

A paradigm of automatic ICT testing system development in practice

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Abstract— In-Circuit-Test (ICT) is an inevitable process for sustaining the quality of Printed Circuit Boards (PCBs) in the assembly and fabrication process. Applying automation to reduce labor and preventing errors in ICT has been studying by academics and industries for decades. Here we demonstrate a robot centric ICT testing system that integrates the peripheral equipment, also including the shop flow control system (SPCS). The graphic programming software – LabVIEW exploits to integrate robot arm, in-circuit test machine, PLC, HMI, and barcode reader. Communication among the facilities and error handling are the main challenges in the automated ICT system development. Heterogeneous communication protocols and third-party devices with unique syntax have caused some programming difficulties. The challenge of error handling is that it might be on hardware, software, or communication. Moreover, these errors may have occurred at 5-6 different facilities with chain effects. The robot arm dominates the main control sequence from the test start to finish. As a result, a steady automated ICT test system with real-time status monitoring has presented. That assists field personnel in eliminating problems quickly and promotes overall production line operation efficiency.

Index Terms — In-Circuit test, Labview, Robot

I. INTRODUCTION

In-Circuit Test technology (ICT)[1] performs the circuit assembly quality check mainly for shorts, opens, and resistance in the electronics product manufacturing process to confirm the assembly fabricated correctly. This article reveals the automatic load/unload process design and proposes an architecture for connecting peripheral facilities and optimizing the overall operation. The host program illustrates the integration process in practice.

The robot arm exploits load/unload PCBs and triggers the testing process on ICT test machines. The host computer of the ICT connects the robot arm playing a vital role in communication as well. In the process of integration, a graphic control software, LabVIEW[2], uses as glue-software to connect those machines in operation and also shop flow control system(SFCS) to provide instant information. SFCS is a process controlling system that prevents the disorder in the manufacturing process[3].

The test time of each circuit board is not always the same since the deviation among the process. Therefore for improving overall efficiency, the host computer of ICT test machines should try to minimize the idle time of the ICT machines by informing the robot arm the nearest vacancy ICT fixture. The experiment depicts the real case of the electronic production line in the industry. The graphical control interface (GUI) provides

information that helps field test engineers in troubleshooting. The system architecture can be an excellent example of relative researches or applications in industries.

This study starts with constructing sequential control among these machines and integrating SFCS, error handling, and efficiency improvement. Further, the system integration manner can also apply to some similar testing processes like automatic test equipment (ATE)[4] or other testing types of equipment. This paradigm can also apply to some other electronics manufacturing processes[5], [6].

II. DESIGN AND ARCHITECTURE

This section reveals the design and architecture of the automated testing base on the typical manufacturing process of circuit boards. Explain the required elements to build an automated test system.

A. Typical process

The assembly process of PCBs mainly includes surface mount technology (SMT) machine, reflow soldering machine, and automatic optical inspection (AOI) machine. Figure 1 illustrates the typical PCB fabrication workflow from right to left – components mounting, reflow (soldering), and fabricated assembly inspection.

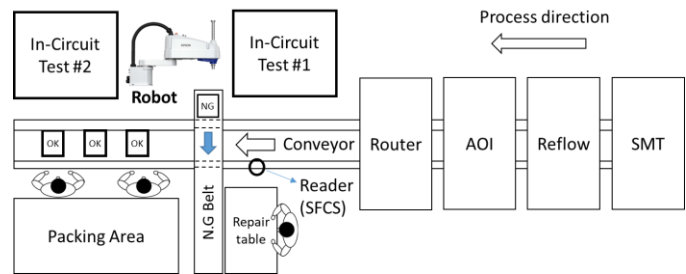


Fig. 1. Typical PCB manufacturing and In-Circuit Test flow

Regarding manufacturing efficiency, PCBs often designed as a PCB cluster called multi-block or panel. The large PCB has margin edges as the contact points for belt conveyors to carry. It can avoid unintended damage to the components on the board. At the end of the assembly inspection, the router machine (or call routing machine) cuts the panel into individuals, and then transfer those PCBs to subsequent ICT testing. Also, there is a visual barcode reader beside the outlet of the router to record the numbers of PCB for process tracking.

The upper left corner of Figure 1 is the core in the entire operation where is including robot arm, two In-Circuit testers (#1 and #2), conveyor, belt conveyor for NG stand. Since the ICT machine is relatively expensive compared to other equipment in terms of price, improving the efficiency or utilization ratio becomes the main studying topic here. The cycle time of a conventional electronics production can be

double-digits in second (e.g., 10 sec) for all assembly stations. The ICT testing cycle time is usually longer than the time needed in fabrication, which could be double or triple in time (e.g., 30 sec).

In the design of the testing process, the testing capacity should have an extra 25% buffer to handle the unintended situation, such as PCB errors, testing program false, tester malfunction, network interruption, and power outage. In the ICT test machines, each equips two fixtures (nail beds) and carries out the test independently. Maintaining these four test fixtures in high reliability can help minimize test capacity buffer, thereby reducing the cost of redundant resources.

Although many parameters in the assembly process are well-controlled and component quality also verified before conducting fabrication, it is still difficult to achieve consistency in the testing time of each PCBs. In the process of ICT testing, the interval time difference among devices remains up to 50% of the time, that is, at the same machine and program.

Based on the experience in practical operation, a device with standard 30 sec test time could increase the extra time up to 45 sec or even longer. When the machine encounters a test program error or a poor contact (between the board and test probe on fixture), it may also cause more extended test time. Therefore, to improve test efficiency, we have tried to optimize the operation by removing the PCB board from the ICT machine in the shortest time once the test completed.

The end effector of the robot arm is designed as a rotary pad to improve the efficiency of load/unload. In this way, it performs loading/unloading operations by a simple rotation in one travel to the ICT test machine. The robot arm executes the program from the beginning to the completion of the test. It transfers the PCB from the conveyor to the ICT test machine, and then sends the PCB back after completion. The tested PCB transfers to the central conveyor belt or placed the failed PCB on the NG belt conveyor for repairing based on the results from the ICT test machine.

The communication between the robot arm and manual operation stations (packing area and repair table) relies on SFCS, and there is no automatic data transmission but only manual scanning barcode by operators.

B. System architecture

The central part of the ICT test system is the controller (RC-180) of the G20-A04S robotic arm and the host computer (laptop) with a graphical user interface (GUI) developed by LabVIEW. These two entities are connected through the IO port and linked with the rest facilities via Ethernet.

Figure 2 illustrates the connection of all facilities in the system. The automatic ICT testing system includes a robot arm (Epson, G20), ICT test machine (Agilent)[7], a laptop(LabVIEW), a barcode reader (Datalogic), and a programmable logic controller (OMRON) with a human-machine interface (HMI). All devices connect to the ethernet router, which links to the Web Service[8].”

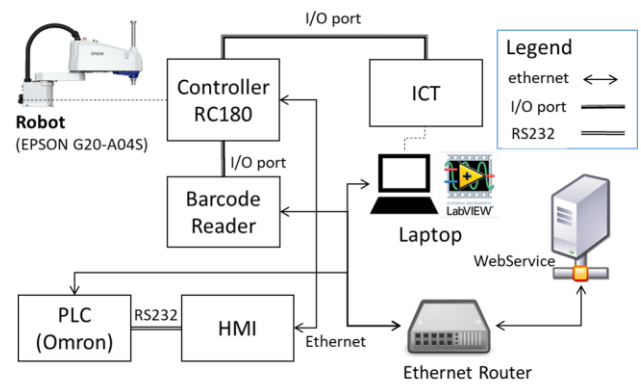


Fig. 2. Test system architecture

The primary communication ports include Ethernet, robot IO port, and RS-232 three types. The Ethernet exploits for data exchange between machines. The robot arm has a direct connection to the ICT test machine and barcode reader via the IO port. It mainly used to confirm the status of the physical objects, such as the positioning of the device. The configuration of the robot IO port refers to the robot manual[9]. Last, the PLC connects to the HMI via RS232 protocol. Figure 3 shows the configuration of the communication ports.

Device	IP	Port	Robot IO port	Memo
Reader (vision)	192.168.0.8	8080	203	(Matrix 210)
LabVIEW	192.168.0.77	9001 9002	204 205	(A)1, 2
	192.168.0.78	9001 9002	206 207	(B)1, 2
Robot	192.168.0.10	8080 9090	201 202	(Output to Robot)
PLC	192.168.0.11			
HMI	192.168.0.12			

Fig. 3. Communication port

The reader (vision type), besides the router, scans the barcode on the circuit board. The PCB moves forward to the pick-up point, and the barcode number sent to the SFCS simultaneously. The reader technical data refer to the user manual provided by the manufacturer, Datalogic[10].

Two Agilent ICT control PCs (Laptops) are installed with the LabVIEW program and communicate by two IPs, respectively. Individual IPs start two communication ports 9001 and 9002. The port 9001 is for receiving the barcode number, and the port 9002 used to receive ICT machine test completion messages. The two machines defined as (A) and (B). The fixtures (nail bed) tested are labeled as (A)1, (A)2, and (B)1, (B)2.

The PLC(OMRON) used to control the conveyor with an HMI (human-machine interface) via RS232 protocol, and it communicates with the peripheral facilities via Ethernet. The robotic arm controller integrates the information of Agilent ICT, PLC, and reader to find the nearest vacancy fixture to conduct tests.

III. SYSTEM FLOW AND PROGRAMMING EXPLAINS

The system flow and programming plan reveal how to construct the system. Figure 4 illustrates that the entire test flow

from the system starts to the test finish. The program explains the portion is providing the communication setting and technique information in the integration process.

A. System Flow

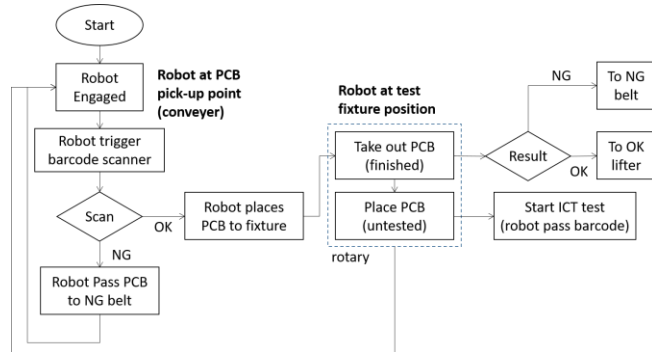


Fig. 4. The operation flow of ICT testing

After the system activated, the robot arm stays in an initial stage at the PCB pick-up point. Once the robot arm engaged, it is waiting for the work in the ICT tester. At this time, the LabVIEW program installed in ICT also needs to confirm the standby status. It mainly provides three functions, including operation interface, status information, and SFCS feedback information. In the status information section of the laptop, the GUI window shows the state of each step regarding the flow chart shown in Figure 4. That is quite helpful and convenient for operators in maintenance and troubleshooting.

There are two decision making blocks (diamonds) in the system operation sequence. The first one is to judge whether the PCB meets the criteria for entering the test machine by the message from SFCS or not. If the PCB matches, the robotic arm takes it to the fixture of the ICT test and start the test.

To reduce the cycle time, we have a rotary-pad design on the end effector of the rotor arm. The robot arm takes PCB toward the test fixture and takes out the finished one (if there is). Then, the end effector of the robot arm rotates 180 degrees to the side, which holds the untested PCB and places it into the fixture on the ICT machine. The robot arm controller passes the barcode number to the ICT test machine and executes the test program.

The second one is to judge if the board passed the test or no. According to the test result from the ICT test machine, the robot arm transfers the good test PCB to the conveyor (OK lift) toward the packaging area. On the contrary, if the result is failed (NG), it would place on the NG belt and send to the repair table for repair work.

B. Programming explains

This section explains several essential designs, such as the functional global variable, web service, robot-ICT interactive, LabVIEW-ICT communication module, and the master program - the robot.

Functional global variable

The Functional Global Variable (FGV)[11] prevents the "Race Condition." in data transmission to ensure the correct display of machine status messages.

The main control program provides the machine status information on the laptop display. The status messages like,

"Wait for robot trigger.", "Generate start text to call ICT, Barcode: BAR232295796GA21.", "Inform robot barcode result.", "Upload SFC, Barcode: BAR232295796GA21.", and "Wait for robot trigger." That helps on-site engineers or operators to perform maintenance and troubleshooting easier.

Since the program adopts the modularized design, multiple programs are running simultaneously. Failure to adopt the FGV may cause data disorder due to race conditions. Figure 5 shows the sample of applying FGV in the program. Ensure that the ICT test results can send out in time correctly.

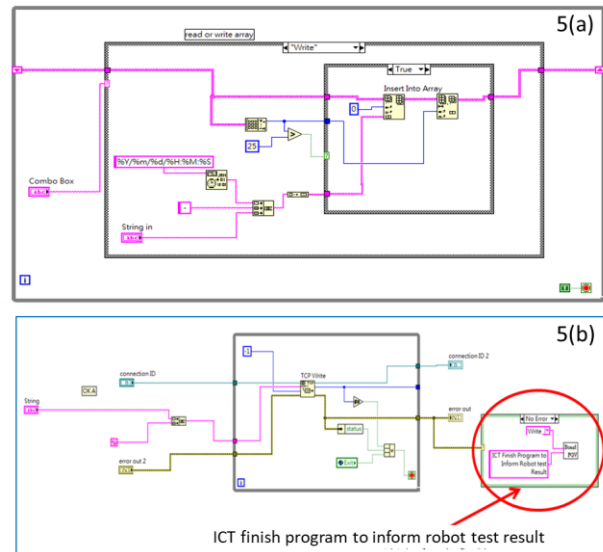


Fig. 5. Functional Global Variable – graphic program

WebService

Besides, LabVIEW software provides the function of Webservice. Through this function, we can communicate with the SFCS system of the factory information center through the network. SFCS can confirm the PCB information and location (station). It makes every product to complete the work station according to the standard operating procedures. For instance, if the information of the untested is incorrect, the robot stops to put the PCB into the ICT machine for testing. Figure 6 illustrates the web service function applied to update data on SFCS.

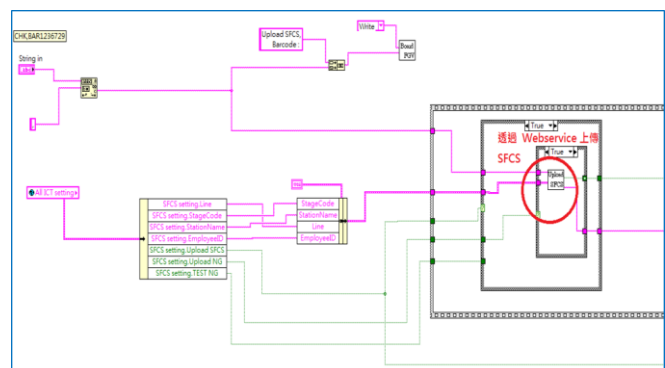


Fig. 6. Webservice – connecting SFCS

Robot-ICT interactive

The whole testing action starts with the EPSON RC180 robotic arm controller. Figure 7 shows the control flow between the Robot Controller (RC180) and the ICT test machine.

Besides the robot arm placed PCB in the fixture, the host PC of the ICT test machine conducts the test regarding the message from TCP/IP and IO ports.

As Figure 7 shown, the robot controller RC-180 sends a test start message to the ICT host PC via a non-protocol setting. The LabVIEW starts the program, and the call txt lets the ICT main test program start the test. After the test, the request for this test deleted. The host PC transmits the result to Controller RC-180 to end the test procedure.

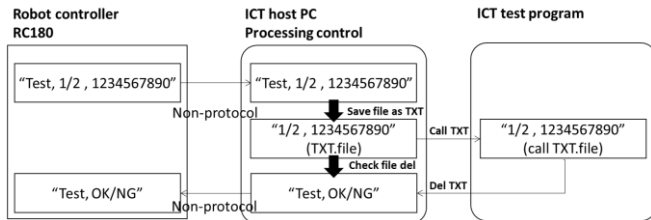


Fig. 7. Control flow between Robot Controller (RC180) and ICT

LabVIEW-ICT communication module

For LabVIEW, in the TCP/IP communication section, 9001 Port and 9002 Port performs sending and receiving function with the ICT machines. Figure 8 illustrates the TCP/IP communication module of the LabVIEW program.

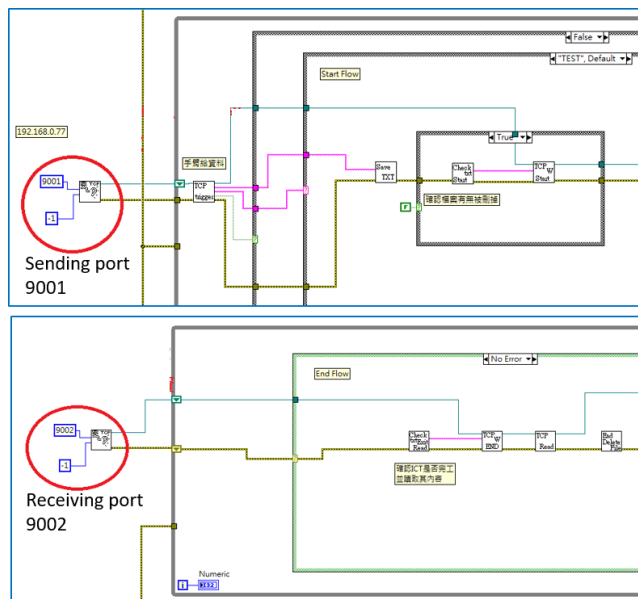


Fig. 8. TCP/IP communication module (non-protocol)

Master program – the robot

Except for the LabVIEW program, this project also includes the central system (Robot) control program. The following explains the communication portion of the Robot program and LabVIEW and the difficulties encountered by this project and corresponding solutions.

Figure 9 illustrates the program executes the action taking out the tested board and placing the new board. In the first step, the EPSON robotic arm checks the ICT test box opened or not according to the IO signal given by PLC (Omron).

One thing that needs attention is that there is no PCB in the default fixture (named BOX in the program) for the first time test. The function setIniBoard_F("A", 2) should place in the

control structure of the "if...else.", as the red marks shown in Figure 9.



Fig. 9. Open and close the ICT box

Figure 10 reveals the process between LabVIEW and ICT tester in the program. First, the Epson robot arm establishes communication with LabVIEW through the IO port. Second, the robot arm received the data string from LabVIEW that contains which fixture to place the under test board (UTborad). Last, the robot feedback to LabVIEW program and then conducts the loading/unloading.

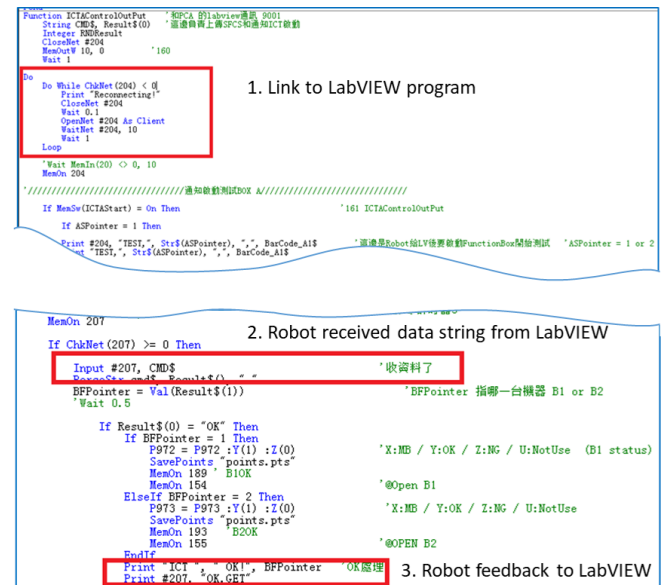


Fig. 10. The process between LabVIEW and ICT tester in the program

IV. ENCOUNTERED PROBLEMS

This section explains the problems encountered in the design of automated ICT tests and the implementation stages, such as production tempo and system sustaining.

A. Production tempo

The designed automated equipment usually succeeds if the architecture is correct. In this paradigm, the central control device, a robot arm, exploits the core of issuing orders, which is considered a successful case.

The system has achieved specific stability in the initial commissioning of the complete program control and information exchange between machines. It was not able to keep up with the speed of the conventional production line when officially launched. Due to system faults, line changes, and mechanical limits, the automatic test line cannot always

keep up with manual operation stations, such as packaging and repair stations.

The first thing is a system fault. When a fault occurs, it signifies production stagnation, allowing operators to force machine actions can save time in idle. For instance, we lease some IO direct control functions like the vacuum nozzle solenoid valve, fixture box limit switch, and simple robot arm movement control to field engineers. Therefore, they can quickly eliminate abnormal conditions that occur during production.

The second one is the production changes. It is a frequent situation to change product models on production lines. The personnel can change the position of equipment (like barcode reader) and get back in work quickly. On the contrary, the automatic line needs to reset the parameters and correct the position of equipment. We try to make a quick component replacement module for each product model directly replace the accessory module and set a calibration reference point to shorten the setting time of new products.

For example, when the product model changed, the barcode reader needs changes its position and parameters. We design a frame with a set so that operators can simply change the base of the barcode reader on conveyors.

The limit of the robot speed regards the load/unload time. The robot speed limitation and the requirement of cycle time sometimes are unchangeable. The way to solve the time insufficient is to eliminate the time waiting for messages. For example, some of the characteristics of ICT machines are slow in replying to messages. Because in 9001 port is set to upload SFCS and start two items. Therefore, to gain time, during the last round of data transmission, the program directly issues a command to start the test without waiting for the ICT to start the signal to save time.

Here are the problems we encountered during the system development and the methods for solving them. In practice, there are more production tempo issues with different attempts for solutions.

B. System sustaining

The actual output of the electronics industry is quite astonishing. For instance, the production line runs at 10 sec cycle time. The production volume per day could be 3,600 units with ten working hours. Based on working 25 days per month, the monthly production capacity is close to 90,000 units. The ICT test system is under the condition of long-term high-speed operation, and it is necessary to have preventive maintenance actions.

The automation equipment should have a simply designed interface, easy to operate, and very durable. However, it is unrealistic to expect the equipment to be very rugged and completely free of maintenance. Therefore, providing simple and practical training for the operators should put in the plan and conduct appropriate service periodically.

Regarding the actual verification, we found the top three frequently malfunction cases: 1. fail on reading the barcode, 2. vacuum pressure abnormal (could drop the PCB if out of minimum vacuum level), and 3. PCB misalignment. The above problems cause the operation interruption.

The indoor lighting in the production line and barcode quality have a significant influence on reading the barcode. Usually, the ambient lighting of barcode reading remains the same as initial settling, so there is less problem with lighting.

The barcode quality relates to the printed quality and fabrication process in which the barcode could get dirt and partially unreadable. Nowadays the enforced reader (vision) is capable of compensating for the missed information. The unreadable situation reduced by modulating the parameters in advance.

Also, the color variation of each batch of the printed circuit boards is a commonly seen cause of unreadable. Usually, the PCB suppliers are more than two to reduce the risk of material shortage in industries. With different suppliers, the reader should have a specific setting for dedicated suppliers. This type of problem can be solved. We only need to check the code of suppliers and switch the setting in a different situation.

Vacuum pressure abnormal terminates the PCB testing process could cause by pneumatic supply issue, vacuum generator adapter fails, nozzle damage, or foreign objects blocking air. Daily inspection of utilities and regularly replace the nozzle and the associated parts can reduce the termination times. Moreover, reviewing the nozzle design and adapting high-quality components helps to improve the reliability of the whole system.

The last common seen problem in operation is misalignment or failure to approach the fixture in the test box. There are a variety of factors that could cause the PCB board, not in the position. The board deformation and burr of edge results in lousy contact between the board and vacuum nozzle. The root causes can be the tool worn-out of the router. Also, the end effector of the robot arm can cause a misalignment in operation since the parts loosen of vacuum nozzle installation.

V. CONCLUSION

Automation is a project that many factories have actively undertaken over the past few decades. In the future, we believed that more and more robotic arms and machine vision would apply to the more automatic applications. The real-time information, Industry 4.0 features, AI artificial intelligence, and a large amount of data analysis can contribute to the development of the ICT test automation as well.

By the execution, we summarized three points that help in the success of this project.

1. the right choice of the core controller
2. advantages of graphic control software
3. familiarization of the test process

The above three points help to build an automated testing system. Proper training, quick troubleshooting SOP, and good maintenance plans can achieve a successful automatic test system. Whatever the development of automated systems must be cost-effective, stable, and long-lasting durability.

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