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An Undergraduate Independent Study Project on the Design of a Home Automation System Using Global System for Mobile Communication

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Abstract

This paper explores how to expose undergraduate students to topics in wireless communications through an independent study in the area of Global System for Mobile Communication (GSM) technology.

With a rigorous Electrical and Computer Engineering curriculum and not enough resources available such as having a dedicated research space, few opportunities exist at smaller teaching-focused institutions for an undergraduate student to experience technical research in an area of their interest. An independent study is an option for undergraduate students at York College of Pennsylvania (YCP) to gain and apply a deeper understanding of a content area that is not covered in-depth in any courses. It provides a student with the opportunity to apply their learning to a well-defined research project, to work closely with a faculty member within their discipline, and to gain academic credit for their work. The project is usually carried out independently without formal class meetings. An effective independent study is characterized by an increase in the individual student's responsibility and initiative in the learning process.

This paper will highlight the importance of undergraduate research and independent study opportunities. It will also describe the home automation system that was designed by a fourth-year electrical engineering undergraduate student at YCP during their semester-long independent study on Global System for Mobile Communication (GSM) technology. The system operates on a 2G communication network where the user sends a command via Small Message Service (SMS) on their mobile phone to a microcontroller which then does the corresponding action requested. Some of the functionality implemented into the system was the ability to control a three-way light bulb and provide the user with the temperature in a room. Through the process of investigating, designing, building, and testing the physical prototype, the student developed technical research abilities and also personal development skills that will benefit them in the future engineering career.

Introduction

Undergraduate research is a high-impact educational approach that can be used to enhance student engagement and enrich their active learning experiences [1, 2]. These research opportunities can be structured in a variety of ways where students can be working voluntarily unfunded, paid a stipend, or obtain course credits for participating. Although independent studies or for-credit research project options exist at many higher education institutions, they may not be utilized to the fullest by undergraduate students.

Currently, literature is limited on undergraduate research experiences in the engineering disciplines. This may be attributed to multiple factors such as a significant emphasis on mathematics and science in the first two years of engineering curriculum, a strictly sequential degree path, and a lack of flexibility in the program requirements [3].

The purpose of this work is to detail how a small teaching-focused four-year institution incorporates undergraduate research opportunities in its academic programs through the use of independent studies specifically in the Electrical & Computer Engineering discipline. This paper will emphasize the importance of undergraduate research opportunities and outline how independent studies are structured at York College of Pennsylvania (YCP). It will also describe the research work that was conducted by an undergraduate Electrical Engineering student at YCP during their independent study project in Spring 2020. The work focused on designing and prototyping a home automation system using Global System for Mobile Communication (GSM) technology.

Methods

Involvement in research opportunities allows undergraduate students exposure to technical research in a topic of their interest while working alongside their research mentor's expertise and interest. Students are introduced to open-ended problems that may have multiple solutions and may require a detailed, methodical approach to analyze the problem and arrive at a solution [3]. The research experiences can vary significantly from one student to another, and from one discipline to another. Research activities can include performing experimental work, assisting graduate students in their research, conducting a simulation study, completing tasks involving data collection and analysis, etc [3]. The student might be involved with all the steps or a few steps in the research process, depending on the scope of their project and the level of involvement of their research mentor.

Existing literature suggests that undergraduate research stimulates student enthusiasm in the subject matter, resulting in an enhancement of critical thinking skills and improvement of career awareness [4]. The perceived benefits of these experiences are not limited to only those students who pursue graduate degrees as there is also a noted improvement in skills associated with metacognitive development such as understanding of new content, gaining knowledge of the research process & techniques, ability to work independently, time-management and self-efficacy [1, 4, 5]. However possible challenges of managing students can also arise including difficulties with an unproductive student, a student being unable to complete the project on time, the open-endness of the project and excessive project complexity resulting in lack of student

motivation [3].

A common approach for an undergraduate student to obtain course credit while participating in research is through an independent study. An independent study can be a for-credit project allowing a student the opportunity to work more closely with a faculty member on a topic that is not usually covered in a regular course [6, 7]. In the engineering disciplines, independent studies have been used to support a faculty member's teaching [6, 8] and research obligations [6, 9, 10]. Some examples of this include a student helping in developing new course content or gathering data that a graduate student can then use in their thesis project. The author in [6] remarked that the experience of an independent study helped students feel that they are more than just a number and it can be a great opportunity for resume building while for the faculty member, they offer a way to become more effective by delegating work to competent individuals.

Throughout the independent study, the faculty supervisor may hold weekly meetings with the student to discuss the project progress as well as answer questions and clear up any misconceptions the student may have. These meetings provide an opportunity to discuss other avenues of inquiry to research further or experiment with. The student may also keep an online or physical project journal documenting the progress made and reflecting on the work completed. The faculty supervisor may choose to review the journal to provide feedback.

The rules and structure for an independent study vary widely with departments and institutions. They may be letter-graded or graded as pass/fail. Many institutions require a syllabus or a contract between the student and faculty supervisor with the contract required to specify deliverables. The student must understand the expectations of what the faculty supervisor will provide and what they will need to develop. Before the start of the project, the faculty supervisor must also determine if the student has the appropriate training and experience to carry out the project. Common assessments include weekly report out meetings and interim or final reports. Unlike in a regular course, there is no one to compare the student with and it is tough to predict what the outcome will be, and thus grading tends to be arbitrary.

At York College of Pennsylvania an independent study can be between 1-6 credits and has a prerequisite of a student having earned 60 or more credits and a minimum cumulative grade point average of 2.5 at the time of application. Most students usually reach these prerequisites after completing their second year of study. An independent study project typically spans one semester, a 15-16 week period, but it can be extended. The written application of the independent study has three main sections comprising of the learning objectives, learning activities, and evaluation format of the course. In the learning objectives section, it describes what the student hopes to learn from this experience. The learning activities explain in detail the proposal of the independent study. Lastly, in the evaluation section, the student describes how the faculty advisor will evaluate and assess the project. The student takes an active role in designing their learning outcomes and learning objectives with the advice of their faculty supervisor. This document can also serve as the learning contract between the student and the faculty supervisor. Once the application is completed it is submitted to the department chair for approval. The faculty supervisor also receives overload pay for taking on an independent study.

In a three-credit independent study in the engineering disciplines at YCP, the three main phases of the research process usually focused on are literature review, design, and implementation. In

determining the final grade it is an overall analysis of how well the student achieved the learning outcomes, documentation of work conducted throughout the semester, and completion of a final prototype.

The research and design stages of an independent study can be similar to that of an Engineering Capstone project however there are some key differences in the student experience. First, in an independent study, the student usually initiates the creation of the project to explore a topic of mutual interest with a faculty member. At smaller teaching-focused institutions, many advanced technical topics in a student's major are not covered in-depth and some students would like more experience in a particular area out of pure interest or to prepare themselves for a future career in that field. Secondly, the student is not part of a student design team and often works independently in unstructured work sessions to accomplish the project tasks. There is little faculty supervision and the student must be self-reliant and motivated to make progress in the project while also knowing when to ask for help. A third distinction is that the results of an independent study may result in novel preliminary findings that can contribute to new knowledge or original work. A capstone project is typically focused on application and the results obtained may not be original. Students may use an independent study as an opportunity to further their Senior Capstone project by finishing any additional work needed to conclude the project. These types of experiences are very similar to the typical Capstone project and are not the focus of this paper.

The next section will detail the work completed by a fourth-year Electrical Engineering undergraduate student at YCP during their independent study project. The independent study spanned one semester and was 3 credits.

Student Project Work and Results

Project Overview

Automation, as defined by the International Society of Automation, is the creation and application of technology to monitor and control the production and delivery of products and services [11]. Designing a process or system to operate automatically can reduce the number of laborious tasks that were typically required to be completed manually. Today automation systems are widely used in large-scale projects to control or assist with manufacturing equipment but other applications of automation include use in homes, banking, laboratory environments, or buildings. Utilizing wireless technologies in automation processes can further enhance and optimize how these systems operate [12].

A fourth-year Electrical Engineering undergraduate student at YCP designed and assembled a prototype of a home automation system using wireless technology during the Spring 2020 semester. The idea for the project was motivated by the student's desire to learn more about GSM technology and how to apply this type of communication network to an automation or control system. GSM technology is typically not a topic that is discussed in-depth in undergraduate wireless communications courses. The system operates by having the user send a command using Small Message Service (SMS) from a mobile phone through the 2G wireless network to communicate with an Arduino Uno microcontroller using the GSM protocol. The microcontroller will then do the corresponding action requested to control various appliances and/or adjust its setting. Figure 1 depicts the block diagram of this system.

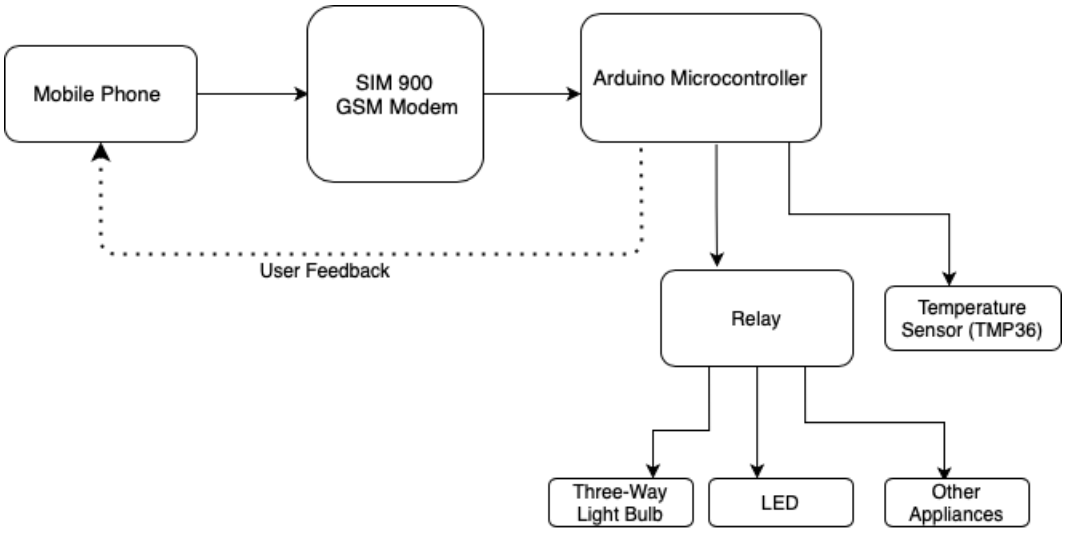


Figure 1: Block Diagram of System

Similar wireless network systems have been developed by undergraduate engineering students at other institutions [13, 14, 15] and more advanced systems using programmable logic controller also exist [16, 17]. An online repository for undergraduate research projects, including independent studies and Senior Capstone projects, is currently being developed at YCP. The work completed in this project, including the software code and other supporting materials, will be made accessible through this online repository.

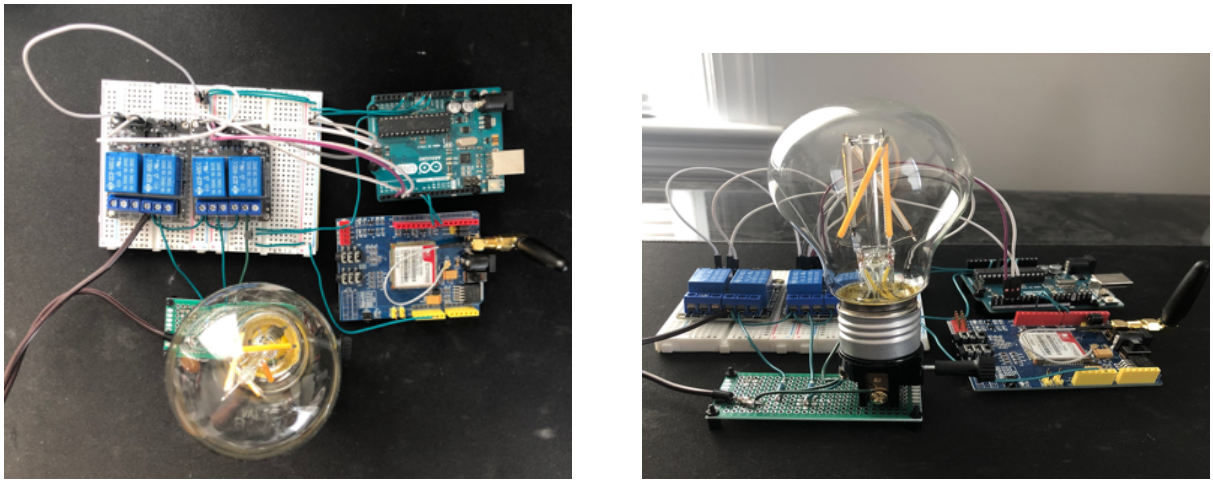
Hardware and Software Design

The SIM900 GSM/GPRS shield is a commonly used GSM modem [18] that is compatible with Arduino and can connect onto any global GSM network with any 2G SIM card. The GSM modem is capable of a baud rate between 1200-115200 bits per second (bps) so for this system, it was set to 9600 bps which is a typical rate for Arduino applications. However, when implementing functionality for both sending and receiving data, a higher baud rate of 19200 bps was used for the system to operate more efficiently.

The software code utilized ATtention (AT) commands [19] specific to the GSM technology including many SMS-related commands. The software code was separated into functions for modularity, readability, and interoperability. This transition minimally affects the performance of the system with less than a one-second delay. This also made the code more concise without repetitive statements and allowed for easy troubleshooting when implementing new functions. Delays were also added into the software code to allow the system to have time to process data preventing it from rejecting data while it was still processing previous information or from shutting down.

Before the communication process begins, the software code will verify the GSM modem is operational by checking the signal quality, if the SIM card in the modem is operational and if the SIM card is communicating with the GSM modem. Then the GSM modem is set to text mode and configured for all incoming messages to formatted in a specific structure so it can be read by the system.

At the start of the communication process, the user will send an SMS message from their cell phone to the corresponding number of the SIM card associated with the GSM modem. After the incoming data is available and read, then the software will search within the data for a registered statement. The current list of registered commands includes LED1_ON, LED1_OFF, LED2 _ON, LED2_OFF, TEMP, and HELP. If a registered command is successfully decoded, it will call a function corresponding to the command received. The function will then turn on or off the intended appliance using a relay or retrieve data from a sensor. The home appliances in the physical prototype were initially modeled using an LED since most appliances, such as a light bulb, TV, or wall outlet, operate using on/off functionality. Other ”appliances” later added to the system were a three-way light bulb, as seen in Figure 2, and a TMP36 temperature sensor.



(a) Top View

(b) Side View

Figure 2: Hardware layout of the system with the three-way light bulb

User feedback control was also added to the system to be able to offer a suggestion based on an input such as an unregistered command in the system, adjust a component such as a thermostat based on desired temperature readings and sensor data, and offer ”smart” options based on user data from previous day usage and sensor data. ”Smart” options may include powering on/off appliances based on the time it was most frequently used which could lead to power saving benefits. When the software code was set up to accept a Yes/No response from the user it was able to correctly complete the process associated with the registered command.

Further research was completed into using a better microprocessor and upgrading to a 3G GSM modem due to a reoccurring problem of the incoming data concatenating with previous data which limits the ability to manipulate the incoming data. However, due to time constraints of the project, the items were not implemented into the system.

Conclusion and Future Work

Undergraduate research opportunities made possible through independent studies enrich the learning experience for students. This paper detailed the importance of independent studies in undergraduate education and focused on the work completed by an undergraduate student at York

College of Pennsylvania in the application of GSM technology. Although the work completed did not produce any novel results the student was able to design and build a rudimentary prototype that could be improved in the future to contain more involved functionality. Implementing user feedback control with a better microprocessor and GSM modem will improve upon its ability to be applied to various appliances not currently included in the design by making the algorithm capable of higher-level computations. The work completed in this project could also be adapted to be used as a mini project or laboratory activity for an undergraduate wireless communications course.

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