



## Undergraduate Research-based Learning for Engineering Technology Students

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## **Abstract**

This paper presents undergraduate research experience for Electrical and Computer Engineering Technology students mentored by the author of this paper. Research projects in the areas of smart house systems and fault tolerant digital systems are presented. Results, including engaging strategies, challenges, lessons learned of the undergraduate research based learning are discussed.

## **I. Introduction**

The importance of involving undergraduate students in research-based learning is presented in a large number of publications and supported by organizations such as the Council on Undergraduate Research. Faculty members enhance their teaching and contribution to society by remaining active in research and by involving undergraduates in research, and students succeed in their studies and professional advancement through participation in undergraduate research [1]. The Boyer Commission suggested that research-based learning should become the standard for undergraduate education [2].

With the recent increased emphasis on applied learning activities, it is becoming more common for higher education institutions to include undergraduate students in research experiences both in and out of the classroom. Outside the classroom, many college, school and department-wide opportunities are available that promotes undergraduate research experience [3].

This paper presents undergraduate research experience for Electrical and Computer Engineering Technology students at Farmingdale State College. Research projects in the areas of smart house systems and fault tolerant digital systems developed over the past three academic years are presented. Students engaged in the area of smart house design worked on research projects focusing on: (i) efficient use of resources; (ii) authentication and security; (iii) safety; (iv) human interaction, developing intelligent and user friendly interfaces; (v) increased comfort and support for vulnerable people. Students engaged in in the area of digital systems designed and implemented fault tolerant digital systems using FPGA (Field Programmable Gate Arrays) technology and HDL (Hardware Description Languages). In their research students applied knowledge from the digital design, microcontrollers and technical elective courses.

The rest of the paper is organized as follows: Section II presents social aspects of engineering education and the rationale for selecting the research projects presented in this paper. Section III presents the characteristics of student population at Farmingdale State College. Section IV presents briefly students' research projects. Section V presents results of undergraduate research based learning. Section VI concludes the paper.

## II. Social Aspects of Engineering Education

Addressing the future of engineering and technological needs, higher education institutions face a great challenge. They have to build a strong technical curriculum and address the social consequences and implications of technological and engineering advances. Understanding the impact of engineering solutions in a global, economic, environmental, and societal context is an important objective supported by the Accreditation Board for Engineering and Technology [4].

In an article published in 1975, Toba was advocating the socially responsible engineering model as a profession [5]. Toba said engineering needed new minds that would combine science and human values to solve problems that technology might cause. Toba also stated that engineering was viewed negatively as a profession by the young people of the day and to change this perception, engineering needed to focus on social issues. In one of her presentations at ASEE conference and ECEDHA meeting, Leah H. Jamieson, past president of IEEE, presented data about the public perceptions of engineering which showed that engineering is viewed as a profession that creates economic growth but is not sensitive to social, environmental, and quality of life issues. While the data did not show a negative public perception, Jamieson presented irrefutable data that the public did not view engineering as a profession that was going to make a difference [6]. There is an extensive literature on the perception of the engineering discipline in general, such as [7-11]. Surveys of high school students show that engineering is perceived as a highly technical field that is not very multifaceted and has no connection to social issues. Even college students who left engineering stated that they wanted to take classes that allowed them to express opinions and views and not just learn theories and equations [11].

In order to attract high school graduates to engineering, it is necessary to portray the satisfaction and reward of engineering profession. Many of this generation want to make the *world a better place* but may not perceive that they can do this with engineering. In order to recruit them it is necessary to educate them on the social relevance of engineering and show them how technology enriches lives, help communities and make the planet a better place to live [12]. According to M. Hynes and J. Swenson, "*one group of people associated with engineering projects are those for whom engineers engineer for*" [13]. Engineered innovations have been paramount to the evolution of human society. Recent developments made possible by Internet technologies, such as Twitter, have provided means by which oppressed people can organize to protest their governments. The engineers and designers behind these developments may not have created their technologies specifically for such purposes, but, as in Twitter's case, they were aware that the real-time connecting of people and information was a breakthrough in the way people would share and receive information. Numerous other engineered innovations (e.g., electrical grids, the telephone, the automobile, the Internet, human genome sequencing, etc.)

have had tremendous societal implications that engineers in one way or another addressed in their work [13].

One way to integrate societal needs and challenges into the engineering curriculum is through research projects. At Farmingdale State College, faculty members are strongly encouraged to include undergraduate students in their research projects and strong institutional support is available through grants, mentorship, research stipend for faculty and students.

### **III. Characteristics of Student Population at Farmingdale State College**

Over 90 % of Farmingdale State College students are commuting on daily basis from the greater New York metropolitan area and they hold full time jobs. Around 35% are first-generation college students (e.g., neither parent has earned a 4- year degree), and 30% are minority. The student population includes large numbers of “New Americans” (i.e., they or their parents were born outside of the US). Many students have considerable financial need (with 30% receiving Pell grants). Distinctive characteristics and special needs of the “new normal” students who attend Farmingdale State College (and most American institutions) are presented in detail in reference [14]. One of the conclusion of the study regarding student population at Farmingdale State College is: *“to educate today’s new undergraduate student effectively, one needs to engage students in active, experiential learning”*, which is the focus of the pedagogy presented in this paper.

The Department of Electrical and Computer Engineering Technology at Farmingdale State College plays an important educational role in the region, attracting a large number of students from New York metropolitan area and region. The mission of the School of Engineering Technology is *“to promote the transmission, expansion, and application of technical knowledge through teaching, research, and community service”* [15].

### **IV. Research Projects**

The research projects presented in this paper were carefully selected based on the rationale presented in section II, and the characteristics of student population presented in section III. All projects were sponsored by the Provost Office, C-Step Program, Renewable Energy and Sustainability Center and Title III grant, proof of strong institutional support.

Students who were selected to work on these research projects were enrolled in undergraduate courses taught by the author of this paper. Interviews were conducted to select motivated and hardworking students. Each project required strong commitment from students and mentor. Students met during summer intersessions and weekends for instruction on new concepts and techniques. These working sessions provided students with technical knowledge and skills not covered in required undergraduate curriculum courses. Students received research stipends from C\_Step program or Title III grant. The high school student was selected through high school - college mentorship program.

## **Smart House Design**

Students engaged in the area of smart house design worked on research projects focusing on: (i) efficient use of resources; (ii) authentication and security; (iii) safety; (iv) human interaction, developing intelligent and user friendly interfaces; (v) increased comfort and support for vulnerable people. While the majority of the research papers dedicated to smart house design focusses on one or two of the research areas previously enumerated, the smart house system presented in the next paragraphs implements creative functions covering several areas of smart house research. Reference [16] presents in detail literature review on the existing systems and techniques used to design smart houses.

The first small scale prototype of the Smart House was designed and implemented in the summer of 2015 and during the academic year 2015-2016. Four undergraduate EET and CET students and a high school student were engaged in this research project.

The entire system is built around the Arduino platform. The local control is achieved through a keypad and a LCD display, while the remote control includes an Arduino Ethernet based micro web-server, and an Android based app, which can be used from any Android supported device. The system is affordable, user friendly and easy to adapt, allowing to add new devices and functions, without altering previously built functions. All the functions of the smart house were tested and are fully functional, proving the feasibility and effectiveness of the design. Figure 1 presents the prototype of the smart house, while Figure 2 presents the hardware modules.



Figure 1. Smart House Prototype

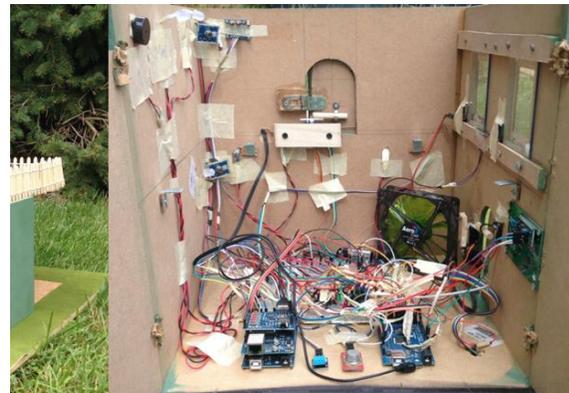


Figure 2. Hardware Modules

The functions of the house can be controlled locally or remotely as seen in Figure 3.



Figure 3. Local and Remote Control of the House

For local control, a display (LCD screen) and a keypad are the user's interactive interface. The LCD shows a menu indicating different areas of the house that are being monitored by the subsystem such as: first floor, second floor, balcony and garage. Every area of the house is allocated a sub-menu that displays the temperature, humidity, movement, light status, and fan speed for that specific location (rooms, garage). Each mentioned area has a character of the keypad assigned to it. In order to access a particular area, the user has to use the keypad and select that specific area. For remote control, the Arduino microcontroller uses an Arduino Ethernet shield module that behaves as an embedded server. A web graphical user interface was developed to allow remote control of different functions of the house. The GUI (Graphical User Interface) displays different areas of the house monitored by the subsystems previously mentioned. It displays temperature, movement, humidity. Currently the prototype is used for live demonstration during academic open houses and to raise public awareness regarding the advantages of an environmental friendly smart house as part of the mission of the Renewable Energy and Sustainability Center at Farmingdale State College [16].

The second prototype of the Smart House System was designed and implemented in the summer of 2016 and during the academic year 2016-2017. The project continues in the current academic year. Four undergraduate junior EET and CET students are engaged in this research project. Recently a graduate student, enrolled in the MS in Technology Management program at Farmingdale State College joined the team. Using his current industrial and previous undergraduate research experience, he is offering excellent mentorship and support to the undergraduate students.

The focus of the current project is the design of a smart house system fostering enhanced living experience for its inhabitants. Smart house research domain offers means for supporting special needs of people with disabilities Figure 4 presents the prototype of the smart house system, while Figure 5 presents the hardware modules. The entire system is built around the Arduino microcontroller platform and the following sub-systems were implemented: safety and security system, finger print scanner and door control system, elevator control system, and messaging system Figure 6 presents the finger print scanner and door control system.



Figure 4. Second Prototype of the Smart House

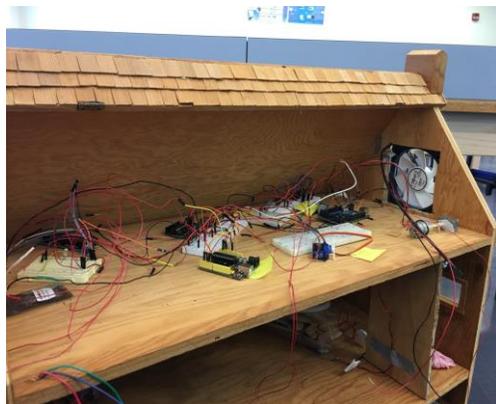


Figure 5. Hardware Modules

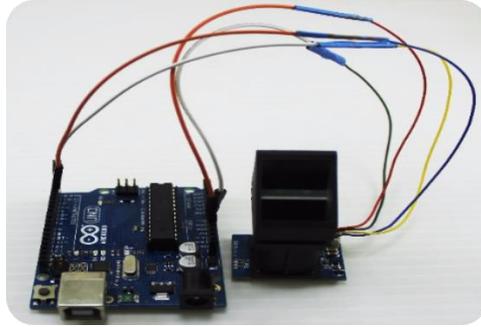


Figure 6. Finger Print Scanner and Door Control System

### **Fault Tolerant Digital Systems**

In the last decades, digital systems have been incorporated into commercial and military flight control systems, forcing designers to find new ways to improve the dependability of these systems. Dependability issues are becoming important also for ground applications due to the continuous increase in the integration level of systems and the occurrence of faults that can dramatically affect the behavior of the system. Novel mechanisms are required to increase the dependability of digital systems with respect to possible errors occurring during their normal function. Adding fault tolerance attributes to a system is one of these mechanisms. A fault tolerant system is a system that continues to perform its functions in spite of faults.

The proposed research focusses on the design and implementation of fault tolerant digital systems, using Nexys 3™ board based on Spartan-6 FPGA, manufactured by Digilent Inc. [17]. FSMs represent the “core” of digital systems. An errant Finite State Machine can cause considerable damage to the device it is controlling. Even a well-designed state machine can be subject to random errors. There are various ways to encode the states of a state machine, and the type of encoding makes a difference in the susceptibility of the state machine to faults, such as radiation. Various methods have been proposed to generate a fault-tolerant state-machine, one of them being through State Encoding (Binary, One-Hot, Hamming 2 and 3). The addition of fault tolerance requires more resources and the state machine will operate slower [18].

Three undergraduate EET and CET students were engaged in this research project during the academic year 2016-2017. The research continues in the academic year 2017-2018 and summer 2018, another team of students being involved. Students engaged in the first stage of the research project designed, simulated and implemented digital systems based on FSMs (controller for an elevator, vending machine, display). Different methods of state encoding for FSMs were investigated, area and hardware resources being compared. The focus was designing functional digital systems and understanding the concept of fault tolerant FSM through state encoding. Figure 7 presents the state diagram of a controller for an elevator.

## Elevator State Diagram

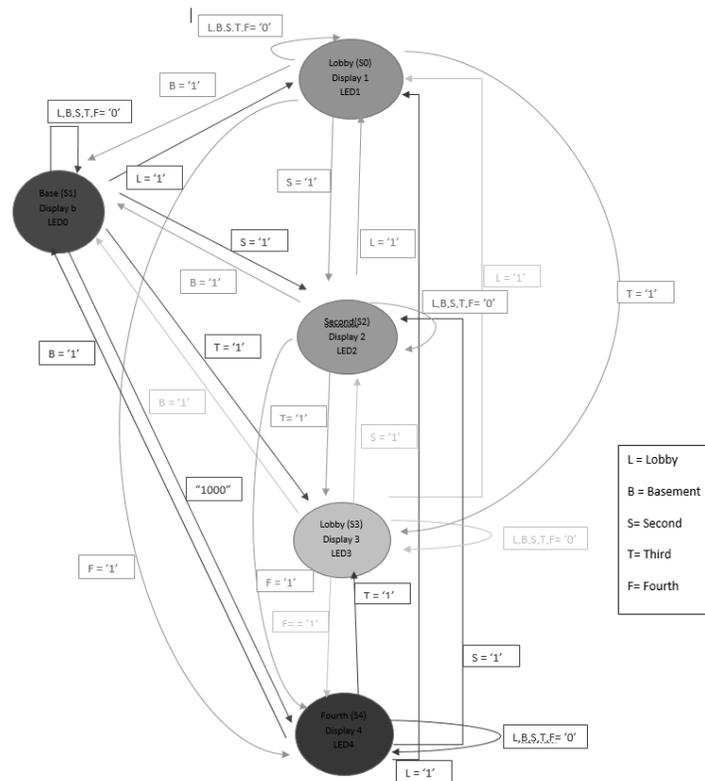


Figure 7. Controller for an Elevator

In the second phase of this research (academic year 2017-2018 and summer 2018), students will design new digital systems and a fault (error) generator based on references [18] and [19]. Other fault injection techniques will be investigated also. Fault injection will be applied to the targeted FSMs and the fault tolerance capability will be investigated.

## V. Undergraduate Research Results

The objectives of the research project are: (i) to provide students with an opportunity to work on real-world problems using technologies and software languages currently used in industry and academia; (ii) to expose students to actual areas of research; (iii) to educate students how to communicate the results of their research, both written and oral communication.

Anticipated outcome (i): The students learn to design, implement, test and evaluate digital systems based on microcontroller and FPGA platforms.

Anticipated outcome (ii): The students learn how to do a literature review (literature gathering and screening, literature processing).

Anticipated outcome (iii): The student learn how to use various computer-based-tools so they can successfully present research results to an audience and as a written paper.

The following methods were used to assess the learning outcomes: (i) Students documented the progress of their research by demonstrating their fully working projects to large audiences (conferences, open houses); (ii), (iii) Students submitted their work for publication in professional journals and/or presentations at professional conferences. Additionally, the mentor followed up with the students to see if the research experience helped them to secure internships, fellowships, admission to graduate programs. Table 1 summarizes the results of the undergraduate research: conference presentations, journal publication and awards.

**Table 1. Results of Undergraduate Research**

<b>Research Project</b>	<b>Publications, Conference Presentations and Awards</b>
Smart Energy House	<p><i>“Smart Energy House”</i></p> <ul style="list-style-type: none"> <li>- Poster and oral presentation at the IEEE International Energy and Sustainability Conference, Farmingdale, NY, October 2015.</li> </ul> <p><b>The team of students won the Outstanding Student Poster Award.</b></p> <ul style="list-style-type: none"> <li>- C_Step Conference, New York, April 2016.</li> <li>- Advanced Energy Conference, New York, April 2016.</li> <li>- Brookhaven Undergraduate Research Conference, April 2016.</li> </ul> <p><i>“Design and Implementation of a Reliable and Environmental Friendly Smart House System”</i></p> <ul style="list-style-type: none"> <li>- Published in the International Journal of Smart House, vol. 1, January 2017 [16].</li> </ul>
Smart House System for Vulnerable People	<p><i>“Design and Implementation of Smart House System for Vulnerable People”</i></p> <ul style="list-style-type: none"> <li>- Presentation at the 14<sup>th</sup> International Conference on Remote Engineering and Virtual Instrumentation – Columbia University, N.Y. March 2017.</li> <li>- Presentation at SUNY Undergraduate Research Conference, April 2017.</li> </ul> <p>The team of students working on this research project enrolled in the New York State Business Plan Competition at Farmingdale State College, spring 2017. Inspired by this research project, the team entered the Business Competition with the project named <b>“STACK HOUSE”</b>. The idea was to develop and market an educational coding toy to spark young girls’ interest in STEM. <b>The team won the Long Island Business Plan Competition-regional level.</b> It was the first time for Farmingdale State College students to win the grand prize at the</p>

	<p>regional level, product category level. The team won \$10,000 Grand Prize. The team advanced to the next level and presented their business project at the state level in Albany, April 2017.</p> <p><i>“Smart House System: Enhanced Living”</i></p> <ul style="list-style-type: none"> <li>- Student Poster Competition at the 2017 IEEE International Energy and Sustainability Conference, Farmingdale, NY, October 2017.</li> <li>- Celebration of Scholarship, Farmingdale State College campus, October 2017.</li> </ul>
<p>Fault Tolerant Digital Systems</p>	<p><i>“Fault Tolerant Controllers”</i></p> <ul style="list-style-type: none"> <li>- Celebration of Scholarship, Farmingdale State College campus, October 2017.</li> </ul>

As a result of their outstanding work, students involved in the above mentioned projects received academic scholarships, internships and were admitted to graduate programs.

- Two students received the Barnes & Noble’s STEM Scholarship (2015, 2016).
- Two students received internships at Brookhaven National Laboratory (2015, 2016).
- Two students received the D3 scholarship (2015, 2016).
- One student was accepted for the MS in Technology Management at Farmingdale State College (2017).

The process of developing solutions to the research problem, preparing abstracts, presentations and manuscripts as well as presenting their work in a conference setting proves to be a great learning experience for students and an excellent students engaging strategy [3]. Another engaging strategy was to allow students to present their research findings as part of their Senior Project experience.

One of the main challenge of the research process was to keep the team of students interested to work on these projects on a long term, not only during the summer, especially freshman and high school students. “Navigating” students’ busy work and school schedules during the academic year was another obstacle. Working with sophomore and juniors presented its own challenges in term of technical knowledge, limited written and oral communications skills, maturity level.

Some of the lessons that the author of this paper took away from mentoring undergraduate students are:

- Thoroughly interview every student before starting the research project,
- State clearly the goals and objectives of the projects,
- state clearly deadlines,
- Start very early preparing and rehearsing conference presentations,

-Prepare and sign written agreements between mentor and student, clearly stating schedule, report submission deadlines, etc.

Mentoring students was extremely rewarding for the author of this paper also. She was awarded the C-STEP *Research Mentor Award* in 2016 and CTLT (Center for Teaching and Learning and Technology) *Outstanding Faculty Mentorship Award* in 2017. She was selected as research mentor for RAM (Research Aligned Mentorship) program at Farmingdale State College.

## Conclusions

This paper presents undergraduate research experiences for Electrical and Computer Engineering Technology students at Farmingdale State College mentored by the author of this paper. The goal of the undergraduate student research is to nurture students' desire for knowledge and commitment to long life learning. Based on previous experiences, the author is confident that engaging students in research and solving real world problems is a solid path to academic success, and improve students' chances to pursue successful professional careers.

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