121st ASEE Annual Conference & Exposition
Indianapolis, IN
June 15-18, 2014
Paper ID #9272

RFID Reader System Project

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Abstract

As part of the requirements in a junior-level wireless communications course for an Electrical and Computer Engineering Technology program, students are required to design and implement an RFID reader system to record multiple tag IDs. This lab project utilized the ThingMagic M5e-C embedded RFID OEM module. This OEM module was mounted in a plastic enclosure box with an attached antenna and a flexible cable for I/O connections. A printed circuit board was designed to interface the assembly to a standard lab breadboard. The enclosure box, OEM module, PCB, and RFID tags were then provided to each student team. The overall objectives for this lab project included connecting a PC to the RFID module via RS-232 and designing LabVIEW software to control the module. The students were required to configure the RFID module, read 5 tag IDs (using the GEN2 protocol), store the tag IDs to a file on disk, and add header information to the file containing the students' names and a time & date stamp. A detailed listing of the command and response packets is provided, along with an example of the tag IDs. A summary of the contents of the student reference materials and the lab handout are also included. Assessment results showing grading statistics, lab report format, and grading rubric are provided. An example of a student's results for the project is shown, and recommendations are included to help ensure student success on the project.

Introduction to the Wireless Communications Systems Course

The wireless communications systems course is a junior-level course for Electrical and Computer Engineering Technology students, and it is required for students in the Electrical Engineering Technology option and one of several possible technical electives for students in the Computer Engineering Technology option. Course topics include wireless communications technology, transceivers, modulation techniques, serial communications, and applications which consist of Personal Area Networks (PAN) and radio frequency identification (RFID) systems. The students' background includes LabVIEW with data acquisition (DAQ) devices for the design of measurement systems[1-3]. Additionally, students complete a course on high-level programming applications of object-oriented and procedure-oriented languages for electrical and electronic problem solving.

The course is 3 credits and consists of 2 hours of lecture and 2 hours of lab per week. The lab content is designed to reinforce concepts discussed during lecture. Each lab is considered a design project since it contains a series of engineering requirements and takes either 2 or 3 weeks to complete, depending upon the scope of the project. Each project is completed by a student team that consists of no more than 2 students (some students prefer to work by themselves). Students pick their team members at the beginning of the semester.

For nearly all of the projects, students are expected to work outside of the scheduled lab time in order to complete the objectives. The grading rubric for each lab project is shown in Table 1. There is a 5% reduction per day for late lab report submittals.

Table 1. Lab Project Grading Rubric.

Items for Consideration	Grade %
All the objectives of the lab assignment successfully completed with technically accurate results.	60
Content of lab report	30
Spelling, grammar, and writing style	10

A listing of the projects for the course is shown in Table 2. During the last three weeks of the semester, students complete the RFID reader system design project. The purpose of this paper is to describe the details about the RFID project.

Table 2. Lab Project Schedule.

Lab #	Lab Title	# of weeks to complete
Lab 1	Signal Generation & Spectrum Analysis	2 weeks
Lab 2	Filtering and Digital Graphic Equalizer Design	2 weeks
Lab 3	Serial Communication for Voice Transmission	2 weeks
Lab 4	IR Telemetry System	2 weeks
Lab 5	Wireless Sensor Network	2 weeks
Lab 6	Bluetooth-Enabled Instant Messaging	2 weeks
Lab 7	RFID Reader System	3 weeks

RFID Reader System Design Project

The RFID reader system design project consisted of one laboratory exercise, and it was designed to be completed in three weeks. Just prior to this project, students were introduced to RFID technology, RFID standards, and product tagging during the lecture[4-5]. Earlier in the semester, serial communications and communications protocols were covered.

For the RFID project, each student team was provided an enclosure box that contained a ThingMagic M5e-C embedded RFID OEM module mounted to the bottom of the box, a flexible flat cable interfaced to a 12-pin 1mm pitch ZIF (zero insertion force) connector on the RFID module, and a half-wave dipole antenna mounted to the side of the box. Additionally, each team received a PCB with a surface mount ZIF connector interfaced to the same flexible flat cable and a 0.1" spacing header that can be used to mount the PCB directly onto a breadboard. An image of the enclosure box, RFID module, and PCB is shown in Figure 1.

In order for students to be successful, the lab handout consisted of two sections: an exercise part and a software design part. The exercise part was designed to introduce students to the commands for manually controlling the RFID module. The software design section provided the detailed engineering requirements for the design project.

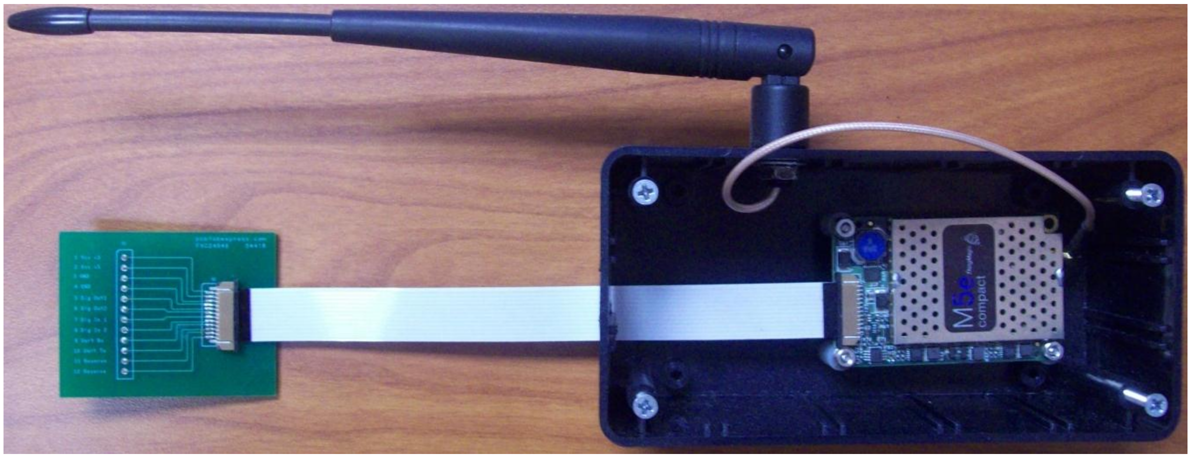

Figure 1. Enclosure Box, RFID Module, and PCB.

Exercise Section of the Lab Project Handout

For the exercise part of the lab project, the students interfaced the RFID module to the PC RS-232 port. This required them to design the hardware interface that would link the RFID module to the PC's RS-232 port. They referenced the developer’s guide for the RFID module to check the pin-out of the ZIF connector on the RFID module[6]. Then they used an RS-232 transmitter/receiver to convert between the proper voltage levels.

An executable LabVIEW RS-232 terminal program was provided which allowed them to send command packets to and receive response packets from the RFID module. Each packet contained HEX values for the data length, command OpCode, and CRC-16 character. Each student team was given 5 squiggle RFID tags and asked to configure the RFID module for the region code and tag protocol, and to read the tag IDs. This portion of the lab could be considered a "spike" solution and allowed the students to verify their hardware interface as well as gain familiarity with the devices operation.

A response packet was sent from the RFID module for each command packet it received. Tables 3 and 4 show the configuration for the command and response packets.

Table 3. Format of Command Packet.

Header	**Data Length**	**Command**	**Data**	**CRC-16**
1-byte	1-byte	1-byte	0 to N bytes	2-bytes
Start of packet. Equal to 0xFF	Defines the number of bytes N (in HEX) in the data field of the packet	Command OpCode (in HEX)	Defines the data (in HEX) required for the command	Determined by CRC polynomial 0x1021. High byte is first.

Table 4. Format of Response Packet.

Header	Data Length	Command	Status Word	Data	CRC-16
1-byte	1-byte	1-byte	2-bytes	0 to M bytes	2-bytes
Start of packet. Equal to 0xFF	Defines the number of bytes M (in HEX) in the data field of the packet	OpCode of the previous command (in HEX) received	Status of the last command (in HEX). 0x0000 for no errors	Data (in HEX) returned in response to the command	Determined by CRC polynomial 0x1021. High byte is first.

Students referenced the developer's guide for the RFID module to determine the OpCode for each command. An executable LabVIEW program for determining the CRC-16 character was also provided to the students. Table 5 shows the commands and responses obtained by a student for configuring the RFID module to read one tag ID.

Table 5. Examples of Commands and Responses for Reading One Tag ID.

Command	Command OpCode in Hex	Total # of bytes in received packet (in decimal)	Status word in Hex	Data received in Hex (if any)	Received Packet CRC in Hex
Get Version	03	27	0000	0710 2300 0100 0003 2008 0620 0100 3769 0000 0010	1BE1
Boot Firmware	04	25	0000	0000 008F 5469 6C64 656E 4472 6976 6572 2E63	88DF
Set Region	97	7	0000		779E
Set Tag Protocol	93	7	0000		371A
Read Single tag	21	21	0000	E200 3412 DC03 0118 1503 9153	AAD0

Lastly, students configured the RFID module to read five tag IDs and recorded them in a table. Table 6 is an example of the results obtained by a student.

Table 6. Example of Five Tag IDs.

	12-byte Hex tag ID
Tag 1	E200 3412 DC03 0118 1503 9148
Tag 2	E200 3412 DC03 0118 1503 9149
Tag 3	E200 3412 DC03 0118 1503 9147
Tag 4	E200 3412 DC03 0118 1503 9153
Tag 5	E200 3412 DC03 0118 1503 9151

Software Design Section of the Lab Project Handout

For the software design part of the project, students needed to automatically send the command packets for configuring the RFID reader, display the response to each command, and use separate buttons for reading the tag IDs and storing them to disk. Detailed engineering requirements are listed below.

<u>User Interface Requirements:</u>

- One Boolean control (pushbutton) on the front panel to read all 5 tag IDs.
- One Boolean control (pushbutton) on the front panel to store all 5 tag IDs to disk, along with the students' names and a time and date stamp.
- One Boolean control (pushbutton) on the front panel to terminate the program.
- Text indicators displaying responses to all commands, and an additional text indicator displaying the 5 tag IDs.

<u>Functional Requirements:</u>

- Configure RFID reader by sending the following commands:
    - Get boot loader/firmware version
    - Boot firmware
    - Set current region to North America (region code 0x01)
    - Set current tag protocol to GEN2 (0x0005)
- Display response packets for all commands on the front panel by using string indicators set to display Hex values.
- Read all 5 tag IDs when a pushbutton is depressed on the front panel
- Create a text file containing all 5 tag IDs, students' names, and a time & date stamp when a pushbutton is depressed on the front panel

Deliverables:

- Soft copies of VI and all SubVIs
- Soft copy of lab report

Software Design for Project

For the software design, a state machine was used. Table 7 lists each state of the state machine, along with the function of each state.

Table 7. Project State Machine Design.

State	Function
Configure	Configures the RFID module by sending the command packets for the following commands: • Get boot loader/firmware version • Boot firmware • Set current region to North America (region code 0x01) • Set current tag protocol to GEN2 (0x0005) Additionally, data received for the response to each command is displayed.
Wait	Allows the program to re-loop until an input pushbutton (Read tags, Store tags, and Stop) has been depressed. When a pushbutton is depressed, the state machine transfers to the appropriate state.
Read Tag IDs	Sends command packets for the following commands: • Read tag ID multiple • Get tag ID buffer Additionally, data received for the response to each command is displayed, along with all of the tag IDs.
Store Tag IDs	All tag IDs are stored to disk, along with the students' names and a time & date stamp.

Figures 2 and 3 show screen shots of the front panel and a portion of the block diagram of a student's LabVIEW program. The front panel contains text indicators to display responses to the commands and the tag IDs, and it also shows the pushbuttons for reading and storing the tag IDs and for stopping the program. The block diagram shows the first frame of the Read Tags state, the 200mS scan time of the state machine, and scanning of the input pushbuttons to determine the next state for the state machine.

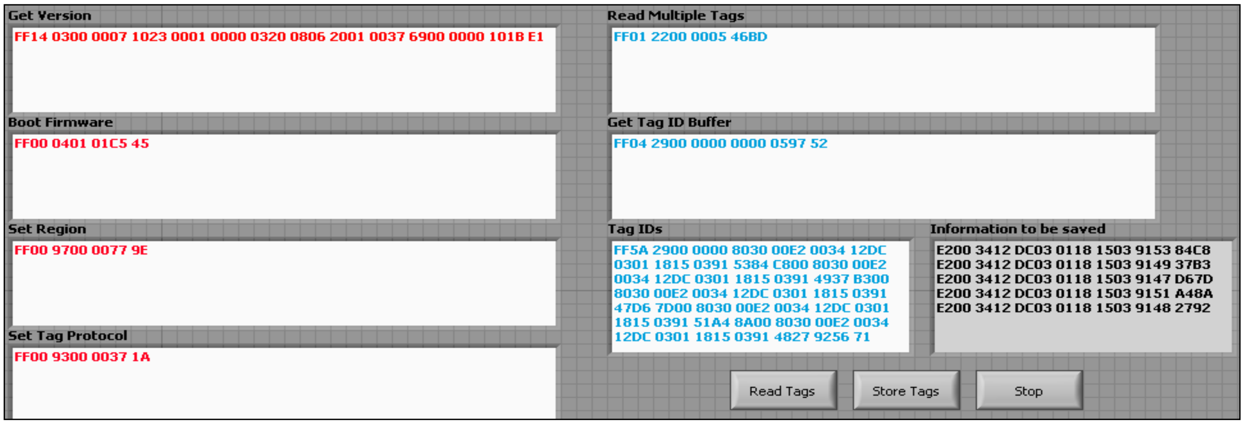

Figure 2. Screen Shot of LabVIEW Front Panel.

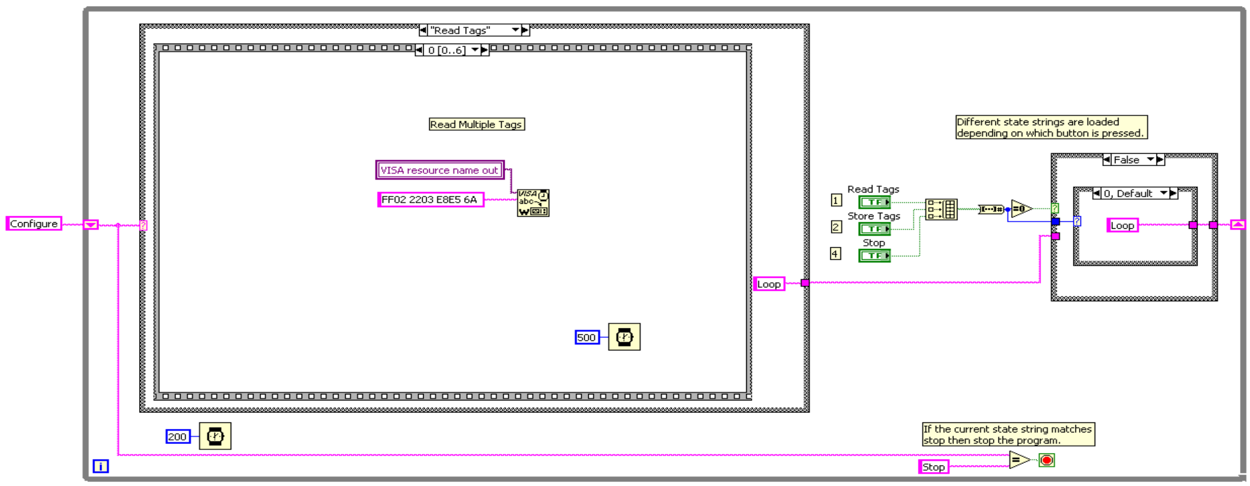

Figure 3. Screen Shot of LabVIEW Block Diagram.

Grading Assessment

As shown previously in Table 1, the content of the lab report is worth 30% of the overall lab project grade. The lab report format for Lab Projects 1-5 from the previously shown Table 2 is a detailed executive summary containing:

- Detailed summary of the design
- Detailed summary of the results
- Brief summary of what was learned from the lab experiment
- Attachment section containing theoretical formulas and calculations, measured results, simulation results, tables of results, and schematics

For Lab Projects 6-7, no executive summary is required. Instead, the lab report contains the following detailed items:

- Tables of all results
- Flowchart of the software design program
- Complete schematic
- Screen shots of LabVIEW front panel and block diagram windows

Table 8 shows the grading statistics for all of the lab projects during the spring 2012 semester. (There are no grading statistics shown for 2013, since the faculty member who has taught the course for many semesters was on sabbatical). Grades were recorded for all students participating in each lab project. Each student in the team received the same grade, and one lab report was provided per team. There were initially 8 student teams, but two students (1 team) stopped participating in the lab projects during the semester. Grades less than 70% generally indicate that the student team was unable to meet all of the engineering requirements for the lab. Grades greater than 100% indicate that the student team met all of the engineering requirements for the lab and received extra credit for significant additional work. Grades for Labs 6-7 are higher than for the previous labs primarily due to not requiring an executive summary.

Based on the grading for Lab 7:

- All of the students successfully completed all of the engineering requirements.
- All of the students were able to provide adequate project documentation.
- The average student grade was an A.
- The student grade distribution was:
    - 8 A (93% - 100%)
    - 4 A- (90% - 92.9%)
    - 2 B+ (87% - 89.9%)

Table 8. Grading Statistics for 2012 Lab Projects.

Lab #	Lab Title	Average Grade	High Grade	Low Grade
Lab 1	Signal Generation & Spectrum Analysis	87.0%	96%	65%
Lab 2	Filtering and Digital Graphic Equalizer Design	83.4%	94%	71%
Lab 3	Serial Communication for Voice Transmission	88.6%	95%	69%
Lab 4	IR Telemetry System	78.9%	89%	50%
Lab 5	Wireless Sensor Network	82.9%	95%	50%
Lab 6	Bluetooth-Enabled Instant Messaging	97.7%	105%	91%
Lab 7	RFID Reader System	94.1%	99%	89%

Table 9 shows the grading statistics for Lab 7 from 2009-2012. With the exception of 2009 (the first time this project was given to the students), the average, high, and low scores were very consistent with no score less than an 88%. During 2009, there were only 8 students (5 teams) participating on this project, and 2 students (1 team) received 53% since they did not successfully complete all of the engineering requirements.

Table 9. Grading Statistics for RFID Project from 2009-2012.

Year	Average Grade	High Grade	Low Grade
2009	83.1%	96%	53%
2010	91.7%	96%	88%
2011	95%	100%	89%
2012	94.1%	99%	89%

Conclusions

In this paper, an RFID reader system design project is shown for a junior-level wireless communications course. Details about the project handout, with the complete engineering requirements, are included. Hardware and software aspects of the project, an example of a student's results for both the exercise portion and software design portion of the project, and an assessment of grading statistics are presented.

Student performance on the project was very good. The exercise portion of the project allowed students to verify their hardware interface and the formatting requirements for the command and response packets for the RFID module. This was useful to help ensure student success on the software design portion of the project.

Recommendations

LabVIEW has been an excellent software development tool for implementing all of the course projects, including the RFID reader system design project discussed in this paper. However, prior to the start of the course, it is necessary that students will have learned programming techniques with LabVIEW, including the design of state machines. Prior to the start of the RFID reader system design project, students will need to have utilized LabVIEW for implementing serial communications and communication protocols.

There are several important aspects about the hardware required for this project. The RFID OEM module was the most costly part. To reduce costs, an educational discount along with a quantity discount may be available. Also, the PCB was necessary to allow the students to use a protoboard to interface to the RFID module. Other modules may be available that offer similar functionality with reduced costs.

Acknowledgement

We would like to thank Daniel Heise, a then junior in our program, who completed the RFID reader system design project and provided results from the exercise portion of the project and screen shots of the LabVIEW program for the software design portion of the project.

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