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Telemetry Project For An Introductory Communications Systems Course

Dr. Harold R Underwood, Messiah College

Dr. Underwood is an IEEE Senior Member with an Amateur Radio Extra Class license (KB3OOM). He received his Ph.D. in Electrical Engineering at the University of Illinois at Urbana-Champaign in 1989 and joined the faculty of the engineering Department at Messiah College in 1992. Besides teaching Communications Systems and other courses, he supervises undergraduate engineering students on credited work in the Integrated Projects Curriculum. His on-going project interests include improving flight tracking and messaging systems for small planes in remote locations and developing assistive communication technology for those with cognitive and behavioral challenges such as high-functioning autism or PTSD.

Telemetry Project

For an Introductory Communications Systems Course

Harold R. Underwood[1]

1 Associate Professor, Engineering Department at Messiah College, Mechanicsburg, PA

Abstract

Advances in electronic communications technology require corresponding innovations in the undergraduate electrical engineering curriculum. Recent trends include digital signals processed by code-controlled hardware, as in Software-Defined Radio (SDR) applications. Engineering educators often assign computer simulation exercises and/or lab work on communications topics preparing students for project-work later. However, sufficient background for a hands-on project with hardware and software elements in an introductory course remains a challenge. This paper addresses the challenge by reporting on a software-defined telemetry project recently deployed in a senior-level course for electrical engineering students. The project meets students at their level of preparation, requires an amount of work-time that fits within the limits of a one-semester course, and offers opportunities for creative extension. This paper identifies the project origin and motivation, including its structure and implementation in the course, and presents initial student feedback with lessons learned and ideas for future improvement.

Keywords

communications, project-based, telemetry, Software-Defined Radio (SDR)

Introduction

Communications technology has trended from analog to increasingly digital techniques, and from exclusively hardware to more software-oriented signal processing, supporting a range of wireless applications. Some examples include smart-phone data communication, wi-fi connectivity, flight navigation systems, and remote telemetry. Several recent ASEE papers describe how educators of electrical engineering (EE) and engineering technology (EET) attempt to meet the challenge of preparing students for next steps in this field: an applied course combining software and hardware tools requiring minimal background[1], systems simulation approaches[2], exercises with a realistic signal database[3], full-fledged courses in Software-Defined Radio (SDR) including a range of options[4-6], an analog radiofrequency circuit & system design project[7], and a prefabricated hardware system with configurable blocks connected to model digital and analog techniques[8]. While each of these approaches has a certain advantage and intrinsic value, a communications engineering educator must choose among the alternatives, or a mix[1], considering several key factors of institutional context, such as student level (grad or undergrad), career track (e.g, EE or EET), anticipated student course background, and other critical resources (e.g., time and money) afforded by the instructor, course, curriculum and department.

The author teaches a communications systems (coms) course for senior level undergraduate EE students in the engineering department at Messiah College. These students usually have had most of the traditional course background including circuits, devices, electromagnetics, linear systems and possibly control systems, but occasionally a student may take one of the upper divisional courses concurrently with coms. Since the coms course is introductory, no room in the curriculum presently exists for a sequence allowing further advanced specialization. Further, the course has no official lab component assigned with it, meaning that any hands-on lab or project activity must be planned within the limits of expected student time spent outside of class and/or compensated by reduced lecture time in-class. Besides these constraints for coms, the instructor has other upper divisional EE courses to teach, including undergraduate project supervision, and typical requirements regarding educational scholarship and institutional service.

As a unique solution satisfying these constraints, and a work in progress, this paper reports on a telemetry/SDR project implemented in an introductory coms course during Fall 2017, with initial student feedback. This project exposes undergrad EE students at the senior level to some of the latest coms techniques, offers flexible opportunities for creative design, uses an Arduino variant (familiar to students) adaptable to other telemetry applications, and fits within reasonable limits of cost and time for this type of course. Furthermore, seeing the result of their working project demonstration excites students; temperature, humidity and intrusion data appear in the color display of the local receiver unit, as in Figure 1 below. Thus, the project displays a functional standalone telemetry coms system that helps students synthesize material throughout the course.

a) b)

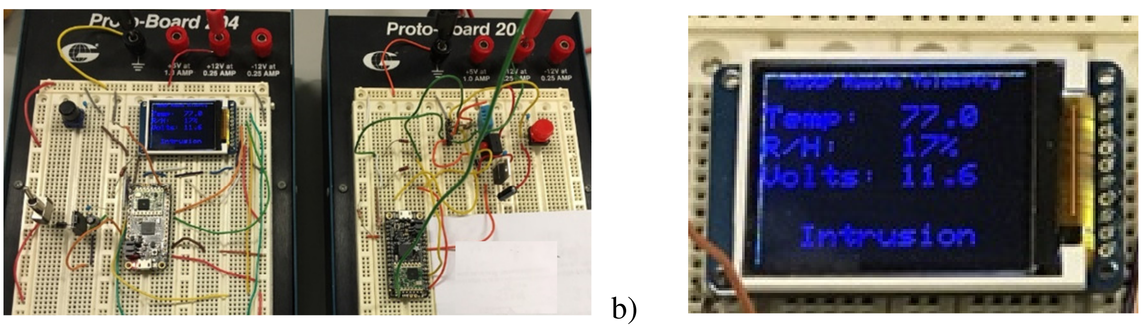

Figure 1: Telemetry system demo including a) local Tx (left)& remote Rx (right) units with b) magnified display unit

Methods: Curricular, Course & Project Parameters

The Communications Systems (coms) course offered in the engineering department at Messiah College is a 3-credit course required for all students in the Electrical concentration. The coms course has Electrical Devices as a prerequisite, which in turn requires Analog Electronics, Circuits I & II. So, these students have been exposed to basic DC/AC analog & digital circuits, and circuit applications including diodes, transistors and op amps such as amplifiers and filters. Linear Systems and Electromagnetics are recommended for coms but are not listed as required. Electrical concentration students must take Embedded Systems and Control Systems to graduate, and due to sequencing, typically have had Embedded, but may or may not yet have had Controls. Currently coms is offered only during the Fall semester. However, with the 2018/19 academic year, coms will likely be offered in the Spring semester, a more ideal place in the curriculum. Students taking coms during the spring of their senior year have the maximum benefit of applying other applicable courses in the curriculum, except perhaps for concurrent courses. As others have noted, a coms course offers excellent opportunities to synthesize subject material in several other areas of the electrical curriculum[5]. On the other hand, an introductory one-semester course does not have the luxury of delving very deeply into advanced topics.

Although students have learned some of the basic building blocks, they cannot be expected to be familiar with fundamental techniques of communications, as coms is a first introductory course. Thus, the course surveys the standard analog and digital coms emphasizing the use of essential functional blocks, and how they connect to achieve the desired goal. A top down approach is often utilized for identifying system design specifications. Topics include modulation, coding techniques, methods of information recovery, and assessment of critical performance. Frequency domain analysis includes signal bandwidth estimation, distortion and noise characterization. Transmitter and receiver designs are compared at the circuit and system levels. Emona TIMS[8] Biskit boards are utilized at key points during regular class time to further illustrate signal effects of functional blocks at each stage of the system. Currently as offered during the fall semester, the class is scheduled for three fifty-minute lectures per week. Outside of class, students are assigned four labs to do on an open-lab basis. These lab activities focus on using a spectrum analyzer to evaluate modulated signals and applying time domain reflectometry as a diagnostic technique. No more than four or five labs can be assigned during the semester, since as a three-credit course without an official lab component, time must be compensated out of lecture sessions to make up for the open-lab out of class activities. Students are assigned to work in groups on both the labs and the SDR telemetry project (worth 10% of the course grade), for collaboration, and to economize on the usage of limited equipment and project resources.

The concept of the SDR telemetry project implemented in the introductory coms course during the Fall 2017 semester was recently published[9] by radio amateur Glen Popiel. The system consists of one local unit using the Adafruit Feather 32U4 RFM95 LoRa as the receiver (Rx) interfaced with an ST7735 TFT Color LCD display, and one remote unit using an identical Adafruit Feather board as the 915 MHz GFSK transmitter (Tx), interfaced with temperature, humidity and intrusion sensors. Since the project was originally intended for radio amateurs, but with the expressed intent to allow for creative modifications, this author adapted the circuitry for the educational setting as a prototyped version instead of the original outdoor "field" application.

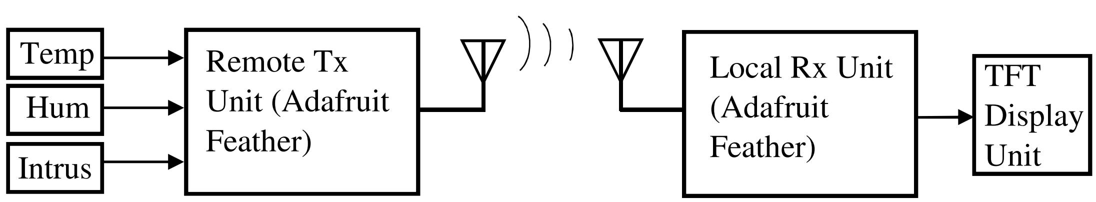

Figure 2: Block diagram of wireless telemetry system (remote & local units) interfaced with sensors and the TFT display

For example, the sensor cables were eliminated with short direct connections, antennas were replaced with a short piece of solid-core hookup wire, and the perf-board circuit assembly and housing substituted with a bread-boarded version on the Global Specialties Proto-board 204 including its built-in 12-volt supply (Figures 1 and 2 above). During the evaluation phase, to assess suitability of the project for student learning, the author assembled a complete prototype of the Remote and Local Units and uploaded the Arduino sketches to test the system for functionality.

To construct the evaluation prototype, the author followed published guidelines[9] and consulted with Glen Popiel to resolve several issues with the hardware circuitry and modified code to work with the TFT display unit acquired. In the end, the SDR telemetry system functioned as advertised.

A project prompt was developed including instructions and grading parameters for students to guide their completion of the project and associated report. The project prompt for students included an introduction, motivation, procedure, specifications for testing, and questions for discussion. Table 1 summarizes the general distribution of credit for grading purposes, with further details available from the author on request[10].

Table 1: Grade distribution for the telemetry project as assigned during Fall 2017

Description of Assigned Project Activity and/or Report Section	%age Points
Remote Tx Telemetry Unit Demo (data shows in the local Rx unit display)	30
Further Questions and Testing (details available from the author by request)	50
Proposal and Support for Creative Extensions / Modifications	20
Total	**100**

The thirteen students in the course were organized into four project teams, consisting of three groups of three, and one group of four students each. As a matter of practicality to meet time constraints, the instructor had students build the remote Tx unit only, upload Arduino existing sketches to the Adafruit feather boards, and once completed, test its functionality with the existing local Rx unit. Thus, the circuitry was distributed to each group, with links in Canvas to the required Arduino sketches and Libraries available online. Table 2 below shows the total cost at the time of this writing with a breakdown of the remote unit Tx hardware circuitry used in the educational version of this project. Other details of these project items are available on request.[10]

Table 2: Telemetry project circuitry, source and cost

Item	Vendor	Total Cost
Capacitors (2 x 0.1μF ceramic-50v, 1 x 10μF electrolytic-35v)	Mouser/DigiKey	$ 0.46
Resistors (2 x 10kΩ, 1 x 3.9kΩ, 1 x 1kΩ, all 1/8 W)	Mouser	$ 0.40
Diode (1 x 1N4001)	DigiKey	$ 0.11
Voltage Regulator (LM7805 +5 volt)	DigiKey	$ 0.83
Power Switch (1 x SPST push button latch-ON latch-OFF)	Adafruit	$ 1.76
Connector (6 pin mini DIN female chassis mount receptacle)	DigiKey	$ 3.19
Humidity/Temp Sensor (DHTll)	Mouser	$ 5.00
Intrusion Detect Switch (normally open push button type)	Adafruit	$ 5.95
Adafruit Feather 915 MHz Radio (32U4 RFM95 LoRa)	Mouser	$34.95
Total for Remote Tx Unit (per student project group)	see above	$52.65
Total for Local Rx Unit (one for test & demo purposes)	Various as above	$68.68

In the initial implementation of the project, students accessed the assignment prompt via Canvas and began working on the project with roughly three weeks remaining in the semester. Reasons for that timing include 1) digital communications material located in the second half of the semester, and 2) a draft of the prompt and procedure for students had not been created until then.

Students spent approximately three periods working on the project in class, and the remainder of the time completing the project with report outside of class.

Results: Student Achievement

Overall achievement of students on the SDR telemetry project in the introductory coms course seemed quite satisfactory considering it was the initial implementation. All four student groups eventually completed a successful working demonstration of the remote Tx telemetry unit communicating with the local Rx unit, as verified by sensor data appearing in the color display. However, prior to demonstration, one group "blew" an Adafruit feather-board by failing to sufficiently check and troubleshoot the power supply circuitry and related connections before turning on the power switch. Students performed the specified testing and answered the given questions about telemetry system adequately. For example, students explained GFSK modulation after some research, described and documented appearance of the 915 MHz signal on the spectrum analyzer, quantified average power draw of both Tx and Rx units, identified factors that would affect maximum wireless range, and compared SDR telemetry versus an exclusively hardware approach. Finally, for the report, students were asked to propose a creative extension to the project including their rationale for what applications it might have and who would benefit. Some suggestions for creative extension were given to students in the project prompt, but students could also suggest their own. Either way, students were instructed to be specific about their design modifications, and how they would implement them, using a circuit schematic, adjustments to the flow chart, and/or modified statements in the sketch. If possible, students were to implement and test their design modifications to provide "proof of concept." Grading of this part was based partly on how challenging the group's design proposal was, and partly on their plan for implementation, including any test results. Some groups suggested software modifications to the Arduino sketch, such as a warning to indicate a critical level of temperature, and others suggested hardware changes, such as an additional sensor or a reset for the intrusion detection on the remote unit end. Due to the time constraints for completing the project, the instructor generally accepted student proposals if they seemed feasible, although the level of support for implementation varied. Scores on the group reports in this initial implementation ranged from 93 to 98 percent.

Results: Student Feedback

Seven students out of the thirteen in the class responded to the telemetry project survey.

Table 3. Statements and corresponding student ratings on a Likert-type scale for the telemetry project

Statements	Likert Avg.
A. I enjoyed the experience of doing the project.	3.8 ± 0.4
B. I learned something from doing the project.	4.3 ± 0.5
C. The project involved an appropriate amount of creative design opportunity.	3.3 ± 1.2

The student feedback survey consisted of three statements for student response on a Likert-type scale (1 = Strongly Disagree, 2 = Somewhat Disagree, 3 = Undecided, 4 = Somewhat Agree, 5 = Strongly Agree), and four open-ended response items. Table 3 above shows the statements and the student response averages with standard deviation for the first three items.

Open-ended items involved statements for student response by completion, as shown in Table 4. The most frequent responses (3) to D were suggestions to the effect of including more class time to explore creative extensions or introducing the project earlier in the semester. Other ideas included "a little more involvement in the programming," clarified expectations on grading or detail expected in the creative extensions and having the Arduino libraries better defined. The most common response (3) to E was "how GFSK works" or "the type of modulation used". Other comments included how SDR differs from other forms of telemetry and applications of SDR / telemetry and "seeing the entire course's objective in a physical way…" Responses to F varied, but all mentioned something students enjoyed, such as "interplay of software and hardware", "that we could add the creative section to go beyond a regular lab", "brainstorming creative elements and physical assembly of the system" and "utilizing Arduinos since I use that for my project…" Finally, responses to G included the difficulty of having lab groups of more than 2 people, recommending all the necessary files be put in a zip folder, and introducing the project earlier.

Table 4. Statements for open-ended student response on the telemetry project

Statement	# of Responses
D. The project could have been improved by…	6
E. Something I learned from doing the project in this course is…	7
F. Something I enjoyed or did not enjoy about doing this project is…	6
G. Other comments or suggestions I have are…	3

Discussion, Conclusions and Future Work

While choosing pedagogy for an introductory communications systems course is not a trivial task, finding a project (such as the telemetry/SDR) that meets the constraints of the course is worth the effort. While implementation remains a work in progress, important lessons have been learned from the initial experience. The achievement of students was notable; even blowing a valuable Adafruit Feather board by student error results in a memorable lesson (i.e., it "pays" to verify the power supply and related connections beforehand)! Student feedback is very helpful to evaluate the success of the project toward educational objectives and identify ways to improve the experience going forward. Outcome of the Likert-type scale items suggest that on the average, all students at least somewhat enjoyed and learned from the project, even if they disagreed with each other on how much creative design opportunity it should include. The author agrees with the student suggestions to provide more time for work on the project and plans to introduce it earlier in the semester next time; earlier introduction would have been done the first time had it been possible. Open-ended responses of students on what they learned from the project confirm the author's intentions and encourage further attempts. Most notable is the student comment "The telemetry project was quite helpful for seeing the entire course's objective in a physical way. Before that time, all of our labs had not actually transmitted anything; we had simply looked at the details of something one could send." I encourage educators at other institutions to try either a version of this project or another that fits well within the constraints of your context, to experience some benefits of project-based learning, not the least of which is increased student satisfaction.

References

1 Aurenice Menezes Oliveira, "A Hands-On Course in Data Communications for Technologists," Proceedings of the American Society for Engineering Education (ASEE), ASEE, ASEE Annual Conference at San Antonio TX, 2012, pgs. 25.56.1-17.

2 Miguel Bazdresch, "Common Pitfalls in Communications Systems Simulation," Proceedings of the American Society for Engineering Education (ASEE), ASEE, ASEE Annual Conference at Indianapolis IN, 2014, 24.290.1-11.

3 Joseph Hoffbeck, Andrew Melton, "RF Signal Database for a Communications Systems Course," Proceedings of the American Society for Engineering Education (ASEE), ASEE, ASEE Annual Conference at Pittsburg PA, 2006, pgs. 11.1097.1-13.

4 Alexander Wyglinski, "Digital Communication Systems Education via Software-Defined Radio Experimentation," Proceedings of the American Society for Engineering Education (ASEE), ASEE, ASEE Annual Conference at Vancouver, B.C. Canada, 2011, pgs. 22.502.1-13.

5 Sven Bilen, "Implementing a Hands-On Course in Software-Defined Radio," Proceedings of the American Society for Engineering Education (ASEE), ASEE, ASEE Annual Conference at Pittsburg PA, 2006, pgs. 11.724.1-8.

6 Kurt VonEhr, William Neuson, Bruce Dunne, "Software Defined Radio: Choosing the Right System for Your Communications Course," Proceedings of the American Society for Engineering Education (ASEE), ASEE, ASEE Annual Conference at New Orleans LA, 2016, pgs. 1-19.

7 Stephen Frempong, "The Importance of Having a Critical Thinking Hands-On Project for Students in Electronic Communications Course," Proceedings of the American Society for Engineering Education (ASEE), ASEE, ASEE Annual Conference at New Orleans LA, 2016, pgs. 1-19.

8 Jiahui Song, Douglas Dow, "Using Telecommunication Instructional Modelling System (TIMS) in Communications Systems Course," Proceedings of the American Society for Engineering Education (ASEE), ASEE, ASEE Annual Conference at Columbus OH, 2017, pgs. 1-9.

9 Glen Popiel, More Arduino Projects for Ham Radio, ARRL, Newington CT, 2017, pgs. 14-1 to 14-31.

10 Harold Underwood, further information available on request at HUnderw@messiah.edu.

Harold Underwood

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