

Wireless Digital Communication using LabVIEW and ZigBee

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Abstract

Electronic Instrumentation is one of the required courses in the curriculum of the Electronic Systems Engineering Technology program at Texas A&M University. The learning objectives of this course include: be able to design a virtual instrumentation system; be able to use a wireless module to communicate between two computers; be able to use a communication protocol for data transmission. Based on these learning objectives, faculty designed a series of laboratory sessions and a course project. LabVIEW was used extensively in the laboratory sessions to help students understand how virtual instrumentation works. LabVIEW was selected for two reasons: its diverse features for data acquisition, control, and flexibility in displaying data and its popularity in industry. Through using LabVIEW, students not only learn concepts in virtual instrumentation, they also acquire the skill of using a software package that many companies use. Wireless technologies are used more and more in our daily lives. Even though wireless communication is covered in another course in the program curriculum, it is crucial that students understand the importance of wireless communication in instrumentation systems. ZigBee was selected for use in the laboratories and course project for its simplicity and popularity in industry. Industry standards, open architecture, and wide use in industry were considered during the selection of communication protocol. As a result, Modbus was selected. A course project was then developed to provide students with an opportunity to create a virtual instrumentation system that utilizes closed loop motor speed control with two computers that communicate through ZigBee modules. The details of the labs and course project are discussed in this article.

Introduction

The Electronic Systems Engineering Technology (ESET) program at Texas A&M University is a four year BS program accredited by ABET ETAC. In response to the needs of industry, the ESET program is moving its focus towards product and system development¹⁴. As a part of this curriculum modification effort, the electronic instrumentation course (ESET 359) has been revamped to focus on digital instrumentation²¹. ESET 359 is a required course in the ESET program.

The learning objectives of ESET 359 include:

- be able to design a virtual instrumentation system;
- be able to use a wireless module to communicate between two computers; and
- be able to use a communication protocol for data transmission.

To achieve these learning objectives, a series of laboratory sessions and a course project were designed to reinforce the retention of the knowledge taught in lectures. To maximize the benefits, the software for virtual instrumentation, the wireless modules, and the communication protocol used in the laboratories exercises and a course project were carefully selected.

LabVIEW was selected as the software for virtual instrumentation for two reasons: its diverse features for data acquisition, control, and flexibility in displaying data and its popularity in industry. The use of LabVIEW in various engineering and engineering technology majors for data acquisition, instrument, and control has been well documented^{1,2,3,5,8,9,12,16,17,18,20}. The conclusions from these articles were that students learned instrumentation concepts best through hands-on experience using LabVIEW. LabVIEW is also used in product development in industry^{4,7,15}. By using LabVIEW in the laboratories, students not only learn the concepts in virtual instrumentation, they also acquire the skill of using a software package that many companies use.

Wireless technologies are used more and more in instrumentation systems and in our daily lives. Even though wireless communication is covered in another course in ESET program, it is crucial that students understand that wireless communication can be an important part of instrumentation systems. ZigBee was selected for use in the laboratories and course project for its simplicity to use and its popularity in industry^{6,13,19}.

For the selection of communication protocol, industry standard, open architecture, and wide use in industry were taken into consideration. As a result, Modbus¹⁰ was selected. A course project was developed to provide students an opportunity to create a virtual instrumentation system that utilizes closed loop motor speed control with two computers that communicate wirelessly through ZigBee modules.

An earlier attempt made by Zhan *et al.*²¹ was partially successful. Wired communication through RS 485 was used between two computers to control motor speed and temperature. A software bug was identified within LabVIEW (version 2010 and older), where a local variable inside a case structure would not work as intended. This software issue was reported to NI. Another issue with the LabVIEW Modbus was that the bus only allows one slave as opposed to multiple slaves. The labs and the course project were redesigned in order to overcome these problems and add the wireless component to the course project. This paper presents the redesigned labs and course project.

Laboratory exercises

Five laboratory exercises were completed before the students attempted the course project. Most of these laboratory exercises create the building blocks for the course project.

Lab 1: Basic LabVIEW training

In this lab, students first follow the self-paced training material posted on the NI website¹¹ to go through eight of the nine modules of Learn LabVIEW: LabVIEW Environment, Loops and Execution Structures, Data Types and Structures, Graphical Programming, Programming Tools, Debugging and Handling Errors, MathScript and Text-Based Programming, and Help Within LabVIEW. Module 8 (Signal Processing) was skipped since this lab was the first lab of the semester and students had not learned signal processing yet. After the Learn LabVIEW modules, students complete the two of the modules in Learn Data Acquisition: Connect to Hardware and Acquire and Generate Data. Some students had exposure to LabVIEW in other courses they took; these modules were mostly a review with some new material. For students who were completely new to LabVIEW, they may not have enough time to go through all the modules completely in the lab. They were required to start the following modules: LabVIEW Environment, Loops and Execution Structures, Data Types and Structures, before Lab 1. These only involve using of LabVIEW software and do not require data acquisition card, therefore students can complete these using their personal laptops. Free LabVIEW software was provided to students by the university.

Lab 2: Motor speed Open loop PWM control

In this lab, students build a VI for open loop motor PWM control. The pulses from the motor encoder are counted using a counter channel in NI data acquisition card (NI 6521). The motor speed is calculated based on the counter signal. A user input on the front panel of the VI specifies the PWM duty cycle. By manually changing the duty cycle, one can increase or decrease the motor speed. The motor speed is plotted on the front panel.

Lab 3: Closed loop control with constant desired speed as user input

Based on the VI developed in Lab 2, simple control logic is added to make the motor speed control system a closed loop system. The user input is now a desired speed instead of a duty cycle. The control logic takes the desired speed and the measured speed as the inputs and calculate the PWM duty cycle. The pseudo code is as follows:

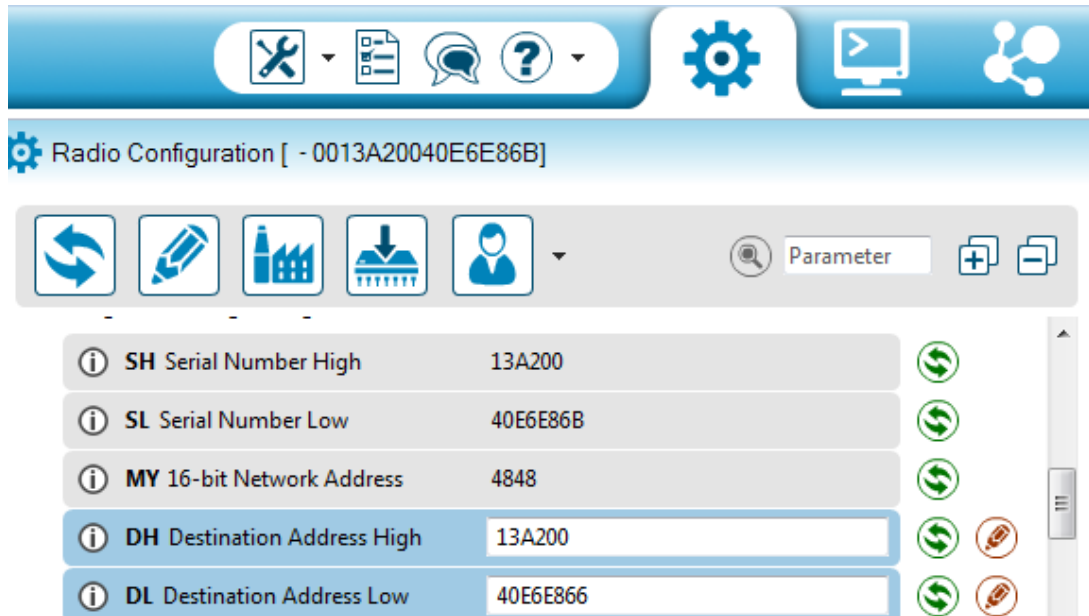
```
If desired_speed > measured_speed  
    {duty_cycle is increased by duty_cycle_increment_1}  
elseif desired_speed < measured_speed  
    {duty_cycle is decreased by duty_cycle_increment_2}  
else  
    {duty_cycle remains the same}
```

The two control parameters *duty_cycle_increment_1* and *duty_cycle_increment_2* are used to calibrate the controller so that the control error is minimized. This simple control logic is intuitive and does not require advanced knowledge of control system design. This course is a pre-requisite for control system course; therefore, students are not familiar with concept of proportional control.

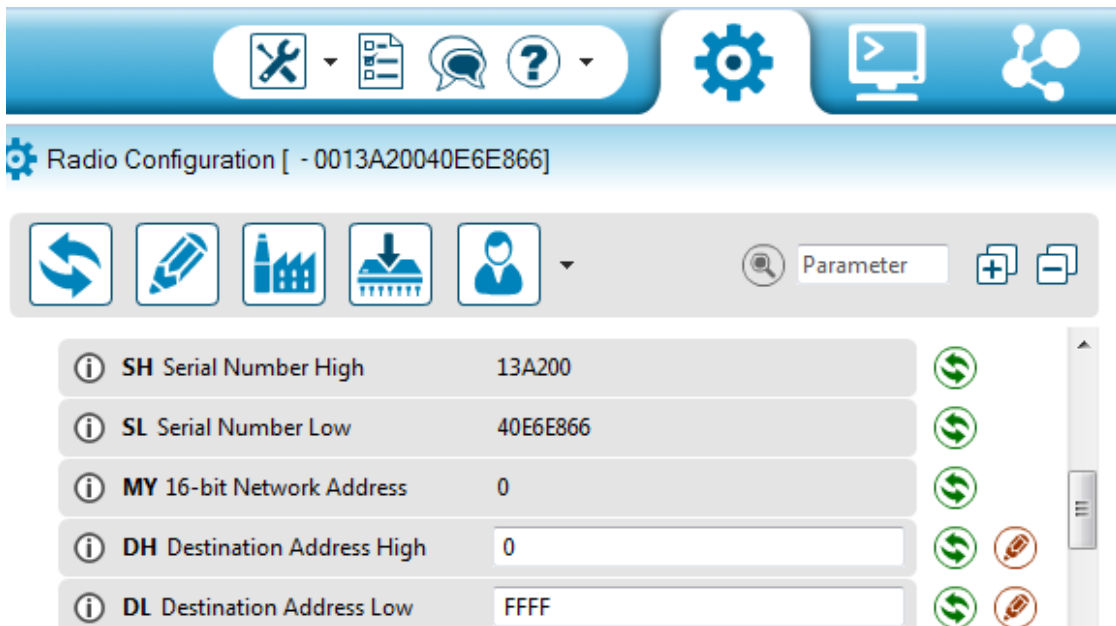
Lab 4: ZigBee set up and manual testing

This lab is designed to familiarize students with ZigBee modules. Each team receives two ZigBee radios. Students learn to use the free software X-CTU to set up the radios for wireless communication, as illustrated in Fig. 1. There are two settings to be used: One is two radios talking exclusively to each other. In this case, the radios are configured such that the Destination Address High/Low (DH/DL) of one radio is the Serial Number High/Low (SH/SL) of the other radio. The other setting is for one radio (coordinator) to communicate with multiple radios. In this case, the coordinator has 0 as DH and FFFF as DL, as shown in Fig. 1 (a, b).

A development module as a ZigBee to USB adaptor is provided for each radio so that students can use X-CTU and an USB serial port to send and receive message to/from the ZigBee radio. In this lab, all the messages are typed in by students in X-CTU.



(a)



(b)

Figure 1. XCTU for ZigBee configuration and testing

Range tests, as shown in Fig. 2, are performed to see how far the radios can be apart before communication drops out.

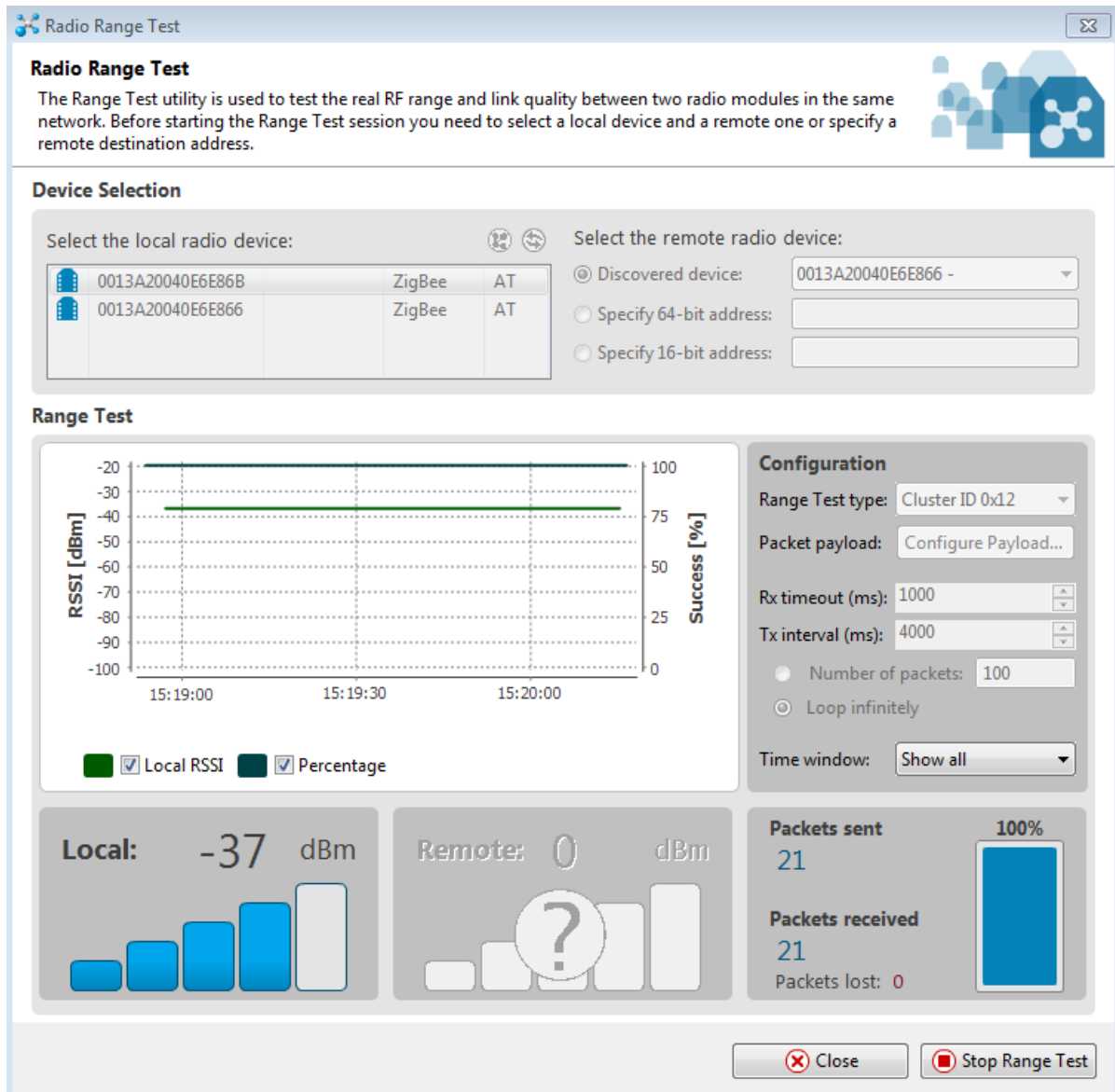


Figure 2. Range test for ZigBee radios

Lab 5: Transmitting motor speed using ZigBee via USB serial port

In this lab, students build a LabVIEW VI to send and receive messages through the USB serial port where the ZigBee radios are connected. The message is automatically generated by the VI with some variable that changes over time. The values for the variable is transmitted from one computer to another and plotted on the front panels. To reduce the number of computers used by the student teams, initial tests are conducted in the same computer using two different USB ports. Two types of ZigBee development modules, as shown in Fig. 3, were purchased from Sparkfun to allow communication between the ZigBee module and a PC via an USB ports. The Explorer USB can be directly inserted into a USB port of a computer. The Explorer Dongle

needs a USB to mini USB cable. After initial evaluation, both types were purchased, with each team given one of each Explorer. With the Explorer Dongle, there is no need for the USB to mini USB cable. However, for some computers, the size of the Explorer Dongle prevents two Dongles from being plugged in at the same time.

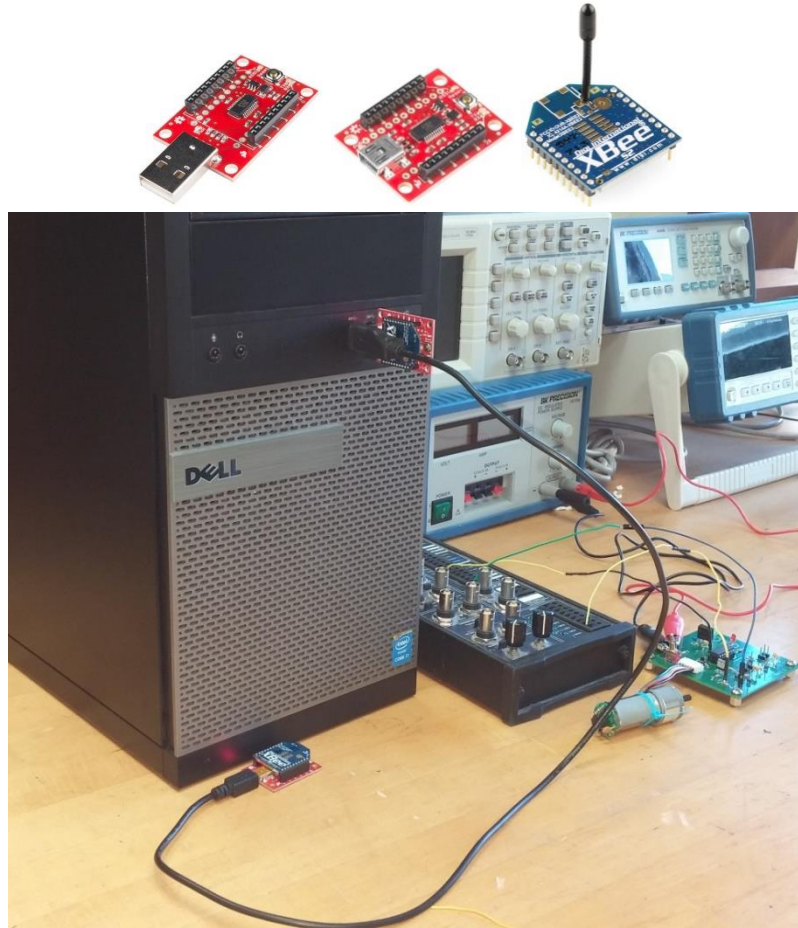


Figure 3. ZigBee module and Explorer USB/Dongle

Course project

The course project is to build a distributed control system (DCS) with a master, multiple slaves, and MODBUS communication between the master and slaves. Each slave has a closed loop motor speed controller. The desired speed for each slave is sent from the master to the slaves periodically. The measured speed for each motor is then sent back from the slave to the master. The communication between the master and the slaves takes place through ZigBee modules. The master and slaves reside in different desktop computers, where LabVIEW VIs are running to control the communication (for master and slaves) and the motor speed control (for slaves). The setup is illustrated in Fig. 4, where only two slaves are shown.

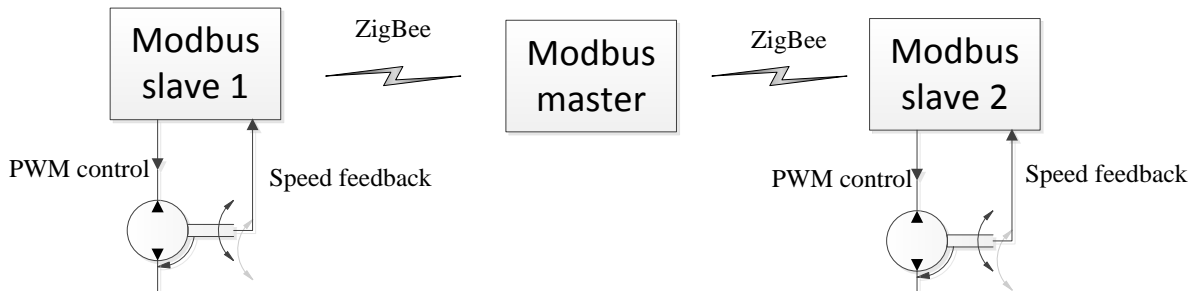


Figure 4. Motor speed control

The master contains the user interface, which allows the user to specify the motor speed profile for each motor. This is done by specifying the speed values at different times. As illustrated in Fig. 5, six coordinates (time, speed) are given and the speed profile is generated using linear interpolations. The speed profile and the measured speed for each slave are plotted on the same graph to illustrate how closely the measured speed follows the desired speed.

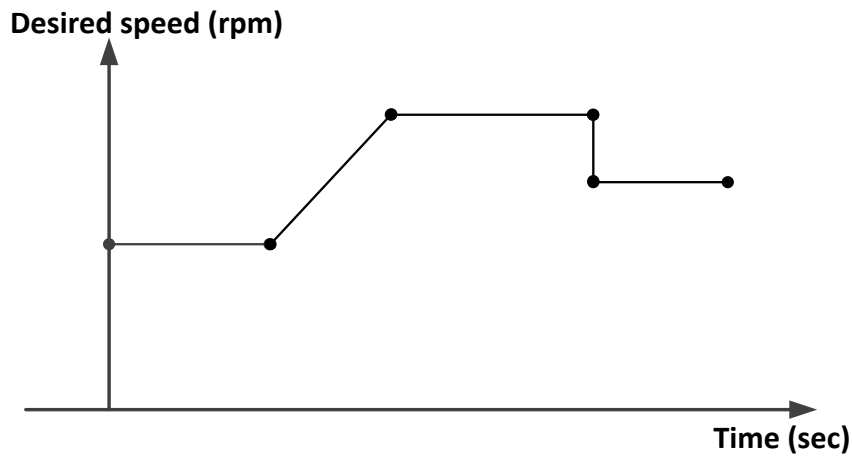


Figure 5. Motor speed control profile

An example of the front panel of the master is shown in Fig. 6. In addition to the speed profiles, the user of the master VI can select slave identifications, the serial port, and a baud rate. On the front panel of the slave VI, there are calibration parameters for the closed loop motor speed controller, a low pass digital filter, slave identifications, the serial port, and baud rate. The slave id and baud rate must match between the master and slave VIs, otherwise the slave will not respond to the requests given by the master. On both front panels of the master and slaves, the Modbus messages are displayed (not shown in Fig. 6).

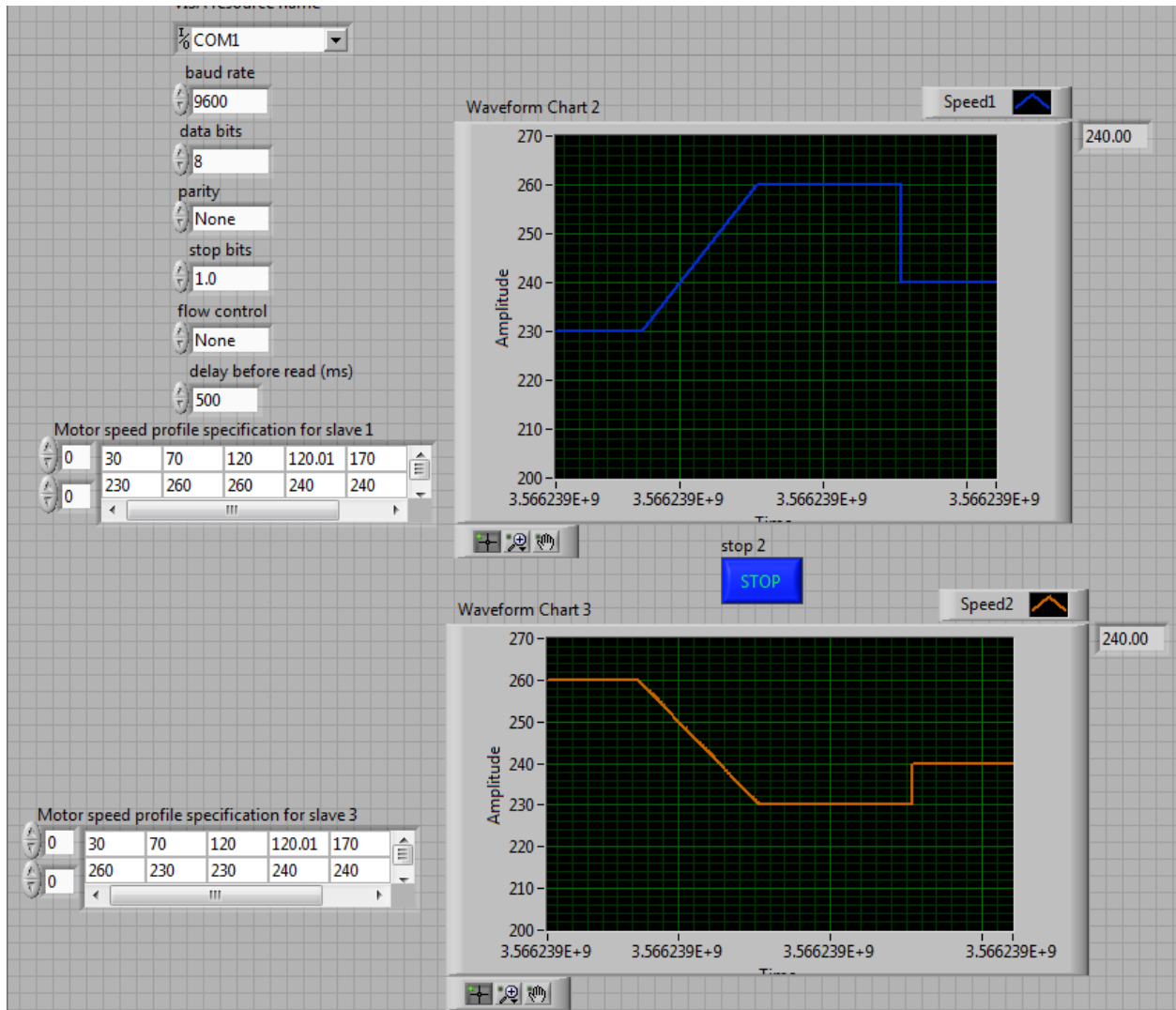


Fig. 6. Front panel of a Modbus master VI created by a student team (2 profiles, 2 slaves)

In the course project, the Modbus example provided by NI is not used because of the problems that arose with local variables inside a case structure and the use of multiple slaves. Thus, students were required to develop their own VI for Modbus communication. To reduce the work load, only the two function codes needed by the motor speed control were implemented. The multiple slave issue was avoided by using wireless communication.

Conclusions and future work

The revamped laboratories and course project provided students with opportunities to learn LabVIEW programming, configuration of ZigBee modules, closed loop motor PWM control, and Modbus communication protocol. Students gained hands-on experience in developing a DCS with virtual instrumentation. All five labs and the course projects have been implemented in

ESET 359. These do not involve change of learning objectives, lecture hours, lab hours, or course description, therefore, the changes can be done at course levels without approval from the higher levels.

Further enhancement of the laboratories and course project includes making slaves a microcontroller-based control system, as well as adding a light sensor and LED to form a closed loop control system that provides feedback in the form of analog signals. With the motor speed control project, there is one drawback, that is, all signals are digital. The addition of the light sensor adds the analog component to the DCS. Student learning will be evaluated through surveys as the laboratories and course project are finalized.

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