

## **Design, Build, and Installation of an Automated Bike Rental System as a Part of Capstone Design**

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## **Abstract**

The Mechanical, Electrical, and Computer Engineering Programs at York College of Pennsylvania have mandatory co-op programs in which each student receives three semesters of engineering work experience. Our senior design courses further develop our students' design and project development skills by intentionally targeting projects that emphasize working within a larger team. For example, we have built autonomous robots for the International Ground Vehicle Competition (IGVC) and formula style race cars for the Society of Automotive Engineering Formula Student Design Competition (FSAE). While successfully developing our students' project development and group communication skills, these projects lacked the personal interaction with a customer with well (or sometimes poorly) defined specifications and constraints. To fill this need, and to help build community relationships, one of this past year's senior design projects sought to design and build a bike rental system. The product will connect the college campus to the downtown York business district. Two representatives from companies in the business district were the customers who helped the students develop specifications, participated in planning meetings, and attended design reviews of the bike rental system. We and our business partners hope that the bike rental system will increase the number of students frequenting downtown York and its businesses.

In the first stage of this project, in the 2014-15 academic year, two teams of engineering students developed their own independent designs. Each team had about eight mechanical, electrical, and computer engineering students. Faculty advisors from all three disciplines advised on the projects. The initial phase of the project was conducted over two semesters. The design work was completed in the first semester (summer 2014), and the construction and testing of two prototypes was completed in the second semester (spring 2015). After prototype completion, both designs were presented to the company representatives to solicit their feedback. This concluded the first phase of the project.

After receiving feedback from the customers, the second phase of the project, spanning the 2015-16 academic year, began with a new group of students. These students further developed the mechanical, electrical, and computer designs this past summer (2015), combining the best aspects of the two prototype designs. These students will construct two bike racks (spring 2016) for implementation. We intend to place one bike rack on campus and the other in downtown York when they are complete.

## **1. Introduction**

From their inceptions, the York College of Pennsylvania Mechanical, Electrical, and Computer Engineering Programs have always prided themselves on being "hands-on" engineering programs. Lab experiences are used heavily throughout the academic curricula to reinforce lecture material, and all students are required to complete three separate terms of co-op experience as a graduation requirement.<sup>1</sup> The capstone design sequence follows this "hands-on"

approach and contains two semesters of design, build, and test phases. Whereas the students gain experience working on small project designs during their co-op semesters, the capstone course contains a large scale project where the students are divided into subgroups that work together to complete the entire project. The projects typically contain 10-20 students broken into subgroups of 3-4 students. While there is some overlap, the first semester of the capstone sequence focuses on the design aspects of the project, and the second semester of the project focuses on the build and testing of the prototype. Because the York College Engineering Programs have a required co-op program, the first semester of the capstone sequence is always taught in the summer<sup>1</sup>. The students then complete a co-op during the fall semester, and complete the second semester of the design sequence the following spring. An example of the type of capstone project students have completed is the design and build of a vehicle to compete in the Society of Automotive Engineers Formula Collegiate Design Competition (FSAE)<sup>2</sup>.

This past year, an automated bike rental system project was included in the capstone design projects along with two Society of Automotive Engineers (SAE) sponsored design projects (formula and baja). The SAE projects have done well in fulfilling the educational objective of students working together as a part of a larger team to complete a large scale design project. However, when completing projects like the SAE cars, students simply follow a rule book for developing their designs. There is no customer interaction in developing project specifications. The bike rack offered the opportunity for students to interact with two community business owners, who had a stake in the project outcome, who were serving as the “customers” for the bike rack project. The business owners worked with the students in developing their project specifications, gave feedback during preliminary design reviews, and evaluated the final designs.

Adopting the bike rack project was also partially motivated by the long range plan of the college including more community outreach. Both college and community leaders have committed to forming a stronger bond between the college and the city of York, and this project would help strengthen this bond. Having the community business owners involved in the project helped to serve this purpose. Additional motivation came from an increased effort to attract more women and minorities to engineering. It has been shown in the literature that student competition projects involving automotive applications typically attract white males, while women and minorities are often more interested in social impact projects.<sup>3,4</sup> The bike rack project provided an alternative to vehicle design and offered a community outreach aspect with environmental benefits.

The motivation behind the automated bike rental system was to create a small rental system where students could check out bikes on campus and ride them to the downtown area providing students greater access to the local York Community. In addition, people who live in downtown area could check-out bikes and take them to campus giving them better access to college activities. There is an existing rail trail that makes the connection easy. Therefore, the project built stronger relationships through better engagement between students and the local community. Having the community business owners serve as customers helped to make this solidify this bond. It would also promoted sustainability through the use of renewable energy and by provided a greener form of transportation that would enhance local economic vitality.

The first year of the project began with two different groups of students exploring two different design alternatives and building prototypes for analysis. The second year of the project would involve one slightly larger group of students examining the work from the previous year, completing a final design, and constructing two rental systems.

## **2. Project Organization**

### **2.1 Local Customer**

While the project was funded through college capstone funds, two business owners from the city of York agreed to serve as the customers of the bike rental system project representing the interests of local businesses. Meetings were set up between the students and the customers to determine design specifications, review design alternatives, and get feedback on final prototypes. The students were ultimately responsible to these customers to convince them that the final design included what was best for the community and included the design alternatives that they thought were most important. This insured that the design was not just what the students thought best from an engineering standpoint, but that is also satisfied the needs of the local community.

### **2.2 Instructor Roles**

The instructors for the capstone course served as project managers and included mechanical, electrical, and computer engineering faculty. The instructors set milestone dates, offered advice as the designs developed, and evaluated student work. Students were required to give bi-weekly updates to the faculty and the rest of their design team. Customer interactions were initiated by the instructors and consisted of 3-4 meetings spread throughout each semester.

### **2.3 Team Organization**

For the first year of the project, there were two project teams (each having 8 students) investigating two different design alternatives. Each project team was broken down into four subgroups. A group of three mechanical engineering students were responsible for the design of the basic structure and locking mechanism for the bikes. A group of two electrical engineering students were responsible for the power system. A group of two computer engineering students were responsible for design and development of the embedded systems to control the bike rental station. A final student was responsible for the various electromechanical devices required by the rental station and system integration. The design work was done for the two different design alternatives during the summer semester of 2014. Prototypes of the designs were created in the spring of 2015.

The second year of the project involved one larger team (20 students). These students were broken into seven subgroups: mechanical, power systems and power electronics, electromechanical and electrical interfacing, sun tracking system, embedded system and user interface, GPS bike tracking, and backend server. Students were responsible for creating a final design using what was learned in the construction of the two prototypes the year before. The design work was completed during the summer of 2015, and the goal is to complete the build of two bike rental stations during spring 2016.

### **3. Project Requirements**

The project requirements were developed in conjunction with the local customers during the first design semester. This interaction insured that the final design included aspects that considered the needs of the local community. A list of the requirements follows:

- 1) Bikes available for student and community use
- 2) Bike rack expandable in groups of 5 bike stations
- 3) Weatherproof and theft resistant electronic system for locking bikes
- 4) Includes a kiosk to house power and electronics with ATM-style user interface
- 5) Independent from power grid (uses alternative energy – can return bike without power)
- 6) GPS tracking with web interface to locate bikes
- 7) Cloud-based backend server to manage rental information
- 8) Cellular communication systems to transmit data to/from the backend server

### **4. Learning Outcomes and Assessment**

The learning outcomes of this project were consistent with overall learning outcomes of the capstone course, which map back to the program outcomes of the mechanical, electrical, and computer engineering programs. Assessment was completed using student written work, presentations, feedback from local industry, and student evaluations.

#### **4.1 An ability to design, fabricate, and test a system**

While the second group of students were able to base their design work on the previous year's prototypes, they were still required to complete the design analysis for all the components in their design. Both groups of students were certainly required to complete the full design cycle including all necessary analysis, testing and debugging. This outcome was assessed using final written reports from both semesters. In addition, feedback was collected from industry representatives who were not involved in the project at an oral presentation.

#### **4.2 An ability to learn independently to complete a design problem**

The first phase of the project was specifically dedicated to research. Students were required to develop specifications, benchmark existing systems, and research design solutions. While the second group of students started with the prototypes from the previous year, they were still required to complete their own research and evaluation. After the initial research was complete, the students were required to independently determine (with the guidance of the course instructors) what analysis was required and complete the design work. Clearly both groups of students were demonstrating the skills required for life-long learning. Formal assessment was done using students oral presentations, final written design reports, and student course evaluations.

#### **4.3 An ability to work professionally on a team and compete a project on schedule and within budget**

The students were certainly working together as a team to meet milestone dates for both design and fabrication of their project. Without good group communication and time management skills, the projects would not have been completed on time. They were also given a budget at the beginning of the semester, and were required to work together to insure the entire project was

completed within that budget. Assessment of teamwork was completed by the instructors using their own observations in conjunction with peer assessment data collected from the students.

#### **4.4 An ability to effectively use written and oral communication to document design decisions**

Through both the design and build phases, students were required to give oral, bi-weekly progress presentations to the entire design group and instructors. They were required to communicate what they had accomplished over the past two weeks, what their personal plan was for the next two weeks, and how it fit in the overall completion of the project. In addition, they were required to keep an electronic notebook of all design and fabrication work. The notebooks were evaluated at the bi-weekly oral presentations and feedback was given to the students. Finally, each student was required to turn in a formal written report documenting all design and fabrication work at the end of each semester. Assessment rubrics were used by the instructors for all written and oral presentations.

In addition to the formal course requirements, the students were also required to interact with the local business owners who were serving as customers. This interaction was done in formal design presentations as well as informal meetings, and insured that the students were taking into account the needs of the local community.

### **5. Final Product Design**

The final design, created by the second group of students, was a combination of some of the best features of the two prototypes that the first year's students had created.

#### **5.1 Mechanical Components**

The final design made use of solar power, so a tower was designed to mount the solar panel high enough to make it difficult for vandals to reach and so that it would receive adequate sunlight for powering the device. The solar panel was connected to a kiosk that included the user interface. The kiosk was 4 feet tall and was connected to five locking stations for the bikes. Together, the five locking stations were 13 feet wide and 20 inches deep. The design included the option for adding additional bike racking stations as needed and can be seen below in figure 1.



Figure 1: Bike Rack System

The bikes are secured using the frame, just above the front tire. As shown below in figure 2, a bracket is secured to the bike frame using tamper resistant screws. The bracket has a tongue protruding from the front that makes a positive lock with a solenoid pin in the bike rack. The bracket also includes an enclosure for the GPS tracking unit. An inductive charging unit charges the GPS tracker when the bike is secured in the rack.

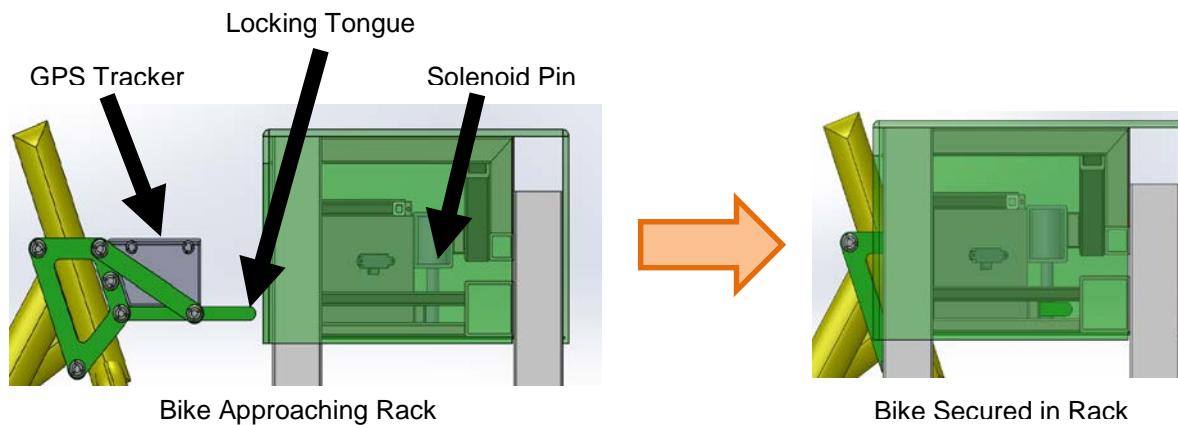


Figure 2: Bike Locking Mechanism

## 5.2 Embedded Systems

The system utilizes a distributed embedded system design consisting of five ARM Cortex M0+ microcontroller boards and a single Raspberry Pi. Communication between each of the processing elements is done over a Controller Area Network (CAN). Each of the five locking stations contains an ARM Cortex M0+ processor to control the solenoid for the locking mechanism. Additionally, each Cortex M0+ utilizes data from infrared sensors and a Near Field Communication (NFC) reader to detect the presence of and to unique identify a bike that has been inserted into a locking station. Finally, the Cortex M0+ is used to sense the battery level of the GPS tracker attached to each bicycle. All of this information is transmitted to a Raspberry Pi housed in the kiosk.

The Raspberry Pi collates the information from the five Cortex M0+ processors and uses the information to determine which bicycles are available, which bicycles are rented, and which bicycles are returned. The Raspberry Pi also drives a display and receives input from a variety of buttons and a magnetic stripe card reader. Finally, the Raspberry Pi utilizes a 3G modem and the cellular network to communicate the status of the system and payment information to a backend server.

## 5.3 User Interface

The user interface for the bike rental station consists of a low-power 10 inch display with physical ATM-style buttons along the side of the screen to select menu options. A mockup of the main menu is shown in figure 3. The menu provides a user with the ability to rent a bike as well local information, and a detailed weather report. The user interface also includes a 9 digit keypad to allow users to input numeric information and a magnetic stripe card reader in which a user can swipe their credit card.



Figure 3: Mockup of ATM-style User Interface for Kiosk

## 5.4 Power

Automated bike rental system (ABRS) has dual power input: photovoltaic (PV) and electric grid. The primary source of power is a PV system with at least five days of battery backup capability. A switching circuit is designed to connect the ABRS with the electric grid in case of emergency. This circuit monitors PV terminal voltage and battery output to perform switching actions. When the condition is appropriate the ABRS connects to PV system for normal operation. PV system uses a maximum power point tracking (MPPT) charge controller to regulate voltage and current for efficient energy harvesting.

Power processing and conversion uses various converters to supply 24 V, 12 V, and 5 V loads as well as to connect with electric grid. Power system design included an option to expand the ABRS from 5 bikes to 25 bikes in the future.

## 5.5 Bicycle Tracking

Each of the bikes is fitted with a small GPS tracking module as shown in figure 2. The GPS tracking module utilizes a GSM+GPRS+GPS cellular module to determine the geographic position of each bicycle. The cellular module periodically transmits the bicycle's location information to a backend server via a 2G cellular network. Each GPS tracking module contains a rechargeable lithium ion battery that provides 48 hours of battery life. The lithium ion battery is inductively charged when the bicycle is locked into one of the rental station locking mechanisms.

## 5.6 Backend Server

In addition to the bike rental station, a backend server was implemented to manage all aspects of the bike rental system. The backend server receives data from all bike rental stations and all of the GPS tracking modules. It provides an administrator the ability to quickly see the health of each rental station and the geographic position of all bicycles. The backend server provides a central location where all payments are processed and records of each rental are maintained. Using a backend server also allows for additional features such as the ability to rent a bike from one rental station and return it to another.



## **5.7 Electromechanical Interface**

This sub-team is responsible to create interface among mechanical, electrical, and computer subsystems using sensors and actuators. Through use of sensors, information is gathered from the physical world, for example a button is pressed or a motion sensor is triggered. The actuators allow the system to act on the physical world in reaction to information gathered by the sensors. The sub-team's responsibilities include: sensor selection, circuit development to interface with various subsystems, PCB design, and working with the embedded systems sub-team to develop and implement a control algorithm. This sub-team designed keypad interface circuit, LCD backlight toggle circuit, solenoid driver circuit for locking mechanism, IR sensor implementation circuit to sense bike, and dc motor driver PCB for solar tracking system.

## **5.8 Solar Tracking**

Solar tracking consists of algorithm development, sensors, actuators, and mechanical structure. This tracking system uses fixed pitch and has only 1-axis freedom (yaw) to track the sun. The solar tracking algorithm is developed using four light detecting resistors (LDR) in a matrix pattern. The purpose of LDR is to increase in resistance as the amount of UV light on them increases. The LDR will then be put in series with a known resistor, in our case a 1k ohm resistor. The same voltage is then put across the four pairs of series resistors and depending LDR resistance the voltage in between the resistors will change then. The middle voltage on the 4 pairs will change and it can be determined which resistors are seeing the most light at that time. This input will then be used to activate the actuator to move the PV panel to the desired position. The electrical interface circuit is developed using a microcontroller, converter, H-bridge, dc motor, and slip-ring to perform the desired action.

## **6. Future Plans**

Once the final bike racks are built, business students will become involved with an economic and marketing analysis. The engineering programs will pay for the construction of the bike racks from funds budgeted for the capstone class. An initial thought is for local business to sponsor each of the bikes. As an incentive, they will be allowed to put an advertisement for their business on the bike they sponsor. A small monthly fee will then be charged to continue the sponsorship. The fees collected will be used to contract with a local bike shop to maintain the bikes. The implementation of the final bike racks is truly the final step in maintaining the community relations link.

## **7. Summary and Conclusion**

Students designed, built, and will install two automated bike rental systems (ABRS) as a part of the capstone design project. This capstone project provided interdisciplinary design experiences for mechanical, electrical, and computer engineering students. Students demonstrated individual and team skills on engineering design, fabrication, and problem solving. Students transformed customer ideas into engineering design and gained real world engineering experiences. Local business owners served as customers to insure that the students were gaining the experience of including customer input into the design specifications, design development, and were satisfied with the final design. They also provided the link necessary to make sure that the designs were addressing the needs of the local community, and helped build stronger relationships between the

college and community. In addition, this capstone project taught students how to incorporate societal impacts in engineering design. The design objectives of the project were assessed using written design reports, oral presentations, feedback from local business owners, and student observations. The ABRS project was a good way to engage student in engineering design while including the needs of a local community.

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