# Low-Cost Solutions for Wireless Communication Systems for Undergraduate Engineering Technology Students

Otilia Popescu
Old Dominion University, Norfolk, VA
opopescu@odu.edu

Vukica M. Jovanovic
Old Dominion University, Norfolk, VA
v2jovano@odu.edu

Ana M. Djuric
Wayne State University, Detroit, MI
ana.djuric2@wayne.edu

## Abstract

Training engineering technology students requires hands-on projects in addition to simulation-based experimentation performed using software packages like Matlab or Labview. The emergence of low-cost platforms such as Raspberry Pi or Arduino enables the use of free open-source code for experimentation and provides flexibility, resulting in projects with low overall costs. In this paper some applications of low-cost microprocessor platforms in the area of wireless communications will be discussed. These include a transmitter-receiver system using Raspberry Pi and software defined radio boards, along with a wireless sensor network with Arduino and Raspberry Pi processors. Additional applications discussed include low-cost control systems using wireless-enabled devices, which students can program using the Bluetooth interface of their smartphones. These platforms allow students to experiment with visual programming block languages to program different types of mobile devices. Having opportunities to use low-cost shared and customizable hardware platforms students can learn how to use various wireless technologies to create communication networks that integrate electrical and mechanical components as symbiotic parts of mechatronic (electro-mechanical) systems, and incorporate these designs in their capstone projects.

## Introduction

The use of low cost microcontrollers and single-board computers, such as the Arduino or the Raspberry Pi, has seen a significant increase in recent years, as demonstrated by the multitude of projects and education platforms based on them, as well as by the vast amount of published papers discussing their use, which will be briefly reviewed here. They are used in a wide range of applications by hobby groups and professionals, as well as by academic institutions, for both teaching and research projects. Aside from being affordable, an additional benefit is provided by the wide support available for their use through open source code libraries and online engineering communities and forums. This makes the learning of how to use microcontrollers a less daunting endeavor for novice users [1]. A parallel between different options for teaching robotics with technology, including Arduino and Raspberry Pi, is presented in [2]. Raspberry Pi, Arduino and BeagleBone Black processors are compared from an Internet of Things perspective in [3] and the analysis favors Raspberry Pi as the best choice in terms of price, features and performance.

A plethora of application examples is available in the literature, with different levels of complexity, coming from a variety of areas, such as environment monitoring, biomedical applications, or interfacing devices. In the first category we note the use of solar energy-powered sensors along with low-cost customizable devices that include an Arduino microcontroller and XBee communication modules [4 - 6]. A smart city application in which a Raspberry Pi and a ZigBee sensor network are used to control street lighting is presented in [7]. Medical applications of low-cost hardware platforms include numerous projects that use Arduino microcontrollers and Zigbee sensors to build affordable wireless sensor networks for collecting data or controlling biomedical devices. An example in this direction is a low cost retina-controlled device consisting of a head mount and a wrist tilt designed to assist people affected by paralysis using a computer or a smartphone [8]. Another biomedical application consists of a wireless sensor network for heart rate monitoring in sport training [9], which uses Arduino-Nano and XBee wireless modules to determine the intensity of a training session or race by measuring the heart rate. In vision research Arduino was used to generate a pulse-width modulation signal to control LEDs to provide linear light intensity control for light stimuli, an affordable application that offers flexibility for a wide range of research projects and for educational purposes [10]. Examples of applications for interfacing devices include the streaming live video feeds from a microscope to a remote location at different resolutions that can be selected by the user [11], an integrated home appliance control [12], wireless networks for mobile robot applications [13] and data acquisition systems [14]. Low-cost microcontrollers, such as Arduino, have both digital and analog inputs/outputs (I/O) which makes them ideal platforms for hosting multiple hybrid sensors for various physical quantities [1] as well as for controlling and coordinating actuators [4]. Additionally, Arduino and Raspberry Pi have been used to provide low-cost localization solutions in standalone applications [5, 15] or in conjunction with smartphones working with the iOS or Android communication protocols [11].

Different academic programs have been introducing in both lower and upper division classes low-cost hardware platforms such as those using the Arduino microcontroller and the Raspberry Pi computer. The SparkFun Inventor's Kit, which contains an Arduino microcontroller, has been used in an undergraduate computer science program in a sequence of courses designed to teach students embedded systems design and microcontroller programming, enabling them to apply computer science knowledge to solve real problems [16]. The same computer science program also introduced Arduino based projects in capstone design courses [17]. For mechanical engineering technology students the SparkFun Inventor's Kit was used in an Introduction to Mechatronics course where they had to work on assignments requiring Arduino programming in online setup labs [18]. An Arduino board and a Raspberry Pi running REX Control System were used along with Simulink for teaching control classes [19]. Arduino-based platforms were also used to teach embedded systems and robotics in [20] as well as wireless sensor network design in [21] as part of an introductory course about circuits and systems. In this latter application, the Arduino is used in conjunction with Zigduino, an antenna-embedded microcontroller board that adds wireless capabilities based on the IEEE 802.15.4 protocol. Both Arduino and Raspberry Pi can be used as teaching platforms for embedded systems and microcontroller programming courses since they have the software/hardware co-design possibility [22, 23]. Raspberry Pi is also considered as a choice for teaching emerging technologies such as the Internet of Things [24].

**Using Low-Cost Hardware Platforms in Electrical Engineering Technology Projects**

In the Engineering Technology Department at Old Dominion University, students pursuing the Electrical Engineering Technology (EET) track are required to complete a hands-on capstone project that consists of designing, building and demonstrating the operation of an electrical/electronic system. Recent projects use Arduino platforms along with sensors and XBee communication modules, which have become very affordable for the student budget, and for which a large library of open source software is available. As the community of Arduino users increases, Arduino-based projects became increasingly intriguing for the students, enabling them to showcase creative components in their designs. Technology students who want to specialize in communication systems can do so by taking a sequence of two technical elective courses, which introduce them to the concepts of frequency analysis, and teach principles of analog and digital modulation. However, while other courses and laboratories have hands-on projects, in these courses Matlab has been used for many years to study basic modulation/demodulation schemes through software simulations, and students had no opportunity to work on hands-on projects in the area of communication systems.

Recently the Raspberry Pi platform was introduced in hands-on communication projects for EET students. An example in this direction is using Raspberry Pi and software defined radio (SDR) platforms to implement a low-cost versatile communication system consisting of a short range radio transmitter with an associated receiver. A SDR consists of a field-programmable gate array (FPGA) core that works in conjunction with radio-frequency (RF) front-end modules and can act as transmitter/receiver for radio signal in various frequency bands. Programming, configuration and experimentation with SDR platforms require connection with a host computer. The use of desktop computers is preferred for heavy programming and development of SDR libraries while portable and embedded computers like the Raspberry Pi are favored for experimentation in indoor and outdoor setups.

Among the various SDR platforms available on the market, the Universal Software Radio Peripheral (USRP) developed by Ettus Research (a National Instruments company) has emerged as the leading choice for educational activities and academic projects [25], and was selected for this particular project. Specifically, two USRP1 boards powered by Altera Cyclone FPGA and featured with basic Tx/Rx daughterboards operating in the [1, 250] MHz band were used to set up a wireless link. A desktop computer was used to control the transmitter while a Raspberry Pi was used for the receiver, and the GNU Radio companion open source software was used to program both of them. The block diagram of the communication system implemented is presented in Figure 1 below. We note that the desktop and Raspberry Pi computers can interchange their roles in the transmitter receiver system, and that two Raspberry Pi computers can be used for added portability.

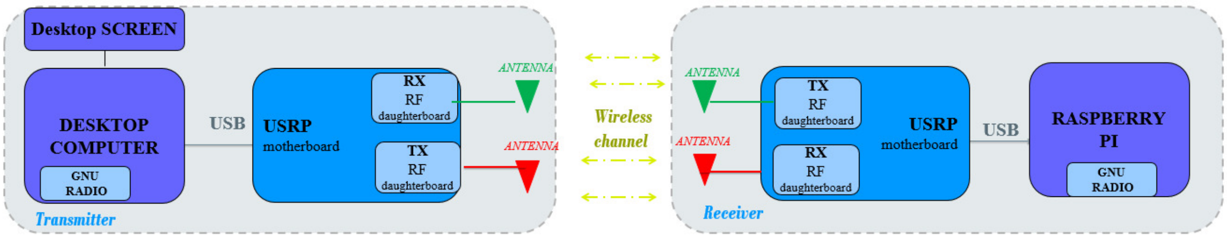


Figure 1: Block diagram of a Raspberry Pi and SDR Communication System

Using the GNU radio companion software students can program the transmitter USRP to generate and transmit a sinusoidal waveform. This signal is received by the second USRP board, which processes it to display the FFT of received signal. Once the system is proved to work with this simple signal, the next step is to perform experiments with more complex transmitted signals and different set-ups of the communication system. Different types of transmitted data as well as indoor/outdoor settings can be considered, and more complex experiments can be implemented that require more processing levels at both transmitter and receiver ends. Various modulation methods can be used, with modulation algorithms implemented on the Raspberry Pi computer and USPR boards, and their efficiency in specific environment settings can be tested.

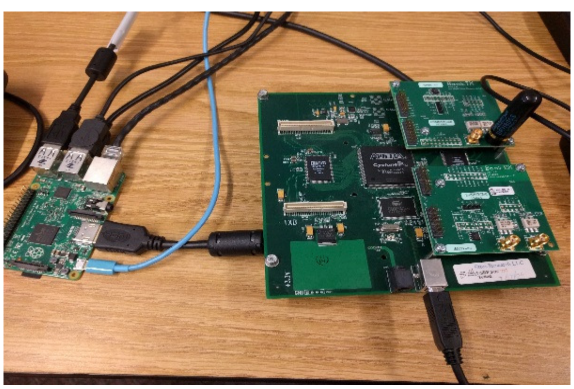

Figure 2: Raspberry Pi and SDR Receiver

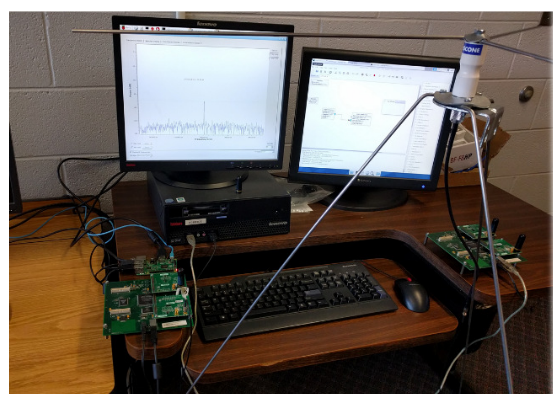

Figure3: The SDR Communication System

Figures 2 and 3 present the receiver and the complete system, with the desktop computer and the antenna. This implementation can be also used for class demonstrations or hands-on experiments associated with communication courses, as different modulation algorithms can be implemented in software and used with the SDR boards.

A second undergraduate project included the implementation of a wireless sensor network using an Arduino microcontroller to interface a sensors and a Raspberry Pi computer to gather the sensor data. Potential uses for this sensor network are in the context of a manufacturing line to monitor parameters of individual stations, in medical rooms, or in the cockpit of an aircraft or unmanned autonomous vehicle, where the need for miniaturization naturally leads to wireless collection and transmission of sensor data, or for some small projects such as a wireless fire alarm that uses a temperature sensor in the design. A block diagram of a wireless sensor data collection system is presented in Figure 4.

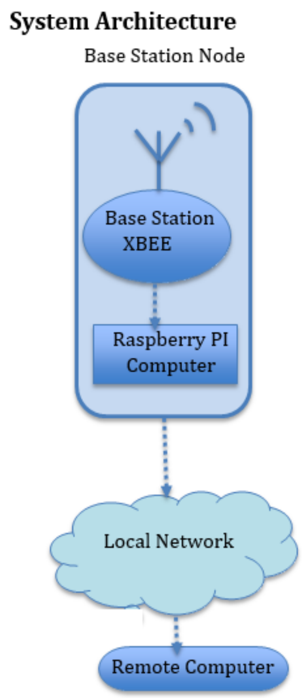


Figure 4: Wireless Sensor Network

The network implemented by students for this project included a remote sensor (for temperature or humidity) from which data was collected using the Arduino microcontroller and wirelessly transmitted to a Raspberry Pi computer. This was further connected to a local network over which the sensor data was transmitted to a remote computer for storage and processing. While Arduino and Raspberry Pi worked as main processors, the XBee ZigBee wireless transmitter/receiver modules were used as wireless radios.

**Using Low-Cost Hardware Platforms in Mechanical Engineering Technology Curriculum**

The Arduino microprocessor is used in Mechanical Engineering Technology program in the Introduction to Mechatronics course [14]. This course deals with the study of mechatronics concepts and their application to real problems encountered in engineering practice. It covers the basics of electromechanical systems, electrical circuits, solid-state devices, digital circuits and motors, all of which are fundamental to the understanding of mechatronic systems.

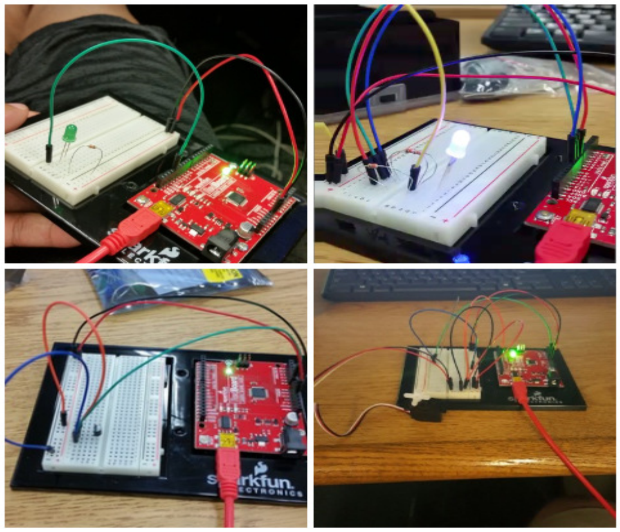


Figure 5: Example labs based on SparkFun Inventor's Kit which are based on Arduino platform

Among notable course objectives we mention focusing on electric circuits and components used in mechatronic systems, microcontroller programming and interfacing, and application of sensors and actuators in mechatronics. SparkFun Inventor's Kit with Arduino platform was used in labs associated with this course for hands-on projects.

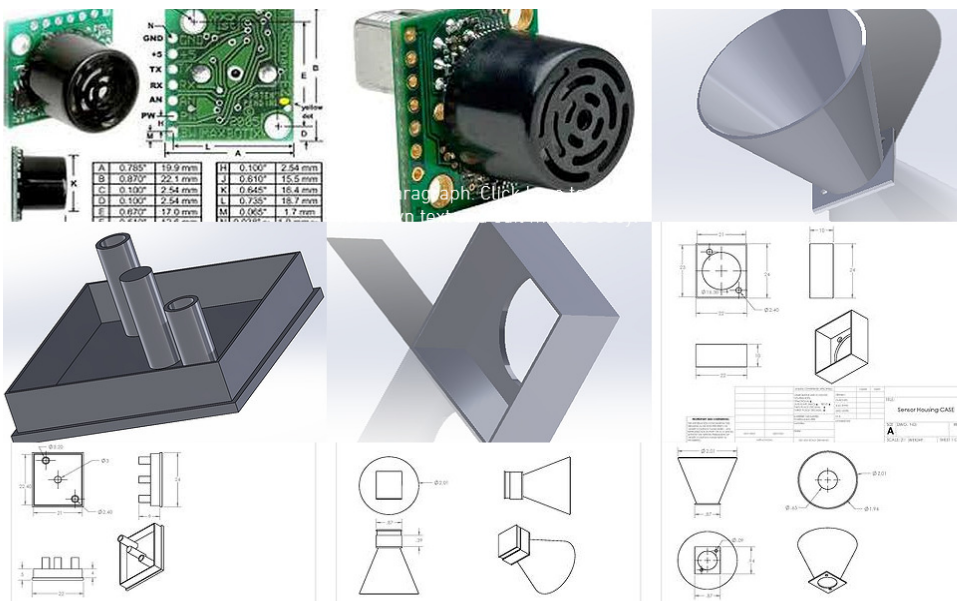

Figure 6: Example of the housing design for ultrasonic sensor controlled by Arduino

One such project on which students worked during this course was suggested by the Department of Physics in the College of Science. Ultrasonic sensors controlled by Arduino processors were used in studio labs where freshman students take Physics courses, and a housing design for these sensors was needed. A sturdy and efficient design was supposed to be printed on the rapid prototyping Makerbot printer. Students were able to compare their proposed solution with one of the solutions available on the market. For a specific sensor they were asked to work in teams to design housing with two degrees of freedom – two rotations necessary for positioning. With this project students integrated the study of processor controlled sensors with the design of mechanical components and the use of design/drawing software.

## Conclusion

Low cost hardware platforms are gaining popularity with students and instructors. As Arduino microcontrollers and Raspberry Pi processors secure more room within a diverse range of academic courses, from programming and embedded systems to communications and mechatronics, students became more confident in using knowledge and devices from their hobbies in actual classroom environment and vice versa. The availability of open source code contributes to the development of a wide community of users and helps to connect people with various backgrounds, from experts to experimentalists. Combinations of these low-cost hardware platforms with XBee communication modules and sensors opens the door to a vast area of applications, and facilitates the low cost wireless connectivity for a variety of processes such as those in machinery, physics experiments, biomedical systems, consumer related applications and so on. The same platforms can be used as instruments of teaching various courses, enabling integrated software and hardware learning environments, may be used to develop capstone projects in which students can show their creative side and apply their academic skills to projects related to their own interests, and can also be used for undergraduate research projects, empowering the students with portability, flexibility of design, and access to affordable hardware and software means.

## Biographies

OTILIA POPESCU is currently Assistant Professor of Electrical Engineering Technology, Frank Batten College of Engineering and Technology, Old Dominion University, Norfolk, Virginia. She received the Engineering Diploma from the Polytechnic Institute of Bucharest, Romania, and the PhD degree from Rutgers University, all in Electrical and Computer Engineering. In the past she has worked for the University of Texas at Dallas, University of Texas at San Antonio, Rutgers University, and Politehnica University of Bucharest. Her research interests are in the general areas of communication systems, control theory, and signal processing. Her research interest also includes engineering education. She is a Senior Member of the IEEE and serves as an Associate Editor for the IEEE Communications Letters. In addition, she is an active member of the technical program committee for several IEEE international conferences including GLOBECOM, ICC, and WCNC conferences.

VUKICA M. JOVANOVIC is currently serving as Assistant Professor of Mechanical Engineering Technology, Frank Batten College of Engineering and Technology, Old Dominion University, Norfolk, Virginia. She received her dipl.ing. and M.Sc. in Industrial Engineering from University of Novi Sad, Serbia, and a PhD in Technology from Purdue University. While at

Purdue she also worked as a PhD student in Center for Advanced Manufacturing, Product Lifecycle Management Center of Excellence. She is teaching classes in the area of mechatronics and computer aided engineering. Her research interests are: mechatronics, digital manufacturing, product lifecycle management, manufacturing systems, and engineering education.

ANA M. DJURIC is an Assistant Professor at Engineering Technology, Wayne State University, Detroit, Michigan. In 2007 Dr. Djuric received her PhD in Mechanical Engineering from University of Windsor. She also held M.A.Sc. from Industrial and Manufacturing Systems Engineering, University of Windsor, (1999). She teaches various courses in Mechanical and Manufacturing Engineering Technology. Her research area is in industrial robotics. She published over 50 journal and conference papers.

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