TO DECREASE ANIMAL DAMAGE TO AGRICULTURE CROPS: AN AUTOMATED SYSTEM

KENNETH G NAGLE

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Summary

The goal of this project was to develop a comprehensive system that would reduce the amount of crop damage caused by whitetail deer and prolong the time it takes for them to habituate to the system. Crop damage caused by wildlife is a serious problem in the United States. According to MacGowan et al, (n.d.) “Wildlife damage to field crops is a widespread concern in the United States, especially in mid-western states, and the assessment and control of wildlife damage to crops have become an important component of wildlife management” (p. 1). The marketplace has targeted this concern over the years by providing farmers and gardeners with three basic wildlife control mechanisms: physical barriers, repellents and scare tactics.

Physical barriers are the simplest and the most effective mechanism. However, building a fence high enough and with small enough gaps to prevent the majority of nuisance animals is extremely time consuming and cost prohibitive (Curtis, Fargione, & Richmond, 1994). Due to the cost of building and maintenance of the physical barriers any large scale deployment would be too costly.

Repellents generally are based on negatively impacting the sense of taste or smell of wildlife. Repellents are often chemicals or compounds used to convince nuisance animals to move on by using offensive smells or tastes. Repellents tend to fade quickly and require repeated applications. Repellents are also of concern because of the chemicals used may negatively impact the taste of produce and products intended for human consumption. The cost to apply repellents and the potential environmental impact of the repellents make the use of them not ideal for large scale deployment.

Most scare tactics have initial efficacy, but animals become habituated to the tactics quickly and render them ineffective. Scare tactics break down into three basic areas: pyrotechnics, visual devices and audible devices. Visual scare tactics like the proverbial scare crow tend to be of minimum to no effect. Pyrotechnic devices may provide a level of effectiveness but raise concerns in a drought prone area such as South Texas. Many of the auditory devices are electronic and fairly inexpensive, but they have little to no effectiveness (Belant et al., 1998, January). Other sound devices have demonstrated some effectiveness. One electronic sound generating device showed great potential, it emitted recorded sounds of deer distress calls. Although, it was only tested in field studies for a few days, the study claims it was 100% effective (Hildreth, Hygnstrom, & Vercauteren, 2013). Also considered an effective auditory device are the standard exploder cannons firing. Additionally, if these cannons are moved regularly, it can further increase their effectiveness (Belant, Seamans, & Dwyer, 1996).

A comprehensive system to increase and prolong effectiveness was not uncovered in the review of literature and available resources. Therefore, the goal of the project was to develop a comprehensive system that would reduce the amount of crop damage caused by whitetail deer and prolong the time it takes for them to habituate to the system. Using tactics that demonstrated effectiveness, while alleviating the requirement for users to physically move

the system on a regular basis. The project was undertaken by community college students and was scheduled to be completed during the 2014/2015 school year.

The project focus was to build a system that utilizes both auditory scare tactics and repellents combined with robotics and computer programing. The method was to provide randomization, movement and physical effects, which in theory would limit or prevent the ability of nuisance animals to become habituated to the system.

This project required knowledge and understanding of five major elements:

1. What animals are considered nuisances?
2. What effects will deter them?
3. How quickly do they adapt to the effects?
4. What measures can hinder or suspend their ability to adapt?
5. What development platform is best suited to the system?

In the review of existing research a number of studies were reviewed pertaining to nuisance animals, as well as studies on the use of animal deterrents and their effectiveness. These studies were used to determine what animal(s) to target and what methods are effective in deterring them. Using programmable hardware, the project attempted to incorporate methods that are most effective and deploy them in a way that reduced or eliminated the chance of habituation. To accomplish this, the system hardware was prototyped on the Arduino micro controller development system, a robust and widely available open-source hardware system. The Arduino platform based on the C++ language provided ample means for peer review due to its robust development community. The open source and widely used Arduino platform was an ideal choice for the core of the system.

The project utilized three basic components: propane cannon, perimeter intrusion detection and a roving autonomous vehicular robot. The research team hypothesized that by providing an array of effects to be used randomly and variably, it would limit and possibly prevent the ability of nuisance animals to habituate to the system. While each component was tested and modified in the lab setting, planned field testing of the project was not completed to verify this hypothesis.

The propane cannon was a standard mechanical propane cannon converted to operate as an electrical system and controlled by an Arduino Uno. The cannon was programmed with a menu to choose between, or in combination, of random/set firing 24hr a day, random/set firing based on the sunlight level, and/or fire when the perimeter has been breached. The menu also contained options for setting and reading various variables in the program, such as current sunlight level, number of firing iterations, and time between iterations.

A perimeter intrusion detection system was designed to operate with the propane cannon when used in the perimeter firing mode. The perimeter intrusion detection was a laser and photo resistor designed to go on the perimeter of the field. Although this design is functional, during the development of the system, it became apparent that a laser beam system is limited in this scope to level ground. It was connected to the cannon via wireless communication using the Xbee wireless Arduino shield, which also has limitations as it is limited to line of sight communications.

Complementing the propane cannon and the laser beam, a vehicular robot was developed to carry and deploy repellents, make audible sounds, and flash lights. The robot was controlled using an Arduino based motor controller and programed to respond to remote control by either a handheld RC controller or cell phone. The robot was intended to have autonomous navigation using photo recognition guidance, which was not implemented requiring additional research.

In order to complete the project in a timely manner, the researcher organized a team of students interested in computer programing (COSC), communication information technology (CIT), and electronics and engineering from Coastal Bend Community College. The students on the development team were enrolled in one or more of the computer science classes at Coastal Bend College. This collaboration provided a real world environment for aspiring students to practice and hone their skills through practical application; provided students with a resume worthy experience; and a potential means of income through royalties.

In the end the project was closed prior to field testing. Time management and the academic calendar year were the primary barriers that caused the project to be closed prior to field testing of the project. Additionally, problems occurred in brainstorming, product design, and product development and prototyping. Overall the project was successful in developing a model for future research and testing. Though, the team was disappointed to close the project prior to field testing, the research process has continued as part of the community college experience.

Review of Other Work

The animals which were identified as a nuisance to agricultural crops were deer, raccoons and groundhogs (MacGowan et al., n.d). In some states, feral hogs would be added to that list, as well as coyotes (only in areas that grow melons). As noted by Sramek, (n.d.) “Coyotes are known for their particular fondness of watermelons and cantaloupes and will readily seek them as a food source” (Coyote diets, para. 3). We limited the project to whitetail deer, due to a readily available test field located in an area populated by whitetail deer; and whitetail deer are ranked as one of the leading animals causing crop damage (Belant, Seamans, & Tyson, 1998, January). Additionally, whitetails have shown the ability to habituate very quickly to many techniques used to scare them off (Hildreth, Hygnstrom, & Vercauteren, 2013). Given that whitetail deer are skittish by nature, the project was designed to use various scare tactics and other methods scientifically shown to have a measurable degree of effectiveness in order to overcome the deer’s ability to habituate.

A number of products exist on the market designed to reduce crop damage by deer. The team used peer reviewed studies to evaluate which devices have demonstrated some efficacy. The research clearly demonstrates that the best method to keep deer out of crops was the use of a fence. However, fencing is cost prohibitive and requires a significant level of upkeep (Curtis et al., 1994). Cost factors have led many farmers to use propane cannons which have been widely used to scare off deer from farms and gardens. The standard cannon fires at a regular interval, with a 60% effectiveness for a limited duration (Belant, Seamans, & Dwyer, 1996). A better choice as noted by Belant et al, (1996) is the"…motion-activated exploder [which] reduced the daily mean number of intrusions by 80% for 6 weeks." Furthermore, it was mentioned that cannons should be moved regularly to decrease the chance of habituation (p. 577).

Because of the loud noise produced by propane cannons, some manufacturers make sonic and ultrasonic sound generating devices. Contrary to marketing claims touting the effectiveness of sonic and ultrasonic devices, studies demonstrated that they had little if any effect (Belant et al., 1998, January). Due to the lack of demonstrable effectiveness of sonic and ultrasonic devices, they were not used in this project. Bio-acoustic devices had recently been employed to some effect. One study using bio acoustics showed great promise (Hildreth et al., 2013). It used eight distress calls of deer (recorded during capture and release events) then played back when a deer crossed into the feeding area. Although the device was only tested for two weeks, the "deer-activated bioacoustics frightening device (DABAFD) … was nearly 100% effective at reducing the number of times deer entered protected sites and 100% effective at reducing feed consumption." (Hildreth et al., 2013, p. 110). The limited duration of the study notwithstanding, a bio acoustic type device was intended to be incorporated into the project.

The team hypothesized that the use of multiple techniques would increase effectiveness compared to each individual device and limit the chance of habituation. To accomplish this, the project used a programmable controller to incorporate, and control the timing and movement of the system components. A micro controller was found to be the simplest and most likely choice, because, it allowed for the control of numerous electrical components.

However, selecting a specific brand or style of a micro controller for a specific project was challenging, but some basic guidelines, were used to limit the choices. The major criteria for selecting them were "(a) wide availability and reliable sources (b) meeting the requirements efficiently and cost effectively [and] (c) availability of the software development tools like compilers, Assemblers and debuggers etc." (Parai, Das, & Das, 2013, p. 230). In the end, two basic choices in micro-controllers were identified for the project, they were the Picaxe and Arduino systems. Given the size and diversity of the developer community, as well as the availability and selection of components, combined with the ease of compiling debugging and loading, the Arduino system seemed the logical choice for this project.

With the ability to program the system the project had the capability to incorporate the ability to move the devices around which, according to existing research would decrease the likelihood of habituation even further (Belant et al, 1996). For this reason, mobility was incorporated into the project and accomplished with the use of a vehicular robot using the Wild Thumper chassis from www.sparkfun.com. The actual navigation system of the robot proved to be the greatest challenge.

In many robots the use of passive infrared and ultrasonic sensors have been used for obstacle avoidance type of navigation such as following a wall or turn at a hallway. That would not work for navigation on this project due to the nature of the required task and the desired scalability of the product. Likewise, GPS is a common source of navigation. However, given the degree of accuracy needed in this project and data found in the blog post “GPS GUIDED AUTONOMOUS ROBOT” by Thulana Vimukthi and found at http://garagelab.com it was demonstrated that GPS alone would not have adequate accuracy.

A more promising navigation system utilized the ARToolKit, which is a “software library for building Augmented Reality (AR) applications” found at www.hitl.washington.edu/artoolkit. The ARToolKit provides accuracy to within a few pixels, by using predetermined designs with a high contrasting color and viewed through a camera. This feature allows image recognition software to pinpoint the pixel location of sharp edges and corners in the design. Pixel coordinates can then be put into an algorithm to map the location of the robot. Disappointingly in testing this object recognition application was only useful at short distances when using mid-grade optics. Further research identified the use of Qualcomms, Vuforia mobile augmented reality software development kit (SDK) combined with the unity game engine as a promising set-up for an object recognition type navigation system. The idea of using it in this project was accidental in nature, as the game design faculty at the college was evaluating it as a new platform for their degree plan. While evaluating Vuforia, it became apparent that it had a very powerful motion tracking system, and it was effective enough to navigate a virtual maze by simply tracking the change in the location of objects in the camera view.

Rationale

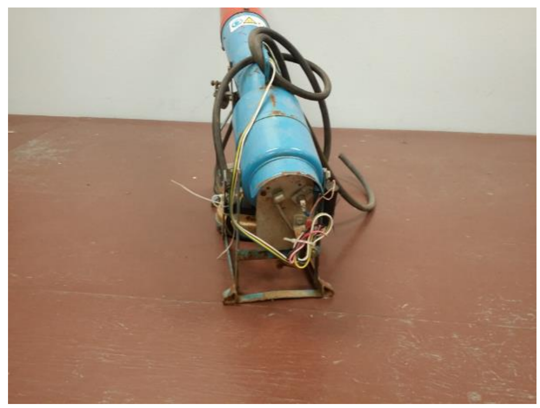
The impetus to develop this project was the lack of a comprehensive system for controlling crop damage by nuisance animals. There are a number of available products on the market, but they are generally stand-alone systems, minimally effective and/or become habituated to by the nuisance animals. Most systems do not incorporate “negative reinforcement,” and thus allow deer to habituate to the system more quickly (Belant, Seamans, & Tyson, 1998). Another drawback to existing systems is the requirement to frequently move the components. This factor is often overlooked and/or underutilized, ultimately leading to diminished effectiveness. By combining systems that have shown a substantial degree of effectiveness, and designing them in a way that links negative stimuli, a more effective deterrent was hoped to be developed.

System Analysis

The design process was iterative in nature with the basic system design of three components remaining the same, but with modifications and enhancements. The researchers planned the system to have three main components: the perimeter intrusion detection, the propane cannon and the roving autonomous robot. The iterations were used to perfect the system and fine tune the component interactions. Each component was developed, tested, modified and retested until a satisfactory level of performance was achieved in the lab setting.

The prototype of the perimeter intrusion detection system consisted of a laser mounted inside a PVC pipe attached to a tripod with anchors to the ground. The laser was pointed at a photo resistor mounted in a PVC pipe of a diameter and length appropriate to limit the amount of daylight reaching the sensor to no more than the light received by the laser. Additionally, a max effective range of the laser was determined to be 250 meters. The laser was set at a height most likely to be interrupted by the presents of whitetail deer, which would trigger a wireless transmission to the propane cannon.

The prototype of the propane cannon consisted of a used standard mechanical cannon. The mechanical mechanisms were removed and replaced with electronic devices. The propane bladder was replaced with a solenoid valve that is normally closed. The piezo sparker was replaced by an electric spark generator. A photo resistor was also attached to approximate the time of day. Additionally, LED lights were added to communicate the status of the system for safety and debugging purposes and operated using an Arduino.



The prototype of the roving autonomous robot was built using a Wild Thumper chassis. For the sake of easy retrieval and deployment the robot was equipped with a radio receiver to use with a handheld RC controller as well as Bluetooth for control with a laptop or cell phone. Initially, the design called for using the ARToolKit for navigation. The ARToolKit was to be monitored by one to three cameras, used for triangulation and image recognition. After a few preliminary tests, however, we soon realized that with moderately priced optics the object recognition navigation system using the ARToolKit would be completely useless at any distance beyond approximately 50ft. As a result, the team immediately started researching other applications to navigate the robot; the most promising application found was Qualcomm's Vuforia in conjunction with Unity's game engine. Although the research team spent a considerable amount of time researching and working on the object recognition navigation system, it required additional research and testing. Subsequently it became its own independent research project.

Figure 1 System Sequence Design

As illustrated in Figure 1: System Sequence Design, the project was intended to operate based on the following sequence: (a) a deer breaks the path of the laser beam which (b) sends a signal to the cannon to fire, (c) followed by a signal to the robot to produce a sound of a deer in distress, then (d) the robot moves to a new location. The sequence would repeat as necessary.

Using students from CBC to populate the research team was based on a number of factors including convenience of access to the students, and the potential benefit to the students. Working on the prototype development provided a real world environment for the students to practice and hone their skills. This type of real world application is frequently lacking and often difficult to achieve in a community college classroom, for a number of reasons including the cost and space required. As an introduction to authentic research, the students benefited by having a project leader who already had developed the project proposal. This allowed students to participate without being overwhelmed by the burden of researching and designing the project from the ground up.

Goals and Objectives

The projects primary goal was to create a comprehensive system to reduce the amount of crop damage caused by whitetail deer and prolong the time it takes for them to habituate to it. The system was designed to capitalize on randomization and mobility while providing a modular build design. The initial design of the project was to develop a product that would increase the effectiveness and the efficiency of current market technology to reduce damage to crops by reducing habituation.

Secondly, develop the prototype and protocols into a useful system that can be scaled for application at the end users level of skill. Considering the target audience of farmers, who may not have a high level of understanding of electrical and computer components, each component was designed to be easily set up and operated. With the exception of the autonomous robot. Which may require a significant degree of technical knowledge, although the use of in-depth tutorials and visual aids may help some with deployment and setup of the robot. This may, however, provide an opportunity for developing a niche job market for qualified service representatives and field techs.

A secondary goal of this project was to provide an interesting real world project for the team to work on that would expand the team's knowledge in the COSC, CIT and electronics fields. This will be addressed in the following five areas;

- Software application and libraries
- Wireless communications
- Electronic components
- Programing languages
- Design planning

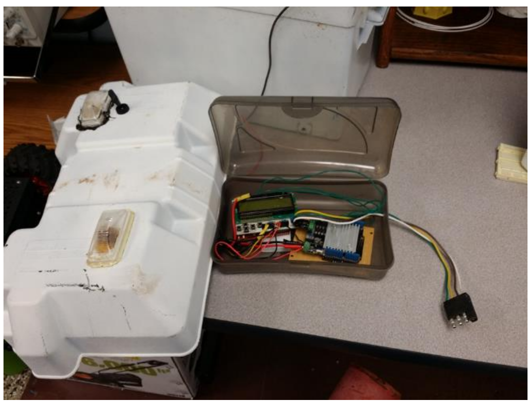
Software Application and Libraries

Although, during COSC and CIT classes, students are informed about the existence and benefits of software application and libraries, and they may even use them to a limited degree. This topic is generally not covered in entry level classes as the focus is often on the basics of programming code, such as, syntax, variable types, and conditional statements. However, having the knowledge that they exist and a basic idea of how they work, provided the students with a good foundation to consider how they might approach different options for accomplishing the programing tasks at hand. Some examples of these tasks included; the LCD screen for which the team evaluated three libraries, the standard LCD library, one that used shift registry, and another that used ic2. Another example, was menu options in which case two libraries were considered. In the end, the team decided it would be more efficient to create the menus through simple arrays. Additionally, while considering options to replace ARToolKit as the image recognition navigation system a number of applications were evaluated. For example, openCV, MATLAB, and Qualcomms Vuforia combined with the Unity game engine as an android application, a PC based option was also considered, using Sikuli which is a python based GUI automation tool. Although, the use and evaluation of the libraries and software application related to these tasks. Because, of these tasks the students gained a better understanding of the selection and use of libraries and software application. Likewise, this experience may have removed some of the frustration typically created in an instructional setting.

Wireless Communication

Wireless communication is virtually everywhere in today's computer driven world. In the classroom, however, this is in the form of wireless routers and Bluetooth connections with cellphone or tablets, with a focus on corporate infrastructure. The basic networking class nonetheless, provided the team with the concept of how a network is set up and its basic components. However, in this project we needed to connect multiple components with each other by means of wireless communication outside of the normal run of the mill wireless networks. The team needed to evaluate the following wireless systems and determine which would be best: Bluetooth, Xbee and RF transmitter/receivers. Each had its benefits and drawbacks. Bluetooth for example, can connect to multiple devices and can transmit a fairly moderate amount of data, but it is limited to line of sight at a very short distance, on the order of a few dozen feet. Whereas, Xbee, which is also limited to line of sight, but has a range of around 100 meters. However, one Xbee can only communicate with one other Xbee. Likewise RF transmitters/receivers can only communicate with others on the same channel, they as well are limited by line of sight, but can reach ranges well over 500m. However, to use them to transmit data. The frequency range must be mapped to a set of data. Given these pros and cons, and weighing them against the project requirements. The team determined if, for example, sending a signal from the intrusion detection system can be done with RF transmitter/receivers or if something more robust is needed. By evaluating and testing these systems, the team was provided with experiences and information that built upon the basic concepts of network structure and wireless communications. Along with, providing the knowledge that mobile devices and wireless routers are not the only way to communicate wirelessly.

Electronic Components



The variety of electronic components and their attributes can be overwhelming to the novice; nonetheless, they are an integral part of the technological era that we live in. Anyone dealing with them should know how to determine the correct component and how it works within a circuit. Accordingly, during introductory basic electrical theory classes most of the class time is often spent learning the various laws of electricity and identifying components and their characteristics. This project, however, provided the team with the opportunity to experiment and test different electrical components and learn how to find and determine if a component was adequate for its intended task. This required the use of datasheets, schematics and breadboard prototyping. This project provided the team with a rich environment to utilize critical thinking in a manner that was fulfilling. For example, as the project required the use of motors that would pull more amperage than the Arduino could handle, the team knew that a transistor would be required. Consequently, that would require the team to consult the datasheets for each transistor they thought might work and verify the maximum and minimum, voltage and amperage to determine if it would meet the requirements. Which is a stark contrast to their basic electrical class where they only learned to identify the component. Whereas, during the project they utilized their basic skills to build a complete system of circuits. With the ability to use components such as micro controllers, integrated chips, transistors and sensors of varying types, team members now have the tools and knowledge to use and further the skills learned in the classroom.

Programing Languages

Although most COSC and CIT classes use one programing language or another, there are many languages and useful scripting languages that are not often mentioned or covered. The project used applications that required the use of languages not often covered in the classes offered to them. During the process of understanding and determining the usefulness of these applications, the team was able to immerse themselves in languages that they would not likely encounter in the classroom. Such as, python while exploring the PC GUI automation tool, or C# and Java with the combination of Vuforia and Unity. By having a basic knowledge of multiple languages team members will have a better chance of getting a job in related fields; it may also inspire them to pursue higher degrees.

Design Planning

Design planning is an essential tool that has broad application. The project helped the team build and fine tune their ability to plan and design ideas. This skill set allows students to take dreams and turn them into plans. Design planning utilized schematics, use case diagrams and the Unified Modeling Language. Being able to read and use these planning tools has likely helped the team become more proficient in regards to future projects and class assignments. By having the ability to plan, design and follow through with ideas, team members are likely to be more successful in all areas of life.

Project Plan and Timelines

Task Number	Task Name and Objectives	Estimated duration	Actual Duration
	Explain project to team and organize into task groups.	1 day	1 Day
	Create parts list and order parts	1 week	6 days
1	Convert propane cannon • remove old mechanical systems • install and test solenoid • install and test spark generator • install electronic components and program microcontroller	1 week	3 weeks
2	Perimeter intrusion detection system. • cut and test PVC for laser • cut and test PVC for photoresistor • determine light level received by photoresistor from laser • attach laser to tripod • mount photoresistor to tripod • install electrical components and program microcontroller	1 week	1 week

3	Assemble robotic vehicle with a sound generating device controllable by both a handheld RC controller and Bluetooth connection. ● assemble the robot chassis ● attach electronics and Arduino microcontroller ● program and test robot via USB ● attach program and test Bluetooth connection ● attach program and test handheld RC controller ● attach program and test sound generating device	2 weeks	6 weeks
4	Program robot to be autonomous. ● attach program and test GPS ● setup and test ARToolKit ● calibrate cameras to ARToolKit ● test navigation with ARToolKit ● conduct comparative testing with GPS with ARToolKit	5 weeks	18 weeks Moved to its own research strand
5	Set system up in field and conduct test ● find suitable location and set propane cannon in place ● set perimeter intrusion detection system in place ● find suitable location and set cameras in place ● place robot ● test system	1 week	N/A
6	Create a user manual and schematics of the system	3 weeks	N/A

Due to the fact that when calculating the initial time frames for each task, the limitation of student participation was not taken into consideration. As a result, Time management was a leading factor in the premature closing of the project. Furthermore, the academic calendar year compounded the issue as team members were graduating and transferring to other institutions. Along with the onset of summer break. Leading to an insurmountable hurdle that caused the project to be closed prior to field testing of the project.

Task 1. Was delayed due to the system freezing up and not perform as expected. After troubleshooting the system. We found that an electromagnetic field created by the spark generator was at fault. Although the solution in the end was simple and a quick fix, we did not figure that out until after trying other more complex solutions first. Such as, using a diode to prevent an electrical force from traveling backwards through the system, or a noise filter to limit the interference.

Task 3. Was delayed significantly due to the failure of the motors that required the ordering of replacement parts, which ended up on back order for three weeks. However, during this time the team addressed the issue of battery life, resulting in the recognizing the potential of Proton exchange Membrane hydrogen (PEM) fuel cells.

Task 4. Was delayed due to the ARToolKits being completely ineffective for this project. As a result, the team started researching other application to replace the navigation system.

Task 5 & 6. Were not attempted due to time constraints issues, the ending of the academic school year, and extended research into making the robot autonomous, leading to the closure of the project before full implementation.

Project Development

The goal of the project was to develop a comprehensive system that would reduce the amount of crop damage caused by whitetail deer. The system design went smoothly; however, deployment and testing were not pursued due to time constraint issues, the ending of the academic school year, and extended research into making the robot autonomous. The overall project was successful in developing a model for future research and testing, and produced some unexpected secondary benefits, such as the additional research in augmented/virtual reality and Proton Exchange Membrane Fuel Cells.

Project implementation at a community college was exciting for both the researcher and the community college students. The team of community college students worked together in a cohesive manner and exceeded expectation when faced with major setbacks in the development of the project. The team took great pride in researching and justifying solutions to identified problems. Their positive attitude and professionalism showed from the kickoff meeting thru the closing of the project. While the team was disappointed to close the project prior to testing, the research process has continued as part of the community college experience.

Time management and the academic calendar year were the primary hurdle that caused the project to be closed prior to field testing of the project. In spring 2015, the project began as an optional activity for the college students, many of whom worked and all carried full time course loads. In hindsight, the timeline did not allow for a project of this scope to be fully realized. In addition to time constraints and semester break issues, problems occurred in three primary phases in the process: brainstorming, product design, and product development and prototyping.

The kickoff meeting that started the development process went very well and all members left feeling exuberant. Ironically, the level of enthusiasm hindered the creation of the components and parts list. Some of the team was so excited to come up with a top notch product they spent an exorbitant amount of time engrossed in all the possible solution.

Because the students were volunteers in the project, a daily meeting time was not easily achieved; therefore, a certain amount of time was spent redirecting and focusing the team. The team came back together and focused on creating a simple system and was then able to finish the parts list one day ahead of schedule.

We approached the conversion of the mechanical propane cannon and the perimeter intrusion detection system (PIDS) simultaneously. Removing the old mechanical system on the propane cannon and converting it to an electrical system went smoothly. In testing, however, the system would freeze up and not perform as expected. A considerable amount of time was lost troubleshooting the system. Which involved the team reproducing and isolating the symptoms, and then searching the Arduino and electronics forums for solutions. It was finally determined the culprit was an electromagnetic field created by the spark generator. Several solutions were attempted, including: diodes, noise suppressors and rewriting the software, these solutions were not successful. In the end, the best solution was simply moving to propane cannon farther away from the control box. Unfortunately the trouble shooting process caused this stage to go past the planned completion date by two weeks.

The perimeter intrusion detection system (PIDS) finished on time, but had some minor usability issues. The Xbee wireless system is easy to use and has a reasonable range, but is limited to line of sight. Which in the case of tall crops can be a problem. However, this can be overcome by moving the antenna to a higher elevation. On the other hand, it might be better to address this issue in future iterations of this system and find a wireless system with a reasonable range that is not limited to line of sight. Additionally, the use of a laser beam limits the (PIDS) to fairly level terrain, which theoretically will work in most farming areas as farming generally occurs in relatively flat areas. Although, the PIDS was proven to work in the laboratory, it will need to actually be field tested to prove its actual functionality. However, in future iterations of this system a better PIDS should be considered, such as fiber optics with a spectrum analyzer.

The robotic vehicle was programed to use RC and Bluetooth control. However, major problems arose, ranging from battery life, usability in loose soil and navigation issues. The battery life was a limiting factor anticipated in program development. The battery life of the robot is approximately 26 minutes. We hoped to overcome this with the use of an onboard solar panel. But a solar panel of a small enough size to fit on the robot, was not large enough to effectively recharge the battery. To deal with this problem we decided to research proton exchange membrane fuel cells. These showed great potential by extending the battery life from 26 minutes to over one hour. Potentially, with increased hydrogen storage and onboard electrolysis, lasting 3 hours to a week or better.

The robot developed additional issues during the testing phase, however. The Wild Thumper chassis, the robot prototype selected, was not suited for the terrain in which it was expected to operate. The motors ceased working on the Wild Thumper chassis. This was realized when we took it for a test drive in an area that had loose sandy soil. After driving around for a few seconds in the loose soil, it was noticed that tires would make large roster tails when traveling at full speed. This was identified as a major problem given the amount of electronics on board the robot. Within a few minutes of trying slower speeds the first motor stopped working making the vehicle inoperable. Furthermore, after the team took the robot inside and gave it a thorough cleaning, a second motor quit working a few days later.

Navigation of the robot was an area that required modifications to the original scope of work. Initially the ARToolkit appeared to be a feasible solution to develop a navigation system. After a few preliminary tests, however, we soon realized that with moderately priced optics the object recognition navigation system using the ARToolKit would be completely useless at any distance beyond approximately 50ft. The size of the target, at any significant distance would have to be so big that it would be unmanageable. As a result, we immediately started researching other applications to navigate the robot in the field, some promising applications are: Qualcomm's Vuforia in conjunction with Unity's game engine. Although, game design may seem an unlikely candidate for robotic navigation, while testing the application for a completely unrelated use; we found it was very successful at navigating a virtual maze by simply tracking the change in the location of objects in the camera view. This would alleviate the need for multiple cameras tracking a large target all across a field. However, this concept will require much more research and testing, as the team has not found any documentation of these application being used for this purpose.

In closing, the project was closed due to time constraints, component issues and implementation hurdles prior to field testing. The results of the project have been used to start new and better focused research objectives for this year's community college students. The robot system navigation and battery usage are the foundation for two smaller scale research projects. The research for the navigation system is based in augmented/virtual reality in which we will be taking a close look at the condition under which the camera can track movement. Along with, its rate of deviation over time and distance. The second research strand that has resulted from this project pertains to extending the operational time of the system, though the use of a PEM fuel cell. Where we will look at the amount of time and distance the fuel cell will extend the performance of the robot compared to a battery alone. Furthermore, we will look into the feasibility of storing and producing hydrogen on-board the robot.

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