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A Prototype of Knowledge-Based System for Fault Diagnosis in Automatic Wire Bonding Machine

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Abstract

In the modern world, computing is essential in all aspects of manufacturing activity. Computers have brought to life terms like artificial intelligence, and have played a critical role in reinvention of manufacturing industry. In continuing quest to decrease the interval time between conceptualization of a product, information technology has been fused with manufacturing practice. This paper describes the use of an expert system shell to develop a knowledge-based system (KBS) for an automatic wire bonding machine in the hi-tech semiconductor industry. The main aim of the KBS is to diagnose and solve the problem of an automatic wire bond machine. The diagnosis method was based on maintenance requirements such as measurement, machine, and material. In the semiconductor industry, production equipment and machine have depended heavily on the use of human expertise for maintenance and it is costly. Without a knowledge-based system, their experience will be lost when they are unavailable or resign. With the developed KBS, the diagnosis process for the automatic wire bond machine is standardized and accuracy will be increased compared to the conventional way. Therefore, the quality of products that are produced will improve. The constrain values for KBS are based on the design data and experience of the engineer. The KBS is to improve bonding quality by reducing the production yield loss.

Key words: Semiconductor industry, Automatic wire bond machine, Knowledge-based system, Troubleshooting

Introduction

In the new millennium, computer-aided engineering (CAE) will focus on its original objective, the integration of engineering functions and, in particular, the co-coordinating functions of manufacturing engineering. Engineering and its associated technologies are, of necessity, evolving into a production support function, in which internal customers represent the end user in terms of quality (ease of manufacture), cost (robust designs and processes), and delivery (efficient communication) (Hetem, 2000). Computer Science is a valuable technology and it is a powerful tool for machine fault diagnosis. Some companies like DLI Engineering Corporation, a rotating machinery assessment company, has offered an expert system to its customers to diagnose the machines, which best meet customer requirements including reduce machine downtime, reduced labour costs associated with unplanned maintenance, reduce number of equipment spares, and improve overall plant reliability.

In the semiconductor industry, production equipment and machinery are depended heavily on the use of human expertise for maintenance and repair. In order to develop the expertise, considerable effort is required to train the work force. In some situation, expertise is not available on a reliable and continuing basis. Experts are expensive, scarce, and in high demand. It is also easy to lose expertise through separation, job transfer, and retirement. Therefore, KBS is emerged in the field of artificial intelligence (AI) with strong potential and capability for reducing training cost, maintaining consistent expert knowledge, and improving productivity and the quality of the task performed (Jackson, 1992).

Knowledge based system emulates the behaviour of human expert within a well-defined, narrow domain of knowledge (Liebowitz, 1995). In the past, KBS was used by various investigators to select engineering parts, processes, and materials in the industry. Arezoo et al. (2000) developed a KBS for selection of cutting tools and conditions of a turning operation. A KBS was developed by Sapuan et al. (2002) for material selection of ceramic matrix composites for engine components such as piston and piston ring. Er and Dias (2000) have developed a rule-based system for casting process selection, and described an ongoing rule prototype development. Mookherjee and Bhattacharyya (2001) have developed a KBS, namely EXTOOL, which automatically select turning/insert or milling insert, the material and the geometry, based on the requirement of users. Similar studies on the KBS of fault diagnosis were carried out by Wu et al. (2007a) and Wu et al. (2007b), but the KBS served as consultants for fault diagnosis of vehicle engines. Afgan et al. (2006) developed an expert system to diagnose faults and monitor gas turbine combustion chambers. Chan (2005) developed the expert decision support system for monitoring, control, and diagnosis of a petroleum production and separation plant. Yang et al. (2005) proposed a KBS, called VIBEX (VIBration EXpert), to aid plant operators in diagnosing the cause of abnormal vibrations of rotating machinery. Qian et al. (2005) developed a KBS to diagnose the error in chemical processes.

This research was conducted in a multinational semiconductor company. Automatic wire bonder is used for aluminium wedge bonding process by the Dpak production line. Dpak product is a power transistor manufacturing line. It includes the process of assembling and testing Dpak power transistors. Dpak power transistors are mainly used in the automotive industry as a controlling device for auto-braking system (ABS), ignition system, and power window. The developed KBS consists of several modules such as knowledge acquisition module, inference engine module, and user interface module. The backward chaining method is used in the development of the system. The developed system provides systematic fault diagnosis guide for the machine operator and technician. A user-friendly interface consisting of images, menu, and buttons was designed to help user during data input to the system and obtain the complete results. The process engineers can choose the right solutions to solve the problem during wire bonding process and hence reduce time loss.

Front End Assembly

The wire bonding process is one of the processes in Front End Assembly as shown in Figure 1.

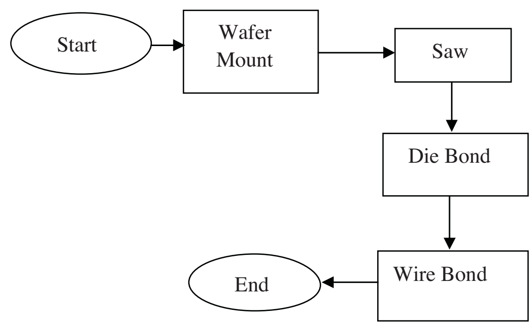

Figure 1. Front End Assembly process.

This assembly consists of 4 types of machines: Wafer Mounter, Saw, Die Bond, and Wire Bond. The Integrated Circuits (IC), which is also known as ‘die’ in the assembly/production floor, come in wafer shape from the wafer fabricators. The wafer is mounted to wafer ring using Mylar tape before it is taken to the saw machine to cut the wafer into die form. At the Die Bond machine the dies are attached to lead frame flag using a type of glue known as epoxy. The Wire Bond machine will attach wire to the input/output (I/O) of the die to the leads of the frame. The I/O point on the die is known as pad or bond pad. Figure 2 shows the basic step in the Front End Assembly.

Automatic Wire Bonding Machine

The auto wire bond machine used in this research is fully automatic high-speed ultrasonic bonder. It bonds the wire between die and lead frame using an ultrasonic energy. The major systems of the machines are electronic and mechanical. They are linked with a variety of interchangeable tooling, process control, and electronic accessories. The machine will enable a fully automatic process using a pattern recognition system with an automatic lead frame handling system.

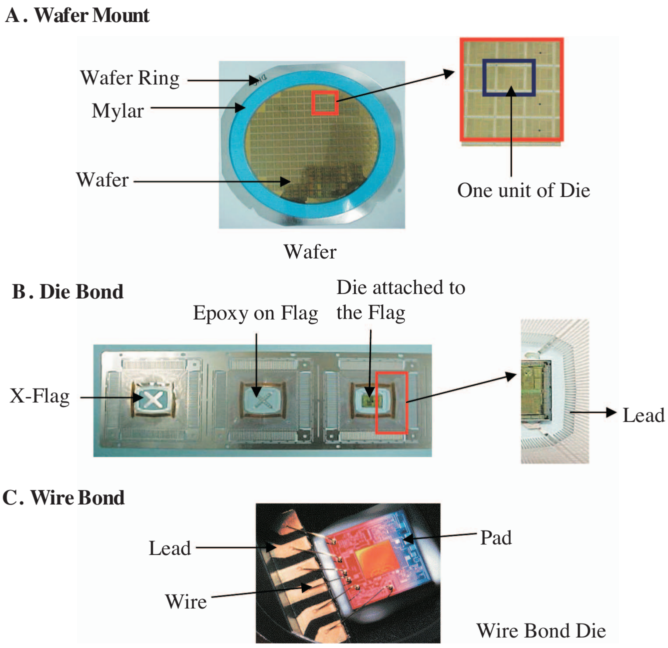

Figure 2. Basic steps in Front End Assembly: A. Wafer Mount, B. Die Bond, C. Wire bond.

System Description

The KBS for automatic wire bonding machine was developed based on heuristic rules and the experience of maintenance experts. Classification and reasoning of fault diagnosis are carried out using a rule-based system approach. This includes knowledge acquisition, choosing the selection criteria, selection of user interface; define the knowledge hierarchy, program code writing, program validating and testing, documentation, and maintenance. The development of the KBS involves 5 major phases.

Phase 1. Knowledge Acquisition

The development of a KBS requires many problems to be solved. The expert knowledge is heuristic and difficult to gather. The most dominant source for this project is the domain expert. The sources for knowledge acquisition are from:

(i) Sessions with Experts

The domain experts involved in this knowledge acquisition process were a senior equipment engineer, a technical specialist, and a senior staff engineer. The knowledge from the domain experts were extracted from discussions and meetings. The fish bone diagram was used to record all the root causes. To ensure the highest level of creativity and participation by domain experts, critic, praise or discussion on the root causes were carried out at each meeting. For each root cause, the domain expert needed to clarify it.

(ii) Machine Record Card

The machine record was used to record the problems occurred, and the solution for the problem in auto wire bond machine. These records were documented by the line technicians wherever they attended the machine problem. These records were analysed and commented by the experts.

(iii) Manufacturer Operating Manuals

The machine operating manuals contained technical information about the wire bonder and its operation. The manual was considered as in-depth knowledge or technical knowledge of the domain, as compared to the heuristic knowledge, which is primarily based on the experience.

(iv) Process and Equipment Specification

These specifications were developed internally by maintenance and process engineers. It contains general procedure for wire bond process, machine start-up procedures, and operating procedures.

(v) Total Control Methodology

It is a comprehensive document that was created for each and every process. This document contains process and equipment database to operate a machine. It also contains preventive maintenance program and activities related to machine diagnosis.

Phase 2. Design

After the knowledge acquisition from the domain expert, the next task is to select the knowledge representation technique and control strategy. A prototype system is built to validate the research and to provide guidance for future work. Figure 3 shows the general configuration of the proposed system.

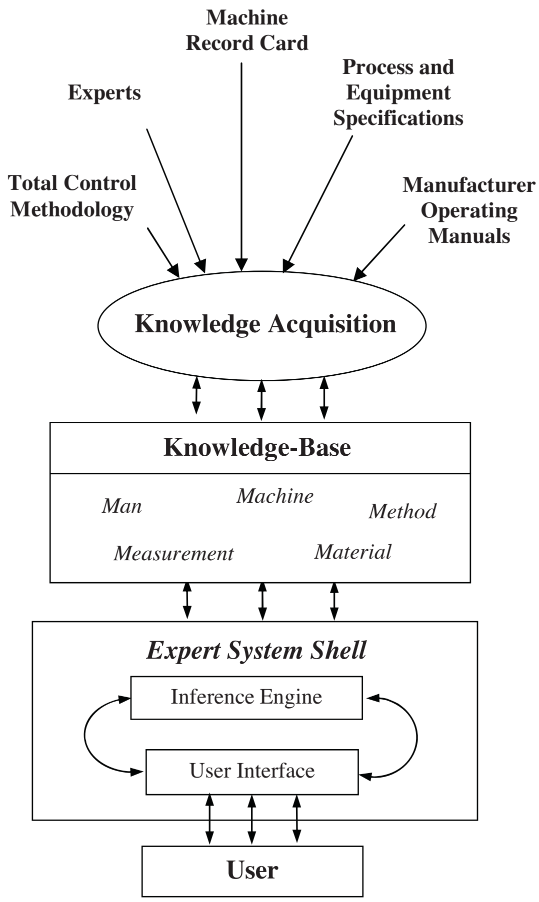

Figure 3. The structure of the proposed system.

The following stages are in the design phase:

(a) Selection of Prototype Development Tool

The selection of development tool for KBS must satisfy certain criteria in order to save time and effort in fulfilling its objective. For the present problem, selection must satisfy the following basic conditions:

(i) It must support hybrid knowledge representation techniques.

(ii) It must have varied inferencing facility.

(iii) It must support good interface facilities with external programs and systems.

Considering the above criteria, Kappa-PC expert system shell (1997) was chosen for the present problem. Apart from its powerful object oriented capabilities, Kappa-PC allows for the representation of knowledge using production rules. It enables the knowledge base to be built by using heuristic knowledge, as well as permitting work with algorithms. It also provides a variety of user options.

(b) Selection of Knowledge Representation Technique

In this stage, a knowledge representation technique that best matches the way the expert mentally models the wire bond problems was required. Therefore, a rule-based system was chosen to design the KBS, and the following approach was applied:

If (X) Then (Y)

Figure 4 shows a rule structure, which is used in fault diagnosis for the auto wire bond machine. If the condition of the rule is satisfied, then the conclusion of the rule is set as the result.

(c) Selection of Control Technique

Backward chaining is used in this research project because the expert first considers some conclusions (defects mode) and then attempts to prove it by searching for supporting information. The expert is mainly concerned with proving some hypothesis or recommendations.

IF

defect	=	lifted_pad_&_post	AND
deformation	=	deformation	AND
cut_wire	=	yes	AND
bond_angle	=	yes	AND
wire_guide	=	yes	AND
wedge_height	=	yes	AND
wire_free_flow	=	no_binding	AND
pivot_s_play	=	no_side_play	AND
pivot_binding	=	no_binding	AND
heat_sink_clamp	=	yes	AND
bond_head	=	not_binding	AND
heater_block_firm	=	yes	AND
touch_down_sensor	=	yes	AND
overtravel_height	=	yes	AND
table_side_play	=	side_play	

THEN

Action = inform_equip_group_to_service_table;

Figure 4. Rule structure for the expert fault diagnosis system.

(d) Develop the Prototype

The system development used an expert system shell. The prototype is a model of the final system. Its basic structure, in terms of the way it represents and processes the problem's knowledge, is the same as in the final system.

(e) Develop the Interface

The user interface is developed to provide an easy access and avoid confusion to the user. The language used in the interface is a consensus of that used by operators and engineers. Figure 5 shows the user interface of the system. Figure 6 shows the defect help module.

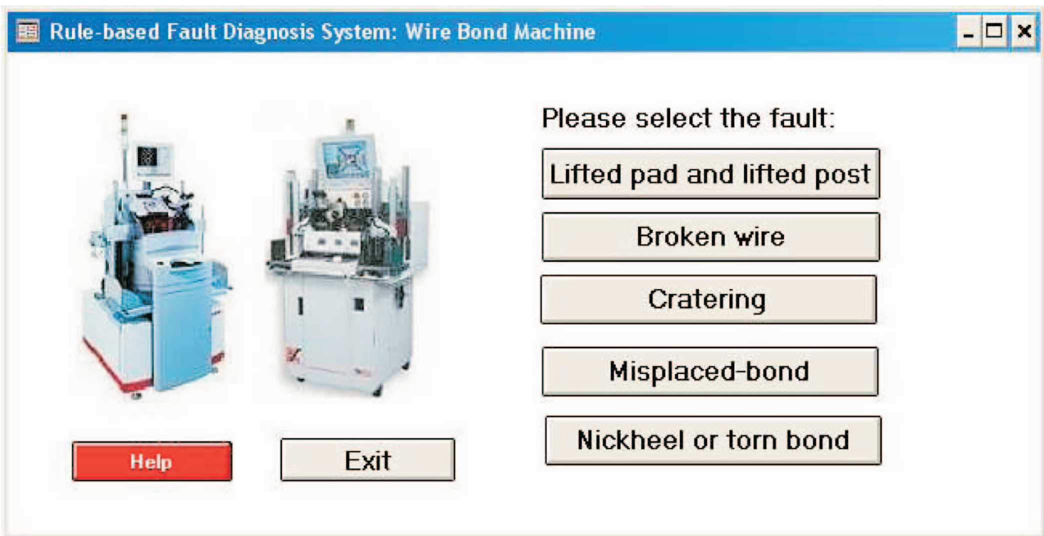

Figure 5. The fault selection window.

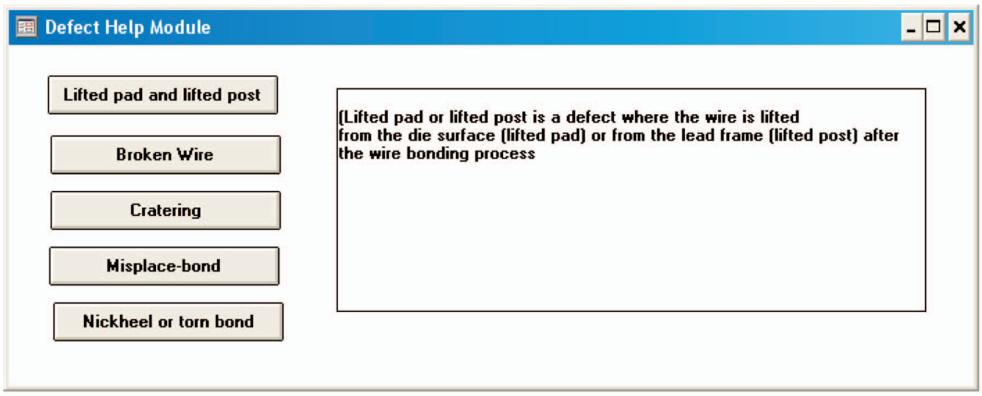

Figure 6. The defect help module.

(f) Develop the Product

The developed system should let the user update the system when there are new rules or techniques available.

All information about the maintenance and fault diagnosis is stored in the knowledge base. An inference engine will scan the storage by using Kappa-PC tool and applying "if-then-rules" in order to find the suitable solutions of the problem. The inference engine interacts with the knowledge base in backward chain method to solve the problem.

Phase 3. Testing and Validation

The developed expert system is tested and evaluated to ensure the software performance is converging towards established goals. The evaluation process is more concerned with system validation and user acceptance. Validation efforts determine if the system performs the intended task satisfactorily. User acceptance efforts are concerned with issues impacting how well the system addresses the needs of the user. There are 3 tests that are involved in the development of the expert system.

(a) Preliminary Testing

This test is to evaluate the complete knowledge base. The test applies all possible combinations of answers to the questions asked by the system. The test provides the early verification of the system. The developed system was tested separately based on the module.

Immediately following the development of the prototype system, an informal test of the system, evaluating the complete knowledge base, is conducted. The test applies all possible combinations of an answer to the question asked by the system. System-derived solutions are verified for each set of answers. This type of test provides early verification of the system. Since the expert system is designed using several separate modules, each module is tested separately. This approach not only makes it easier to test the entire system, but also permits the author to continue to perform a complete test later in the projects as the knowledge base grows. Figure 7 shows a typical data input form for lifted pad and post module. Figure 8 shows the result screen with recommendation.

(b) Informal Validation Testing

The system was tested against real problems from its domain. The objectives are to determine the effectiveness of the system in solving the wire bond defects and uncover system deficiencies. Past cases were used for testing.

The purpose of stage 2 is to determine the effectiveness of the system in solving the wire bond defects and to uncover system deficiencies by using the off-line method. Table 1 show the results of KBS when it is used to diagnose past cases.

There were certain incorrect results provided by KBS. These incorrect results were discussed and reasoned out with domain expert. Mistakes were corrected immediately by modifying the knowledge base.

Figure 7. A typical data input form for lifted pad and post module.

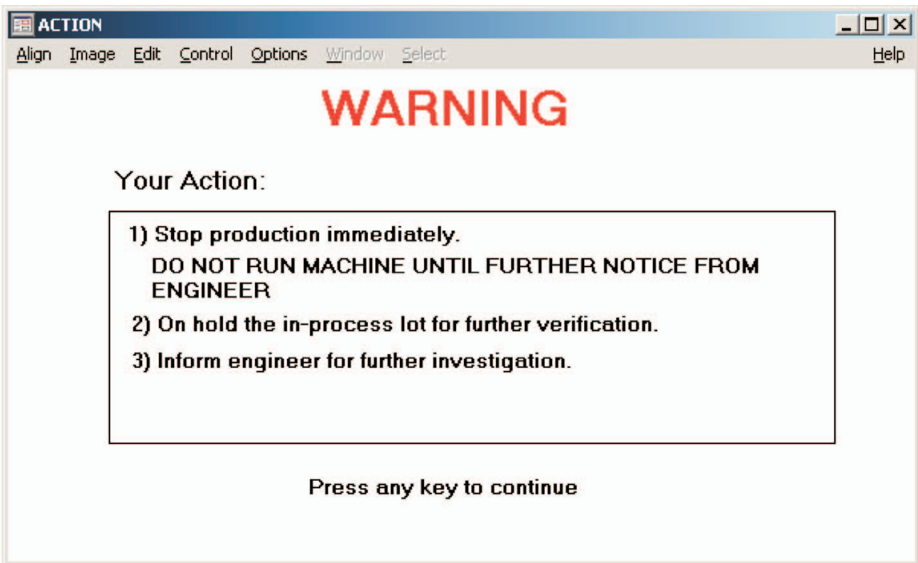

Figure 8. The result screen for lifted pad and post module.

Table 1. Informal validation test results.

Case no.	Defect	Actual Root Cause	ES Result	Match
1	Broken wire	Wire clamp solenoid	Adjust solenoid gap	Yes
2	Broken wire	Wire flow path	Clear wire path	Yes
3	Misplaced bond	XY table	Service XY table	Yes
4	Misplaced bond	Eye-point	Re-teach eye point	Yes
5	Lifted pad & post	Shinning surface	Inform engineer	No
6	Lifted pad & post	Bond head	Calibrate bond head USG	Yes

Table 2. Field case study results.

Technician no.	Defect	Root Cause	Problem solved by ES?
1	Broken wire	Capillary out of alignment	Yes
2	Broken wire	Service wire	Yes
3	Misplaced bond	Die placement	Yes
4	Misplaced bond	Eye-point	Yes
5	Lifted pad & post	Adjust clamping station	Yes
6	Lifted pad & post	Adjust bond angle	Yes
7	Lifted pad & post	No die	No
8	Lifted pad & post	Missing metallization	No

(c) Field Testing

The developed system is deployed into the work environment and exposed to wire bond real world problem. A few technicians are requested to use the expert system to trouble shoot the wire bonder. The objective of the test is to determine if the system meets its original goals. This test also determines the validation of the system and assesses the user's acceptance.

While the stage 3 testing is conducted in the field, there will be some degree of uncertainty in the performance and acceptability of the system. During this study, the system was deployed into the work environment and exposed to a real world wire bond problem. A few technicians are requested to use the KBS to troubleshoot the wire bonder and the results are shown in Table 2.

During the field test, there were other defects, such as no die or missing metallization, were detected. These defects rarely happened in wire bonding and are not included in the expert system. The expert fault diagnosis system was improved by adding in "other defects" and modifying the knowledge base.

Phase 4: Documentation

The documentation serves as the diary of the project. It contains all the material collected during the project and used as reference. The information that needs to be retained and recorded in the documentation serves 3 purposes: reference for developing expert system, reference for writing the final report, and reference for maintaining the expert system.

Phase 5: Maintenance

The final phase of this research project is the system maintenance. Maintenance is required since most expert systems contain knowledge that is evolving overtime. The company may require new equipment or develop new products or change the procedures. This changing state requires appropriate modifications to the system. Due to security purposes, it is important that only designated individuals are allowed for maintaining the system.

Results and Discussion

An expert fault diagnosis system for Auto Wire Bond Machine was developed and tested. The developed expert fault diagnosis system has the ability to diagnose machine problems and thus recommend precise and systematic troubleshooting procedures. The database of the system can be changed and upgraded easily by user. The program was tested for all possible scenarios such as the defect on misplaced bond as shown in Figure 9. The system will give an error message if the user makes a mistake in entering the required data or answering the question. Therefore, the system was tested to validate the proposed system. It involves 3 stages where the first stage will test the complete knowledge base for logic and consistency. The next stage is to demonstrate the system to the domain expert. While in the third stage, the developed system is deployed into work environment and exposed to a real world wire bond problem.

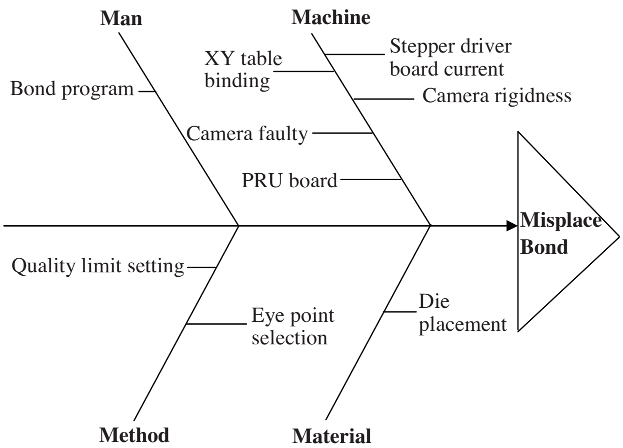

Figure 9. Example of defects on a misplaced bond in a fish bond diagram.

As the project proceeds, the developed expert system is periodically tested and evaluated to assure that its performance is converging towards established goals. The evaluation process is more concerned with system validation and user acceptance. Validations efforts determine if the system satisfactorily performs the intended task. User acceptance efforts are concerned with issues that impact how well the system addresses the needs of the user.

The fault diagnosis process of the developed system is reasonably satisfactory and systematic to the knowledge engineers. The flow of the diagnosis is flexible, allowing the user to reset conclusions, to go back for a new diagnosis, to review input values until he/she is satisfied with the results.

Conclusions

This project presented a knowledge-based system for fault diagnosis of automatic wire bonding machine. The system enables the user to diagnose the problems in an auto wire bonder machine that is used in hi-tech industries. The developed system is to guide the experienced and non-experienced technicians in troubleshooting wire bonder machine faults. In addition, it also served as a tutor to new technicians in order them to acquire their wire bonder fault diagnosis skills. The results showed that the KBS in fault diagnosis have a significant impact on an automatic wire bonding machine. The developed system has the following characteristics: (i) using the knowledge dictionary; (ii) flexible and modular type where the fault diagnosis database can be upgraded and integrated with other systems, such as scheduling process; (iii) using multiple input forms to avoid input error; and (iv) using the explanation technique. Kappa-PC, supported by object-oriented programming and rule-based reasoning, was used to develop KBS for fault diagnosis and it is reliable and easy to use. The KBS is interactive with user and gives feedback information to follow the diagnosis procedures. By adopting the KBS as a fault diagnosis tool, it takes less time compared to the manual method. The developed KBS supported the designer in selecting the best diagnostic method for the automatic wire bonding machine.

The recommendations for the future development for the system are: (i) allowing greater number of users to use the system and collecting their feedback to improve it; (ii) training a new generation of technicians or engineers in the field through utilization of an education system; (iii) encouraging the utilization of computer technologies in this field; and (iv) inclusion of further aspects of the latest available auto wire bond machine.

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