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Dr. Wei Zhan, Texas A&M University

Wei Zhan is an Assistant Professor of electronics engineering technology at Texas A&M University. Zhan earned his D.Sc. in systems science from Washington University, St. Louis, in 1991. From 1991 to 1995, he worked at University of California, San Diego, and Wayne State University. From 1995 to 2006, he worked in the automotive industry as a System Engineer. In 2006, he joined the electronics engineering yechnology faculty at Texas A&M. His research activities include control system theory and applications to industry, system engineering, robust design, modeling, simulation, quality control, and optimization.

Dr. Joseph A. Morgan, Texas A&M University

Joseph A. Morgan has more than 20 years of military and industry experience in electronics and telecommunications systems engineering. He joined the Engineering Technology and Industrial Distribution Department in 1989 and has served as the Program Director of the Electronics and Telecommunications programs and as the Associate Department Head for Operations. He received his B.S. degree in electrical engineering (1975) from California State University, Sacramento, and his M.S. (1980) and D.E. (1983) degrees in industrial engineering from Texas A&M University. His education and research interests include project management, innovation and entrepreneurship, and embedded product/system development.

Dr. Jay R. Porter, Texas A&M University

Jay R. Porter joined the Department of Engineering Technology and Industrial Distribution at Texas A&M University in 1998 and is currently the Program Director for the Electronics and Telecommunications programs. He received a B.S. degree in electrical engineering (1987), a M.S. degree in physics (1989), and a Ph.D. in electrical engineering (1993) from Texas A&M University. His areas of interest in research and education include product development, analog/RF electronics, instrumentation, and entrepreneurship.

Teaching Digital Communication using LabVIEW

Abstract

In response to the needs of the power industry, the Electronics Engineering Technology program at Texas A&M University has been revamping the instrumentation course to focus on digital instrumentation, in particular, digital communication protocols. Modbus was selected for its simplicity, open architecture, and wide use in industry as the communication protocol for two course projects in an instrumentation course.

LabVIEW was extensively used in the laboratory sessions, which better prepared students for the course projects. Two course projects were designed to familiarize the students with virtual instrumentation, data acquisition, Modbus communication, and simple closed loop control. One involved the instrumentation and control of a brushed DC permanent magnetic motor; the other involved the instrumentation and control of a small scale temperature chamber. Students used one computer, functioning as a Modbus slave, to measure the motor speed or temperature inside the chamber and to turn the motor or the light bulbs on and off. Another computer, functioning as a Modbus master, reads the measurements using Modbus communication protocol via RS-485 wires, compared the measurements to the set points, made control decisions, and sent the commands to the Modbus slave for actuation. Details of the course projects will be discussed in this article.

1. Introduction

As a practical discipline, engineering requires hands-on experience. There have been extensive discussions on the role of laboratory, and how to strike a balance between theory and practice[8]. Laboratories can be expensive and time consuming. Theoretic study can be difficult to understand, and boring. But, without the fundamental understanding of theories, laboratory work can become inefficient trial-and-errors. One of the solutions proposed by many scholars is to use tools such as LabVIEW throughout the engineering education programs.

LabVIEW (short for Laboratory Virtual Instrumentation Engineering Workbench), developed by National Instruments (NI), is a data acquisition, instrumentation, and control programming tool widely used in industry. LabVIEW's graphical programming environment with many software features and hardware options is the main reason for its increasing popularity over the last two decades. Many engineers use LabVIEW for testing and rapid prototyping in their product development process. In higher education institutes, LabVIEW can be used to help students understand complex theories and make a connection to practical problems. Even though instrumentation is mainly a subject of electrical engineering, it is used in almost every engineering major. Many scholars have explored the various capabilities of LabVIEW in laboratory experimentation and data acquisition. The use of LabVIEW in the engineering curriculum for data acquisition, instrument, and control has been well documented. LabVIEW was used to teach Fourier transform[3], analog to digital converter[9], thermodynamics[11], vibration measurement[14], telephone line encoder and decoder[16], material testing[24], biomedical engineering[32], DSP[33], signals and systems[34], dynamic systems[5], and liquid level control[35]. It also has been used as a tool to teach engineering students introductory software programming[18,22], problem solving[12], and digital logic[25]. Many multidisciplinary courses and projects used LabVIEW as the data acquisition tool[10]. Porter *et al.*[26] used LabVIEW as a means to link simulation and laboratory experiments and as a tool for troubleshooting measurement systems. There were several implementations of LabVIEW remote panels and Runtime engine for remote access to laboratory through the Internet, for purposes such as distance education[2,13,23,29]. Naghedolfeizi *et al.*[19] conducted an intensive survey on the subject of web-enabled technologies, including LabVIEW, to build remote experiments. Arthur and Sexton[1] used LabVIEW to upgrade their energy laboratory. With LabVIEW, they were able to convert an old steam power plant and cooling tower into a state-of-the-art control system. Quinn discussed the use of LabVIEW to provide early, continuous and significant laboratory experiences for all engineering students throughout the freshman and sophomore years at Drexel University[28]. There were several other efforts made by scholars to incorporate LabVIEW into the entire curriculum[4,6,15,36]. Erwin *et al.*[7] proposed to use LabVIEW together with LEGO materials starting from kindergarten to graduate school. The conclusions from these articles were overwhelmingly positive. Students learned instrumentation concepts through hands-on experience using LabVIEW.

In response to the needs of industry, the Electronics Engineering Technology (EET) program at Texas A&M University is moving its focus towards product/system development. As part of this curriculum modification effort, the instrumentation course (ENTC359) has been revamped to focus on digital instrumentation[27]. A new course project was created to provide students with hands-on experience in digital communication protocol. The course project has four major components: a LabVIEW[20] based closed loop control system design using the Modbus[17] digital communication protocol; hardware design to replace the Modbus slave with a PCB; software design for the Modbus slave; and system integration. The focus of this article is on the first component, i.e., LabVIEW based closed loop control using Modbus communication protocol.

LabVIEW was chosen to be the tool for the course project because it can provide hands-on experiences for students, which is particularly important for engineering technology programs. Another reason for using LabVIEW was that it was being used by several other courses in the EET program, as part of the curriculum integration effort, LabVIEW was selected to be one of the software tools used throughout the entire curriculum.

Modbus is a serial digital communication protocol developed by Modicon in 1979[17]. It is simple, robust, and widely used in industry. As a result, it has become the de facto standard in industry. It is an open architecture with specifications freely accessible on the web. Other digital communication protocols were also considered with the limitation to open architectures. Foundation Fieldbus and DNP3 were among the candidates for the course projects. Even though they are both open architectures, users need to pay membership fees to obtain copies of the specifications. The actual implementation could be more complicated than Modbus. It was also found that the NI website had free Modbus modules for LabVIEW. All these contributed to the decision to use Modbus and LabVIEW in the course project. Modbus is an application layer messaging protocol that provides client/server communication.

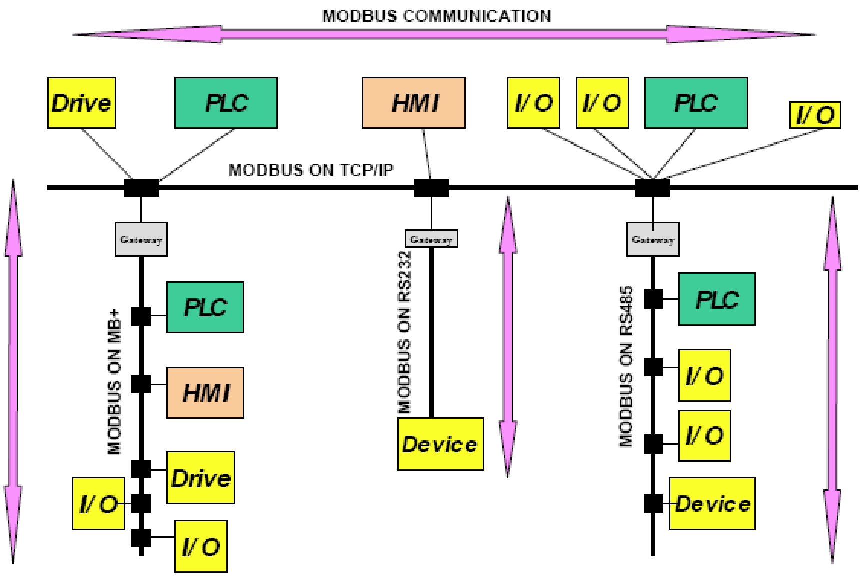


Figure 1. An example of Modbus network[17]

A typical Modbus network is showed in Fig. 1[17]. A Modbus serial line Protocol Data Unit (PDU) consists of address, function code, data, and CRC (or LRC) as shown in Fig. 2.

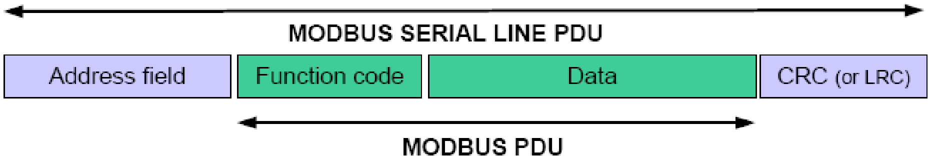


Figure 2. Modbus frame over serial line

The other components of the project, i.e, the hardware design, software design, and system integration were designed to familiarize students with the product/system development process.

The rest of the paper is organized as follows: Section 2 contains the details of the course projects; Section 3 contains the use of LabVIEW in the course projects and the laboratories before the projects; Section 4 contains the conclusions and future work.

2. Course projects

Inspired by the work of Arthur and Sexton[1], three old temperature chambers in good working condition were converted to a closed loop system using LabVIEW and a data acquisition card (DAQ). Fig. 3 shows one of the temperature chambers.

Figure 3. Temperature chamber

DC permanent magnetic motors are widely used in industry for their low cost, ease of control, and reliable performance[30]. They are also used successfully by other engineering educators[31] for curriculum improvement purposes. The motor principles can be explained in a straightforward way. Digital controllers, with software or hardware implementation, can be implemented to control the speed. They require instrumentation to measure the speed for closed loop control design. All these make the motor a good candidate for curriculum integration. Based on these considerations, several low cost motors, including the IG220019*00015R motor from Digilent, were tested as the common platform for vertical curriculum integration. In the spring semester of 2010, a motor control system, shown in Fig. 4, was added so that half of the class could work on the temperature control systems and the other half could work on the motor control systems.

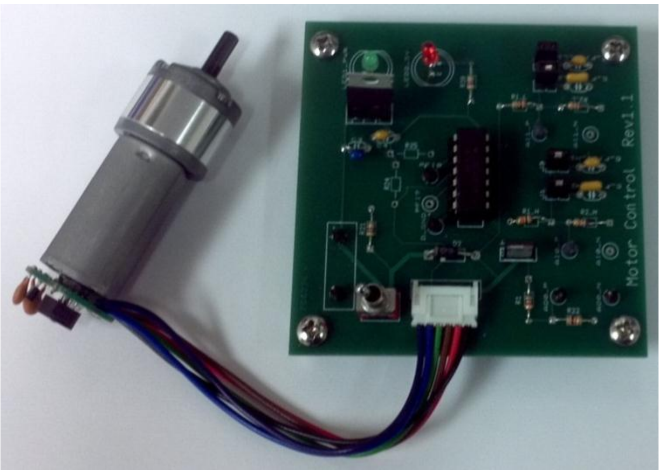


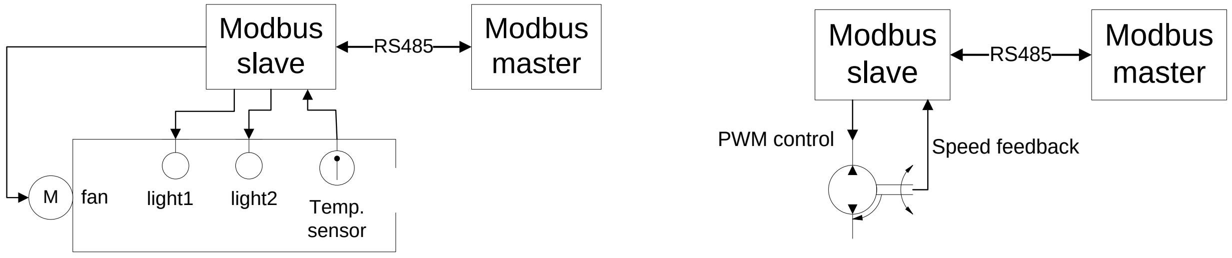
Figure 4. Motor control system

The addition of the motor control systems was based on the following reasons: there were only three temperature chambers, and teams sharing the temperature chambers had conflicts in using them; motor control was used in other courses of the EET program, thus contributing to the curriculum integration effort; The temperature chambers and motor control systems have different types of inputs and output, thus giving student more options to learn and gain hands-on experiences.

The setup of these two systems is illustrated in Fig. 5. For the temperature control system, a temperature chamber is provided. Inside the chamber, a temperature sensor circuit, consisting of a constant voltage potentiometer circuit, is installed, which allows the user to monitor the temperature inside the chamber. Two light bulbs can be turned on and off by sending digital signals to the switches. They can be used to increase the temperature inside the chamber. A fan, whose speed can be controlled by a DC permanent magnetic motor using PWM, is installed at one end of the chamber. The cooling rate can be adjusted by varying the motor speed. Both the lights, motor and temperature sensor circuit need to have external power sources, which are not shown in Fig. 5.

To develop a closed loop temperature control system, a LabVIEW VI needs to be created by students. The VI uses an analog input channel for temperature reading, two digital output channels for turning the light bulbs on and off, and a digital output channel for PWM control of the cooling fan. A DAQ card is provided for data acquisition.

For the motor speed control system, a DC PM brushed motor and a motor control board are provided. The motor has two terminals for power and an encoder for speed measurement. The motor control board allows the user to drive the motor with a PWM signal and read the encoder signal. A LabVIEW VI with a counter channel for encoder signal and a digital output channel for motor PWM needs to be created. A timed loop can be used to calculate the motor speed using the digital signal from the encoder. The motor also has an external power source, which is not shown in Fig. 5.



Temperature control

Motor speed control

Figure 5. Setups of the temperature chamber and motor control systems

The first stage of the course projects requires the students to use a NI DAQ (PCI-6251) to actuate the control (turn on the lights and PWM the motor) and read the feedback signals (voltage from the temperature sensor circuit and encoder from motor). The Modbus master and slave are ran on two separate desktops in the LabVIEW environment. The communication between the master and slave is through an RS-485 bus cable. The slave reads the desired temperature or motor speed every second from the master. The controllers reside in the slave VI. The feedback and actuation are done in the slave through the DAQ card. The slave also performs tasks such as digital filtering, conversion from voltage to temperature, and counting pulses for speed calculation. The slave sends the current output (temperature or motor speed) to the master. The master allows the user to set a profile, which the user specifies by defining the discrete points on the profile and connecting two adjacent point with a line segment as illustrated in Fig. 6. The profile can be the desired temperature or motor speed. Various graphical and numerical displays are also required on the front panel of the master and slave.

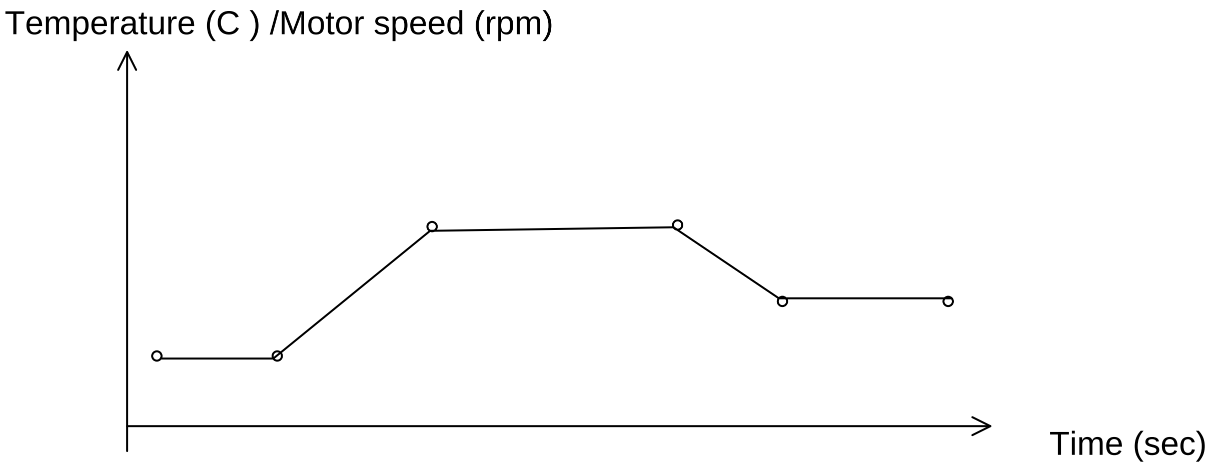


Figure 6. The temperature/speed profile created on the front panel of the master VI

After successfully implementing the LabVIEW based closed loop control systems, students then design a PCB to replace all the functionalities of the slave.

3. LabVIEW based closed loop control and laboratories lead to the projects

EET program at Texas A&M University uses LabVIEW in several courses: ENTC 359, ENTC 355, ENTC 352. ENTC was one of the first courses in which students were exposed to the LabVIEW software. Students then use LabVIEW in the other courses. The idea is through repeated exposure to LabVIEW in various courses students will master the software and be able to use it effectively to solve engineering problems. In ENTC 359, the basic concept of virtual instrumentation is taught followed by online LabVIEW training modules[21].

One of the issues we had with the ENTC 359 course project was that many student teams ran out of time for the course project[27]. To help students focus on the main topic of digital communication and product development process, the laboratories were revised so that students were better prepared for the course projects. Five laboratories were created in order to familiarize students with using LabVIEW to read analog and digital inputs and to send analog and digital outputs.

Lab 1: Online LabVIEW training[21]. Only the first six modules were used in ENTC 359: LabVIEW Environment; Passing Data and Debugging; Loops; Timing and Storing Data; Array, Clusters, and Text Based Nodes; and Variables.

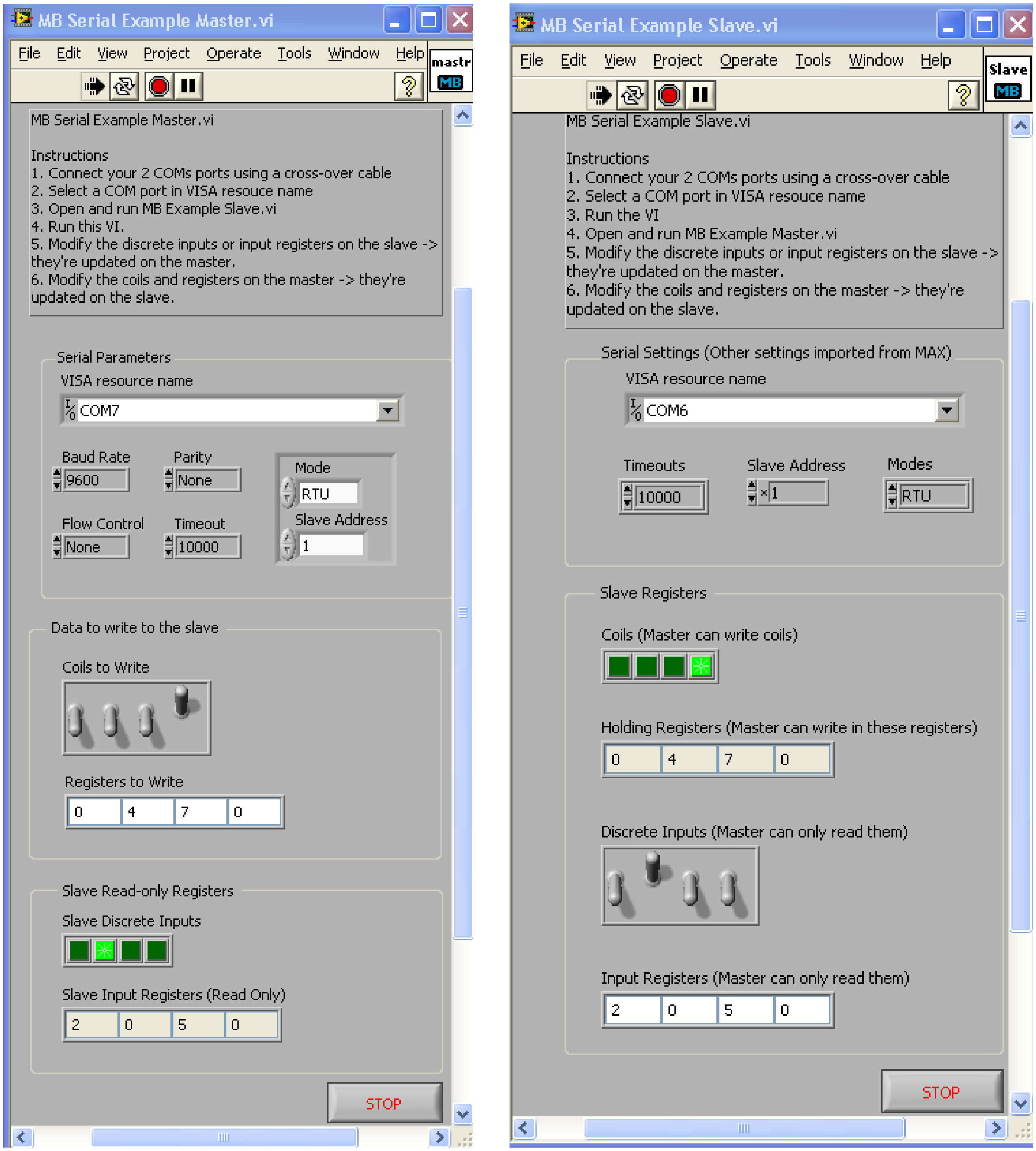
Lab 2: Data acquisition using LabVIEW DAQ: Analog input. A constant potentiometer circuit was used for temperature and light intensity measurements.

Lab 3: Using LabVIEW analog or digital output to turn a light on and off followed by combination with Lab 1 to use temperature or light intensity to turn the light on/off.

Lab 4: Develop a closed loop temperature control system with a single VI. A user defined temperature profile is part of the VI.

Lab 5: Develop a closed loop motor speed control system with a single VI. A user defined motor speed profile is part of the VI.

After these five labs, students were asked to download the Modbus master and slave VI from the NI website. Simple communication between two desktops can be established using the example VI, whose front panels are shown in Fig. 7. In the screen shoot captured in Fig. 7, the master had four coils and four registers. They have the values of “False, False, False, True” and “0,4,7,0”. These values were transmitted through an RS 485 communication bus to the slave and displayed on the front panel. The user also set the values for four discrete inputs and input registers to “False, True, False, False” and “2,0,5,0”. These values were also transmitted to the Modbus master. The NI Modbus module provided a basic platform for digital communication between the two computers. The students can then build a closed loop temperature or motor speed control system using this platform as a required task for the course project.



MB Serial Example Master.vi

Instructions
1. Connect your 2 COMs ports using a cross-over cable
2. Select a COM port in VISA resouce name
3. Open and run MB Example Slave.vi
4. Run this VI.
5. Modify the discrete inputs or input registers on the slave -> they're updated on the master.
6. Modify the coils and registers on the master -> they're updated on the slave.

Serial Parameters

VISA resource name: COM7

Baud Rate: 9600

Parity: None

Mode: RTU

Slave Address: 1

Flow Control: None

Timeout: 10000

Data to write to the slave

Coils to Write

Registers to Write: 0 4 7 0

Slave Read-only Registers

Slave Discrete Inputs: 🟩 🟩 🟩 🟩

Slave Input Registers (Read Only): 2 0 5 0

MB Serial Example Slave.vi

Instructions
1. Connect your 2 COMs ports using a cross-over cable
2. Select a COM port in VISA resouce name
3. Run the VI
4. Open and run MB Example Master.vi
5. Modify the discrete inputs or input registers on the slave -> they're updated on the master.
6. Modify the coils and registers on the master -> they're updated on the slave.

Serial Settings (Other settings imported from MAX)

VISA resource name: COM6

Timeouts: 10000

Slave Address: 1

Modes: RTU

Slave Registers

Coils (Master can write coils): 🟩 🟩 🟩 🟩

Holding Registers (Master can write in these registers): 0 4 7 0

Discrete Inputs (Master can only read them)

Input Registers (Master can only read them): 2 0 5 0

Figure 7. Modbus master and slave front panels

The Modbus master and slave VIs are not only a starting point for students to build their closed loop control systems, they are also a learning tool for Modbus. The details of forming the Modbus PDU can be added to the front panel. The output from the slave VI can be displayed in an oscilloscope, which allows students to understand the Modbus message down to single bits as illustrated in Fig. 8.

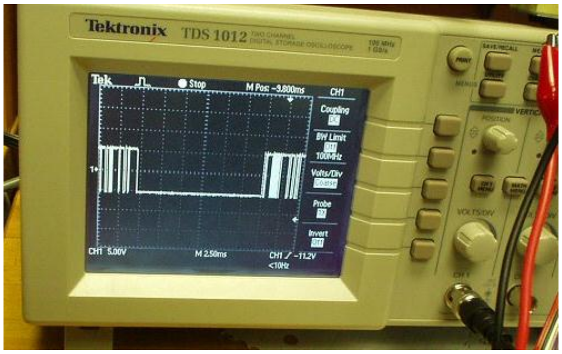
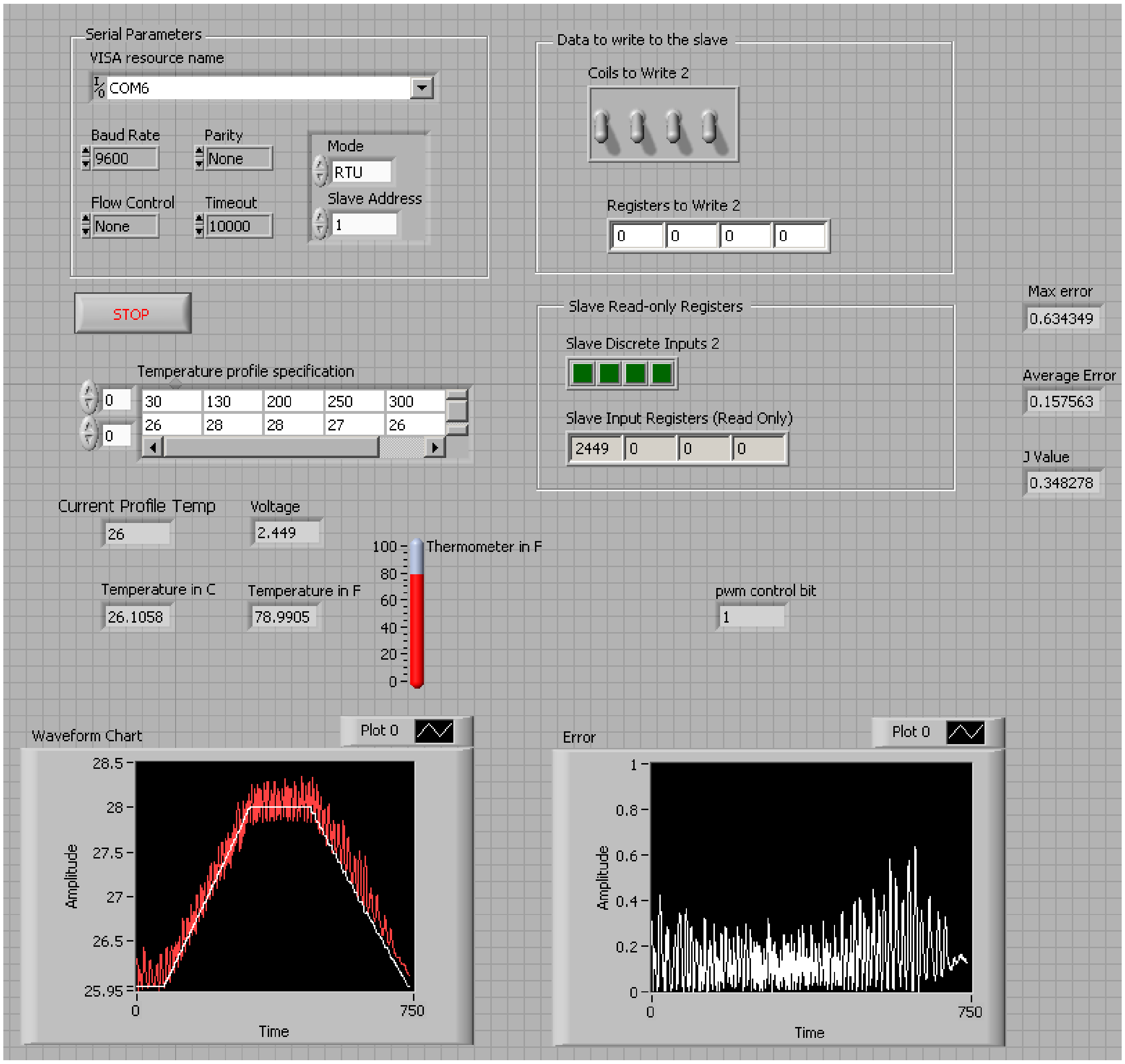


Figure 8. Modbus message captured with an oscilloscope

The front panel of a Modbus master VI created by a student team is shown in Fig. 9.


Serial Parameters
VISA resource name: COM6
Baud Rate: 9600
Parity: None
Mode: RTU
Flow Control: None
Timeout: 10000
Slave Address: 1

Data to write to the slave
Coils to Write 2
Registers to Write 2: 0 0 0 0

STOP

Max error: 0.634349
Average Error: 0.157563
J Value: 0.348278

Slave Read-only Registers
Slave Discrete Inputs 2: 🟩 🟩 🟩 🟩
Slave Input Registers (Read Only): 2449 0 0 0

Temperature profile specification

30	130	200	250	300
26	28	28	27	26

Current Profile Temp: 26
Voltage: 2.449
Temperature in C: 26.1058
Temperature in F: 78.9905
pwm control bit: 1

Figure 9. Front panel of a Modbus master VI created by a student team

The temperature profile (white trace) and the actual temperature (read trace) were plotted on the same chart. The error was also displayed on the front panel. The students taking ENTC 359 had not taken the Controls class, therefore their control algorithm was basically logics based on common sense. A typical control logic looks like this:

```
If temperature < desired temperature – 0.5 $^oC$
Then turn two light bulbs on and turn the fan motor off;
Else if temperature < desired temperature
Then turn one light bulb on and turn the fan motor off;
Else if temperature > desired temperature + 0.3 $^oC$
Then turn both light bulbs off and send a high PWM duty cycle to the fan motor;
Else turn both light bulbs off and send a low PWM duty cycle to the fan motor.
```

Some students also figured out how to avoid the flicking of the lights by adding a hysteresis to the control logic. It is planned as a part of the curriculum integration effort that the temperature or motor control systems be used in the laboratories of the subsequent Controls course, where PID control can be applied to the controller to further improve the result.

A software bug was identified for LabVIEW (version 2010 and older), where a local variable inside a case structure would not work as it was supposed to. This issue was reported to NI. Another issue with the LabVIEW Modbus was that the bus only allows one slave as opposed to multiple slaves. This prevented us from controlling both the temperature chamber and motor speed with one master and two slaves.

4. Conclusions and future work

A LabVIEW based Modbus communication project was created for an instrumentation course. Five laboratory classes were created to support the course project. Three small-scale temperature chambers were upgraded with the LabVIEW based data acquisition and control system. A DC permanent magnetic motor control system was developed to be an alternative course project. The two systems offer more options to students for learning different aspects of instrumentation. Students learned LabVIEW, data acquisition, instrumentation, and Modbus communication protocol in this project. It has become a core piece in the overall curriculum integration effort for the EET program at Texas A&M University.

After the successful completion of the LabVIEW based control systems, students were then tasked to design a printed circuit board, including a micro-controller on the board, to replace the LabVIEW-based Modbus slave. Instead of using National Instrumentation’s Data Acquisition Card (DAQ card), sensor circuits, signal conditioning circuits, and a micro-controller were used for data acquisition, Modbus communication, and controlling of the motor or light bulbs.

As an effort to continually improve our education program, the effectiveness of the course projects will be quantitatively and qualitatively monitored through student and faculty surveys, feedback from former students, and results of examinations. These results will be shared with other educators in a future publication.

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