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Mechatronic Modular Design of an Apparatus for PC Board Inspection

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Abstract

The design to market time of printed circuit boards (PCBs) is a function of individual cycle times of different processes that comprise the production of the PCBs. Production of a family of PCBs with common electronic component layout, composition and interconnections can also be greatly reduced by implementing the principle of Reverse Engineering (RE). This will reduce the PCBs cycle time and improve product introduction into the market. RE of PCBs can be achieved by visual inspection, which forms part of quality assurance of PCB's.

This project proposes an apparatus, designed using modular mechatronic principles. The apparatus can also be used as an inspection station. The developed apparatus uses vision technology to acquire the information on the design of the finished prototype PCBs i.e. electronic component composition and layout, and PCBs' artwork. Single sensor mechanics is used as a scanning system to capture the image of the finished prototype circuit for RE and inspection. Efficient PCBs' image acquisition is achieved stepwise by implementing the camera position module and the rotating table module. The PCB mover module is used to transport PCB's to and from the rotating table. The developed apparatus uses low cost power electronics and sensor circuitry to achieve the desired levels of motion control and intelligence.

1 Introduction

A product's economic life cycle consists of the following phases [Cronje et all, 1995]: (See figure 1)

- Development phase: few products developed for testing and limited markets
- Growth phase: follows successful product marketing and development
- Maturity phase: market saturation reached
- Decline phase: caused by technological obsolescence or competitive pressure

To reap the benefits of the maturity phase, product

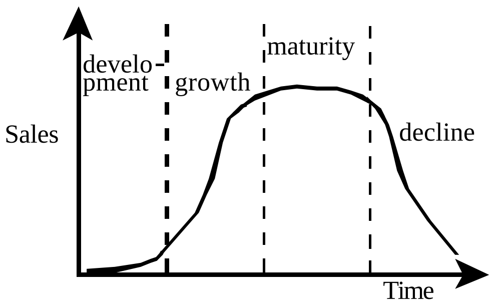

Figure 1. Economic Product Life Cycle.

development should be accelerated.

The product life cycle in the electronics industry is very dynamic. Product life cycles of electronic products are becoming shorter. This compression of life cycles requires that the manufacturer be efficient in product introduction. Efficient product introduction can be achieved by implementing engineering principles such as Design for Manufacture, Concurrent Engineering and RE.

This paper explores the concept of RE implementing an optical inspection apparatus. Generally, optical inspection systems that are currently implemented in the industry are used for inspection purposes only. They employ more than one sensor incorporating complicated lighting systems. Some of inspection systems currently used in the market can be seen in Table 1. For example, the AOI System Corporation developed the AOI-20 product, which employs as many as 20 CCD cameras and can perform parallel processing. The major limitation of the existing inspection systems is that all the software algorithms need a special hardware platform in order to achieve the desired real-time speeds, which make the systems extremely expensive. Any improvements in speeding up the computation process algorithmically could reduce the cost of these systems drastically. The challenges confronting the automated visual inspection research are the development of generic inspection equipment, hardware and software, capable of handling a wide variety of inspection tasks, including RE of PCBs [Moganti, 1993].

This project presents a PC based, automated optical inspection (AOI) apparatus for inspection and RE of PCBs that utilises low-cost auxiliary electronics, vision and lighting systems. The developed lighting module is simple in design and reduces the amount of software algorithms

System	Inspection Methods	Vision System
AOI system AOI-20	Design rule checking (8 kinds of detection sensors) and comparison method	20 CCD Cameras Reflection / transmission lighting
Mania MOP – 5002	Simultaneous use of design rule and image comparison	2 CCD Cameras Halogen lamp lighting
Shin-Nippon Steel PT-2130	Design rule checking and comparison method	Halogen lamp, Multi-directional illumination Speedy CCD camera
Orbotech PC-1450	Design rule checking and comparison method (Golden board or CAD download	Reflective and diffusive Omni lighting
Orbotech Vision Blaster	Design rule checking and comparison method (Golden board or CAD download	Flourescent technology (blue laser)

Table 1 - List of Commercially Available Inspection Systems [Moganti, 1993].

needed. Strategic incorporation of low-cost sensors into the apparatus design, in conjunction with the development of suitable computer control algorithms and software, resulted in the proposed optical apparatus exhibiting certain levels of intelligence and information management. The AOI apparatus should be able to interact effectively with its environment, or it should be easily incorporated into a computer integrated manufacturing (CIM) cell, to improve information sharing capability of a manufacturing system. Flexible and efficient PCB design and manufacturing processes will be realised.

2 Reverse Engineering and Inspection of PCBs

RE of populated PCB's using vision technology is a task that requires acquiring multiple images of PCB's and storing them for further image processing. Images that are required for efficient image processing are images of individual electronic components comprising the PCB and an image of the whole PCB to reveal the PCB's artwork. A database of components characteristics e.g. shape as

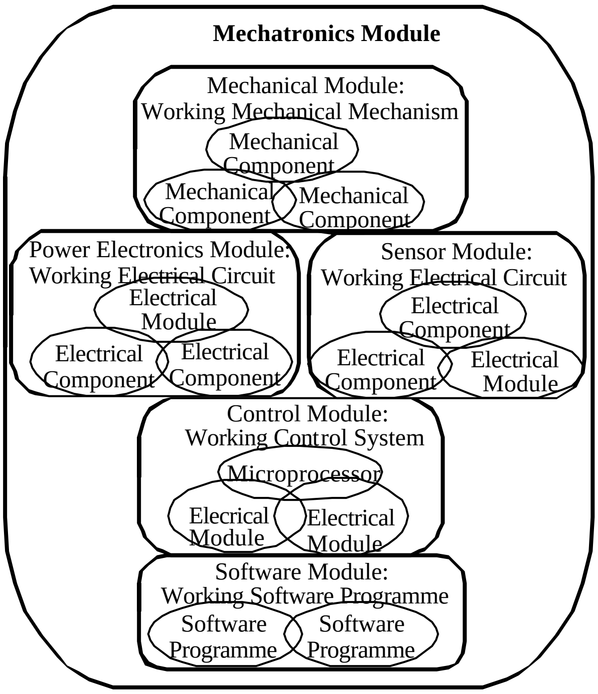

Figure 2. Modular Mechatronics Design Principle.

viewed from the top, writings inscribed on the electronic components etc can be used to identify individual electronic components. Advanced image processing can be used to identify components' interconnections [Moganti, 1993].

RE of the artwork of multi-layered PCBs, or the artwork hidden underneath the electronic components can be achieved by implementing X-ray laminography. Laminography provides cross-sectional X-ray imaging which separates the top and bottom sides, or any other layer of the PCB, into cleanly separated images [Bond, 1991]. This technology was never tested in this project.

Currently, optical inspection of populated PCBs is used for quality assurance only. Some of the commercial systems capabilities are to inspecting holes, measuring dimensions of bare-boards, indicating faulty solder joints, indicating misaligned and missing electronic components. Some can make exact measurements of board features or perform inspection in line with the production process [Savage, 1993]. For manufacturing, the most complete (and most expensive) systems can execute all these functions.

3 Design of the AOI Apparatus

3.1 Modular Mechatronic Design

Mechatronics can be defined as the systematic integration of mechanical engineering, electrical engineering and IT to produce a high quality working system [Bolton, 1999]. Modular mechatronic design of the AOI apparatus was achieved by breaking down each and every module of the apparatus into its elementary modules [Tlale, 2001]. The smallest elementary modules that can be identified are termed low-level modules. When a number of elementary modules are combined to from a working module with a particular purpose, then the combined modules also form another module. This process is continued until the working, high-level module can be identified (Figure 2).

3.2 AOI Apparatus Description

The AOI apparatus was composed of four high-level modules:

- PCB Mover Module.
- PCB Stop Module.
- Rotating Table Module.
- Camera-Positioning Module.
- The Vision System Module.

The function of the PCB mover module was to transport the PCBs into the AOI apparatus and position them onto the rotating table module. It also transported the PCBs out of the AOI apparatus from the rotating table module. During transportation of the PCBs into the AOI apparatus, the PCBs were placed onto top of their pallets on the conveyor belt of the PCB mover module. During the transportation of the PCBs out of the AOI apparatus, the same conveyor belt pushed out the PCBs and their pallets (ref Figure 3).

In order to stop PCBs from passing the rotating table with the conveyor belt of the PCB mover module, the PCB stop module was implemented. The PCB stop module, in the Engaged position, positioned the PCBs onto the rotating table module during transportation of PCBs into the AOI apparatus. In the Engaged position, the PCB stop module interfered with any rotation of PCBs by the rotating table module(ref Figure 3). Thus, the PCB stop module was put in the Disengaged position during the operation of the rotating table module.

The principal function of the rotating table module was to align (or orient) the axes of the PCBs with that of the camera before image acquisition (ref Figure 4).This meant that less image processing algorithms could be used during PCB's image analysis, since the requirement of rotating and flipping PCB's images would have been removed. Character and shape recognition processes would be made simpler as well because of proper orientation of characters.

The camera-positioning module moved the imaging camera above PCB mover module and the rotating table module (ref Figure 5). Once the rotating table module had finished aligning the PCB axis with the axis of the camera, then the camera-positioning module would be used to

Figure 3. PCB Mover and PCB Stop Modules.

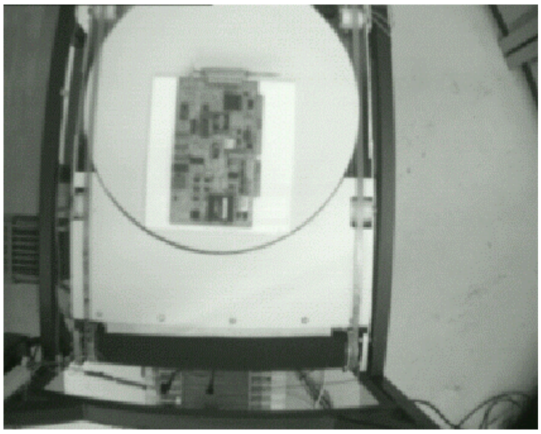

Figure 4. PCB on its pallet on the Rotating Table Module.

move the camera to the desired position above the PCB, depending on the area of interest on the PCB. Orientation module (ref Figure 5). Once the rotating table module had finished aligning the PCB axis with the axis of the camera, then the camera-positioning module would be used to move the camera to the desired position above the PCB, depending on the area of interest on the PCB. Orientation of the PCB would then be the same as the orientation of the AOI apparatus axis. Thecamera-positioning module consisted of two modules: the X-axis (which moved the camera in the lateral direction) and the Y-axis (which moved the camera in the longitudinal direction).

A PC based vision system module implementing a FlashPiont frame grabber and a Saerim 500 CCD camera was used. The lighting module of the vision system module was implemented by using a round fluorescent bulb. The imaging camera was position at the centre of the fluorescent bulb.

The camera-positioning module moved the camera and the fluorescent bulb in this constant configuration (ref Figure 5). A round bulb ensured that shadows of components were eliminated from the acquired images by providing a high intensity, uniform lighting of the scene. Another component of the lighting module was the white perspex cladding on all the sides of the AOI apparatus.

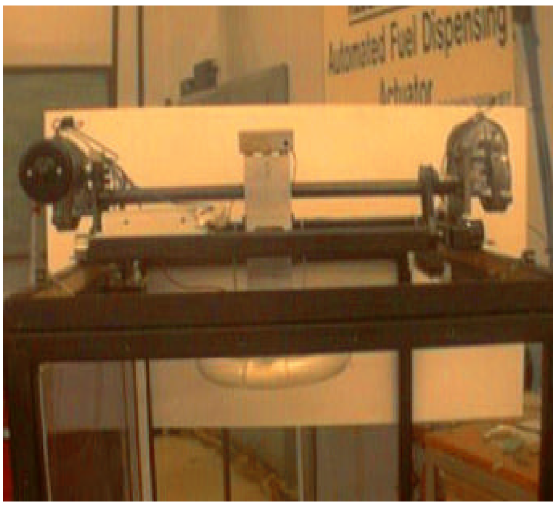

Figure 5. Camera Positioning Module with the Lighting Module.

Noise from the ambient lighting was suppressed by perspex cladding. The result was lesser image processing algorithms and interpretation errors due to shadow-free and specular lighting free images [Tlale et al, 2002].

Four adjustable legs supported the AOI apparatus. The adjustable legs ensured that the height of the AOI apparatus could be varied depending on the reach/height of the material handling system incorporated with the apparatus. The Perspex cladding ensured that the AOI apparatus could be implemented under most environmental lighting situations. The adjustable legs and the cladding made the AOI apparatus flexible.

3.3 Electronic Design

All mechanical modules (mechanisms) of the AOI apparatus used DC motors as actuators. The control circuitry of the DC motors were chosen depending on the positional accuracy and loading requirements. Two control circuitry were used: the digital module and the analogue module.

The digital module employed a transistor-relay circuit to control the high power to the DC motor, depending on the two signals from the computer interface card (ref Figure 6). The first signal determined the direction of the motor, while the second signal determined whether the power to the motor should be switched on or off. The digital modules were implemented in modules that needed a constant supply of power and little positional accuracy. These modules were: the PCB mover, the PCB stop and the X-axis modules.

The analogue module used a low cost LM12 chip circuitry. The input signal to the circuitry determined the speed and direction of the motor (ref Figure 7). The speed was proportional to the input signal. Negative signal turned the DC motor in the CCW direction, while positive signals turned the motor in the negative direction.

The apparatus implemented three modules of sensor circuitry. These are:

- Short-range infrared sensor module
- Modulated infrared module
- Light Dependent Resistor (LDR) module

The LDR modules were implemented to detect the presence of PCB at the entrance of the AOI apparatus and to determine the position of the conveyor belt of the PCB mover module. The modulate infrared modules were implemented to determine the centres of the X and Y mechanisms. The short-range infrared sensor modules were used to determine the position of the camera mover

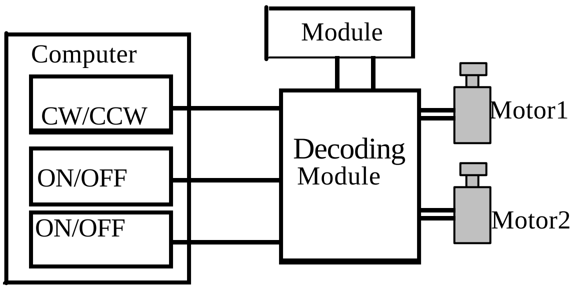

Figure 6. Digital Decoding Module and its Different Components.

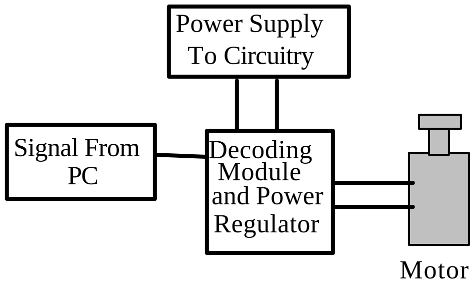

Figure 7. Analog signal decoding Module and Power Regulator.

module and to determine the position of the PCB stop module.

3.4 Control and Software Design

The integrated control of the different AOI apparatus modules or systems was implemented on the PC. PC-based control improved flexibility and user interfacing. All the systems comprising the AOI apparatus were interconnected via the PC. The PC was used to monitor the signals, process the signals and send out the control signals to the relevant AOI modules. The control principle of the AOI apparatus was operator orientated i.e. the operator had to make decisions regarding the different control processes on the AOI apparatus. The operator based, mechatronic control principle of the AOI apparatus is depicted diagrammatically in Figure 8.

In order to achieve a smooth operation of AOI apparatus, software implemented on the AOI apparatus guided the operator in a stepwise fashion through the command available. The main control programme gave the operator the following choices, which invoked sub-programmes that controlled different actions of the AOI apparatus' modules (ref Figure 9):

- PCB mover module's control
- Rotating table module's control

4 Performance of the AOI Apparatus

Optical inspection of PCBs required a limited number of images to be taken, while RE required detailed images of electronic components comprising the PCBs and their immediate surrounding areas. Performance of the AOI apparatus was thus tested for implementation of RE only. This included:

- Camera mover module's control
- Control of the CCD camera and vision system module

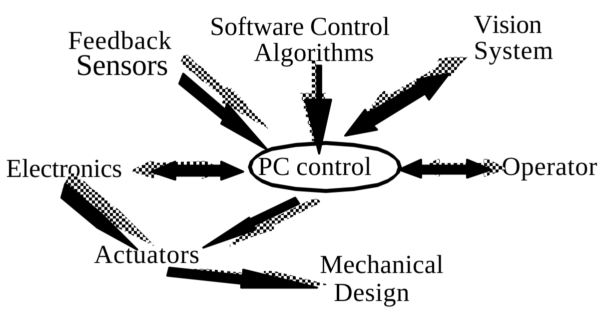

Figure 8. Control Principle of the AOI Apparatus.

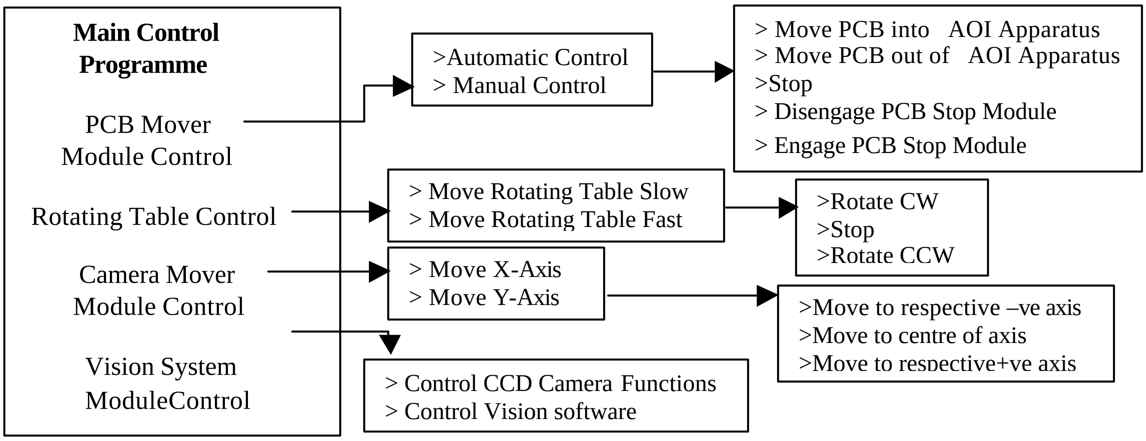

Figure 9. Structure of Software Control Programme.

The overall performance of the AOI apparatus was determined by the sum of individual times taken by each module of the AOI apparatus to perform their required tasks. Therefore, the total cycle time of the AOI apparatus can be evaluated as follows:

$$T_{total} = T_{PCB\,move} + T_{rot\,tab} + T_{cam\,pos} + T_{image} + T_{ima\,proc}$$

where,

T_{total} = total cycle time for reversing engineering PCBs on the AOI apparatus,

$T_{PCB\,move}$ = time taken by the PCB mover module to place PCBs on the rotating table and to transport them back to the SLM conveyors,

$T_{rot\,tab}$ = time taken by the rotating table to rotate the PCB by the desired angular value,

$T_{cam\,pos}$ = time taken to position the CCD camera above the desired area of interest on the PCB,

T_{image} = time taken by the image acquisition system to store the PCBs images,

$T_{ima\,proc}$ = time taken by the software image processing algorithms.

This paper is not concerned with advanced image processing algorithms used for RE of PCBs. Consequently, $T_{ima\,proc}$ was not evaluated in this project. It should be note, however, that acquiring digital images of the PCBs' features can be done in parallel with image processing on this apparatus. The overall cycle time would not be adversely affected by the image processing time.

The total cycle time of acquiring images of a single sided PCB with the electronic component population of 150, and overall dimensions of 200 x 200 millimetres, on the AOI apparatus, excluding the image processing time was found to be:

$$T_{total} = T_{PCB\,move} + T_{rot\,tab} + T_{cam\,pos} + T_{image} \quad (4.2)$$

$$= 27 + 420.6 + 1522.2 + 348$$

$$= 2317.8 \text{ seconds}$$

$$= 38 \text{ minutes } 37.8 \text{ seconds}$$

$\approx$ 40 minutes (or 1 electronic component per 16 seconds)

This is considerable time reduction as compared with manual methods, where it can take a number of days to get the same information.

5 Conclusion

A prototype optical inspection apparatus was designed, built and tested to verify its image acquiring capabilities for RE and inspection of PCBs. Experiments verified that the apparatus was very efficient in acquiring the images of individual electronic components comprising the PCBs. Information acquired on the AOI apparatus about the PCBs can be shared between the apparatus and other sub-systems of the manufacturing cell to improve system performance and flexibility.

Further research is ongoing concerning the AOI apparatus to incorporate the necessary advanced image processing algorithms and to test its overall performance.

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