Smart Home Environment Management Using Programmable Logic Controller

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Abstract—**The trend of smart home applications is growing, and the final operation and calculation are still needed to go back to the automatic control technologies of the system. Automatic control focuses on the flexibility and finesse of control. The Programmable Logic Controller (PLC) has the advantages of simple function, high speed, high reliability, high noise resistance, and high stability, which is very beneficial for automatic control applications. Therefore, this study applies PLC combined with the home environment to complete the multi-faceted home automation control functions. In order to facilitate the operation and use of the various home environment, this study uses the human-computer interaction interface to humanize the integration of home control related functions. In addition, we through the ladder diagrams to show the various plans and cooperation of home control and to achieve a variety of home automation control functions, including anti-theft control, lighting control, temperature control, fire control, and sleep mode. Finally, a small house that simulates a home situation is used to demonstrate the home automation function achieved. This study will help to derive PLCs into future smart homes to provide more stable and efficient home automation control functions.**

Index Terms—**Smart home environment management, programmable logic controller, human-computer interaction interface, simulation house**

I. Introduction

RESIDENTIAL buildings must provide a safe, convenient, healthy and comfortable home environment, such as safety and disaster prevention, health care, convenience and comfort, and energy-saving and carbon-reduction functions to meet the needs of modern life. With the increasing number of home security devices, the global residential theft rate has been significantly reduced, but the residential theft rate is still the first place in the people's livelihood theft. In order to solve the problem of housing theft of people's livelihood and construct smart houses that meet the needs of life, many technologies is applied [1], and relying on various information and communication such as wireless sensor networks [2] as well as new service technologies are the inevitable trend for residential construction.

In the past, many research literatures on smart home have been proposed. In the area of smart home energy management, Pedrasa *et al.* described algorithmic enhancements to decision support tools that residential consumers can use to optimize smart home access to electrical energy services. Decision support tools optimize energy service provisioning by enabling end users to first assign values to the required energy services and then arrange their available distributed energy (DER) to maximize net benefits [3]. Han and Lim proposed a green home energy network using the new Smart Home Energy Management System (SHEMS) based on IEEE 802.15.4 and ZigBee (we call it the "ZigBee Sensor Network"). They developed a new routing protocol, DMPR (based on disjoint multipath routing) to improve the performance of their ZigBee sensor network [4]. In terms of home automation control, Teymourzadeh *et al.* examined the potential of "Full Home Control", which is the goal of home automation systems in the near future. They used Global System for Mobile Communications (GSM) modems to control the analysis and implementation of home automation technologies for home appliances (such as lighting, conditional systems, and security systems) through Short Message Service (SMS) text messages [5]. Kumar offered a flexible, stand-alone, low-cost smart home system that communicates with micro-web servers based on Android applications, providing more than switching functionalities. This smart home application has been tested successfully in performing smart home operations such as switching, automatic environmental control and intrusion detection, generating emails in the later cases and the siren goes on [6]. On the other hand, implementing security in the IoT environment has been identified as one of the biggest obstacles to achieving smart, energy-efficient home and building visions. Jacobsson *et al.* had conducted risk analysis of smart home automation systems developed in research projects involving major industry players. Their discussion of the impact of risk analysis results suggested that a more general security and privacy model needs to be included in the design phase of the smart home. Utilizing this security and privacy design model, it helps strengthen system security and enhance user privacy in smart homes, helping to further realize the potential in such IoT environments [7]. Jose and R. Malekian provided a comprehensive description of different

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home automation systems and technologies from a security perspective, highlighting various security vulnerabilities in existing home automation systems and explaining the future direction that home automation security research may take [8]. Furthermore, in order to intelligently control and improve living environment in real-time monitoring method, Lingjie proposed a kind of indoor environmental parameter monitoring system based on ZigBee Wireless Sensor Network [9].

Programmable Logic Controller (PLC) [10], which has a digital electronic device of the microprocessor, can be used to automatically control the digital logic controller, and load control commands into the memory for storage and execution at any time. The future development of PLC is geared to high speed, large capacity, multi-variety and programmable automation controllers. In order to improve its processing capacity, today's PLCs must have better response speed and greater storage capacity. PLC is mostly used in small and medium-scale applications. In order to meet the needs of various markets, PLC is bound to develop in many directions, especially in the direction of super large and ultra small [11]. There are now very large PLCs with I/O points of more than 10,000 points. They use 32-bit microprocessors, multi-CPU parallel work and large-capacity memory, and are powerful. At the same time, ultra-small and micro-PLCs that meet market needs, low cost, simplicity, and flexible configuration are also one of the directions for technology development.

Information and communication technology is especially important in the realization of smart home technology, including the construction of a friendly user interface, stable data transmission, efficient data processing, and a perfect communication network [12]. Using PLC to realize data transmission, processing and system monitoring, in order to meet the needs of automation and flexible manufacturing, it is necessary to improve the network communication speed and function between PLC and PC. Optical fiber has been used as a transmission medium to meet remote I/O module control. In addition, the enhancement of function enhancement and application instructions, and the advancement of semiconductor and microprocessor technology have made the development of PLC tend to be polarized. Small PLCs are moving in light, thin, short, and small directions, and add a lot of application instructions. The medium and large PLCs gradually use 32 or 64 bit microprocessors, multiple CPUs and large-capacity memory to make the scanning speed faster, and the functions of mathematical operations, data processing and network communication are greatly enhanced. It is more convenient to use and helps to be applied to the realization of smart homes.

In order to facilitate the operation and use of the home environment, this study uses PLC combined with the home environment to integrate the functions of anti-theft control, lighting control, temperature control, fire control, and sleep mode to make it play a holistic and efficient service function for ensuring the safety of the home, the health of the living environment and the convenience of life, and providing a comfortable quality of life, as well as creating a humane living environment.

II. METHODS

This study uses PLC to combine home environment to achieve home automation control, which is divided into (1) PLC and Human Machine Interface (HMI) hardware, (2) ladder diagram, (3) human-machine interface, (4) human-machine interface connection, and (5) MODBUS RTU communication.

(1) PLC and Human Machine Interface (HMI) hardware

The programmable logic controller body used in this study uses FATEK FBs-24MA◇Δ–◎–C [13]. It can be compiled by WinProladder software [14], which is responsible for receiving the data of the temperature device and the transfer of the analog data. Its specifications are 14 points 24VDC digital input (2 points high speed 100KHz, 6 points medium speed 20KHz, 6 points medium speed sum 5KHz); 10 point relay or transistor output (2 points high speed 100KHz, 6 points medium speed 20KHz); one RS232 Or USB communication port (up to 3).

In the user-friendly machine interface, Weintek MT8070IE is used. It is convenient for the user to operate related controls, written by EasyBuilder Pro [15], and connected to the programmable logic controller via RS232 [16].

(2) Ladder diagram

The ladder diagram [17] is the automatic control graphic language developed during the Second World War. It is the oldest and most widely used automatic control language. The ladder diagram can be divided into logical combination and logical sequence. Explain as follows:

a. Logical combination

A loop structure in which a single or more input elements are combined (string, parallel, etc.) and then sent to an output element (coil, timing/meter, or application command, etc.) as shown in Fig. 1. In Fig. 1, a normally open switch X0 is used for loop1. In normal times, the switch X0 contact is not connected, and the bulb Y0 is not lit. If the switch X0 is pressed, the switch X0 contact is turned on, and the bulb Y0 is lit. For loop2, a normally closed switch X1 is used. When it is normal, its switch X1 contact is turned on, and the bulb Y1 is lit. If the switch X1 is pressed, the switch X1 contact is not connected, and the bulb Y1 is not lit. For loop3, a normally closed switch X2 and two normally open switches X3 and X4 are used. In normal times, the switch X2 contact is turned on, the switch X3 and X4 contacts are not connected, and the bulb Y2 is not lit. To make the bulb Y2 light, the switch X2 contact or the switch X3 contact must be turned on, and the switch X4

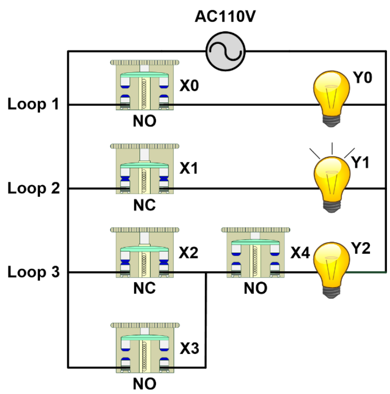

Fig. 1. The structure of the logical combination.

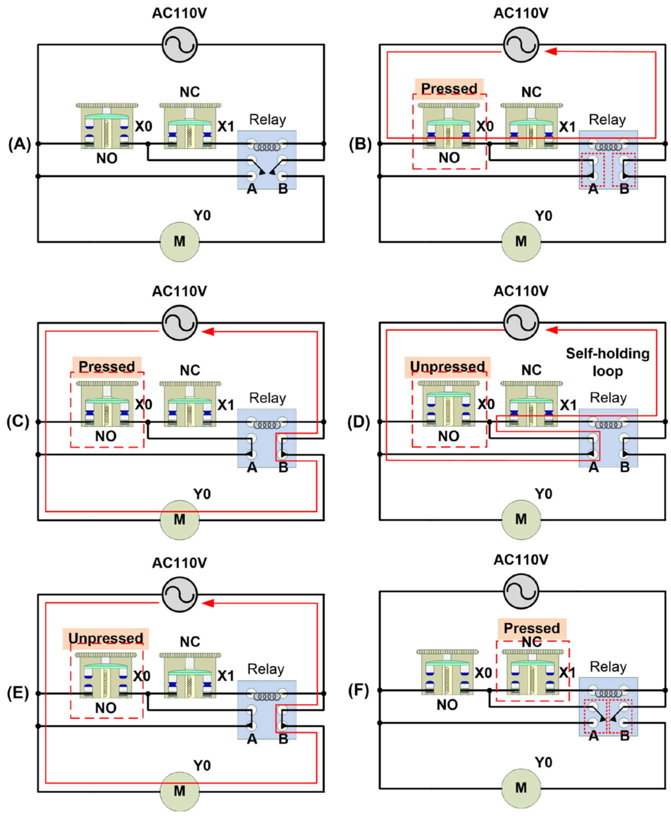

Fig. 2. The structure of the logical sequence.

contact is turned on.

b. Logical sequence:

A loop with a feedback structure, that is, the loop output is pulled back to the input condition, so that under the same input condition, different output results will be obtained due to the difference of the previous state or the sequence of actions as shown in Fig. 2. First, when the power is turned on, the switch X0 is OFF, and the switch X1 is ON, so the relay does not operate, and the motor Y0 is in a stopped state, as shown in Fig. 2-(A). When the switch X0 is pressed, the relay is turned on. At this time, the contact A and the contact B are simultaneously turned ON, as shown in Fig. 2-(B). Since the contact B ON, the power supply forms a loop with the motor Y0 to make the motor Y0 start to operate, as shown in Fig. 2-(C). Then, when the switch X0 is not pressed, since the relay power supply is kept back by the feedback of its own contact A, the self-holding loop is formed, as shown in Fig. 2-(D). Therefore, when the switch X0 is not pressed, the motor Y0 remains still in operation, as shown in Fig. 2-(E). Finally, when the switch X1 is depressed, the relay power circuit is disconnected, and the contact A and the contact B are also turned OFF to make the motor Y0 stop operating.

Each PLC has different ladder diagram compiling software. In the ladder diagram writing, this study uses the WinProladder of FATEK to write the ladder diagram required by PLC. Its characteristics are described as follows:

- WinProladder adopts Windows operating system and is designed according to the operating habits of Windows environment. It is easy to learn and use. It can be operated in a very efficient way for beginners or experienced users.
- The project concept is used to visualize the development content of the program in a hierarchical way, so that the relevant work content can be seen at a glance. The development or maintenance of the program can be carried out in a very intuitive way.
- The well-designed keyboard and mouse operation method is provided according to the difference between the job site and the office operating environment, and the program can be edited and tested in an efficient manner regardless of the working environment.
- Diversified connection methods, providing direct connection, modem connection, and Internet connection, etc., and can name and store different connection settings (such as transmission rate, phone number, IP address, etc.) As a result, the next operation is only necessary to select the connection settings from the pre-stored connection to connect.

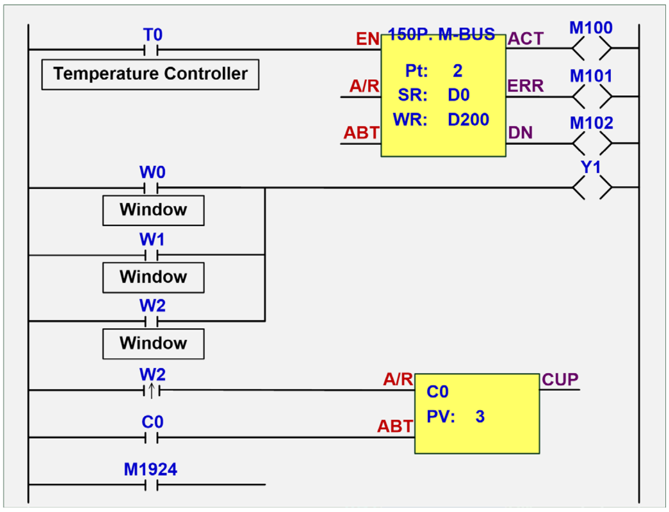

Fig. 3. PLC program ladder diagram for temperature control.

Figures 3 to 9 are ladder diagrams of the proposed study. Fig. 3 shows the ladder diagram T0 for temperature control combined with PLC. The temperature data is transmitted through the MODBUS (described in the following section) communication protocol module, which ACT is the communication transmission signal, ERR is the communication error signal, and DN is the communication complete signal. The study designed X0, X1 and X2 for windows, which are connected to the Y1 buzzer through a

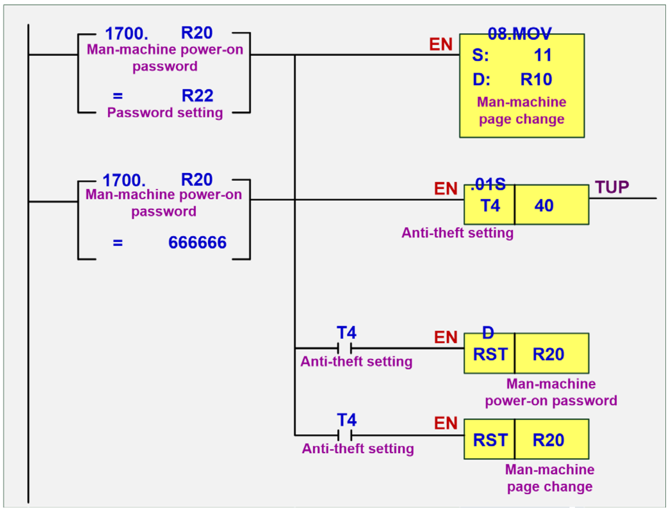

Fig. 4. PLC program ladder diagram for lamps settings.

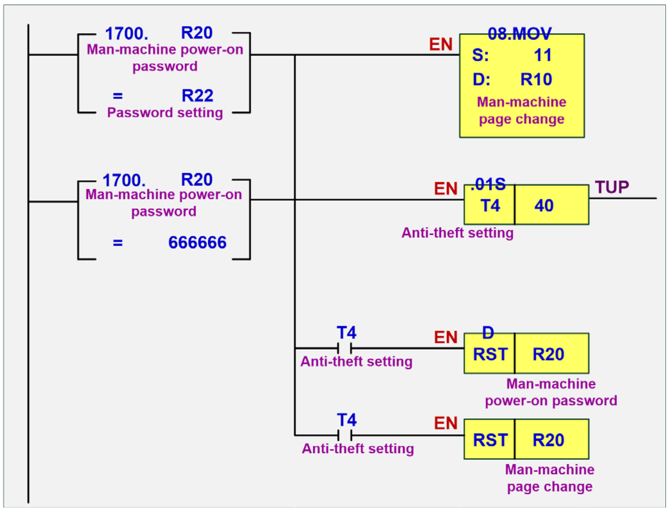

Fig. 5. PLC program ladder diagram for login setting.

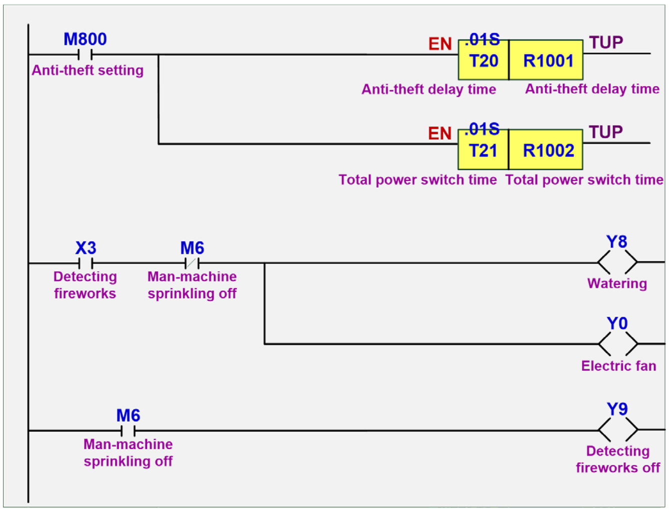

Fig. 6. PLC program ladder diagram for time and disaster prevention settings.

reed switch. The C0 is the light control of the room one. The M1 counting function is used to control the lamp 1 for Y3 and the lamp 2 for Y4. When the switch is pressed and C0 = 1, the lamp 1 for Y3 is lit; when the switch is pressed twice and C0 = 2, the lamp 2 for Y4 is lit, as shown in Fig. 4.

Fig. 5 is a PLC program ladder diagram of the password login page of the human machine interface. If the user inputs the password as the set password, the T4 anti-theft system is turned off, and the page is switched to the main screen.

Fig. 6 shows after the anti-theft is activated, the delay is turned on and the total power is turned off according to the set time to perform energy saving. X3 detects whether the pyrotechnic concentration exceeds the set concentration, and when it is reached, it will open the watering system and electric fan for exhaust.

Figures 7 and 8 show the sleep mode of the fan. Through the 13. (*) multiplication operation, it is judged that the current temperature is greater than the set value, and the percentage rate of the adjustment code reaches the speed. In Fig. 7, when the temperature is greater than 28 degrees, M51 is started. M51 of Fig. 8 controls the value set by the user, and converts the analog output to the motor speed controller to adjust the current speed of the fan.

Fig. 9 shows the daily mode of the fan. 17.CMP determines the speed to reach the set value of 10 seconds to achieve a

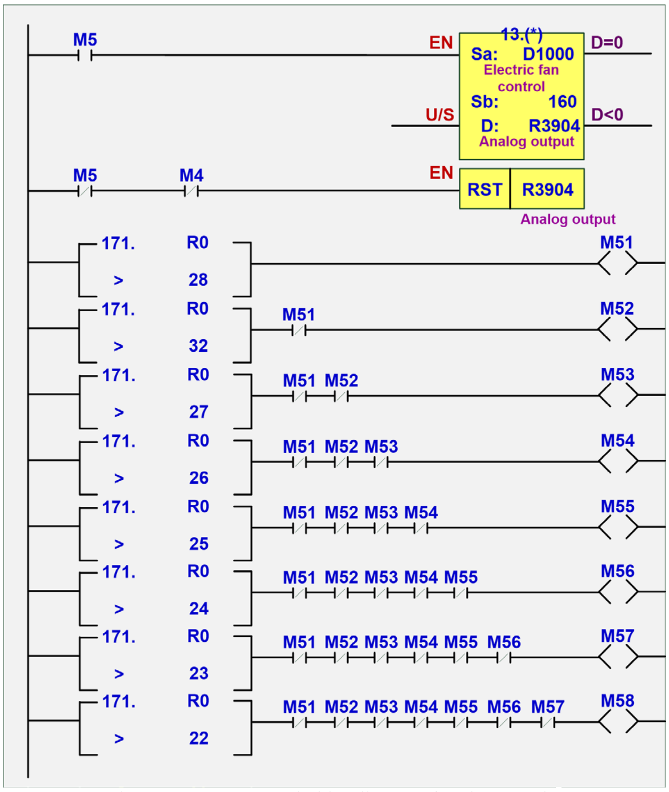

Fig. 7. PLC program ladder diagram for sleep mode.

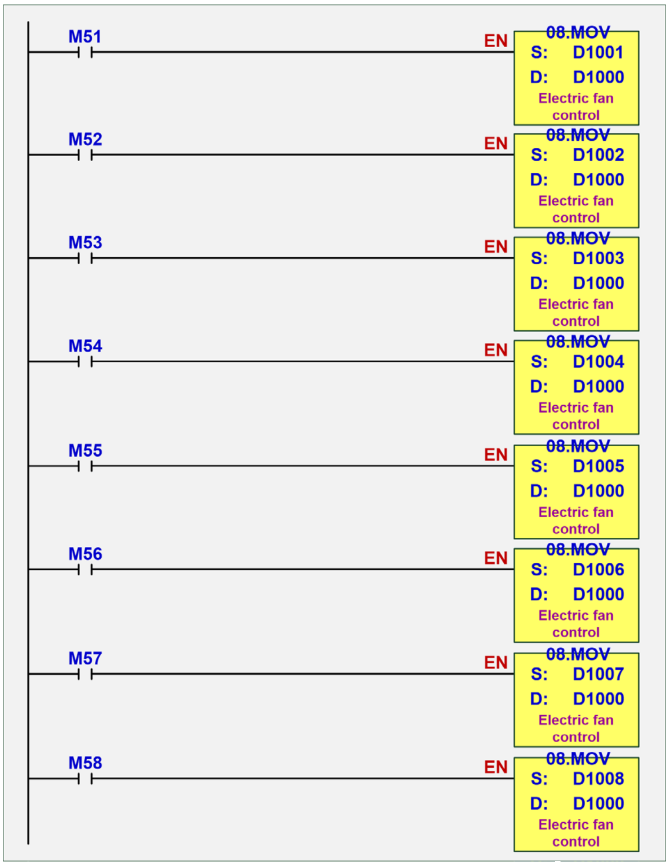

Fig. 8. PLC program ladder diagram for fan control.

natural wind that is fast and slow.

(3) Human-machine interface

EasyBuilder Pro is an editing software for configuring the human interface and setting the matching address. It contains many databases to facilitate the user's beautification and configuration of the operation interface. Its

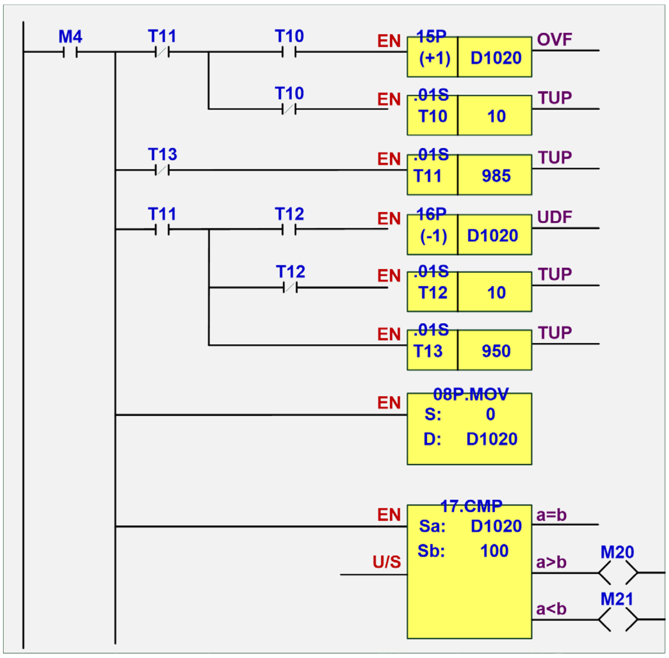

Fig. 9. PLC program ladder diagram for daily mode.

characteristics are described as follows:

- EasyBuilder provides system gallery. The gallery has a library of different combinations, so that users can use it conveniently. It can also change the frame color and related color of the object to meet the needs of users, and improve the efficiency of the user's design object.
- The shortcut bar of the vector map/picture library can quickly change the style of the selected object (one or more) in addition to previewing the contents of the gallery. Users simply change the style of the selected object by simply double-clicking on the image in the gallery or by clicking the checkmark in the lower right corner of the image.
- The range of the visible area can be seen in the relevant ruler, which can roughly know the position of the object and the cursor. But if you want a neat sort, use the convenient feature of the line to drag or scale the object to the desired position and size.
- Connect and communicate with the computer through the Ethernet network through the Ethernet network, and then input the computer-edited interface and control definition into the human-machine interface.

(4) Human-machine interface connection

A set of IP addresses consists of A.B.C.D codes. When setting up the human-machine interface and PLC, the two groups need to be in the same local area network. Before setting the IP address three codes A.B.C, the two groups should be the same and in the same area network. The machine connection IP address between device and device can not be the same as the fourth group D code. The subnet mask must be filled with 255.255.255.0.

When setting the man-machine interface and PLC, the two groups must be the same in the first three lines of the same area network. Therefore, when the network mask is 255.255.255.0, the public IP192.168.0.X is used for setting. The road communication protocol is selected as IPV4, so that

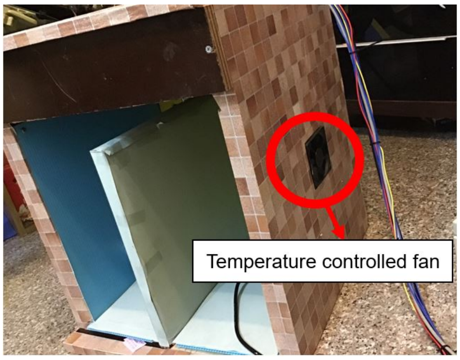

Fig. 10. Temperature controlled fan of the simulated house.

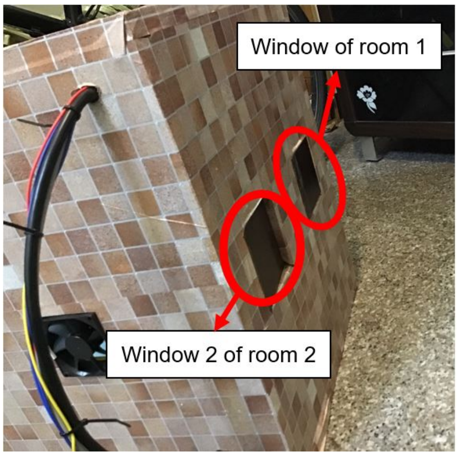

Fig. 11. Windows in room 1 and room 2 of the simulated house.

the PLC and the human-machine interface are in the same regional network, and the PLC and human-machine interface are connected through RS232.

(5) MODBUS RTU communication

Temperature control for this study was used to Modbus [18], a serial communication protocol that Modicon (now Schneider Electric) published in 1979 for the use of PLC communications. Modbus has become the industry standard for communication protocols in the industrial sector and is now the usual connection between industrial electronic devices. The main reasons why Modbus is used more widely than other communication protocols are:

a. Publicly published and without copyright requirements.

b. Easy to deploy and maintain.

c. There are not many restrictions for vendors to modify mobile native bits or bytes.

Modbus allows multiple (approximately 240) devices to be connected to the same network for communication, for example, a device that measures temperature and humidity, and transmits the results to a computer. In the Data Acquisition and Surveillance Control System (SCADA), Modbus is typically used to connect monitoring computers to remote terminal control systems (RTUs).

III. Result and Discussion

A. Simulated house for home automation

Figures 10 to 13 show the simulated house used in this study to present the home automation functions. In Fig. 10, the temperature controlled fan of the simulated house is controlled by the speed motor in the control box of this study

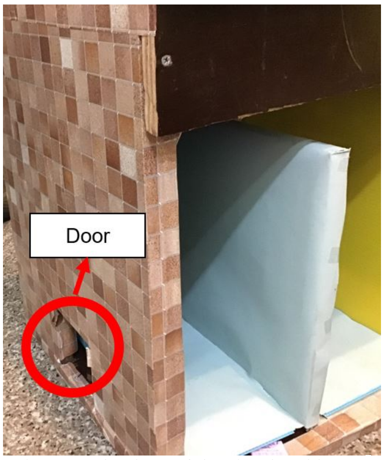

Fig. 12. The door of the simulated house.


Fig. 13. Interior side view of the simulated house.

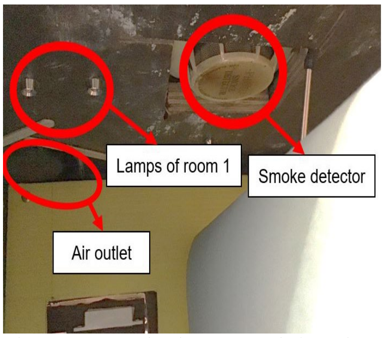

Fig. 14. Lamps in room 1, smoke detector, and air outlet of the simulated house.

to control the temperature. Fig. 11 shows the windows of the simulated room 1 and the room 2. Fig. 12 shows the door of the simulated house. When the door or window is opened after the anti-theft is activated, the buzzer will be triggered and recorded in the PLC. Fig. 13 is a side view of the interior of the simulated house.

Fig. 14 shows two lamps in a simulated room, which can be easily opened and closed using a human-machine interface panel. Next to it is the smoke detector of the simulated house. When the concentration of the indoor smoke exceeds the set value, the fan in the air outlet will start to exhaust and start the watering.

Fig. 15 shows the lamps in room 2 of the simulated house. The side temperature sensor will be combined with the temperature device to sense the current temperature, and

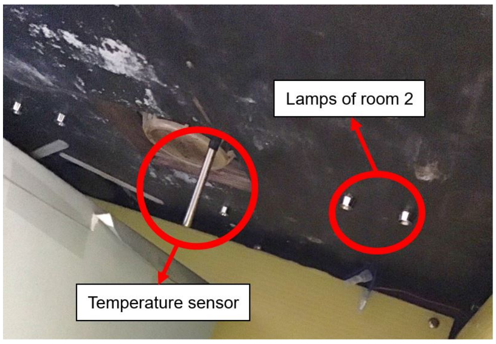

Fig. 15. Lamps of room 2 and temperature sensor of the simulated house.

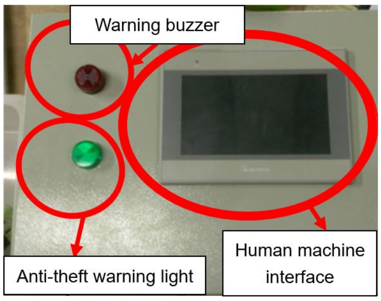

Fig. 16. Appearance of the PLC control box.

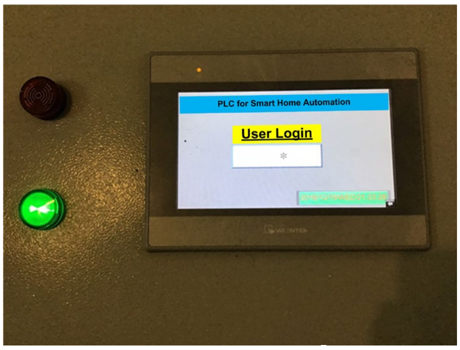

Fig. 17. Login screen.

Fig. 18. Main screen after the control box is logged in.

match the speed value of temperature controlled fan in the simulated house.

Fig. 16 shows the appearance and contents of the control box, including the human-machine interface, and the anti-theft warning light (green) and warning buzzer (red) for simulated house alarms.

Fig. 17 shows the login screen of the control box. The user can set the password of 6 digits. When the system is logged out, the anti-theft warning light will light up.

Fig. 18 shows the main screen after the control box is

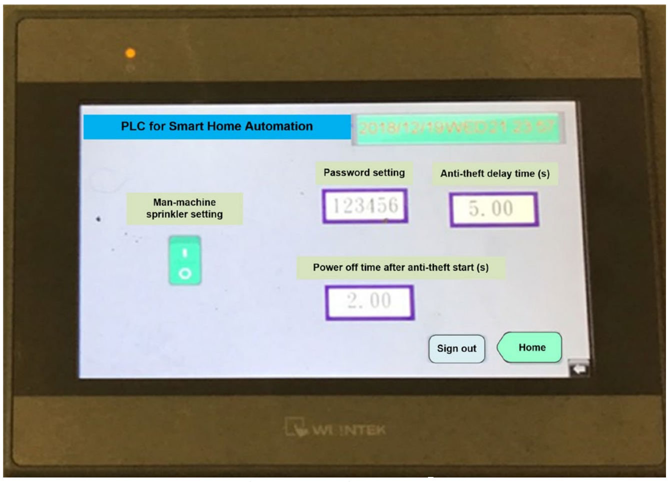

Fig. 19. Settings page.

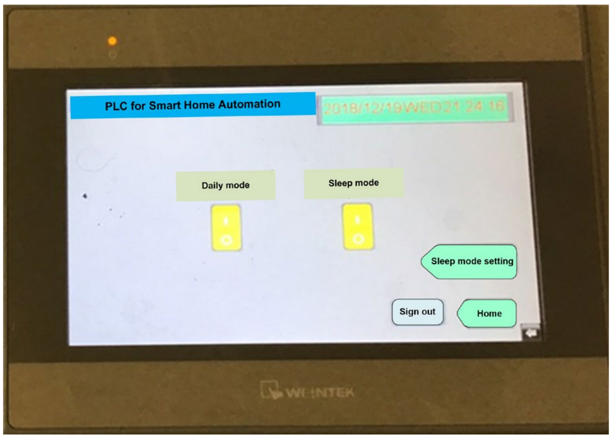

Fig. 20. The settings of situational mode of the simulated house.

logged in. The current temperature will be displayed, followed by the lamps of the room 1 and room 2, as well as the lamps for the walkway. The status of the current fan, window and door is also displayed.

Fig. 19 is a setting interface of the simulated house, including the password setting of the login screen, the setting time of the anti-theft delay, and the setting time of the power-off after the anti-theft is activated.

Fig. 20 shows the settings of situational mode of the simulated house, which is divided into daily and sleep modes. When the daily mode is turned on, the temperature control fan will start to work, and the natural wind that is fast and slow will keep the air flowing. When the sleep mode is turned on, the fan will quickly or slowly running with the current temperature to achieve the temperature control effect.

Fig. 21 shows the recording area of the simulated house. When the anti-theft is activated, if the door and window are opened, the time and status will be recorded in the recording area of the simulated house. When the smoke detector is activated, the time and concentration are also recorded in the area.

Fig. 22 shows the contents of the control box, including loop protector, thermometer, programmable logic controller, power supply, total power input, AC signal output, DC signal output, DC signal input, DC fuse and motor relay.

B. 3.2. Comparison of home controllers

The development environment for today's home control topics is mostly ARDUINO or RASPBERRY PI [11]. Table I

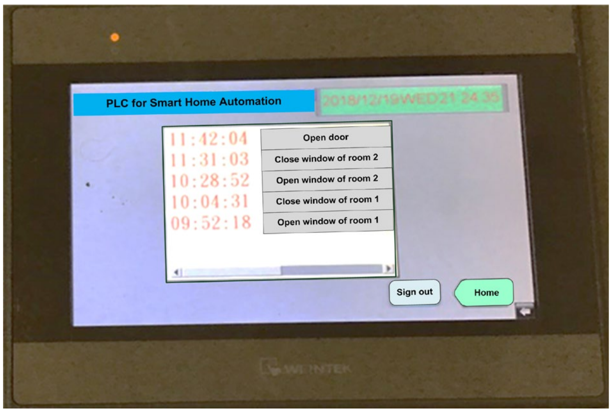

Fig. 21. The recording area of the simulated house.

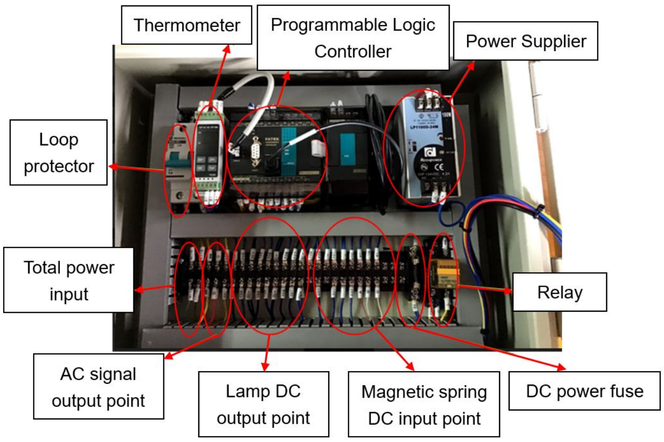

Fig. 22. The internal configuration of the PLC control box.

compares the hardware and software of PLC with ARDUINO and RASPBERRY. As shown in Table I, although the PLC price is more than the other two, the PLC's free voltage (AC100V~AC240V) still has advantages used in furniture and home appliances. The high temperature resistance and anti-interference characteristics can also make the PLC for the normal operation and use under harsh environment. Although

TABLE I
COMPARISON OF HOME CONTROLLERS FOR PLC, ARDUINO, AND RASPBERRY PI

Controller / Characteristic	PLC	Arduino (UNO)	Raspberry Pi (Model B)
Input voltage for connecting home appliances	No need to transfer voltage when connecting home appliances	Booster module is needed for connecting home appliances	Booster module is needed for connecting home appliances
Anti-interference	Excellent	Worse	Good
Volume	60mm*175mm*130mm	L: 70mm W: 54mm H: 14.7mm	L: 85mm W: 56mm H: 17mm
Operating temperature range	-20°C~95°C	-35°C~80°C	-40°C~85°C
Price	USD 135-560 dollars	USD 6-20 dollars	USD 33-150 dollars
Number of writes	Write 100,000 times	Write/clear 100,000 times	Save 100,000 times

the size of the PLC is relatively large, the number of times it is written is same as that of the other two, and there are more data that can be accessed.

IV. Conclusion

This study discusses how to integrate automatic control with home and simply and conveniently. A PLC was used to make the main controller of the automatic control, jumping away from the stereotype that we used to think that PLC is only suitable for large industrial or large machines. From the implementation of this study, PLC can indeed achieve the basic home control functions, and its operation can fully demonstrate the functions without any delay. The simple and clear interface designed with EasyBuilder Pro allows the first contact to get started right away. Technically, the WinProladder ladder diagram program is used to complete the connection between the human-machine interface and the home device. The step-by-step design method makes it more efficient and convenient to design. The home control functions realized in this study have functions such as electric light, temperature control, anti-theft and smoke detection, which have already constituted the basic necessary conditions for smart home application. In addition, the simulation house realized in this study has a balance between daily life and safety concerns. In the future, other functions can be added due to user needs.

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