2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering Education for 130 Years
Paper ID #37273

Design and Implementation of Automation Systems as Electro-Mechanical Engineering Technology Senior Design Projects

Dr. Rasoul M. Milasi, Pennsylvania State University
Dr. Andrzej J. Gapinski, Pennsylvania State University, Fayette Campus

Design and Implementation of Automation Systems as Electro-Mechanical Engineering Technology Senior Design Projects

Abstract

The senior design project is the capstone design course in Penn State - Fayette's electro-mechanical engineering technology (EMET) curriculum. It is a two-semester project work composed of EMET403, design project preparation, and EMET440, project design implementation, courses. Students worked in teams to complete the projects with faculty guidance. Six senior design projects with seventeen EMET students were completed successfully in the 2021-2022 academic year. Three projects, with an emphasis on control and automation, were selected to be presented in this paper. The projects include an automatic bicycle derailleur system, an autonomous lawn mower, and an automatic medicine dispenser. The objective of all the projects was to involve students in project management, design, computer simulation, and finally real-time implementation as well as project documentation and group presentations. To ensure simple programming and lower system costs, many projects were based on Arduino Uno or Mega. Multiple sensors are used to detect the environment and system conditions. Moreover, servos and motors were used as actuators to perform the required tasks. The physical design of the projects was designed using SolidWorks and made using 3D printers. MATLAB, Multisim, and other software simulators were used to simulate circuit designs. Projects were successfully implemented and met design specifications and performance requirements. Furthermore, the projects' authors participated in the campus Learning Fair in the Spring of 2022.

1. Introduction

Engineering technology senior projects intend to develop vital competencies in applying technical and non-technical skills. The electro-mechanical program, interdisciplinary by nature, combining electrical and mechanical areas of study, prepares graduates for industrial and manufacturing environments in product design, development, and production. Naturally, the importance of capstone project experience has been appreciated for a long time in an engineering education but not without some controversy, where Hoole [1] wrote in 1991, that "Universities should concentrate on teaching the theory, leaving the completion of the engineer's education to industry." Since then, the importance of capstone project experience is universally acknowledged and built into educational programs, especially in engineering technology programs. Literature provides many examples of capstone project experiences [2, 3, 4, 5] to list a few. The importance of the capstone projects is reflected in Accreditation Board for Engineering and Technology (ABET) criteria and assessment protocols. [7]

2. EMET Senior Projects at Penn State - Fayette

At Penn State – Fayette EMET program the senior project coursework is based on required EMET 403 and EMET 440 courses. The EMET 403 is a one-credit course on design project preparation that includes the selection of the topic and initial design work that involves planning, creation of design schematics or blueprints, and design specifications, and culminates in the Preliminary Design Report (PDR) with a budget and schedule of all activities including implementation stage. Since the EMET program does not provide a separate course on project management principles with associated software and critical path method (CPM), the topic was covered at the beginning of the semester together with a review of the teamwork principles. A guest speaker with long industrial experience in project management provided practical information on the topic. The EMET 440, a three-credit course focused on the development and implementation of designs with frequent two meetings per week between team members and supervising engineering faculty. The senior projects play an important role in satisfying competencies criteria expressed in the Penn State – Fayette EMET [7] learning objectives that coincide with ABET [6] students' outcomes for EMET program:

> (1) an ability to apply knowledge, techniques, skills, and modern tools of mathematics, science, engineering, and technology to solve broadly defined engineering problems appropriate to the discipline
> (2) an ability to design systems, components, or processes meeting specified needs for broadly defined engineering problems appropriate to the discipline
> (3) an ability to apply written, oral, and graphical communication in broadly defined technical and non-technical environments; and an ability to identify and use appropriate technical literature
> (4) an ability to conduct standard tests, measurements, and experiments and to analyze and interpret the results to improve processes
> (5) an ability to function effectively as a member as well as a leader on technical teams.

In the 2021/22 academic year, seventeen students participated in six different senior projects on the following topics: automatic bicycle derailleur system, automated lawn mower, automatic medicine dispenser, firefighting robot, automated biodiesel process, and automated robot sensing gases. In the Fall of 2021, the university still followed the pandemic teaching policies with masking, physical distancing, and incorporation of various teaching modalities which required pedagogical flexibility by teaching faculty.

The focus of industrial 4.0 is automation and connectivity. Consequently, at Penn State - Fayette, we explored the design and implementation of senior design projects that focused on process automation. Three of these projects are presented in this study: an automatic bicycle derailleur system, an automated lawn mower, and an automatic medicine dispenser in the following three sections. All projects took part in the annual campus learning fair, which promotes student initiatives and research.

3. Automatic Bicycle Derailleur System

On a standard manual mountain or road bicycle, there is a mechanical system included to change gears for making climbing hills easier with lower gears. [8] This system also allows for greater efficiency on flat surfaces with higher gears. Changing gears allows the user to keep a certain cadence throughout the ride, putting less stress on both the user and the hardware of the bike itself. Automating this system with an Arduino board [9] would take away the need for the user to switch gears manually, to allow for a more leisurely experience. To keep cadence as constant as possible, it is measured using a tachometer made from hall sensors and magnets mounted to the crank of the bicycle. To switch gears, the manual ratchet system that comes stock with the bicycle was replaced with a servo motor. This add-on system includes an Arduino Uno microcontroller, small electrical components such as wires and other small components, a servo motor with sufficient torque to pull the cable to the rear derailleur, a designed tachometer using the microcontroller, and any designed/manufactured housing and systems needed to complete the project. With producing this add-on system, it would allow the user to manipulate desired speed values for specific gears in the Arduino program, the bike would be in the desired gear when in the correct situation, and it will put less stress on the main mechanisms of the bicycle. It will also provide practicability and convenience. Major technical steps in completing the project:

- Design a functional and accurate tachometer
- Design cable housing “spool” to be attached to the motor
- Develop code for communication between the tachometer and motor
- Create proper housing and mounts for all components for protection
- Physically attaching all components to the bicycle
- Testing for verification

The electronics used in the system are based on the Arduino Uno, which receives inputs from an A3144 hall effect sensor [10]. The code uses the hall effect sensor input to control an ASMC-04B 180kg-cm servo motor, which rotates clockwise or counterclockwise depending on the rotational speed read by the Arduino. The A3144 is selected for this application due to its simplicity and size since it must fit between the crank and the bicycle frame. A magnet is placed on the crank which allows the user’s movement to be translated into a digital input. The ASMC-04B servo motor is used for a few reasons: Firstly, it can output more torque than an average human’s wrist. Second, not all derailleurs have the same spring on the lever arm, and having a higher torque ensures its effectiveness on other models. Additionally, it operates more consistently under different environmental conditions. A 20V, 2Ah battery is used to provide power for the closed-loop system. Since the motor operates between 12-24V, this was an excellent option for the prototype. The 2Ah variant would give the motor over 4 hours of runtime under load conditions (< 500mA). All electronic components are mounted onto the bike frame itself. The constraints include the size of the servo motor and battery for the primary housing. A secondary housing was used for the hall sensor near the crank. The specific design for each is still in consideration but acknowledging the constraints simplify this step. As shown in Figure 1, the servo motor and battery housing are located on the frame below the saddle while the hall sensor is located on a section of the frame that intersects with the rotational path of the crank as shown. Table I shows the design justification for the project.

Table I: Design Justification

Requirement	Design Solution
Automated Shifting	Servo response due to hall sensor tachometer.
User Friendly	Parts are accessible through housing and components in safe positions on the frame.
Operate in wet/dry conditions	Sealed housing to keep water, dust, and dirt away from components.
Manual override – allows user to switch gears manually (manual mode)	Implement a switch to operate the system in manual mode.
Longevity of system	2Ah battery will allow the motor to have a runtime of roughly 4 hours. This excludes idle time.

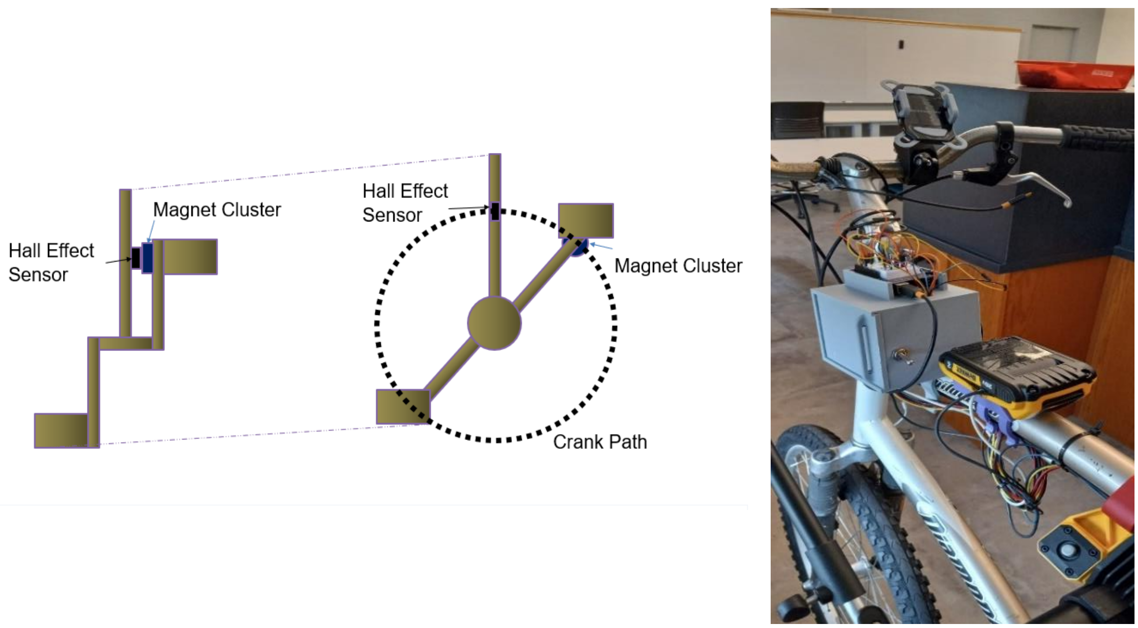

Figure 1: Diagram of Hall Sensor Mount Locations and Bicycle Derailleur System

4. Automated Lawn Mower

A lawn care service is often sought after by people who need grass maintenance. Services for maintaining lawns can be very pricey [11]. This issue has a simple fix that will both save time and money over time by eliminating the need for personnel to cut the grass: an automated lawn mower that is programmed to cut the grass on its own. Moreover, a benefit of having an automated lawn mower is that the user's lawn will constantly be mowed and at a good level. Grass constantly being cut keeps the grass healthier and better looking.

The proposed design will ensure that the mower would move in a boundary area that is set up by the user using special wires. The mower will detect the wire and stay within it to cut the grass. It will efficiently mow in a back-and-forth motion to be sure to cover the entire lawn. The mower will then return to a designated area known as the home following the boundary wire. The home will most likely be in a corner of the lawn and can be defined by the user. The mower is expected to accomplish 95% of the grass inside this area in the boundary to be mowed. The grass should be within a defined tolerance of around 3 inches when done. The mower is also designed and coded to avoid objects that are in its path. There is an ultrasonic sensor mounted on a micro servo motor to perform object checks in front of the mower. The final prototype of the automated lawn mower is shown in Figure 2.

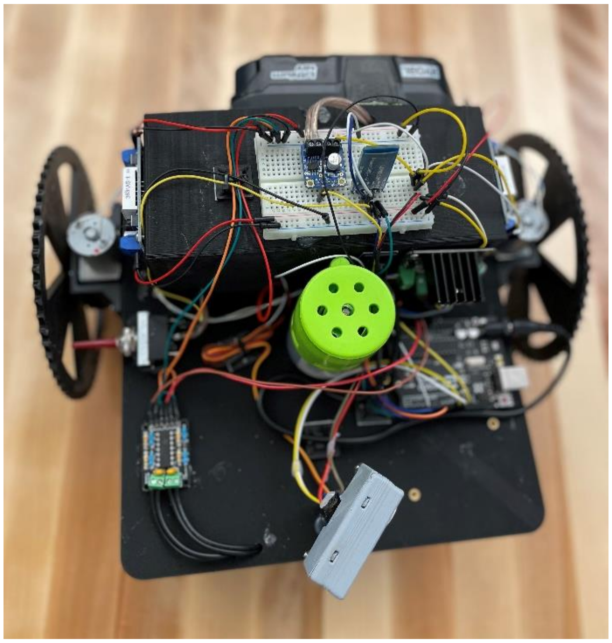

Figure 2: Final prototype of the Mower

5. Automatic Medicine Dispenser

This section focuses on the design of an automatic medicine dispenser. This automated medicine dispenser is most suited for those with deficient memory, as well as those who struggle to open their pill containers because of arthritis or other physical restrictions. This product will simplify the procedure by offering a medical device that can dispense an end user's daily medication with the touch of a button, as opposed to the present techniques of struggling to open various pill containers. The project requirement includes:

- Using a touch screen and internal memory, the user can interface with the device without having to download an app or struggle to find the basic functions of the device.

- The design includes three pill basins for medication to the stored in and dispensed from. Once the user sets the number of pills to be dispensed from each pill basin, only one button is required to be pressed to administer the medication.
- A buzzer will sound after the medication has been dispensed. A different buzzer sound will be emitted when a pill basin is out of pills or has not dispensed the correct quantity of pills.

The other objectives of the project include accurately dispensing medication, preventing misfeeds, ease of assembly and disassembly of pill basins, and designing a user-friendly interface. Using the end user's data entries, communication between the touchscreen display and Arduino Mega will activate one servo motor and its corresponding infrared sensor at a time. Activation of the servo motor will rotate the disk back and forth to populate the open slots of the disk and by ejecting exactly one pill. Ejection of the pill will be detected once the infrared sensor beam has been interrupted. The buzzer will sound when a pill is dispensed or when a pill basin is out of medication. Communication between the Arduino Mega and the infrared sensor will count the number of pills dispensed and the pill basin the medication was dispensed from. Coding of the touchscreen and Arduino Mega are critical to the project's success and completion of the objectives previously listed. By creating a device that can consistently dispense the correct quantity of medication, a reduction in medication nonadherence can be achieved. The final product is shown in Figure 3. A flowchart of the system program is provided in *Figure 4*.

Figure 3: Final prototype of the automated medical dispenser

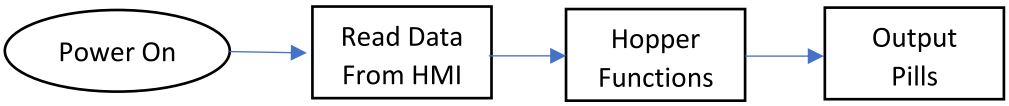

Figure 4: Flowchart for the automated medicine dispensing program

6. Conclusion

In EMET program at the Penn State – Fayette campus the senior capstone projects play an important role in developing vital competencies for engineering technology students. Two-semester-long design and implementation work was successful for all participating students. In this paper, three selected undergraduate senior design projects are presented: an automated bicycle gear shifter, an automated lawn mower, and an automatic medicine dispenser. The overall system algorithms are programmed on Arduino boards due to the relative simplicity of programming and the lower cost of the boards. Most mechanical designs were done through SolidWorks and built using available on-campus 3D printers. The systems consist of sensors as well as actuators that communicate with Arduino boards. All projects were completed on time and met the design specifications and requirements.

References

1. Hoole S.R.H. (1991) Engineering Education, Design, and Senior Projects, IEEE Transaction on Education, Volume 34, Issue 2, pages 193-198.
2. Ellis B.D., Berube K., Allen J. (2018) Introduction of Electromechanical Projects within a Mechanical Engineering Technology Capstone Program, ASEE Conference for Industry and Education Collaboration, San Antonio, Texas, session ETD 425.
3. Allison B., Ludwick S., Birmingham W.P. (2012) A Mechatronics Capstone Project with an Interdisciplinary Team and an Industrial Partner, ASEE Annual Conference and Exposition, San Antonio, Texas.
4. Jezernik K. (2010) Mechatronics Projects at the University of Maribor. IEEE International Conference on E-Learning in Industrial Electronics, Glendale, Arizona, USA.
5. Gapinski A. (2012) Automation of Functionalities. Examples of EET Student Projects, IEMS Conference Proceedings, Cocoa Beach, Florida, pages 74-79.
6. Accreditation Board for Engineering and Technology, Inc. www.abet.org
7. Electro-Mechanical Engineering Technology, Penn State Fayette. https://fayette.psu.edu/academics/baccalaureate/electro-mechanical-engineering-technology
8. Swanner N. A Beginner's Guide on How to Shift Bike Gears. https://www.themanual.com/outdoors/how-to-shift-bike-gears/
9. Arduino boards and applications. www.arduino.cc
10. DigiKey Electronics - Electronic Components Distributor. www.digikey.com
11. Wikilawn, Lawn Care 101: Your Seasonal Guide to Lawn Care & Maintenance. https://www.wikilawn.com/lawn-care/