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A cost-effective knowledge-based reasoning system for design for automation

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Abstract: Design for assembly automation (DFAA) is an important part of the concurrent engineering strategy for reduction of product manufacturing costs and lead times. An intelligent knowledge-based system (KBS) for design for automation and early cost modelling within a concurrent engineering environment has been developed. This paper focuses upon the development of the design for an assembly automation system. The system framework encompasses an extensive knowledge base reasoning system, a CAD system, a design analysis for automation module, a design improvement suggestion module, and a user interface. The development process of the system involved three main stages: creating the KBS, developing the design improvement module, and integrating the KBS with the CAD system. The developed system has the capability to: (a) select the most economic assembly technique for the product at an early design stage; (b) estimate the assembly time and cost for manual, automatic, and robotic assembly methods; and (c) analyse the product design for automation and provide the designers with design improvement suggestions of a product to simplify assembly operations without any compromise of the product functionality. The above capabilities of the system have been demonstrated and validated through a real case study.

Keywords: design for automation, concurrent engineering, knowledge-based systems, assembly cost estimation

1 INTRODUCTION

Assembly is one of the most important processes of the product development cycle that affects the product's quality, lead time, and cost. Research results have proved that over 70 per cent of the production costs of a product are determined during the conceptual design stage [**1, 2**]. In addition, assembly cost often accounts for over 40 per cent of the total manufacturing cost [**3–6**]. Therefore, it is essential to take into consideration all the requirements of assembly during the early design stages, otherwise additional cost and time to redesign already finished designs is inevitable. In addition, specifically assembly automation and robotic assembly are highly specialized fields. Furthermore, most designer engineers do not normally have the necessary knowledge to meet all requirements to achieve a good design from the assembly point of view [**7**]. Therefore, they need an efficient tool to support them during the design process and to overcome the above limitation. Naturally, there are some overlapping considerations in the two major design for automation (DFA) categories, namely design for manual and design for automated assembly. However, in product design requirements, manual assembly differs widely from automatic or robot assembly owing to the differences in ability between human operators and any automatic method of assembly. An operation that is easy for an assembly worker to perform might be impossible for a robot or special-purpose workhead [**8**].

To date, a significant amount of research work has been achieved on various issues of design for assembly, such as product and process design methodologies [**9**], assemblability analysis and evaluation [**10**], automated assembly of specific components [**11**], detailed analysis of assembly operations [**12, 13**], automated sequence planning [**7, 14, 15**], joining processes and related technology [**16, 17**], computer

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simulation of assembly process [**18**], etc. However, the most well-known DFA methods are those of Boothroyd and Dewhurst [**8**] and the assemblability evaluation method (AEM) by Hitachi [**10**]. The drawback of the former technique is that the product analysis is complicated and quite time-consuming, despite available personal computer (PC) programs. Furthermore the technique depends only on the functional analysis of the product, without taking into consideration the manufacturing cost of complex components. Clearly, the cost of complex components could possibly erode any advantage gained in reduction of assembly costs. AEM by Hitachi [**10**] is suitable for typical mass products, such as tape records or vacuum cleaners. Shortcomings of this approach are that the costs for component handling and orienting are not considered and that the estimation of the actual assembly costs is uncertain. Further details about the reviews on the different aspects of design for assembly can be found in references [**12, 19, 20**].

Much effort has been done on the development of DFA knowledge-based expert systems [**3, 13, 21–25**]. In general, these systems consist of a design tool computer-aided-design (CAD), a knowledge-acquisition and storage tool, and an inference engine. The famous knowledge-based design for assembly systems was developed by Lucas Engineering [**21**]. This system is the most advanced in design for the assembly process, yet not necessarily the most effective in reducing assembly cost. It comprises the definition of an assembly sequence and the analysis of each component and its liaison for ease of handling and fitting. This results in handling and fitting indices. It also takes account of availability of gripping surfaces. Zha *et al.* described in a number of papers [**3, 22, 24**] the development process of a knowledge-based approach to support top–down design for assembled products [**3, 22**] and an agent-based expert system for concurrent product design and assembly planning [**24**]. The proposed intelligent approach and framework [**3, 22**] focused on the knowledge-based integration of product design, assemblability analysis and evaluation, and design for assembly with economical analysis. An intelligent system for product design for assembly within a concurrent engineering environment has been presented by Daabub and Abdalla [**23**]. Moreover, their system enables designers to minimize the number of components of a product and select the assembly method for that specific product. The general rules and guidelines of DFA methods accompanied by illustrated examples can be found in reference [**26**].

A review of available literature indicates that, so far, little research work has been done on product design for assembly automation at an early stage of the design process. In particular, suggestions for product re-designs improvement for easy robotic assembly operation, without any compromise of the product's functionality, have received less attention from researchers. In addition, the previous systems are carried out on a completed product design. At that stage of design the necessary redesigning is very expensive and the lead time of the product is increased. Additionally, these techniques relied on asking the designers, who lack the necessary design for assembly knowledge, to answer a set of questions regarding the functionality and the various parts of the product.

The present paper presents details of the development of an intelligent knowledge-based system (KBS) for design for automation to overcome the above shortcomings. However, the current system is a further development of a design to cost system that has been developed by the current authors [**1, 27–29**]. The major achievement of the latest version of the developed system is that it unified the product cost modelling and design for assembly automation into an integrated system. Therefore, the main objectives of this new version of the developed system are to: (a) estimate the assembly cost; (b) select the most economic assembly technique for the product at an early design stage; and (c) analyse the product design for automation and provide the designers with design improvement recommendations to simplify assembly operations, based on a design feasibility technique.

2 SYSTEM FRAMEWORK

The system framework for design for assembly comprises a knowledge-based reasoning system, a CAD system, a design analysis for robotic assembly module, a design improvement suggestion module, and a user interface. The basic architecture of the system model is illustrated in Fig. 1. Three main steps have been involved in developing the system: building the KBS, creating the design improvement module, and integrating the KBS with the CAD system. The developed system was designed in such a way in order to allow designers to analyse and/or modify the product at any stage of the design process. It works in a fully interactive mode.

The designer communicates with each module via the user interface. He/she has to specify, to the system, the basic product specifications and the production data such as production volume, number of components, and number of working shifts. These data are employed in the system to select the most economic assembly technique for the product. The system then commences the design analysis for the selected assembly method. The

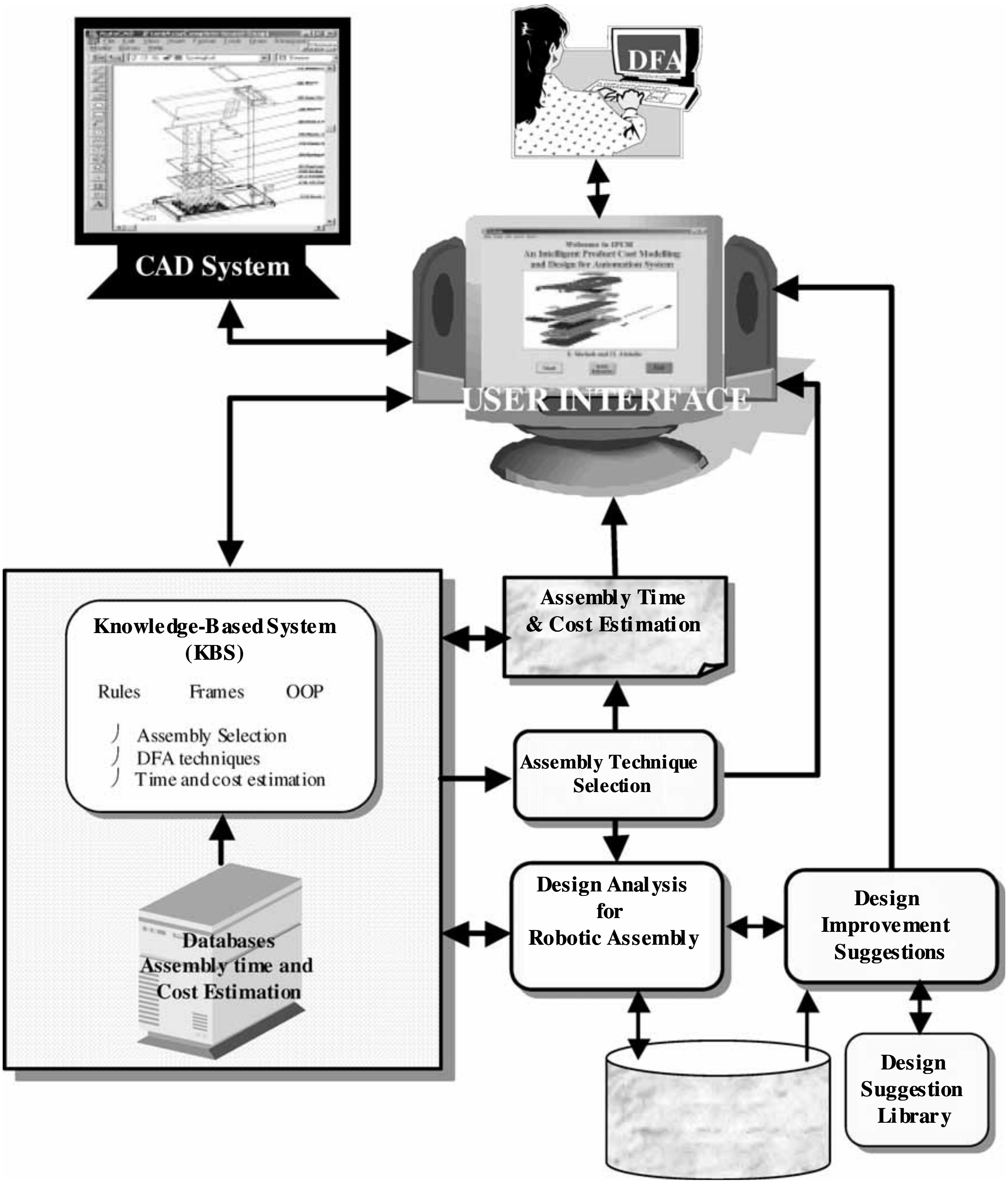


Fig. 1 The structure of design for assembly system

system presents the design analysis in an efficient user interface.

The developed design for the automation system has the capability to apply the design criteria for robotic assembly. The roles of the design improvement module are to:

(a) identify automatically the candidate component(s) for redesign;
(b) specify the various component features that cannot be assembled robotically;
(c) provide possible alternative redesign suggestions.

An expert system, Kappa-PC [**30**] toolkit developed by Intellicorp, Microsoft Excel database, and AutoCAD as a CAD tool have been chosen to develop the proposed system. Kappa-PC supports frame-based objected oriented programming and high-performance rule-based reasoning. It also provides a programming environment and integrated set of tools to build a KBS for commercial and industrial applications.

Discussion of each module is presented in the following sections. Further details about product design improvement for robotic assembly will be outlined.

2.1 Design for assembly knowledge representation techniques

Knowledge representation is the formal description of the knowledge with symbolic encoding. It deals with how to organize and encode knowledge in the best form so that the problem can be easily solved. In the domain of DFA, the knowledge base contains knowledge that provides assembly selection, assembly time and cost estimation, design analysis, and heuristics of redesign suggestions.

In this research study, open literature and handbooks of design for assembly are one of the main sources of the knowledge used in building the knowledge base for assemblability analysis and evaluation [**8, 9, 12, 20, 31, 32**]. Moreover, other sources come from the consultation with manufacturing experts in a company or factory. Hybrid knowledge representation techniques are employed to represent the knowledge-base of component feeding, handling and insertion in this research. These techniques, such as production rules – frame and object oriented – are described in detail below.

2.1.1 Production rules. More than 900 rules have been created in the present research project. The rules are connected to each other so that the conclusion of one rule is included in the premise of another rule. This technique is called 'chaining'. Both forward and backward chaining techniques have been employed in the developed system. The following is an example of production rules used in the system to estimate the manual handling time (MHT).

MHT_Rule_1

IF	(The component is manipulated by one hand)	AND
	(Tools are required to manipulate the component)	AND
	(The required tools are tweezers)	AND
	(Optical magnification is not required)	AND
	(The component is easy to grasp)	AND
	(Thickness is greater than 0.25 mm)	AND
	(The degree of alpha symmetric (α) is equal to 360°)	AND
	(The degree of beta symmetric (β) is less than 180°)	
THEN	(the manual handling time is equal to 4.8 s)	

2.1.2 Frame-based and object-oriented knowledge representation. A frame is a data structure for storing interconnected information about a design and an object. The frame system offers both inheritance and exception handling properties. Furthermore, it is very flexible so that images and active values can be attached to any slots to monitor changes in value. An example of frame representation of an object used within the developed system is shown in Fig. 2.

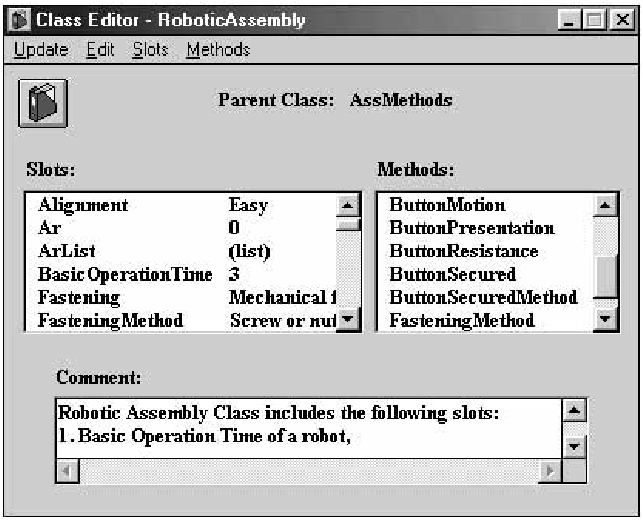


Fig. 2 Frame representation of an object

Object-oriented programming systems have several characteristics such as data abstraction, inheritance, and modularity. The inheritance property enables the designer to define a specific value into a higher class: each can be inherited by the lowest class of the hierarchy. Using such a technique, design, manufacturing, and assembly techniques, such as manual assembly, automatic assembly and, robotic assembly can be organized into various classes represented in hierarchies. Figure. 3 shows object-oriented representation of the redesign suggestions and the various assembly methods employed.

2.2 Design analysis for robotic assembly module

As stated earlier, the importance of robotic assembly is well recognized, but many designers do not have the necessary knowledge of this assembly technique. The advantages of robotic assembly, such as stability of product design, slashing the product cost, accommodation of product style variations, and no restrictions on part size if the part can be presented in pallets or part trays. This system provides the capability of carrying out design feasibility and obtaining design improvement suggestions for robotic assembly. The architecture of design analysis for robotic assembly is illustrated in Fig. 4. The first stage in design improvement is to identify the weak

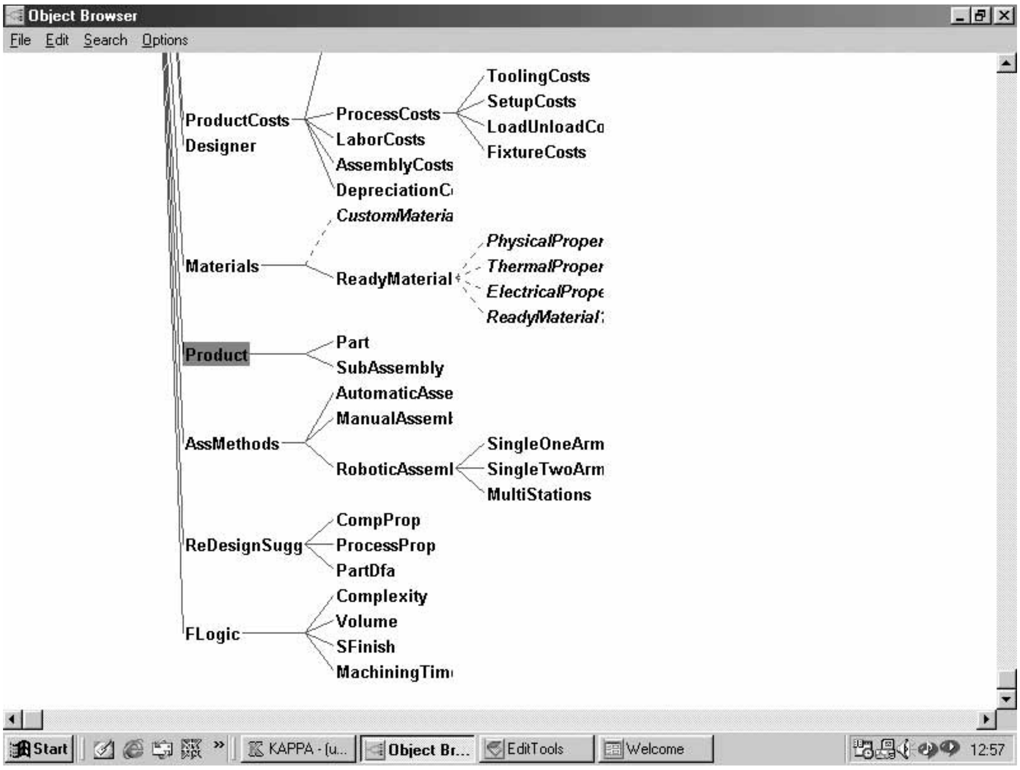


Fig. 3 Object-oriented representation of the various classes of assembly systems and redesign suggestions

points in the product design. The design criteria for robotic assembly have been applied for each component. The system evaluates, technically the separate subassemblies and components, as well as the whole assembly, for the possibility of robotic assembly. The component and subassembly properties used are stiffness, vulnerable shape, sizes, symmetry, quality, weight, and joining method (see Fig. 4). The assembly properties include the number of components, base component, and product length. The assembly process properties are categorized into status during feeding, assembly direction, the need to be held down during insertion, alignment difficulty, resistance to insertion, and the degree of motion during insertion. Score points are assigned automatically by the developed system based on the degree of compliance of each component specifications with the robotic assembly criteria. The database of property values is used to store all the assemblability score values and corresponding properties for the product, and the database of the score values saves the target value for each property. The target value is obtained from the objective value and the lowest score of the property. A design analysis report is generated for the designer. Attention in the redesign stage for the robotic assembly technique focuses upon the relatively highest component scores. The property with the highest score for a component infers that this property is a subject for redesign.

2.3 The design improvement module

Redesign suggestions are the most difficult task in the developed system. Practically, a redesign suggestion is heavily dependent on experienced engineers and should be a teamwork task. In order to initiate the suggestions for redesign, the design improvement module performs three functions. First it identifies automatically those components with the highest total scores. Second it specifies the component and assembly process properties that are candidates for redesign. Finally it provides suggestions for redesign, which will simplify the task of robotic assembly.

A comprehensive library of design improvement suggestions has been built in the developed system. The options for product redesign to simplify the assembly process are set out in Fig. 4. These include feeding, handling, and composing processes. Examples of the feeding processes are nesting, overlapping, tangle, and orientation. Handling processes include stiffness, vulnerable component weight, and shape. The composing processes include tolerances, resistance to insertion, assembly direction, composing movement, joining method, and alignment difficulty. A series of design modifications are provided to assist in simplifying the assembly process. The design suggestions are displayed for the designer in a professional way. An example of a re-design suggestion is shown in Fig. 5.

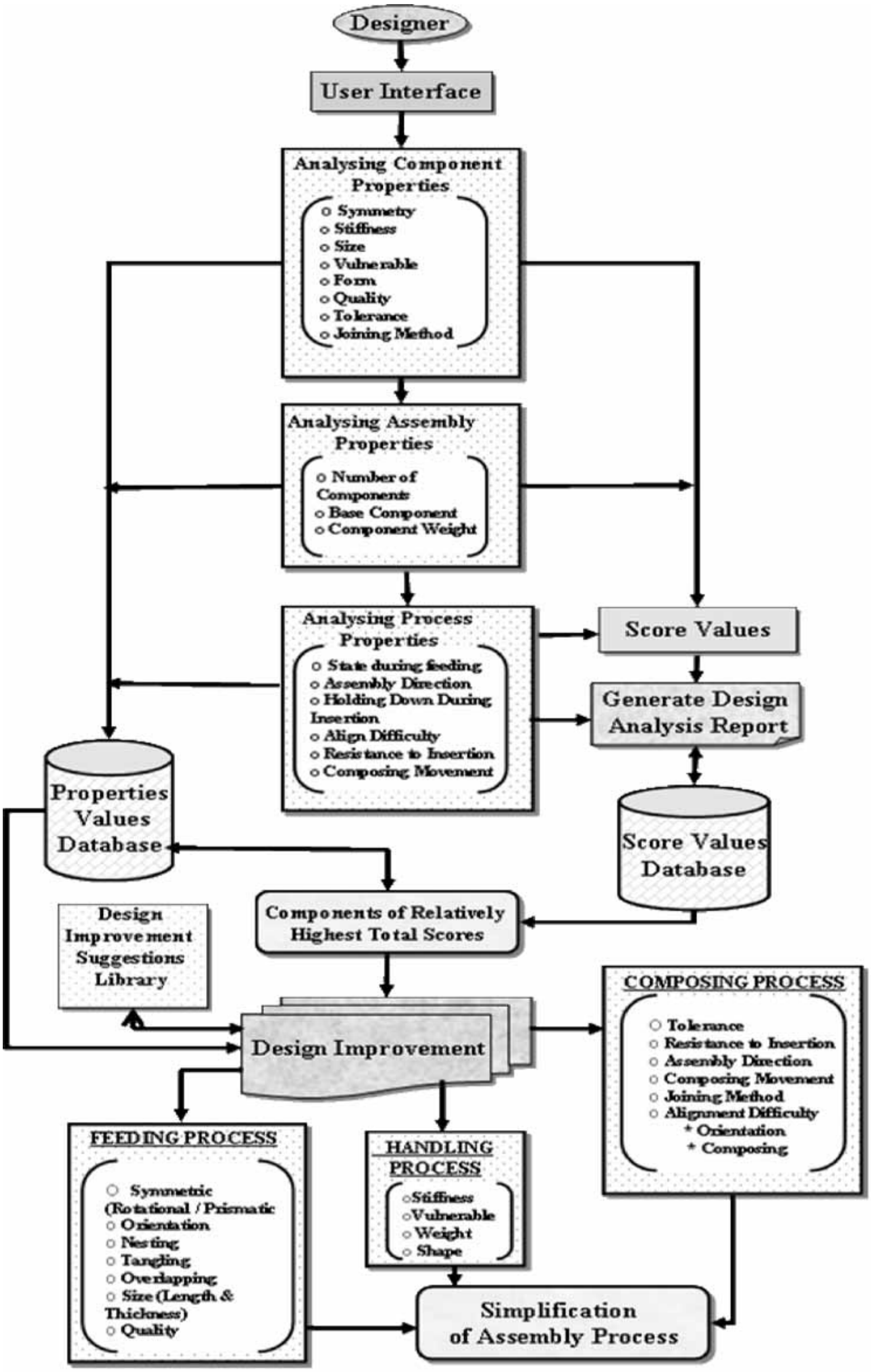


Fig. 4 Architecture of design analysis and improvement for robotic assembly

2.4 User interface

A user-friendly interface has been developed (Fig. 6), as an important part of the proposed system, in order to enable the user – even a new user – to use the system easily and efficiently,. It is the section of the system with which a user comes into contact, and which he/she forms an initial impression. The design analysis and recommendations for redesign suggestions are displayed on separate screens. The various elements of the product assembly cost are reported to the user in a Kappa-PC window. Graphics were used in the development of the prototype

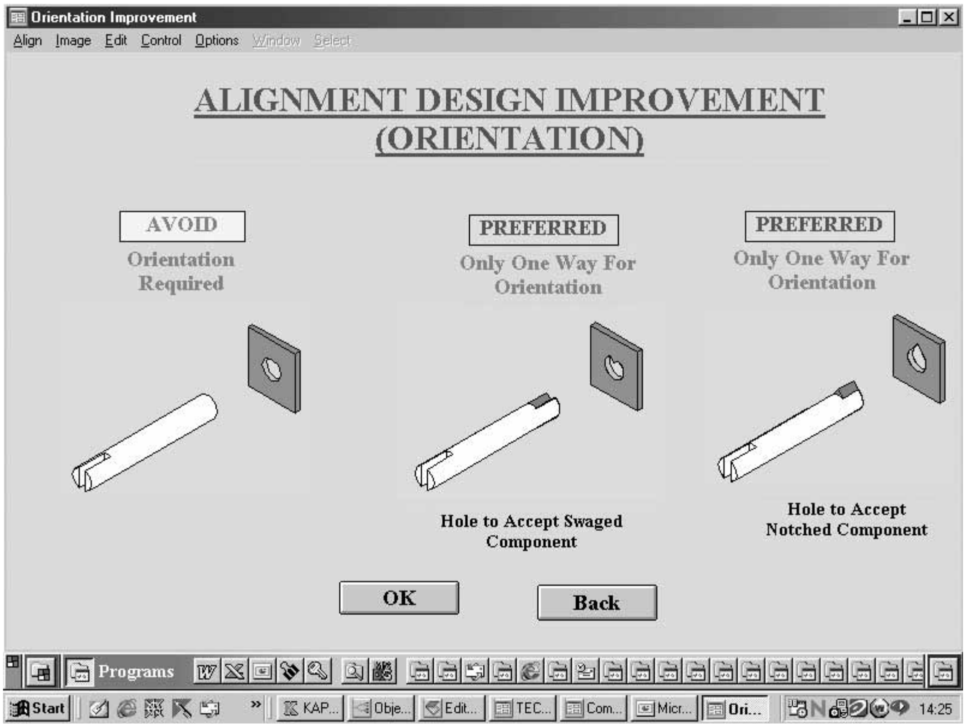


Fig. 5 An example of a redesign suggestion

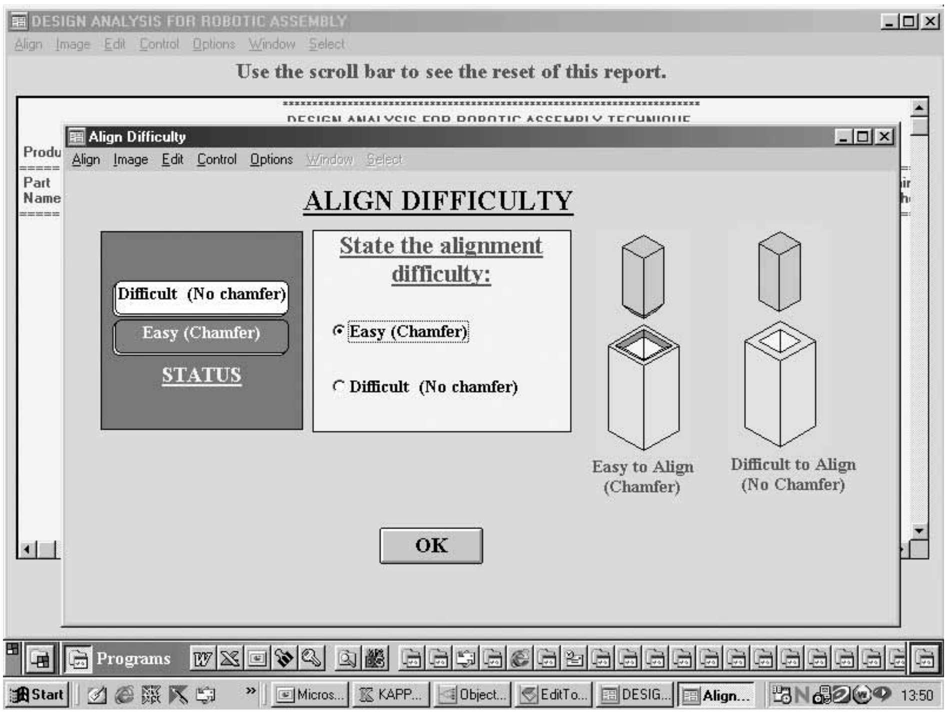


Fig. 6 An example of the user interface developed in the system

system. Finally the user is provided with options to clear the working memory and restart another application, to produce a hard copy of the system recommendations and reports, or quit the system altogether.

2.5 Database

The proposed model for DFA includes four groups of databases: assembly systems, time and costing for assembly methods, assembly properties score values for a specific product, and target score values for the assembly properties. The first group consists of the assembly system selection data, such as assembly system types and their applications. The second group involves data concerning assembly operations, time, and cost. The third group contains the assemblability score values and corresponding properties for the product. The final group includes the target value for each assembly property.

The proposed system operates with two types of database: permanent (static) and temporary (dynamic). The permanent database, such as the target score values for various assembly operations, is not altered as a result of using the system over a period of time. On the other hand, the temporary database, such as properties values database is updated as a result of running the system.

3 THE SCENARIO FOR DESIGN ANALYSIS FOR AUTOMATION

The scenario for analysing a product for design for assembly is commenced by specifying the basic product specifications and the production data (production volume, number of components. etc.). Based on these data the system selects the most economic assembly technique for that specific product. As stated earlier, detailed knowledge of the product design is not required to select the assembly method selection. The reason that early assembly selection is important is that manual assembly differs widely from automatic or robotic assembly in the requirements it imposes on the product design. The recommended assembly method is examined in the early stages of the design process to ensure it is considered in the product design process. The system scenario is illustrated in Fig. 7.

The system was designed in such a way as to allow designers to analyse the product economically for the selected assembly method, i.e. manual, robotics, or high-speed automatic. Production rules, developed specifically for each of these techniques, are used to obtain the data that in turn are used to assess the components in the design, for ease of handling and insertion. For instance, in the case of analysis of the product for manual handling and insertion, assessment is based on estimating manual assembly costs and using time data corresponding to particular component design specifications together with operator wage rates.

The system has the capability of carrying out design feasibility and providing suggestions for the design improvement of the robotic assembly to manufacturing companies. The designer/user interacts with the system through a well-designed user interface, which allows the input of the product and process properties. The product and process properties are differentiated into component, assembly, and process properties. The design criteria for robotic assembly have been applied for each component. In other words, the separate subassemblies and components, as well as the whole assembly are technically evaluated based on the score of each component. The system can identify, automatically, the components with the relatively highest total scores, so as to initiate the suggestions for redesign. A design analysis report is then generated for the designer. Attention in the redesign stage in robotic assembly focuses upon the relatively highest component scores. The various components in assembly operations are considered for redesign, to simplify the assembly process, including the feeding, handling, and composing processes. The property with the highest score, for a component, indicates that this property must be subjected to redesign. A series of design modifications are proposed with the purpose of simplifying the assembly process.

4 SYSTEM BENEFITS AND VALIDATION

The major benefit of the developed system is that it provides the designer with the facility to select the most economic assembly technique for the product, based on the basic product specifications and the production data (production volume, number of components, etc.), at the early stages of the design process. Assembly automation and robotic assembly are highly specialized fields, and most designers do not have the necessary knowledge to meet all requirements to achieve a good design from the assembly point of view. Therefore, the main functions of the system, besides estimating the assembly time and cost for manual, high-speed automatic, and robotic assembly techniques, are to analyse the product design for automation and provide the designers with design improvement suggestions to simplify the assembly operations via a user-friendly interface.

In order to validate and demonstrate the capabilities of the developed system, a scientific calculator was the domain chosen as a case study. The system begins with analysing the product for ease of assembly. The system then recommends the most economic assembly technique. Based on this recommendation, the system estimates the assembly time and cost required for assembling the calculator. Moreover, the components that are candidates for redesign are highlighted by the developed system. Finally the system provides redesign

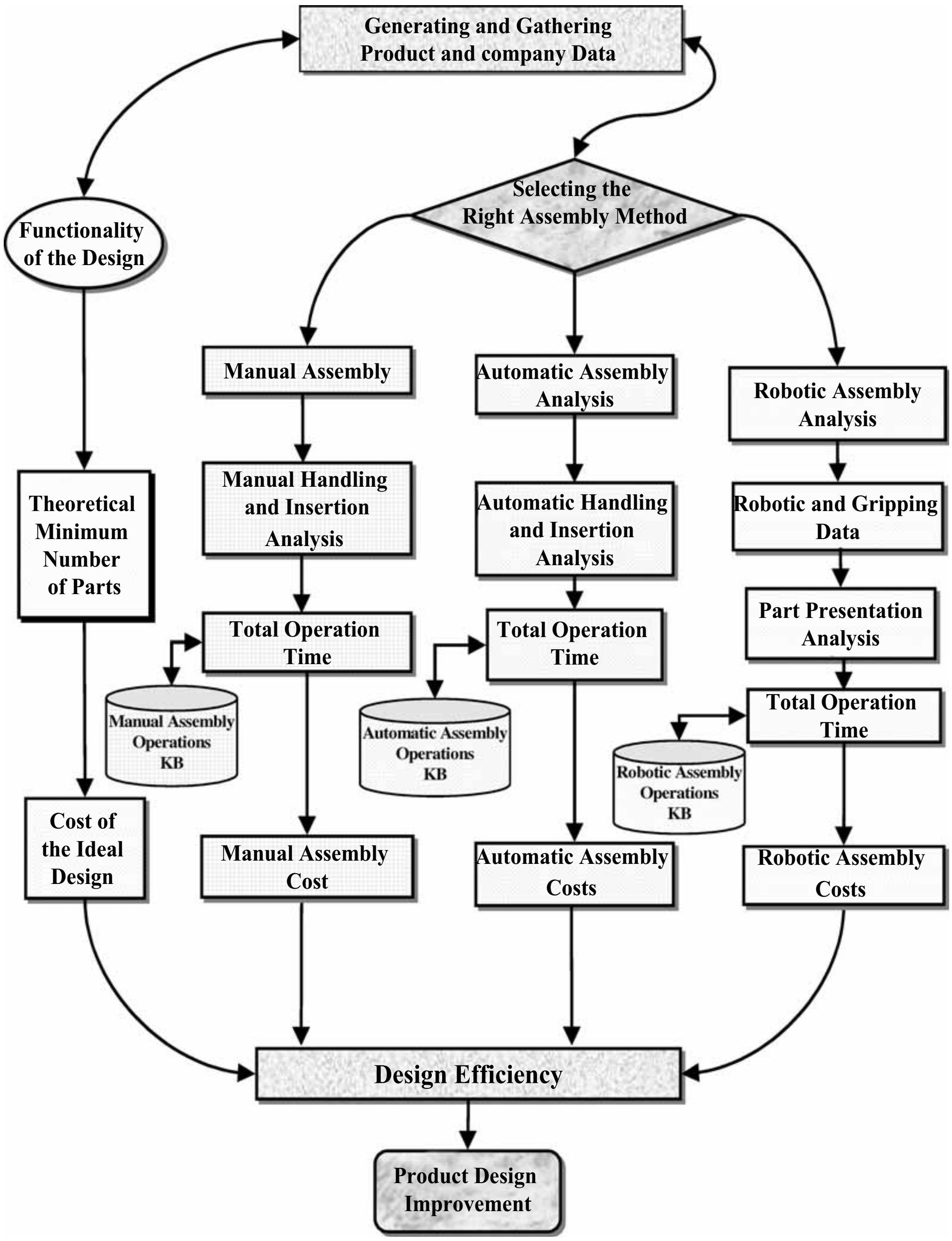


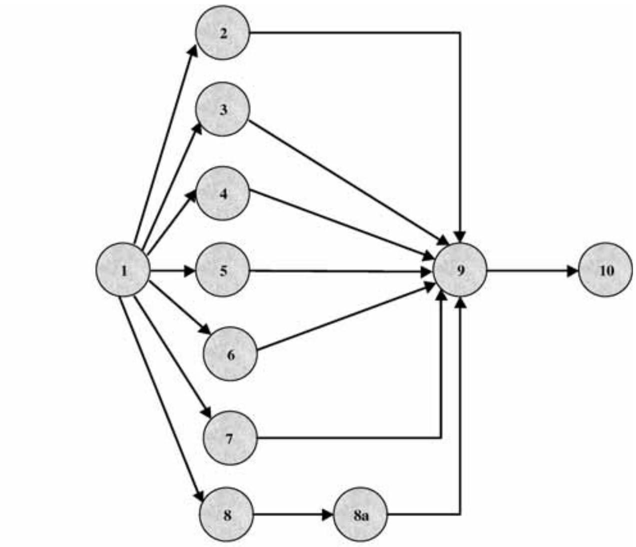
Fig. 7 The system scenario

improvement suggestions to simplify the assembly operations. In addition to the product structure, the above aims are discussed in details in the following sections.

4.1 The product structure

The scientific calculator is composed of fourteen components. In addition to four screws to secure fastening the internal parts such as printed circuit board (PCB) assembly and keyboard, the other joining method used is snapping. Front, rear, and battery covers, and adapter end are also the main components of the calculator.

The assembly structure involves the sequence of and the relationships between single-assembly operations. This is determined by the manner in which the product assortment and the product structure are built up from subassemblies and other components, which in turn determine the interrelationships between product components. For the current case study (calculator), all the components can be inserted vertically in a layer fashion from above. The assembly structure and processes for the com-



(1) Load front cover Assembly on the work fixture
(2) Adapter End
(3) Spring
(4) Keyboard
(5) Spring Foil
(6) Dome Foil
(8) PCB
(8a) Screws x 4
(9) Rear Cover
(10)Battery Cover

Fig. 8 Precedence diagram for complete assembly of the scientific calculator

plete assembly of the scientific calculator, as shown in Fig. 8, are as follows:

(a) mount the 'front cover' (component 1) on a fixture, add to it the 'adapter end' (2), the 'spring' (3), and the 'keyboard' (4);
(b) snap the 'spring foil' (5);
(c) add the 'dome foil' (6), and the 'plastic cover' (7);
(d) snap 'PCB' (8) and tighten the four 'screws' (9, 10, 11, 12);
(e) snap the 'rear cover' (13) and add the 'battery cover' (14).

4.2 Selecting the most economic assembly technique

Product design plays an important role in determining the cost and quality and thus the effective life of a product. At the early design stages, the designer should be aware of the nature of assembly processes and should always have sound reasons for requiring separate components; these will lead to higher assembly costs, rather than combining several components into one manufactured item.

The reason that early selection of an assembly process is important, is that manual assembly differs widely from automatic or robotic assembly in the requirements that it imposes on the product design. As mentioned earlier an operation that is easy for an assembly worker may be difficult for a robot or special-purpose workhead [**8**]. The developed system has the capability to recommend the most economic assembly technique in the early stages of the design process. The system selected the most appropriate assembly technique based on the following data that were entered into the system:

Product name	Scientific calculator
Annual production volume	250 000
Number of production shifts	3
Design style	5
Number of components	14
Number of different components	2
Product market life	4 years
Parts defective	0.8 %
Annual cost per operator	£14 625
Capital expenditure allowances	£25 000

As a result of the design product analysis and the production parameters (production volume, number of components, etc.), the system recommended the robotic assembly system as the most economic assembly technique for assembling the calculator. The procedures for assembly technique selection are outlined in reference [**19**]. Figure (9) shows the system output for the recommended assembly technique.

4.3 Cost estimation for robotic assembly

After the appropriate assembly technique was selected, the system began to estimate the cost of assembly by analysing the product design. The design analysis of the calculator's components, for ease of robotic assembly, was examined for the various assembly processes. These assembly processes include the difficulty of component placement, direction of assembly, and the difficulty of insertion of the components.

For presenting a component to a robot, three presentation techniques are used. These are programmable feeder (PF), special-purpose feeder (SF), or manually loaded magazine, pallet, or component tray (MG). The system requests the user to specify which of these methods should be used for each component in the product.

To estimate the costs for robotic assembly, it was necessary to have the total cost of robots, grippers, and all of the special-purpose equipment. The main specifications of the robot system that were input to the system and used to estimate the assembly cost of the present case study are illustrated in Table 1. A combination of heuristics data, algorithmic approach, and fuzzy logic techniques were implemented. The developed system allows users

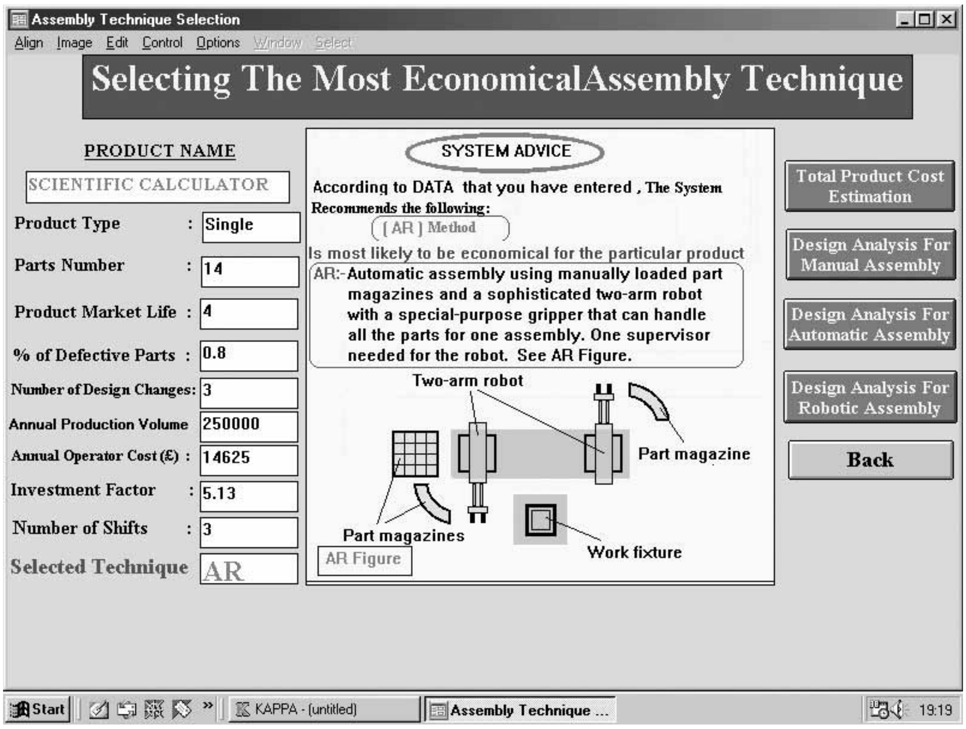


Fig. 9 System selection of the appropriate assembly technique for the scientific calculator

Table 1 The main specifications of the robot system for the present case study

Technique implemented	Figure used
Cost of standard assembly robot with controls, sensors, etc.	£50 625
Number of stations on the multi-station system	5
Standard gripper cost	£3125
The robot basic operation time	3 s
Cost of one station on free transfer machine including buffers and controls	£15 625
Cost of special work carriers associated with one station on a multi-station system	£3125

to generate accurate cost estimates for new designs and explore alternative materials and processes. More details of these various cost estimation techniques are presented in reference [**19**].

The multi-station assembly system cost estimation report for the scientific calculator generated by the system, is illustrated in Fig. 10. A summary of the analysis is shown below:

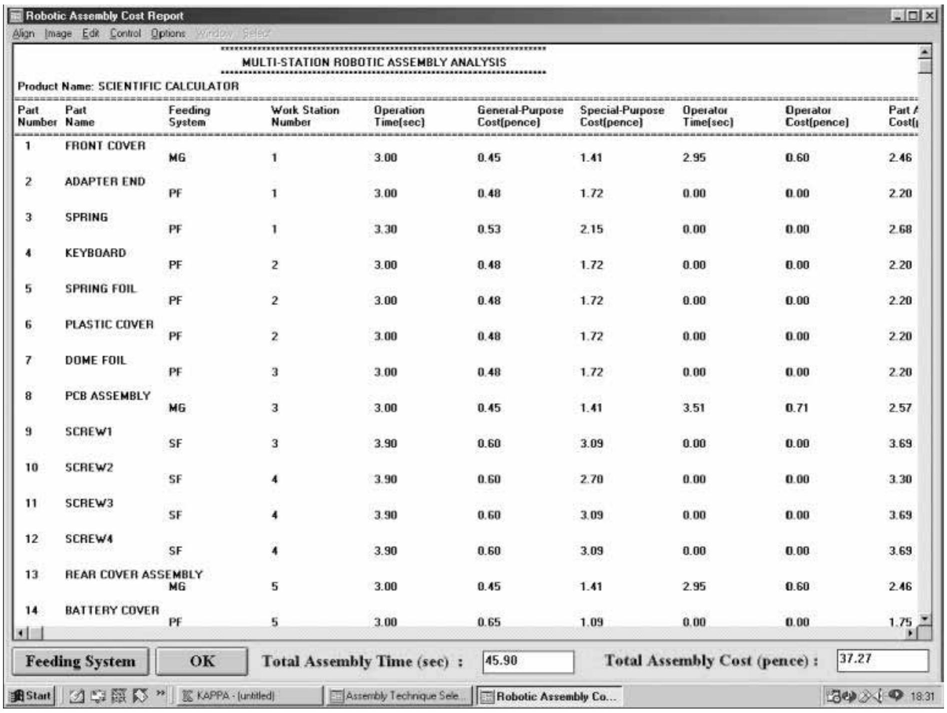
(a) No. of work stations: 5
(b) Assembly time: 45.90 s
(c) Assembly cost: 37.27 p

4.4 Design analysis and redesign improvement suggestions

The main objectives of the design analysis of the product were to (a) ensure that the product is designed for robotic assembly technique, and (b) facilitate design improvement suggestions for ease of assembly by identifying weak points in the design. The suitability of using robotic assembly for the scientific calculator design is presented below.

The analysis of the calculator design was carried out using the developed system. A novel assemblability evaluation score methodology was developed and used to assess design quality or difficulty of assembly operation as discussed in section 2.2. It is an effective tool to improve the design quality for ease of assembly operations. In the early design stage, weaknesses in the design's assembly producibility are pointed out by this technique.

In this technique, the design criteria for robotic assembly have been applied for each component. In other words, the separate subassemblies and components, as well as the whole assembly, are evaluated based on the score for each component. Figure 11 shows the assemblability evaluation report, generated by the system, for the robotic assembly technique. Figure 12 illustrates that three



Part Number	Part Name	Feeding System	Work Station Number	Operation Time(sec)	General-Purpose Cost(pence)	Special-Purpose Cost(pence)	Operator Time(sec)	Operator Cost(pence)	Part / Cost(
1	FRONT COVER	MG	1	3.00	0.45	1.41	2.95	0.60	2.46
2	ADAPTER END	PF	1	3.00	0.48	1.72	0.00	0.00	2.20
3	SPRING	PF	1	3.30	0.53	2.15	0.00	0.00	2.68
4	KEYBOARD	PF	2	3.00	0.48	1.72	0.00	0.00	2.20
5	SPRING FOIL	PF	2	3.00	0.48	1.72	0.00	0.00	2.20
6	PLASTIC COVER	PF	2	3.00	0.48	1.72	0.00	0.00	2.20
7	DOME FOIL	PF	3	3.00	0.48	1.72	0.00	0.00	2.20
8	PCB ASSEMBLY	MG	3	3.00	0.45	1.41	3.51	0.71	2.57
9	SCREW1	SF	3	3.90	0.60	3.09	0.00	0.00	3.69
10	SCREW2	SF	4	3.90	0.60	2.70	0.00	0.00	3.30
11	SCREW3	SF	4	3.90	0.60	3.09	0.00	0.00	3.69
12	SCREW4	SF	4	3.90	0.60	3.09	0.00	0.00	3.69
13	REAR COVER ASSEMBLY	MG	5	3.00	0.45	1.41	2.95	0.60	2.46
14	BATTERY COVER	PF	5	3.00	0.65	1.09	0.00	0.00	1.75

Fig. 10 Multi-station robot assembly cost estimation report for the present case study

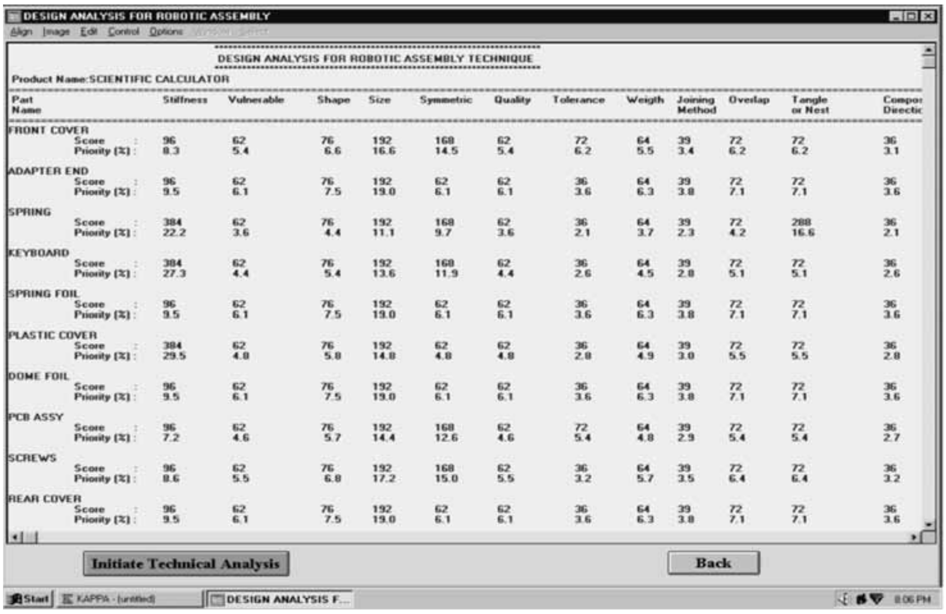


Fig. 11 The design analysis report of the calculator for robotic assembly generated by the developed system

components, – (PCB), keyboard, and spring – have a relatively high total score. Redesign of these components is thus necessary to facilitate the robotic assembly operations.

It is important to adapt the design of the product to utilize automated assembly. For this reason, a series of suggestions for modifications of the current design of the calculator, without any compromise to its function, were proposed with the purpose of simplifying the assembly process. The redesign considered both the product design and the assembly operations. The design modifications were carried out in two levels, the product structure level and the product components level. The redesign stage focuses particularly on the three components that have been mentioned in section X.X. The system displayed the various properties of the three components which must be considered for redesign. For

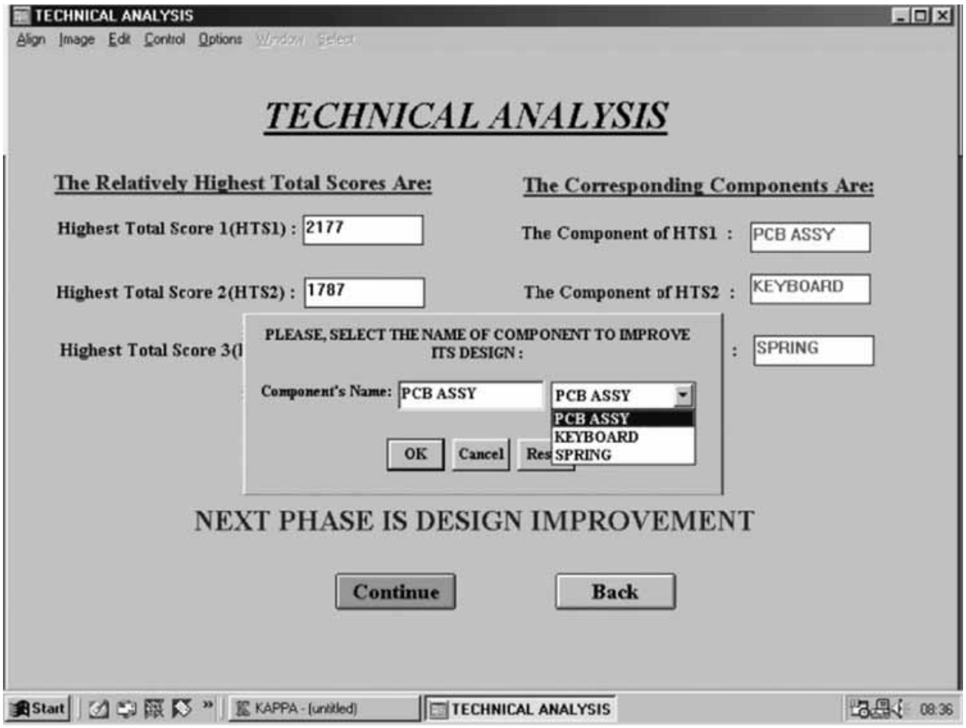


Fig. 12 The candidate components for redesign

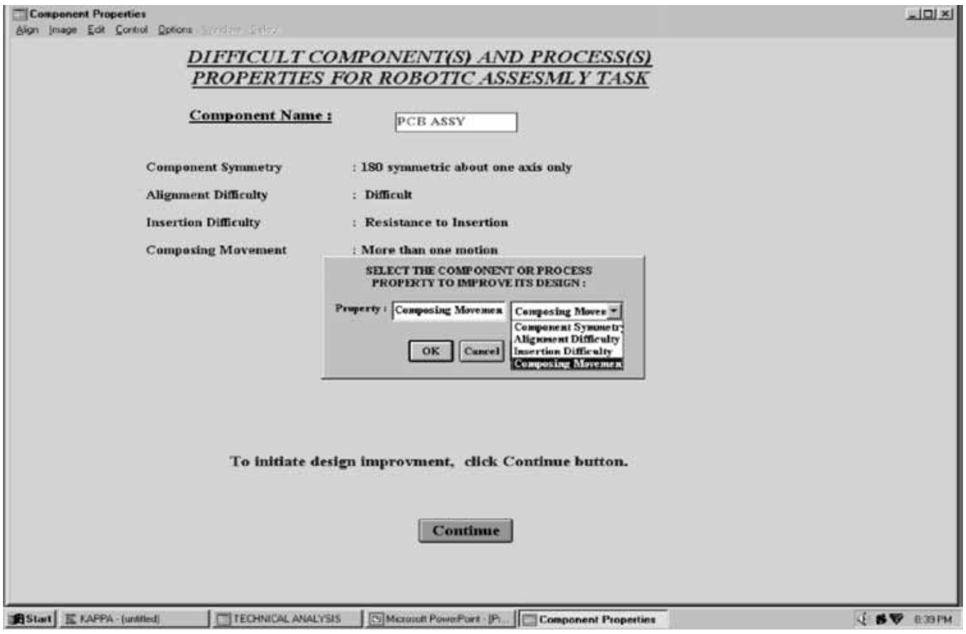


Fig. 13 The system result showing the various properties of PCB component, which must be considered for redesign

example, these properties of PCB component were alignment difficulty, component symmetry, insertion difficulty, and composing movement as shown in **Error! Reference source not found**. For the composing movement, three motions – tilting, moving, and snapping – required for insertion of the PCB onto the front cover [see Fig. (14)]. This is because of the bad design of the snaps. The PCB could be snapped easily by a human operator, but would involve complicated motions for a robot [see Fig. (14)]. Therefore, the snaps at the keyboard area of the front assembly are redesigned to accommodate only one motion for insertion as shown in Fig. 15.

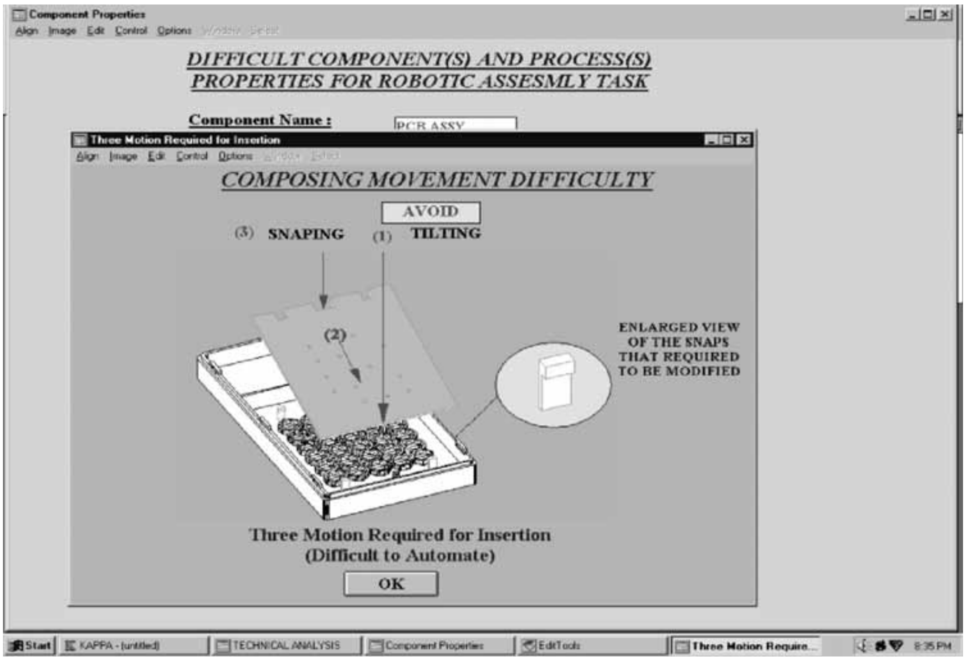


Fig. 14 The three motions required for insertion (difficult to automate)

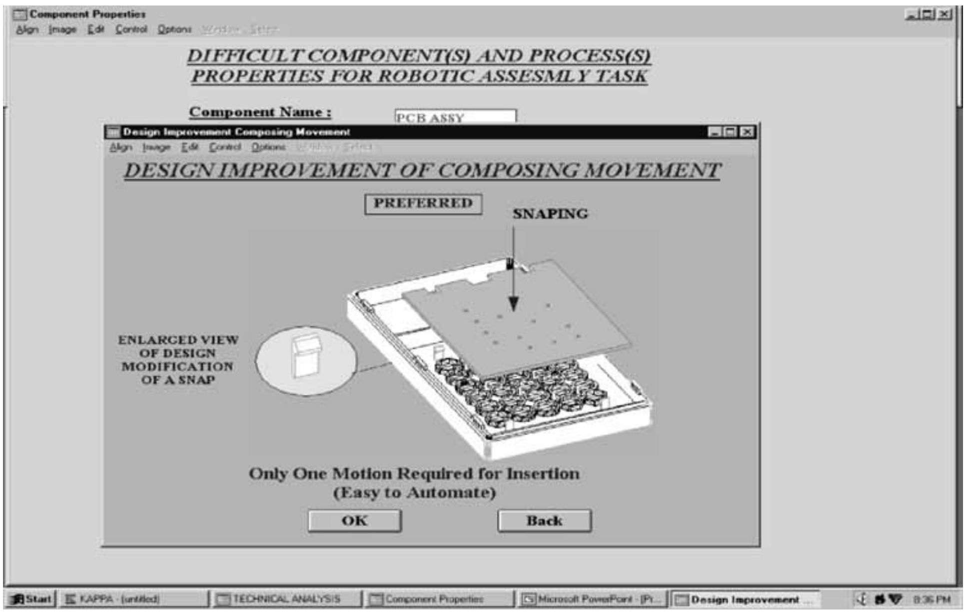


Fig. 15 One motion required for insertion (easy to automate)

5. CONCLUSIONS

The developed prototype system for design for automation has been presented in this research paper. The system framework consists of CAD system, KBS, design analysis for automation module, design improvement suggestion module, and a user interface. Hybrid knowledge representation techniques – such as production rules, frames, and object oriented – are employed to represent various types of assembly knowledge in this research. A user-friendly interface, which grows via the utilization of powerful features such as multiple-choice menus, active images, sessions, pop-up windows, and buttons, has been developed for providing the designers with easily input data to the system and complete results of the analysis.

The system has the capability to, besides estimating the assembly cost, select the most economic assembly technique for the product at an early design stage, and analyse the product design for automation and provide the designers with design modifications suggestions to improve the design of the product to make it more suited to automated assembly. The developed system has been tested using a real product (Scientific Calculator). Satisfied results have been obtained from the developed approach as well as the software system.

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