ICIC Express Letters
Part B: Applications
Volume **8**, Number **9**, September **2017**

ICIC International ©2017 ISSN 2185-2766
pp. 1243–1252

EMBEDDED CONTROLLER DESIGN FOR CURTAIN MOTOR OPERATION WITH BLUETOOTH AND MODBUS COMMUNICATION

Cheng-Yi Chen[1], Rong-Ching Wu[2], Chung-Long Pan[2,*], Chao-Ming Hsu[3] and Shinn-Horng Chen[3]

[1]Department of Electrical Engineering
Cheng Shiu University
No. 840, Chengcing Rd., Niaosong Dist., Kaohsiung City 83347, Taiwan
albert.cc0479@gmail.com

[2]Department of Electrical Engineering
I-Shou University
No. 1, Sec. 1, Syuecheng Rd., Dashu Dist., Kaohsiung City 84001, Taiwan
rcwu@isu.edu.tw; *Corresponding author: ptl@isu.edu.tw

[3]Department of Mechanical Engineering
National Kaohsiung University of Applied Sciences
No. 415, Chien Kung Rd., Sanmin Dist., Kaohsiung City 80778, Taiwan
{ Jammy; shchen }@kuas.edu.tw

Received April 2017; accepted July 2017

Abstract. *The controller of a motor operation device plays an important role in industrial and home automation processes. When greater demands are placed upon manufacturing and home processes, precise control of the motor operation device will increase the quality of manufactured products and the quality of life for residents. An embedded controller design in a motor operation device with RS-845 and Bluetooth communication can be used to improve the automation hierarchy of manufacturing and home systems. This article proposes a motor operation controller design for a curtain system. This controller design uses local, remote and Modbus media methods to build a single-device control mode and a multi-device control mode. With Modbus communication, the proposed motor operation device can be applied in monitoring and control systems. Actual tests verify that the proposed motor operation device controller is useful and could be successfully applied in the field of smart home systems.*
Keywords: Motor operation valve, Modbus protocol, Embedded controller, Bluetooth

1. **Introduction.** In petrochemical-related manufacturing processes or other manufacturing processes employing process controls, the controllability of fluid valves plays a very important role. Traditionally, control elements such as flow rate, and flow pressure must be controlled manually to achieve the predetermined parameters required by a given manufacturing process. However, with progress in industrial technologies and the maturing of automatic control technologies, the continuous process gradually gained importance, as the industry process attempted to achieve large-scale production. In terms of improving product quality in manufacturing processes, the move toward automatic process controls was an unavoidable trend. Because the performance of automatically controlled fluid valves is a basic and necessary element for improving an automated manufacturing process, quite a number of motor-driven control valves have been developed [1-4] and widely applied in automatic product formulations and in process controls.

Embedded motor controllers for controlling the forward/reverse rotations of motors also have other applications, such as in household appliances. For example, they can be used as controllers in motors used to open/close window blinds. Improving controllers in motor-driven window blinds would allow quality products to be manufactured for households and professional decorators. Traditionally, window blind controller technology was designed from the perspective of institutional users and aimed to achieve automatic control using simple, single-motor-driven control systems [5,6]. However, as industrial/commercial activities become more complex and quality of life requirements for homes continue to multiply, simple manual control of window blinds can no longer meet these needs, so the use of wired and wireless communication technologies to control window blinds has been gaining momentum. One example of this is the application of radio frequency/Bluetooth communication technology in window blind controllers. Recently, with the rapid growth in integrated circuit and electronic communication technologies, embedded systems have become small and affordable. Now, they are widely used in products for both controlling and processing functions [7]. For applications in consumer or industrial products, the demand for automatic process controls cannot be met simply with powerful computer systems, because industrial applications must take into consideration both price and performance.

Currently, due to the rapid advancements in automatic process controls, there is a trend toward increased use of electronic systems in process control systems. A good communication system is very important for allowing the components of process control systems, such as electronic systems and control devices, to share information and give the electronic systems of entire manufacturing plant functionalities such as error diagnosis, self-repair and data fusion [8,9]. For many devices, Modbus communication provides effective solutions to the problems of relaying commands and exchanging information. Today, Modbus communication technology is widely used for equipment automation and electronic monitoring in various industries and in manufacturing plants. The requirements for system reliability, execution speed and cost effectiveness in even basic communication equipment, plus the increased use of heterogeneous communication equipment and larger communication loads between equipment, are putting a strain on overall monitoring systems. A recent trend to increase the performance of a given monitoring system is to choose a uniform communication mode and interface; this helps lower the complexity encountered by the monitoring system when integrating various communication protocols [10], allows the swift integration of master- and client-side monitoring system designs, shortens development cycles, lowers the overall system development cost, and increases the competitiveness of the monitoring system.

In this article, we describe a window blinds control system with both wired and wireless components. By integrating the research, development and design of firmware and hardware, we have developed an intelligent, embedded control system comprised of several components, including motor controls, proximity operating systems, remote monitoring systems, Modbus communication, wireless controls, power systems, system planning, security mechanism settings and interface. Using open-source firmware, a single-blind or multi-blind control system can be built and coupled through a Modbus communication interface to a host computer or connected through wireless control technology and controlled remotely. The advantage of the proposed design is to build a seamless application with smart home automation system.

Section 2 addresses the tubular mechanical system design of an intelligent curtain operation, which includes tubular motor, mechanical design, embedded controller design and the corresponding firmware design. In Section 3, the experiment results are presented with discussion. Finally, Section 4 concludes with a brief result and represents the future work of this paper.

2. **Tubular Mechanical System Design.** In this article, we will describe an intelligent window blinds control system with both wireless and wired control capabilities that can be proximity operated and wirelessly controlled and that has system planning and security setting functionalities. The system can be operated in either single-blind or

multi-blind mode and has self-diagnostic functionality, which will automatically pinpoint system problems and assist engineers during installation and maintenance.

2.1. **Tubular motor and mechanical design.** Currently, the up-down movements of automatic window blinds are driven by tubular motors, with the forward/reverse revolutions of the motors controlled externally. In this article, we propose an integrated design incorporating several components, including tubular transmission mechanisms, reducer, drive motor, start capacitor, and up-down limit mechanisms. As shown in Figure 1, the window blind control system uses an induction drive motor that through the designed transmission mechanism can achieve 28rpm and deliver torque of 6N.m. The required electrical power is 110/230VAC. The system detects the upper and lower movement limits through mechanical limit switches; the design (Figure 2) includes features such as a right-end fixture, electrical conduction, blinds operation, upper and lower limit detection and antenna exit. When the upper limit position is reached, the upper limit relay is activated; conversely, the lower limit relay is activated if the lower limit position is reached. The upper and lower limit positions can be set via a mechanical knob. The induction motor also plays the role of a brake when it is not driven. The brake is released when the motor is driven. The planetary gear reducer adjusts the rotational speed of the induction motor as required and increases the torque of the tubular motor. In addition to detecting the upper and lower limits, the control adjustment mechanism also supports, fixes and serves as the inlet for the power lines.

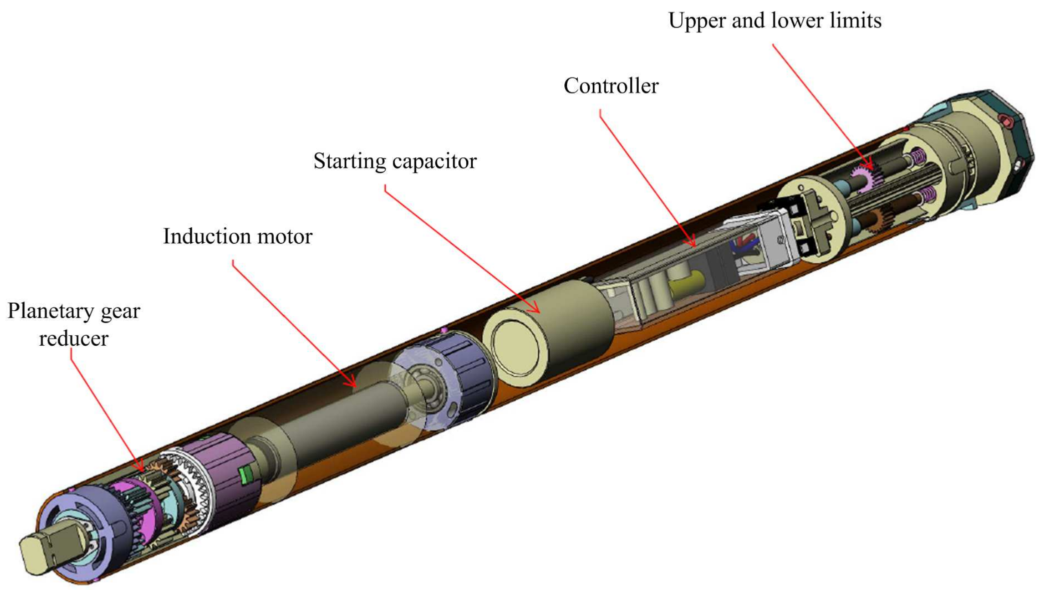

Figure 1. Tubular motor

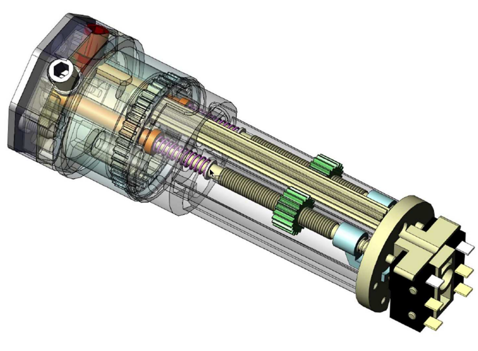

Figure 2. Upper and lower limit mechanism

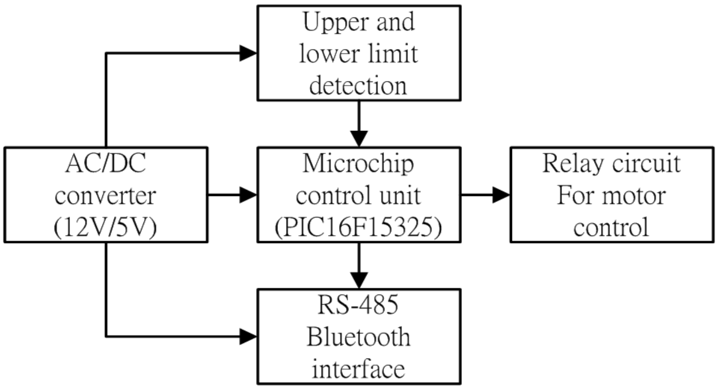

Figure 3. A function block diagram of the embedded controller for the tubular motor

Table 1. Controller functional descriptions

Item	Name	Description
1	Microchip controller circuit	Customized circuit design (PIC16F15325)
2	AC/DC converter	110VAC to DC 5V
3	Relay/SSR circuit	Rational control for induction motor (3A)
4	Bluetooth	Bluetooth wireless (433M, 2.4G)
5	RS-485 circuit	Modbus RTU protocol
6	Modbus address ID	Setting by software
7	Upper and lower limit	Upper and lower limit mechanism

2.2. **Embedded controller design.** As shown in Figure 3, the embedded controller for the window blinds integrates several functionalities, including controlling the direction of motor revolution, detecting upper and lower limits, managing the wired/wireless communication interface, and adjusting the power. Table 1 indicates that through the integrated design of the electrical circuits and the design of the firmware, the tubular motor can receive commands from both wired and wireless systems simultaneously and execute established control movements. In Figure 4, we present the system power circuit design working in independent mode. A power supply of 110VAC is stepped down to DC 12V by R-C circuit and rectifier, and further stepped down to DC 5V by a high-efficiency linear regulator, LM1117. The relay circuit for rotational motion control of the induction motor is illustrated in Figure 5. The AC motor starting capacitor causes a phase difference to start the AC motor. When the R1 relay is activated, the motor spins forward, and when the R2 relay is activated, the motor spins in reverse. A circuit diagram incorporating a PIC 16F15325 microprocessor chip, manufactured by Microchip Technology Inc., is illustrated in Figure 6. Utilizing the firmware design, this microprocessor is used to detect the upper and lower limits of the blind movements, and it sends a signal to the relay circuit to control the rotational motion of the induction motor. Other components on the circuit board include LED status indicators, an RS-485 communication bus for network control, and an interface circuit for the Bluetooth module. The final completed PCB circuit board layout, drawn using Altium designer software, is shown in Figure 7. The size of the PCB board is 50mm×20mm×20mm.

2.3. **Firmware design with modbus RTU and Bluetooth communication.** A flowchart for the Modbus RTU slave device communication protocol is presented in Figure 8. The configuration of the series communication is set at a baud rate of 9600bps, 8 data bits, no parity bit, and one stop bit. When a Modbus RTU slave node is excited and operated in standby mode, the slave device will begin to receive commands and start

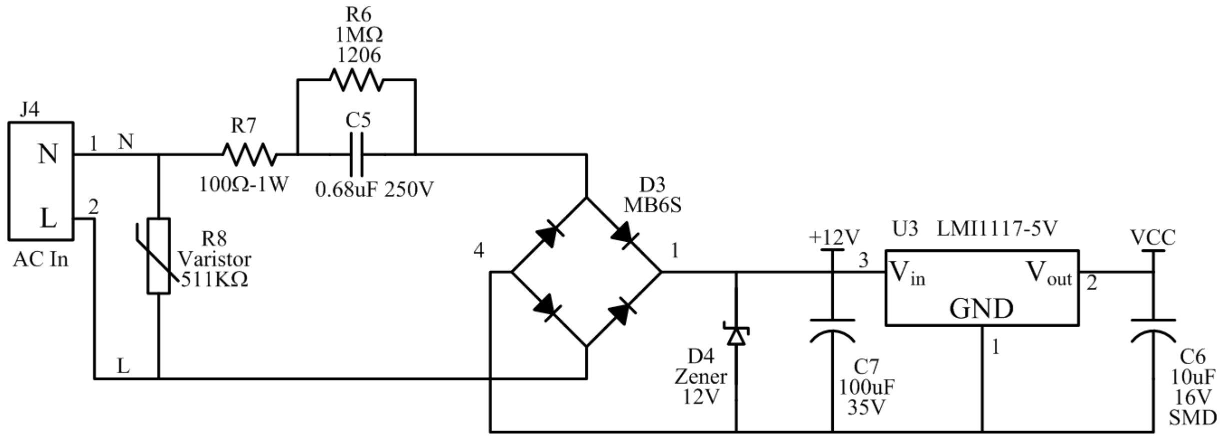

FIGURE 4. The system power circuit

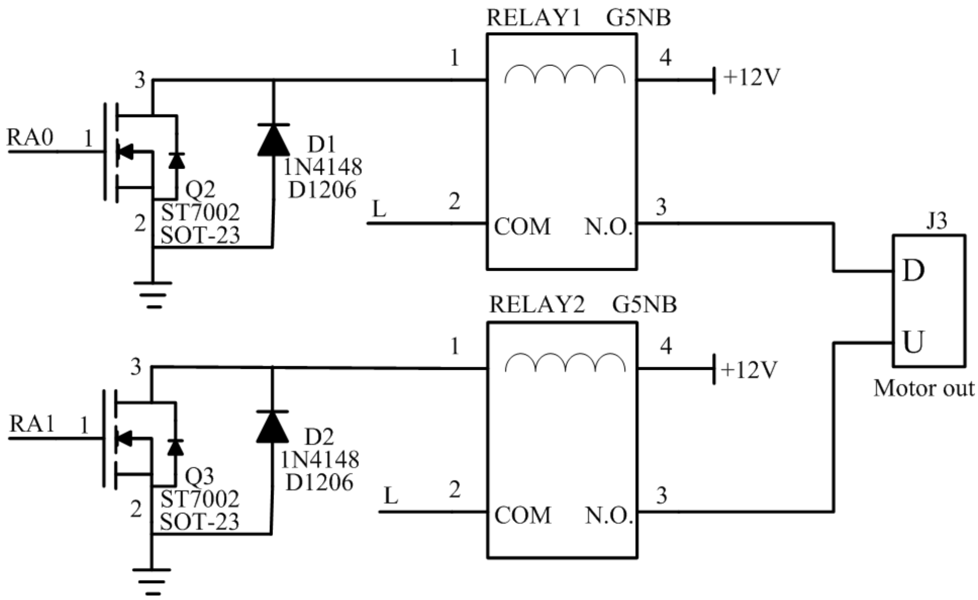

FIGURE 5. Relay circuit for rotational motion control of the induction motor

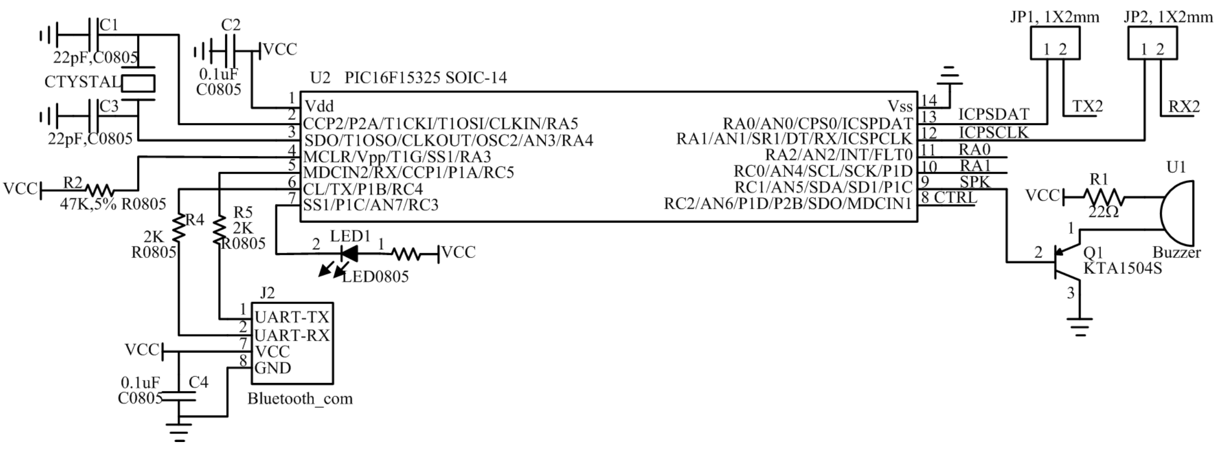

FIGURE 6. The microprocessor circuit with RS-485 and Bluetooth interface

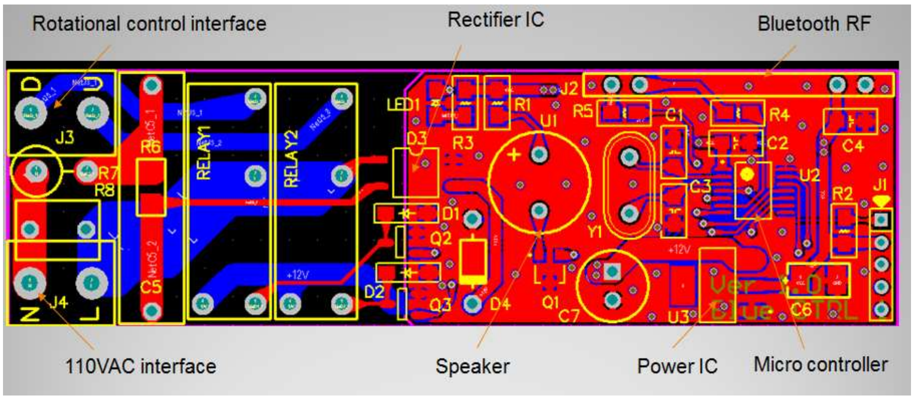

Figure 7. PCB circuit with embedded controller design

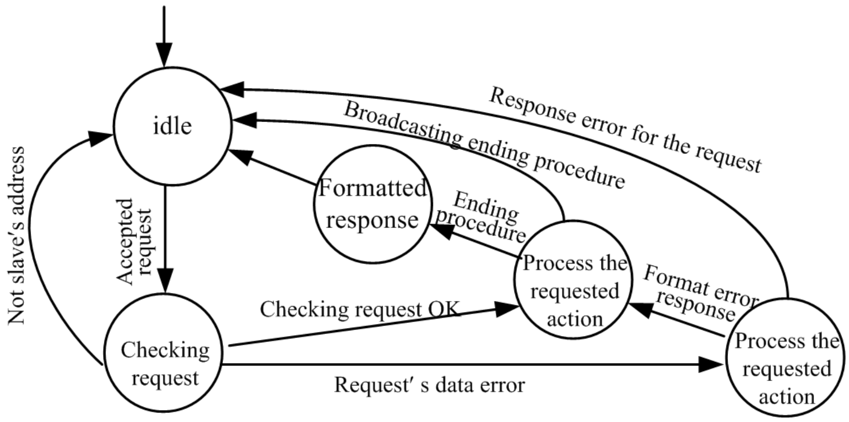

Figure 8. Status machine flowchart for Modbus RTU slave device

Table 2. Modbus function supported by embedded controller

Modbus function	Address	Data bytes	Description
05 / 01	0	2-Byte	Motor clockwise rotation
05 / 01	1	2-Byte	Motor anti-clockwise rotation
05 / 01	2	2-Byte	Motor stop
04	0	2-Byte	Reading the degree of curtain opening
04	1	2-Byte	Reading the controller status
04	2	2-Byte	Reading the firmware version
04	3	2-Byte	Reading the testing timer value
04	4	2-Byte	Reserved for future use

execution. Single-node communication applications execute this by confirming whether the format of the communication packet and its address match those of the slave node. In broadcast communication mode, the slave node will only check whether the format of the communication packet is correct. If the slave node confirms that the communication packet contains commands from the master node to itself, it will begin to process the commands. After completing the commands, it will not reply to the master node if the communication is in broadcast mode. Otherwise, in a one-way communication mode, the slave node will make a corresponding reply based on the content of the command. The communication commands supported by the slave node of the embedded controller's Modbus described in this article are listed in Table 2. Since the Bluetooth hardware uses an HC-05/HC-06 Bluetooth module, there is built-in Bluetooth-to-RS-232 communication conversion; it also supports an AT command set. Thus, the communication program design for the embedded controller requires only the simple RS-232 serial communication signal receiving and transmission mode, "u" representing up (forward rotation), "s" representing stop and "d" representing down (reverse rotation).

3. Experimental Results and Discussion. The design of the tubular motor master controller includes both Bluetooth receivers and Modbus RTU communication modules, as shown in Figure 9. As the window blind master controller can simultaneously receive commands from the Bluetooth app of a smartphone and the serial communications of the Modbus RTU interface, the master controller employs power lockouts as a way of prioritizing control, with the latest commands having higher priority over previously received commands. The controller can relay its current status to the host computer through the Modbus RTU communication of the RS-485. That is, the host computer has to take a query-and-response approach regarding communication to the controller. The controller can control the forward/reverse rotation and stopping of the tubular motor. It can also record the current digital output status and transmit the status back to the host computer through communication channels. A test system for the window blind is illustrated in Figure 10.

Under Bluetooth wireless control mode, control of the window blind is achieved through the connection made via the wireless device of the smartphone and the Bluetooth module. First, Java Development Kit 1.6, Integrated Development Environment Eclipse, Android

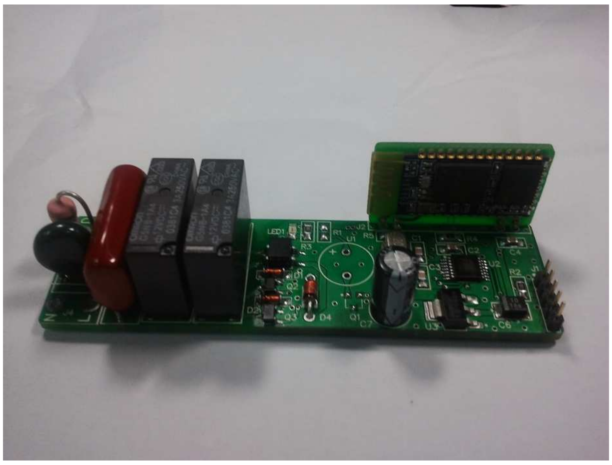

FIGURE 9. Prototype of the embedded controller

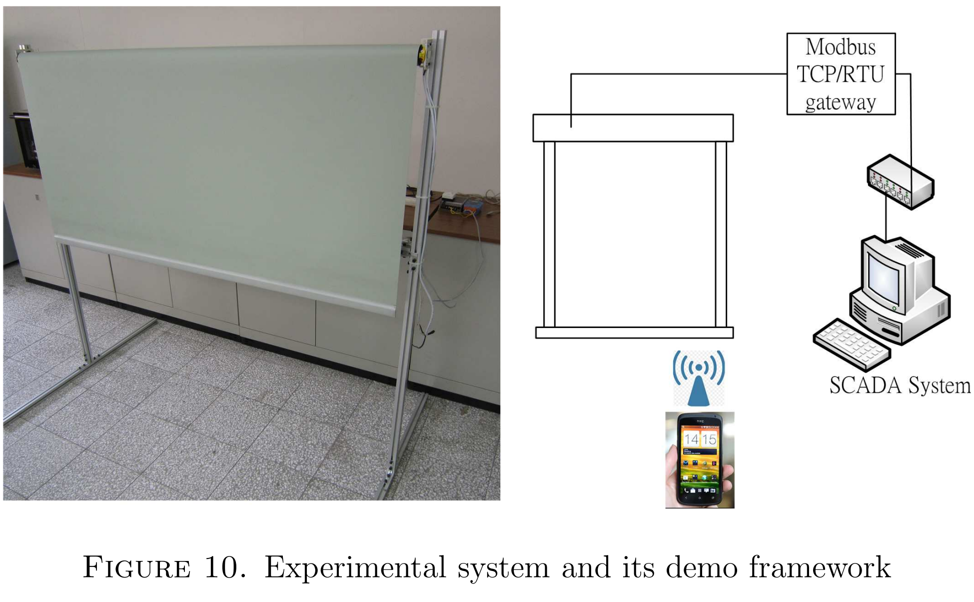

FIGURE 10. Experimental system and its demo framework

Abstract Data Type (ADT) and Android Software Development Kit (SDK) are installed on a personal computer to create a development environment for the Android smartphone app. As the embedded controller has a Bluetooth module that can convert Bluetooth communication to RS-232 communication of the TTL data, all that is needed to transmit American Standard Code for Information Interchange (ASCII) commands to the target embedded controller is to design a Bluetooth communication for the smartphone's app program. The embedded controller can then execute the corresponding request once it receives commands. Sample commands include "u" for going up (positive rotation), "s" for stop, "d" for going down (reverse rotation), etc. The configuration of the RS-232 serial communication is set at a baud rate of 9600bps, 8 data bits, no parity bit, and one stop bit. An application program designed for Android smartphones with a human–machine interface is partially shown in Figure 11. The program description for the smartphone app is as follows. 1) Click the "Search device" button to search for Bluetooth devices in the vicinity. 2) Press ▾ to choose the device to connect. 3) Press the "Connect device" button to connect the Bluetooth device. The connection indicator will light up. 4) Press "Open Bluetooth device" to start transmitting commands and receiving responses. 5) Press "Up" for going up (forward rotation), "Stop" for stop or "Down" for going down (reverse rotation). At this time, messages such as "curtain rolling up, curtain stop and curtain rolling down" will appear in the message window in Chinese. 6) If the "Exit" button is pressed, it means the user wants to end the app and disconnect the Bluetooth device.

The monitoring system is designed using professional software such as InduSoft Web Studio [8], and the design of the human-machine interface is shown in Figure 12. The main function of the monitoring system is to display the extent to which the window blind is

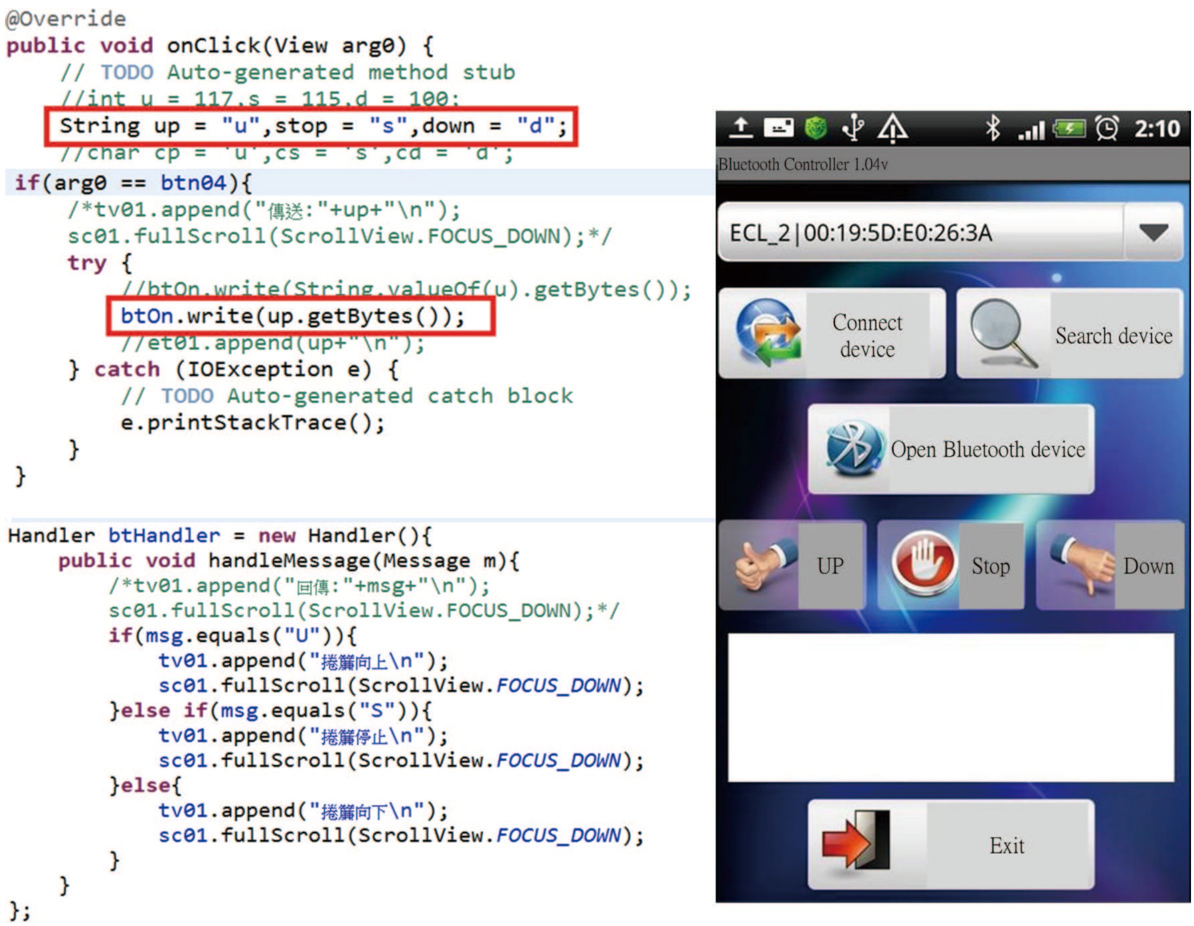

FIGURE 11. Partial program and human-machine interface for smartphone

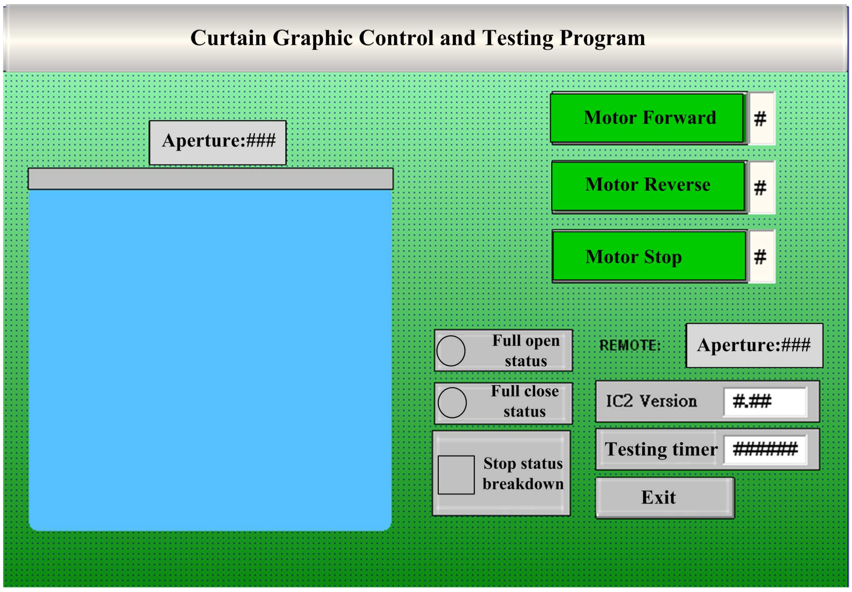

Figure 12. Human-machine interface for a PC-based curtain control system

opened, fully open status, fully closed status, motor malfunction status, software version, and count values from the test timer. In addition, the user can press buttons such as "Motor clockwise", "Motor counter-clockwise" or "Motor stop" instead of "Curtain roll-up", "Curtain roll-down" or "Curtain stop", respectively. The PC-based curtain control system uses the Modbus TCP communication protocol to transmit its commands, which are shown in Table 2. The control system then converts the Modbus TCP commands to Modbus RTU through the μPAC-7186EX-MTCP gateway, thereby controlling the extent to which a single blind is opened. In addition, an intelligent building-monitoring system can be built by integrating a wired Modbus RTU interface with a building's monitoring systems, creating a better living environment.

4. **Conclusions.** In this article, we described our development of a wired and wireless window blind control system integrating a tubular motor, motor transmission system, communication system and power system. Through the integrated development and design of firmware and hardware, we created an intelligent, embedded control system with the functionalities of motor control, proximity operation, remote monitoring, Modbus communication, wireless control and power systems, and an interface. Based on the embedded control system developed, single blind or multi-blind control modes can be built using open-source firmware designs. In addition, the embedded controller can be integrated with the Modbus communication interface and host computers to create a monitoring system that can be used to control the extent to which blinds are opened, through wireless radio frequency/Bluetooth wireless communication technology. The motor control system with network communication described in this article allows a window blinds system to be integrated with a building's monitoring systems through a Modbus RTU communication interface. An extension to this work, an embedded controller design for industry motor operation can be further developed with remote control technique for enhancing the convenience in apply in supervisory control and data acquisition system.

REFERENCES

[1] J. L. Robinson, *Motor Operated Valve Assembly*, United State Patent 4705063.
[2] *IEEE Draft Guide for Motor Operated Valve (MOV) Motor Application, Protection, Control, and Testing in Nuclear Power Generating Stations*, IEEE Std P1290/D2, 2014, pp.81-88, 2015.

[3] L. Castellini, M. D'Andrea and N. Borgarelli, Analysis and design of electro-mechanical actuator for gate valve in oil & gas applications, *International Symposium on Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM)*, pp.378-384, 2014.

[4] A. G. Garganeev and V. V. Mashinsky, Design principles of pipeline valve mechatronic systems, *IEEE the 13th International Conference and Seminar of Young Specialists on Micro/Nanotechnologies and Electron Devices (EDM)*, Erlagol, Altai, pp.330-332, 2012.

[5] S. P. Arjunan, H. Weghorn, J. O'Connor, D. Kumar, S. Shahebjada and T. Bastos, Towards better real-time control of smart wheelchair using subtle finger movements via wireless (blue-tooth) interface, *The 4th International Conference on Intelligent Human Computer Interaction (IHCI)*, Kharagpur, India, pp.1-5, 2012.

[6] C.-Y. Liu, C.-Y. Chen and Y.-C. Huang, Smart electric receptacle with APP accessibility, *ICIC Express Letter*, vol.9, no.3, pp.813-818, 2015.

[7] M. A. Mazidi, R. D. McKinlay and D. Causey, *PIC Microcontroller and Embedded System Using Assemble and C for PIC18*, Pearson Prentice Hall, 2008.

[8] C.-Y. Chen, C.-Y. Liu, C.-C. Chou and C.-T. Liu, Integrated application of the intelligent power control system, *ICIC Express Letter*, vol.9, no.2, pp.493-499, 2015.

[9] C.-Y. Chen and S.-Y. Huang, Integration of Modbus TCP and PLC using embedded gateway controller, *Journal of Cheng Shiu University*, vol.21, pp.17-34, 2008.

[10] MODICON, Inc., *Modicon Modbus Protocol Reference Guide*, PI-MBUS-300 Rev. J, 1996.