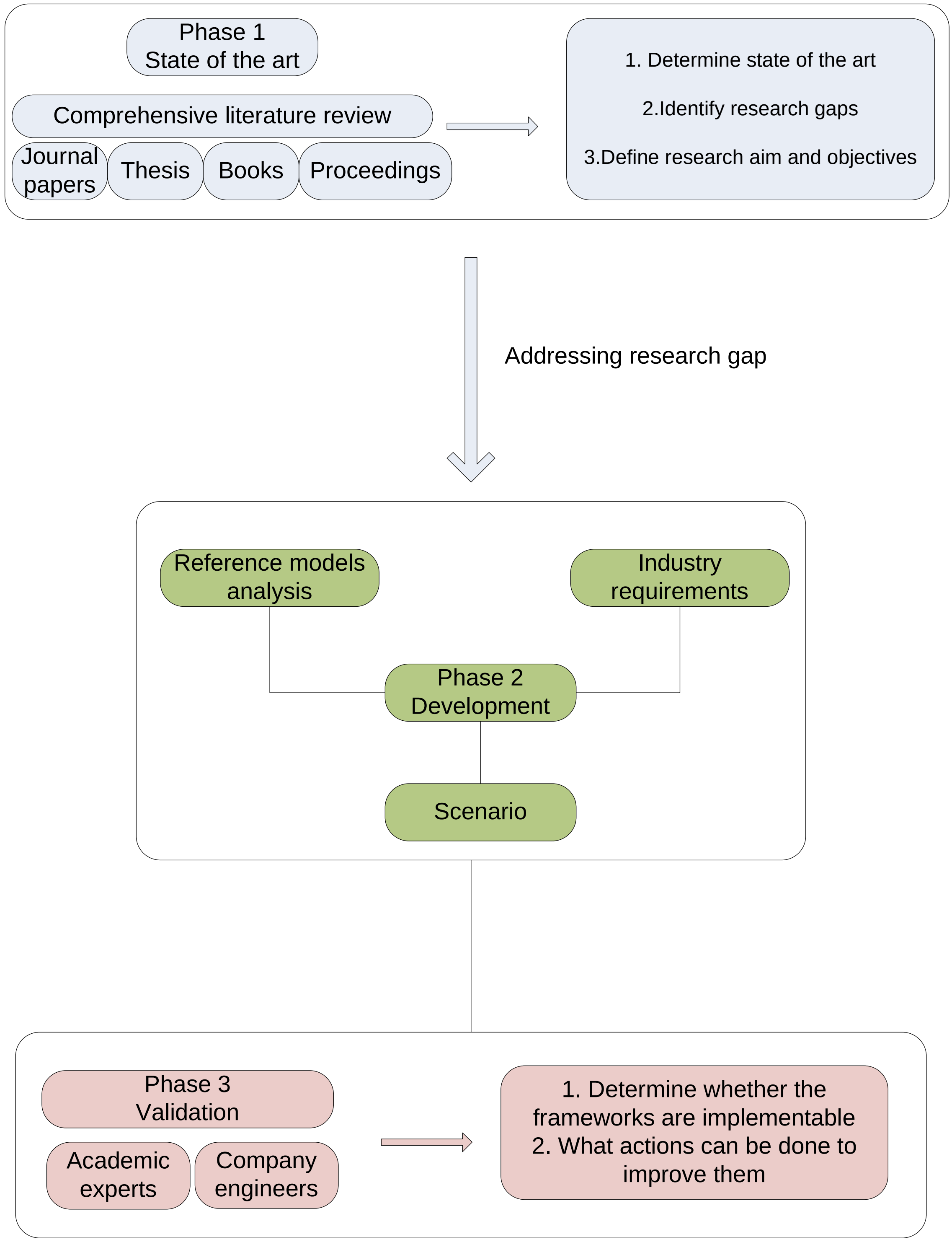

Figure 3-1 Research Methodology

The researcher was aware of the role of COMAC as a newcomer to the world aerospace industry. The selection of literature was focused on the aerospace industry, such as those from Boeing, National Aeronautics and Space Administration (NASA). And the researcher believes COMAC will therefore benefit from these leaders in the aerospace industry.

3.2.2 Development of Frameworks

Two Frameworks were developed to address the research gaps, namely, a cost benefit analysis framework and an implementation framework. Frameworks or models developed by other researchers were picked up for analysis on the basis of the literature review. Useful elements were derived from reference and critical factors of frameworks were therefore identified. Industry requirements or situations, in particular the current status of maintenance in COMAC, were taken into consideration for further analysis.

Then, the frameworks were developed. A scenario was subsequently proposed to investigate the usability and feasibility of the frameworks.

Specific Features of Chinese Aerospace Industry

The Chinese aerospace industry has specific features. The framework development process had taken care of these features. And these features were used to make suggestions for constructing the scenario.

Augmented reality is new to the Chinese aerospace industry. Few people understand it and so there is little chance for them to implement this technology. The frameworks should be simple and easy to understand so that users with limited understanding of AR will find it handy to develop projects.

Moreover, safety is of major concern in the aerospace industry. In order to catch up with competitors and build up a worldwide reputation, COMAC must pay special attention to this factor. As AR has not reached full maturity in use, it may be risky for COMAC to employ it for maintenance at present due to safety concerns. The scenario was therefore constructed from training related departments.

Methodology for the Development of Frameworks

The proposed cost benefits analysis framework is based on literature and references. Useful theories and methods were derived from successful models by taking into consideration the state of augmented reality and the background of the Commercial Aircraft Corporation of China (COMAC). For example, an experiment aimed to compare augmented reality with conventional maintenance methods currently used in COMAC was proposed. There are three pieces of work in this framework. The first one, mainly based on the NASA cost estimating handbook (NASA, 2004), performs a cost estimation to generate a rough number C_t for implementing an augmented reality system. The second one carries out a benefit analysis to decide the direct cost saving B_s and intangible benefit B_I. The hidden benefit is determined through the cost-effectiveness analysis by comparing augmented reality with conventional maintenance methods, manual based for instance. Also, a risk assessment was carried out to identify the potential cost incurred C_r from AR system adoption or failure. Finally, these three tools were then integrated into a single framework.

Another framework of augmented reality implementation was developed using the same method. The cost benefit analysis was taken into consideration as an element, and was integrated into this framework.

Both the two frameworks were applied to a scenario chosen from COMAC to investigate the feasibility and usability.

3.2.3 Validation of Frameworks

The last part of the research methodology is the validation of frameworks. It was undertaken by experienced engineers from the company and academic experts.

Four experts from Cranfield University were interviewed separately. A presentation of the two frameworks was given and two questionnaires were presented afterwards. They were asked questions about: (1) if the given elements in the framework are enough? (2) Are the frameworks completed? (3) What are the benefits of the frameworks for industry? (4) What are the weaknesses of the frameworks? What actions can be taken to improve?

Mr Hu Guangping and Mr Guo Zhongbao are senior engineers from the Commercial Aircraft Corporation of China. And they are director and deputy director of Safety, Reliability and Products Support Department of COMAC respectively. The wo senior engineers who have worked in the Chinese aerospace industry for over twenty years were involved in the industry validation. They were presented with the document first, and further communication was helped by telephone and email. Two directors had a meeting to discuss the two frameworks later on.

The same questionnaires were used for both university and industry respondents.

All the respondents provided feedback and comments on the frameworks. The frameworks were validated to find out if they are rigorous and implementable and what actions can be taken to improve them. Afterwards the research thesis will be written and submitted.

3.3 Summary

This chapter introduced the three parts of research methodology, namely state of the art, development and validation. The details of each part was given, with the main tasks of each part covered.

4 COST BENEFIT ANALYSIS FRAMEWORK

4.1 Chapter Aim

Although AR has achieved dramatic progress over the past few years, little work has been done to understand the cost and benefit for implementing AR (Dias et al., 2007). And currently there is no significant related research which can be found in a large database, Cranfield University library or search engine. The aim of this chapter is to present a framework which enables the aerospace industry to perform an overall evaluation of costs and benefits associated with the potential application of augmented reality, in order to determine its economic and technical feasibility. This chapter also introduces the methodology for the development of this framework and explains how this framework has been developed. Finally, the results of this framework will be analysed.

4.2 Overview of Framework

There are three pieces of work in this framework (See Figure 4-1). The first one, mainly based on the NASA cost estimating handbook (NASA, 2004), performs a cost estimation to generate a rough number C_t for implementing an augmented reality system. The second one carries out a benefit analysis to decide the direct cost saving B_s and intangible benefit B_I. The hidden benefit is determined through the cost-effectiveness analysis by comparing augmented reality with conventional maintenance methods, manual based for instance. Also, a risk assessment was carried out to identify the potential cost incurred C_r from AR system adoption or failure. Finally, these three tools were then integrated into a single framework.

If the total benefit $B_t = [(B_s + B_I) - C_t - C_r] > 0$, in other words the total benefit exceeds the aggregate cost (Molinos-Senante et al., 2011) in monetary terms, augmented reality system will generate profits for the aerospace industry, airlines in particular, offering a good option.

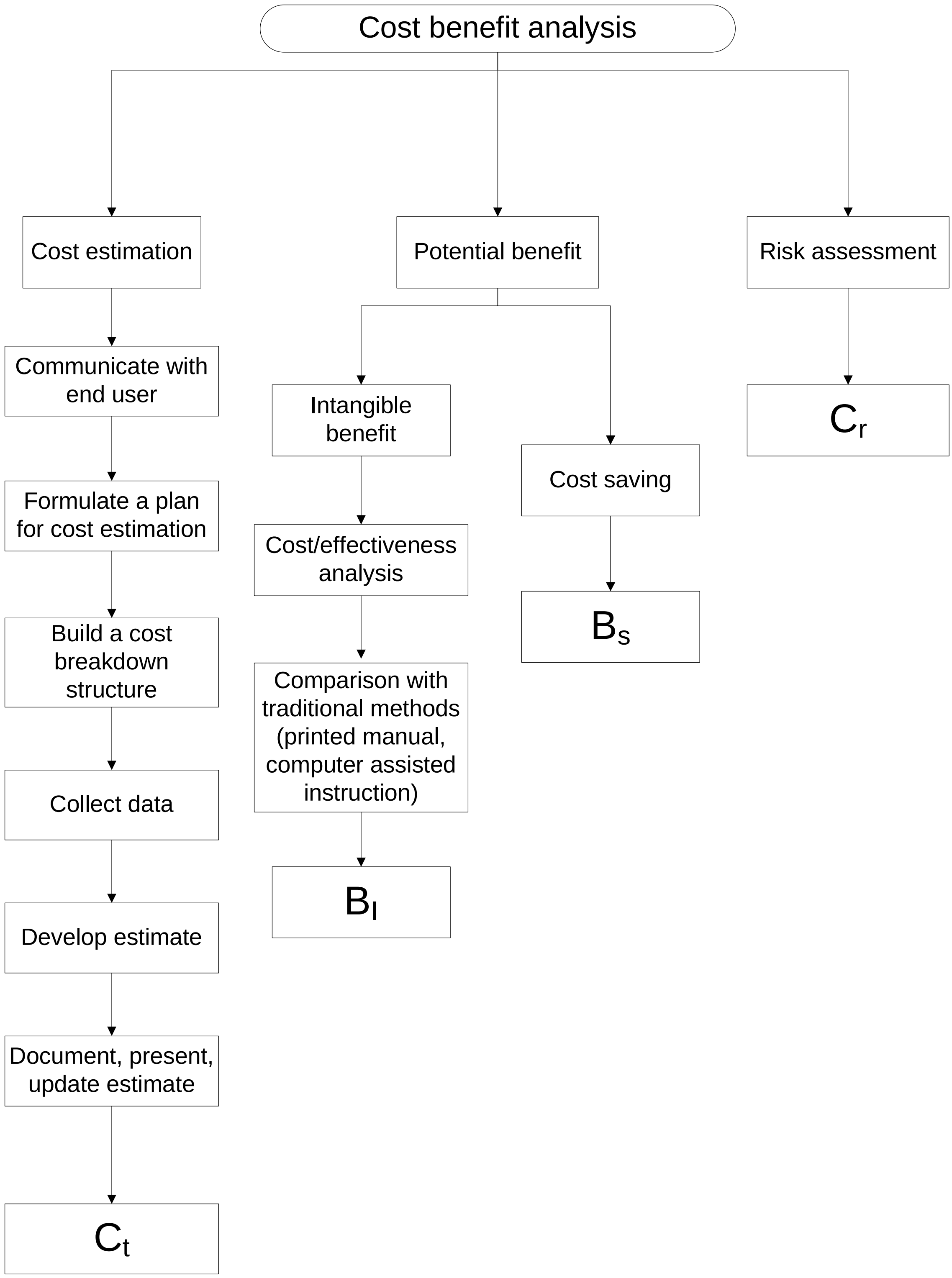

Figure 4-1 Cost Benefit Analysis Framework for Augmented Reality

4.3 Cost Benefit Analysis

The proposed cost benefits analysis is on the basis of the literature review and references. The steps are coming from useful theories and methods in successful models. Specific features of the Chinese aerospace industry were taken into account to make suggestions.

4.3.1 Cost Estimation

There are many cost estimation processes, such as quantitative and qualitative cost estimating from Roy (2001) and cost modelling for Airbus by Scanlan et al. (2002), but the NASA cost estimation process (NASA, 2004) is one of those considered to be best practice in the aerospace domain, because it has a close relationship with aerospace industry.

(1) Communicate with End User

At the inception of new commercial projects, the first principle to be established is the level of market interest and what price the market will pay for the goods or services that are provided (Salas, 2004). The real and tangible effects of AR have not been identified yet. The primary aim of this step is to establish effective communication between cost estimators and end users in order to find out their willingness to pay for this innovative application. If end users have every confidence in investment in an augmented reality system, the cost estimators could move on to the following step of identifying the requirements of this system. Or otherwise, this project might come to an end.

This research aims to develop a framework for implementing an augmented reality system within the Chinese aerospace industry. Airlines are, visibly, the end users of this maintenance application. Given that manual oriented maintenance currently serves as a major method among airlines, whether the airlines want to take advantage of an augmented reality system as a practical tool or for training inexperienced engineers needs to be specifically predefined. Accordingly, the specifications of an augmented reality system can be drawn up. Training, for instance, does not require accurate registration, whereas precise registration, fast processing is crucial for applications in practical use. And many other aspects, like safety and ergonomics, should taken into consideration as well.

(2) Formulate a Plan for Cost Estimation

After communicating with customers, cost estimators will focus on understanding the project and defining the scope of cost estimation. The objective of this task is to draw up a plan for the following cost estimation process. Four critical elements, data, expectation, resource and schedule (NASA, 2004), need to be carefully studied.

Data concerns are with the data type and availability. Reliable cost estimation is based on selecting proper information from a wide scope of resources. Drawings and specifications are useful. Also, designers and vendors are common sources to seek for technical and cost information on estimating objects (Roy et al., 2011). For implementing an augmented reality system, data such as system description, hardware and software and labour costs should be included. And it is also imperative to evaluate whether these data are suitable and sufficient for estimation.

Expectation reflects the outcome or usage of cost estimation. It addresses issues about expectations of the decision maker and estimating team, and the purpose that it is going to be achieved.

Resource indicates the number of people and budget available for cost estimation. Schedule is about the time to complete the estimation. These two aspects are of minor concern as this research focuses on cost estimation rather than the process of estimation.

(3) Build a Cost Breakdown Structure

After gathering relevant information about customer needs and system requirements, and laying down a set of general guidelines for cost estimation, process moves onto the next stage of building a cost breakdown structure. This task aims to provide a structure which includes all elements of a project whose costs can be estimated, such as specific amounts of labour, specific procurements and services, etc. (Aster, 2008).

In the case of an augmented reality system, the cost breakdown structure should clearly indicate what kind of displays, trackers, interaction devices and processing equipments have been employed in the augmented reality system. It also shows which platform and software are incorporated in this system. Additionally, cost breakdown structure records all activity related costs such as training, system test and management cost.

(4) Collect Data

To produce an accurate cost estimate, it is essential to seek a variety of sources for relevant information and offer them to the cost estimator.

Typical data sources are basic accounting records, historical database, technical database, engineering specifications and drawings (NASA, 2004). Also, data can be collected by request for quotation, contractor reports, manufacturer website, earlier documented cost estimates and published cost studies. Questionnaires or surveys with individuals can be used to help obtain data as well (Williams, 2008).

Moreover, before the data can be used, normalisation is required to ensure the uniformity and completeness of costs (Habib-Agahi et al., 2011). In other words, adjustments should be made to correct for known biases and inconsistencies, inflation rates for instance.

(5) Develop Estimate

Once the necessary data has been collected and normalised, it is able to develop a cost estimation. Niazi et al. (2006) introduced a typical classification of cost estimating techniques. They presented four major cost estimation methodologies (See Figure 4-2). Analytical methodology was selected due to the following reasons:

1) An augmented reality system is innovative so no previous system can be compared to it to identify similarities. Qualitative methodology is therefore not appropriate;

2) This research aims to perform a cost estimation of implementing an augmented reality system within the aerospace industry rather than a cost estimation of developing an augmented reality system. Implementation is a comprehensive process which consists of materials, activities and operations. Analytical methodology, mainly focusing on the analysis of the design process and features of the product, serves as an optimal tool.

The total cost is calculated by adding up all the figures of cost that are determined at the previous stages. It is an estimated figure or educated guess for the decision maker and buyer to measure the product.

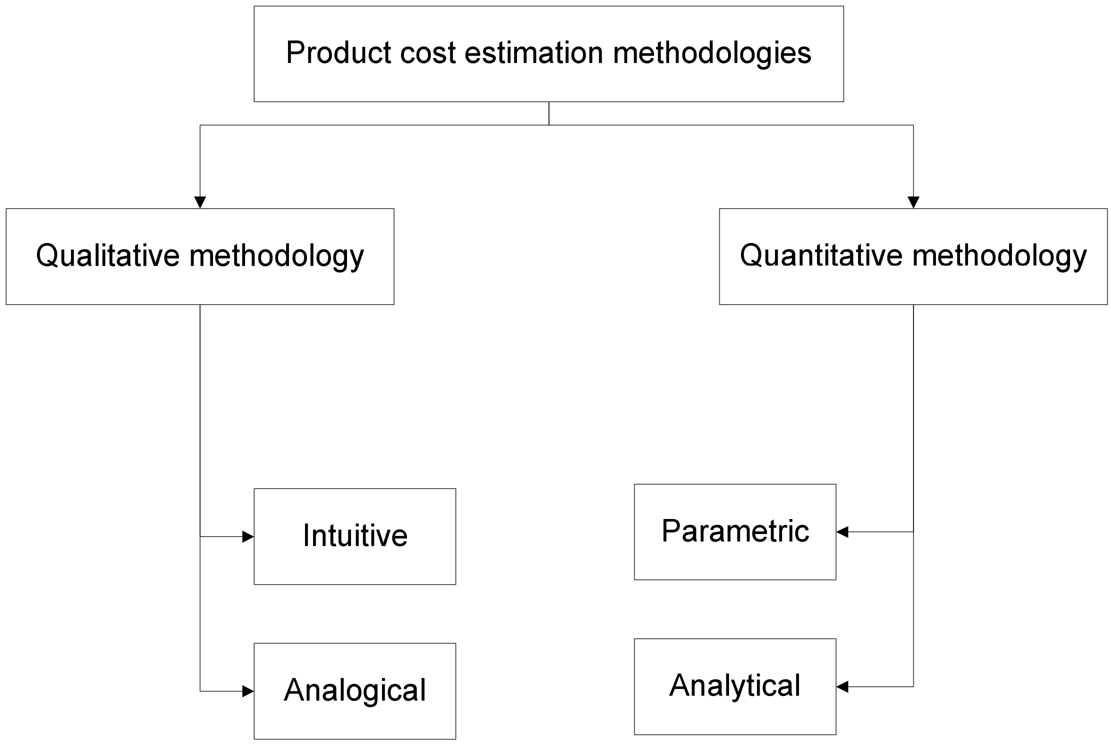

Figure 4-2 Classification of Cost Estimation Methodologies

(6) Document, Present and Update Estimate

In this task, the entire estimation process should be recorded and presented to the decision maker and customer. By organising a proven cost estimation process and the relevant cost data, documentation will help re-estimation or update, and lead to more effective and consistent estimation (Kinney and Soubiran, 2004). In the case of augmented reality, given the rapid changes of electronics used in the system, periodical data adjustment is essential to ensure the accuracy of cost estimation.

4.3.2 Assess Potential Benefit

Cost Saving

Price, market price in particular, is a reasonable starting point that can be assigned to a variable to measure benefit (Williams, 2008). However, the market price may not be applicable to this research:

1) Commercial Aircraft Corporation of China (COMAC) is a state-run company. Government intervention may affect the market as well as the price;

2) An augmented reality system may not be directly sold but provided as part of customer service. As such, the benefits are not associated with price.

Thus, alternative methods can be considered to value the benefits:

Williams (2008) suggested averted costs as a potential proxy in various areas. In other words, the salaries of personnel and the costs of equipments saved by employing an augmented reality system can be calculated to measure the benefits. Take the operating costs in the airline industry (Tsai et al., 2004) for instance, salaries of maintenance engineer, costs of parts and components, and hangar costs that are reduced through employing this system can be counted as benefits B_S.

Intangible Benefits

Chung et al. (2002) pointed out that in the evaluation stage of a design, three major types of attributes could be used to determine the potential benefits, namely system, task performance and human. System attributes are concerned with system functions and specifications such as maintainability and reliability. Task performance mainly deals with the quality and quantity output like time of completion and number of errors. Human attributes, meanwhile, reflect behavior and response of humans by physiological indices and subjective assessment.

Through experiment, potential benefits can be quantified in terms of time saved and performance improvement on the basis of the previously mentioned criteria. An experiment for cost-effectiveness analysis will be discussed later. The time saved and performance improvement in maintenance is proportional to the flight hours, which has direct impact on income from each aircraft. Hence, the potential benefit B_I can be calculated in monetary terms.

Falck et al. (2010) pointed out that cost benefit analysis has difficulty in determining the figures and facts. Cost-effectiveness analysis, which used for determining projects with same goal, therefore offers a useful alternative to measure the intangible benefits of augmented reality.

A well controlled experiment can be conducted to compare augmented reality with other traditional maintenance methods: manual and computer assisted instruction (CAI). The main types of measurements are task performance such as the time of completion, improved accuracy and reduced errors, as well as the reduced cognitive load of the task. This experiment is distinct from some previous work done by Tang et al. (2004) and Henderson and Feiner (2009). Tang et al. (2004) only focused on the assembly task, whereas this experiment considers the diversity of maintenance tasks such as removal, assembly and inspection, as well as the balance of the age, gender, and background of participants. Henderson and Feiner (2009) did not draw a comparison between augmented reality and the traditional printed manual, which remains the principal method for maintenance in the aerospace industry nowadays.

4.3.3 Risk Assessment

The cost of one accident is much bigger than other costs. In particular, a failure of any part or system within the aerospace industry leads to catastrophic consequences. Hence, it is vital to carry out risk assessment and calculate the risks incurred costs C_r

The risks are associated with AR system failure and safety issues that may incur costs. On the other hand, AR can reduce the risk of having a catastrophic failure in maintenance. This may reduce costs.

4.4 Scenario for Demonstration and Validation

In order to investigate the feasibility and applicability of this framework, a scenario is developed based on COMAC. This cost benefit analysis framework will be applied to this specific scenario.

4.4.1 Scenario Description

One possible scenario is that the product support and customer service department in COMAC would like to make use of an augmented reality application to support maintenance technician training in order to replace the conventional manual and computer based ones. The following paragraphs will describe how to evaluate costs and benefits of an augmented reality system under this circumstance.

Step 1 Communicate with End User

COMAC will establish a communication with airlines in an attempt to ascertain their willingness to pay for an augmented reality system in the first place. In terms of safety, airlines may indicate reluctance to accept such a novel technology. However, consider following reasons:

1) Augmented reality is used to support training rather than introduce a radical change in maintenance;

2) Virtual reality applications have increasingly appeared in the aerospace industry in the past few years, which bear evidence that airlines have a strong intention to improve maintenance.

This research makes an assumption that airlines will be delighted to take part in the trial on the basis of the above analysis.

As the augmented reality system will not be exploited in practical work under the scenario, accurate registration and high performance computers are not necessary for engineers. This system will be built to satisfy basic requirements.

Step 2 Develop Cost Estimation Plan

Following Table 4-1, Figure 4-3 and paragraphs illustrate the plan of cost estimation:

1) Expectation: This cost estimation aims to help decision makers within COMAC and airlines gain an appreciation of implementing an augmented reality system in monetary terms so as to reach a decision.

2) Data:

Table 4-1 Data of Cost Estimation

Data	Data Sources	Notes
Technical Data	Technical database Engineering Specifications Drawings	Constitutions, description and characteristics of this system
Labour Cost	Contracts Statistics	Salary level
Production Cost	Vendor Historical database	Costs of the hardware and software
Service Cost	Statistics Historical database	Cost of system test, management and energy cost

3) Resource: The number of people required and budget available to conduct the cost estimation should be identified at this step;

4) Schedule: For implementing an augmented reality system for training purposes within COMAC, specifications and characteristics of aircraft are required. Therefore, the cost estimation should start from the conceptual design stage of an aircraft, and end after the detailed design stage. Only at that time, will all the necessary data be available.

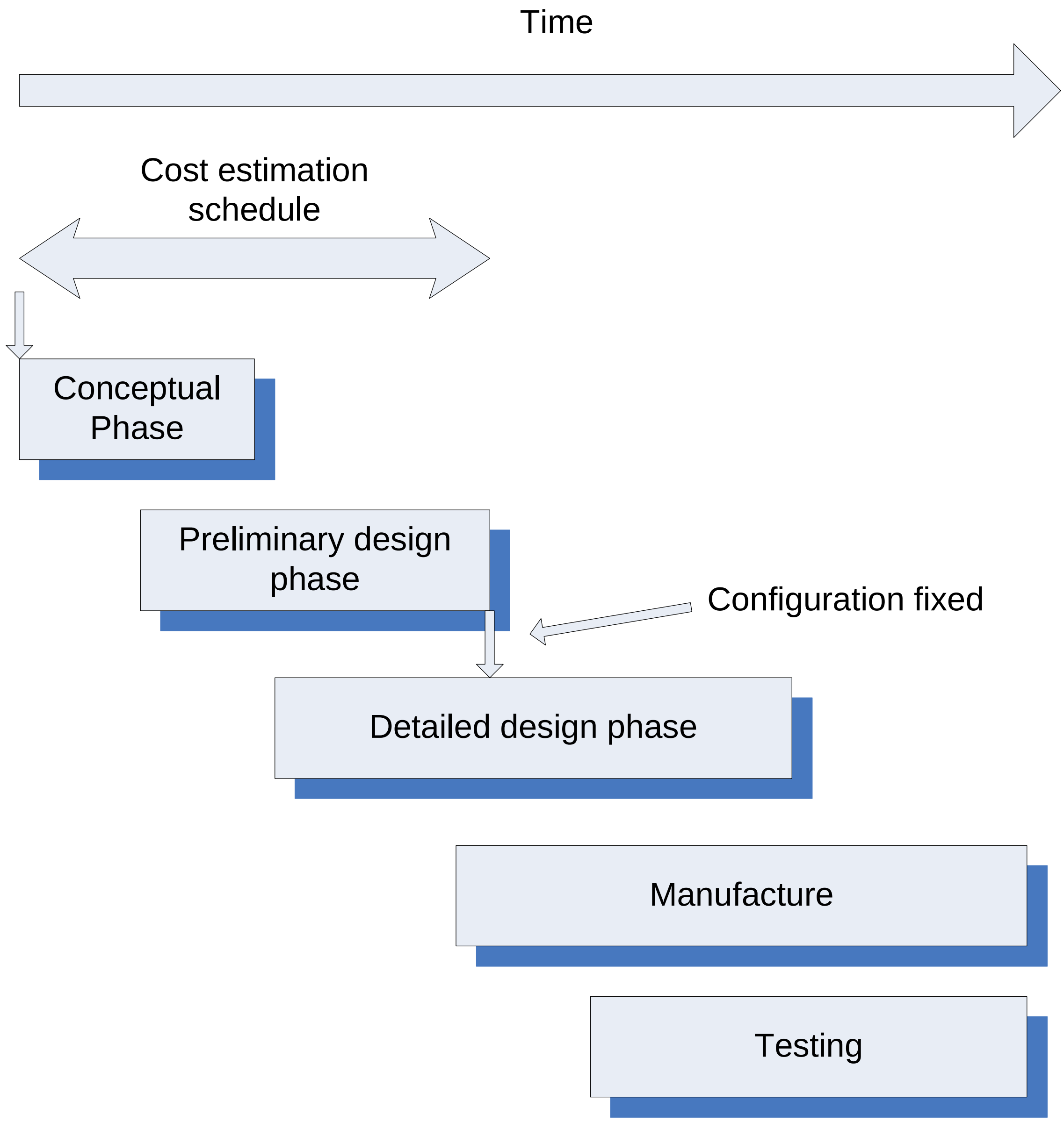

Figure 4-3 Cost Estimation Schedule

(Jenkinson et al., 1999)

Step 3 Build a Cost Breakdown Structure

How to select various technologies to implement an augmented reality system will be discussed later in chapter 5. Given that the configuration of an augmented reality system for this research has been determined, all cost breakdown structure elements related to cost will be categorised and listed below in Table 4-2, Table 4-3 and Table 4-4.

1) Infrastructure:

Table 4-2 Infrastructure Related Cost

Hardware	Optical see-through head mounted display
	Tracking system(model-based computer vision)
	Laptop
	Smartphone
Software	Studierstube/ ARToolKit professional
	Windows™ operating system
Networking	Wi-Fi infrastructure
Overhead Cost	Office, labouratory, furniture, stationery, energy cost

2) Activities:

Table 4-3 Activities Related Cost

System Setup	System integration Virtual objects generation
System Test	All costs associated with system test
Data Access and Management	Hardware for data access and storage Labour costs related to these activities
Maintenance	Hardware and software maintenance, data maintenance
Training	Training facilities, personnel, site operation for training

3) Management:

Table 4-4 Management Related Cost

Planning	Cost involved in drawing sketch for whole project
Administration	System management, personnel management

Step 4 Collect Data

In this step, all the potential data collection sources for the above elements will be listed:

1) The cost of hardware can be obtained from a request for a quotation from vendors;

2) The cost of software can be obtained from the manufacturer website, Microsoft for instance, and a request for quotation. However, it is recognised that actual prices may be different based on negotiation;

3) Networking and overhead costs can be calculated by assuming they account for a certain percentage of the original investment;

4) Labour cost refers to all costs generated in activities and management that are associated with personnel. It can be calculated by salary level and time.

Step 5 Calculate Total Cost

The total cost can be obtained by summing up all costs identified during the previous step. As some required data from China is currently not accessible, this research takes advantage of data collected within the UK to make the calculation. For instance, labour costs are collected from PayScale (2011) and the hardware price is from WorldViz (2011).

Considering the rapid development of computer, network and Smartphone technologies, cost estimation is made on a 5-year design life assumption.

To simplify the calculation, activities and management related costs are counted into overhead cost. And the researcher assumes the overhead cost accounts for 10% of the overall application cost. System set-up has direct a relationship with application, it is therefore calculated separately.

Table 4-5 Cost Estimation

Item Description	Cost (£)	Notes	Source
Optical see through display	3000-20000		WorldViz
Tracking	500-4000		WorldViz
Laptop	300-800		Vendor
Smartphone	200-500		Vendor
ARToolkit Professional	5000	Support 700-1500 per year	WorldViz
Windows XP Operating System	50-100		Manufacturer Website
Wi-Fi infrastructure	10-50	Networking 500-1000 per year	Vendor
System setup	1000-2500	Per application per day	PayScale

The average cost of one application is approximate £28000.

There are 5-10 maintenance engineers for each aircraft. Hence, 8 sets of applications are required, which is 28000*8=£224000.

Overhead cost=224000*10%=£22400.

Therefore, the total cost C_t=224000+22400= £246400.

Step 6 Calculate Benefits

The averted costs by adopting an augmented reality system for training in COMAC are:

1) An augmented reality system saves the computation costs involved in constructing complex virtual environments (Vacchetti et al., 2004) while the instruction information is projected onto the real world. And it eliminates the costs of printing manuals which are normally tens of thousands of pages;

2) Aircraft maintenance is a comprehensive and multidisciplinary subject, which includes structure, aerodynamics, avionics, hydraulics, etc. Therefore, the maintenance engineer training requests a group of specialists from different

areas. By employing an augmented reality system, the considerable costs of employing professionals can be saved;

3) By replacing conventional computer based training (CBT) with augmented reality based training, the costs for device and site operations can be cut;

These costs can be directly counted into the benefits of augmented reality in terms of money (See Figure 4-4).

There are about 40 manuals delivered with aircraft. If every two engineers share one set, 4 sets of 40 manuals are needed for 8 engineers. The cost of manuals is as follows on the basis that each manual costs ￡100:

Cost of manual=4*40*100=￡16000.

Training for maintenance engineers normally consists of 3-5 sessions and about 10 experts from various areas are involved in each training session. The cost of training personnel can be calculated if each of the expert charges ￡300:

Cost of personnel=4*10*300=￡12000.

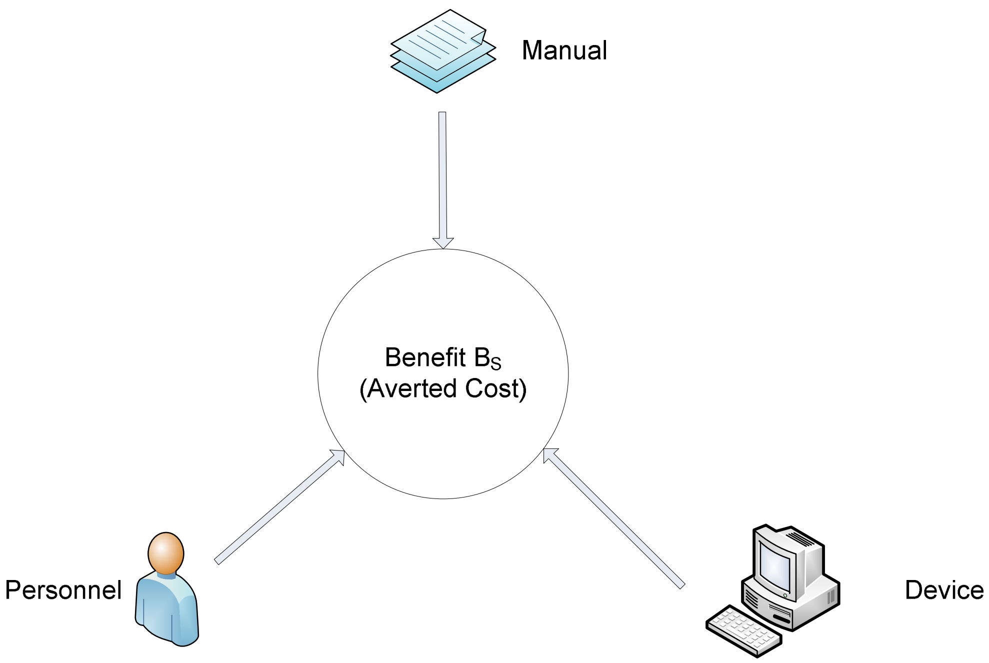

Figure 4-4 Illustration of Benefits B_S (Cost Savings)

Boeing Computer Based Training (CBT) software charges ￡25000. If two engineers share one platform, 4 platforms are required for 8 engineers. The cost of training devices is therefore calculated:

Cost of device=25000*4= ￡100000.

Cost saving B_s=16000+12000+100000=￡128000.

The intangible benefits of adopting augmented reality system for training in COMAC are:

1) With the adoption of augmented reality based training, the time of experienced engineers and experts can be saved due to on the job training, which results in increased productivity in maintenance;

2) Interaction between users and an augmented reality system is intuitive, which guides engineers to perform tasks efficiently and prevents them from misunderstanding maintenance procedures;

3) Maintenance engineers may be enthusiastic about an augmented reality system due to its novelty. Besides, it offers multimedia information to engineers and they will be more willing to listen, watch and read (Carmigniani et al., 2011), thus boosting productivity;

4) By adopting an augmented reality system, a maintenance engineer does not have to keep lots of information in working memory, and therefore their mental workload reduces significantly (Tang et al., 2004);

5) The time spent on searching manuals for instructions and retrieving information can be saved by making use of an augmented reality system, which decreases the maintenance time (Haritos and Macciarella, 2005). The percentage of the time saved and performance improvement can be identified by the cost-effectiveness analysis. Thus, the intangible benefits can be monetarised by operating costs of airlines using percentage of downtime decreased (See Figure 4-5).

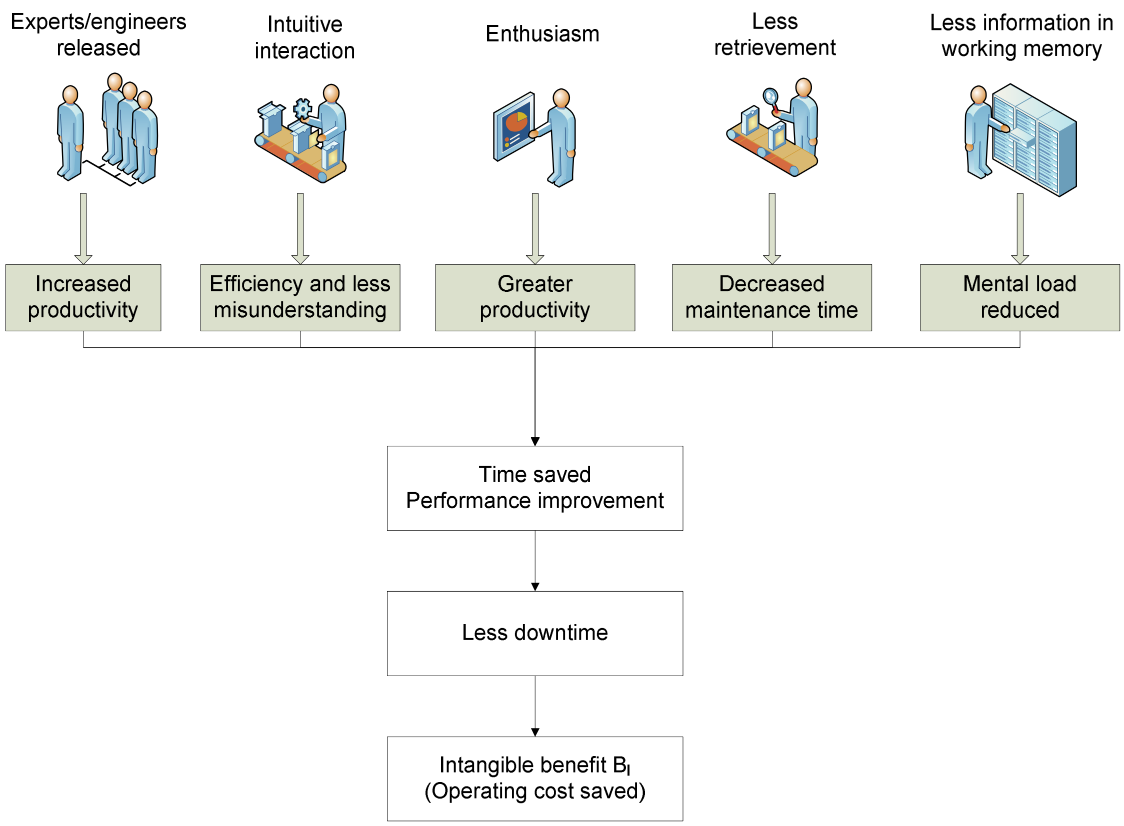

Figure 4-5 Illustration of Intangible Benefits

Step 6.1 Cost-effectiveness Analysis

A controlled experiment will be designed to determine the effectiveness of augmented reality.

Participants

A group of participants will be divided into three teams while each team has the same number of people by gender. Every participant shares similar educational background and working experience, and has the same knowledge about augmented reality.

Maintenance Tasks

Participants will be asked to perform oil pump fault check and isolation tasks, which involve inspection (determination of the faulty parts), removal (disassembly of the oil pump) and assembly (replace faulty parts).

Experiment Conditions

The experiment will be carried out on real aircraft under the same weather conditions. Three teams make use of traditional manuals, augmented reality and computer assisted instruction (CAI) as instruction media respectively.

1) Augmented reality: All necessary information such as maintenance procedure and annotation is superimposed upon real objects. Participants follow the instructions to fulfill the task;

2) Manual: Participants carry the relevant chapter of the aircraft maintenance manual (AMM) and the aircraft illustrated parts catalogue (AIPC) with them, and they are allowed to consult manuals anytime;

3) Computer assisted instruction (CAI): A laptop providing instructions is positioned at the workplace.

Measurements

Time of completion: The total time cost for each participant from the start of experiment procedure until he/she finishes the job.

Number of errors: Unconformity or failure on one piece of normal procedure in the manual will be counted as one error.

Mental workload: NASA task load index (Tang et al., 2004) will be employed to rate the parameter.

Experiment Procedure

Firstly, participants will be guided to adjust the augmented reality system and laptop. Participants from each team then start work at the same time on three aircrafts of the same model in the hangar. The time they spend and number of errors they make will be recorded. After the maintenance tasks, participants will take part in the test by the NASA task load index rating. Another three participants from each team will repeat the procedure afterwards until all participants finish. All results will be recorded for statistics.

Calculate intangible benefit

By comparing the three parameters, COMAC and airlines are then able to arrive at a conclusion whether augmented reality is more effective compared with the other two methods. And the percentage of time gained and performance improvement by employing an augmented reality system will be used to value the intangible benefits.

According to related research, augmented reality may improve the performance by 10%, which is equivalent to 10% less downtime. Assuming downtime cost accounts for 30% of total operating cost, and the operating cost of each aircraft per year is ￡365000:

Intangible benefit B_I(5-year in total) =365000*30%*5=￡547500.

Step7 Risk Assessment

Safety is a matter of utmost concern within airlines. Any potential risks introduced or reduced by applying an augmented reality system must be carefully studied. And airlines may incur a heavy loss or gain a heavy profit through these risks.

1) Continuously wearing bulky head mounted display may cause fatigue;

2) Head mounted display with narrow field-of view raises safety issues when performing maintenance tasks in cramped conditions;

3) Liquid crystal display used for interaction demonstrates poor visibility in bright outdoor conditions (Rose et al., 2010);

4) Precise registration remains a major challenge since tracking systems suffer from illumination conditions, occlusion and rapid motion (Platnov et al., 2006);

5) Since augmented reality transfers multimedia content, network connection speed, and reliability raise a key issue (Rose et al., 2010);

6) Augmented reality making use of global positioning system (GPS) for tracking is subject to the reliability of location data (Rose et al., 2010);

7) Occlusion of the real world by poor layout of virtual objects may affect performance, even resulting in safety issues (Ong et al., 2008);

8) It takes time for engineers to adapt the new system, which indirectly increases the maintenance time.

Figure 4-6 illustrates the incurred cost through system failure and safety issues.

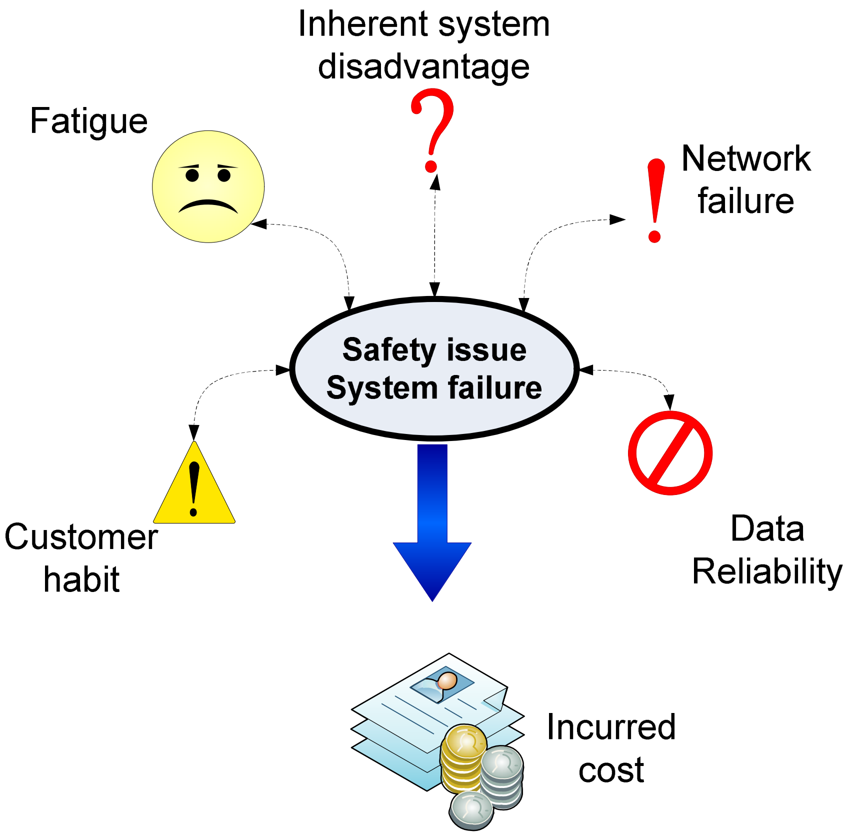

Figure 4-6 Incurred Cost through Systems Failure and Safety Issues

It is a challenge to quantify the cost incurred by an augmented reality system failure. A potential method is to calculate the probability of system failure and impact, which then can be used to determine the cost C_r.

Assuming both direct and indirect costs related to health and safety of per engineer per year is ￡1000 (based on annual commercial medical insurance) and the probability of risks incurred by fatigue and customer habit is 30%:

Costs incurred by safety issues (5-year in total) =1000*8*30%*5=￡12000;

In case of AR system failure, the conventional maintenance method has to be readopted. The cost of system failure can be divided into aircraft maintenance engineers' cost and system recovery cost. Assuming the labour cost is ￡240000 (8 engineers in total), the system recovery cost is ￡20000 (10% of system cost), and the probability of AR system failure is 5%:

Costs incurred by system failure (5-year in total) = (240000+20000)*5%*5= ￡65000.

Human error rates range from 0.006 to 0.06 based on numerous factors (Vesley et al., 2002). In other world, the probability of risks that AR reduces ranges from 0.6% to 6%, given the labour costs of conventional maintenance is ￡240000 per year:

Costs reduced by positive risks of AR (5-year in total) = 240000*3%*5=￡36000

Costs incurred by risks C_r=12000+65000-36000=￡41000.

Step8 Conclusions

$B_t = [(B_s + B_I) - C_t - C_r]$ = (128000+547500)-246000-41000=388500 > 0

According to the calculation, augmented reality is an acceptable application in this scenario.

4.5 Summary

This chapter has proposed a cost benefit analysis framework for augmented reality. The details of each step are given and a possible scenario is chosen to investigate the usability and feasibility of this framework. Validation of this framework by academic experts and company engineers will be introduced in the following chapter.

5 IMPLEMENTATION FRAMEWORK FOR AUGMENTED REALITY

5.1 Introduction

In this chapter, the framework for selecting and implementing augmented reality within the Chinese aerospace industry will be established and described. Firstly, the aim and methodology for developing this framework will be introduced. The following section presents details of this framework. Finally, the validation of this framework will be given.

5.2 Chapter Aim

The efficient training of engineers becomes more and more significant due to the considerable complexity and strict requirements of aircraft maintenance tasks. The study of augmented reality for maintenance training is widely conducted by a number of research groups (Webel et al., 2011). However, there is not yet a systematic process for the implementation of augmented reality within an aerospace industry. The primary aim of this framework is to provide a set of general guidelines and identify basic requirements for applying augmented reality to the Chinese aerospace industry to support maintenance.

5.3 Framework for Implementing Augmented Reality

Figure 5-1 is the framework for implementing augmented reality. The whole process starts with an evaluation of overall feasibility, including need analysis and task analysis. Also the result of cost benefit analysis provides support to the implementation. To develop an augmented reality application, the type of augmented reality system should be determined in the first place. Similarly, it is essential to decide on the operating system before selecting the software. The choice of other augmented reality technologies are based on the type of system and will affect each other. Details of this framework will be explained in the following paragraphs.

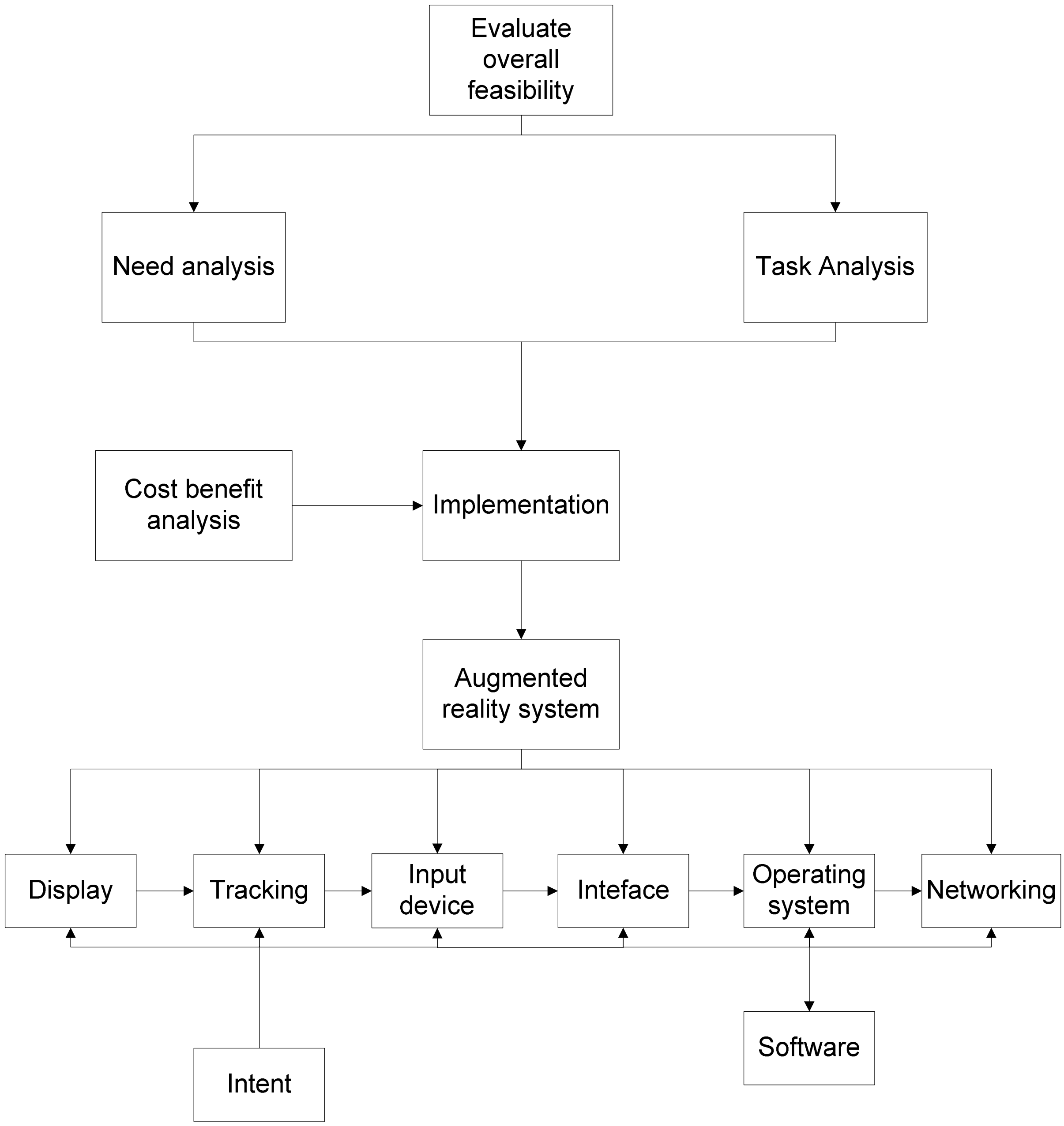

Figure 5-1 Implementation Framework

5.3.1 Evaluating Overall Feasibility

It is critical to investigate the overall feasibility of an application before developing the process (Chung et al., 2002) to determine if this application is implementable and feasible, and which technical alternatives are available. Two steps are included in the feasibility study: need analysis and task analysis. The need analysis states the reasons for building this application. Task analysis describes the requirements that need to be met in this application, in particular, the work environment, degree of resolution and possible interference. For example, the size of the work area, the illumination of the work area and available facilities within the area should be specified for the work environment.

In addition, the overall feasibility evaluation is enhanced by a cost benefit analysis which has been systematically analysed in a previous section 4.3.

5.3.2 Implementation of Augmented Reality

This part will discuss detailed implementation on the basis of overall feasibility evaluation and cost benefit analysis. Each augmented reality technology will be carefully examined and a summary table or conclusion will be given as a range of general design criteria of technology choices for implementing an augmented reality system.

(1) Augmented Reality System

An augmented reality system can be mainly divided into five categories: fixed indoor system, fixed outdoor system, mobile indoor system, mobile outdoor system and mobile indoor and outdoor system. The option of the type of augmented reality system should be determined in the first place when building a new augmented reality application, as it will be of help in determining further configuration such as the type of display and tracking system (Carmigniani et al., 2011). Mobile systems are on the rise because they provide users with the flexibility to move freely. And as mobile indoor and outdoor system is applicable to most cases, it has better chance to reach public market.

(2) Display

There are three kinds of displays available for developing a new augmented reality application, namely head-mounted displays, handheld displays and projection-based displays, which have their respective strengths and weaknesses. They could be employed under certain conditions to meet the requirements of specific applications. For example, handheld displays can be used for mobile systems because of their inherent full mobility. One of the most important aspects of developing an augmented reality application is to properly select the display since it will guide the development process to determine potential tracking techniques, operating systems, and networking.

Head mounted displays are fundamentally categorised into two types: video-see through and optical-see through. They are currently dominant displays (Krevelen and Poelman, 2010) as they are easy to implement. Head mounted displays, can be employed in maintenance tasks which require both hands for interactions since they have the ability to set two hands free. Additionally, they are suitable for both fixed and mobile augmented reality systems. But they are not ideal for jobs lasting a long time in terms of weight, because they cause discomfort and fatigue after a period of time of wearing. Also, they cannot effectively support collaborative work and multiple users (Zhou et al., 2008).

Video See-through Head Mounted Display: Since the real scenes are blended with the virtual objects before displaying, some objects from the real environment could be removed before synchronising. As a result, video see-through head mounted display is a good choice for maintenance tasks involving a number of components. Some parts can be removed deliberately to give engineers a better view of the work pieces. In addition, due to the synchronisation process, the brightness and contrast of virtual images come close to matching the real images, which makes video see-through head mounted display a suitable candidate for maintenance where illumination conditions are strict. Take engine indication and crew alerting system (EICAS) for instance. EICAS employs different light colours to signify different hazard levels. The colour is of great significance for maintenance engineers. Video see-through head mounted display offers maintenance engineers using augmented reality for fault diagnosis a robust solution to recognise the colour. However, video see-through head mounted display has a limited field of view. It is not advisable to be used in cramped environment where sharp edges or objects out of view may pose a threat to engineers.

Optical See-through Head Mounted Display: Because the real world is directly seen by the users, it is much safer to take advantage of optical see-through head mounted displays in adverse maintenance conditions, as opposed to video see-through ones. Especially when the power fails, the users can still see the real world (Krevelen and Poelman, 2010).Nevertheless, users realise the time delay caused by virtual object processing whilst view of the real world is direct. It cannot be used for tasks related to time response. Also, the brightness and contrast of images is decreased in contrast with video see-through ones due to the adoption of transparent mirrors and lenses. It is less appropriate to assist outdoor maintenance. Take aircraft transit check for example. Most checks are external checks and carried out in open air. Virtual objects generated by an augmented reality system may suffer from bright sunlight yielding a negative result.

Handheld Display: There are three different classes of handheld displays commercially available for augmented reality systems: Smartphone, PDA and tablet PC (Wagner and Schmalstieg, 2006). Of all these devices, the tablet PC like the popular Ipad 2 developed by Apple is too heavy to carry with a single hand, or even extended two hand use. It is not good for maintenance tasks including removal and installation that require both hands free at most times. But it has a large size screen and powerful processors making it promising in a mobile augmented reality system for visualisation and simulation. Smartphone is widespread and is familiar to maintenance engineers. And with recent advances in technologies, GPS, a powerful processor, touch screen and high resolution camera have been integrated into Smartphone. The combination of GPS and touch screen especially provides a method for tacking and interaction. The disadvantage is similar to all other handheld displays: users have to hold the display with their hands. It is therefore a promising method for fault diagnosis consisting of interaction and information feedback where both hands are not needed. PDA has become less popular than Smartphone in the last two or three years. It is currently unable to cope with 3D and floating point computation (Papagiannakis et al., 2008) and not enough software has been developed for this platform, making its use difficult for augmented reality. As a result, PDA is a suboptimal handheld display for an augmented reality system.

Spatial Display: Three major spatial displays for augmented reality are existing: screen-based video see-through, spatial optical see-through and projector- based spatial display. Spatial display is placed in the environment and the users do not have to wear or carry the display. It supports group users, and thus allowing collaboration between users (Carmigniani et al., 2011).However, spatial display limits the interaction. It is good for presentation and training. Finally, due to the way spatial displays register the images, it is confined to fixed augmented reality systems.

Table 5-1 gives the summary of displays selection criteria:

Table 5-1 Displays Selection Criteria

	√	×
Video see through	Tasks that require hands free; Fixed and mobile system; Complex components; Strict Illumination conditions.	Long time tasks; Cramped environment.
Optical see through	Tasks that require hands free; Fixed and mobile system.	Long time tasks; Tasks related to time response; Outdoor with bright sunlight.
Tablet PC	Fixed and mobile system; Visualisation and simulation.	Tasks that require hands free.
Smartphone	Fixed and mobile system; Fault diagnosis.	Tasks that require hands free.
PDA	Fixed and mobile system;	Tasks that require hands free.
Spatial display	Fixed system; Collaborative task.	Mobile system.

“ √ “-applicable

“×“-not applicable

(3) Tracking

Tracking is a major obstacle and is a popular topic in augmented reality research in the past few years. This is because it plays an important role in connecting the virtual images and the real objects. There are two main tracking techniques: sensor-based and vision-based. For some applications one method is unable to provide a robust solution so hybrid tracking can be adopted. Sensor based tracking employs trackers such as magnetic, inertial, acoustic, optical and mechanical while vision based tracking takes advantage of image processing.

Sensor Based Tracking: A mechanical tracker makes use of direct mechanical linkage like a string pulley, which may cause collision or even damage to other objects within small space. Aircraft, in particular, are packed with a multitude of parts in a limited space. Therefore, it is not a good option to make use of a mechanical tracker based augmented reality on an aircraft. If the tracker can be placed properly, the mechanical tracker can be employed for simple exterior checks in outdoor spacious areas. Since magnetic tracker can be affected by magnetic field disturbance caused by metallic objects nearby, it is suboptimal for aircraft maintenance because there are a number of electronic and electromagnetic elements on aircraft. Inertial tracking can be well used in cases of rapid directional changes, both acceleration and deceleration (Pinz et al., 2002). With the recent advances in technologies, global positioning system (GPS), solid state accelerometers and gyroscopes are self contained in most Smartphones, making inertial tracking ideal for mobile augmented reality. However, it is useless for slow motions and small changes in translational speed. A fixed augmented reality system will not make use of inertial tracking. An acoustic tracker uses the transmission and sending of sound waves, and requires a line of sight between emitters and receivers (Welch and Foxlin, 2002). It may suffer from outdoor environment interference, humidity, wind, temperature and air currents for instance. It can be used for normal maintenance tasks such as illumination replacement in cabin or cockpit where environment disturbance is minimal. Similarly, optical tracker, making use of light sources and optical sensors, requires a line of sight between the two. It suffers significantly from the occlusions. Considering the interior complex environment of an aircraft, optical tracker is not a robust solution.

Vision Based Tracking: The aerospace industry realised the need to place markers on aircraft as a limitation of augmented reality. The computer vision dealing with markerless tracking appears to be a better solution (Crescenzio et al., 2011). Most available computer vision tracking techniques can be categorised into two groups: feature-based and model-based (Pressigout and Marchand, 2006). Feature based tracking is ideal for tracking where visual patterns exist in the scene such as points, segments, circles and object contours. Feature based tracking is sensitive to illumination. It is therefore not ideal for maintenance tasks where illumination changes frequently. A model based approach makes use of CAD models of 2D templates of tracked objects. It is a more robust solution for aircraft because modern aircraft design mainly takes advantage of computer software, which means CAD models and 2D templates are available in most cases. Additionally, there is an increasing consensus to develop close loop tracking that takes advantage of the inertial tracking and computer vision technologies (Zhou et al., 2008). This is due to the widespread adoption of GPS in Smartphones and availability of geography data. Nevertheless, this combination is less suitable for aircraft maintenance because the workspace is relatively small and engineers move slowly or even stay still most of the time.

Besides, Robertson and Macintyre (2004) suggested that accurate registration is not important in many situations. For instance, if an engineer is instructed by an augmented reality system to move a monitor in a warehouse and only one such monitor in this region is being augmented, accurate registration is not essential. The communication intent should be taken into account when select tracking technology.

Following Table 5-2 summarises the tracking selection criteria:

Table 5-2 Tracking Selection Criteria

	√	╳
Mechanical	Outdoor spacious area.	Interior checks.
Magnetic	No disturbance of magnetic field.	Aircraft maintenance.
Inertial	Rapid change occurs.	Aircraft maintenance.
Optical	Clear view.	Where occlusions exist.
Acoustic	Where disturbance is minimal.	Adverse outdoor condition.
Feature based	Visual patterns (points, segments) exist in the scene.	Not enough texture; Illumination changes.
Model based	CAD models or 2D templates available.	-

" √ "-applicable

"╳"-not applicable

(4) Input Device

There are various types of input devices that have been brought into use. For example, mouse, keyboard and speech input. As a result of widespread availability and utilisation, it will not take long to accustom most engineers to using traditional input devices like the mouse and keyboard in an augmented reality system. However, the use of mouse and keyboard are cumbersome, for example, the keyboard requires space and a flat surface. Thus they are not applicable to mobile augmented reality systems. Also, mouse and keyboard are unable to support complex operations. Speech input saves the hands of users for other operations. But its accuracy suffers due to problems with recognition and ambient noises. Others, such as Reitmayr and Schmalstieg (2003) employ gloves in their mobile augmented reality system. Feldman et al. (2005) utilise a wireless wristband. For Smartphone and PDA, the device itself can be employed as an input tool (Carmigniani et al., 2011). It is difficult to lay down a set of guidelines for selecting an input device for augmented reality because it largely depends on the type of the application. Aircraft maintenance serves as a good example. Maintenance tasks normally consist of inspection, removal and installation which require engineers to have both hands free. The selection of an input device to build an augmented reality system should allow the users to use both their hands.

The following Table 5-3 summarises the input device selection criteria:

Table 5-3 Input Device Selection Criteria

	√	×
Mouse/Keyboard	Fixed system.	Mobile system; Tasks that require hands free; Complex operations.
Speech input	Tasks that require hands free.	Noisy environments.
Wireless wristband	Tasks that require hands free; Complex operations.	No wireless network support.
Glove	Complex operations.	No wireless network support.
Conclusions: Selection of input devices depends on the type of application. Augmented reality system developers are encouraged to design specific input devices for particular applications on the basis of current technologies.		

" √ "-applicable

"×"-not applicable

(5) Interface

One of the great challenges faced in developing an augmented reality system is to develop a proper user interface to facilitate the communication between user and virtual contents. Major methods of interaction employed in augmented reality systems are: tangible interface, collaborative interface and multimodal interface (Carmigniani et al., 2011).

A tangible interface takes advantage of physical objects and tools. For instance, Mistry et al. (2008) proposed an interface in which the user takes advantage of objects he/she carries in daily life as an enquiry tool to locate him/her or find useful information on the map. A tangible interface is influential as the users are familiar with and have no difficulty in using these physical objects (Zhou et al., 2008). With each interface having its strengths and weaknesses, a tangible interface combined with gesture, speech, sound and vision leads to a multimodal interface which provides the user with a more robust solution. A research from Mistry et al. (2009) serves as a good example. The virtual information is projected onto surfaces and walls, with which users can interact by arms movement or hand gestures. Collaborative interfaces take advantage of multiple displays. The information can be shared between local and remote users. It is a likely candidate for aircraft maintenance since remote experts can be involved to support local maintenance engineers. Gautier et al. (2007) proposed a collaborative workspace to support fault diagnosis for unplanned maintenance on an aircraft.

The selection of the interface should be based on the type of application and other aspects such as the choice of display and input devices. The ultimate goal is to provide acceptable solutions for users to interact with the virtual contents efficiently in an augmented reality system.

(6) Operating System

Personal computers/laptops and Smartphones/tablets/PDA devices function with dedicated augmented reality software dealing with image processing and augmentation. These platforms support different programming languages and are designed for particular operating systems. It is therefore essential to determine operating systems before selection of software. Current major operating systems include:

Personal computers/laptops: Microsoft Windows, Linux, MacOS.

Smartphones/tablets/PDA: Symbian, Android, iOS.

Additionally, a wide range of other operating systems have come rapidly on the market over the past few years. Examples are Windows mobile developed by Microsoft, Bada from Samsung, Palm/HP’s webOS and Nokia/Intel’s MeeGo

(Rose et al., 2010). They receive modest market share worldwide and limited support at present.

Microsoft Windows: It is a series of operating systems which mainly consist of Windows XP, Windows Vista and Windows 7. The most recent version Windows 8 is expected to be released soon. As of September 2011, they have approximately 86% of market share (Market share, 2011). Microsoft Windows are applicable to all augmented reality systems employing desktops and laptops. They support popular software like ARToolKit and Studierstube. It is advisable to select Microsoft Windows as a first choice.

MacOS & iOS: They are desktop and mobile operating systems designed by Apple. Their market share keeps rising all the time and stand at 6% and 4% respectively. In particular, iOS makes up to 50% of mobile/tablet operating system market share (Market share, 2011). Much software such as OpenCV and ARToolKit have MacOS versions (Prochazka and Koubek, 2011). And a number of mobile applications have been developed for iOS, Layar Wikitude and Junaio (Rose et al., 2010) for instance. Mac OS and iOS offer a good choice for augmented reality development, for both fixed and mobile systems.

Android: It is a free source and popular platform developed by Google. It constitutes a large portion of market share. Likewise, ARToolKit, Layar Wikitude and Junaio can be operated on the Android system. It is advisable to take advantage of Android for a mobile augmented reality system.

Linux: Linux is free and it is an open source operating system which can be installed on both desktops and mobile phones. However, Linux accounts for a small percentage of market share. There are versions of ARToolKit and OpenCV for linux as well (Prochazka and Koubek, 2011). Linux can be used for both fixed and mobile augmented reality systems. As its user community is limited, it is not supposed to be a popular choice.

Symbian: It used to be the most popular mobile platform worldwide. Due to the lack of functionality and usability compared with competing platforms (Rose et al., 2010), its market share has decreased significantly in the past two years. Only a few software platforms are specifically designed for this operating system like Wikitude. Therefore, this operating system could not be a first choice for augmented reality designers.

According to the aforementioned market share statistics, operating systems have developed quickly in recent years. It is difficult to select a suitable operating system for augmented reality, mobile augmented reality in particular. Nevertheless, taking into account the fact that most software is cross-platform, as well as the personal habit of customers, popularity with customer and functionality of software, this selection is easy. Microsoft Windows and MacOS are optimal for an augmented reality system employing PC or laptop, while iOS and Android are attractive options for a mobile augmented reality system at present.

The following Table 5-4 gives a comparison of operating system.

Table 5-4 Comparison of Operating System

	Fixed System	Mobile System	Market Share	Software Support
Microsoft Windows	√	√	86%	Excellent.
MacOS	√		6%	Medium.
Linux	√	√	1%	Medium.
iOS		√	4% (dominant in mobile operating system)	Excellent.
Android		√	Increasing significantly	Excellent.
Symbian		√	Decreasing sharply	Limited.

“ √ “-applicable

(7) Software

Augmented reality software platforms were originally developed for specific operating systems. Therefore, selection of software is determined by the selection of an operating system. There are some other prerequisites that must be taken into consideration when choosing the software: price of the software, difficulties for new user and possibility of further extensions. It is not easy to select a piece of software which completely satisfies all the criteria of an augmented reality system. Take ARToolKit for instance. It is open source software which suits the financial requirement of a particular company. The development has stopped and its latest version was issued in 2007 (Prochazka and Koubek, 2011). Compatibility with any new version of the operating system or other features cannot be guaranteed. The Table 5-5 below gives the characteristics of major software platforms for reference purpose.

Table 5-5 Software Platform Selection Criteria

	Open Source	Cross Platform	Further Support	Extension	Mobile System Support
ARToolkit	√	√	×	√	√
OpenCV	√	√	√	×	×
Studierstube	√	√	-	√	√
ARToolkit Professional	×	√	-	√	√
Layar	√	√	√	√	√

(Prochazka and Koubek, 2011, Ong et al., 2008, Rose et al., 2010)

"-"Uncertain

"√"-applicable

"×"-not applicable

(8) Network

An augmented reality system employs networks to transfer and receive lots of data content. On occasion, the network serves as a complementary method for location and registration. Owing to the differences of speed, bandwidth, latency and availability among various networks, it is crucial to select a proper network for an augmented reality system (Papagiannakis et al., 2008).

Networks are mainly divided into two types: wired and wireless. And wireless network can be categorised into wireless wide area network (WWAN), wireless local area network (WLAN) and wireless personal area network (WPAN).

Wired Network: It is connected by cables, and as such, it is more reliable compared to wireless ones that suffer from interference. It supports high speed in terms of connection. However, the cables support small scale mobility and may raise issues relating to safety. The use of wired networks for augmented reality is limited. It is ideal for fixed systems especially where a lot of data transfer is needed, but it is not necessarily suitable for mobile systems.

Wireless Wide Area Network (WWAN): There are several options in wireless wide area network from global system for mobile communications (GSM) and code-division multiple access (CDMA) in 2G to 3G with fast speed. 2G WWAN can be used where less data transfer is required. 3G WWAN is developed to support multimedia applications and therefore offers a good choice for mobile augmented reality systems (Papagiannakis et al., 2008). Nevertheless, 3G WWAN is in its early stage in most countries; the coverage and cost should be carefully evaluated.

Wireless Local Area Network (WLAN): Wireless local area network covers a small range such as an office or a building and has high data rate and low latency (Goldsmith, 2005). Wi-Fi (Wireless Fidelity) network is a good example. Wi-Fi is a feature available on most mobile devices and enjoys a large following nowadays. A Wi-Fi network is simple and cheap to build up requiring merely a wireless modem. One access point (Hotpoint) of a Wi-Fi network typically has a range of approximately one hundred metres. As a result, it offers an optimal solution for a mobile augmented reality system to support aircraft maintenance tasks where a mechanic just moves within a hangar or parking apron.

Wireless Personal Area Network (WPAN): Wireless personal area network, making use of Bluetooth and infra-red technologies, aims to build connections among computers and has small range of a few meters. It can be used to create one-to-one connections among engineers, experts and managers and thus build up a collaborative workspace to support maintenance. Besides, interference would be prevented and information privacy is well protected because of the selective connection feature of WPAN. Wi-Fi is, basically, on the borderline between WLAN and WPAN (Goldsmith, 2005).

The following Table 5-6 gives a comparison of network.

Table 5-6 Comparison of Network

	Fixed system	Mobile system	coverage	Transfer quality
Wired	√		Limited	Excellent
WWAN	√	√	Need to be evaluated	2G-Bad 3G-Good
WLAN	√	√	Normally less than one hundred meters for one access point	excellent
WPAN	√	√	A few meters	medium

“ √ “-applicable

5.4 Scenario for Demonstration and Validation

In order to investigate the feasibility and applicability of this framework, a scenario will be developed based on COMAC. The implementation framework will be applied to the specific scenario.

5.4.1 Scenario Description

One possible scenario is that the product support and customer service department in COMAC would like to make use of augmented reality to support maintenance technician training to replace conventional manual and computer based ones. The following paragraphs will describe the factors that need to be considered while implementing an AR system.

Need Analysis

COMAC has set an ambitious goal to become one of the world class commercial aircraft manufacturers. To be competitive with Boeing and Airbus, which currently take up a dominant position in this market, it is essential to take advantage of advanced technologies. Augmented reality has a good case.

The current training of pilots and maintenance engineers in COMAC is mainly based on traditional methods which are manual based and instructor based. These are costly, time consuming and less efficient. Augmented reality based training saves the cost of manual and labour. Also, it has the potential to cut the time on training and boost efficiency by providing intuitive interaction and novelty.

Task Analysis

The following list illustrates the nature of the maintenance training tasks and requirements that need to be met by an augmented reality application:

- Local environment.

-The training environment can be both indoor in a room and outdoor in the hangar or on the parking apron.

- Aircraft is normally fixed by tools.

-Regular local area network or wireless network is available on demand.

- Nature of tasks.

- A wide range of tasks involving: inspection, installation, removal, assembly.

-Both interior and exterior of aircraft.

-Both individual and collaborative tasks.

-Maintenance engineers do not stay still, but the movements are slow and small.

-Engineers normally require their hands to be free.

- Restrictions.

-Owing to the existence of electromagnetic parts on airplane, it is a tough environment for magnetic tracker.

-Due to the existence of wires bundle and cables, objects with sharp edges are not allowed.

-Owing to the existence of occlusion, it is a rough environment for optical tracker.

- Usability.

-The AR application should be able to provide enough information, for example maintenance procedures, to maintenance engineers by computer generated texts, graphics and annotations.

-Local information gathered by maintenance engineers can be input and output for feedback fault diagnosis.

- Safety.

If head mounted display is used, maintenance engineers must have sights of the real world in the case of power failure.

Implementation

This section will discuss the selection of technologies for implementing an augmented reality system on the basis of the above task analysis:

1. Augmented reality system.

As engineers move around when performing the maintenance tasks, a fixed system is not applicable. Also, since training of engineers will be carried out indoor and outdoor, the indoor and outdoor system is a better choice. Consequently, a mobile indoor and outdoor augmented reality system will be selected.

2. Display.

Video see-through head mounted display is excluded due to safety concerns. Most maintenance tasks normally require hands free. Handheld display is therefore excluded. Given the cramped environment inside aircraft compartments, spatial display is not applicable. Hence, optical see through head mounted display offers a good choice.

3. Tracking.

Due to the nature of maintenance tasks and restrictions, inertial, magnetic, mechanical and optical trackers are suboptimal for this application. As aircraft design in COMAC is mainly based on computer software such as CATIA and AutoCAD, the 2D templates and CAD models are available for registration. Model based tracking provides a robust solution.

4. Input devices and interface.

For some tasks like fault diagnosis, feedback is needed. Baratoff and Regenbrencht (2004) proposed a portable computer worn on the belt with a small touch screen for pen-based interaction. Likewise, the Smartphone like iphone , along with a laptop, can be used for input. Additionally, iphone provides the speech input and communication with other engineers, which makes collaborative interface available. In particular, the engineers should be able to communicate with remote experts sharing virtual images through the iphone and laptop setup.

5. Operating system.

Given the market share, software support and current customer choice, Windows operating system is the best choice among all the options.

6. Software.

Based on the analysis in a previous section, development of ARToolKit has stopped. OpenCV does not support a mobile system. Layar is mainly for Smartphone operating system. Hence, open source Studierstube or commercial ARToolKit professional can be chosen.

7. Network.

Wired network is not applicable to the mobile system. 3G is expensive and not fully mature at this moment. Bluetooth and infrared are out of date and the connection speed is slow. Therefore, Wi-Fi is optimal for mobile augmented reality systems.

Result

The following Table 5-7 summarises the technologies that have been chosen for the augmented reality based training application:

Table 5-7 Proposed Configuration for Chosen Scenario

Augmented Reality System	Mobile outdoor and indoor system.
Display	Optical see through head mounted display.
Tracking	Model-based computer vision.
Input device	Laptop, iphone.
Interface	Collaborative.
Operating system	Windows.
Software	Studierstube/ ARToolKit professional.

Network	Wi-Fi.

5.5 Summary

This chapter has introduced a framework for selecting and implementing an augmented reality system. The criteria for selecting different augmented reality technologies have been established and have been applied to a proposed scenario chosen from COMAC. Validation of this framework will be achieved by academic experts and company engineers in the following chapter.

6 VALIDATION

6.1 Introduction

The validation of the cost benefit analysis framework and the augmented reality implementation framework will be achieved by some academic experts at Cranfield University and engineers from the Commercial Aircraft Corporation of China in this chapter. Section 6.2 will introduce the methodology for validation. Section 6.3 will present the validation by the academic experts. Company engineer validation will be given in section 6.4. Section 6.5 will summarise this chapter.

6.2 Methodology

In order to validate the two frameworks, some experts were interviewed. The presentation of the two frameworks was given and two questionnaires were used afterwards. They were asked questions about: (1) if the given elements in the framework are enough? (2) Are the frameworks complete? (3) What are the benefits of the frameworks for industry? (4) What are the weaknesses of the frameworks? What actions can be taken to improve them?

The first validation was based on academic experts from Cranfield University. Four experts validated the frameworks using their experience and knowledge.

The company validation was achieved by two engineers who have rich working experience in the aerospace industry. They were given the framework description document further explained through email and telephone. Two engineers discussed in a group meeting and gave feedback.

The same questionnaires were used for both university and industry respondents.

6.2.1 Validations Overview

The first validation had been performed by academic experts at Cranfield University. Experts who have deep knowledge of cost engineering or innovative design were interviewed which promises that they are suitable for validating the work. The researcher discussed with four experts and gave a presentation on the two frameworks. Then, the experts were asked for comments and feedback on the frameworks. The whole validation was about four hours.

The company engineer validation was carried out by senior engineers from the Commercial Aircraft Corporation of China. Two directors who are in charge of maintenanceability, safety and reliability evaluation and have worked in the aerospace industry for over twenty years were involved. The whole validation lasted for one week. They were presented with the document first, and further communications were carried out by telephone and email. The two directors had a meeting to discuss the framework later on and gave their comments and feedback on the two frameworks afterwards.

6.2.2 Background of Respondents

Windo Hutabarat is a research fellow and project manager currently managing the Innovative Manufacturing Research Center (IMRC) project “Designing a Product Service System (PSS) for Complex Micro-integrated Devices”. He has an aerospace engineering background and is keen on aerodynamic design optimisation.

Dr John Ahmet Erkoyuncu is currently developing an attribute trading tool, referring to the key requirements for an aerospace engine, and taking part in a European consortium (VISION Advanced Infrastructure for Research) with over 20 universities participating.

Dr Yuchun Xu is a lecturer at Cranfield University. He worked at Queen’s University Belfast on Whole Life Cost (WLC) modelling for aircraft in collaboration with QinetiQ and Airbus UK. His research areas include: Cost

Engineering, Manufacturing Engineering, Reverse Engineering, and Mechatronics.

Dr Christopher Turner currently works on an Engineering and Physical Sciences Research Council (EPSRC) follow-on funded project to produce a commercial business process mining prototype capable of identifying and extracting process patterns from data logs to reconstruct an overall process flowchart.

Mr Hu Guangping and Mr Guo Zhongbao are senior engineers from the Commercial Aircraft Corporation of China. And they are director and deputy director of Safety, Reliability and Products Support Department of COMAC respectively. They have worked in the aerospace industry for over twenty years

6.3 Results from Academic Validation

The validation results are given in the following Table 6-1:

Table 6-1 Results from Academic Validation

Correspondent	Comments
Windo	**Cost benefit analysis framework**
	He believed the cost benefit analysis framework is well designed, which makes customers clear about the costs and benefits of implementing an augmented reality system. And since he was unaware of similar research on this topic, he thought this framework will benefit future work. He suggested that this research should take into account the cost of redesigning working processes by employing augmented reality in companies. Also, he advised that certain terms, like the intangible, used in the framework can be changed to eliminate the ambiguity.
	Implementation framework
	He argued that the implementation framework clearly specifies the elements needed to implement an augmented reality system and gave users a good structure to follow. He gave suggestion for future work that this framework is analogous to an open loop at this moment. Some feedback can be extracted from certain stages to develop a closed loop which can make the framework more robust.

<table>
<tr><td rowspan="4">John</td><td>Cost benefit analysis framework</td></tr>
<tr><td>He thought that the cost benefit analysis framework is detailed enough which clearly demonstrates the work, and it will improve maintenance. He pointed out that the obsolescence cost and spare part cost should be counted. Besides, he suggested limiting the framework to a specific area in order to make it more applicable</td></tr>
<tr><td>Implementation framework</td></tr>
<tr><td>He believed that the implementation framework contained complete information, which made different user groups, namely, customer, designer and developer understand their responsibilities.

He also mentioned the feedback in the framework. He argued a closed loop can be made in the future to make it more reliable. And he pointed out the time spent on each step can be specified because the whole process may be time consuming.</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td rowspan="4">Yuchun</td><td>Cost benefit analysis framework</td></tr>
<tr><td>He commented on the cost benefit analysis framework that since he was unaware of similar work for augmented reality, he believed that this research will help the customers understand the cost and benefits of augmented reality. And it will help customers determine whether they can afford this technology. He also pointed out that the costs and benefits listed in this framework are reasonable.

He suggested more people and sources should be taken into consideration when collecting data for evaluation to improve the reliability of data, and the long term investment may be considered in this framework.</td></tr>
<tr><td>Implementation framework</td></tr>
<tr><td>he gave feedback on the implementation framework. He argued that this framework can help the decision makers to address the associated issues of augmented reality and gain more understanding of the whole picture. It is viable to make use of the framework to implement an augmented reality system.

He also made suggestions on the future work. He advised that the time to complete the process and the environment impact can be taken into account.

Finally, he believed the industry will benefit from the work.</td></tr>
</table>

Christopher	**Cost benefit analysis framework**
	He believed the cost benefit analysis framework is complete and it clearly demonstrates the direct and indirect benefits of augmented reality, which can benefit the industry especially the training significantly. And since he was not aware of similar research, he believed that this framework provides a good high level example for the industry. He mentioned that the cost of an external sensor should be indicated clearly because people consider it as a part of a tracking system in some cases.
	Implementation framework
	He argued that the implementation framework is a complete way to start a new augmented reality programme, and it will be of great benefit to the aerospace industry. He also said that the whole framework is completed and viable to implement an augmented reality system. He suggested that more expertise should be involved in certain stages of the framework as augmented reality is not fully explored at present.

6.4 Results from Company Engineers Validation

Firstly, Mr Hu Guangping and Mr Guo Zhongbao thought that they can understand the two frameworks clearly and it can be implemented. The two frameworks were rigorous and they insisted that the two frameworks were needed and helpful for the company. Currently, most employees in COMAC are unaware of augmented reality. The two frameworks will help the company evaluate and implement this brand new technology. They would give their support on this project in the future. And the two frameworks were tools which may improve the competitiveness of the company in the future.

For a cost benefit analysis framework, they highlighted the benefit of product quality being improved by employing augmented reality and the cost saved by eliminating virtual reality software, manual edit and management software used in COMAC, as well as the labour costs related to these activities. In addition, they suggested more cost engineers can be involved in evaluating this framework.

They gave suggestions on the implementation framework that more links and feedback to aircraft design process can be taken into consideration, because implementing augmented reality to support aerospace industry maintenance requires information from technical drawings, documents and models. And the availability of these resources is limited in some stages during the whole aircraft design process. Besides, the customer's needs are of great importance in aerospace industry. Aircraft design engineers change their sketches and drawings to meet customer's needs. The framework for implementing augmented reality is subject to change accordingly.

Furthermore, they mentioned that safety is a major concern in the aerospace industry. Future work should concentrate on how to incorporate safety into the two frameworks.

Finally, they thought that the researcher should continue the research after returning to the company.

6.5 Summary

This chapter has demonstrated the results of validation. The academic experts and company engineers had given feedback and comments on two frameworks. The suggestions were gained from both university and industry sides. Therefore, this chapter has achieved the validation of the cost benefit analysis framework and implementation framework in the university and the company.

7 DISCUSSION AND CONCLUSIONS

7.1 Introduction

The experience obtained through the research will be shared in this chapter. Section 7.2 will present the completed aim and objectives of this research. Contribution of this research is indicated in section 7.3 and the research limitations and future work, as well as the conclusions will be introduced in the following sections.

7.2 Discussion

This research aims to develop frameworks for selecting and implementing augmented reality to support maintenance within the Chinese aerospace industry. Several objectives were developed to achieve this aim:

(1) Identify different types of AR technologies and their strengths and weaknesses for maintenance.

(2) Develop a framework for performing cost-benefit analysis for augmented reality within the maintenance industry.

(3) Develop a framework for selecting and implementing augmented reality in activities and validate the framework.

7.2.1 Research Achievements

Three steps have been followed to achieve these objectives:

Stage 1

The researcher concentrated on understanding this subject in this stage. A comprehensive literature review, including journal papers, books, conference proceedings and other researchers' theses in this area, were reviewed to study the state of the art and to identify the strengths and weaknesses of different augmented reality technologies. Also, the research gaps were determined in this stage.

To the best of the researcher’s knowledge, there is no systematic process for selecting and implementing, as well as evaluating augmented reality within the Chinese aerospace industry. Few people understand augmented reality and so there is little chance for them to implement this technology. This research therefore decided to address this gap.

Stage 2

In this stage, the cost benefit analysis framework and implementation framework were developed. Firstly, several useful methods were picked up on the basis of literature. The methods selected could help to identify the critical elements of the frameworks. Cost benefit analysis was developed in the first place and it supported the implementation framework development.

Stage 3

The validation of the frameworks was achieved in this final stage. Academic experts from Cranfield University and senior engineers from the Commercial Aircraft Corporation of China gave their comments and feedback to validate the frameworks. Also, the suggestions were given to enhance the work in the future.

Academic experts and company engineers believed that the frameworks were rigorous and understandable. They said that it is possible to implement the frameworks and engineers showed their support to this project. Therefore, the validation objective was accomplished in this stage.

7.3 Contributions

In China, little research has been done to understand the usability and feasibility of the AR technology. This research has developed two frameworks for evaluating and implementing augmented reality within the Chinese aerospace industry to support maintenance.

7.4 Research Limitations

There are some limitations of this research as follows:

1) These frameworks have not been implemented in the company, because the augmented reality cost estimation and implementation is a long-term job, which may last several years. For a year's research, there is not sufficient time to implement the frameworks in a company.

2) Augmented reality is still at its infancy. Only a few commercial applications and users can be found. And most current applications are for demonstration and advertising. This research was unable to contact the wider industry users for their feedback on augmented reality.

3) Not all the respondents from COMAC supplying information for the questionnaire on cost benefit framework have a clear understanding about cost engineering. If more employees, especially those who have cost engineering backgrounds, were interviewed, the result would be more accurate.

7.5 Future Work

In the future, the researcher will improve the work on the basis of the validation feedback and comments.

1) Feedback will be derived from different stages, and the two frameworks will be developed into closed loop equivalents.

2) More literature about augmented reality will be reviewed and airlines in China will be visited to identify more critical elements for developing and improving these frameworks.

3) More cost benefit methodologies will be studied so as to identify the best practice to evaluate augmented reality.

4) More details will be added to the implementation framework to help users develop a new augmented reality system quickly.

5) Continuous research on augmented reality will be carried out in order to gain more knowledge and more comprehensive understanding of this technology in order to support maintenance in the Chinese aerospace industry.

7.6 Conclusions

The research has fulfilled the primary research aim and accomplished the objectives. The following conclusions can be made:

1) Different types of augmented reality technologies have been identified as well as their strengths and weaknesses for maintenance.

2) A cost benefit analysis framework has been developed to evaluate augmented reality.

3) An implementation framework for selecting and implementing augmented reality has been developed.

4) The primary aim of this research to develop frameworks for selecting and implementing augmented reality to support maintenance within a Chinese aerospace company has been achieved.

Although there is still a long way to go, augmented reality has demonstrated its dramatic impact and considerable potential in manufacturing and business. And the ongoing research will promise its tremendous success in the future. Undoubtedly, the aircraft maintenance industry will benefit from augmented reality significantly and advance one step further.

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APPENDICES

Appendix A Questionnaire of Cost Benefit Analysis Framework

This questionnaire was designed to investigate the completeness and usability of cost benefit analysis framework. Feedback collected from correspondents was used to improve the framework.

No.	Questions
1	Is the list of benefits enough?
2	Is the list of costs enough?
3	Is this process completed?
4	What actions are required to improve the process?
5	What are the benefits of process for the industry?
6	What is the weakness of process? How to improve it?
7	Are you aware of similar research for augmented reality?

Appendix B Questionnaire of Implementation Framework

This questionnaire was designed to investigate the completeness and usability of implementation framework. Feedback collected from correspondents was used to improve the framework.

No.	Questions
1	Are the proposed aspects enough to cover the whole augmented reality system?
2	Is this process viable to implement augmented reality system ?
3	Is this process completed?
4	What actions are required to improve the process?
5	What are the benefits of process for the industry?
6	What is the weakness of process? How to improve it?
7	Are you aware of similar research for augmented reality?