ORIGINAL ARTICLE

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Design and implementation of Web-based diagnosis and management system for an FMS

Abstract Given the rise in competition within the global market-place, the paradigm for manufacturing has changed dramatically. While downstream activities have become the focal point for global competitors, manufacturing remains at the root of a firm's competitive edge. To remain competitive, firms are progressively shifting their manufacturing operations to overseas markets. Foreign markets offer a host of advantages to manufacturers but one of the obvious key advantages is cheaper labor. Even in industries where the required labor-to-capital input ratio is relatively low within the production process, lower labor costs allow the production of more competitively priced products. The emergence of this paradigm, however, has led to a number of managerial problems. Operating a manufacturing facility overseas creates difficulties for management both in the area of personnel and resource allocation. In this project we developed a Web-based remote control platform using digital cameras, a PLC controller and a PC-based Visual Basic human-machine interface (HMI) to create a flexible manufacturing system (FMS). An FMS can be easily controlled and monitored through an Internet-based PLC-control system using a PC-based HMI platform. From remote locations, this platform enables management to effectively monitor, control and diagnose a manufacturing process via the Internet.

Keywords Factory automation · FMS · HMI · Remote diagnosis

1 Introduction

The new paradigm in manufacturing is value-driven production. Manufacturing has progressively moved from a production

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orientation to a market orientation, wherein product specifications are determined by the value-laced expectations of customers. Not surprisingly, the development of the global marketplace has accelerated this process. Continuous improvement is no longer the exclusive practice of many Japanese manufacturers, but rather the worldwide basis by which firms compete. Concurrent with the practice of continuous improvement, cost reductions in the manufacturing process have become essential for a firm's survival in the marketplace.

One cost reduction strategy for firms has been to shift their manufacturing facilities to overseas markets to gain a marginal advantage on labor costs. For example, thousands of Taiwanese manufacturing plants have moved overseas in the last decade to capitalize on lower labor costs in these markets. While this transition has been vital for these Taiwanese firms to remain competitive, this process is problematic. Foremost of these problems is the need for a firm to have more skilled labor, including a management team, at the production site. Technical and managerial staff must travel back and forth to a foreign facility to diagnose and maintain the manufacturing facility. Albeit necessary at times, frequent overseas travel creates organizational problems within a firm, as well as problems for the family members of those that travel.

With the rapid development of the Internet and the telecommunication industry, firms can now monitor factory operations from remote locations through electronic and wireless devices. For example, decision makers can currently access information regarding the current status and quality of production, such as production trends, machine availability, failure reports, critical events, and reports on manufacturing quality [7]. As speed and security issues have improved for data transmission and image delivery, the reality of the e-factory has emerged. An e-factory is a manufacturing information management solution coupled with other digital manufacturing technologies, designed to aid management in the most demanding of information management environments. It provides a platform for the management of data for manufacturing [8].

In a variety of product manufacturing industries, the most automated form of production is a flexible manufacturing system

(FMS). These were first introduced in 1970s. Since the FMSs can provide a high potential for improving productivity within batch manufacturing, the number of FMSs has grown substantially [3]. The rapid diffusion of FMSs throughout the world is due to the increased global competition, reduced manufacturing cycle times, and cuts in production costs.

In this project, our goal is to develop a Web-based remote control platform with digital camera, PLC controller and PC Virtual Basic-based (VB-based) human-machine interface (HMI) for the FMS at the National Kaohsiung First University of Science and Technology (NKFUST). The paper is organized as follows: Sect. 2 introduces the configuration of the FMS and its controller. Section 3 presents the development of the Web-based remote platform. Section 4 contains the results and discussion. Section 5 ends with conclusions and future work.

2 Description of the FMS

Generally, an FMS consists of a group of machines or other automated workstations that form modular subsystems, such as CNC (Computer Numerical Control) machines, robots, vision systems, and process station. These are interconnected by a materials handling system and are usually driven by a computer [4, 6]. Each modular system requires an individual modular control system with different components being controlled by individual controller units. Computers control all of the modular subsystems as usual. These controllers perform their intended tasks under the supervision of a higher-level controller. To the system, both of the control devices, as well as the flow of information, need to be automated. The key aspect of an FMS is its ability

to adapt to changes in the control tasks. This flexibility includes the quantities and varieties of part types it can produce, the order in which operations may be performed, and its ability to reroute parts back into flow paths. In the end, the control platform should have the capability to automate the flow of information [5].

The FMS at NKFUST is shown in Fig. 1. It is composed of four modular cells, an automatic storage system (ST), a carving machine (SC), a vision-based inspecting system (IS), an assembly cell (AS), and a delivery trolley (AGV). Each cell is equipped with a robot to execute loading and unloading tasks. Each station is interconnected and controlled by a PC and programmable logic controllers (PLC) with network capability.

2.1 Operational description

The FMS on the factory floor at NKFUST automatically makes a stamp assembly. The working cycle for the FMS proceeds in the following manner:

1. Initially, raw material stocks or semi-finished goods are seated on the bar-coded brackets. The delivery trolley is empty and available for the workpiece to be loaded onto it from the parts presentation station (the automatic storage station).
2. Robots at each station execute the loading/unloading of the part onto/from each station. The guided cart moves linearly as it is being loaded.
3. Once the part is loaded on the carving machine, the carving machine sculptures the part as required.
4. After sculpturing, the part is delivered to the vision-based inspecting cell. The vision system analyzes the part and outputs a signal that directs robot to accept or reject the part.

Fig. 1. FMS at NKFUST
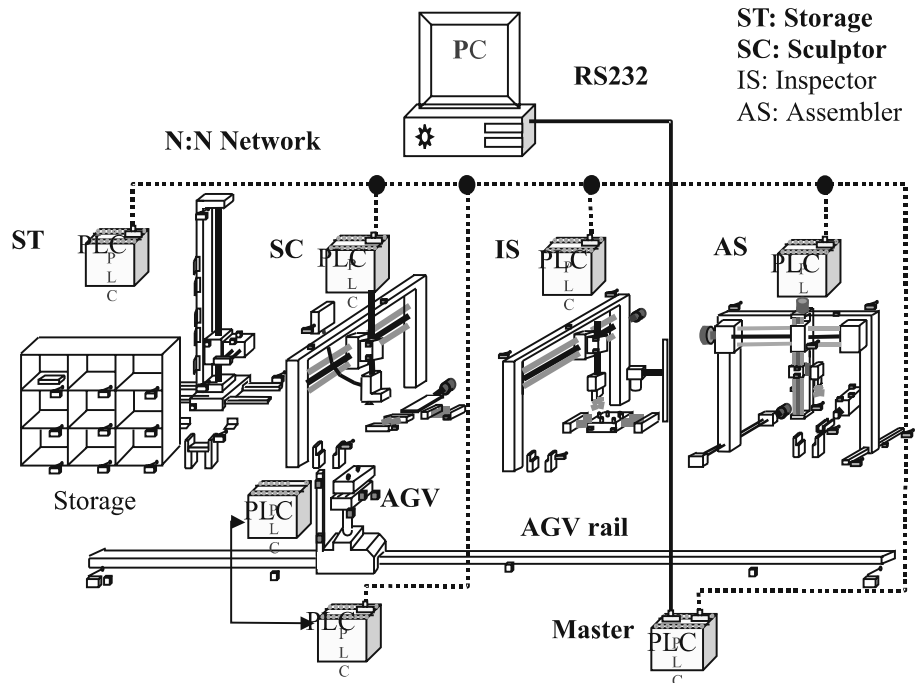
5. The accepted part is then delivered to the assembly area for installing a handle bar.
6. Once the stamp with handle is completed, it is removed and delivered back to the storage bin.
7. The guided trolley is released from the system and the new cycle is started.

Steps 1 and 2 above constitute the "loading and unloading state" for the FMS. Steps 3 to 7 constitute the "working state" for the FMS.

2.2 Controlling the FMS with networked PLC

A PLC is widely used in industrial process control. Generally, a PLC consists of a CPU, a memory bank, input/output units, and a programming device. It is capable of storing instructions to implement control functions such as sequencing, timing, counting, arithmetic, data manipulation, and communication to control industrial machines and processes. In this application, seven small MITSUBISHI PLCs are employed to control the part presentation unit, machining station, inspection system, assembly area, and delivery trolley. The status of PLCs and information flow are uploaded to the central PLC via a multi-drop networking configuration.

The control logic of PLCs is programmed in the sequential function chart (SFC) command of IEC61131-3 standard for OPEN-PLC. The FMS control program ladder logic is developed and documented on PC using the editing software SWOPC-FXGP/WIN-E, which is provided by the PLC maker. A typical SFC and associated step ladder program (STL) and instruction list program (IL) are shown in Figs. 2 to 4, respectively.
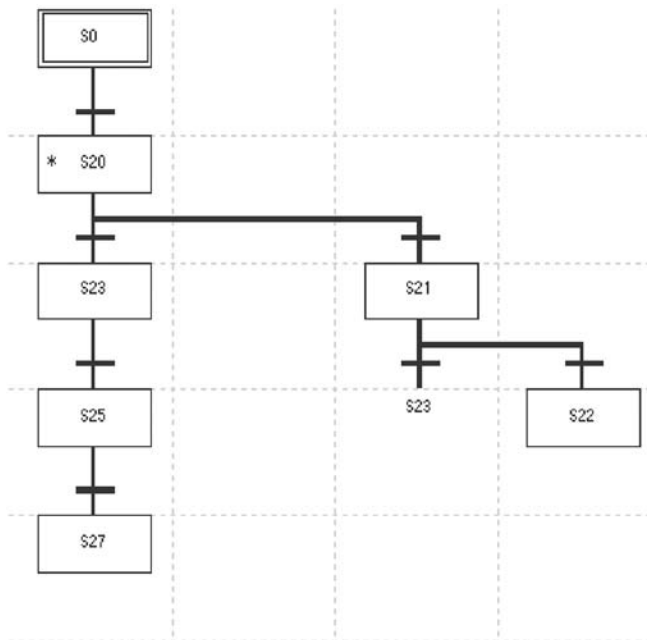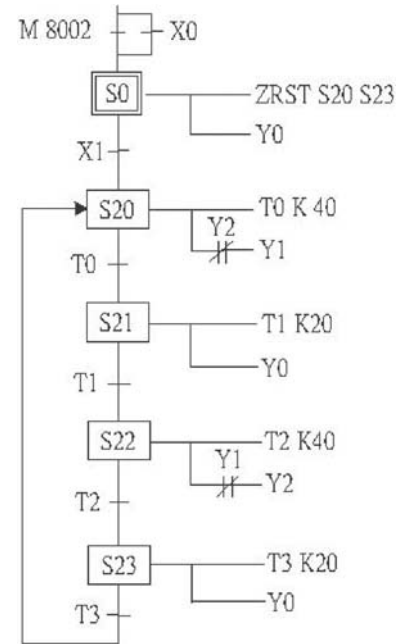

Fig. 3. Typical STL program of PLC

0	LD	M8002			27	OUT	Y000	
1	OR	X000			28	LD	T1	
2	SET	S0			29	SET	S22	
4	STL	S0			31	STL	S22	
5	ZRST	S20	S23		32	OUT	T2	K40
10	OUT	Y000			35	LDI	Y001	
11	LD	X001			36	OUT	Y002	
12	SET	S20			37	LD	T2	
14	STL	S20			38	SET	S23	
15	OUT	T0			40	STL	S23	
18	LDI	Y002			41	OUT	T3	
19	OUT	Y001			44	OUT	Y000	
20	LD	T0			45	LD	T3	
21	SET	S21			46	OUT	S20	
23	STL	S21			48	RET		
24	OUT	T1	K 20		49	END		

Fig. 4. Typical IL program of PLC

2.3 PC-based visual HMI

With the convergence of different computer technologies and software techniques, the PC has become very useful for operator interface applications. A PC, which is running HMI at the front-end and contains useful graphics and reporting tools, enables powerful operational interfaces. Information from PCs can be distributed through a company local area network or the World Wide Web using client-server technologies.

The functions of the visual HMI are: (1) It opens a window between the operator and the process and then displays the process information on the CRT; and (2) It also allows the operator to modify the parameter settings of the process. That is, it provides monitoring and control functions between the operator and the process (see Fig. 5). In this project a VB-based HMI was design and developed. Figure 6 shows a typical PC VB-based HMI screen.
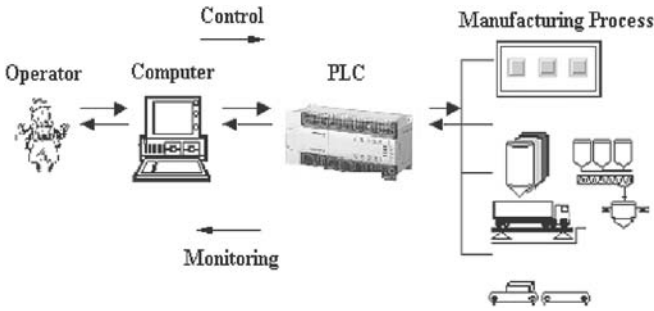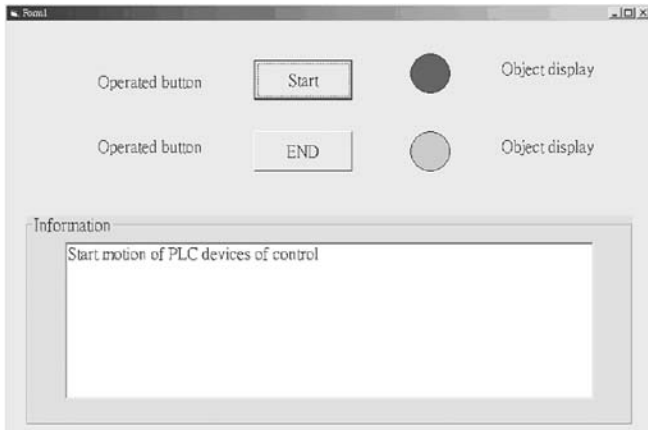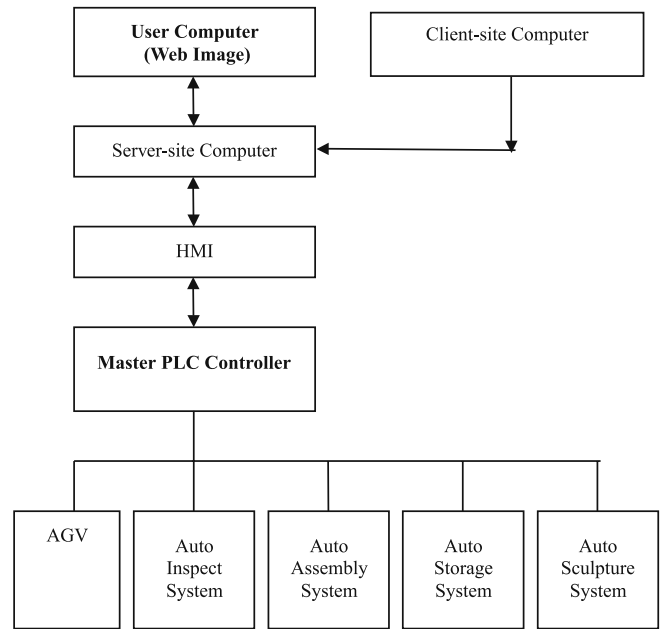

Fig. 2. Typical SFC diagram of PLC

Fig. 5. Functions of HMI

Fig. 6. Typical HMI screen

3 Web-based remote platform

The purpose of this project is to design a Web-based remote platform for an electronic and cybercentric FMS. Figure 7 shows the framework of this Web-based remote platform. This remote platform contains three parts. First, design and implement of operational sequences for the FMS. Next, design and establish the server platform. Finally, design and implement the client platform.

3.1 Operational sequence design

In this project, we adopted Petri nets (PN) theory to design the operational sequence of the FMS. PN is a mathematical formalization interpreted through the use of a directed bipartite graph for discrete event dynamic systems. With a graph, the connectivity of events can be represented using obvious interpretations. PN allows users to mathematically model discrete dynamic systems. PN is able to model "distributed state diagrams", the control flow of concurrent programs, or queuing networks with synchronizations [1]. PN has been developed and demonstrated as effective tools for discrete event control systems [2]. The PN theory has been widely used in order to overcome sophisticated sequence operation program design and performance validation for complicated manufacturing systems. The operational sequences
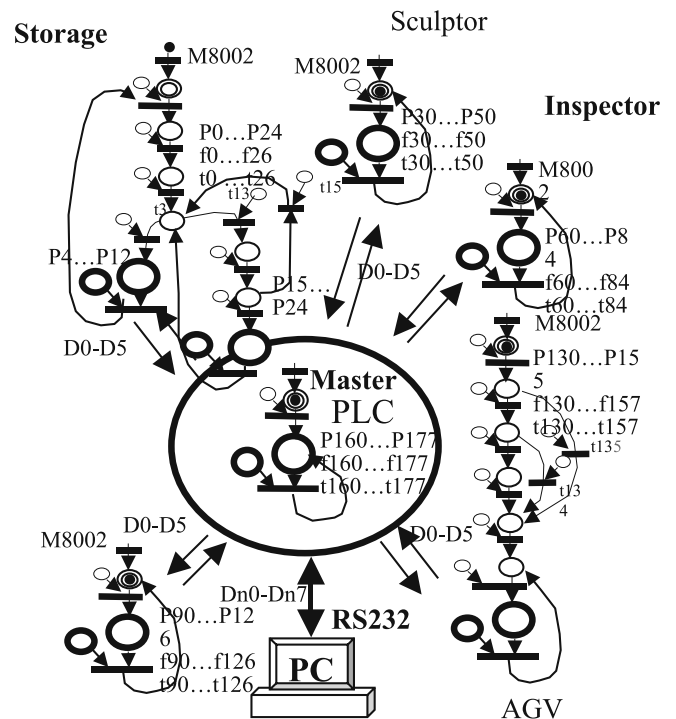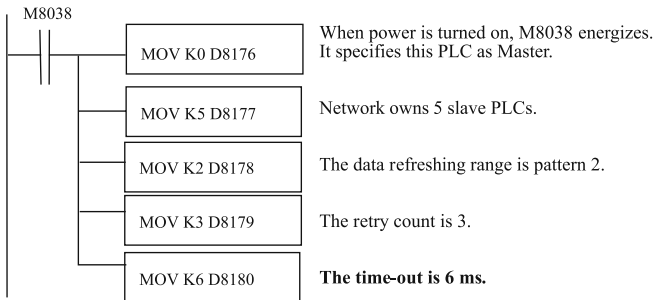

Fig. 7. Web-based remote platform

described in Sect. 2.1 are well designed and evaluated by the PN theory. The PN model for the FMS is shown in Fig. 8. After the operational sequence is evaluated, the SFC program for the FMS can be interpreted directly from the PN model.

Fig. 8. Petri nets model of the FMS

3.2 Design of the server platform

In this FMS, each cell is controlled by an individual PLC with network capability. The status of the local PLC then uploads to the central PLC via a multi-drop configuration. An N:N Network, which is produced by MITSUBISHI, is commonly used with PLCs. The setting of the N:N Network protocol in the PLC program is shown below. In this study, each setting for the N:N Network became valid when the program was run or when the power of the PLCs was turned on.

MOV K0 D8176	When power is turned on, M8038 energizes. It specifies this PLC as Master.
MOV K5 D8177	Network owns 5 slave PLCs.
MOV K2 D8178	The data refreshing range is pattern 2.
MOV K3 D8179	The retry count is 3.
MOV K6 D8180	**The time-out is 6 ms.**

M8038

At the server PC, two communication setups must be completed: (1) The central PLC and server PC, and (2) The server PC and client PC. The central PLC provides operational information on the manufacturing process to a PC-based server via serial communication port, RS-232 standard protocol. The client PC duplicates the information on the server PC via the TCP/IP protocol. The attribute of the object MSComm in VB has to be set as "9600,e,7,1". In order to remote control the PLC at the PC screens, the "X" elements have to be modified into "M" elements in the PLC program. For the TCP/IP protocol setup of the server PC and client PC, the object Winsock has to be initiated to allow the client PC to connect. The typical VB program for Winsock is shown below:

```
Private Sub Form_Load()
    With Winsock1
        .Protocol = sckTCPProtocol
        .LocalPort = 690
        .Listen
        Label1(0).Caption = "IP:" & .LocalIP
        Label1(1).Caption = "Host:" & .LocalHostName
        Label1(2).Caption = "port:" & .LocalPort
        Label1(3).Caption = "Protocol:TCP"
        Me.Caption = "Server:" & .LocalIP & ":" & .LocalPort
        ConnectionStatus (.state)
    End With
    blnconnect = False
    blntaskbar = True
End Sub
```

3.3 Design of the client platform

From the client PC, information on manufacturing process can be duplicated as indicated on the server PC. The object Winsock has to be initiated to connect to the server PC in order to receive the information of the manufacturing process via the TCP/IP. In the VB program at client PC, we use the object WebBrowser setting to navigate the live image picture of the Web camera to monitor the FMS plant. The typical VB program for Web-Browser is shown below:

```
Private Sub Form_Load()
WebBrowser1.Navigate "163.18.54.89"
    blnReply = False
End Sub
Private Sub Winsock1_DataArrival(ByVal bytesTotal As Long)
End Sub
Private Function SendData(sData As String) As Boolean
End Sub
```

3.4 Web video server

An axis video server and Web camera is employed to navigate the FMS plant via the Internet in this project. The video server includes a built-in Web server that enhances traditional surveillance systems and provides added networking connectivity for distributing monitored images over a secure intranet or Internet. The advantages are its ease of configuration and installation, and open-network structure. With the feature of open-network structure, it minimizes the need for costly coaxial cabling and optimizes imaging broadcasting for a minimal connection overhead. The Web image technology provides a smart and cost-effective solution for the sophisticated demands of a modern interactive surveillance and remote monitoring system. The typical application configuration is shown in Fig. 9.

4 Results and discussions

In this project, we proposed a Web-based remote platform for an e-factory solution. It includes networked PLC-control, PC-based VB HMI, live Web video, and client-server platform. A case study of a mini-scale FMS was carried out to demonstrate the feasibility of Web-based remote platform. Numerous VB-based HMI screens were designed and executed on the client and server PCs. The results and discussion follow.

4.1 Server platform

The function of the server station is to receive process information from the central PLC, and then disseminate this information to the client. With the intuitive HMI screens and live Web images, the server platform is able to monitor and control the FMS plant from a remote location. Plant managers can effectively monitor and control the manufacturing plant from any location in the world with access to a PC and Internet. The client-server and Web solution thus allows the remote management manufacturing process.

A typical HMI screen on the server-site is shown in Fig. 10. Figures 11 to 15 show HMI screens for each station. Typically, the server station is in the central control room. At the

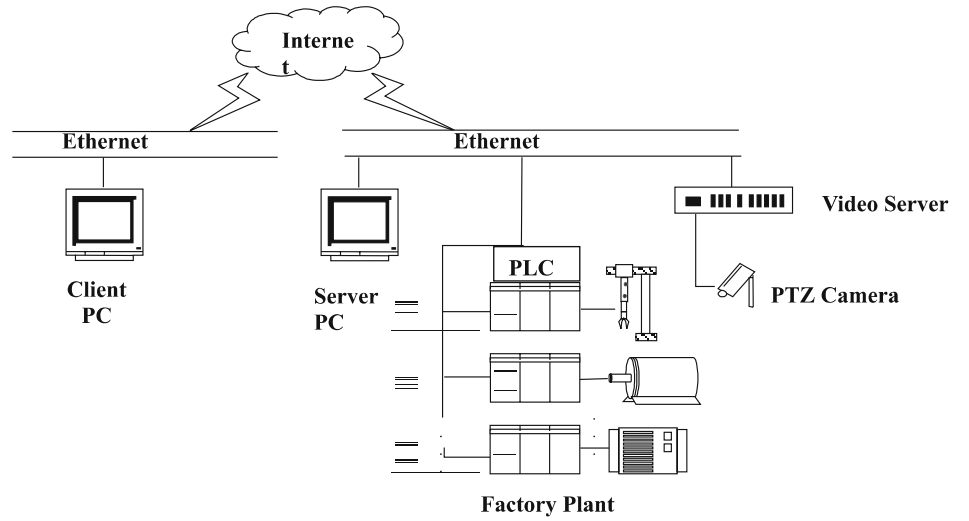**Fig. 9.** Typical application configuration
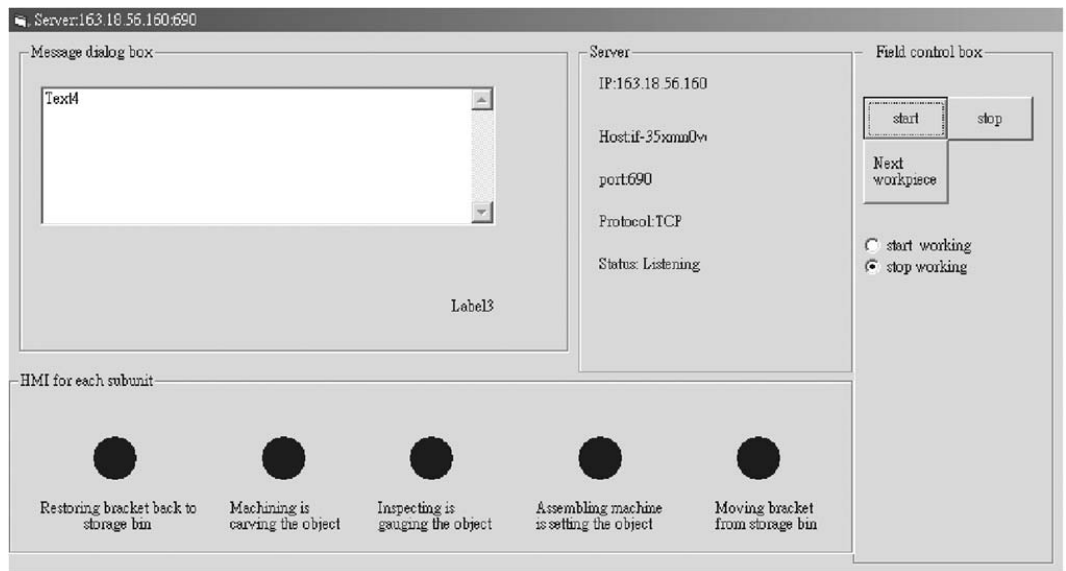

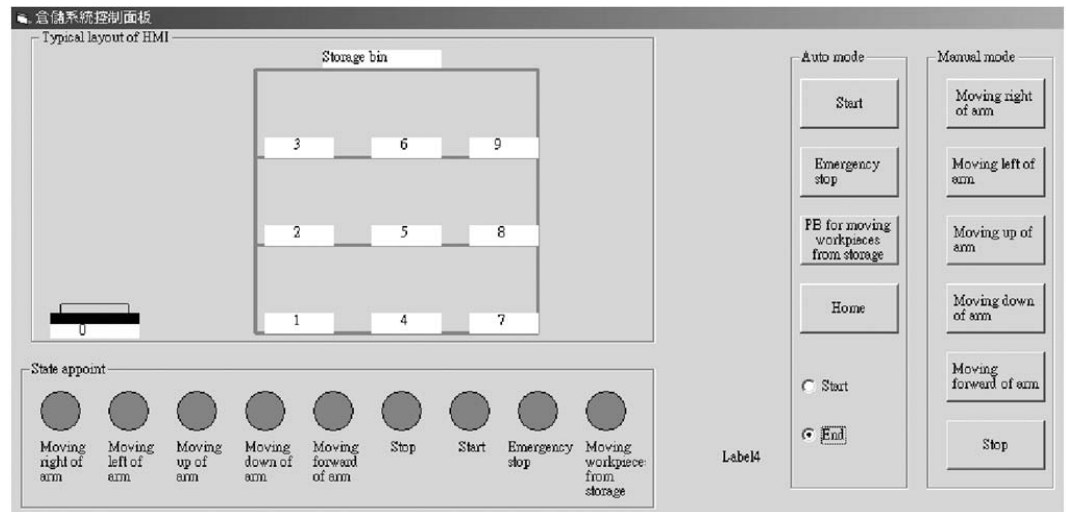**Fig. 10.** A typical HMI screen of server

Fig. 11. HMI screen for automatic storage system
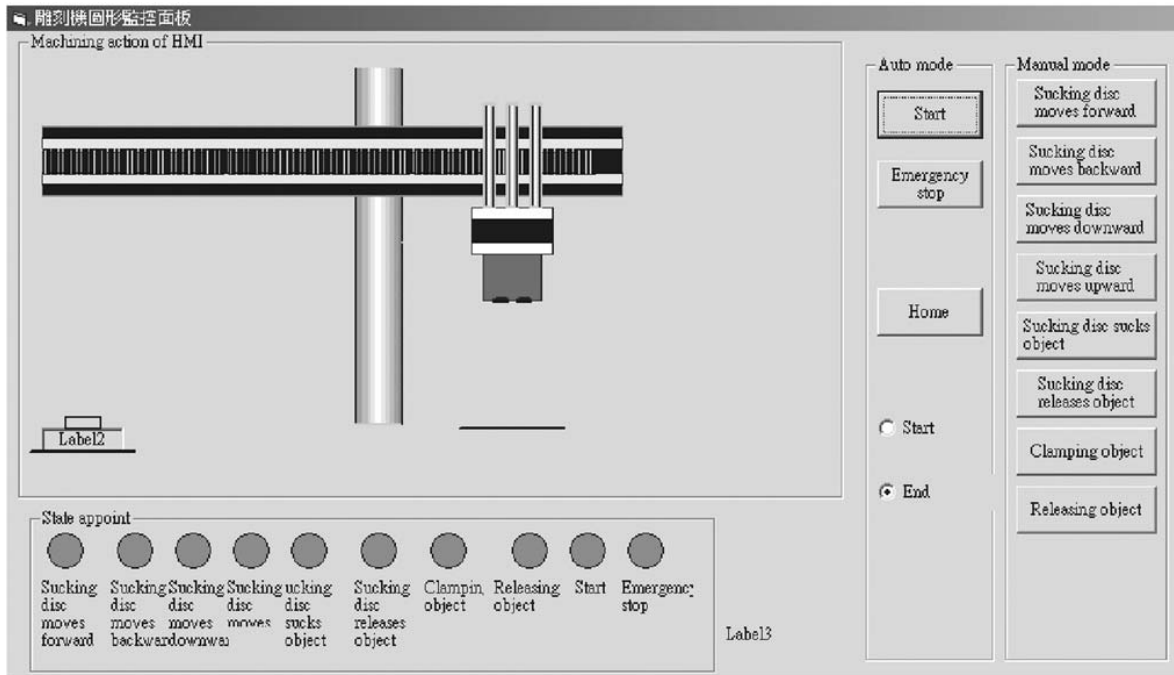
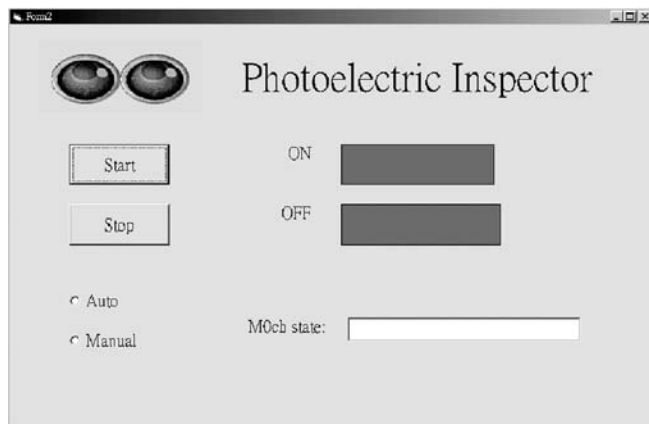**Fig. 12.** HMI screen for sculpturing cell

Fig. 13. HMI screen for vision inspecting cell

server PC, the function of the HMI provides both local mode and Web mode. The purpose of local control mode is to allow the operator to overlook the entire process or to individually control every single machine within the system at the local scene, thereby monitoring the process status of each machine. Engineering and management staff can easily manipulate the process and facility without visiting the plant. Furthermore, it can help diagnosis the process if a malfunction of FMS occurs. Any problems in the process can be resolved quickly.

From Fig. 10, the message dialog area shows the status of the manufacturing process. It presents the current operational message. The operator can also select individual cells from the selecting menu. From Fig. 11, the status of the automatic storage

system is well explored. The screen is divided into four areas: auto mode selecting menu, manual mode selecting menu, status indicators, and pictorially monitoring area. Figure 12 shows the sculpturing station. This screen is very similar to the screen on the auto storage unit. It shows the operational status of the robot. Figures 14 to 15 show the vision-based inspecting station and auto assembly station respectively.

4.2 Client platform

Generally, the HMI screens in the client site duplicate the information from the server platform via the Internet. In conjunction with the Web page of the axis video server for an FMS plant, operators can observe the live image of the plant via the Internet (see Fig. 16). Operators have to key in a user name and associated password to access this screen. That is, it is secured by password protection.

4.3 Problems and strategies

In this project, several problems were experienced and our corresponding strategies are discussed as follows:

1. **Noise signals received on PLC**: A noisy environment may have caused this problem. A programming technique with recurrence loop or timer/counter delay is adopted to filter out the troublesome noise.
2. **Inconsistent positioning of HMI and machine:** This inconsistency may have been the result of the time delay in communication and the speed of the computer. We created a fine tune timer on the screen to eliminate this problem.

Fig. 14. HMI screen for color-grade inspecting cell

Fig. 15. HMI screen for assembly cell
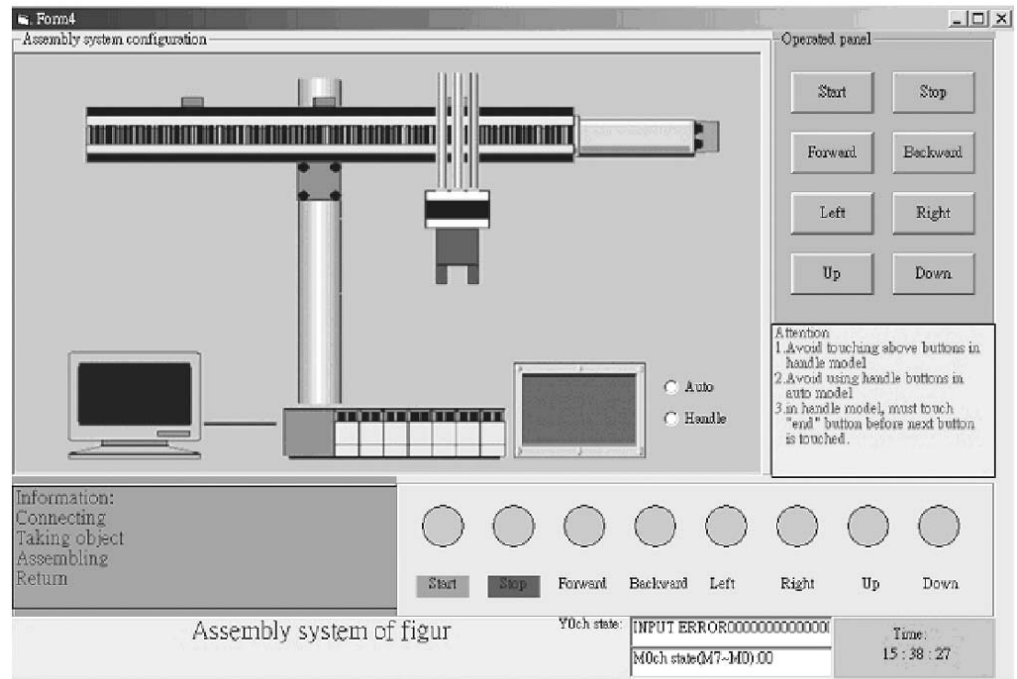
5 Conclusions

Due to global competition, manufacturing overseas has become essential. However, the cost and induced problems of management traveling overseas is undesirable. In this paper, an e-factory solution is presented. Using the techniques of a client-server and Web-based image delivery, this study de-veloped a remote platform that is able to successfully mon-itor and control the factory plant through the Internet. More than automation, e-factory solution is able to provide informa-tion about current status and quality of production, including production trends, machine availability, failure reports, criti-cal events, and remote control and diagnosis on manufacturing system. That is, the experiment showed that the proposed e-factory system is able to provide a cost-effective alternative to

Fig. 16. Live Web-based image screen

the traditional approach to managing an overseas manufacturing facility.

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