A.I.V.

Autonomous Irrigation Vehicle

Senior Design 1 Final Document

SAMUEL M. RICHIE, PH.D

Sponsored by: Guard Dog Valves

Group Number 4 Members:
Joshua Betetta (EE)
Parameswari Chandrasekar (CpE)
Stuart Munich (CpE)
Roberto Santos (EE)

Table of Contents

Table of Figures

List of Tables

List of Formulas

1.Executive Summary

Programmable Revolutionary Irrigation for a Sustainable Environment is a project that aims to change how modern homes will be irrigating their property. Originally, the idea of revolutionizing modern home irrigation systems was to restructure the valve layout and control of a typical irrigation system. Most modern homes have an irrigation system that have a valve that controls each sectioned zone on the property. The group has proposed to replace that system with an innovative solution of having one valve control all of the sections. This manner of water management and control would allow the consumer to save on water usage.

Once the group had met up with the sponsor and other groups that had petitioned to work with the sponsor, it had been decided to revolutionize the modern home irrigation system by creating an autonomous irrigation vehicle. The newly proposed autonomous irrigation vehicle was to be outfitted with a water tank, a home base, and a mesh network of moisture sensors. After meeting and discussing with the other groups, the autonomous irrigation vehicle had a few revisions. The main revisions being that the original water tank size was too large which had to be scaled down and then completely removed. When the water tank was scaled down to a smaller size, a tethered hose was proposed to be used in unison with the tank. At the same time, there was to be a solar panel installed on the home base but was later then removed. The final revision of the autonomous irrigation vehicle had the water tank completely removed, solar panels removed, and have a tethered hose from the home base.

As such, the final revision of the autonomous irrigation vehicle will be equipped with a tethered hose, be able to recharge its onboard battery at the home base and be able to communicate with the mesh network of moisture sensors. With the autonomous irrigation vehicle having a tethered hose, the vehicle itself will have an easier time traversing its given environment. The autonomous irrigation vehicle will have a sprinkler head which will be activated by a solenoid that is located at the home base. The activation of the solenoid will be triggered by the autonomous irrigation vehicle itself once it receives data from the mesh network of moisture sensors.

The setup of the mesh network of the moisture sensors is a complicated yet simple method. In essence, the operation of the mesh network behaves a colony of information. That is to say that whatever information a moisture sensor has, it will relay its data and information to the nearest moisture sensor on the network. From there, the moisture sensor that receives the information will be able to relay the received data as well as transmit its own moisture data. This effect will branch out like a spiderweb of information until all of the moisture sensors on the mesh network have information from all of the other moisture sensors. This set up is crucial since the home base and the autonomous irrigation vehicle will also be communicating with the mesh network of moisture sensors that are already in place.

The home base operation will also be a huge impact on the autonomous irrigation vehicle operations. The home base will be the starting point of the autonomous irrigation vehicle. From here, the autonomous irrigation vehicle will venture and begin taking in data. While the autonomous irrigation vehicle is out and about, the home base will be monitoring the water pressure and as well as waiting for it receive a signal from the autonomous irrigation vehicle. The signal will activate a solenoid at the home base which will then send water to the autonomous irrigation vehicle to begin watering the designated area. While the autonomous irrigation vehicle is at the home base, it will be able to recharge its onboard battery.

The autonomous irrigation vehicle will also be working autonomously as the namesake says. In order to achieve autonomous operations for the autonomous irrigation vehicle, it will need to be programmed with an algorithm and equipped with a few sensors. The sensors will provide the autonomous irrigation vehicle with vision intelligence, the ability to analyze and collect data from its immediate surrounding environment. To process the information and data received from the sensors, a machine learning algorithm will be incorporated to the autonomous irrigation vehicle's programming. Machine learning algorithms will allow the autonomous irrigation vehicle to learn from its previous experiences as well as recognize patterns. With these sensors and algorithms, the autonomous irrigation vehicle will behave and operate autonomously while avoiding any obstacles in its direct path.

The project consists of 3 working groups. The first group is the mechanical engineering group which will handle the home base and water flow aspect of the autonomous irrigation vehicle. The second group is comprised of electrical and computer engineers and are in charge of the autonomous vehicle's autonomous operation. The third group is also comprised of electrical and computer engineers and are in charge of the mesh network for all devices to communicate with each other. The parent sponsor is Guard Dog Valves.

2.Project Narrative Description

While performing marketing analysis of modern home irrigation systems, the group found that the majority of competitive products are using the classical method of transporting water through irrigation piping. The team's original idea was to innovate the yard's valve layout. Most common home irrigation systems have a valve that controls a section of sprinklers; for example, one valve controls the backyard while another valve controls the front yard as seen in Figure 1.

In order to innovate the team proposed a modern approach which would have an individual sprinkler head control as seen in Figure 2. The control of the individual water flow would conserve water usage. After a couple of meetings with the sponsor the team suggested to possibly not use pipes, so in pursuance of revolutionizing the modern home irrigation system, the group proposes to use an autonomous mobile vehicle which carries a scalable quantity of water, as well as a hose attachment which would be used to irrigate the dry portions of the yard. Allocating the water with this kind of precision and efficiency would save the consumer money by cutting down the costs of water usage through accurate data.

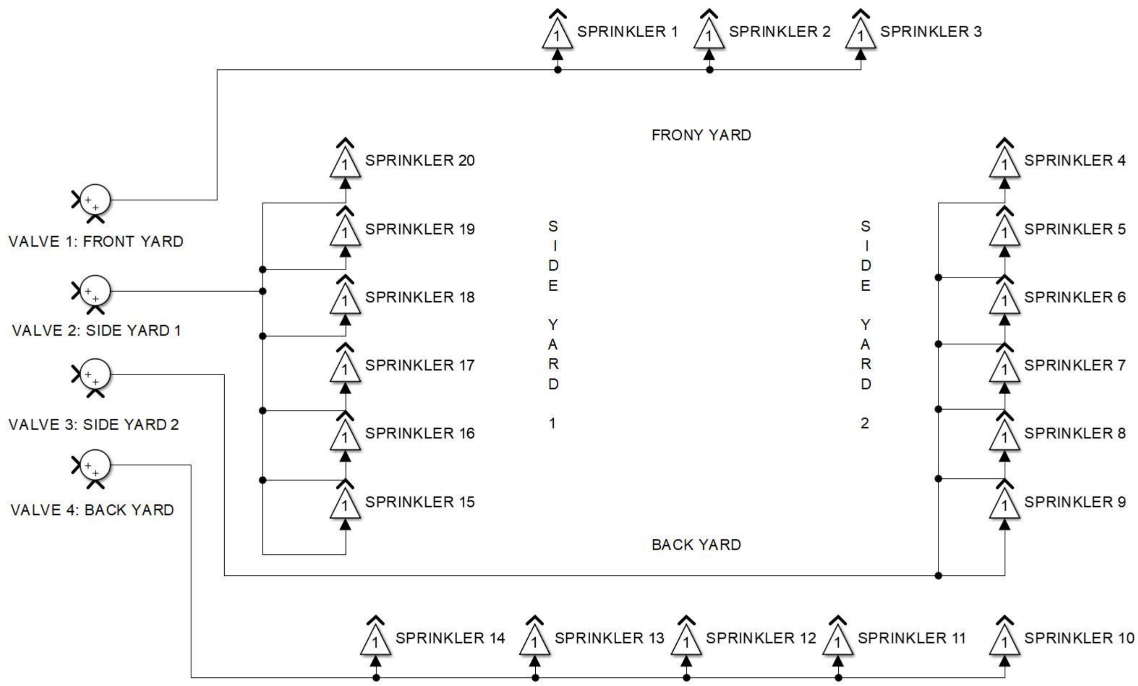


Figure 1: Sectional Valve Layout

Our autonomous vehicle will operate using vision intelligence and machine learning algorithms that utilize data received from a Light Detection and Ranging sensor (LIDAR). Visual intelligence enables the vehicle to identify obstacles in the surrounding environment and avoid collisions. Machine learning algorithms allow the vehicle to learn and make predictions based on data stored from previous experiences by recognizing patterns in the visual signals. These algorithms will allow the vehicle to adapt and traverse new environments.

The time and location of when and where the vehicle will water is dependent on a mesh network of soil moisture sensors. The mesh network will work with a central hub that is able to communicate with all of the moisture sensors within range to collect and return the collected data. The sensors within range of the central hub will relay the message to other neighboring sensors outside of the central hub's range, and so on to other neighbors, whereby the central hub will eventually obtain all of the information available from all of the sensors on the mesh network. Depending on the type of grass and moisture desired, the vehicle will be dispatched to water the location deprived of moisture. Another feature discussed in the meeting has been watering other plants other than grass in the yard. This will be accomplished by allowing the user to program the amount of water needed by that specific pant using a graphical user interface (GUI). Each plant will have a specific Radio-frequency identification (RFID) so that the vehicle will know where the plants are and how much to water them based on the user input.

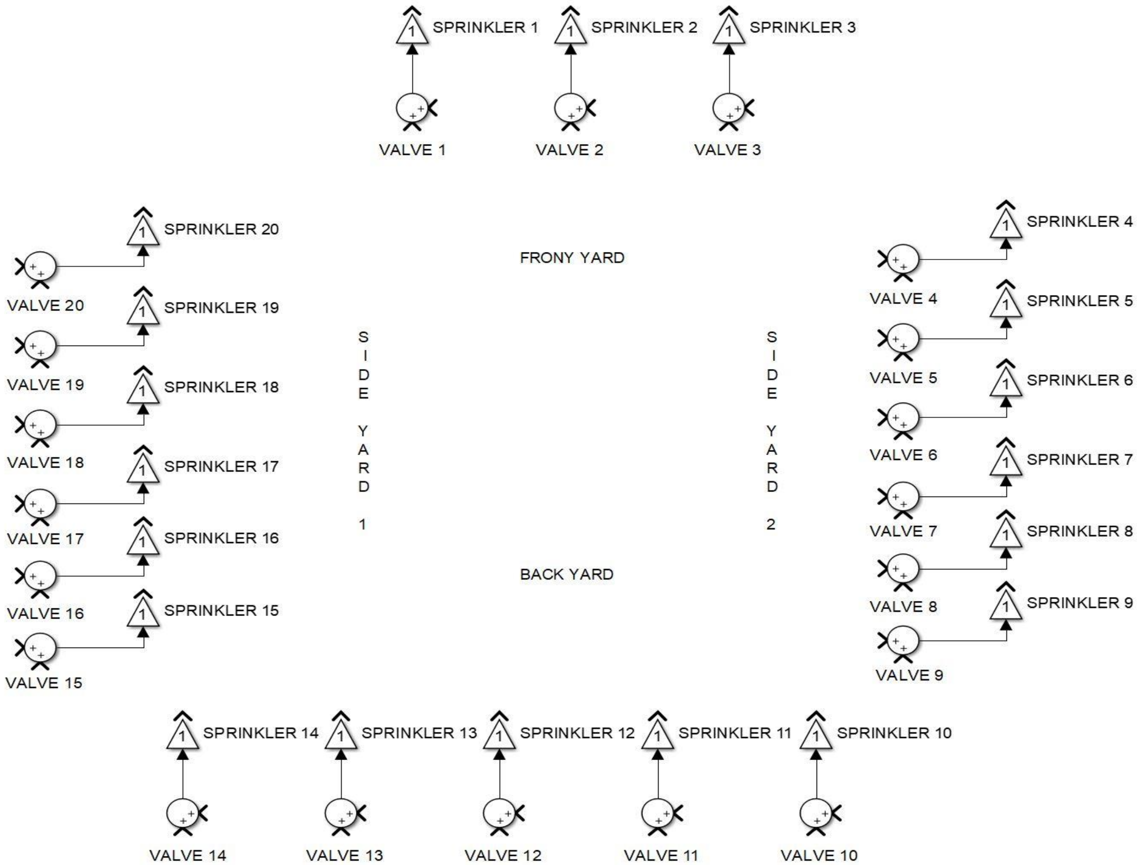


Figure 2: Individual Valve Layout

When the vehicle is not in use, it will be stationed at a home base until it is called upon to dispense water based on data from the sensors to water a designated area. The home base will feature a water reservoir and a charging station. The vehicle will be able to refill its watering tank from the water reservoir. The water reservoir will also be able to collect rainwater for reuse as well as have a garden hose attachment in case there is not a sufficient amount of water. For proof of concept, the team has decided to make a hybrid system which includes a small tank as mentioned above, but most of the water will come from a hose. The hose system will automatically retract into a spool providing an adequate amount of slack for the irrigation vehicle to traverse a yard. While at home base, the autonomous vehicle will be able to recharge its battery thereby powering its DC motors, the PCB it houses, and the sensors. Home base will also be powered by a solar panel to ensure a clean and renewable source of energy. For proof of concept, the team has decided to add a hose to the vehicle, an alternating current (AC) power cord will also be used to provide power most of the time. Through these proposed means, irrigation methods will be revolutionized. Pictured below in Figure 3 depicts the overall system diagram.

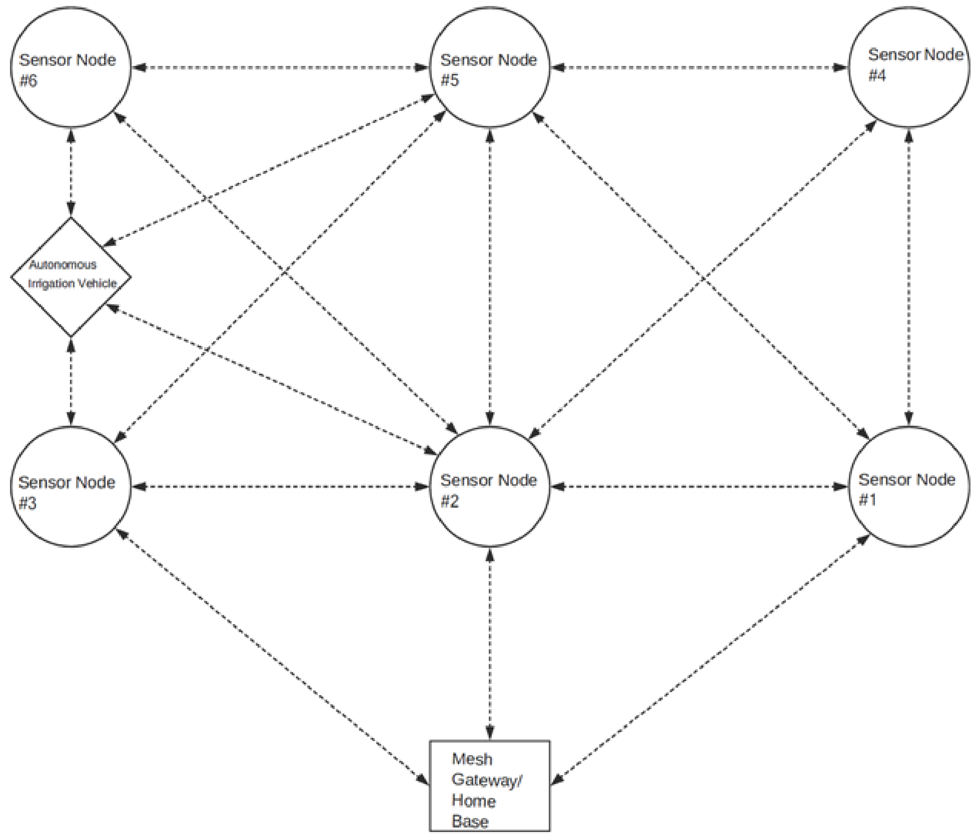


Figure 3: Overall System Schematic

The mesh network portion of the project will be researched and designed by another Electrical/Computer engineering team which is part of the bigger sponsor. The home base, muscle and skeleton of the vehicle, and the water flow elements will be researched and designed by the Mechanical team which is also part of the bigger Guard Dog Valves sponsored team.

2.1 Team Motivation

The team's motivation to choose this specific project comes from one of the first assignments completed for our Senior Design 1 class. The assignment was given before we had picked teams and had each student in the class come up with an idea for a project. Two of the members of our group came up with ideas that included renewable energy sources. The first idea was a portable electronic charger that could function using solar, wind, and hydro energy. The second was a farming robot that would autonomously plant the seeds and grow the plants. Once we began forming teams, we decided to make the farming robot, but power the robot using the three-renewable energy sources form the charger. As professor Samuel M. Richie presented the sponsored projects, we became interested in the Guard Dog Valves irrigation project. Since this project was about being green and saving water the team was excited that something similar to our original idea was proposed, and we decided to take on the challenge.

Another factor motivating the team is that we all live and go to school and work in Florida. Water conservation is a big deal in the state of Florida because of the Floridan aquifer. The is the lifeline for all the great natural springs in Florida that tourists and locals alike enjoy all year long especially in the summer months. The Floridan aquifer is also used by all the citizens of the state as a water source. As water in the springs is depleted they turn into sinkholes. Our project could help preserve the springs.

2.2 Sponsor Inspired Motivation

The Guard Dog Valves sponsor spoke to us in the meeting that one of the reasons for wanting to produce this product was an article written by the University of Florida. The article states: "*Researcher Michael Dukes found that for three of four soil-moisture sensors tested, water savings ranged from 69 percent to 92 percent, compared to grass watered without the help of sensors*." (Anderson). The article also mentions "*Taking the human component out of the watering process certainly seems to help reduce overwatering, said Kathy Scott, section manager for conservation projects with the Southwest Florida Water Management District, which sets water policy for some 4.5 million residents*." (Anderson). In addition, it mentions that over watering the lawn is actually a bad thing because the grass does not grow long roots because it thinks that water will always be available. The short roots make the lawn prone to diseases and pests. In summary, overwatering not only costs more money but makes the grass weak. The product being developed hopes to use moisture sensors in conjunction with the mesh communication network, and the irrigation vehicle to take the human factor out of watering residential lawns and saving customers money and making their lawns healthy and strong.

Another motivation article shared by Guard Dog Valves is published by the EPA. The article is about how during the summer months the hotter weather causes more water to be needed, as much as two to four times the amount. Since most home irrigation systems are not smart and must be manually changed, a lot of homeowners forget to adjust them back after the summer is over. Not adjusting the irrigation system causes over watering during the colder months that do not require as much water. Even though summertime requires more water, a lot of overwatering occurs according to the article "*Depending on the region, homeowners use between 30 and 70 percent of their water outdoors." (When it's Hot)" and Experts estimate that "50 percent of the water we use outdoors goes to waste from evaporation, wind, or runoff due to overwatering." (When it's Hot).* The article also gives customers tips for saving money:

1. The first tip is knowing how much water the lawn needs and that it's better to water during early morning or late afternoon when the sun is not as hot.

2. The second tip is upgrading to a smarter home irrigation system with local weather data.

3. Another tip is for residents to be aware of the different zones in their irrigation systems and adjust the zones depending on the type of plants and of much time they spend in the sun or in the shade.

The product we are designing will allow the consumer not to have to remember to change the setting after summers are over. The autonomous irrigation vehicle will automatically know how much water each zone of the lawn needs, so the consumer will not have to worry about that or how much time the zones are in the sun or the shade. The autonomous irrigation vehicle will save money by water during the hours that are most beneficial for the lawn. This one-time purchase will cover all the recommendations made in the article allowing the consumer to have the ease of mind that they are saving money and the yard is properly hydrated. All of these factors make the autonomous irrigation vehicle a great product for Guard Dog Valve to market.

2.3 Motivation Goals

The Goals for the project are for the autonomous irrigation vehicle to provide the consumer with an irrigation system that does not over water the grass causing shallow roots that make the lawn more susceptible to pests and diseases and cost more money, not just in the water bill but also the extra money spent on curing the diseases and getting rid of the pests. While properly irrigating the lawn will not get rid of diseases and pests it will allow the grass to grow long deep roots that making it strong and therefore less susceptible to the pests and diseases. These goals will all be achieved by removing the human factor from the whole process.

The lawn caretaker will no longer have to remember to change the automatic timers as the seasons change. They will also not need to be aware of how much water the lawn needs or if it has rained recently. How much sun or shade a certain zone gets during the weather changes will not need to be something the consumer has to think about anymore. These factors are great selling point for the autonomous irrigation vehicle.

The first time the consumer sets up the autonomous irrigation vehicle they will have to input the days and times the local government allows them to water their yard so that autonomous irrigation vehicle does not cause them to pay a fine for watering on restricted times or days. As well as install the proper amount of mesh network moisture sensors. The amount of mesh network moisture sensors will depend on the size of the lawn. Once that is complete, they can be worry free about the yard irrigation. With a single investment, the consumer will have more free time to do more important things while knowing they will have a properly irrigated lawn that is healthy, strong, and grows deep roots all while saving money.

2.4 Objectives

The objectives of the autonomous irrigation vehicle are simple yet at the same time, are of great significance. As a group, we have discussed about what the autonomous irrigation vehicle's main objectives should be in order to satisfy customer needs as well as market needs. With that being said, determining the objectives for the autonomous irrigation vehicle was no easy task as the vehicle itself has gone through a few revisions since its conception. As the autonomous irrigation vehicle evolved, the objectives evolved alongside the vehicles technological development. Along with the evolution of the autonomous irrigation vehicle, there were considerations as to what would make the project itself feasible and also have objectives that pertained to the vehicle's process of operations. As the autonomous irrigation vehicle evolved, some of the technologies and objectives have been changed or removed but these decisions were made in order for the vehicle to succeed given its surroundings.

The Main Objectives:

- Effectively irrigate a 30x20 ft plot of grass
- Effortlessly avoid obstacles
- Traverse terrain with minimum error
- Reduce water consumption
- Effective communication with mesh network of sensors
- Sense battery capacity
- Control rate of water flow

As mentioned before, the list of main objectives above is what remains after technological growth of the autonomous irrigation vehicle. The 30 by 20 feet plot of land is the average size of a given backyard that is assigned from a typical neighborhood in which homes are built with relatively the same home design and layout. As such, the autonomous irrigation vehicle function will be dispensing water in the most uniform fashion to provide the backyard with a sufficient amount of water. In order for the autonomous irrigation vehicle to dispense the water in a uniform fashion, the vehicle itself will need to be able to avoid and travel around whatever obstacles may be in its way in any given backyard. As the autonomous irrigation vehicle itself is a machine, it will be prone to making errors while it travels. As this is an expected outcome, the group will do its best to mitigate errors whilst the autonomous irrigation vehicle is traveling through machine learning algorithms. As the autonomous irrigation vehicle traverses the plot of land more and more, it will adapt and learn its surroundings thus reducing errors while traveling as well avoiding obstacles. While the autonomous irrigation vehicle is traveling and dispensing water to sections of the backyard that have signaled that the area's soil moisture is low, the vehicle will be effectively delivering water to aforementioned designated areas. Water consumption is an elephantine problem most consumers encounter whilst irrigating and maintaining their lawn so the autonomous irrigation vehicle aims to cut down water consumption by only delivering the sufficient amount of water that the designated area requires. To accomplish this objective, the autonomous irrigation vehicle will have a water flow sensor that will be able to determine how much water has been dispensed and then proceed to shut off the water valve in order to minimize water consumption. For the autonomous irrigation vehicle to properly dispense the sufficient amount of water that is needed by the designated area, it must be able to effectively communicate with the mesh network of sensor. The mesh network of sensors will be providing the autonomous irrigation vehicle with real time updates and soil moisture data which the vehicle will use to determine whether or not a designated area will require watering. Whilst the autonomous irrigation vehicle is on a watering venture, there will be times where the vehicle's on board battery will start to have low reserves of energy. The autonomous irrigation vehicle will need to determine whether or not to continue to the next designated watering area or to return to the home base in order for the vehicle to recharge its battery.

As previously mentioned, the autonomous irrigation vehicle has been revisioned a couple of times before deciding on the final product's direction, architecture, and functions. With the first revision, the initial project idea and suggestion called to make a mesh network for all of the sensors in the ground to be able to communicate with each other and provide other sensors in the designated region, the data from each individual sensor. Each sensor was to collect a variety of data that would be uploaded into the mesh network and sent to the other sensors on the network to communicate with the user or whatever device that was also connected to the mesh network. The initial project was dropped and then became an autonomous irrigation vehicle that carried a water tank in order to dispense water in designated areas based on the data received from the sensors in the mesh network. The autonomous irrigation vehicle also had a proposed solar panel installed on the vehicle itself to charge its onboard battery supply. The autonomous irrigation vehicle would be connected to the mesh network as well to be able to analyze and determine where to water and how much water was needed in that designated area. Due the mountainous encumbrance of the water tank and the added weight from the water, the idea of the water tank on the vehicle was reduced from a 300 gallon tank to a mere 3 gallon tank. Also, the proposed solar panel on the autonomous irrigation vehicle was to be installed on the home base where the vehicle would be able to charge and refill its water tank. In the autonomous irrigation vehicle's last revision, the water tank had been completely scrapped to lower power requirements and allow the consumer a user friendly product. As such, the autonomous irrigation vehicle's previous objectives were practically the same but with additional but now unemployable objectives.

The Previous Objectives

- Effectively irrigate a 30x20 ft plot of grass
- Effortlessly avoid obstacles
- On-the-go battery charging with Solar Panel
- Traverse terrain with minimum error
- Reduce water consumption
- Carry sufficient quantity of water

- Effective communication with mesh network of sensors
- Control rate of water flow

As previously mentioned, the autonomous irrigation vehicle was to be installed with a solar panel to charge the vehicle's onboard battery as it traversed its given terrain. Along with the once proposed solar panel, a water tank was also envisioned to be installed on the autonomous irrigation vehicle in order for the vehicle to irrigate any designated area that required watering. A solar panel was also proposed to be installed but was then redacted to allow more power to be used by the autonomous irrigation vehicle. After careful consideration, the autonomous irrigation vehicle is now in its final stage of research and development.

2.5 Requirement Specifications

In regard to the specifications of the given projects, there are a few sensors that will be utilized by the autonomous irrigation vehicle in order to traverse whatever terrain the vehicle is in as well as determining proper amount of water to be dispensed. Aside from sensors, the vehicle will have a printed circuit board and microcontroller working in unison in order to communicate with the vehicle's sensors as well as the moisture sensors installed in the ground. The vehicle's battery life will have to be designed to output a sufficient amount of power that the vehicle will require whether traversing the terrain with a varying amount of water in the water tank or the varying rate of water flow while irrigating designated areas and plants. Power management will be a critical asset for the autonomous irrigation vehicle to achieve a successful irrigation pattern and effective object detection.
Sensors such as LIDAR, power management, and water level will allow the vehicle to safely traverse its surrounding terrain, monitor battery charge and water tank's level in order to determine whether or not to return to the home base to recharge and refill its battery and water tank. The LIDAR sensor will have range from 2cm up to 6m with a 180 degree view to detect and avoid obstacles in its immediate frontal surroundings. A battery management sensor will be installed in order to monitor the autonomous irrigation vehicles level of battery charge. When the level of charge reaches a certain point, a signal will be transmitted to the vehicle indicating the vehicle to return to its home base. In order for the vehicle to determine where to dispense water, it will need a wireless receiver antenna and transmitter to communicate with the measurement sensors that are on the mesh network. As the vehicle will be dispensing water to designated areas, its water level will drop so a water level sensor will also be implemented in the vehicles design. As with the battery management sensor, a signal at a certain threshold of water will indicate that the vehicle needs to return to the home base to refill its water tank.

In order for the vehicle to make the decisions of where to dispense water and when to return to home base, there will be a need for a printed circuit board and microcontroller to be installed on the vehicle. printed circuit board and microcontroller will have to be designed in a manner that they are small enough for both of the components to fit comfortably on the autonomous irrigation vehicle. The printed circuit board will function as an intermediary between the sensor data and data processing of the microcontroller. Signals that are generated by the on board sensors will be communicated with the microcontroller in order to determine where water will be dispense, if there are any obstacles in the vehicle's path, and whether or not the vehicle needs to return to home base to refill its water tank or recharge its battery. The microcontroller will be handling all of the sensor data processing as well as movement and obstacle detection per its installed motors and LIDAR sensor, respectively. With the autonomous irrigation vehicle being capable of movement, there will need to be a certain velocity that the vehicle can safely traverse the terrain that it is in so as to minimize jerking motions.

In terms of power demand, the autonomous irrigation vehicle will be requiring a substantial amount of power in order to traverse the terrain with the water tank. Depending on how much water the tank will be carrying, will dictate how much power will be needed in order for the vehicle to travel with the given weight. As such, a battery unit with a sufficient amount of voltage and amperage will be needed. Furthermore, as the vehicle itself will be operating out in the open, the battery will either need to be housed to prevent damage from the elements, have a specific amount of water resistance, or have a high resilience to outdoor activity. The power generated by the battery will also need to be distributed accordingly in regard to the demands of the sensors, motors, and water dispensing mechanism.

In regard to dispensing water at the designated watering location, the autonomous irrigation vehicle will have an additional method of transporting water. The vehicle will have a water tank attached as well as a tethered hose. The purpose of the hose is to minimize power consumption of the vehicle's on board power supply as the water tank can add additional weight which requires a higher power output. With the hose attached, the water tank can be scaled down in size to minimize the weight, size, and power consumption of the vehicle itself. With the help of the sensors and microcontroller, the vehicle will be able to detect if the hose has been entangled with an obstacle. If the case arises of an entangled hose, the vehicle will be able to self disconnect the hose and continue to water with its own water supply. Once the hose has been detached from the vehicle itself, it will begin to retract itself to the home base or where ever the base of the hose is located.

The original project was a sensor based smart technology which focused on controlling the flow of water to sprinkler heads. Each of the sprinkler head would have had a sensor attached to it which would take in readings for soil moisture, ambient temperature, and online weather data for rain. When the data is read and processed, a microcontroller would have processed the data and would have determined whether or not the designated sprinkler head would dispense water to the designated area. In order to power the sensors on each of the sprinkler heads, a small but efficient solar panel would have been implemented to have provided power to the unit. With each of the sprinkler head sensors collecting data from the sensors, a machine learning algorithm could have been implemented to autonomously optimize watering schedules. In order to for the system to optimize the watering schedules, each of the sensors would have to been connected or linked to each other in to what is called a mesh network. In the mesh network, each of the sensors would be communicating and relaying data with each other with would provide the algorithm with enough data to begin to learn how to optimize watering schedule. Along with the proposed mesh network of sensors, mobile device application would have been designed to accompany the propose sensor technology. With the application on the mobile device, it would have been able to give the end user the ability to alter and directly be able to water any designated area with the sprinkler that was in the area. By giving the user, or customer, the ability to directly control the watering schedule, the system could also learn and develop routines based on the user's inputs for the watering schedule. Along with providing the customer with the opportunity to control, designate, and set watering schedules, the mobile device application would have also provided the customer with valuable data such as moisture levels of the soil of a specific region, errors that may have occurred, and provide the user with current an up to date watering routines. Below is Table 1 which lays out the targeted specification goals.

	Measures
Vehicle Size	21.10" x 24.13" x 5.55" (L x W x H)
Obstacle Detection Distance	2 cm to 6 m
Time to water designated area	≤1 hour per zone
Targeted rate of Water Flow	24 Gallons Per Minute
Average Lawn Size	$10890 ft^2$ (.25 acre)
Battery Life	≤1 hour
printed circuit board size	6" x 5" (L x W)

Table 1: Project Specifications

As previously mentioned, the list has a desired goal of specifications that the team would prefer to achieve in order to implement a successful working autonomous irrigation vehicle. The size of the autonomous irrigation vehicle has been decided to be an efficient size to allow safe and uninhibited travel through a grassy terrain. Obstacle detection is an enormous hurdle that will be dealt with accordingly and successfully. Water deployment will also play a crucial role in an successful performance for the autonomous irrigation vehicle.

2.6 House of Quality

The House of quality shown in Figure 4 represents inner relationship between the marketing requirement and engineering requirements as well as the correlation matrix shows how the engineering requirement impact each other. Each requirement is associated with positive or negative polarity.

The marking requirements are focused on what the customer need and expects. Cost is one of the main constraint in marking requirement. The cost constraint represents how much lower the customers want the price to be and it also has negative polarity which shows that the lower the cost, higher the demand for the product. Likewise, Power consumption is a measure of how much power the autonomous irrigation vehicle would consume to complete the target tasks.

User friendliness is another crucial part of marketing requirement because it defines how easily the autonomous irrigation vehicle can be operated by the end user. As well as the function of the vehicle should to easy to maintain. When customers buy new product (vehicle) first they check how reliable the product is. The reliability represents how well the autonomous irrigation vehicle will perform for this specific task. Increasing the user friendliness and reliability of the product will make the product more desirable among buyers, so both requirements represented in positive polarity.

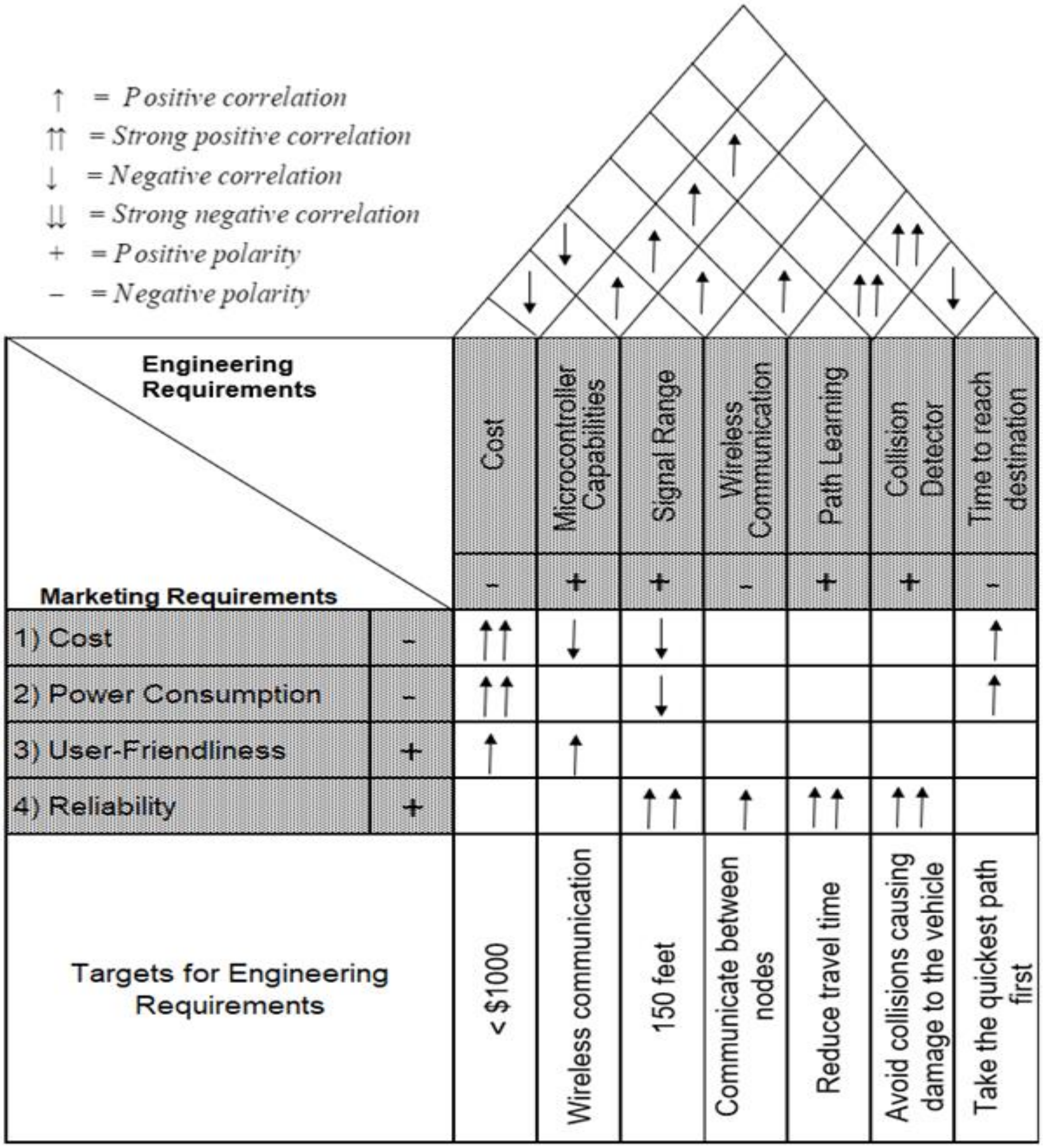


Figure 4: House of Quality

The engineering requirements represents how the engineers could design the product which will meet customer needs. As we talked about in marking requirement the lower the cost is better the demand. Thus, the cost is representing in negative polarity. Since Microcontroller is the brain of the autonomous irrigation vehicle, microcontroller enable engineers to interface mesh network and autonomous irrigation vehicle. Having a high capabilities microcontroller will allow engineers to reach the target more efficiently. Evidently the signal range is another significant part of engineering requirement. Each sensor node must communicate with microcontroller. Thus, the microcontroller capabilities and signal range are represented in positive polarity. Path learning will help the vehicle to reach the target node in the quickest way as well as it helps the autonomous irrigation vehicle to avoid the collision. Evidently Increase the collision detection and path learning will make the vehicle more desirable.

2.6.1 Signal Range

As the autonomous irrigation vehicle will be communicating with the mesh network of sensors that will be placed in the given terrain of a customer, signal ranging will be a determining factor. The autonomous irrigation vehicle will need to have the ability to effectively communicate with the sensors in the mesh network and in order to do so, it will need a suitable and sufficient amount of signal range. The signal range of the autonomous irrigation vehicle will be determined by a few factors. The first factor will be based on the power draw of the wireless communication sensor that will be implemented in order to allow proper communication between the sensors. The second determining factor will be the distance between the location of the sensor node and the present location of the autonomous irrigation vehicle.

IEEE 802.15 operates as a radio wave which is an electromagnetic field. Through an electromagnetic field, information can be sent and received by 2 or more components. The electromagnetic field range is given by a combination of Maxwell's equations taking the form of a electromagnetic wave in a volume of free space. These fields are impacted not only by time but also by electric potential as well as the distance between 2 points. When both are combined, they generate an electromagnetic field in which components can communicate with each other.

Effective communication will play a critical role in the successful execution of the autonomous irrigation vehicle delivery of water to certain designated areas. Accomplishing the communication will be determined by the effectiveness and strength of the autonomous irrigation vehicle's onboard wireless communication device. As such, there are multiple wireless signals that can be used. For instance, based on the Institute of Electrical and Electronics Engineers (IEEE for short) association standards, the 802.15 radio frequency, a wireless personal area network, operates on the ISM (Industrial, Scientific, and Medical) band and is commonly used for 2 pieces of hardware to communicate with each other. The IEEE 802.15 comes in many different variations but due to the autonomous irrigation vehicle's needs for wireless communication, only four different types of wireless personal area network will be considered.

IEEE 802.15.1 is a task group that is based on bluetooth technology. That is to say that it defines physical layer and media access control specifications within a personal operating space that allows wireless connection of fixed, portable, and moving devices. IEEE 802.15.4 is a low data rate WPAN which promotes a very long battery life as well as providing a very low level of complexity. IEEE 802.15.4a is an amendment for the IEEE 802.15.4 which specifies additional physical layers thus providing higher precision, throughput, a longer range, lower power consumption as well as cost. IEEE 802.15.4b is an improvement to the IEEE 802.15.4a that reduced complexity and increased flexibility among security key usage. Through careful research and consideration, an acceptable device has been chosen.

2.6.2 Wireless Communication

An effective method of communication must be established in order for the autonomous irrigation vehicle to be able to dispense water accordingly and efficiently to certain designated areas. The mesh network of sensors that will be placed within the autonomous irrigation vehicle's given terrain, will communicate with the vehicle as it traverses the given terrain. The autonomous irrigation vehicle will be connected to the mesh network of sensors in order to determine which designated areas requiring water and proceed to the location relayed by the sensors. In order to accomplish an effective and efficient method of communication between the autonomous irrigation vehicle and the mesh network of sensors, three types of wireless personal area networks have been considered.

With IEEE 802.15, a wireless personal area network is established which allows the interconnectability of multiple devices within a certain designated area. IEEE 802.15 operates within the 2.4 gigahertz frequency band. Another perk of the IEEE 802.15 standard is that it allows any two or more wireless personal area network equipped devices to be able to communicate with each other, a mesh network.

2.6.3 Path Learning

Path learning is a crucial component of engineering requirement. The autonomous irrigation system should be able to reach the destination midpoint in specific time. The impact of path learning in marketing requirement is reliability. autonomous irrigation system takes some time to learn the path at the beginning while it travels to the destination midpoints. When autonomous irrigation vehicle travel to the destination midpoints, it uses the computer vision obstacle detection system to detect any obstacles such as any hard objects, big stone, small tree, lawn status and etc. Once it detects those obstacles, it updates the map. And whenever the autonomous irrigation vehicle travel to the midpoints it keeps update the map constantly. Having this updated map data wound help the autonomous vehicle to reach the target points quickly. Besides, the goal of using path learning in this project is to reach the destination midpoint or midpoints in the quickest possible time. Having this updated map data and effective path algorithm would help to reach the goal this component. In addition, path learning algorithm which is the nearest neighbor algorithm (NNA) will generate the shortest path to reach the target node and make sure that the vehicle water the lawn effectively. Also, path learning has a strong correlation with reliability. The better the autonomous irrigation vehicle learns the path the higher the reliability of the product. Evidently, Increase the path learning will make the vehicle more desirable.

2.6.4 Collision Detector

Collision detector is another significant component of autonomous irrigation vehicle. During the learning phase the autonomous irrigation system takes some time to learn the path while it travel to the destination midpoints as well as it uses the computer vision obstacle detection system to detect any obstacles such as hard objects, big stone, small tree, lawn status and flipping over pond. Once the computer vision obstacle detection system detects those obstacles, it updates the map. And whenever the autonomous irrigation vehicle travel to the midpoints it keeps update the map constantly.

Having this updated map data wound able to help the autonomous vehicle to reach the target points without being stuck by any obstacles. In addition, all of this data will be necessary for the computer vision obstacle detection system to safely travel around the lawn to deliver the needed water. Since we want the collision detector to have more capability to detect the obstacles, the collision detector is represented in positive polarity in the house of quality. Also, it has strong positive correlation with one of the marketing requirement of the reliability. In marketing perspective, the goal of the collision detector is to increase the reliability of the autonomous irrigation vehicle. Evidently, Increase the collision detection will make the vehicle more desirable.

2.6.5 Time to Reach Destination

Time to reach destination is important factor of engineering requirement. The autonomous irrigation vehicle has to meet the destination midpoint within the specific time. The mesh network will provide the sensor details such as which sensors need water and where is located in the two dimensional array. Reaching the midpoint on quickest time is mostly depend on the how effectively the path finding algorithm works. Nearest neighbor algorithm(NNA) is chosen as a path finding algorithm because it starts from a location and chooses the nearest unvisited destination by comparing the lowest distance to travel from its current location to all other available destination. And the algorithm repeats the same process from the next destination. Also, this nearest neighbor algorithm will generate several paths, in case if all the neighbors are equally close to each other then it will take the shortest path to reach the destination. Having the algorithm to do this processes, it is guaranteed that the autonomous irrigation vehicle will reach the destination on time. In addition, in the house of quality time to reach destination constraint is represent in negative polarity because the goal is to reduce the autonomous irrigation vehicle travel time. Also, it has positive correlation with cost and power consumption which is marketing requirement components. The faster the autonomous vehicle moves the higher the price would be on market. Evidently, decreasing the travel time will make the vehicle more desirable

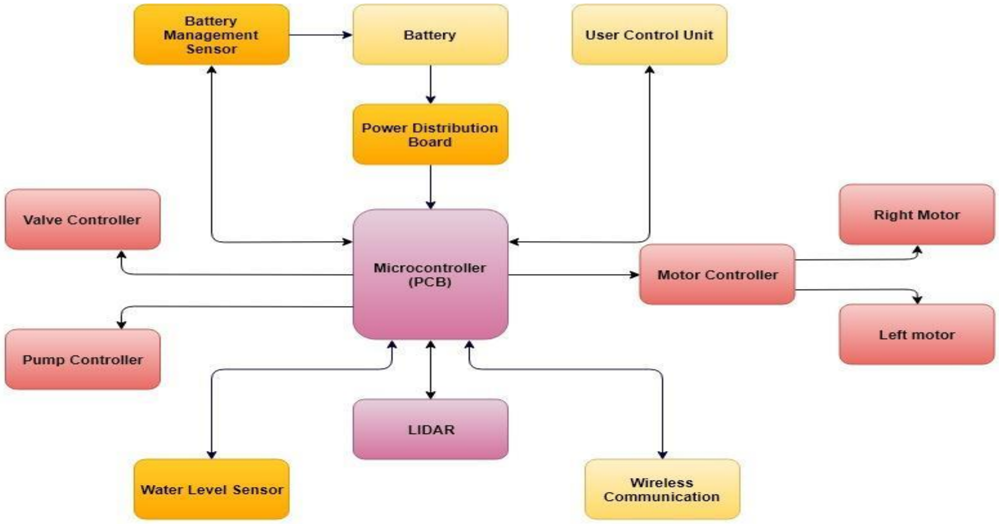
3. Hardware Diagram

The hardware diagram seen in Figure 5 starts with the power which will be provided by a battery that can withstand the outdoor elements. The battery will be connected to a power distribution board as seen in Figure 5. The power distribution board will be responsible for regulating the voltage and delivering the proper amount of power to the microcontroller and other elements that might not be powered through the printed circuit board that the microcontroller is mounted on. Once the printed circuit board provides power to the microcontroller, which will act as the brains of the autonomous irrigation vehicle, the various sensors will be able to send and receive information to/from the microcontroller through the printed circuit board.

One sensor will be responsible for monitoring how much charge is left in the battery. The software will be programmed to use the battery management sensor as seen in Figure 5 so that the autonomous irrigation vehicle will always have enough charge in the battery to make it back to home base where it can refill its water tank and recharge its battery. The battery management sensor might be designed onto our custom printed circuit board or a pre-fabricated silicon chip sensor may be purchased.

Another monitoring sensor will be the water level sensor as seen in Figure 5. The purpose of this sensor is to monitor the amount of water in the tank so that the autonomous irrigation vehicle knows when to return to home base and refill its tank. These sensors come in various types. The pressure level sensor works by detecting the amount of pressure when the tank is full and as the level changes so does the pressure. The ultrasonic and radar variants work in a similar fashion by sending a signal and recording the amount of time taken to reach the water level. The capacitance sensor as a rod in the tank that sends an RF signal and measures the capacitance between the rod and the tank. Which of these types will used will have to be further researched to come to a solid conclusion.

The autonomous irrigation vehicle will receive user input through a user control unit. It will be attached to the microcontroller so that the user can turn off, reset, and override the moisture sensors to send the autonomous irrigation vehicle to water any specific areas desired. The microcontroller will also have wireless communication capabilities and use WiFi, Bluetooth, or a certain radio frequency to send and receive information from the mesh network of moisture sensors.



Block Description	Block Satus
Battery Management Sensor	Research / Not Acquired
Battery	Research / Not Acquired
User Control Unit	Research / Not Acquired
Power Distribution Board	Research / Not Acquired
Microcontroller (PCB)	Research / Not Acquired
LIDAR	Research / Not Acquired
Wireless Communications	Research / Not Acquired
Water Level Sensor	Research / Not Acquired

Figure 5: Hardware Diagram

The vehicle vision component will be handled by the LIDAR as seen in Figure 5. It uses optical sensing to measure the distance to an object by illuminating it with light. The LIDAR works by using a rotating mirror to sweep the light beam 360 degrees, and a receiver records the time taken by the light beam to return to calculate the distance to different objects. The motor controller, as well as left and right motors, will also be managed by the microcontroller to move the autonomous irrigation vehicle through the yard. The valve controller and pump controller will be turned on and off by the microcontroller to regulate the flow of water.

3.1 Revised Hardware Diagram

After multiple meetings with the mechanical engineering students and other electrical and computer engineering students that compose the Guard Dog Valves team, the project went through several major design changes and a revised hardware diagram has been developed and can be seen in Figure 6. From the top down the first major change is that the autonomous irrigation vehicle will no longer be similar to a fire truck with a tank of water but will instead have a hose attachment for water delivery. The water tank was removed due to weight because carrying enough water to irrigate a 20x30 plot of grass proved to be significantly heavy. Since the water tank has been removed there will be no need to have a pump controller since there will be no pump and all the pressure will be coming from the hose attached to the customer's home.

Another portion that has been removed because there will no longer be a tank is the water level sensor, since there is no need to detect the level of water left in the tank. The valve controller has also been removed from the design because the microcontroller printed circuit board will not be driving the solenoid that controls the water flow coming from the hose. The valve controller that controls the water flow has been moved to the home base. The reason being that if it were to be on the autonomous irrigation vehicle the built-up pressure when not watering would weight it down. The extra weight would need more power to shortening the battery life time of the autonomous irrigation vehicle. The alternating current power cable that was talked about in the project description which was going to be tethered to the autonomous irrigation vehicle has also been removed making battery management and conservation an even more important aspect of the project.

The wireless communication that will be used is now known and the mesh node network team of electrical and computer engineers has chosen the E01-ML01IPX which enables the autonomous irrigation vehicle to communicate with the mesh network of sensors. Its uses the 802.15 standard and sets up a wireless personal area network with the all the nodes and the autonomous irrigation vehicle that does not interfere with the customer's WiFi. It is also low cost and more energy efficient than regular WiFi.

As a backup obstacle avoidance system, we are using ultrasonic range finders which work similar to the LIDAR but instead of light they use a specific frequency of sound waves to calculate the distance from the autonomous irrigation vehicle to the obstacle in its path. A LIDAR servo has also been added to the hardware diagram to make a 180-degree LIDAR that is water proof. The details are explained in section LIDAR Setup.

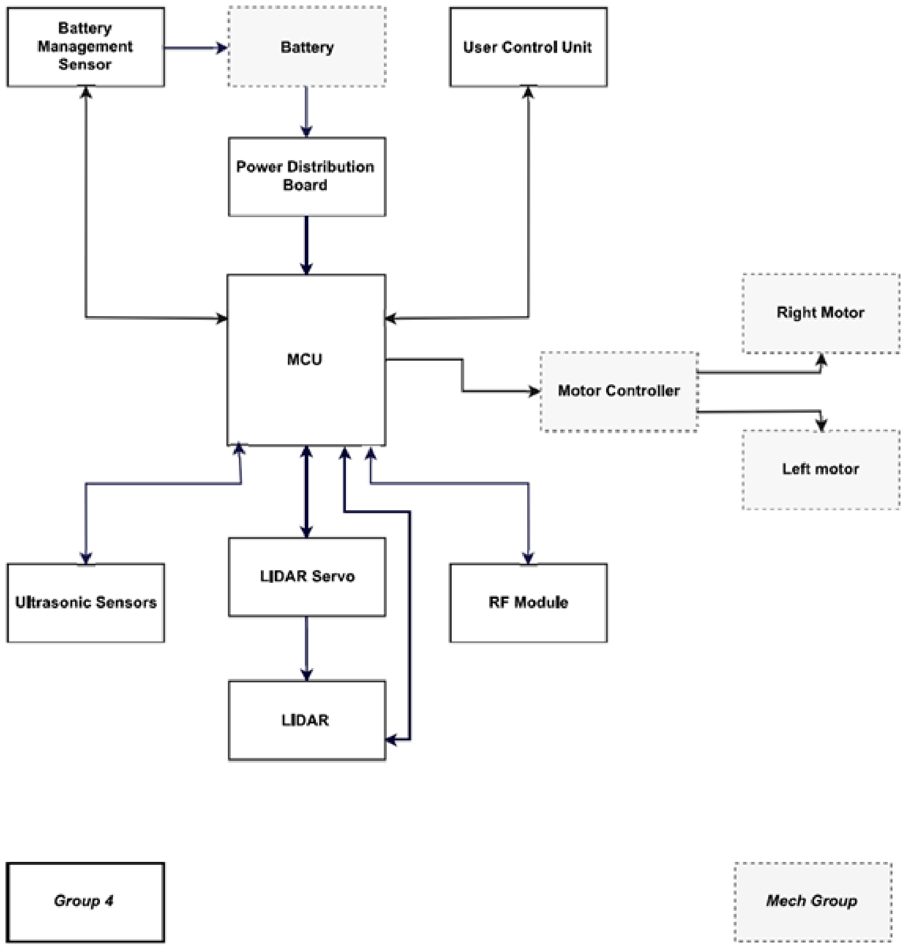


Figure 6: Revised Hardware Diagram

3.2 Existing Related Projects

While conducting research, our group could not find any projects that related to autonomous irrigation vehicles. We did find a couple of projects that, when combined, have similar concepts to our overall project. The senior design project we researched is called Fundamental Agriculture Resource Monitor (F.A.R.M.). F.A.R.M is closely related to our team's original idea of innovating the yard's valve layout and adding mesh network of sensors to efficiently and autonomously water the grass. The F.A.R.M project proposed using an array of sensors including, solar, water, humidity, and temperature. Our idea was to use weather, moisture, flow, rain, and temperature sensors. One of the main ideas we borrowed from the F.A.R.M project was researching more about the ZigBee Radio Transceiver for the mesh network and other related alternative hardware technologies for the communication between the autonomous irrigation vehicle and the mesh network of sensors.

Once our team decided to focus on the autonomous irrigation vehicle, new research had to be conducted. Searching for related projects our team came across a project done in 2013 called The Manscaper Autonomous Lawn Mower. While it does not have anything to do with irrigation one of the main tasks of The Manscaper is to navigate the lawn and avoid objects using robot vision autonomously. Then Manscaper proposed to use an ultrasonic PING sensor in combination with a webcam to avoid objects in the lawn. The ultrasonic PING sends out an ultrasonic signal, and if the signal does not bounce back from an object, the lawn mower continues to move forward. The webcam is used in conjunction with an edge detection algorithm. Our autonomous irrigation vehicle proposes to replace the ultrasonic PING and webcam with a LIDAR to serve the same purpose. The LIDAR works in a similar fashion to the ultrasonic PING sensor except that the signal is light-based instead of sound. The other difference is the LIDAR sweeps 360 degrees. The LIDAR detects the shape of the object using the reflected light, similar to the webcam function on The Manscape.

3.2.1 Existing Related Products

While performing research on related products in the marketplace we came across two products that are similar to the autonomous irrigation vehicle our team is designing:

The first is called Droplet. According to the Droplet website "*Droplet is the world's first smart sprinkler system that combines the latest technology in robotics, cloud computing and connected services to transform the way sprinkler systems function. Droplet keeps your plants healthy without wasting water by drawing upon a vast system of data to intelligently determine how best to care for your plants. By being smart, precise and frugal, Droplet can lower your sprinkler water consumption by up to 90%; on average Droplet saves $263 a year!*" (Droplet) While the description of their product seems extremely similar, the implementation is quite different. The first difference is that the Droplet requires the user to use a smart device to enter information about the location and type of vegetation so that the droplet knows when and where it needs to water. The autonomous irrigation vehicle that we are designing uses a mesh network of sensors in combination with RF chips to autonomously determine when and where to water. In order to precisely deliver water, the Droplet uses live data from weather stations as well as a database of soil samples to know how much to water. Our autonomous irrigation vehicle uses soil moisture sensors designed by a mechanical engineering group in 2017. The project was called Integrated Water Monitoring System and was also sponsored by Guard Dog Valves. The Integrated Water Monitoring System will be connected to the mesh network to accomplish this function. While the Droplet has an easier installation and setup – since it does not require a mesh network of sensors – our irrigation should be able to provide more efficient water allocation because our data is coming from the consumer's lawn and not a database

Another product out on the market that has inspired our autonomous irrigation vehicle is the Roomba robotic vacuum. While it may not have anything to do with irrigation, the main concept of our autonomous irrigation vehicle is applied to an indoor autonomous robot. The Roomba tasks are to vacuum multiple rooms in a house while maneuvering around objects on the house floor. Another major feature that the Roomba has that our autonomous irrigation vehicle will have is what the Roomba website calls Recharge and Resume which means the Roomba "*Automatically recharges itself and resumes cleaning until the job is done*" (Roomba). The autonomous irrigation vehicle will similarly have the capability of irrigating the lawn and if it runs out of battery during the irrigation go back to home base to recharge and finish watering the rest of the lawn.

The robot vision and object detection for the Roomba is handled by a camera that points forty degrees up in front of the Roomba. The data received from the camera is processed using a Vision Simultaneous Localization and Mapping (VSLAM) program. This program works by taking pictures received from the camera and looks for distinguishing patterns in the pixels of the pictures. With these patterns, it builds a map of its environment allowing it to learn and remember where objects are located. The Roomba does this indefinitely as objects in a house are moved around and continues updating its map of the house.

Our autonomous irrigation vehicle uses the LIDAR to detect objects instead of the camera. The LIDAR sweeps its laser in three hundred and sixty degrees and calculates how much time the light from the laser takes to come back to the LIDAR; the time is used to determine how far away an object is and to take the proper steps to avoid the object. The mapping portion of the autonomous irrigation vehicle uses to the mesh network and sets up a two-dimensional integer array map. As the autonomous irrigation vehicle runs into an object or obstacles it updates the two-dimensional integer array in order to remember their positions. Once the map is updated the next time the autonomous irrigation vehicle is summoned, it will take the fastest route while avoiding the obstacles

The Roomba uses Wi-Fi to connect the users to an app which allows the user to set up a schedule for when it is convenient for the user for The Roomba to vacuum the house. The autonomous irrigation vehicle will use Wi-Fi to establish a mesh communication network that the vehicle uses to build a map and navigate the yard as well as communicate with the moisture sensors and decide which areas need watering. The autonomous irrigation vehicle will also have a user control unit on the vehicle and a GUI for the mesh network. This will allow the user to override the autonomous irrigation so that the vehicle may water whatever yard zone the user desires. The option to schedule when the autonomous irrigating vehicle is allowed to water is actually a must because depending on what state and county you live in the government does not allow the lawn owner to water whenever they want. The watering schedule permitted depends on a lot of factors. The number of days depends on whether it's daylight savings time or not. Second, the time of the day you are allowed to water restricts the hours so that residents do not water when the sun is hottest because if they do, the water evaporates before the lawn can properly absorb the water. Another restriction is that each zone can only be watered a maximum of one hour during the allowed days and hours. These restrictions may not have to be followed or may vary depending on where the user's property is located. While the Roomba's Wi-Fi enabled scheduling, feature is there for the convenience of the customer the autonomous irrigation vehicle scheduling feature is mandatory due to government regulations as well as the convenience of the customer. Also, the Wi-Fi communication for the autonomous irrigation vehicle is a core feature for the basic function of the autonomy, while the Roomba does not require the Wi-Fi for its autonomy.

3.3 Strategic Components

The autonomous irrigation vehicle requires a certain list of components that will help ensure the successful design, construction, and proper execution of all of its desired assignments. Each component has been carefully and extensively researched to make certain that the autonomous irrigation vehicle executes its desired goals. As the autonomous irrigation vehicle has gone through a couple of revisions, there have been a handful of components that have been discontinued or modified to attain the desired results.

3.3.1 Sensors

Sensors will be playing an integral role in the autonomous irrigation vehicle's responsibility of traversing terrain, detecting objects, proper dispensation of water and monitoring its current battery charge. Each sensor was specifically chosen to cater to the given requirements of the autonomous irrigation vehicle. The autonomous irrigation vehicle will be outfitted with sensors that will promote its success when it is out in the field while performing its specified tasks. Although a few sensors have dropped from the autonomous irrigation vehicle's final design, the main sensors have stayed and will be implemented.

3.3.1.1 LIDAR

The light detection and ranging sensor, or LIDAR for short, is an imperative component for the autonomous irrigation vehicle. The LIDAR will enable the autonomous irrigation vehicle to see its surrounding environment. By providing the autonomous irrigation vehicle with a sense of sight, the vehicle will be able to detect obstacles that can possibly obstruct its path. With the autonomous irrigation vehicle equipped with the LIDAR sensor, it will be able to traverse to the designated area to commence proper watering within suitable time through obstacle avoidance.

3.3.1.2 Power Management Sensor

The Power Management Sensor will be necessary because the autonomous irrigation vehicle will have the capability of returning to home base in order to recharge its battery. The power management sensor will allow the microcontroller to determine when the autonomous irrigation vehicle needs to return by polling the battery every so often and when a set battery life is reached the autonomous irrigation vehicle will automatically know to return to home base. The power management sensor my also allow the autonomous irrigation vehicle to know how efficient it should run in order to get back to the changing station. Below is Figure 7 which is circuits designed on Eagle Cad for the power management sensor which can be built into our PCB design.

The only problem with the circuit without the capacitor in Figure 7is that the battery is going to be powering the left and right motors for the autonomous irrigation vehicle which are heavy current loads. With heavy current loads the voltage tends to drop and could lead the autonomous irrigation vehicle microcontroller to falsely read and return back to the charging station. One of the solutions to falsely reading the battery is to only have the microcontroller read the power management sensor when the autonomous irrigation vehicle is not moving preventing the heavy current load form the motors. Another solution is to connect a capacitor between the battery voltage and the ground of the power management sensor circuit shown in Figure 7. Since the capacitor resists change in voltage this allows the microcontroller to get steadier reading form the power management sensor circuit even under heavy current loads such as motors. The power management sensor circuit with the capacitor seen in Figure 7 allows the microcontroller to monitor the autonomous irrigation vehicle battery even while moving through the lawn. Both power management sensors work the same way. Selecting the proper resistor values allows the range Vlog to be chosen according to the application.

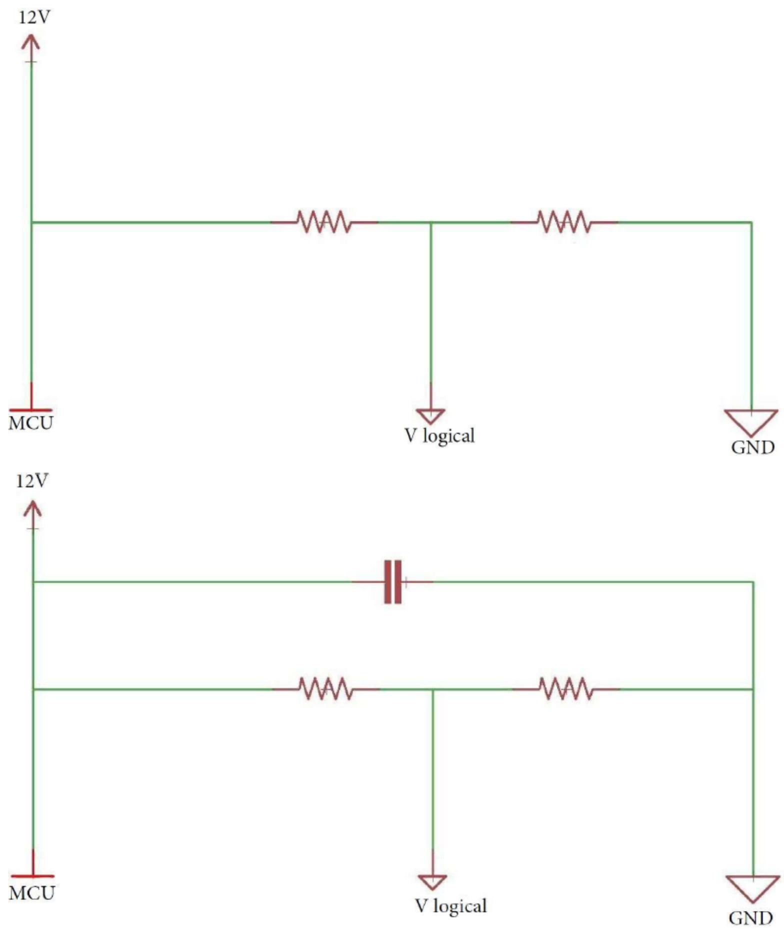


Figure 7: Power Management Sensor

3.4 Power Distribution Board

The power distribution board will provide an organized way of connecting the LIDAR, ultrasonic sonic range finders, servo, and radio frequency module to the battery of the autonomous irrigation vehicle. A typical power distribution board has negative labeled pads or terminals that are all connected. Similarly, power distribution boards have positive labeled terminals or pads that are all connected. The fact that they are labeled and are all connected make it easy to solder the black wires to the negative terminals of the power distribution board and all the red wires to the positive terminals or pads of the power distribution board. Once this is done, assuming the battery is also connected to the power distribution, all of the components will have power. Some power distribution boards include additional battery eliminator circuits which is a fancy way of saying voltage regulator. The voltage regulator circuit on the power distribution power is responsible for regulating the batteries voltage to a specific voltage required by the devices. A power distribution board without a voltage regulator must have all components solder to it run at the same voltage. The reason voltage regulators are called battery eliminator circuits is because if the power distribution board has a voltage regulator you may attach components with different voltages to the same power distribution board eliminating the need for a different voltage battery. When deciding which power distribution board will be needed the team must first find how much current will pass through it which means find out what the maximum current of each of the components attached requires. The team has still not decided if we are using more than one battery or not. The reason we are still unsure is that we believe that the battery that comes with the drive train might be able to provide power to all the components specially because it will not be running at full throttle since the purpose is to avoid obstacles while watering a yard or lawn. The concern with using the battery from the drive train is the potential of damaging the battery trying to splice the wires. Until the team knows exactly what battery comes with the drive train the choice of what power distribution board to use will have to wait.

3.5 User Control Unit

The user control unit will be a set of buttons that gives the user options to override the autonomous functions of the vehicle. The first button will turn on the autonomous irrigation vehicle. The second button will turn off the autonomous irrigation vehicle. In case the autonomous irrigation vehicle is malfunctioning or not performing up to customers satisfaction there will be a reset button that will reset all microcontroller and Raspberry PI. Another user feature that will be controlled by a button on the user control unit is a manual override to water a specific node. This feature is a great for marketing purposes because if a home owner plants a new patch of grass that requires a little more water than usual even if the moisture sensor is not notifying the autonomous irrigation vehicle the customer can override the moisture sensors and water that specific area of grass. The user control unit could also have a LED screen that displays the battery life of the autonomous irrigation vehicle. The same LED screen could also display the node area it is traveling to go water. All these functions would be operated by push buttons or switches for the functions that only have one choice. For the override to go water a specific node feature, which will require more than one choice, a rotary switch or a dial will be used. All the buttons will have two wires. One of the wires will run to ground, so all the ground wires of the buttons will be daisy changed together and attached to a ground on the printed circuit board. The other wire of the buttons will be attached to a pull up resistor. The ground and pull up resistor will have to be designed directly on the printed circuit board. Another option would be to have the buttons attached to the Raspberry PI which depending on which model we use it could have programable pullup/pulldown resistors.

3.6 Printed Circuit Board (PCB)

The printed circuit board will be mounted inside of the enclosed autonomous irrigation vehicle frame pictured in Figure 8.

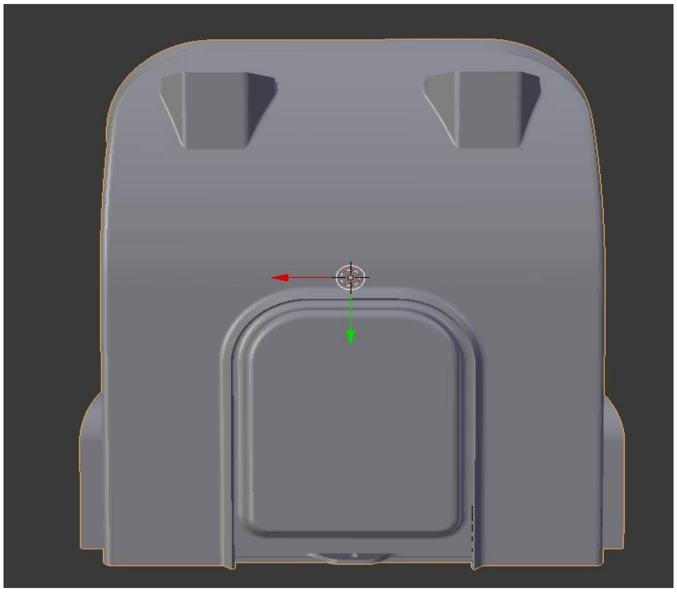


Figure 8: Autonomous Irrigation Vehicle Prototype Frame

The enclosure features a sliding door on the back of the frame pictured in Figure 9 for easy installation and maintenance of the printed circuit board and other enclosed electrical components. The custom printing of our circuit board will guarantee that all the required input and outputs for power, motors, and sensors are met. The custom printed circuit board will also guarantee it will be small enough to fit inside the enclosure and be properly protected from minor collisions and outdoor weather. Another benefit from a custom printed circuit board is that we can guarantee that we will be able modify it according to design changes.

The custom printed circuit board will be fitted with a ATmega328 made by ATMEL for all our projects processing needs. The ATmega328 8-bit processor will provided sufficient processing power for the controlling the LIDAR, the motor control unit, battery monitoring unit, valve controller, pump controller, water level sensor, and the wireless communication device. Basic on, off, and reset buttons on the user control unit will be connected to the printed circuit board. With all of the processing power provided by the Atmega328 will more than what the autonomous irrigation vehicle needs.

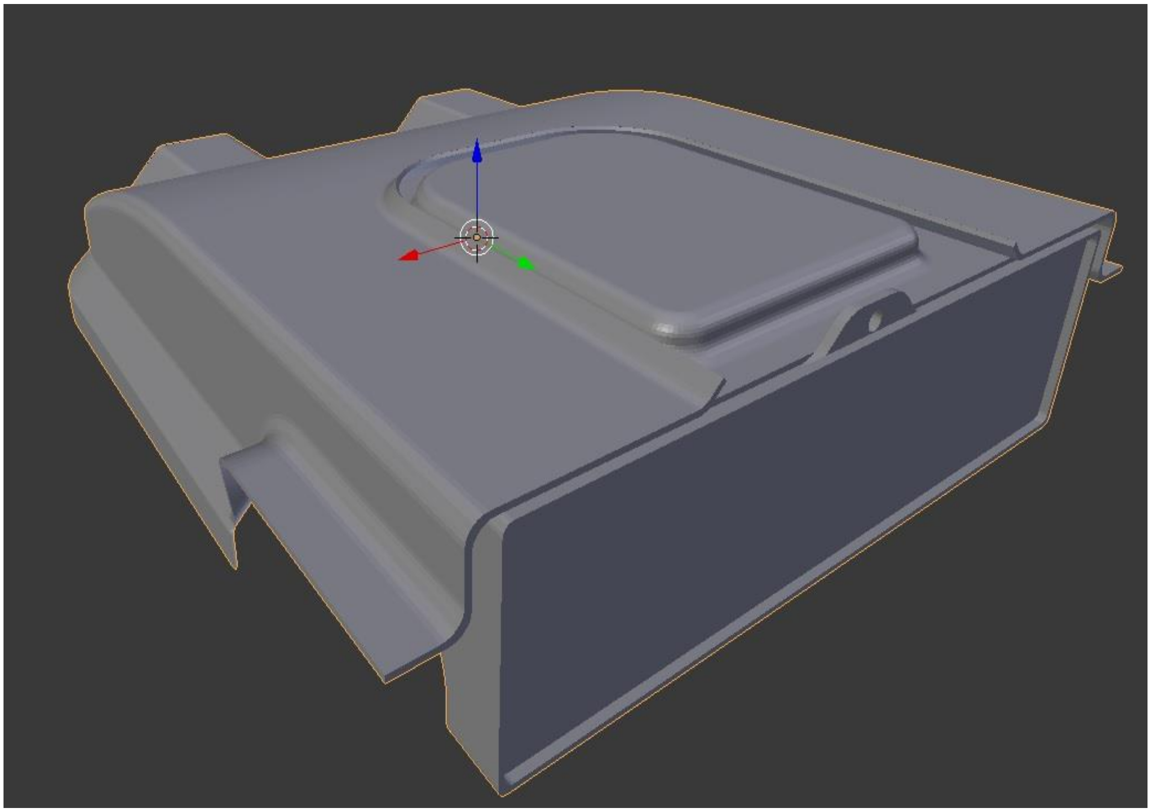


Figure 9: Autonomous Irrigation Vehicle Prototype Sliding Door

The autonomous irrigation vehicle will be operating as effectively and efficiently as possible as what the printed circuit board would allow. In order for any kind of process to begin, for a servo to move, or to transmit a data instruction set, there will need to be a source of power. In order for each of the sensors and electronics to work together, there must be a source of power but also, an appropriate route in which the power is directed towards. Here's where the printed circuit board design comes into play. The printed circuit board will be in charge of how each of the pieces received power, the intermediary between sensors and electronics communication as the signals will pass through the circuit board.

3.6.1 Specification

In terms of the specifications of the printed circuit board, there are only a couple that are of utmost concern in regards to the autonomous irrigation vehicle's success and operational abilities. The specifications for the printed circuit are simple in that the printed circuit board needs to be able to draw as little power as possible. On top of low power draw of the autonomous irrigation vehicle's printed circuit board, the printed circuit board also needs to be a small size in order for it to fit inside the autonomous irrigation vehicle's chassis.

3.6.2 Schematic

As seen in the schematic below, there are multiple connections that must be made in order for the printed circuit board to operate as needed and to be properly used by the autonomous irrigation vehicle. The microcontroller itself will need to be soldered to the various sensors on board the autonomous irrigation vehicle. The servos that will be used to give the autonomous irrigation vehicle a forward driving motion will be operated by the motor controller unit which is also connected to the microcontroller. There will also be another servo motor that will be used to control the direction the LIDAR is facing. With the movement of the autonomous irrigation vehicle taken care of, the connections of the sensors are now to placed strategically. Below is a rough draft, Figure 10, of the proposed schematic for the printed circuit board for the autonomous irrigation vehicle.

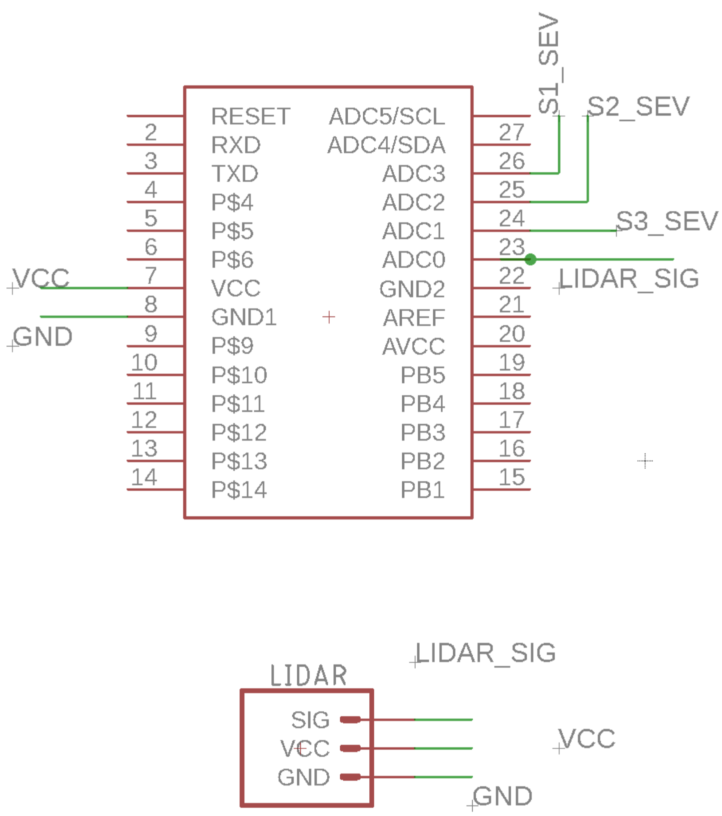


Figure 10: Printed Circuit Board Rough Draft

Placement of the sensors will have to be in the most optimal positions that can be allowed on the printed circuit for the autonomous irrigation vehicle. As it currently stands, the autonomous irrigation vehicle will be using three sensors to navigate through any given terrain. The sensors are the LIDAR, ultrasonic detection, and a battery management sensor. The LIDAR will behave as a set of eyes for the autonomous irrigation vehicle in which it will map out the objects that are directly in a 60 degree field of view in front of the autonomous irrigation vehicle. The ultrasonic detection sensor will be providing support to the LIDAR by supplementing the detection abilities already provided by the LIDAR. The battery management sensor will be in charge of monitoring the charge of the on board battery of the autonomous irrigation vehicle.

3.7 Motor Controller

In order for the autonomous irrigation vehicle to be able to traverse any given terrain, it will require motors to drive the wheels. Although the motors will be operational, there will be additional control and regulation that will need to be implemented so as the motors of the wheels do not draw an excess amount of power. In order to regulate and minimize the power draw of the motors, a motor controller will be implemented. On top of regulating the power draw of the motors, the motor controller will also be in charge of the speed and direction of rotation of the motors by manipulating the voltage sent to the motors. Along with regulating speed, direction, and power draw, the motor controller plays another critical role by preventing an initial high power surge which could compromise the integrity of the wheel motors.

3.7.1 Software

Programming of the microcontroller unit will be relatively straight forward. The microcontroller requires no intense or complex algorithm in order for the unit itself to operate as intended. The microcontroller's programming code will need to efficient and sufficient enough so that all of the operations that it will be carrying out, are executed without any kind of flaw. As such, there will be a need for an integrated development environment software which will allow the microcontroller to be programmed. The programming code of the microcontroller itself will need to meet exact requirements and specifications that will be needed by each of the sensors and onboard electronics.

The software that will need to be programmed into the microcontroller unit for the autonomous irrigation vehicle will need to short and concise yet efficient and reliable enough for the vehicle to operate as desired. For the autonomous irrigation vehicle to accomplish its given task. the programming code will need to incorporate all of the sensors on the vehicle itself. The programming code will not only have the onboard computer processor interacting with the sensors but also have each sensor interacting with any other desired sensor or electronic device. Since the autonomous irrigation vehicle will be using its onboard sensors to navigate through the terrain, it will need to be constantly updating and maneuvering its sensors and servos as needed.

The autonomous irrigation vehicle doesn't require any mobile application. The environment we will develop in is Visual Studio or Eclipse which are an Integrated Development Environment(IDE). We chose to use Integrated Development Environment(IDE) because it is easy to maintain different classes, variables and functions as well as it has the IntelliSense which is a useful feature which will correct any spelling error in the the code while we are writing. In addition, using Integrated Development Environment will make it easier to debug the code. The debug feature would be able to stop the program at any specific point also we can run one function at a time to check where the errors are occurring and have it avoid any spelling mistakes. As we are working as a group of four people the Integrated Development Environment would be easy to collaborate and manage the project. Another advantage of using Integrated Development Environment is that it will increase efficiency of the program. The high level language will be used for path learning algorithm such as C++. C++ was chosen because it is one of the powerful language and it provide more controls compared to other languages. Besides, it increases the performance and compare to other programming language C++ considered to be the faster one. Nowadays C++ is used in most of the industries so it is a much known programming language for developer. since we did not get a chance to learn the C++ programming language in any of the classes, it would be great hands on learning experience which we can add it to our resume. Since C++ has more functionality, it would be the more reliable programming language to use for robotics.

The path learning algorithm is the nearest neighbor algorithm (NNA). The nearest neighbor algorithm is chosen for this autonomous irrigation vehicle project because nearest neighbor algorithm starts from a location and chooses the nearest unvisited destination by comparing the costs to travel from its current location to all other available destinations and selects the one with the lowest cost for it to move to and repeats the process from that next position until all destination midpoints have been visited. This will generate at least as many paths as there are destinations, more if at any point there are multiple neighbors who are equally close to each other and the path needs to split. From all the paths generated, the shortest distance path, or the path with the lowest cost if dealing with other constraints, is chosen. Also, the high level language will be used for microcontroller part as well as the open source libraries will be used.
Software requirements

- The autonomous irrigation vehicle should receive the sensor data from mesh network
- The software shall be able to calculate the nearest midpoint using NNA algorithm.
- The software shall be able to detect the obstacles and avoid collision
- The software shall be able to update the two dimensional matrix array every time it travel to the midpoints.

- The software shall be able to send a feedback to sensor to indicate the dryness level

3.7.2 Energy Consumption

As the autonomous irrigation vehicle carries out its given objectives and tasks, it will be consuming a certain amount of power. Power draw is a serious concern for any given system. With predetermined tasks of the autonomous irrigation vehicle, power draw of the microcontroller will need to be brought down to a minimum. The lower the power consumption of the microcontroller, the more power can be allocated to the other component of the autonomous irrigation vehicle. As such, the microcontroller will have a minimum power requirement in order for the microcontroller unit to operate.

A benefit of a microcontroller, or any microcontroller for that matter, is that a typical microcontroller's power consumption is a relatively small value. That is to say that on average, a microcontroller unit's current draw is roughly about 500 nanoamps at 2 volts when it is on standby mode. When the microcontroller is being operated and carrying out its programmed tasks, the current draw jumps to 15 microamps at 2 volts and 32 kilohertz and 170 microamps at 2 volts and 4 megahertz. With the microcontroller operating at such a low voltage and having a low current draw, it's power consumption will also be low. With the microcontroller's power consumption being on the low spectrum, it will allow the autonomous irrigation vehicle to have a higher amount of power to route to the other sensors and electronics that will require power.

3.7.3 Comparison Between MCUs

The autonomous irrigation vehicle's success depends on the operational efficiency that the microcontroller can produce. Efficiency is an important topic for the autonomous irrigation vehicle as it will be dispensing water and tending the lawn. The microcontroller will have to run on as little power possible as well as handling an instruction set from programming code. As such, there have been multiple microcontroller units that have already been considered such as the PIC16F87A -I/SP depicted in Figure 11.

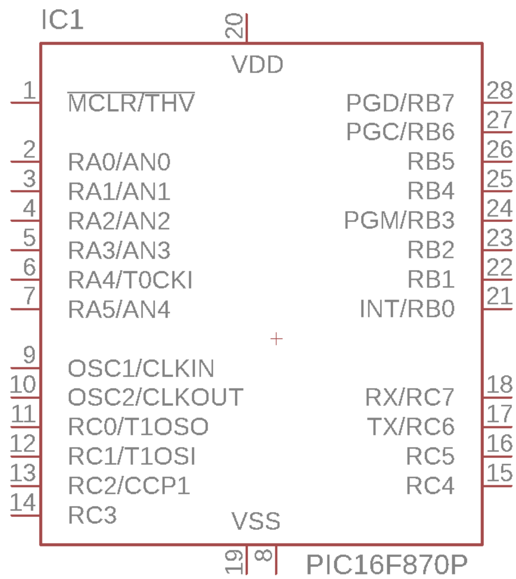


Figure 11: PIC16F87A-I/SP microcontroller

First candidate consideration for the autonomous irrigation vehicle's microcontroller unit is the PIC16F87A-I/SP microcontroller as pictured above. The PIC16F87A-I/SP microcontroller itself is a high performance reduced instruction set computer central processing unit. With an operating speed set at 20 megahertz and 200 nanoseconds, the PIC16F87A-I/SP is able to process 35 single-word instructions. On top of that, the PIC16F87A-I/SP boasts a flash memory size of 14.3 kilobytes or 8192 words. Most importantly is that the PIC16F87A-I/SP itself has 22 I/O pins and 3 I/O ports. The PIC16F87A-I/SP also provides, a variety of timers from 8-bit timer/counter with an 8-bit prescaler and a 16-bit timer/counter with prescaler. There is also a synchronous serial port which operates under two modes, SPI Master and I2C Master & Slave.

The next candidate to be the autonomous irrigation vehicle's microcontroller is the PIC18F258-I/SP microcontroller as pictured below in Figure 12. As with the last microcontroller, the PIC16F87A-I/SP, this candidate's performance surpasses the previous microcontroller. The operating speed of the PIC18F258-I/SP is at 40 megahertz and up to ten million instructions per second. Along with its speed, the PIC18F258-I/SP's flash memory has been upgraded from 14.3 kilobytes to 32 kilobytes which is equivalent of 16,384 words. The PIC18F258-I/SP also comes with added features such a power saving sleep mode, a selectable oscillator options from 4x phase lock loop of primary oscillator and a secondary oscillator clock input which operates at 32 kilohertz. As before, the PIC18F258-I/SP also has 22 I/O pins as well as 3 I/O ports. There is also a high current sink and source of 25 miliamps. The PIC18F258-I/SP also comes with 4 timers. The PIC18F258-I/SP also comes with a controller area network communication protocol which allows the node with the higher address number to yields the bus to the lower addressed node. This could help the autonomous irrigation vehicle communicate effectively between all of the other sensors and electronics on board the vehicle.

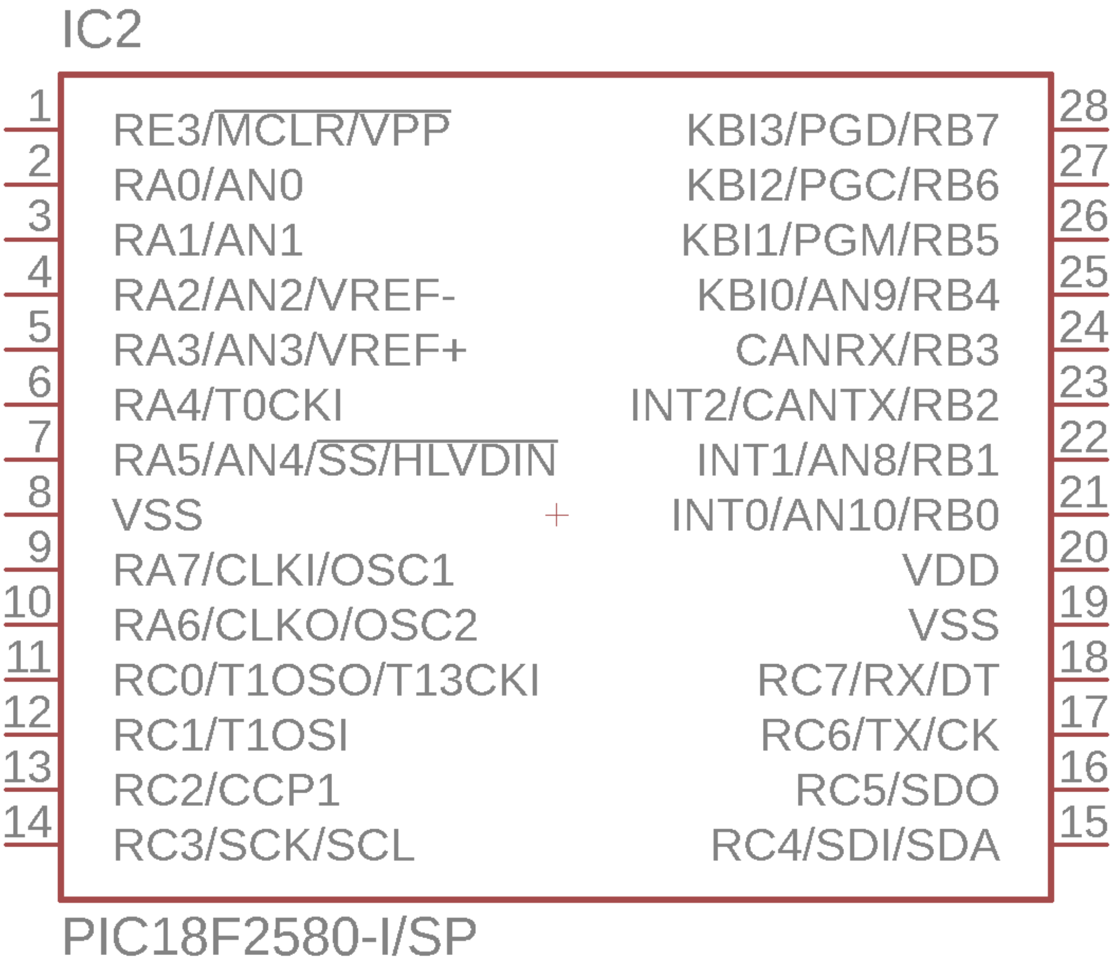


Figure 12: PIC18F258-I/SP 28 DIP

The ATMEGA328P-PU microchip is also being considered because it's a low cost and low power chip allowing the team to save on money and power consumption. The ATMEGA328P-PU features 32 registers and a robust instruction set. The Arithmetic Logic Unit and 32 registers are directly connected to each other. This feature allows two registers to independently be accessed in one instruction set and both be executed in one clock cycle. These architectures feature mentioned above are code efficient which leads to faster throughput.

As such, the ATMEGA328P-PU with an advanced reduced instruction set computer architecture. Alongside that feature, offers high endurance non-volatile memory segments. The ATMEGA328P-PU carries 23 kilobytes of in-system self-programmable flash program memory, data retention of less than 1 PPM over 20 years at 85 degrees Celsius and then at 100 years at 25 degrees Celsius. This memory retention is an ideal feature as the autonomous irrigation vehicle will certainly be operating at degrees of 100 degrees Fahrenheit thus keeping any memory loss during the vehicle's life cycle.

The ATMEGA328P-PU peripheral features should also not be underestimated. The ATMEGA328P-PU comes with two 8-bit timer and counter with separate prescaler and compare mode. Alongside the two timers, there is a 16-bit timer and counter with separate prescaler, compare mode, and a capture mode. The ATMEGA328P-PU also carries a real time counter with a separate oscillator, 6 pulse width modulation channels, six of which are 10-bit ADCs with a temperature measurement. As seen in Figure 13, the ATMEGA328P-PU contains 23 programmable I/O pins out of the total 28 pins.

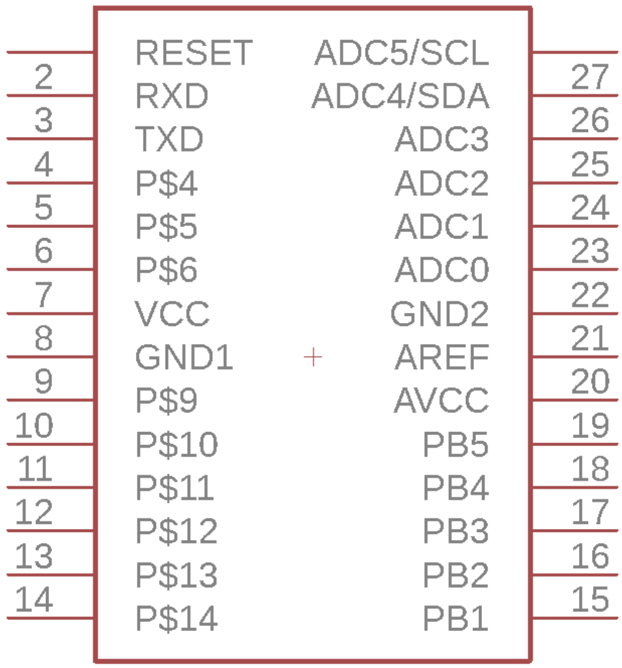


Figure 13: ATMEGA328P-PU

The ATMEGA328P-PU also comes with a programmable serial universal synchronous and asynchronous receiver, a master and slave serial peripheral interface, and a byte orientated 2 wire serial interface which is compatible with Philips I2C. Finally, for the peripherals features is the programmable watchdog timer with a separate on-chip oscillator, an on-chip comparator, and an interrupt and wake up on pin change.

The ATMEGA328P-PU also comes with a host of special features that separate it from the ATMEGA family of chips. Of the special features, the ATMEGA328P-PU comes with a power-on reset, a programmable brown-out detection, and an internally calibrated oscillator. There is an additional feature of the ATMEGA328P-PU which is the external and internal interrupt sources. This feature allows the ATMEGA328P-PU microcontroller unit to be put into a low power state whilst waiting for an interrupt, from either an external or internal interrupt source, before executing a programmed instruction set and to conserve power. Last but not least, is that the ATMEGA328P-PU comes with six sleep modes. The six sleep modes the ATMEGA328P-PU comes with are the idle, ADC noise reduction, power-save, power-down, standby, and an extended standby mode.

The ATMEGA328P-PU comes with a multitude of features that can greatly benefit the operation processing of the autonomous irrigation vehicle. As such, the ATMEGA328P-PU also has varying speeds at which it operates at as it processes instruction sets. The ATMEGA328P-PU can operate at a speed of 3 megahertz from 1.8 volts to 5.5 volts, 10 megahertz from 2.7 volts to 5.5 volts, and 20 megahertz at 4.5 volts to 5.5 volts. One of the most attractive feature of the ATMEGA328P-PU is its low power consumption as previously stated. In the ATMEGA328P-PU active mode, the current draw is .2 milliamps at 1 megahertz, 1.8 volts at 25 degrees Celsius. Whilst the ATMEGA328P-PU is in power down mode, the current is .1 microamps at 1 megahertz, 1.8 volts at 25 degrees Celsius. The power save mode of the ATMEGA328P-PU has a current draw of .75 microamps, which includes a 32 kilohertz RTC, at 1 megahertz, 1.8 volts at 25 degrees Celsius.

As the aforementioned details have stated, there is a multitude of microcontrollers that can accomplish and achieve the needs of the autonomous irrigation vehicle. While the performance of the microcontroller will affect the performance of the autonomous irrigation vehicle, the microcontroller will need to be of a rugged profile. That is that the ATMEGA328P-PU can endure a large load, continuous operation in a very warm environment, and has a low power usage which promotes a long life time. As such, the proposed microcontrollers will have a decisive candidate but will still subject to change during the construction of the autonomous irrigation vehicle. The autonomous irrigation vehicle will operate as needed and desired regardless of the selection of the microcontroller unit since the duties of the microcontroller unit will only be limited by how much energy is provided to it and how durable it is in regards to its surrounding environment

3.7 Wireless Module

The autonomous irrigation vehicle will be traveling about its given terrain and as such, will be doing its best to avoid any obstacles to reduce the chances of collision. The autonomous irrigation vehicle will be avoiding whatever obstacles in its path in order to reach the designated area to begin dispensing water. Although the autonomous irrigation vehicle will able to move forward and avoid any obstacles within its path, the autonomous irrigation vehicle will need the additional data provided by the mesh network of sensors. The additional data provided by the mesh network of sensors will be the guide of the autonomous irrigation vehicle by providing the vehicle with a dryness reading.

Since the data that will be provided by the mesh network of sensors, it only makes sense that the autonomous irrigation vehicle is also connected and plugged into the mesh network itself. That is that the autonomous irrigation vehicle will be apart of the mesh network of sensors and will be able to communicate with the sensors on the mesh network . For the autonomous irrigation vehicle to gain the ability to communicate with all of the sensors on the mesh network, a radio frequency module will be needed. The radio frequency module will have to meet a few certain requirements so that the autonomous irrigation vehicle can successfully accomplish any given task that is at hand.

3.7.1 Comparing Different Models

In order for the autonomous irrigation vehicle to achieve its success, its wireless module will need to meet a few requirements. The first of which is that it will need to be operating with the IEEE 802.15.4 standard. Another requirement will be a low power consumption to maximize the autonomous irrigation vehicle's time out navigating its given terrain on a given task. Since the module will need to fit inside of the autonomous irrigation vehicle's chassis, the size of the radio frequency module will be required to be small in dimensions. As such requirements are needed for the radio frequency module, a number of candidates have been selected.

First of the candidates to be the autonomous irrigation vehicle's main radio frequency module, is the MRF24J40 transceiver. The MRF24J40 transceiver operates using the IEEE 802.15.4 standard. The MRF24J40 transceiver has multiple models, Model A, Model B, and Module C, with different specifications. Model A of the MRF24J40 transceiver offers a current draw of 23 milliamps for transmission, 19 milliamps for reception, and 2 microamps while in sleep mode. Model B of the MRF24J40 transceiver operates with a longer range and thus has an active current draw of 130 milliamps for transmission, 25 milliamps for reception, and 5 microamps in sleep mode. The MRF24J40 transceiver's Model C current draw is 120 milliamps for transmission, 25 milliamps for reception and 12 microamps for it is in sleep mode.

The second candidate to be considered to be the autonomous irrigation vehicle's main radio frequency module is the E01-ML01IPX transceiver. The E01-ML01IPX transceiver itself operates at a low power consumption. The current draw of the E01-ML01IPX transceiver while it is transmitting is 12 milliamps, 11.5 milliamps for reception, and a 1 microamp while in sleep mode. Another added benefit of the E01-ML01IPX transceiver is its small size. The E01-ML01IPX transceiver comes in a 12 x 19 millimeter squared. As seen in Figure 14, the E01-ML01IPX transceiver has multiple holes to allow different kinds of data to be received and transmitted.

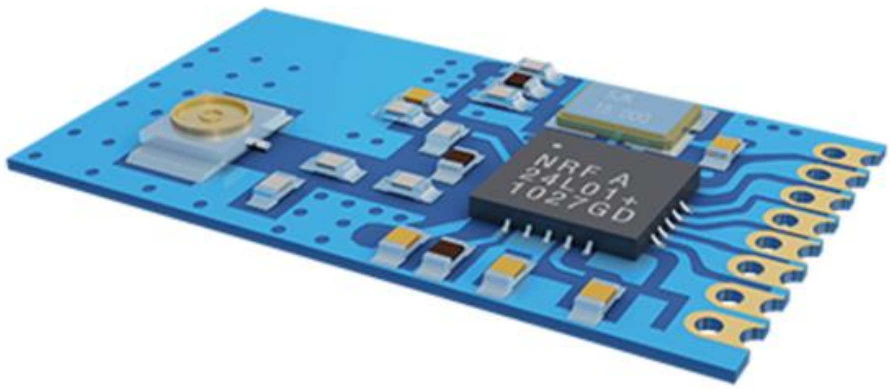


Figure 14: E01-ML01IPX Transceiver

With the E01-ML01IPX transceiver being able to receive and transmit signal data to and from the mesh network of sensors, the range will also be a factor. Although the autonomous irrigation vehicle location of operation will be within a 20 x 30-foot area, the range will be covering more than enough spacing to ensure effective communication. The 100m range of the E01-ML01IPX transceiver is a gratuitous amount needed for the autonomous irrigation vehicle's immediate surroundings but implies that it is possible to scale up the number of sensors for the mesh network.

Another candidate that is currently being considered to play the role of main radio frequency module for the autonomous irrigation vehicle is the ATZB-24-B0. The E01-ML01IPX transceiver has a current draw of 18 milliamps while transmitting and 19 milliamps for reception. The dimensions of the ATZB-24-B0 are relatively small as they are 18.8 mm x 13.5 mm x 2 mm thus allowing the module is easily fit inside of the autonomous irrigation vehicle's chassis. As the autonomous irrigation vehicle will most likely be operating in the outdoors because of the tasks it needs to accomplish, the inside of the chassis will warm up greatly. As heat could possibly be a problem, the ATZB-24-B0 can operate safely up to a temperature of 85 degrees Celsius. All these features provided by the ATZB-24-BO can possibly play a critical role within the autonomous irrigation vehicle's signal relay system.

4. Related Standards

The standards we are adhering to for this project are received from Institute of Electrical and Electronics (IEEE). These IEEE standards are used to create specifications and procedures that guarantee the reliability of things people use in everyday life such as services, methods, products, and materials. Standards allow for interchangeability of parts which leads to mass production which saves money for all the companies in the related industry. Interchangeability in electrical components is achieved through standard protocols that assure compatibility and functionality for products. Another important factor that standards improve is consumer safety and public health. Listed below are the standards for software, sensors, microprocessor, and wireless communication.

1. The first standard related to our autonomous irrigation vehicle deals with software portion of our design, therefore, the collision-detection and pathfinding algorithm. It is called IEEE Std 1044-2009 which is a revision of an older standard called IEEE Std 1044-1993) - IEEE Standard Classification for Software Anomalies the description on the IEEE website states “This standard provides a uniform approach to the classification of software anomalies, regardless of when they originate or when they are encountered within the project, product, or system lifecycle. Classification data can be used for a variety of purposes, including defect causal analysis, project management, and software process improvement (e.g., to reduce the likelihood of defect insertion and/or increase the likelihood of early defect detection).” (IEEE).

2. The seconded standard that associated with the autonomous irrigation vehicle relates to the uses of sensors in our project. It is named 1554-2005 - IEEE Recommended Practice for Inertial Sensor Test Equipment, Instrumentation, Data Acquisition, and Analysis and is abstracted on the IEEE as “Test equipment, data acquisition equipment, instrumentation, test facilities, and data analysis techniques used in inertial sensor testing are described in this recommended practice.” (IEEE) Another standard the relates to sensors we must adhere to is the 2700-2014 - IEEE Standard for Sensor Performance Parameter Definitions the purpose of this standard according to the IEEE is “This standard presents a standard methodology for defining sensor performance parameters in order to ease system integration burden and accelerate time to market (TTM). This standard fulfills the need for a common methodology for specifying sensor performance that will ease the non-scalable integration challenges. This standard defines a minimum set of performance parameters, with required units, conditions, and distributions for each sensor. Note that these performance parameters shall be included with all other industry-accepted performance parameters.” (IEEE).

3. On the hardware side of the autonomous irrigation vehicle there is a standard related to microprocessor architecture called IEEE 1754-1994 - IEEE Standard for a 32-bit Microprocessor Architecture which is described on the IEEE website as “A 32-bit microprocessor architecture, available to a wide variety of manufacturers and users, is defined. The standard includes the definition of the instruction set, register model, data types, instruction op-codes, and coprocessor interface.” (IEEE).

4. For the communication with the wireless mesh network the autonomous irrigation vehicle must follow the IEEE Std 802.11-2016 for Information technology—Telecommunications and information exchange between systems Local and metropolitan area networks—Specific requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications which is a revision IEEE Std 802.11-2012. The scope of the standard according to IEEE is

“The scope of this standard is to define one medium access control (MAC) and several physical layer (PHY) specifications for wireless connectivity for fixed, portable, and moving stations (STAs) within a local area.” (IEEE). The purpose of the standard as stated on the IEEE website is “The purpose of this standard is to provide wireless connectivity for fixed, portable, and moving stations within a local area. This standard also offers regulatory bodies a means of standardizing access to one or more frequency bands for the purpose of local area communication.”. (IEEE) As the design of the autonomous irrigation vehicle develops the standards the relate will change and our team will add and remove the standards related to the project accordingly.

5. Realistic Design and Constraints

Many times over, there have also been restrictions and constraints of any given project that has been developed. The reasoning for any team to develop and realize their own project’s design constraints is to realistically construct said project. As such, there have been many considerations when developing and building and kind of project in regards to economic, environmental, social, and other constraints that can impact the development of a group’s project. During the research process, the group encountered many hurdles that have impacted the design of the autonomous irrigation vehicle. Of the many hurdles, the most prevalent of which determined the size and the autonomous vehicle’s ability to traverse its surrounding terrain.

5.1 Economic and Time Constraints

As a group, we have set up personal deadlines for our group. By doing so, this allows our group to work efficiently and also account for any mishaps that may occur during development and research. Our group has also scheduled weekly meetings to confirm and reinforce a consistent rate of progression. With the group deciding to set a deadline before the designated deadline, the time constraints should be able to be handled with ease as well as minimize the consequences of random occurrences.

Aside from the group’s personal timing constraints, there will also be timing constraints in regards to the irrigation of the designated areas. The suggested time to being irrigation of the designated area is projected to commence at 2:00 AM to 5:00 AM. The reasoning behind this suggested watering time window is so that the designated area does not receive more water than is required. When the irrigation has stopped, water has seeped into the designated area and will sustain the area itself. When the sun rises, water will begin to evaporate during the day which will help prevent a much unwanted complication with home lawns; lawn fungal diseases.

The group has selected Lake Nona, Florida as the autonomous irrigation vehicle's test location. As such, there are watering restrictions in place that will inevitably affect the proposed watering scheduling of the autonomous irrigation vehicle. Originally, a three day watering period was proposed alongside the watering time window of 2:00 AM to 5:00 AM. As the city of Lake Nona is located within orange county in the state of Florida, the proposed three days a week watering schedule has been reduced to a one day a week watering schedule. The new watering schedule of once a week is only applicable from the first Sunday of November until the second Sunday of March then switches to a schedule of twice a week during Daylight Savings Time from the second Sunday of March to the first Sunday of November. Below is a descriptive list and table of Orange county's watering restrictions courtesy of Orlando Utilities Commission. As per Orlando Utilities Commission's informative list and Table 2, watering scheduling will be affected during certain times of the year but it should have little impact in regards to efficient irrigation practices. On top of impacting irrigation operation, it will also end up having the consumer saving money due to the low frequency of lawn irrigation.

- Outdoor irrigation is limited to one day a week during Eastern Standard Time (from the first Sunday in November until the second Sunday in March) and two days a week during Daylight Saving Time (from the second Sunday in March until the first Sunday in November).
- Water only if necessary and not between 10:00 a.m. and 4:00 p.m.
- Water for no more than one hour per zone.

Time of year	**Homes with odd-numbered or no addresses**	**Homes with even-numbered addresses**	**Nonresidential properties**
Daylight Saving Time	Wednesday/ Saturday	Thursday/ Sunday	Tuesday/ Friday
Eastern Standard Time	Saturday	Sunday	Tuesday

Table 2: Orange County Florida Watering Restrictions. Reprinted with permission from OUC

Another major constraint is the amount of funding that was determined by the scope of the project. Funding was heavily affected by how many sensors were to be implemented, the design and fabrication of the autonomous irrigation vehicle's casing, and water consumption during water dispensing. The quantity of sensors required by the autonomous irrigation sensors have affected the overall cost of the vehicle by running an estimated price of $300. As for the fabrication of the autonomous irrigation vehicle's casing, it is also estimated to run for approximately $50 due to the allocation of needed materials. As for the water consumption rate, the group aims to dispense a relatively low amount of water when compared to the typical method of irrigation which would reduce a customer's water bill by a considerable as the rate of irrigation water runs at $1.655 per gallon for the first 19,000 gallons consumed, $3.094 per gallon for the next 11,000 gallons consumed, and then $5.79 per gallon after 30,000 gallons have been consumed for irrigation purposes.

5.2 Environmental, Social, and Political Constraints

In regards to the environmental constraints for the autonomous irrigation vehicle, there are not many to take into consideration. First, as the autonomous irrigation vehicle will be mainly be operating with water, careful consideration has been taken into account to protect the internal hardware. The autonomous irrigation vehicle's case will be housing the electronics and shield the hardware from any foreseeable water damage. Another environmental concern that has been considered is the proper disposal of the autonomous irrigation vehicle's battery. Users cannot simply throw away a battery as harmful chemicals and toxins can leak after extended use. There are no social constraints regarding the autonomous irrigation vehicle's operation. As for political constraints, there are virtually none as the autonomous irrigation vehicle will not be working in conjunction with human beings and solely with water and its given terrain.

5.3 Ethical, Health, and Safety Constraints

As the autonomous irrigation vehicle is a machine that will be conducting all operations outside with no human interaction, there will be no health constraints whatsoever that will impact the vehicle's design. Ethical constraints are also nonexistent due to the nature of the autonomous irrigation vehicle as it has no way of being able to out right offend any one person in particular. Safety constraints may come through the autonomous irrigation vehicle's tether as human beings can overlook and possibly trip over the tether itself. Although the possibility of a human being tripping over aforementioned tether of the autonomous irrigation vehicle has been considered, it is highly unlikely that it could ever occur as the hours of operation of the vehicle will be pre dawn thus cutting down the likelihood of such an event happening.

5.4 Manufacturability and Sustainability Constraints

The autonomous irrigation vehicle will be heavily influenced by manufacturability constraints as it has affected the vehicle's overall design. A contribution to the manufacturability constraint is the feasibility of constructing the autonomous irrigation vehicle's outer casing as it will be housing the electronics that will conduct its overall operation. Another manufacturability constraint is that the autonomous irrigation vehicle must be built as a light weight vehicle so as to not damage the consumer's terrain. Along with minimizing damage to the consumer's terrain, a light weight design will also provide other benefits such as lower power draw due to its weight since the motors will need to adjust their speed according to how much resistive force is presented. An additional manufacturability constraint to consider is the type of hose that will tethered to the autonomous irrigation vehicle. A light weight hose is the preferable choice when considering the manufacturability constraint as it will allow the autonomous irrigation vehicle to travel with less resistive force while the vehicle is not dispensing water.

An additional constraint to consider is the sustainability of the autonomous irrigation vehicle. The autonomous irrigation vehicle will be operating on an onboard battery that will supply all of its power needs. As such, the autonomous irrigation vehicle's battery must be able to persist through all of the vehicle's operation including being able to communicate with the mesh network of sensors as it traverses the given terrain. Given that each zone will only be allotted a watering window of about one hour, it is imperative that the battery last for more than hour in order to effectively water each zone within the time limit. The goal here is to reach all of the designated destinations within the time and power limit that has been put on the autonomous irrigation vehicle.

6. Project Hardware Design

As time has passed, there were many revisions and changes that the autonomous irrigation vehicle had since its conception. Since conception, the overall design of the autonomous irrigation vehicle has changed dramatically. When the autonomous irrigation vehicle was first conceived, there were suggestions of having an onboard water tank for the vehicle itself to haul around. At the same time, there were also solar panels that were proposed to be built on the autonomous irrigation vehicle. Due to practicability, power, and financial restraints have caused the autonomous irrigation vehicle to drop the proposed water tank and solar panels all together.

As ideas and suggestions have dropped from the predesign of the autonomous irrigation vehicle, so did the overall hardware design. When the water tank was proposed, there were plans of incorporating water pressure and a water level sensor to monitor the water tank so that the autonomous irrigation vehicle was aware of its current water supply were dropped. With the new proposal of a tethered hose at the disposal of the autonomous irrigation vehicle, two design restraints were lifted which was the power requirement as well as the size. Although the sensors were scrapped for the water tank portion of the autonomous irrigation vehicle, the vehicle itself could also move more freely about any given terrain.

Another previous design element that was apart of the initial design but then dropped was the solar panel. The solar panel was meant to be the sustainable effort in regards of having the autonomous irrigation vehicle to be self-reliant and be untethered allowing free movement in its given terrain. With the recent revision of the autonomous irrigation vehicle, the proposed solar panel was dropped. In place of the solar panels the autonomous irrigation vehicle will have an onboard battery. In order for the autonomous irrigation vehicle's onboard battery to recharge, the vehicle itself would travel back to a home base.

6.2 PCB Design

The proposed design of the printed circuit board will be incorporating all of the sensors , servos, and electronics that the autonomous irrigation vehicle will be using, In order for the autonomous irrigation vehicle to be able to use all of the sensors, electronics, and servos, each of the pieces will need to be carefully selected and strategically placed on the printed circuit board. By picking the smallest yet most effective sensors, electronics, and servos allowable, the printed circuit board will have all of the necessary connections to maximize free space. With the maximization of space on the printed circuit board design, this will allow for future components to be easily added.

6.2.1 PCB Assembly

The assembly of the printed circuit board will of utmost importance in regards to the success of the autonomous irrigation vehicle. The layout of the printed circuit board will also play a role in how the autonomous irrigation vehicle will be able to access and operate the sensors and other onboard electronics. With the layout of the printed circuit board properly mapped out, the component sizing will play another role in terms of assembly. That is that the size of the selected components will be either be a difficult or a relatively easy step to carry out. Regardless of what circuit element or electronic component that will be designed into the printed circuit board schematic, the assembly must be done with little to no error.

6.2.2 Manufacturer Selection

In order for the assembly of the printed circuit board to begin, there must first be an circuit board that has been printed out with the correct layout. Although the possibility of the group making their own printed circuit board is a reality, it would cut too deep into the scheduling of creating the autonomous irrigation vehicle. As such, there will be a need to have the printed circuit board created within a reasonable timeframe for testing purposes. In order to cover the window of time that the group has to complete the autonomous irrigation vehicle, there will need to be a selection of manufacturer to create the proposed printed circuit board.

The first of manufacturers to be considered is a manufacturer that goes by the name of PCBWay. PCBWay, as a company, has been around for roughly a decade in the business. PCBWay is being considered for their quick turn over time in order to allow quick redesign if needed be. There could also be issues that could arise such as the printed circuit board may not have been printed properly so a quick turn around time could play a critical role.

The second candidate in consideration for the responsibility of ensuring the circuit board is printed correctly is JLCPCB. Just as PCBWay, JLCPCB has also been in the printed circuit board manufacturing industry for over a decade. JLCPCB also provides the speedy turn over that PCBWay offers but also manufactures multi-layer print circuit boards. If by chance the autonomous irrigation vehicle needed a multi-layered printed circuit board, JLCPCB would be able to provide a service in regards to this situation.

6.3 Microcontroller Design

Regarding the design of the microcontroller unit, it will have to be a programming code that offers the best allocation of memory and communication. The allocation of the memory of the microcontroller unit is an essential part since it can help execute instructions in a much speedier manner. The lines of code that are responsible for the communication aspect of the microcontroller unit will need to be quite effective to ensure the signals are sent to the correct device. Depending on the microcontroller that is chosen, it will need to be programmed in an integrated development environment.

6.3.1 Assigning Input & Output Pins

There will be a number of sensors that will be attached to the microcontroller itself as it will act as the central hub of signals. As such, there will be a limited number of pins that the microcontroller unit would have free so the essential pins must be outlined. In regards to assigning the input and output pins, there will be an input pin from the battery management sensor, a input and output from the LIDAR, input from the ultrasonic sensor, and then an input and output for the computer processor. On top of the sensors and compute processor, there will be an additional servo attached to the LIDAR to allow it to have a swiping view.

6.3.2 Connecting All Sensors

Connections of all the sensors that the autonomous irrigation vehicle will be using is a simple feat. The only possible issue is where and how to place all of the sensors will be and which sensor will be commuting with what electronic device. As it currently stands, the LIDAR and ultrasonic sensors will be connected to the microcontroller. There needs to be a way for the autonomous irrigation vehicle to return to the home base when its power supply is running low. In such a case, a battery monitoring sensor will be connected to the microcontroller so that he autonomous irrigation vehicle can remain aware of its current power supply level. there will be a battery monitoring sensor that will be connected to the either the microcontroller unit or to the computer processor unit.

6.3.3 Connecting to Motor Controller & Servos

As the perils lie ahead of the autonomous irrigation vehicle, the vehicle itself must be able to detect a sudden obstacle in its chosen path. Thus in order for the vehicle to maneuver itself safely and securely, it will need to have control over its wheels. Accomplishing the motor control of the autonomous irrigation vehicle has over its own set of wheels is imperative. As such, each wheel on the autonomous irrigation vehicle will be connected to its own servo. Each servo will be in charge of rotating its wheel. The only problem with the servos themselves is that they are activated the moment they receive current. With an uncontrollable electric force, the servos themselves could malfunction due to a current surge and have no way of stopping its actions. This is where a motor controller unit will be a convenient and practical solution to this problem.

The motor controller can adjust the speed of the servo itself by controlling how much power is sent to the servo. Not only can it control the power a specific servo is receiving, it can also make the servo or wheel spin in the opposite direction giving the wheel a backwards motion of rotation. With the wheel itself being able to rotate counter and counter clockwise, it gives the autonomous irrigation vehicle the ability to traverse its environment in a backwards motion.

6.4 Drive Hardware

The drive hardware portion of the autonomous irrigation vehicle is also an indispensable design for the success of the vehicle. The autonomous irrigation vehicle's base will be a Traxxas RC model. From there, There will be servos and motor controllers in place so that the onboard computer processing unit can control the movements for autonomous activity. The servos be directly connected to the wheels to control speed and direction of wheel rotation. The motor controller will be connected to the servos to prevent surge damages and provide further control over servos.

6.5.1 Servos Selection

The autonomous irrigation vehicle will be dealing with quite a large load of water. Since there is a considerable amount of water, weatherproofing these servos would be most beneficial for the autonomous irrigation vehicle. With the consideration of weatherproofing the servos, there will also be an additional cost associated with such a feature. There are a number of ways to create a do-it-yourself weatherproofing of these servos or simply buying out right already weatherproofed servos.

6.5 Wireless Module Hardware

The autonomous irrigation vehicle will need to have a method of communication between itself and the mesh network of sensors. It has already been established that the IEEE 802.15 will be the main choice of communication options available. The hardware itself will behave as a transmitter and a receiver for the autonomous irrigation vehicle. The module itself will be able to receive, analyze, and process data to and from specific devise and sensors. At the same time, it can transmit data back to the sensors or to the user for any current information.

6.5.1 Wireless Module Setup

Setting up the wireless module should not be a daunting task. It will require the module to be connected to a computer in some manner in order to program the wireless module. Once connected, the group will be using an integrated development environment to write the programming code for the wireless module. It should be a relatively simple task of programming the transmitting and receiving operations of the wireless module. It will have to be put into a sleep mode of some sort to converse power during the autonomous irrigation vehicle's operation.

7.0 Ultrasonic Range Finder

The ultrasonic range finder will be used as a backup obstacle avoidance sensor. The ultrasonic range finder works by sending out a specific high frequency sound wave signal through the transmitter and waiting for the signal to come back to the receiver. The transmitter acts like a speaker and the receiver acts like a microphone. The time taken for the sound wave to come back is recorded and since the speed of sound in air is known, the distance to the object that the sound wave bounced form can be measured. The reason ultrasonic range finders are being used as back up obstacle avoidance sensors is because ultrasonic range finders have a widespread detection range that can be easily affected by obstacles that might not necessarily be in the path of the autonomous irrigation vehicle. The false reading would cause the autonomous irrigation vehicle to take longer while navigating the lawn or yard. The combination of the LIDAR and ultrasonic range finders should provide adequate obstacle avoidance allowing the autonomous irrigation vehicle to effortlessly traverse any size yard or lawn. Between two to four ultrasonic sensors will be placed on the autonomous irrigation vehicle. The team will begin testing with two and if we deem it necessary we will add more accordingly to the needs of the project.

7.1 360 LIDAR

LIDAR is a short form for light detection and ranging which uses light in the form of a pulsed laser to accurately detect objects. The light detection and ranging will be playing a crucial role in the autonomous irrigation vehicle's responsibility of traversing terrain and detecting objects. The light detection and ranging will be placed on the autonomous irrigation vehicle to detect objects and avoid collision. When the autonomous irrigation vehicle receives a signal from the mesh network to water a location or locations, it will load a map with all currently known terrain data with coordinates of each sensor from the mesh network.

The shortest path to reach each destination midpoint would be calculated using path finding algorithm which will create a list of coordinates to reach each target location that need to be watered. Once it receives it coordinate list, the autonomous irrigation vehicle begins at its home station. While the autonomous vehicle travel to the target midpoint, the LIDAR sends out pulse laser to identify if there are any objects on its way in the terrain, and waits for pulse to return. Once the pulse return back to LIDAR, based on the return pulse it accurately calculate how far the obstacle is from the autonomous irrigation vehicle and it updates the two-dimensional array map.

After finding the obstacle on its way to the target point, the autonomous irrigation vehicle recalculates the travel path again using the nearest neighbour algorithm. Figure 15 LIDAR flowchart shows the efficient process of finding the obstacle and updating the two-dimensional array map.

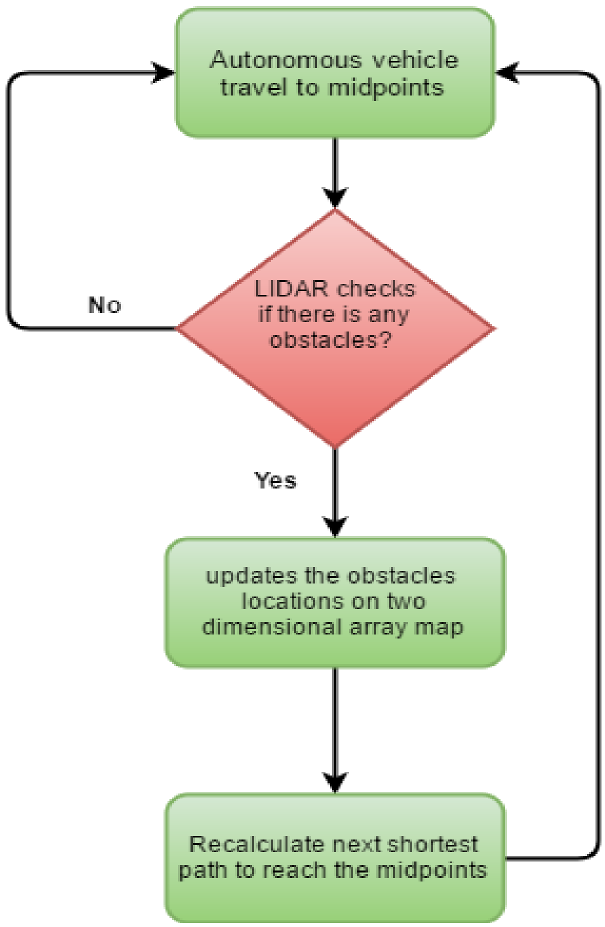


Figure 15: LIDAR Flowchart

There are several types LIDAR available in markets. For the autonomous irrigation vehicle project, we have chosen RPLidar A1M8 model because it has the perfect specs which will help us to accomplish our goal such as efficiently update the data in two-dimensional array map. The autonomous irrigation vehicle will be used in the outdoor and this model works perfectly for outdoor environment. Moreover, the Table 3 shows the RPLidar A1M8 model specifications such as distance range, angular field of view, laser wavelength, motor power supply, and scanning rate. Also, Figure 16 shows the RPLidar A1M8 model picture.

Even Though the autonomous irrigation vehicle need to scan 180 degree, this light detection and ranging scans up to 360 degree from the autonomous vehicle surrounding. Also, it has maximum laser wavelength of 795 nanometer. Furthermore, The RPLidar will be taking in data from the vehicle's surrounding area which will be used in connection with the vehicle's computer vision algorithms that will allow the vehicle to move autonomously. In the flowing document the LIDAR is referenced as computer vision obstacle detection system.

Figure 16: RPLidar A1M8 Model. Reprinted with Permission from RobotShop

	Minimum	Maximum
Distance range	0.2 m	6 m
Field of view	0°	360°
Laser wavelength	775 nm	795 nm
Motor power supply	5 v	10 v
Sample frequency	n/a	2010 Hz
Scan rate	1 Hz	10 Hz
Price	$199	

Vender	RobotShop

Table 3: LIDAR - RPLidar A1M8 Model Specs

7.1.1 Weather Proofing LIDAR

Originally the team had considered a 360 LIDAR as the main obstacle avoidance sensor but has since reconsidered because of the fact that all the electrical components must be waterproof or at the minimum weather proof. While researching how to waterproof/weatherproof a LIDAR we came across two different options. An example of the second option can be seen in Figure 17.

The first option was to manufacture a custom case out of an infrared transparent material which allows the specific wavelength that the LIDAR uses to pass through the material with minimum reflection so that information readings from the LIDAR are accurate. An example of this material is a clear polycarbonate plastic that is easily molded to fit around the LIDAR. Another benefit of using a clear polycarbonate plastic is how inexpensive it is and that ninety percent of the light beam used by the LIDAR passes through it. While researching our team found one way to improve the infrared transparent case which was to add a surface coating to the case such as an anti-reflective coating. The anti-reflective coating would help reduce the amount of signal that is reflected as its passes through the infrared transparent case. Even when using an infrared transparent material there are few things that must be considered.

1. The case would have to be properly sealed form water and rain.

2. The thickness of the case would affect how much light form the LIDAR would be allowed to pass though, the thicker the material the more light would be blocked form the LIDAR. The thickness could also bend the light beam from the LIDAR causing the readings to not be accurate.

3. Any scratches the infrared transparent case may receive would cause errors in the measurements.

4. Any dust that would collect on the infrared transparent case over time would also disturb the signals form the LIDAR.

5. The final reason this method of water proofing the LIDAR was not chosen was because even with the infrared transparent material the emitter and transceiver of the LIDAR would have to be as perpendicular as possible with the surface of the material in order to get accurate reading form the LIDAR. The 360 LIDAR we had previously chosen had a cover over the transmitter and emitter that made this

method difficult without having to take apart the LIDAR and possibly damage the functionally in the process. Since we can't afford to attempt this type of modification we had to continue researching how to waterproof/weather proof the 360 LIDAR.

Figure 17: Dry Box Weatherproofing. Reprinting permission still pending.

The second method of waterproofing the LIDAR that our team came across while doing research was buying a waterproof case such as a dry box. The waterproof case would of course have to be modified for the LIDAR. The modification would require the use to a Dremel tool to cut out holes for the LIDAR's emitter and receiver. The emitter and receiver would be sticking out of the case. Using some silicone rubber compound and gaskets the area around the emitter and receiver would be sealed off so that no water would be able to leak in through the hole made by the Dremel tool.

Another benefit to this method was that by purchasing a bigger water proof case our team could water proof other components such as the custom printed circuit board, Raspberry PI, battery, power distribution board, ultrasonic range finders, radio frequency module and any other components that may be added during the design process. Again, this waterproofing method would not be reasonable choice for a 360 LIDAR because the emitter and receiver would have to sticking out of the waterproof case. As discussed in the previous waterproofing method, our team does not have the luxury of trying to modify the 360 LIDAR and possibly damage the expensive sensor. Since both methods researched where not suited for a 360 LIDAR we researched a solution using an unidirectional LIDAR discussed in section LIDAR Setup.

7.2 Weather Proofing Servo

Now that we have added a servo for the LIDAR it too must be weather/water proof. While our team did some reach into weather/water proofing we came across a popular method used by remote control vehicle enthusiasts. The first step requires disassembling the servo and adding lubrication to the base of the spline which sticks out of the case of the servo. For lubrication, gear grease is used so that when water tries to seep into the servo through the hole of the spline it is repelled by the grease and does not reach the water sensitive electronics of the servo. The second step is to seal all the seams around the servo case.

This can be accomplished by using silicon sealant, liquid electrical tape, or air-dry rubber spray to seal all the seams around the servo. Tape must be used to make sure the spline portion of the servo does not get covered by any of the sealants as this part must be allowed to easily move. Water proof servos are manufactured and sold, the only problem is they cost on average about thirty dollars more for a servo with the same specifications. The waterproofing method discussed above will be tested on some older servos owned by one of our team members and if proven to not work properly a waterproof servo will be purchased for the 180-degree LIDAR setup on the autonomous irrigation vehicle.

7.3 Weather Proofing Ultrasonic Range Finders

The team had learned a lesson form the LIDAR and instead of researching and picking out which ultrasonic range finders we would be using on the autonomous irrigation vehicle we preformed research on how to water proof them first. As soon as we started the research we found that weatherproof ones were available on the market. The entire ultrasonic range finder is not water proof. What they do is separate the printed circuit board part of the ultrasonic range finder form the probe which serves as the transmitter and receiver. The transmitter/receiver probe is weather proof and has a long cable, so the printed circuit board could be placed with the other electronics in safe weather proof box. While the weatherproof ultrasonic range finders are about fourteen dollars more the team has decided that this will be the best option for the autonomous irrigation vehicle.

7.4 LIDAR Setup

While performing research on non-360 LIDARs we came across the Garmin LIDAR-LITE v3. The LIDAR-LITE v3 is a high-performance optical distance measurement sensor which is perfect for autonomous vehicle applications such as our autonomous irrigation vehicle. Some of the other appealing features are how compact it is with a height of 40 millimeters, width of 48 millimeters, and a depth of 20 millimeters which is 1.6 inches in height, 1.9 inches in width, and 0.8 inches in depth. LIDAR-LITE v3 is also light weight coming in at only 22 grams or 0.7 ounces. The LIDAR-LITE v3 also has low power consumption only consuming 130 milliamps operating at 5 volts direct current with an ideal current of 105 milliamps. The LIDAR-LITE v3 also only has a single digital signal processing chip allowing for easy communication with our custom printed circuit board though I-squared-C or pulse width modulation. The easy communication allows our team to adjust the accuracy, operating range, and measurement time of the LIDAR to suit our needs perfectly. This LIDAR is also suitable for both waterproofing methods discussed in the section Weather Proofing LIDAR.

The only issue with the LIDAR-LITE v3 is that it could only range find in one direction. To solve this issue, we came across a solution which requires a few extra parts to transform the LIDAR-LITE v3 into a 180-degree LIDAR which suits our needs perfectly. Since the autonomous irrigation vehicle will now constantly be tethered to the hose we will only need 180-degree obstacle detection maybe even less. The setup requires a servo motor attached to a bracket so that it can be mounted on the autonomous irrigation vehicle. The LIDAR also requires its own bracket so that it can be mounted on the servo motor. The servo motor and the LIDAR will be programed with the microcontroller on the custom printed circuit board in order to transform the LIDAR into a 180 degree LIDAR. A picture of a test setup the team performed is pictured on Figure 18.

Figure 18: Test setup of 180º LIDAR performed by the team

7.4.1 LIDAR Code

The programming of the LIDAR sensor will begin by setting up the serial communication between our printed circuit board and the LIDAR using the I-squared-C communication protocol. I-squared-C is typically used for short communication between interconnected circuit peripherals such as the LIDAR in our autonomous irrigation vehicle. Similar to a universal asynchronous receiver-transmitter (UART) I-squared-C only requires two wires for communication. The communication only requires two signals. One is a clock signal called SCL and the other is a data signal called SDA. It is also supports multiple masters for example, microcontrollers and processors which in our autonomous irrigation vehicle are the printed circuit board and Raspberry PI. In addition, it also supports multiple slaves which would be the LIDAR, ultrasonic range finders, and servos in our autonomous irrigation vehicle. Once the I-squared-C is properly setup the microcontroller will began communication with the LIDAR printed circuit board. The flow chart for programing can be seen in Figure 19.

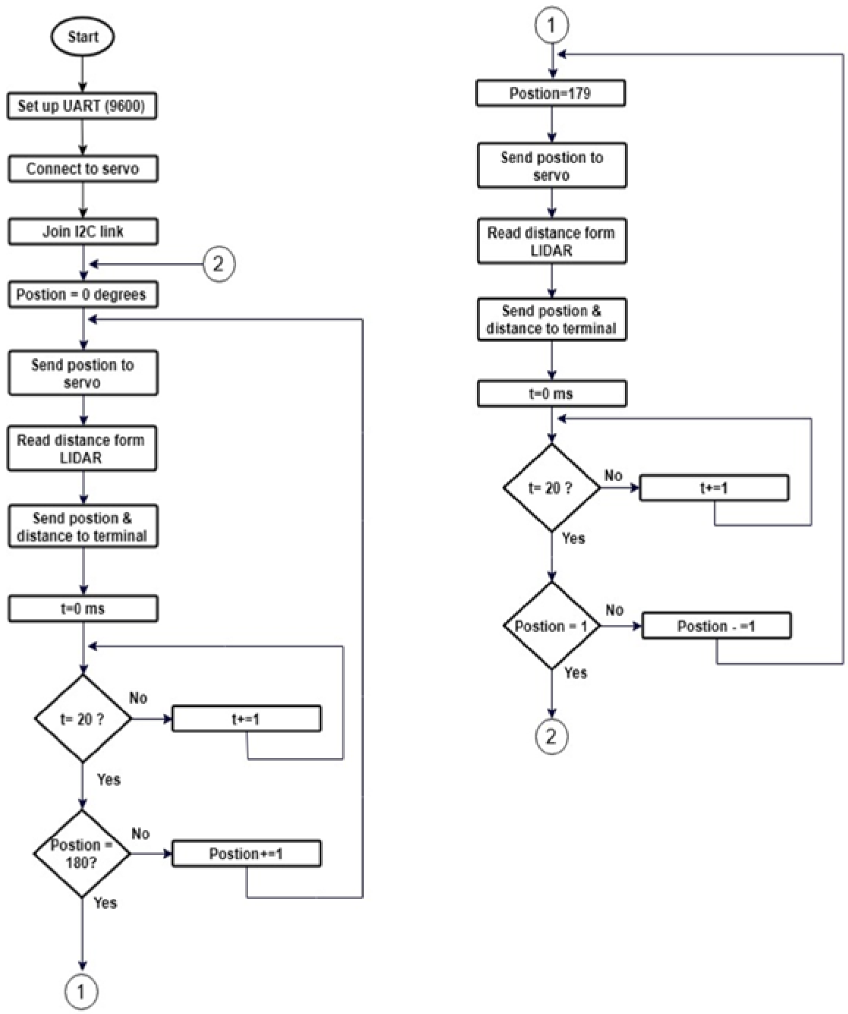


Figure 19: LIDAR Programing Flowchart

The microcontroller lets the LIDAR's printed circuit board know what values to store in the register pointers. The program includes a delay to allow sufficient time for the pointer registers to load. For the first round of testing we will include a function in the program that prints the results of the reading from the LIDAR in degrees for the position of the servo and in centimeters for the distance to the object in ASCII characters to a terminal on a computer. Later in development this function will most likely be changed to some type of serial communication between the printed circuit board and the Raspberry PI.

After the initial hardware configuration and function definitions the main body of the program will begin. The program is composed of two "for" loops. The first loop is responsible for moving the servo from 0 to 180 degrees in increments of one degree and taking measurement readings at every degree. As it takes its readings it will also send the position and distance data to a terminal.

The next loop is responsible for moving the servo from 180 to 0 degrees again in one-degree increments as it takes readings from the LIDAR at every angular position and sends the positions and distance information to the terminal or Raspberry PI. The program will continue to switch back forth between the two “for” loops indefinitely. The programs turns a unidirectional LIDAR into a 180-degree LIDAR allowing the team to get the function needed for obstacle avoidance and saves money over the 360 LIDAR that was originally being considered as the main sensor for obstacle avoidance in the autonomous irrigation vehicle.

7.5 Ultrasonic Range Finder Code

The programing for the ultrasonic range finder begins by setting the echo pin as an input and setting the trigger pin as an output. The echo pin is then set to high. The main program is a loop that sets the trigger pin to low and sets a delay for two microseconds. Next the trigger pin is set to high for ten microseconds. Then the trigger pin is back to low. This setting of the trigger pin to low and high is creating the sound pulse form the ultrasonic range finder. The next portion of the code records how long the sound pulse took to return to the high echo pin and calculates the distance.

The final part of the code creates a delay of 50 milliseconds before looping back around. For testing purposes, the next part of the code will print out the distance of the object in centimeters to a terminal on a computer. After testing this portion of the code will be changed to some sort of serial communication between the printed circuit board and the Raspberry PI. This code can easily be adjusted to multiple ultrasonic range finders by activating their proper trigger and echo pins in the same fashion as the above program explanation. A flow chart of this program can be seen in Figure 20.

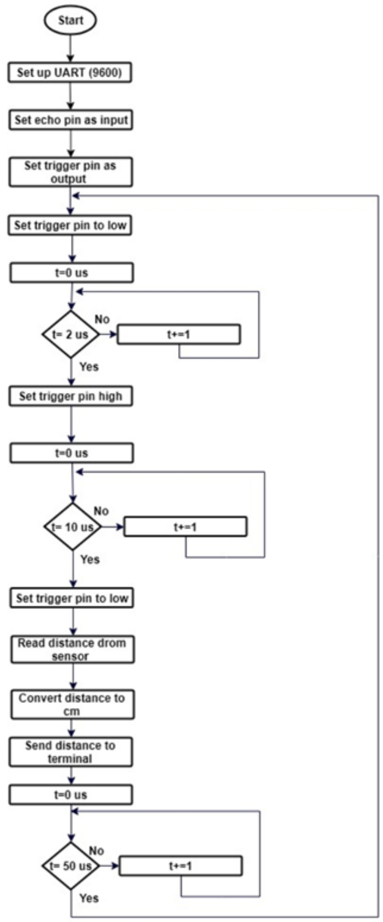


Figure 20: Ultrasonic Range Finder Programing Flowchart

7.6 Hardware Programing Libraries

The Arduino library wire.h will be used in the programing of the LIDAR. The first function used is named Wire.begin and is responsible for joining the I-squared-C bus as a master or slave. In our case the microcontroller is joining as a master. The second function used is called Wire.beginTransmission this function begins a transmission to a I-squared-C slave device with the address typed in the function. In our case it will be LIDAR. The third function is named Wire.write and is responsible for writing data between the slave and master of the I-squared-C protocol. The fourth ends the transmission started by Wire.beginTransmission. The fifth is called Wire.reqestFrom is a function used by the master to get information form a slave device. The sixth is called Wire.read and is used after Wire.reqestFrom and reads the information sent from the slave to the master.

The second library used is called Servo.h and is used to program the servo attached to the LIDAR. The frist function used from this library is called myservo.attach and is responsible for attaching the servo variable to a specific pin. The second function used is named myservo.write and is responsible for writing bytes to the servo motor. The bytes writing to the servo motor control in our program set the angle of the shaft in degrees.

Both the LIDAR and Ultrasonic sensors use the Arduino.h library. The first function they both use is Serial.begin which sets the baud rate for serial communication. The second is pinMode which configures the pin as an input or an output. The third used is digitalWrite which, once the pins are configured, it allows to set them to high or low. The fourth is delayMicroseconds which delays the program for the value entered in microseconds. The fifth reads the state of a pin whether it's high or low and is called pulseIn. The last is Serial.print which prints to a terminal in our case.

7.7 Drive System

The Traxxas summit 1/10th Scale will be used as the base for the autonomous irrigation vehicle and was chosen by the mechanical engineering students of the Guard Dog Valves team. It features a four-wheel drive system with wheels that have a large radius and off-road tread for traction. These features are important because the autonomous irrigation vehicle needs to effortlessly navigate a customer's lawn or yard filled with grass, dirt, weeds, mulch, and rocks. The Traxxas summit 1/10th Scale is meant to be driven off-road so the tread on the wheels will allow the autonomous irrigation vehicle to maneuver any yard or lawn in any type of condition.

Since the wheels are designed for off-road driving the tread on them will not allow the autonomous irrigation vehicle to slip on the lawn or yards even when wet. They will also support the autonomous irrigation vehicle when it experiences steep inclines allowing it to traverse up hills and down slopes. The prototype testing will be performed in Florida and elevation change is highly unlikely but if marketed in different states or countries the autonomous irrigation vehicle will be ready. A top view picture of the Traxxas summit 1/10th Scale without the monster truck shell can be seen in Figure 21.

The mechanical engineering students had performed research on other drive systems that had tank tracks instead of wheels and decided to go with wheels because the tank tracks can be unforgiving on loose landscape. For consumer satisfaction Guard Dog Valves would not want the autonomous irrigation vehicle to destroy or worsen any loose patches in the yard or lawn. The Traxxas summit 1/10th Scale base is approximately two feet by two feet and is the appropriate size for tackling the task of watering a 20x30plot of grass. The compact size of two feet by two feet is also favorable from a marketing stand point because the autonomous irrigation vehicle can be easily stored in a shed or garage without taking up valuable storage real estate.

Figure 21: The Traxxas Summit 1/10th Scale. Reprinting permission still pending

A 3D draft of the layers of the shell that will go on top of the Traxxas summit 1/10th Scale can be seen in Figure 22 with the exact dimensions and was designed by one of the mechanical engineering students of the Guard Dog Valves team. An overall system diagram of the mechanical components and a few electrical components can be seen if Figure 23 that the mechanical engineering students of the Guard Dog Valves team made.

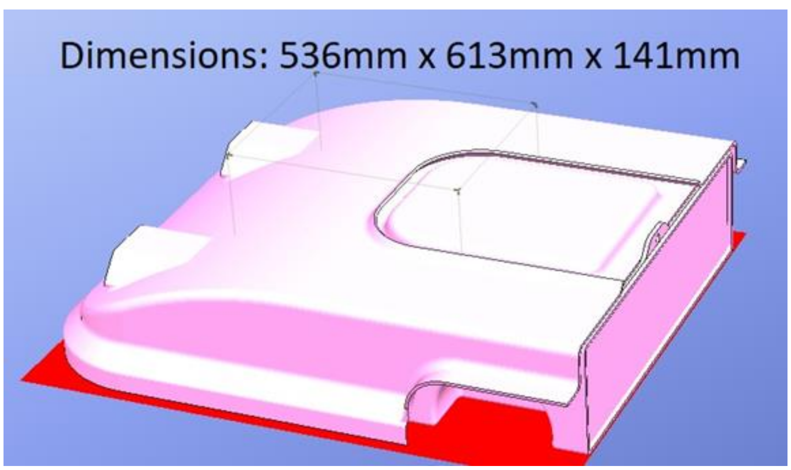


Figure 22: Prototype Dimensions for Autonomous Irrigation Vehicle

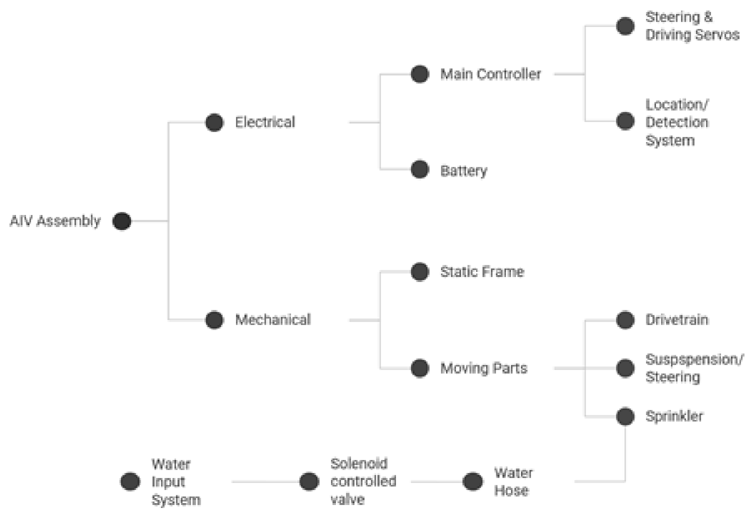


Figure 23: Mechanical System Design Diagram

Some other benefits of The Traxxas summit 1/10th Scale as a base model is a durable suspension deigned specially for off-roading. The Traxxas summit 1/10th Scale was also designed with the remote-control car enthusiasts in mind so all the parts are modular which means performing modifications should be pretty easy. This feature is extremely desirable for the Guard Dog Valves team as electrical and mechanical modifications must be made to build the autonomous irrigation vehicle. The Traxxas summit 1/10th Scale is also relatively low weight coming in at 12.7 pounds which almost any home owner would be able to lift if required. The Traxxas summit 1/10th Scale also comes with a reliable rechargeable battery that has been designed to be outside and the battery and all of the other electrical components such as the motor and transmission and are all water proof. This is a great feature for the autonomous irrigation vehicle as it will spend most of its time outside and will have a sprinkler head attached that will be dispensing water throughout the yard or lawn.

8. Software Initial Design

The autonomous vehicle begins at its charging home station. When it receives a signal from the mesh network to water a location or locations, it will load a map with all currently known terrain data with coordinates of each sensor node from the mesh network that requires watering in a hamiltonian graph. The shortest path to reach each midpoint exactly once is calculated creating a list of coordinates to reach each target node that needs to be watered and factoring in known obstacles in the area, when the list of nodes is empty the vehicle returns to its home station. The vehicle will be attached to a retractable hose tether from its home station to provide water. From the mesh network it gets sensor data such as which sensor is more dry and where its located. While the autonomous irrigation vehicle is traveling to each target midpoints, it uses computer vision obstacle detection system to detect obstacles such as ditches, steep slopes, rocks, trees, or anything that may impede the path or damage the autonomous vehicle. When a new obstacle is detected, it will update its map of obstacles and target nodes and recalculates a new path accordingly. It also constantly monitors for whenever the vehicle enters the range of the next target node on its path. When it does, it turns on its on board water dispensing system and circles once around the node watering the area. Once it completes its circle around the midpoints it shuts off its watering system and heads to the next midpoint on its path list. The overall software design flowchart shown in Figure 24.

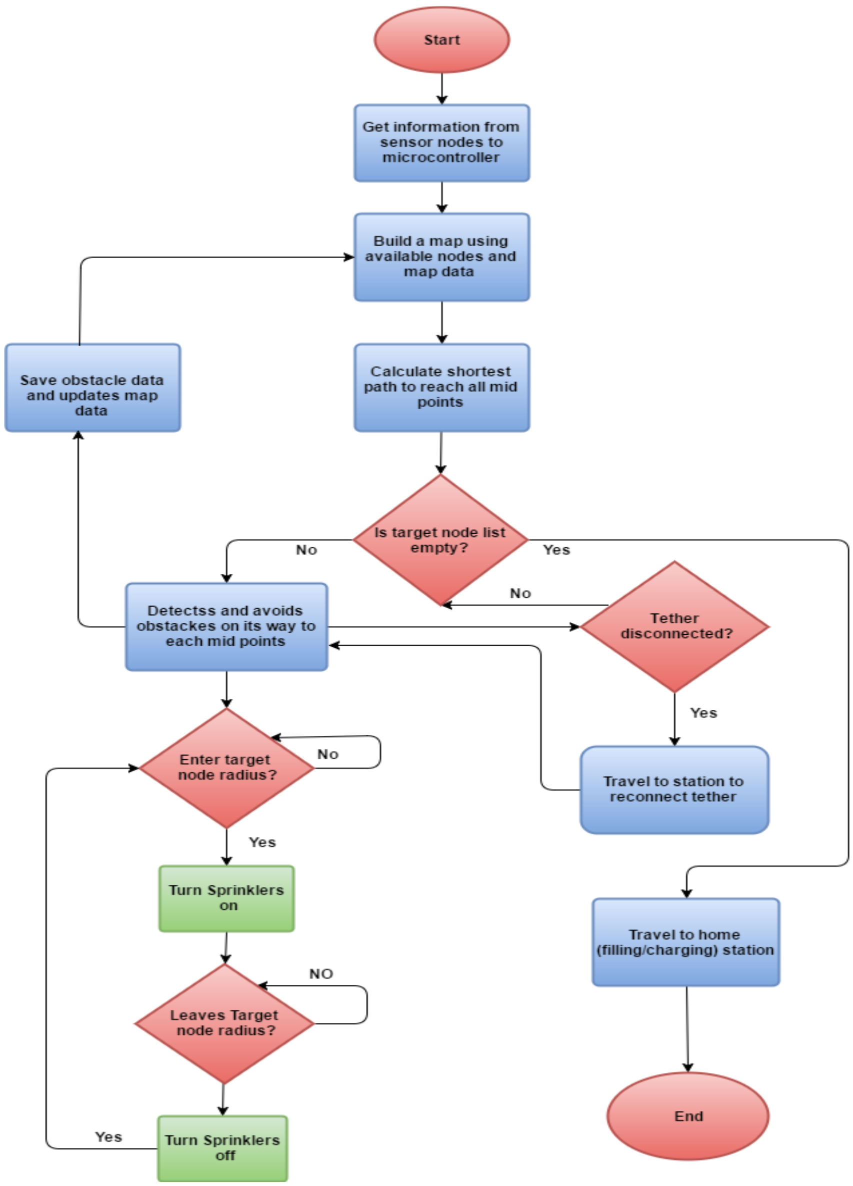


Figure 24: Software Flowchart

This comes across as an example of the classical "Traveling Salesperson Problem" (TSP), which asks to find the shortest possible route to visit each "city" given a list of "cities" and the distance between each pair of "cities. This can be approached using a combination of an uniform cost search (UCS) and a greedy algorithm such as repetitive nearest neighbor algorithm (RNNA) or an A* search algorithm, a Markov Decision Process (MDP) could also work well for this too. With either A* search or Markov Decision Process, heuristics and reward functions could be based on a water dispersion rate, an energy consumption rate, and time or distance costs for it in the future the vehicle becomes cordless with a water tank, but for the time being would start out with only time and distance while it uses the tether, with the tether RNNA may be sufficient enough.

Repetitive nearest neighbor algorithm is basically when you run a nearest neighbor algorithm using each node as a starting node. The nearest neighbor algorithm starts from a node and chooses the nearest unvisited node from the to move to next and repeats the process until all nodes have been visited. This will generate at least as many paths as there are nodes, more if at any point there are multiple neighbors who are equally close to each other and the path needs to split. From all the paths generated, the shortest distance path would be chosen.

8.1 Software Goal

The goal of the autonomous irrigation vehicle project is to provide the end user with an irrigation system that does not over water the grass and reduce the human interaction with the system. Having this autonomous irrigation vehicle, the customer does not have to worry about the changing the sprinkler control manually and turned off the sprinkler controls on rainy day. To obtain the autonomous irrigation vehicle main goal its should effectively and efficiently navigate to the destination location to disperse the accurate amount of water. The autonomous irrigation vehicle should receive the sensor data from mesh network and once the data is received the software shall be able to calculate the nearest midpoint using nearest neighbor algorithm to travel to the target midpoints. The software shall be able to detect the obstacles and avoid collision and the software shall be able to update the two dimensional matrix array every time it travel to the midpoints. The software shall be able to get a feedback from the sensor about sensor dryness reading.

The main software goal:

- Effectively irrigate a 30x20 ft plot of grass
- Effortlessly avoid obstacles
- Prevent collisions
- Dispense accurate amount of water
- Updated the two dimensional integer map dynamically
- Reduce water consumption
- Effective communication with mesh network of sensors
- Control rate of water flow

8.2 Class Diagram

This section explains the class diagram of the autonomous irrigation vehicle. The class diagram shows each of the classes in the autonomous irrigation vehicles. Each class is divided into three components such as class name, attributes and operation. The class is unique to each class, and the attributes could be represented in +public, -private and #protected. The operation component shows the specific operation done by that class. The class diagram for the autonomous vehicle is shown in the Figure 25

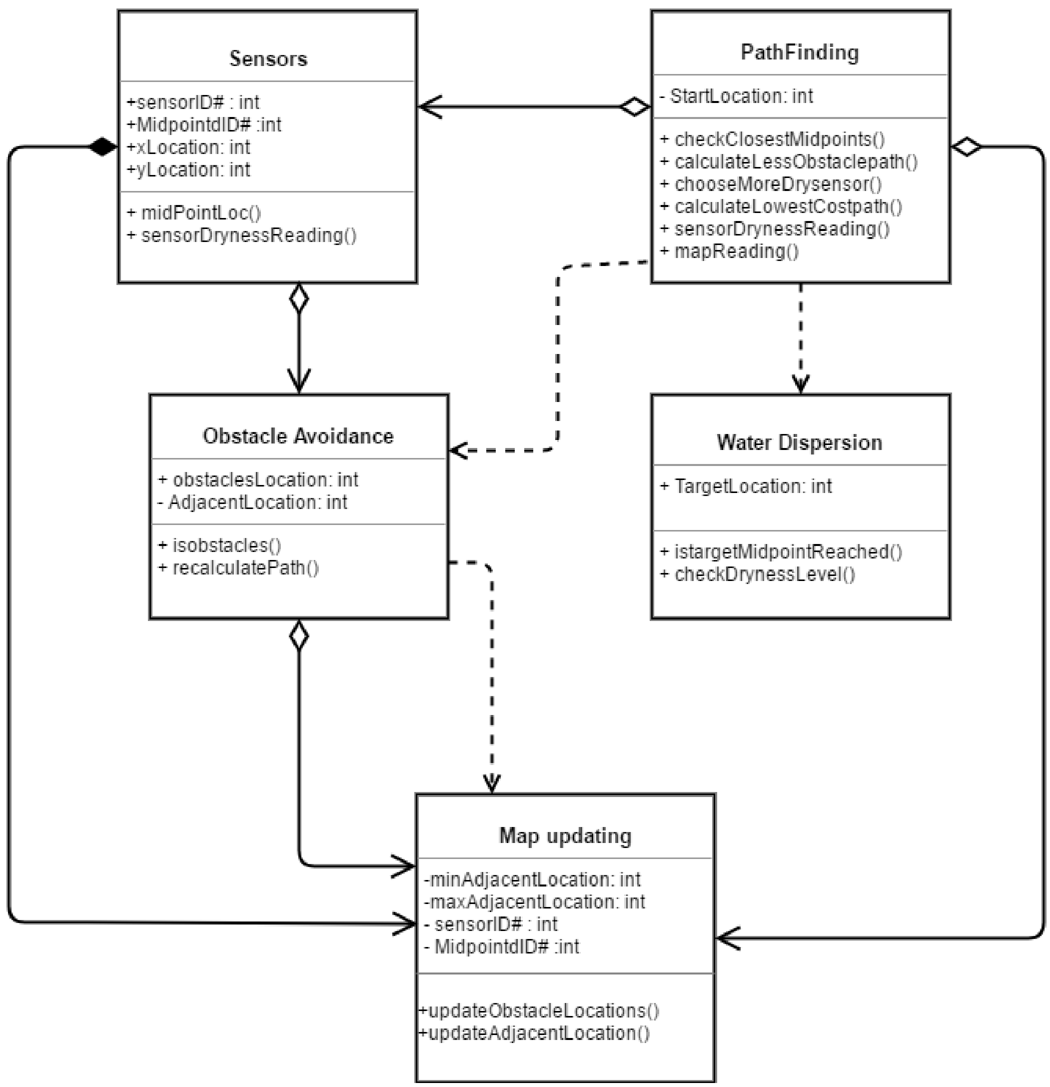


Figure 25: Class Diagram for the Autonomous Irrigation Vehicle

Also, the class diagram shows all classes and the relationship between the classes. The association relationship is denoted by single line that shows what are the classes need to communicate each other and aggregation relationship which denoted by a empty diamond symbol. Besides, composition relationship, which is represented in dark black diamond, shows the strong relationship between each of the classes and the dependency relationship is shown in dotted line.

The first class shown in the class diagram is a sensors class. It has four attributes such as sensor ID number and the midpoint ID number, x and y location of the indices. All four of the attributes are defined as public so it can be accessed in other classes as well. After receiving the sensor data from the mesh network, the x and y locations of each of the sensors in the network is represented as indices for the two-dimensional integer array map and marked as the value one million counting up by the sensor's ID value to easily identify it. In addition 1999999 is used as a flag value for sensor, so the sensor values we can go up to 1999999 which is the upper limit for the sensors value. This value can be increased in the future development if needed. So these sensors values will be stored as a integers in the program and if needed we can subtract the sensor constant value to get the each sensor's actual ID number. Having this sensor value makes it easier calculate the midpoint between the sensors and to determine when to activate and deactivate the sprinkler system in the autonomous irrigation vehicle.

Furthermore, the class will have a unique midpoint ID number and it will have x and y locations of midpoints which is stored in the two dimensional integer array map. In the map two million represents the midpoint locations. At the indices on the two dimensional integer array map for each midpoint location will store the value two million plus the midpoint unique ID number. 2999999 is used as a flag point for the midpoints. If the unique midpoint id is needed, it can be calculated by subtracting two million from the value stored at the indices in the two dimensional integer array map. In addition, the class has two operation functions which is midpointLocation operation and sensorDrynessReading operation. The midpointLocation operation would keep track of how many midpoints are in between the sensor and its locations. When the autonomous irrigation vehicle receives the sensor data from the mesh network, it used the path finding algorithm to calculate the shortest path to reach the target midpoint. The autonomous irrigation vehicle travel to the midpoints between water sensors rather than to the water sensors itself, because by having the sensors read the soil moisture at the edges of the water dispenser's range we would get a more accurate reading of how dry the soil is to provide a accurate amount of water for it. If the sensor were to be in the middle of the path in which the autonomous irrigation vehicle is traveling, then the sensors would give inaccurate readings as soil would be more damp in the middle and the edges may still be dryer than they should be. The sensorDrynessReading operation will be used to keep track of the sensor dryness reading. Once the sensor received the maximum amount of water it sends signal back to the network to stop water that midpoint. The boolean value will be used in sensorDrynessReading operation to indicate the sensor reading, 0 means the sensor is dry it needs water whereas 1 means the sensor is no longer dry. Moreover, the sensor class has aggregation relationship with path learning class and obstacle avoidance class. Also, sensor class has composition relationship with map plotting class. Composition relationship indicate the strong relationship between classes. Map plotting class will not function without the sensor class because the sensor class contain all sensor and midpoints ID number to plot the map.

The other specific class is a path finding class which has a StartLocation attribute and its marked as private to that class. To achieve the goal of the autonomous irritation vehicle, it should effectively and efficiently navigate to the target midpoints in the shortest time in terms of distance and obstacles. This is crucial for the autonomous irrigation vehicle to determine where to go and how to get there in order to dispense water to the destination midpoints. For the autonomous irrigation vehicle, the two dimensional integer array map will store the start location of the vehicle. There are several operations are defined in the pathfinding class. When the autonomous irrigation vehicle receives the sensor data from a mesh to water a target midpoints, the program will load a two dimensional integer array map with all the known sensor location and midpoints location. Choosing which location to travel to dispense water is a major decision of autonomous irrigation vehicle so using the nearest neighbor algorithm the checkClosestMidpointLocation function will calculate closest midpoint to reach each target midpoints locations between dry sensors to supply water to the sensors. While the closest midpoint is selecting the target midpoint path, the calculateless obstacle path function also checks which path has less obstacles. Choosing less obstacle path will help the autonomous irrigation vehicle to prevent form collision.

In addition, if two midpoints are in same distance from the start location, chooseMoreDrySensor function will be used to calculate which sensor is driest in order to go to first. Also calculateLowestCostpath function will be used to calculated the shortest path in a possible less distance from the start location and mapReading function would be used to get the sensor location and midpoints location from the two dimensional integer array. The sensorDrynessReading operation will be used to keep track of the sensor dryness reading. Once the sensor received the maximum amount of water it sends signal back to the network to stop water that midpoint. The boolean value will be used in sensorDrynessReading operation to indicate the sensor reading, zero means the sensor is dry it needs water whereas one means the sensor is no longer dry. To achieve the autonomous irrigation vehicle goal, the pathfinding class associated with several other classes such as it has a aggregation relationship with sensor class and map updating class. Because the pathfinding class needs the sensors and midpoints location data from the sensor class to be able to calculate the shortest path to reach the destination. And the map updating class needs the data form the pathfinding class to be able to update the sensors and midpoints locations on the two dimensional integer array map. The obstacle avoidance class and the water dispersion class have a dependency relationship with pathfinding class because the functionality of the obstacle avoidance dependent on the pathfinding class as well as the water dispersion class functionality depend on the pathfinding class. Because the autonomous vehicle should be able to find the shortest path first to travel to the midpoint to dispense water so without the proper function of the pathfinding operation the water dispersion class could not trigger its function.

Another important class is the obstacle avoidance class. To accomplish the autonomous irrigation vehicle target, it should effortlessly detect the obstacle to prevent collisions. Light detection and ranging will be used in the autonomous irrigation vehicle to detect the objects. It detects objects such as rock, trees, ditches or any other objects that may damage the autonomous vehicle. In class diagram obstacle avoidance class has two attributes such as obstacleLocation and AjacentLoation. The obstacle location is defined as public because the other classes should be able to access the obstacle Locations from that class. And the adjacent location declared as private because it will be only used in the obstacle avoidance class. There would be two operations performed in the obstacle avoidance class. When the data is transmitted form mesh network, the list of midpoints that need to water would be stored in the list. The path finding algorithm which is the nearest neighbor algorithm will be used to calculate the shortest path to reach the target midpoint to disperse accurate amount of water.

While the autonomous irrigation vehicle is on its way to the target midpoint, the isobstacle function will be trigger and the Light detection and ranging detects if there is any objects on its way, if its finds any obstacle its sends signal to that function. Then function will update the obstacle location in two dimensional integer array to keep track f the obstacle location. In the map number nine will be used as flag to represent the obstacle location. Once it sent signal to the function regarding the obstacle, it calls the recalculatepath operation to recalculate next shortest path to reach the target point. If the autonomous vehicle does not find any obstacle on its way its send signal to the function to indicate there is no obstacle found and continue on the same path to reach the target midpoint. The obstacle avoidance class is associated with many other classes such as it has aggregation relationship with map updating and sensors, dependency relationship with pathfinding and map updating. It has dependency relationship with pathfinding because obstacle avoidance is dependent on the all functions of the pathfinding, first the autonomous vehicle should be able to travel to target midpoint to detect any obstacles.

Water dispersion is another important class. It has the TagetLocation attribute and it declared as public since other class should be able to access that variable. The water dispersion class also has two operations such as istargetMidpointReached and checkDrynessLevel. When the autonomous irrigation vehicle travel to the midpoint the istargetMidpointReached function checks if the vehicle reached its destination, if it reached its destination it sends signal to that function and it turns on the sprinkler to start watering the place. While the sprinkler is watering the specific area, the checkDrynessLevel operation keeps checking if the sensor is reached its maximum water level. Once it reached it max level it sends signal to function to turn off the sprinkler and move on to the next target point. This function helps the autonomous irritation vehicle to not to over water the area. The final class is the map updating which is a important part to keep track of the obstacles locations, sensors locations and midpoints locations. Map updating class has four attributes such as sensor ID number, midpoints ID numbers, minimum adjacent location and maximum adjacent locations. All these attributes are declared as private variables and all these sensor, midpoints and adjacent values would be marked in the two dimensional integer array.

The value nine is used to mark the obstacle location on the map and every index adjacent to every obstacle, that does not have the value nine in it, is updated with the number of obstacles that they are adjacent, with the exception of values greater or equal to one million for the sensors. The maximum number of obstacles that can be adjacent to a location is eight while the minimum number of obstacles that can be adjacent to a location is zero. This class has two operations such as updateObstacleLocation and updateAdjacentLocation. When the vehicle travel to the destination point, it checks for obstacles on its way if it is to find any obstacles it updated location on map using the updateObstacleLocation and updateAdjacentLocation operations. Also, the map updating class is associated with several other class such as it has dependency relationship with obstacle avoidance class and aggregation relation with pathfinding and obstacle avoidance class. It has composition relationship with sensor class because without sensor class the map updating could not function well to attain its purpose.

8.3 Use Case

This section explains the use case diagram of the autonomous irritation vehicle. The use case diagram shows that who will interact with the system and what type of communication or action would be perform between the division of the system. As well as it shows the important functionality of the system. In our project the autonomous irrigation vehicle would the actor which will interact with the all component and perform the important functions. The line between the actor and the actions represents that the actor will participate in the use case. Figure 26 shows the use case diagram of the autonomous irrigation system.

In the project the autonomous irrigation vehicle would be performing all functions such as receiving data from sensors, finding the path to reach the destination, disperse water and detects obstacles. In addition, the dashed line with arrow shows that the functionality of the one use case can be described in another use case. In the diagram map plotting is extend to sensors because to be able to plot the sensors data in two dimensional integer array the vehicle needs sensor data from sensor use case. Similarly, the map updating use case is extended to map plotting because to able to update the two dimensional integer array, it should already have the plotted data from map plotting use case. Also, it extend to obstacle avoidance use case because first the vehicle should be able to find the obstacle location in order to update the obstacle locations on the two dimensional integer array map. In addition, the disperse water use case extend to the pathfinding use case because if the vehicle need to water a specific area, at first the autonomous irrigation vehicle should be able to reach the destination point to deliver the accurate amount of water in the specific location.

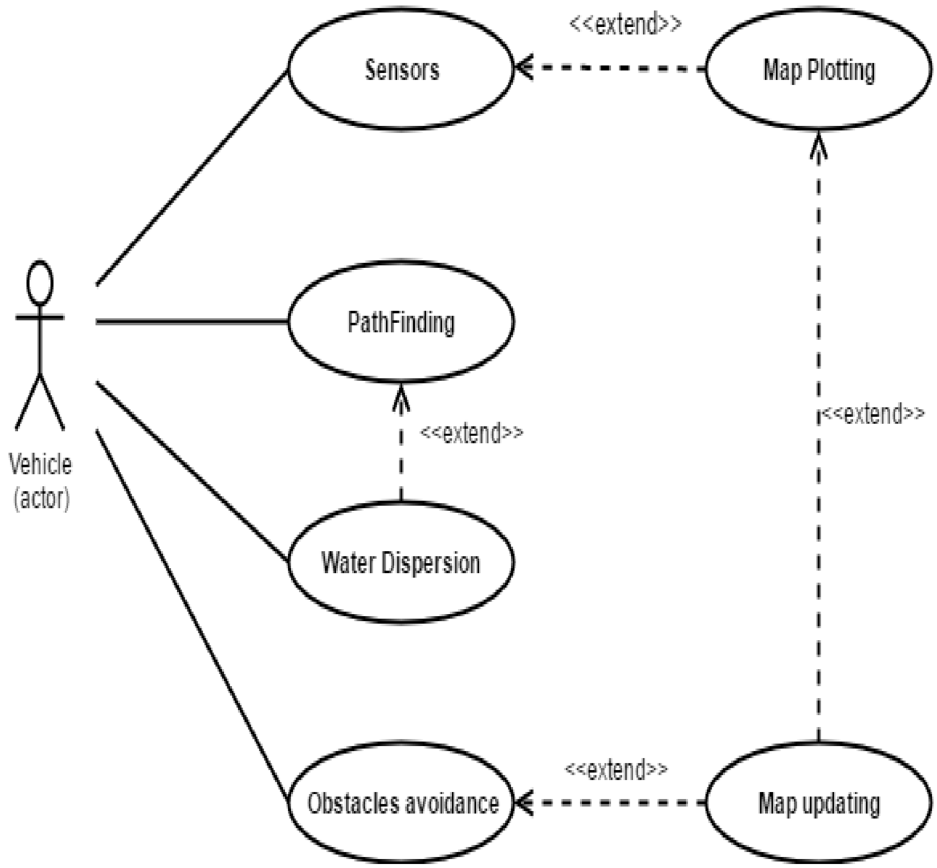


Figure 26: Use Case Diagram for Autonomous Irrigation Vehicle

8.4 Sequence Diagram

This section explains the sequence diagram of the autonomous irrigation vehicle. The sequence diagram shows the interaction between the each components of the autonomous irrigation vehicle. And it shows the time sequence of which component interact first. The each objects are shown in the square box and the vertical dashed lines represents the object's life line and the horizontal lines between the objects life lines represents the messages between each components. Figure 27 shows the sequence diagram of the autonomous irrigation vehicle.

The sequence diagram shows the five different objects, the first one is map plotting the when the sensors data received from the mesh network team, all sensors locations plotted on the two dimensional integer array map. Then it sends the list of dry sensors that need to be watered to the pathfinding algorithm. The main responsibilities of the path finding is that it should find the shortest path reach its destination area. So when the pathfinding algorithm received dry sensors list, using data from the two dimensional integer array map, first it checks which midpoint is the closest from the current location then it calculate the shortest path utilizing the nearest neighbor algorithm. In addition, the next component in the sequence diagram is the obstacle avoidance, while the autonomous irrigation vehicle travel to the destination point it detects if there is any obstacle on its way if the its find any obstacles then it updates the obstacle location on the two dimensional array map. That is in sequence diagram as messee between obstacle avoidance objects and map update objects. If the vehicle does not find any obstacle, it will able to continue on the same path. The next sequence after the map updating is the dispersed water, when the autonomous vehicle reaches its target location, using the ifDestionReached condition to check if the vehicle arrived the correct midpoint to disperse water. If the condition is true then it turn on the sprinkler to deliver the water. This message is shown in the sequence diagram as message between pathfinding and Disperse Water objects. The autonomous irrigation vehicle follows the same sequence whenever it travels to the destination midpoints.

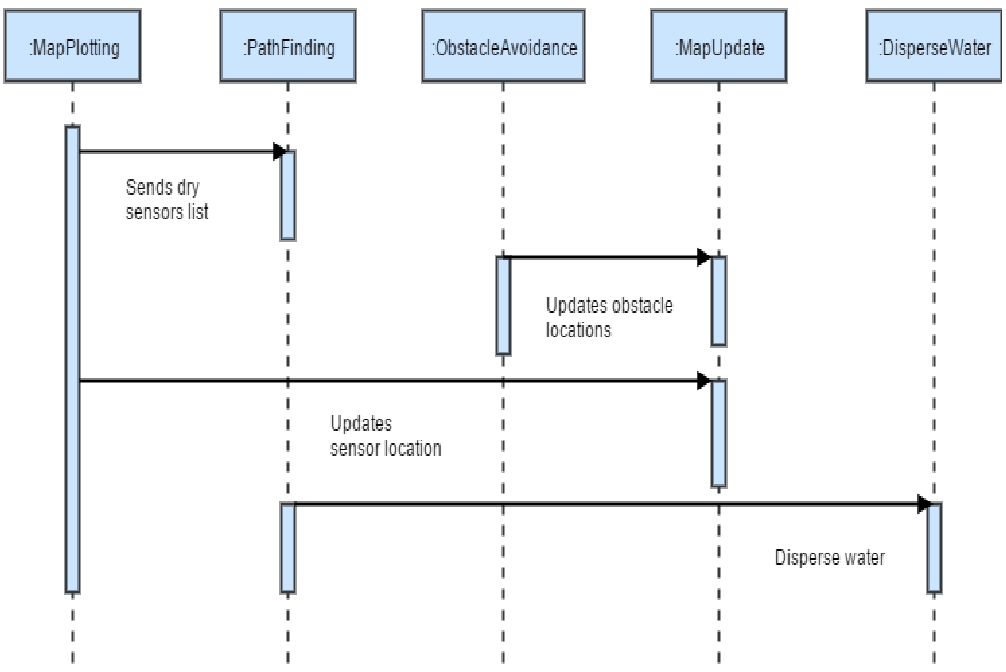


Figure 27: Sequence Diagram for the Autonomous Irrigation Vehicle

8.5 Methodology

A map of the area being watered is represented as a two-dimensional integer array with all its initial values initialized to zero. This will be useful for navigating the autonomous irrigation vehicle based on sensor locations, destination midpoints, and obstacles in order to meet the autonomous irrigation vehicle's goal in the most water and energy efficient manner possible. Figure 28 as seen below, is a depiction of the mapping of the area.

This map will be updated with sensor locations, midpoint destination locations, obstacle locations, and locations adjacent to obstacles to represent their risk of collision with an obstacle. All of this information will be necessary for the autonomous irrigation vehicle to safely travel around the area. With safe travel accomplished, the autonomous irrigation vehicle can deliver the precise amount of needed water to wherever the sensors in the area determine needs to be watered. By realizing and actualizing the watering of areas where watering is needed, the total distance that is needed to be traveled to reach every one of those locations exactly once has been minimized. With these goals being reached, the success of the autonomous irrigation vehicle becomes one step closer.

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 28: (30 x 20)ft^2 Two Dimensional Integer Array Map

8.6 Libraries

This section explains in detail about the libraries which will be used in the software algorithm to effectively communicate with the autonomous irrigation vehicle as well as communicate with mesh network data. In programming standards libraries are resources which can be utilities while writing the program. The libraries usually contain preset of standard function and math formulas. For the autonomous irrigation vehicle project algorithm, we will be using Visual Studio or Eclipse, which are an Integrated Development Environment(IDE), to maintain and develop the program. Integrated Development Environment would be easy to maintain different classes, variables and functions as well having it prevent any spelling error. The high level language will be used for path learning algorithm such as C++. The integrated development environment has several open source libraries for C++, so those libraries would be utilized for the algorithm. Also, there several open source libraries are available for C++ programming language communication and plotting and graphs. Move over, ATmega328 microcontroller will used for communication part. Since the Arduino is an open platform, for this ATmega328 microcontroller communication the Arduino open source libraries will be used.

8.7 Communication Over Wireless

The main purpose of the autonomous irrigation vehicle is to effectively and efficiently navigate the target midpoint in possible shortest time without colliding into any objects. To reach the autonomous irrigation vehicle target, first it should successfully communicate with mesh network. The mesh network sends the all sensor details such as which sensors are dry, how much water it need and where it located in the two dimensional array map. For the effective communication between the mesh network and the autonomous irrigation vehicle the IEEE 802.15 a wireless personal model will be used. Once it established successful wireless connection between mesh network and the autonomous irrigation vehicle. The mesh network sends the sensor data in JSON format and the path finding algorithm convert that format to C++. Then the pathfinding algorithm calculated the shortest path to travel to the target midpoints.

8.7.1 Map Plotting

After the transmitted data from the mesh network is parsed from JSON, the x and y locations of each of the sensors in the network is represented as indices for the two-dimensional array map and marked as the value one million counting up by the sensor's ID value to identify it. So sensor 0 would have the value 1000000 and sensor 1 would and the value 1000001 and so on up to 1999999, which is a distant enough of an upper limit for flexibility in future development and implementation. The count would stop at 1999999 and not go up to 2000000 because the 1 in the millionth digit of 1000000 to 1999999 is the flag that identifies this as a sensor specifically. This in the future could be increased to 1000000000 with 2000000000 as the upper limit if needed, but 1000000 and 2000000 seem sufficient enough for now. These values will be stored as a constant to be used in the software for this very reason. You can subtract the sensor constant value to get each sensor's ID number from the map. Below in Figure 29, is an example of what the two dimensional integer array could look like to the autonomous irrigation vehicle's computer processor.

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	1m	0	0	0	0	0	0	0	0	0	1m	0	0	0	0	0	0	0	0	0	0	1m	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	1m	0	0	0	0	0	0	0	0	0	1m	0	0	0	0	0	0	0	0	0	0	1m	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 29: (30 x 20)ft^2 Map with Sensors Marked

As seen in (map2) below, the locations of six sensors have been recorded on the map from the wireless sensor mesh network at the indices of [4][4], [14][4], [25][4], [4][15], [14][15], and [25][15]. They have been marked with 1m for readability in this example. In the software each of those locations would equal the sensor ID number plus one million for as many sensors listed to avoid conflicting with other values on the map that could be used to identify obstacles, locations adjacent to obstacles, and midpoint travel destinations for the autonomous irrigation vehicle to know where to go. In this case illustrated above the locations of the sensors would be marked from 1000000 to 1000005 with the sensor ID count beginning at 0.

Each sensor will also have its own class in the software storing its ID, x and y indices, a boolean dryness reading value, and a list of all the midpoints it borders. All of these sensor classes will be stored in a list indexed by their unique id number. This will make accessing the information about each sensor much easier for determining when to activate or deactivate the water delivery system, calculating midpoints between each sensor and their neighbors for the autonomous irrigation vehicle to deliver water, and for building a path to where needs water be delivered. The boolean value representing the dryness reading would be updated whenever the autonomous irrigation vehicle receives a signal from the wireless sensor mesh network indicating a change in the dryness level at a particular sensor. This helps the autonomous irrigation vehicle know whether or not water needs to be delivered to any particular region near a sensor and when to shut off the water delivery system in a region its currently providing water.

By including the sensor ID with the one million digit flag, we can identify and access from its location on the map without interfering with any other sensor value flags each sensor's class and therefore retrieve their data concerning their dryness readings, their neighbors, and the calculated midpoint destinations between them and their neighbors. The sensors could also be checked this way to make sure that they are marked at the correct locations as this data would also include their x and y index locations on the two dimensional integer array map. This would make the communication through the data structures easier to determine to nearest sensor to calculate their midpoint watering destinations as well as getting a current reading from the specific sensors data to know that sensors dryness for building the path to water the area most efficiently. This could also be useful in later development to be able to know where each individual sensor is on the map as opposed to having a general single integer value flag just to identify that there is a sensor present in that location.

All this information is important for knowing how to accurately provide just enough water to a specified region without providing too much nor too little water from the water delivery system onboard the autonomous irrigation vehicle. A major goal of the autonomous irrigation vehicle is better water usage efficiency compared to current inground sprinkler plumbing systems and having precise measurements of what locations in a region need water in crucial in achieving this goal. By plotting out the locations of the sensors that indicate whether or not a region needs water on a map representation for the autonomous irrigation vehicle to understand, we can more accurately calculate potential destinations and decide which of those destinations to provide water to while minimizing the waste of water usage. This information can also help determine the most efficient way to deliver water to all of the destinations that need so that the autonomous irrigation vehicle can also reduce its energy consumption as a longer less accurate path could use up more energy to travel.

8.7.2 Sensor Midpoint Calculation

From an two dimensional array provided from the mesh network, we find which sensors have which other sensors as their neighbors in their network. This will allow for calculating the midpoints between two neighboring sensors as destinations for the autonomous irrigation vehicle to travel. Ideally the midpoint between two points is calculated by first getting the midpoint x position by adding the two x indices of the two edge points which is divided by two and then getting the midpoint y position by adding the two y indices of the two edge points which is also divided by two. This can be seen Formula 1 below:

$$m = (\frac{x_2 + x_1}{2}, \frac{y_2 + y_1}{2})$$

Formula 1: Midpoint Calculation

However the indices of the two dimensional array map are integers, so in the event that a midpoint has a decimal value it would be rounded down. For instance, if x_2 and x_1 were 5 and 2 respectively, the midpoint would be calculated as 3.5 but we would take it as 3 for the midpoint x-axis index. This slight adjustment should be negligible and not affect the performance in any real way. Most likely if two sensors are neighboring, the will have the same x values if their y values are different or the different x values if their y values are the same, but this may not be the case for every instance, which is why the input from the mesh network telling which sensors which other sensor as their neighbors have is important. Figure 30 below depicts a sample of a two dimensional integer array as was explained.

The reason we are having the autonomous irrigation vehicle travel to the midpoints between water sensors rather than to the water sensors itself, if because by having the sensors read the soil moisture at the edges of the water dispenser's range we would get a more accurate reading of how dry the soil is to provide a suitable amount of water for it. If the sensor were to be in the middle of the path in which the autonomous irrigation vehicle is traveling, then the sensors would give inaccurate readings as soil would be more damp in the middle and the edges may still be dryer than they should be. Pathing is easier if you have coordinate locations to travel to, hence why the midpoints are calculated to give the autonomous irrigation vehicle travel destinations with the sensors at the edges of its path.

Each midpoint will have a class data structure for each one containing information on its coordinates on the two dimensional integer array map, which two sensors are at their edges, how many of those sensors are dry, and an unique ID number beginning at 0. The at the indices on the map for each midpoint location will store the value two million plus the midpoint unique ID number. The same constant upper limit constant used to check that to prevent the sensors from exceeding 1999999 to maintain their 1xxxxxx sensor flag so that the midpoints can have a 2xxxxxx midpoint flag where it would have a two in the millionth position to identify that this location contains a midpoint. The retrieve the unique ID number of a midpoint from the map, subtract two million from the value stored at it’s indices in the two dimensional integer array map. For this we can set up the value three million as an upper bound for midpoint identification allowing for sensors to be marked on the map ranging 2000000 up to 2999999 in order to maintain the value two in its millionth position as its midpoint identification flag. For this the value three million could be saved as a constant variable to be used in code for simplicity. If in the future for some reason the sensor constant value were to be raised to the value of one billion with its upper bound at two billion, this new two billion upper bound would be used as the new midpoint constant value, however the maximum value of an integer in a 32-bit system is 2,147,483,647 which would have to be used as the new upper board for the mapped midpoint values instead of three billion, unless if the autonomous irrigation vehicle were to be upgraded to a 64-bit system.

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	1m	0	0	0	0	2m	0	0	0	0	1m	0	0	0	0	2m	0	0	0	0	0	1m	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	2m	0	0	0	0	0	0	0	0	0	2m	0	0	0	0	0	0	0	0	0	0	2m	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	1m	0	0	0	0	2m	0	0	0	0	1m	0	0	0	0	2m	0	0	0	0	0	1m	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 30: (30 x 20)ft^2 Map with Midpoints

As seen in Figure 30 above, six sensors have been recorded on the map at indices [4][4], [14][4], [25][4], [4][15], [14][15], and [25][15] marked with 1m for readability in this example. Midpoints have been calculated at [9][4], [19][4], [4][9], [14][9], [25][9], [9][15], and [19][15] and marked with 2m for readability. Between the six sensors there are seven midpoints with unique IDs 0 through 6 for seven total. On the two dimensional integer array map within the software these would be marked as 2000000 through 2000006 at each of their respective x and y indices. With the map on the autonomous irrigation vehicle always being updated, it should be readily available to make any adjustment as needed in real time. As such, the autonomy of the autonomous irrigation vehicle becomes more and more of a realization.

8.8 Water Dispersion

Initially the water delivery system will be off while the autonomous irrigation vehicle is driving to its destination since the water is not yet needed until it reaches where is needed to be delivered. When the autonomous irrigation vehicle reaches a midpoint destination with a sensor or two in range at the edges, the autonomous irrigation vehicle will turn on its water delivery system to provide a sufficient amount of water to the specified region as necessary. By having the water delivery system off until needed, a significant amount of water should be responsibly retained, meeting one of the major goals of the development of the autonomous irrigation vehicle to save water.

Water conservation is a very important subject that affects many industries and the lives of many people. There are many economic benefits to water conservation, water costs money to consume and by reducing the amount used by who ever needs to irrigate their land, an individual could save a decent amount of money. Many regions also suffer from severe drought and water scarcity, which in turn could increase the cost of water as more scarce resources that are in high demand have a tendency to increase in monetary value and water is something that will always be in high demand as all biological life as we know it requires it for its very existence. Developing more efficient water use techniques could help alleviate the strain felt by many of these regions that are subject to these conditions, by helping many of their vital systems that rely heavily on water to function. The autonomous irrigation vehicle being developed is aimed mostly towards residential lawns, but it could be the building block for something geared more towards the other markets, such as the agricultural industry. This would benefit the environment with water conservation and keeping lush natural areas alive to enjoy, as well as proving the industries interested in this technology a product to help them save money on water consumption costs and increasing their net profits and potentially increase the value of their market shares if the general public sees them as doing something good that they may want to invest into.

After the sensor sends the autonomous irrigation vehicle a reading indicating that it is no longer dry, it will shut off its water delivery system and move towards its next midpoint destination to repeat the process. This is so that it does not provide more water than is required to regions that do not need water. If the midpoint destination has two edge sensors it would wait for both sensors to give back readings that they are no longer dry before moving on. However, it could also be programed to calculate another midpoint between the current midpoint and the dry sensor in this scenario. It would use this new midpoint to travel closer to the sensor that is still dry and away from the one that now has enough water until the sensor it is moving closer to is no longer providing a reading of being dry, but whether or not this addition would provide any significant benefit would need to be tested. One sensor could provide a reading of not being dry anymore shortly after the other one does. Also, if there are any obstacles between the midpoint and the sensor that is still dry, then the distance traveled to get a little bit closer may not be enough to show any real difference.

8.9 Pathfinding

The purpose of pathfinding is to determine the shortest path from one location to another, it is usually heavily based on graph theory. This is very important for the autonomous irrigation vehicle to determine where to go and how to get there in order to provide water to destinations where it is needed as efficiently as possible. The more efficient the autonomous irrigation vehicle travels to its destination, the less power is consumed for it to travel. Reducing power usage is a very important factor for the consumers the autonomous irrigation vehicle would be marketed to as something that uses less power, as opposed to something that uses more, would be more desirable as far as financial costs and potentially environmental impacts that many who would use such a product may have interest in.

In graph theory, graphs are mathematical structures that consists of locations known as vertices and the lines connecting the vertices together known as edges. A graph can be directional where the algorithm can from from a particular vertex to another particular vertex along an edge in only one direction, or unidirectional where it can move in either direction between the two vertices. Graphs can also we weighted where each edge has a weight assigned to it to determine the cost of traveling along that particular edge as opposed to another, or unweighted where each edge is treated the same as far as their cost to travel. These costs can represent anything from distance, risk potential, or any other factors that may make an edge more or less favorable to travel. In many directed graphs that are also weighted, traveling in the opposite direction that an edge is directed towards would result in a negative valued weight for that edge. Graph theory can be applied to many purposes such as telecommunications, data organization, computations, physics, chemistry, biology, and finding the best directions to a physical location from another.

For the autonomous irrigation vehicle, the two dimensional integer array map will serve as a weighted undirected graph for the pathfinding algorithm it will use to reach its destinations, where each index in the array is a vertex and the edges are the movement from any location to any of its adjacent locations. Moving from any location to any other location would incur a travel cost of one plus the hazard risk value stored at any location to represent moving from one vertex to another along a weighted edge. The being used graph is unidirectional, so negative valued weights are not a concern as traveling from one location on the two dimensional integer array to another location still adds to the total distance traveled even if the path the autonomous irrigation vehicle were to backtrack its path as it travels, if that is the most efficient way to reach all of its destinations with the least distance traveled and most obstacles avoided. The autonomous irrigation vehicle will factor in obstacles in the area to avoid because these obstacles could slow down its travels, stop it in place if it gets stuck, or cause serious damage that could be expensive for the consumer to repair. By building a path that keeps the autonomous irrigation vehicle safe as it travels efficiently as possible to its destination, the total maintenance costs should also be reduced significantly.

8.9.1 Algorithm Concept

The autonomous irrigation vehicle begins at its home station. When it receives a signal from the mesh network to water a location or locations, it will load a map with all currently known terrain data with coordinates of each sensor from the mesh network that requires watering in a hamiltonian graph. The shortest path to reach each destination location between dry sensors exactly once is calculated creating a list of coordinates to reach each target location that needs to be watered and factoring in known obstacles in the area, when the list of location is empty the vehicle returns to its home station. Choosing which location to travel to deliver the water to is a very important decision to reducing the total distance the autonomous irrigation vehicle travels. The vehicle will be attached to a retractable tether from its home station to provide water and power.

The Dijkstra's Algorithm is a classic path finding algorithm that finds the shortest path from a starting point to all other vertices in a graph. It works with directed weighted graphs, but is unable to work with edges that have negative valued weights. It uses a boolean array to keep track of visited vertices and a priority queue that begins with only the starting edge from the first location in it. While the priority queue is not empty, it travels to the next edge, checks it as visited in the boolean array, and if it makes it to its destination from that edge it returns its weight. If it has not made it to its destination, it adds all unvisited edges neighboring the current edge to its priority queue and repeats the process. Bellman Ford is an improvement from Dijkstra's algorithm that is able to handle negative edge weights with no problem.

This comes across as an example of the classical "Traveling Salesperson Problem," which asks to find the shortest possible route to visit each "city" given a list of "cities" and the distance between each pair of "cities. Neither the Dijkstra's algorithm nor Bellman Ford may be suitable for the Traveling Salesperson Problem in the problem we are working with. A more appropriate method of approaching this could be using a combination of an uniform cost search and a greedy algorithm such as repetitive nearest neighbor algorithm or an A* search algorithm, a Markov Decision Process could also work well for this too. With either A* search or Markov Decision Process, heuristics and reward functions could be based on a water dispersion rate, an energy consumption rate, and time or distance costs. Out of these repetitive nearest neighbor algorithm appears to be the best candidate, which is when you run a nearest neighbor algorithm using each travel position as a starting position. Repetitive nearest neighbor algorithm typically out performs nearest neighbor algorithm, however the autonomous irrigation vehicle is attached to a cord at a fixed starting location, so nearest neighbor algorithm by itself should be sufficient enough. The nearest neighbor algorithm starts from a location and chooses the nearest unvisited destination by comparing the costs to travel from its current location to all other available destinations and selects the one with the lowest cost for it to move to and repeats the process from that next position until all destination locations have been visited. This will generate at least as many paths as there are destinations, more if at any point there are multiple neighbors who are equally close and the path needs to split. From all the paths generated, the path with the shortest distance path, or the path with the lowest travel cost if dealing with other constraints such as obstacles, is chosen. Figure 31 shows how the autonomous irrigation vehicle will be able to traverse its surrounding environment. with four sensors

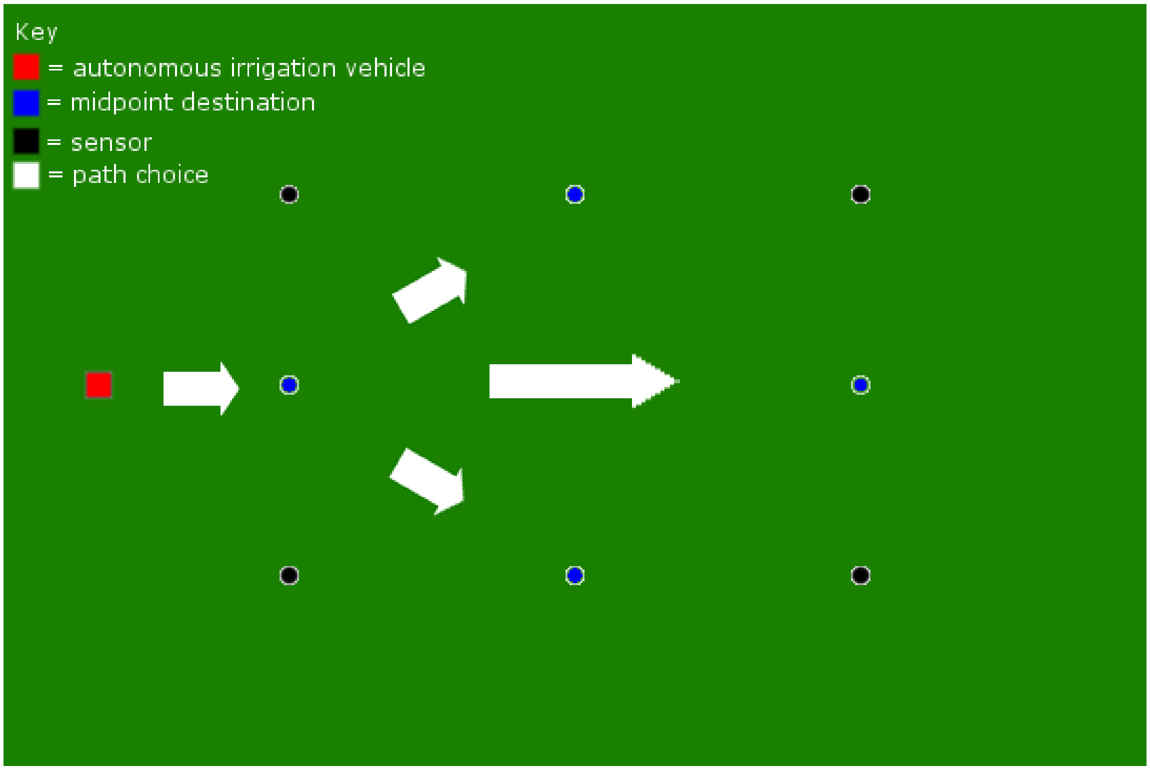


Figure 31: (20 x 30 ft^2) Choices with Four Sensors

In our implementation of this, we will be factoring in the dryness reading of the sensors at the edges of our midpoint travel destinations. It will look to the destination to its left and to the one to its right. If one of them has the more dry sensor reading than the other, it will select it and add it to a list of destinations to travel to. If they both have the same dry sensor readings and they both have sensors that read dry, it will choose the next midpoint destination in front of it. If neither of the two side midpoint destinations have sensors that indicate dryness and require watering, the nearest neighbor algorithm is performed to find the nearest sensors with a dryness reading and the autonomous irrigation vehicle travels to the closest midpoint destination by that sensor. If multiple dry sensors are detected at equal distance from the autonomous irrigation vehicle, the algorithm branches and overall chooses the one with the list of destinations that have the lowest cost for reaching all of the locations that need to be watered. Once it has its list of destinations, it will begin to travel to each of those locations in the order of start to finish from its chosen list. Figure 32 shows how the autonomous irrigation vehicle will be able to traverse its surrounding environment. with six sensors.

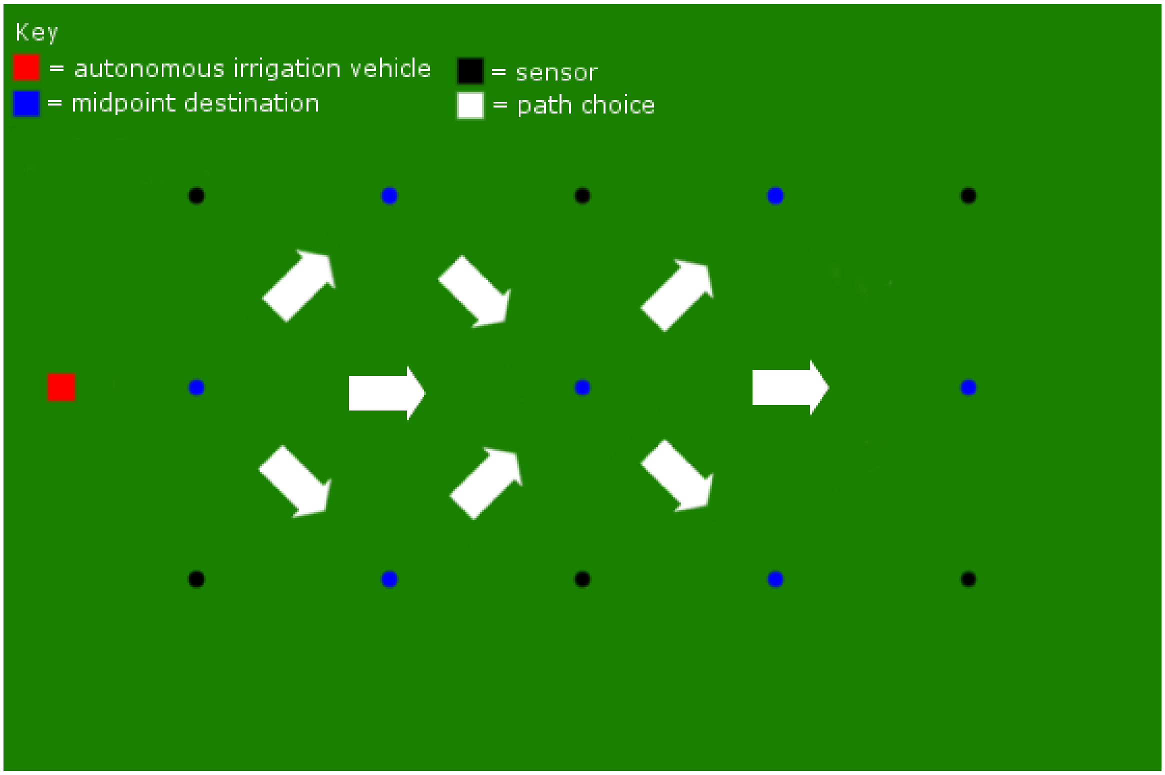


Figure 32: (20 x 30 ft^2) Choices with Six Sensors

Our sponsor will provide us with four sensors to test with, for which with only four sensors we would be able to test the single direction decisions of left, right, forward, and finished without needed to search for more with the nearest neighbor algorithm. However, test cases with more sensors could still be tested by supplying the autonomous irrigation vehicle inputs with the same format as it would receive from mesh network to make it think it is in a larger mesh network with more sensors. When it reaches a midpoint destination, a timer could start in order to simulate a dry sensor at the edge of the midpoint. When the timer goes off, it could send a signal to the autonomous irrigation vehicle to indicate that the sensor is now wet and to move on to the next midpoint destination to water the next sensor or sensors. By doing this you could theoretically make the robot think it is in a mesh network wish as many sensors as you want to test and refine the algorithm to be the most optimal. This could be done in any physical environment, from an open field to a yard that wraps a house at odd angles as the computer vision obstacle detection system should still be able to detect the obstacles that would be present in any of these environments.

As seen above, an area with six sensors would better illustrate a scenario where the autonomous irrigation vehicle may provide water to the left or right midpoint destination close to where it begins on the left side of Diagram 2 and none of the nearest immediate midpoint may have dry sensor readings, but there could still be dry sensors further away in the area towards the right side of Diagram 2. In this scenario, the autonomous irrigation vehicle would shut off its water delivery system and travel to the midpoint destination in the center of Diagram 2 in order to travel to whichever midpoint destination need water near the right side of Diagram 2 where it would reactivate its water delivery system until there are no more dry sensor readings.

8.9.2 Ideal Optimal Path

In order for the autonomous irrigation vehicle's path to each watering location to truly be optimal, the shorted path to the next destination needs to be found to minimize energy consumption cost of the autonomous irrigation vehicle's travels. The path it travels also needs to be a safe one, so it will factor in both distance and hazards of potential paths. By making the autonomous irrigation vehicle more risk averse when plotting its course, it should minimize damages, maintenance or repair, as well as the risk of the autonomous irrigation vehicle getting stuck on an obstacle that could prevent it from traveling around the area performing its functions, to the customer's annoyance. For this, a breadth first search algorithm can be implemented. Figure 33 shows a depiction of how breadth first search algorithm works.

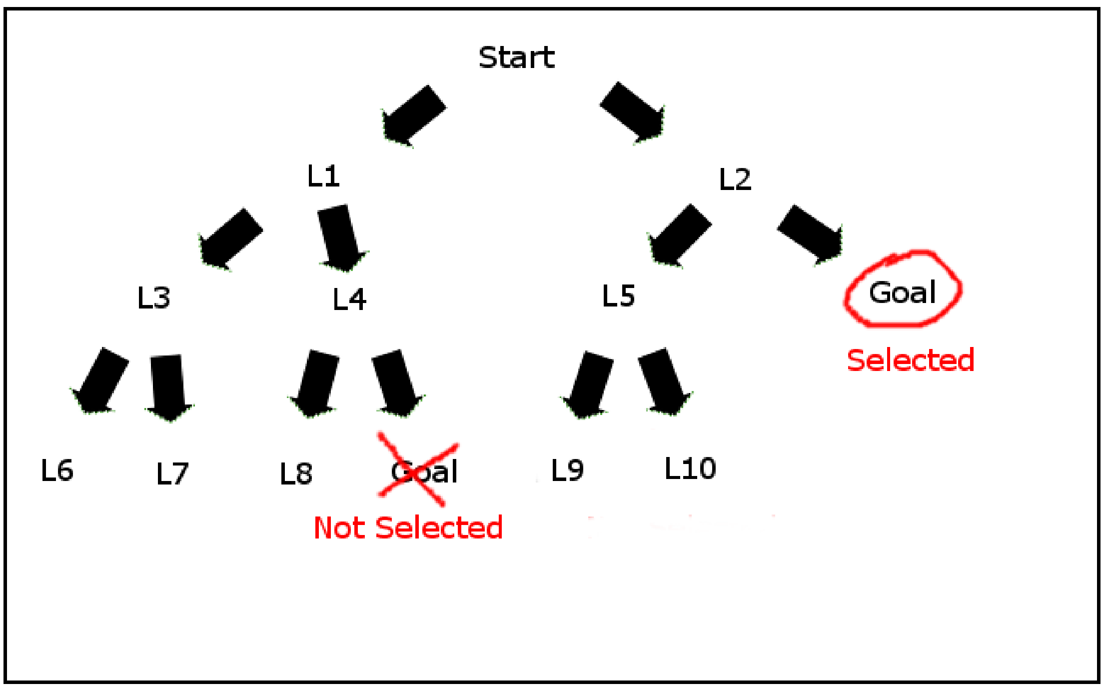


Figure 33: Breadth First Search Illustration

To reach each destination in the most optimal way, a breadth first search can be used to plot a course from one location to the destination's location. The way that breadth first search works is that it searches all paths in a uniform depth from its starting location and expands outward at the same depth for each path storing all adjacent locations stored in a queue ordering by first in first out fashion. It will need to mark the locations it has visited to prevent a path from repeating locations and traveling more than it should. This could be achieved using a second two dimensional boolean array map, with the same dimensions as the integer map, to mark locations as visited or not based on their indices from the integer map. Below is a diagram illustrating the process of how breadth first search finds its goal in a more simplified manor.

For the autonomous irrigation vehicle, each location a potential path enters, it updates its total path cost by adding one plus the value stored in that location on the two dimensional integer array map to its path length count. A location with the integer nine value stored in it will be considered invalid to travel to and avoided. Once a potential path reaches the destination, it sets the final path length value to its path length value and ends all potential path searches that are greater than or equal the final path length until all path searches are ended. This will allow for a more cost effective path to still be valid and returned, if the first path to reach the destination is more hazardous and runs through more locations adjacent to obstacles and a safer path is only slightly more distance to travel. Once all other paths are terminated upon reaching the final cost cap, the lowest cost sequence of locations that forms the path from the start location to the destination location is returned as a list and used as the course for the autonomous irrigation vehicle to follow to reach its destination. Figure 34 shows a depiction of how breadth first search algorithm works with hazard costs.

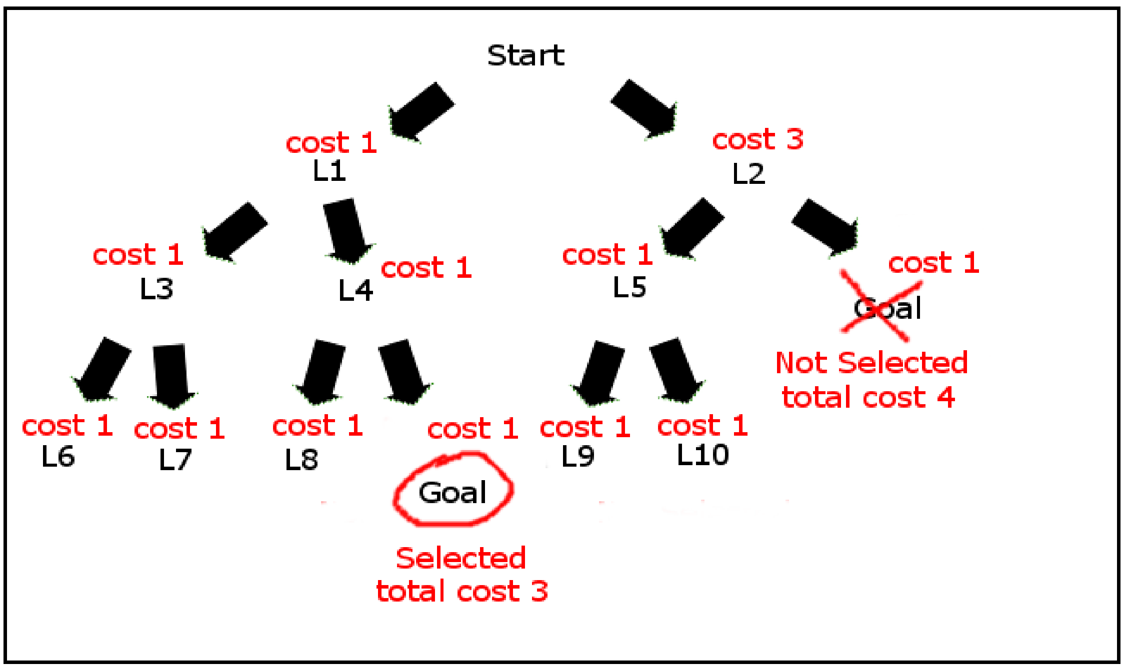


Figure 34: Modified Breadth First Search with Hazard Costs

To keep track of the sequence of positions that build each path, each position is stored as a node struct with its indices for the array, a general integer counter for the depth from the start, an order integer value indicating a count of check locations at its current depth, and a total cost integer to keep track of its depth and hazard costs along the way. These nodes all have pointers pointing to their previous location and to their next location, the destination location points to null for its next and the start location points to null for its previous. Once the most optimal path with the lowest cost from start to finish is found, each node in its sequence is added to a list to be returned.

8.10 Computer Vision

Computer vision is an interdisciplinary field which ties in concepts from biology, computer science, and engineering to create models of human like vision processing in computational systems that can perform tasks based on visual input the way a human can, if not better. Its goal is to make sense out of visual input in the form of an image or video for computer systems to be able to understand and work with for whatever functions to be performed with it. It is able to process both three dimensional and two dimensional visual data input for performing various tasks such as recognition and motion analysis. Much inspiration for computer vision has come from neurobiology where researchers have developed methods to mimic how the human brains works to an extent in the field of machine learning through the use of perceptrons and convolutional neural networks.

Computer vision has been around for decades and has evolved much throughout the years. It was first envisioned in the 1960's but it was in the 1970's when many of the fundamental algorithms that built the field, such as edge detection, were developed. Many more recent computer vision researchers have pushed to boundaries of the field even further for more practical applications such as autonomous vehicles, medical research, and even the pioneering of the field of computer touch. At MIT, Edward H. Adelson works on a project called GelSight which aims to give computers and robots the ability to understand tactile sensation. Audio recognition software is already available in the market in popular products, such as Dragon speech recognition software, with further advances in computer vision and the beginnings of computer touch many mechanical devices are gaining the ability to process information more like the ways a human can which could lead to many more promising prospects.

The autonomous irrigation vehicle will use a form of computer vision to detect obstacles for it to avoid colliding into. The reason for this is that many terrains, such as residential lawns, may contain many obstacles, whether that be rocks, trees, ditches, or anything else that may hinder, if not completely stop or damage, the autonomous irrigation vehicle. It needs to be able to sense its surrounding area in order to safely traverse to where it needs to go to deliver water. Computer vision has been used many times in the research and development of autonomous vehicles to navigate through an environment and to determine whether or not an object is coming towards or moving away from said vehicle, as well as being able to identify objects. Object identification is extremely important in the field of driverless cars for instance, a driverless car would needs to be able to identify traffic signs and signals as well as avoiding other vehicles and pedestrians in order for it to be viable for the consumer market. There may not be any need for something as complex as a convolutional neural network made of perceptrons or classifiers trained to recognize any sort of object since the autonomous irrigation vehicle only needs to be able to locate where hazardous obstacles are to avoid them, so something a little bit more simple similar to a radar system could be very effective to meet this goal.

8.10.1 Obstacle Avoidance and Collision detection

The ultimate goal of the autonomous irrigation vehicle is to effectively and efficiently navigate the target midpoint in possible shortest time. To reach the autonomous irrigation vehicle target, it should effortlessly detect the obstacles and prevent the collisions. This section explains details about how the computer vision obstacle detection system is used in autonomous irrigation vehicle to detect obstacles. While the autonomous irrigation vehicle traverses the terrain several times, it will adapt and learn its surrounding and permanent obstacles. And, Figure 35 shows the autonomous irrigation vehicle's obstacle detection and avoidance flowchart.

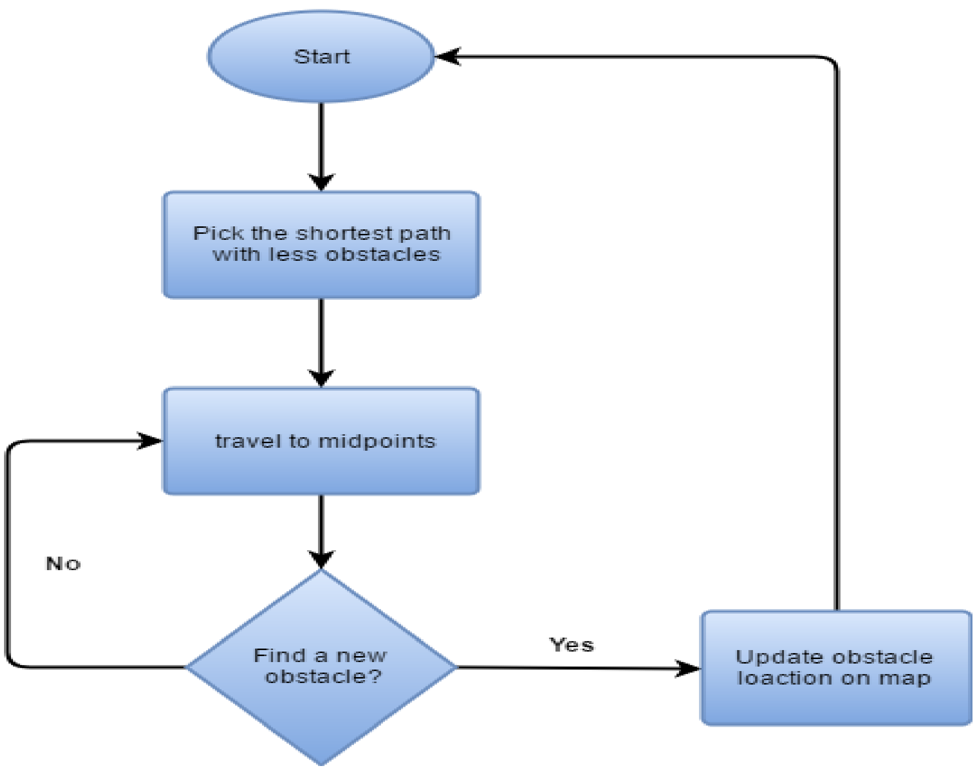


Figure 35: Obstacle Detection and Avoidance Flowchart

During the learning phase the autonomous irrigation system takes some time to learn the path while it travel to the destination midpoints as well as it uses the computer vision obstacle detection system which is LIDAR, to detect any obstacles such as small trees, ditches, big stone, any hard objects, lawn status and flipping over pond. whenever the computer vision obstacle detection system detects any obstacle, it updates the obstacle location and locations adjacent to obstacles on two-dimensional array map.

whenever the autonomous irrigation vehicle travel to the midpoints it persistently update the obstacles coordination on two-dimensional array map. Having this updated map data wound able to help the autonomous vehicle to reach the target points without being stuck by any obstacles. Besides, all of this obstacles data will be necessary for the computer vision obstacle detection system to safely travel around the terrain surroundings to deliver the correct amount of water. The path finding algorithm not only generate the lowest cost path but it also creates the lowest cost path with less obstacle levels path. The autonomous vehicle has a option to choose the shortest path with less obstacle, by choosing a less risk path keeps the autonomous irrigation vehicle safe as it travels efficiently as possible to reach its destination midpoints. Also, it will help the consumer to maintain the autonomous vehicle effortlessly. The computer vision obstacle detection system need to be able to identify its surrounding in order to travel around the lawn to water the target midpoints.

Avoiding the collision is a crucial part of the autonomous irrigation vehicle. Once the map is updated with the locations of the obstacles and locations adjacent to the obstacles, the path finding algorithms recalculate its path to reach all the midpoint destinations that need to be watered based on the lowest cost factoring in the shortest distance while avoiding obstacles as well as passing through the fewest locations adjacent to those obstacles if possible. The Path finding algorithms creates list to keep track of which are the sensors need water, this will enable the autonomous irrigation vehicle to reach its destination more effectively. Once the autonomous vehicle reached all the midpoints in the list, it will return to the home station to charge or wait for another set of data from mesh network.

The computer vision detection system uses LIDAR to detect the obstacles. The LIDAR will be playing a significant role in the autonomous irrigation vehicle's obstacle detection process. The light detection and ranging will be placed on the autonomous irrigation vehicle to detect objects and avoid collision. The light detection and ranging will be able to detect the objects in upto 6 meter distance and the specific LIDAR model A1m8 can go as high as 6 meter and as low as 0.2 meter. Even though, the autonomous irrigation vehicle going to use only 180 degree, this A1m8 model has angular field of view range from 0 degree to 360 degree and it provides laser wavelength as low as 775 nanomater and as high as 795 nanometer. As well as it has maximum sample frequency of 2010 Hertz. This distance range would be helpful for the autonomous irrigation vehicle to detect the obstacle before reaching too close to the object, this will prevents the vehicle from not hitting the object. Moreover, when the LIDAR detects the object using lights, it can also recognize what types of objects it is such as tree, water, rocket or some type of statue. As we know some of the objects such as tree and statues are most likely permanent objects. Based on this data the computer vision detection system updates on the two-dimensional array map as permanent object or non perments objects.

8.10.2 Elevation Detection

As the autonomous irrigation vehicle traverses its course providing needed water to dry regions, one serious type of hazard that could entrap the autonomous irrigation vehicle could be sudden elevation changes. This includes the possibility of the autonomous irrigation vehicle calling into a hole, a ditch, or even a swimming pool where either it could get stuck and unable to fulfil its irrigation duties or severely damaged and needing costly and inconvenient repairs or even replacement depending on the extent of damages. Another possibility could be going up a slope too steep where it could tip over which could result in similar predicaments as the ditch, hole, or pool as far as becoming immobile or damaged enough to no longer serve its purpose.

One solution to this would to have the on board LIDAR elevated and tilted at an angle where its constantly scanning one hundred eighty degrees in front of it. This would be measuring the value for the hypotenuse of the right triangle formed from the ground to the LIDAR and the distance that the LIDAR reaches on the ground horizontally from the autonomous irrigation vehicle. This value can also be calculated by the distance of the LIDAR from the ground divided by the cosine of whichever angle it is tilted at to check if it matches the range the LIDAR is measuring. If this value is constant or falls in a range of values depending on the autonomous irrigation vehicle's tolerance to unevenly elevated terrains, this signifies that it's safe to traverse across level or tolerable the area of the region being irrigated.

One possible angle the LIDAR could be tilted could be at forty-five degrees, this would give a one-to-one ratio for the height of the LIDAR from the ground the distance from the autonomous to where the LIDAR would reach the ground. Sudden changes in the measured distance measured by the LIDAR at is less than the calculated hypotenuse based on the angle and height of the LIDAR from the ground would indicate an obstacle calculated to be the measured distance multiplied by the sin of the angle in degrees as feet away from the autonomous irrigation vehicle. If the measured distance is greater than the calculated hypotenuse, this would indicate an obstacle in the form of a hole, ditch, swimming pool, or any hazardous drop in elevation and the obstacle would be marked on the two-dimensional integer array map at the last known location before where this change in detected range occurred.

For instance, if the LIDAR was three feet off the ground it would reach three feet in front of the autonomous irrigation vehicle with the range measured by the LIDAR of four and-a-quarter feet on a flat and level surface, as three divided by cosine of forty-five degrees is approximately four and-a-quarter. If the LIDAR where to measure two and eight tenths feet, this would indicate there is an obstacle close by as two and eight tenths is less than four and-a-quarter. The obstacle's location would be determined to be two and eight tenths multiplied by the sin of forty-five degrees, which comes out to be two feet and thus an obstacle would be marked as two feet away from the autonomous irrigation vehicle in the direction the LIDAR was pointing and marked on the two-dimensional integer array map accordingly. If the measured value were to dramatically jump from four and-a-quarter feet to twelve and-three-quarters feet, this would indicate a sudden drop of six feet, like in the case of a swimming pool, where the last location on the two-dimensional integer array map that measured four and-a-quarter feet would be marked as an obstacle to avoid. Figure 36 shows a depiction of the LIDAR working at a 45-degree angle.

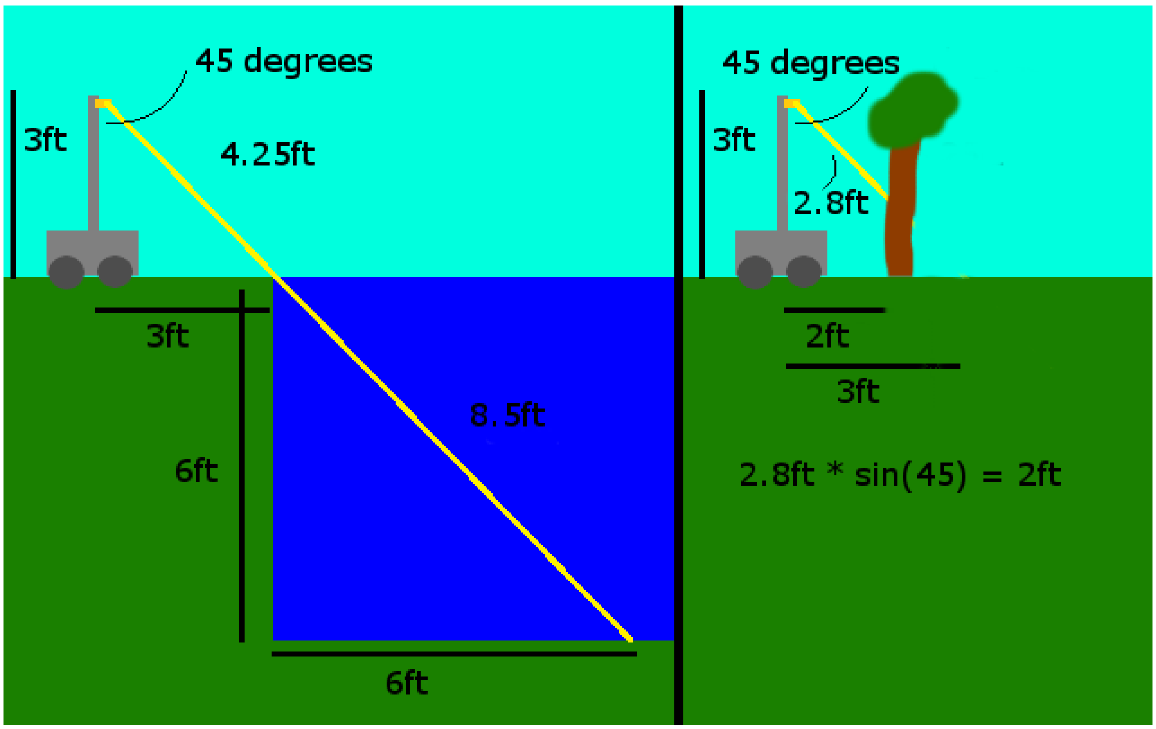


Figure 36: Elevation Detecting LIDAR at 45º Angle

The range at which the autonomous irrigation vehicle can detect obstacles and elevation changes away from itself could be increased without increasing the height at which the on board LIDAR is from the ground would be to increase the angle at which it is tilted. This would lose the one-to-one ratio, but the increased distance away from the autonomous irrigation vehicle could still be calculated by multiplying the height at which the LIDAR is from the ground by the tangent of the new angle and may be more advantageous to do so. The hypotenuse value for a level surface could still be calculated by the height of the LIDAR from the ground divided by the cosine of the angle and the distance from the autonomous irrigation vehicle to any obstacles detected by a measured value less than the hypotenuse value could still be calculated by the measured distance multiplied by the sin of the angle.

For instance, if the angle is increased to seventy-one and six tenths degrees and the LIDAR remains three feet off the ground, the LIDAR would reach three multiplied by the tangent of seventy-one and six tenths degrees which is nine feet. This is triple the range away from the autonomous irrigation vehicle than it would be if the LIDAR was tiled at a forty-five-degree angle. The hypotenuse of the right triangle formed when on a level terrain would be three feet divided by the cosine of the seventy-one and six tenths-degree angle of the LIDAR's tilt which is approximately nine and a half feet. In this case if the LIDAR were to measure eight and four tenths feet as opposed to nine and a half feet, the location of the obstacle that caused this change could be calculated by multiplying eight and four tenths by the sin of seventy-one and six tenths degrees at a distance of eight feet away from the autonomous irrigation vehicle and marked on the two-dimensional integer array map accordingly. Likewise, a measured distance greater than nine and a half feet would indicate an elevation drop where the last location before this change would be marked on the two-dimensional integer array map would be marked as an obstacle for the autonomous irrigation vehicle to avoid. Figure 37 shows a depiction of the LIDAR working at a 71.6-degree angle.

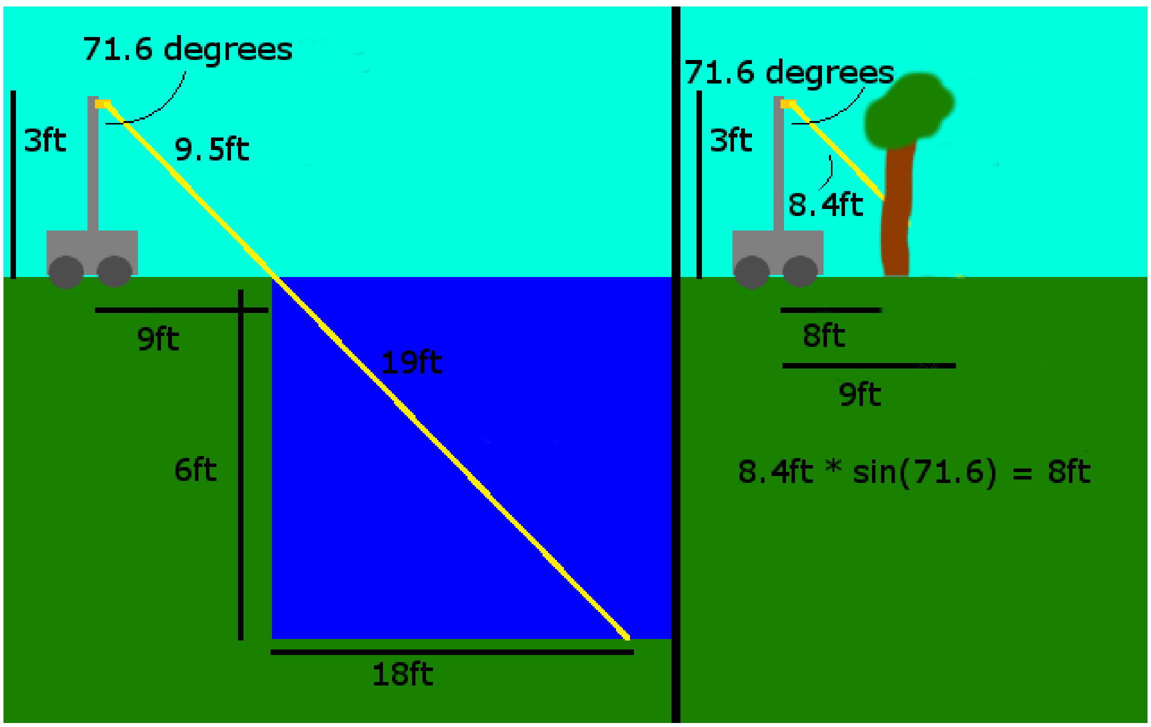


Figure 37: Elevation Detecting LIDAR at 71.6º Angle

The angle could be increased further to increase the range more if need be, but with increased ranges on LIDAR comes with greater financial costs. Realistically the LIDAR does no need to reach the bottom of a region in a deep drop in elevation like a swimming pool. If the LIDAR does not pick anything up in range, its safe to assume its measuring something greater than the calculated hypotenuse and thus a hazardous drop in elevation to avoid. Increasing the detection range also brings up the issues on decreased sensitivity to changes in the measured distance regarding the calculated stable hypotenuse for whichever angle. If there happened to be a very narrow but steep drop in elevation, the LIDAR could hit the other side of the trench where it ends and comes back up with not much of a change in the hypotenuse depending on the angle used and range of the LIDAR range detection system and the width of the pit.

8.10.3 Map Updating

After a potential collision is detected, the location of the obstacle that would cause the collision is represented as indices for the two-dimensional array map and the location at those indices on the map is marked with the value nine. Every index adjacent to every obstacle, that does not have the value nine in it, is updated with the number of obstacles that they are adjacent, with the exception of values greater or equal to one million for the sensors. The maximum number of obstacles that can be adjacent to a location is eight while the minimum number of obstacles that can be adjacent to a location is zero, which is why the value nine is used to mark the obstacles like a flag. General obstacles are to be avoided so there is no need for them to be labeled individually like the sensors. The values within the locations adjacent to the obstacles represent the risk of collision with their neighboring obstacles as the autonomous irrigation vehicle would be more likely to collide into an obstacle if it were in a location adjacent to more obstacles.

One method that could be used in coding this would be by brute force with a worst case runtime of O(m * n) where m is the length and n is the width of the two dimensional integer array map. Where once everything is placed it scans the map in a double loop for each dimension and checks at every location that is not marked with a nine or one million up to two million to see if any of the locations around them are equal to nine. Locations with a value greater than or equal to two million will be moved to the next location adjacent to its current location with a value of zero to keep the autonomous irrigation vehicle safe from getting stuck or damaged from obstacles, if there is no adjacent location with a zero value then the location with the lowest value if selected and its adjacent locations are checked for a zero to transfer the midpoint location to. If all adjacent locations have the value of nine, then the one closest to the next midpoint is selected to check for the lowest of its adjacent locations until a zero is found to place the midpoint destination into. For each adjacent location for nine, a counter that's been initialized at zero increments its value and once all adjacent locations have been checks the current location is marked with the value of the count. The counter then resets to zero and the next location is checked.

Alternatively, you could also check all eight of the adjacent locations of each obstacle while marking the location of an obstacle. All it would need to do is check indices that are minus one or plus one to the x or y index values to see if they are within bounds of the two dimensional integer array map and to increment their stored values by one if they are. This would significantly reduce the runtime because rather than scanning the whole map to find where the locations are all over again, which in itself would have the O(m * n) runtime as mentioned above. The new runtime would only be O(8) which can be simplified to O(1), also known as a constant runtime. This runtime is ideal because the autonomous irrigation vehicle would spend much less time and resources updating its map that could be used towards other critical computations and processes. The treatment of sensor locations and the movement of midpoint locations would remain the same as mentioned before. In Figure 38, we see how the map would behave in a hypothetical situation.

0	0	0	0	0	0	0	1	2	2	1	0	0	0	0	0	0	1	2	3	3	3	2	1	0	0	0	0	0	0
0	0	0	0	0	0	0	2	9	9	2	0	0	0	0	0	0	1	9	9	9	9	9	1	0	0	0	0	0	0
0	0	0	0	0	0	0	2	9	9	2	0	0	0	0	0	0	1	2	3	3	3	2	1	0	0	0	0	0	0
0	0	0	0	0	0	0	1	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	1m	0	0	0	0	2m	0	0	0	0	1m	0	0	0	0	2m	0	0	0	0	0	1m	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	2m	0	0	0	1	1	1	0	0	0	2m	0	0	0	0	0	0	0	0	0	0	2m	0	0	0	0
0	0	0	0	0	0	0	0	1	9	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	3	3	9	2	0	0	0	0	0	0	0
0	0	0	0	0	0	1	2	3	2	1	0	0	0	0	0	0	1	9	9	9	9	2	0	0	0	0	0	0	0
0	0	0	0	0	0	2	9	9	9	2	2m	0	0	0	0	0	1	2	3	3	2	1	0	0	0	0	0	0	0
0	0	1	1	1m	0	3	9	8	9	3	0	0	0	1m	0	0	0	0	2m	0	0	0	0	0	1m	1	2	2	1
0	1	3	9	2	0	3	9	9	9	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	9	9	2
0	2	9	9	2	0	3	9	6	3	1	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	3	9	9	3
0	2	9	3	1	0	2	9	9	1	0	0	0	1	9	1	0	0	0	0	0	0	0	0	0	0	2	9	9	2
0	1	1	1	0	0	1	2	2	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	1	2	2	1

Figure 38: (30 x 20)ft^2 Collision Obstacles & Adjacent Locations

The updated map would be saved for reuse for any future runs, granted there are no changes in the sensor number, sensor locations, or any new obstacles introduced to the area. If there are changes involving the number of sensors or their positions, the map will be reinitialized with the information of those changes received from the mesh network as if it is a new area to be watered. The reason for this is that the sensors are stationary and any drastic changes to them would most likely be that the autonomous irrigation vehicle has been brought to a new location to do its job there. The map will only update its current map when there is a change in the area concerning the number of obstacles or where the obstacles are located as detected from the computer vision obstacle detection system, in such a case the current map will update the position of that obstacle and its adjacent positions all at once with the exception of the values one million up to two million. For values locations with two million and above, the midpoint values are shifted like before to locations with the value of zero that are adjacent to their previous location in a cascading fashion.

The map stores the value nine at the locations of all the obstacles with all of their adjacent locations marked with the count of obstacles they are adjacent to with the exception of sensors. As seen are obstacles of various sizes to demonstrate the values in the adjacent location.

8.10.4 Scan Routines

The presence of stationary obstacles may be dynamic in that someone may leave an object such as a bicycle on a lawn one day and gone the next. This could cause a hazardous collision that the obstacle avoidance system on the autonomous irrigation vehicle would detect and mark on the two-dimensional integer array map to steer clear of on its traversal of the area proving water to where it's needed. When the temporary object is no longer present this area would once again be safe travel through and maybe even favorable at times to travel though to provide water in the most efficient and optimal fashion possible. On the next traversal through the area the autonomous irrigation vehicle should detect this change and remark its location on the map to be all clear, but for the user's benefit it may be safe to include route scanning routines to map out an area for hazards on a separate run where it is no supplying water to any location but only scanning for obstacles. This could be useful for mapping out areas the autonomous irrigation vehicle has not visited to map out before or to reset its mapping of the area by the user due to changes in the hazards and land scape of the area or for any other reason that they may so choose.

The sensors and their neighbors should still be provided by the wireless sensor mesh network where midpoint destinations could still be calculated and plotted onto the two-dimensional integer array map. The autonomous irrigation vehicle could be provided a list of all the midpoint destinations in the area and build a path to reach every single one despite dryness readings as no water would be supplied during this traversal. It could follow the list and sweep the area in a grid like fashion, which would be thorough but not necessarily optimal are far as distance traveled and energy consumption. The autonomous irrigation vehicle could use more advanced pathfinding algorithms such as the nearest neighbor algorithm to reduce travel distance and energy consumption, but there is still also the concern of the tether connecting the autonomous irrigation vehicle to its water supply source getting caught obstacles or tangle with its self as well as the issue of it having to backtrack back to its charging station in the reverse of its course for the sake of preventing either of those stated issues from occurring when its finished with its scan routine. However, because it's not proving water to the area during scan routines, the autonomous irrigation vehicle does not necessarily need to be attached to its water supply tether when all it is currently doing is scanning for obstacles. By freeing the autonomous irrigation vehicle from the constraints of the water supply tether, algorithms more advanced than the nearest neighbor algorithm could be used, such as the repetitive nearest neighbor algorithm of a markov decision process.

The protocol for the scan routines could be initiated by a reset signal sent to the autonomous irrigation vehicle directly from the user. Another option could be a timer that the user could set up to send the signal from at designated times that they may decide for whatever reason on a weekly, monthly, or any other period. Either the direct input or the timer could be directly accessible on the autonomous irrigation vehicle, the wireless sensor mesh network, or from a mobile application that could be developed to give the user more input in a convenient manner.

8.11 Restricted Zones

There may be regions in which it would be unfavorable for the autonomous irrigation vehicle to traverse or provide water to as it could prove to be unnecessary, hazardous, or wasteful. While the obstacle avoidance system should protect the autonomous irrigation vehicle from colliding into stationary obstacles, there may still be some additional factors to consider. This may include things too small for it to recognize such as flowerbeds that could be trampled or more dynamic regions such as a busy high way where cars are coming and going. Driveways and sidewalks may also need to be included as providing water to these regions would be wasteful, which goes against the goal of the autonomous irrigation vehicle's purpose. There could be even more regions the consumer may want to consider further down in development based on currently unforeseen factors the market may demand.

This could be achieved by providing additional geographical input to label various areas as restricted zones on the two-dimensional integer array map. The values from ten up to nine hundred ninety-nine thousand nine hundred ninety-nine were left alone during the initial potting of sensors, midpoints, obstacles, and locations adjacent to obstacles for later use if additional flag types are needed. Restricted zones could be labeled with a single integer value telling the autonomous irrigation vehicle not to enter those regions that could be the same as the obstacles with adjacent locations marked with hazard risk values in the same fashion. Alternatively, restricted zones could be categorized into various classes to be handled in specific ways using the vast pool of available integer flags. One type of restricted zone could have full absolute restrictions like an obstacle to be avoided like a busy road, another could have water restrictions where it could still travel but must not dispense any water to prevent waste such as a sidewalk, there could be a zone designation for travel restrictions where water would be provided but the autonomous irrigation vehicle cannot enter like in the case with flower beds that could be trampled over, or anything else the consumer may ask. Different classes of restricted zones could have different unique integer flags to distinguish them from one another. A digit-based flag method like the ones used for sensors and midpoints if specific restricted zones may have an id value.

The restricted zones could be labeled on the two-dimensional integer array map through a variety of methods. One such method could be through manual input from the user via a mobile application where they could select precisely which regions to mark as restricted zones or type of restricted zone if that is an option. Images from an online source, such as google earth or something similar, could also be used to supply info for labeling or categorization of various restricted zones and any necessary data related to them. Another option could be to supplement or replace the LIDAR system with an even more advanced computer vision system which could utilize machine learning with convolutional neural networks to classify and identify objects via specific visual input from a camera to determine restricted regions to be marked on the two-dimensional integer array map. These three example options mentioned will be further explored in fuller detail in later sections.

8.11.3 Camera

A camera could be attached to the autonomous irrigation vehicle to provide live visual input for it to make decision for improved obstacle detection and restricted zone categorization that could supplement if not replace the current LIDAR system. This would greatly improve the precision and allow additional functionality to the autonomous irrigation vehicle. This could be achieved using more advanced computer vision methods such as object recognition. Another method that could be used is to somehow incorporate using perceptrons, more specifically sigmoid perceptrons as seen in Figure 39.

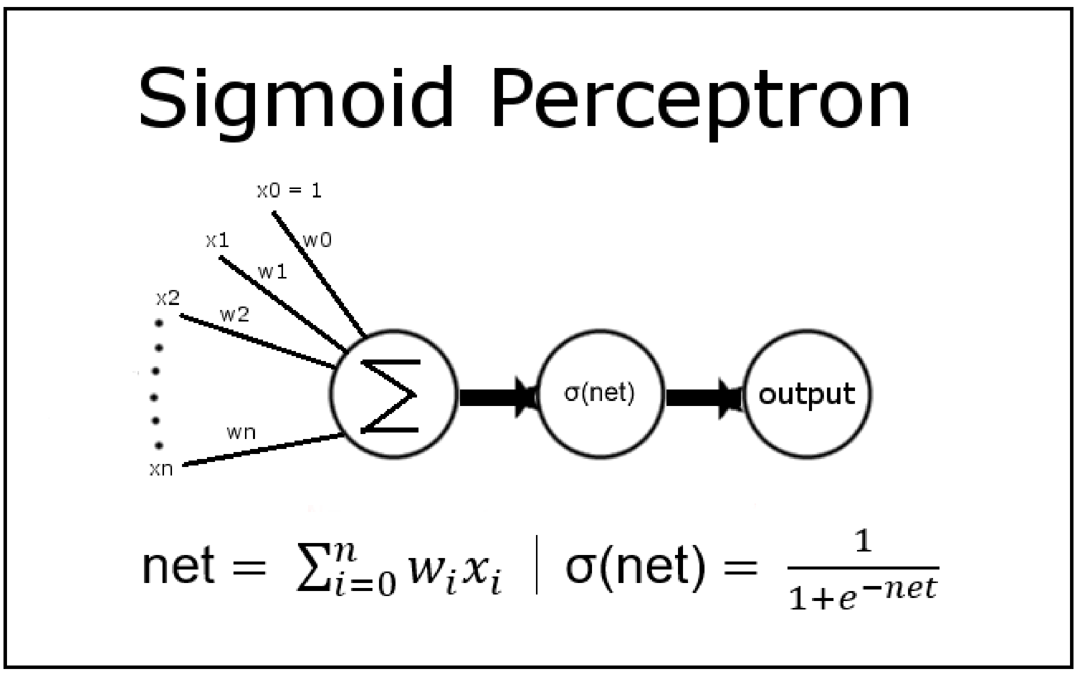


Figure 39: Sigmoid Perceptron

Object detection can be achieved using machine learning with convolutional neural network of a few layers. Machine learning uses training data that could either be proved or collected while performing tasks to improve the performance of the algorithms for certain tasks. Convolutional neural networks are a form of artificial neural networks made up of a collection of artificial neurons such as perceptrons that use a linear classifier to fire a signal when it receives a specific input its trained to recognize based on a weighted value, data points, and its classifier function. The training data used for visual input is usually a set of positive images and a set of negative images to give the system conditions to look for in similar features of the object its trained. Logistic regression is able to adjust their weights and, in many cases, preferable over a threshold function used for classification for better accuracy, perceptrons that use a logistic to classify are called sigmoid perceptrons.

The goal of artificial neural networks is to build a machine learning system inspired by arguably the most effective and advanced learning system known to the world, the human brain. Convolutional neural networks are built from layers of sigmoid perceptrons stacked together where the outputs of previous layers are used as inputs for each following layer until they reach a final output and use gradient decent to train their networks as pictured in Figure 40. Each sigmoid perceptron can classify things that are linearly separable, but for things that are not linearly separable, networks of perceptrons are needed to perform nonlinear regression. Convolutional neural networks have other applications aside from classification to identify objects, they are also useful for information retrieval, image captioning, and detection.

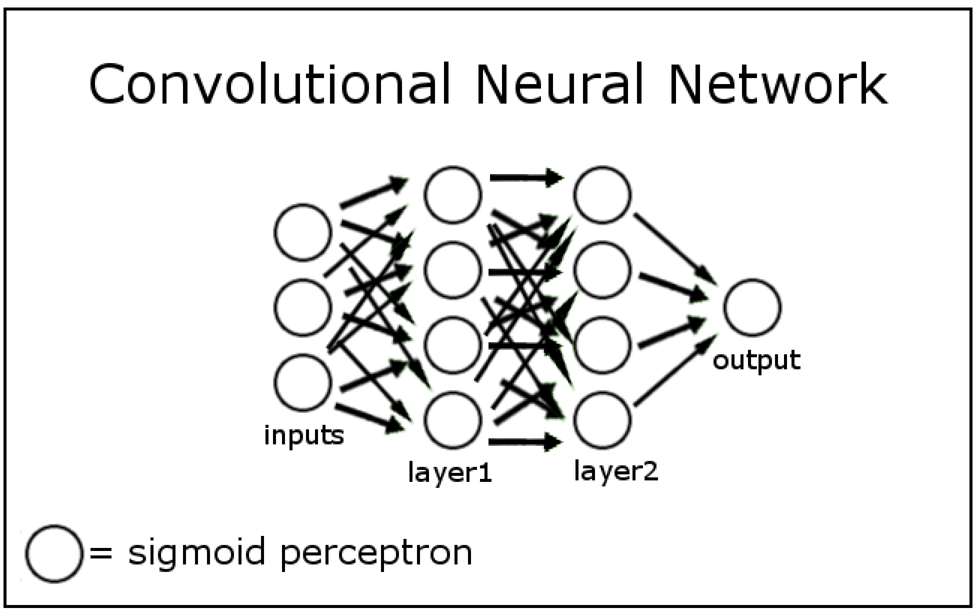


Figure 40: Convolutional Neural Network with Sigmoid Perceptrons

Giving the autonomous irrigation vehicle the ability to receive and process visual input and the ability to identify objects would allow for it to make better decisions and provide more functionality than with just the range detecting LIDAR. With vision capabilities, the autonomous irrigation vehicle could detect gardens or flower beds to provide specialized services for their optimal watering needs, which could also hold significant promise for the agriculture industry as a market. The autonomous irrigation vehicle would also be able to see and identify roads and sidewalks and know to keep water out of those areas as well as avoid moving hazards in real time. The method offers much greater precision and would complement well with a robotic arm with a sprinkler built in with multiple specialized nozzles for various tasks attached to the autonomous irrigation vehicle to vastly improve water delivery capabilities with significant efficiency increase for water conservation.

8.12 Backtracking

When the autonomous irrigation vehicle completes its course through an area, it needs to be able to return to its home charging station to recharge its battery for the next time it is used to provide water to areas that need it. It also would need to reel it tether back up so that its not just laying across the region in a mess where its could get caught, tangled, or damaged which would impeded further use of the autonomous irrigation vehicle with the need for maintenance, repairs, or the replacement of parts at the inconvenient expense of the consumer. The primary plan to handle this is for the autonomous irrigation vehicle to save a copy of its list of destinations it previously visited on its water delivery course and traverse them again in reverse order from finish back to start while driving in reverse. If the tether is made to be retractable, it should wind up safely out of harm and without any tangles as the autonomous irrigation vehicle backs up along its reverse backtracking course back to its home charging station to begin again next time it needs to without any issues. With the retractable water supply tether, it would be faster and possibly more energy efficient to have the autonomous irrigation vehicle placed in neutral where the charging station could reel in the entire thing in a straight line directly back to itself. This would risk damaging the autonomous irrigation vehicle as it could run into hazardous obstacles while being reeled back in, thus the backtracking method of it retracing its previous path in reverse with the tether being retracted at the same pace as it travels, with minimal slack and tension, would be the safest method for it to return to its charging station.

A power supply chord could be included with the water supply chord bundled together as a cable within the tether to solve the issue of it having to return to recharge as it would have a constant and reliable source of power. However, bundling the water supply with the power supply introduces new risks, if any damage where to happen to the tether with both the water and power supply there could be the safety hazards to humans and animals of electrocution, this could a e fire hazard to the user’s property if some areas in the region are still dry and damages to the power supply chord causes a spark that could ignite those areas, as well as a hazard to the autonomous irrigation vehicle itself if power supply chord damages fry any of the on board electronic systems that it relies upon to carry out its functions. This also does nothing to solve the issue of the supply tether being left sprawled out across the region exposed to the elements in harm’s way when the autonomous irrigation vehicle finishes its job. Below in Figure 41, a flowchart depicts the order of processes carried out during this opreation.

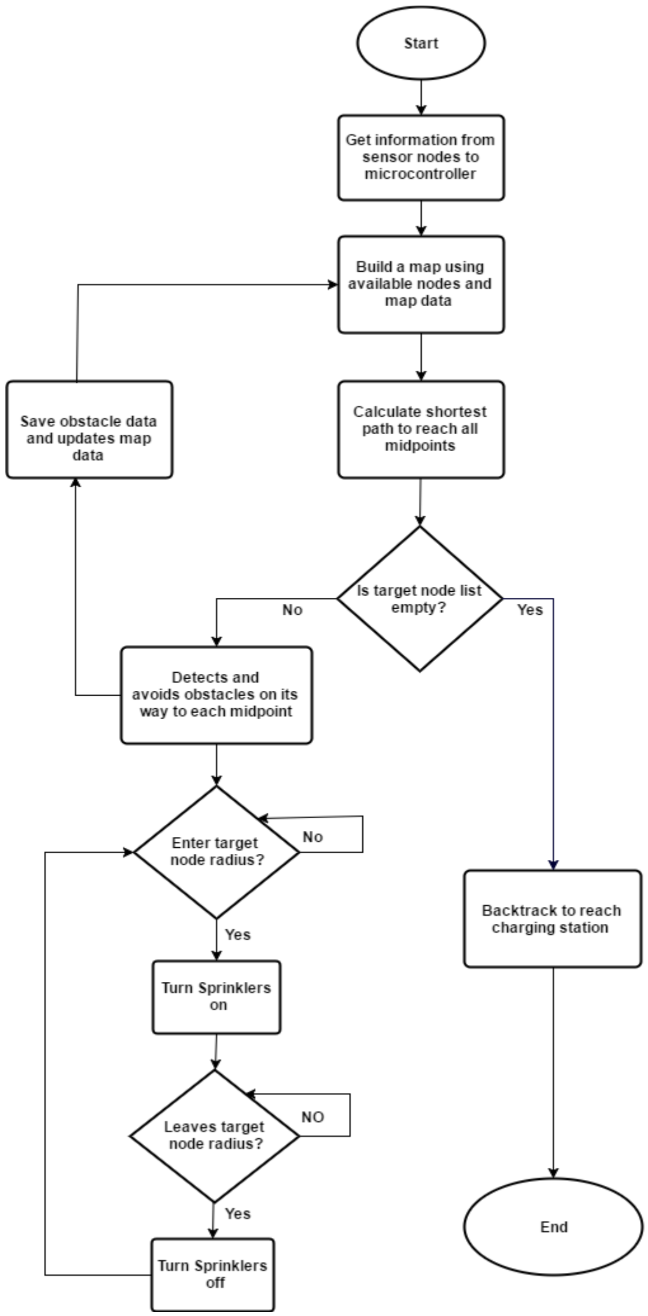


Figure 41: Software Flowchart with Backtracking

Alternatively, the autonomous irrigation vehicle could disconnect from its retractable water supply tether to return to its charging station. The tether could be reeled in back to the charging station and the autonomous irrigation vehicle could calculate a much simpler and more streamlined path back to its charging station from its current location rather than having to backtrack through the full extent of its course in reverse order without the restrictions of being bound to its water supply tether that could get caught or tangled by itself or obstacles in the area. Once the disconnected free roaming autonomous irrigation vehicle returns to its charging station it could reattach to its water supply tether for the next time it needs to deliver water to every single midpoint destination location with at least one dry sensor reading when it is needed.

8.13 Unrestricted Movement

The autonomous irrigation vehicle would have more efficient routes to reach all the midpoint destinations with dry sensor readings within the landscape its responsible for in a potentially shorter distance traveled if it had more freedom for it to move across the area in a less restrictive linear path. A purely linear path may not be the optimal path to travel, but due to current constraints of the design with the water supply tether attached to the autonomous irrigation vehicle, some kind of linear path is inevitable. This linear path constraint restricts the types of pathfinding algorithms that can be used to find paths for the autonomous irrigation vehicle to build a list of which midpoint destinations with sensors that give dry readings at their borders to visit in whichever order is the most optimal.

In the sections ahead, potential modifications will be discussed to help solve or improve this issue that restricts the autonomous irrigation vehicle from finding the best path that it can to reach all the dry regions of the area that need water delivered to them with improved movement freedom in which better pathfinding algorithms can be used. These modifications include the options of a detachable and re-attachable water supply tether that is also retractable to reduce risks of entanglement and backtracking the path from where it ends back to the charging station in favor of a shorter path. The option of an onboard water reservoir tank will also be discussed to elaborate on its potential for breaking free from the linear path constraints as well as determine its feasibility as a design to be implemented. A modified form of the detachable and re-attachable water supply tether that is also retractable with the addition of multiple charging stations at different locations for the autonomous irrigation vehicle to attach from will also be discussed for its improved pathfinding capabilities, its improved maneuverability around more complex obstacles in oddly shaped yards, and its scalability to where a single autonomous irrigation vehicle could provide watering services across many lawns within a neighborhood subdivision.

The implications of how these modifications to the design will allow for stronger algorithms that outperform the current algorithms being used for finding the best path the bring water to dry regions of the lawn determined by the sensors within the wireless mesh network in the fastest and safest manner possible will also be discussed. From options that allow minor algorithm modifications for marginal improvement, to others that would allow for complete freedom of movement across the entire area without physically being bound to the location of the charging station where it would no longer be restricted to linear paths and thus able to use more optimal algorithms to find the shortest and safest route to reach all the water delivery locations, to a more feasible option that grants more freedom of movement within the restrictive bounds of the linear path constraints. An improved algorithm that takes advantage of the additional factors that come to play with less restricted movement to find the order of which midpoint destinations with at least one dry sensor reading to travel to in the least distance traveled would reduce the power cost of the autonomous irrigation vehicle to travel, especially when scaled up to larger areas that would require for it to travel across to perform its duties.

8.13.1 Tether Disconnect

With the water supply tether, the autonomous irrigation vehicle is restricted to follow a more linear path which may not be optimal to reach every single one of its locations in the fastest and safest manner possible. There are also the risks of the autonomous irrigation vehicle's water supply tether getting caught on an obstacle or tangled which would impede the movement of the autonomous irrigation vehicle. Additionally, if the water supply tether were to be damaged by something while the autonomous irrigation vehicle is providing water to dryer areas of the landscape that need it, it would be out of commission and unable to continue its water distribution duties until repair as made or the water supply tether is replaced with a new one.

To lessen the risk of the water supply tether getting caught on obstacles or tangled during the autonomous irrigation vehicle's travels to perform its duties or when it is backtracking back to its charging station to recharge its battery when it is finished providing water to everywhere that needs it, the water supply tether will be retractable, similar to a dog leash as seen in Figure 42. It would release from the charging station at the same rate at which the autonomous irrigation vehicle travels and reels back up at the same rate too so that there is not too slack but also not too much tension. This is something that is being implemented in this project to help, but it helps with some of the issues, it's still far from perfect as it still restricts the autonomous irrigation vehicle's pathfinding to a possibly less than optimal linear path for it to take and if the water supply tether still receives damage while it is in the middle of a path, the autonomous irrigation vehicles would still be out of commission.

An improvement to this solution would to also make the water supply tether detachable from the autonomous irrigation vehicle and re-attachable at the charging station. This would allow for the autonomous irrigation vehicle to detach from the water supply tether if it were to get caught or tangled on any obstacles or itself where the detached water supply tether could be reeled in back to the charging station and the autonomous irrigation vehicle could plot the shortest and safest course possible from its current location to the charging station where it would re-attach to the retractable water supply tether once it is back in place. Right before the retractable water supply tether detaches, the source of water that goes to it would shuts a valve closed to cut off the flow of water through it to prevent excessive amounts of water waste like when a hose is left on unattended flooding an area.

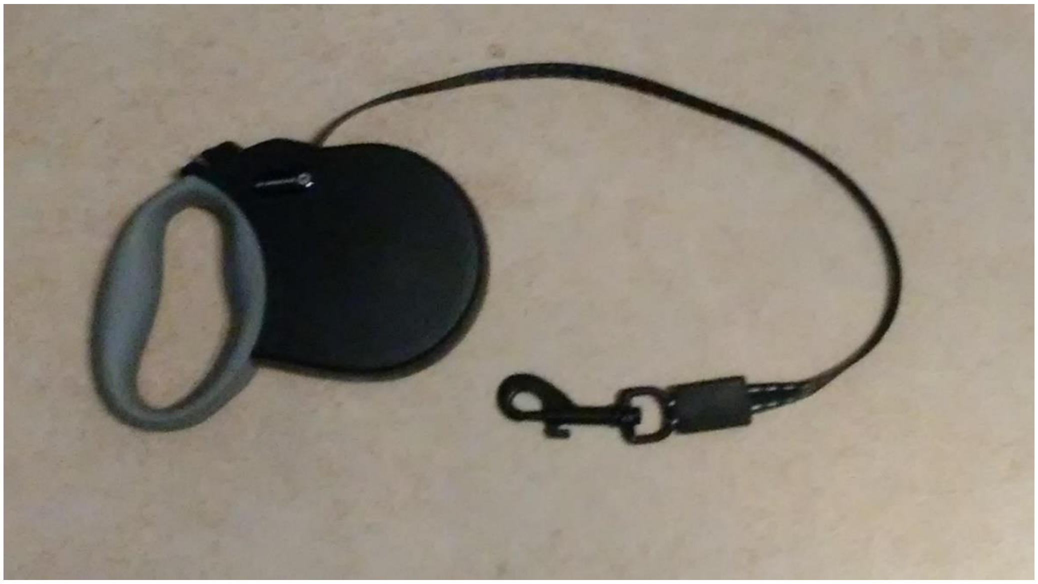


Figure 42: Retractable Dog Leash like the Retractable Tether

Having additional attachable and detachable water supply tethers that are also retractable at the charging station as backups. This would be extremely useful in cases where the previous detached retractable water supply tether is unable to reattach to the autonomous irrigation vehicle. There is a wide variety of reasons as to why this could occur while in the middle of proving water delivery services. This would allow for the autonomous irrigation vehicle to go back to what it was doing before it had to detach the retractable water supply tether until its issues are resolved, whether that be manually freeing it from being stuck, repairing it, or replacing it.

One possible reason could be that the previous retractable water supply tether was damaged while the autonomous irrigation vehicle was providing was to dry regions of the landscape that needed it and had to detach from it to get a new one to complete its job. The damage to the retractable water supply tether could be detected by a water pressure sensor in the charging station that could send a signal to let the charging station and autonomous irrigation vehicle know that the retractable water supply tether had been damaged from a change in water pressure cause by a leak, obstruction, or any other kind of damage it could have received. This would let the autonomous irrigation vehicle know to detach the retractable water supply tether and both charging station and the autonomous irrigation vehicle know not to re-attach to the damaged retractable water supply tether and instead to use one of the backup retractable water supply tether to attach to the autonomous irrigation vehicle to use to complete its course and deliver water to all the remaining dry areas that need it.

Another reason why having multiple retractable water supply tether backups could be useful would be a case where a detached retractable water supply tether could not be reeled back in to the charging stations because either it had gotten stuck on something or it got tangled with itself. There could be a sensor in the charging station by where the retractable water supply tether is connected to that could give a signal that the other end of the retractable water supply tether that connects to the autonomous irrigation vehicle has returned by having something inside it for it to detect when it is near and in place to be reattached. If the autonomous irrigation vehicle does not receive the signal that the retractable water supply tether is in place to be reattached, it will attach to the next available backup retractable water supply tether for it to use for the remainder of its water delivery services.

8.13.2 Water Reservoir

The retractable water supply tether will always restrict the autonomous irrigation vehicle's traversal to linear paths if the retractable water supply is attached to the autonomous irrigation vehicle while it delivers water to all the places of the landscape where it is needed. While the retractable water supply tether may be a very reliable water delivery system to provide the autonomous irrigation vehicle with a supply of water needed to fulfil its duties, the restricted linear movement it enforces could prevent a more optimal path from being chosen by more advanced pathfinding algorithms. The only way for the autonomous irrigation vehicle to truly have unrestricted movement while it is driving around the terrain providing water to the dry areas, it will need to replace the retractable water supply tether with something less restricting that can still supply it with water untethered.

The obvious choice here would appear to be an onboard reservoir capable of storing enough water to provide to all the dry areas that need water. The autonomous irrigation vehicle would fill this on-board water reservoir tank at its charging station to use as a water source to deliver water to all the dry areas of the region that the sensors in the wireless mesh network indicates needs water. When the on-board water reservoir tank runs out of water, the autonomous irrigation vehicle would return to the charging station to refill its water supply before resuming its course providing water to wherever it is needed throughout the landscape guided by the reading of the sensors in the wireless mesh network to recalculate a new optimal path that factors out all the regions previously watered before its water supply ran out.

In a worst-case scenario such as a hot sunny day, a yard would require one and a half inches of water per square foot. There are twelve inches in a foot, so this amount could be converted to cubic inches by squaring twelve inches and multiplying it by one and a half inches which results in two hundred sixteen cubic inches. There are two hundred thirty-one cubic inches in a gallon so two hundred sixteen cubic inches divided by two hundred thirty-one cubic inches per gallon would result in nine hundred thirty-five thousandths of a gallon per square foot, which could be rounded up to one gallon of water per square foot.

For a testing area of 20X30 squared feet, which is six hundred square feet, so to provide all this area on a hot and dry day with enough water a six-hundred-gallon tank would be needed. One gallon of water weighs eight and thirty-three hundredths pounds so with the six-hundred-gallon tank the autonomous irrigation vehicle would need to carry a load of four thousand nine hundred ninety-eight pounds. This is obviously not being a feasible option for an autonomous irrigation vehicle that measures two feet by two feet and three feet off the ground. Dividing the load to carry five or ten gallons of water could still be strenuous on the autonomous irrigation vehicle and require a lot of power as well as one hundred twenty or sixty trips back to the charging station, depending on water reservoir tank capacity, to refill its water reservoir tank throughout its travels to water all the dry parts of the landscape, which is still not feasible.

8.13.3 Multiple Stations

Since there were concerns of the movement of the autonomous irrigation vehicle, a review for methods to increase unrestricted movement of the autonomous irrigation vehicle was under taken. With the autonomous irrigation vehicle having a water reservoir supply tank equipped to the autonomous irrigation vehicle would be too impractical in practice to implement. The other option is having a retractable water supply tether that is both attachable and detachable from the autonomous irrigation vehicle. The tethered water supply also has an option where the autonomous irrigation vehicle can dock at the charging station to reattach its retractable water supply tether.

This consideration has shown a lot of promise, but this still has limitations. This has led to the idea of having multiple charging stations at different locations in the region for the autonomous irrigation vehicle to charge its battery and to attach to a retractable water supply tether. As such, the autonomous irrigation vehicle will be given even greater unrestricted movement throughout the environment in which it is surrounded in. With the autonomous irrigation vehicle moving through its surrounding environment almost unhindered, it can reach any of its predesignated locations with ease. Once it reaches it designated destination of where the sensors have told the autonomous irrigation vehicle is dry, the watering operation commences. Figure 43 shows an example of what is being explained with a clear picture.

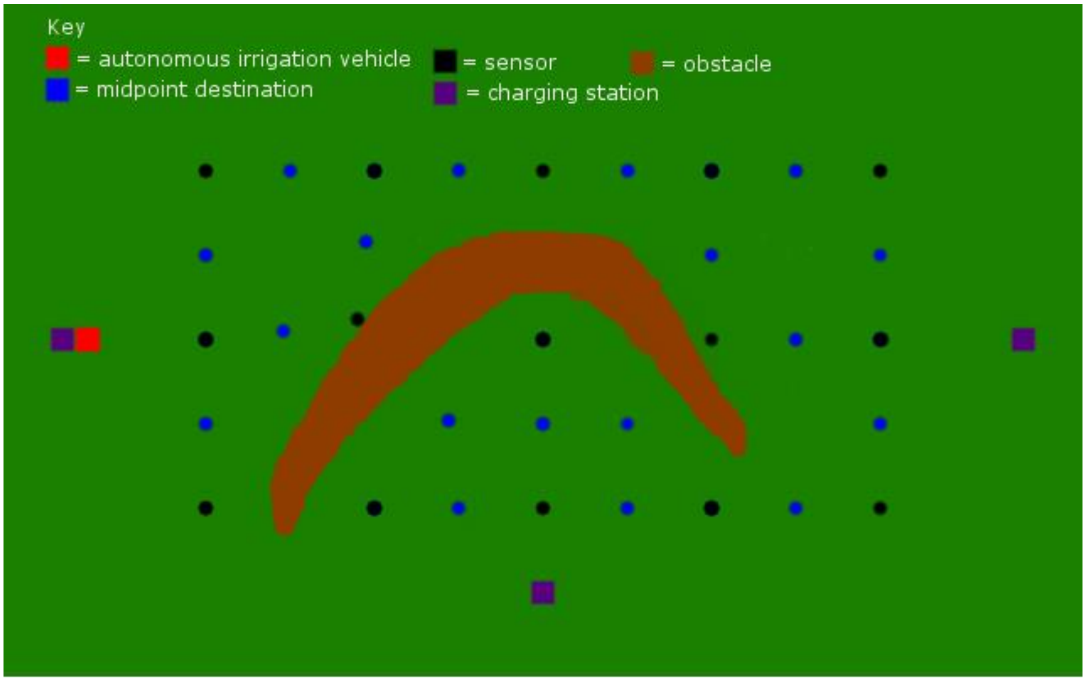


Figure 43: Multiple Stations in Larger Area with Obstacles

From different locations, the autonomous irrigation vehicle may be able to reach various midpoint locations that need water with better ease than it could if restricted to only one starting location due to the limitations of linear paths. Many landscapes may be broken apart by large obstacles such as island bed gardens that can take up large areas in odd shapes. For these cases, if the autonomous irrigation vehicle were to follow a truly linear from one starting location to reach all the dry regions to provide all of them with water and travel back to the one charging station would be very long and the risks of the retractable water supply tether getting caught on something or tangled are more likely, by having multiple charging stations to grab a retractable water supply tether to reach around larger obstacles would significantly reduce this risk.

Having multiple charging and tether stations for one autonomous irrigation vehicle could be expanded to cover larger areas than go beyond where a single retractable water supply tether could reach. An example being multiple lawns within a subdivision where the autonomous irrigation vehicle could dock and attach to retractable water supply tethers from charging stations in different yards. How the autonomous irrigation vehicle deals with sidewalks, driveways, and roads while providing water to dry areas across multiple different yards within the same neighborhood would depend on how it is set to handle restricted zones. All the sensors used across all the lawns within the same subdivision could all be with in the same wireless mesh network which could allow for the autonomous irrigation vehicle to plot a course to visit all their midpoint destinations that need water in a single planned path. The different charging stations could also be marked on the two-dimensional integer array map with their own unique integer flag value to identify them so that the autonomous irrigation vehicle can include them in their path if it is optimal to do so to reach every destination midpoint with dry sensor readings than previously. The depiction of the autonomous irrigation vehicle covering multiple homes can be seen in Figure 44.

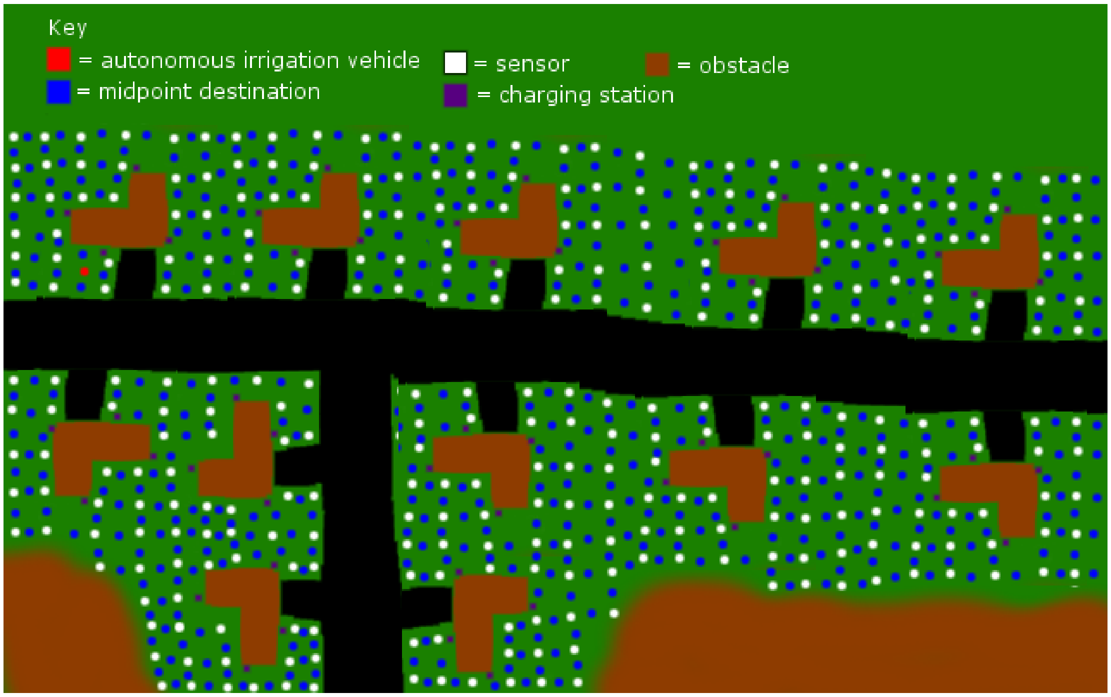


Figure 44: Multiple stations & 1 Autonomous Irrigation Vehicle.

This method seems more feasible, more efficient, and more scalable than the current limited linear implementation or other alternatives to the mentioned. It is still somewhat restricted to linear paths, but the larger linear path can be broken down into smaller linear paths to allow for some freedom of movement for better paths. It is not perfectly unrestricted movement, but it is close and removes many of the risks and inefficiencies of having a single retractable water supply tether as well as allows for more advance pathfinding algorithms.

8.13.4 Alternative Algorithms

With more freedom of movement, more advanced algorithms could be used to find better optimized paths for the autonomous irrigation vehicle to provide precious life sustaining water to all the dehydrated regions of a lawn. The retractable water supply tether carries the risks of getting caught on something or tangled and constrains the autonomous irrigation vehicle to a linear path that may not be as efficient as it would if it had a little bit more freedom with its movements. The autonomous irrigation vehicle will be using a nearest neighbor algorithm to build its path to reach every single midpoint destination with at least one dry reading sensor at its edges to deliver water until there are no more dry sensor readings in the landscape.

With the retractable water supply tethers that can detach from the autonomous irrigation vehicle and reattach to another one when docked at a charging station, the autonomous irrigation vehicle would still be restricted to a linear path. However, the detachable and re-attachable water supply tether that is retractable would eliminate the risks of entrapment on obstacles and entanglement with itself by allowing the autonomous irrigation vehicle to release itself to grab a new retractable water supply tether to continue its water delivery route. With this you could set up the algorithm to tell the autonomous irrigation vehicle to detach from the retractable water supply tether if there is a far away midpoint destination with a dry sensor region that would take longer to reach from the current location and backtrack back to the charging station than it would to return to the charging station in the shortest path and head from there to the distant location after re-attaching to a new retractable water supply tether.

A water supply reservoir tank would allow for completely unrestricted movement of the autonomous irrigation vehicle with the absence of the retractable water supply tether is not physically bound to the charging station. This would allow for algorithms that can out-perform our nearest neighbor algorithm, such as the repetitive nearest neighbor algorithm which performs the nearest neighbor algorithm with every location the needs to be traveled to as a potential starting location then compares all the generated paths where it selects the most travel cost efficient path. The main issue here however is that using an onboard water supply reservoir tank is completely impractical due to weight constraints of using a larger tank and the travel costs of using smaller tanks that would require frequent refill trips.

The option of using detachable and re-attachable water supply tethers that are retractable is the most promising option for something closer to unrestricted movement. This method potentially breaks apart the long linear path with a single source that the autonomous irrigation vehicle travels into multiple smaller linear paths with multiple different sources if it is more optimal to do so. With this setup a weaker repetitive nearest neighbor algorithm that could still out-perform the nearest neighbor algorithm by using any of the different charging stations, where the autonomous irrigation vehicle could attach to a retractable water supply tether, as potential starting locations to reach all the midpoint destinations with dry sensor readings.

9. Final Coding Plan

The path finding algorithm and computer vision obstacle detection system will be used to achieve the autonomous irrigation vehicle project goal. The nearest neighbor algorithm will be used for the path finding concepts and RPLidar A1M8 model will be used detects the obstacle. Once it detects the obstacles it constantly updates the obstacle location into two dimensional array map, the detail explanation of obstacle detection is given in Obstacle Avoidance and Collision detection section. Also, the detail process of nearest neighbor algorithm is given in the algorithm concept section. The process of coding plan is shown Figure 45 to show the coding plan

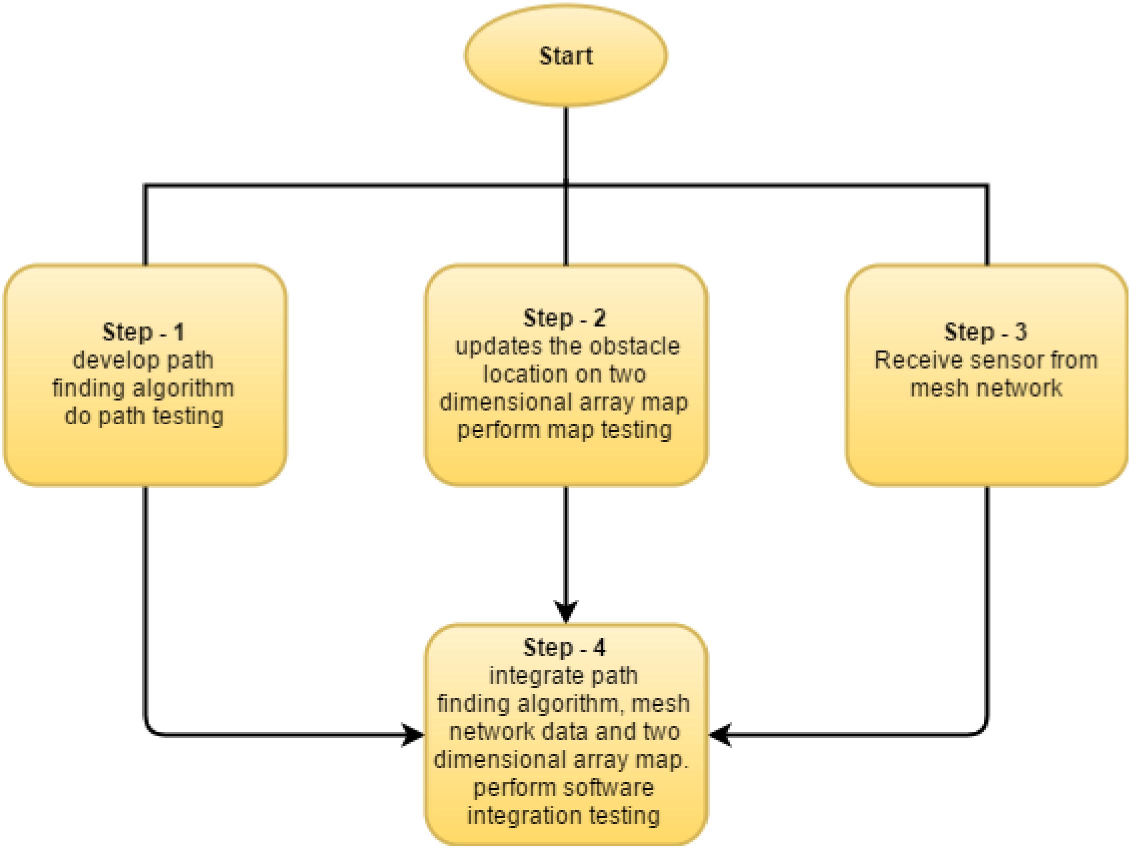


Figure 45: The Process of Coding Plan

10. Software Test Environment

Testing is a significant part of software development. All the testing phases should be done effectively to ensure the quality of the autonomous irrigation vehicle. The test cases will be written for each module to test the functionality of the path finding algorithm and obstacle detection two-dimensional array map. The visual studio integrated development environment will be used as the software testing environment. The visual studio integrated development environment has an available unit test integrated framework. This IDE allows for the testing of public class method using test driver stubs. When the autonomous irrigation vehicle is build, it will be tested in outside environment as well.

The test plan will provide a guide for the verification of the requirement of the autonomous irrigation vehicle. The test plan will help ensure that all the functionality gets properly tested.

- The autonomous irrigation vehicle should receive the sensor data from mesh network
- The software shall be able to calculate the nearest midpoint using NNA algorithm.
- The software shall be able to detect the obstacles and avoid collision
- The software shall be able to update the two dimensional matrix array every time it travel to the midpoints.
- The software shall be able to get a feedback from the sensor about is it still dry or is it wet

10.1 Unit Testing

This section explains the unit testing part of the autonomous irrigation vehicle. The main goal of the unit testing is to find the faults in each module. Unit testing can be done for each module separately, when one modules is done coding it can tested it using by checking the syntax error, inaccuracy of the algorithm or inconsistencies. By performing unit testing for each module, increase the efficiency of the program as well as it prevents future faults. Besides, the two types code review will be conducted to find faults. Followed by the unit testing there are several testings will be done to verify the autonomic irrigation vehicle quality and functions. Figure 47 shows the testing flow chart which shows the sequence of the testing. In the next assignment each testing will be explained in detail.

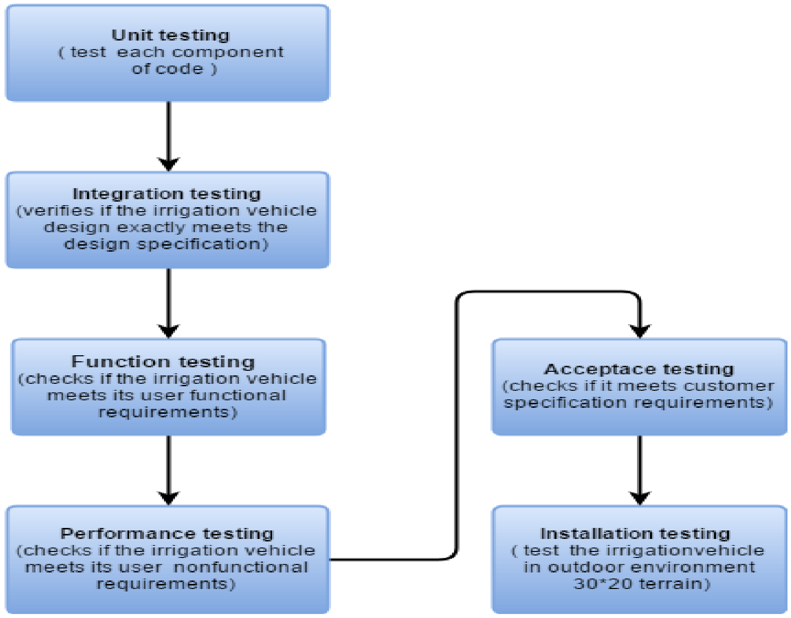


Figure 46: Testing Flowchart

10.2 Performance Testing

Testing is a significant part of software development. All the testing phases should be done effectively to ensure the quality of the autonomous irrigation vehicle. The test cases will written for each modules to test the functionality of the path finding algorithm and obstacle detection two-dimensional array map. The visual studio integrated development environment will be used as the software testing environment. The visual studio integrated development environment has an available unit test integrated framework. This IDE allows for the testing of public class method using test driver stubs. When the autonomous irrigation vehicle is build, it will be tested in outside environment as well.
The test plan will provide a guide for the verification of the requirement of the autonomous irrigation vehicle. The test plan will help ensure that all the functionality gets properly tested.

- The autonomous irrigation vehicle should receive the sensor data from mesh network
- The software shall be able to calculate the nearest midpoint using NNA algorithm.
- The software shall be able to detect the obstacles and avoid collision
- The software shall be able to update the two dimensional matrix

array every time it travel to the midpoints.

- The software shall be able to get a feedback from the sensor about is it still dry or is it wet

This sections explains the performance testing of the autonomous irrigation vehicle. The performance testing checks the nonfunctional requirements of the autonomous irrigation vehicle. Usually the system's non functional requirements are given by the customer, for irrigation vehicle project our sponsor is the customer so the vehicle's nonfunctional requirements are set by our sponsor. The performance testing would inspects how efficiently the algorithm works and its quick response to navigate to the destination. There are several performance testing can be done to validate the nonfunctional requirement of the system. The following performance test will be done to validate the system.

- Stress Test
- Volume Test
- Configuration test
- Compatibility tests
- Regression test
- Timing test
- security test
- Quality test
- Recovery test

The tests listed above are different types of performance testing but we will not use all these test to check the autonomous vehicle requirements but we will be testing only the suitable tests to validate the our system requirements. The stress test analysis how the system would perform if a short period of time it reaches it limits. The autonomous irrigation vehicle project will be using maximum of four sensor to water the terrain. So, when the system receives sensor data from mesh network the algorithm should work efficiently to reach all target sensor in a possible time. so the stress test will be evaluating the vehicle performance when it operates with maximum number of sensors. Furthermore, the volume test evaluates the performance of the autonomous irrigation system when it handle a large amount of data. The configuration test will be performed to evaluate if the autonomous vehicles hardware and software configured correctly. Configuring the vehicle's hardware and software requirement will enable the vehicle to active its goal. Since the autonomous irrigation vehicle has to interact with mesh network to retrieve the sensors data, the compatibility test will be performed to check if one system autonomous vehicle will interact with another component of the system as per the requirements. The timing test can be performed to analyze if the vehicle performs its functions as per the requirements. The environmental test can be done to evaluate how well the system would perform in its actually work environment place. The main requirements of the autonomous irrigation vehicle is that when it reaches the target destination midpoint, it should disperse the accurate amount of water to the grass. So we we done with all the functions of the irrigation vehicle, we will perform the environmental test to make sure that it deliver the right amount of water and not over watering the grass as well as the LIDAR stays away from the water. The quality test would be performed examine the reliability, maintainability and availability of the autonomous irrigation vehicle. The following sections explains the performance testing of the of specific components of the autonomous irrigation vehicle.

10.2.1 Pathfinding Testing

The section explain the pathfinding testing of the autonomous irrigation vehicle. The vehicle should be able to perform the following functions to validate the pathfinding testing.

- The autonomous irrigation vehicle should be able to receive the sensors data from the mesh network
- The autonomous irrigation vehicle shall be able to access the sensor locations from the two dimensional integer array map.
- The vehicle shall be able to identify the midpoint location between the dry sensors on two dimensional integer array map
- The autonomous irrigation vehicle shall be able to spot the obstacle location on the map
- The vehicle shall be able to calculate the shortest path to reach the destination midpoints
- Once it visited all the destination point, the vehicle should be able to backtrack to reach the home station (charging station).
- If the autonomous irrigation vehicle run out of battery on its way to destination it should able to back track to reach the charging station

The autonomous irrigation vehicle should be able to satisfy all these above requirements to attain its goal. The performance testing will be performance to validate the autonomous irrigation vehicle met all the required functionality mentioned above. Especially this testing will check the speed of the vehicle and the accuracy of the calculation. The following test cases executed to ensure the pathfinding performance.

- Send the maximum number of dry sensors to the autonomous irrigation vehicle to check nearest neighbor algorithm calculation accuracy.
- Check the travel speed of the autonomous irrigation vehicle

These test plans will be executed to check the pathfinding algorithm requirements. If the vehicle does not satisfy any of the requirements we will follow the Testing failure process flowchart, which is in software failure process section, to fix the problem and make sure the system performs its function as per the customer requirements.

10.2.2 Obstacle Avoidance Testing

The section explain the obstacle avoidance testing of the autonomous irrigation vehicle.

- The autonomous irrigation vehicle shall be able to detects the obstacles on its way to the destination point
- The autonomous irrigation vehicle shall be able to detects the obstacle in 180 degrees of range.
- he autonomous irrigation vehicle shall be able to detects any objects from 3 feet distance
- The autonomous irrigation vehicle shall be able to recalculate its path if it detects any obstacles
- The autonomous irrigation vehicle should be able to updates the obstacle location on the two dimensional integer array map if it finds any obstacle

When the autonomous irrigation vehicle travel to the midpoints, it should effortlessly detects obstacles to prevent the vehicle from collision. The performance testing will examine all these mentioned requirement to check the performance of the irrigation vehicle. Also we be executing the following step to check the test case for obstacle avoidance.

- First check that the light detection and ranging is mounted at correct angle on the vehicle
- Send some sensor data to the pathfinding algorithm to calculate the shortest path to reach the midpoint
- While the autonomous irrigation vehicle travel to the midpoint, verify that it checks any obstacle from 3 feet distance
- Will monitor the two dimensional integer array in the software to checks, if the vehicle updated the obstacle location correctly
- There will an object place on the vehicle path to checks, once the vehicle find the obstacle it recalculate the next shortest path using pathfinding algorithm

These test plans will be executed to check the obstacle avoidance requirements. If the vehicle does not satisfy any of the requirements we will follow the testing failure process flowchart to fix the problem and make sure the system performs its function as per the customer requirements.

10.2.3 Mapping Testing

This section explains the two dimensional integer array map testing. Here is the requirement of the two dimensional integer array map

- The two dimensional integer array map is used in the autonomous irrigation vehicle to keep track of the sensors location
- Keep track of all Midpoints locations
- Keep track of all Obstacle locations
- Minimum number of adjacent indices should not be less than zero
- Minimum number of adjacent indices should not be greater than nine

When the autonomous irrigation vehicle travel to the midpoints, it should effortlessly detects obstacles to prevent the vehicle from collision. Once it detects any objects it updates the location in the map. The performance testing will examine all these mentioned requirement to check the mapping functionality of the irrigation vehicle. Also we be executing the following step to check the test case for obstacle avoidance.

- Check if the sensors x and y coordination location added correctly on the two dimensional map
- Run the pathfinding algorithm to calculate the shortest path
- Will monitor the two dimensional integer array in the software to check, if the vehicle updated the obstacle location correctly
- Also, double check if the obstacle location's adjacent indices numbers are updated correctly

These test plans will be executed to check the mapping requirements. If the vehicle does not satisfy any of the requirements we will follow the testing failure process flowchart to fix the problem and make sure the system performs its function as per the customer requirements.

10.2.4 Water Allocation Testing

This section explains the water allocation testing. Here is the requirement of the water allocation testing.

- The autonomous irrigation vehicle should be connected to the retractable tether hose before it leaves the home station
- The autonomous irrigation vehicle shall be able to turn on the sprinkler head to disperse water, when it reaches the destination location.
- The autonomous irrigation vehicle shall be able to deliver exact amount of water in the specific area
- The autonomous irrigation vehicle shall be able to turn off the sprinkler, when it receives signal from sensor
- After turned off the sprinkler the autonomous irrigation vehicle should travel to the next destination point.

The crucial function of the autonomous irrigation vehicle is to disperse the correct amount of water in the allocated area. When the autonomous irrigation vehicle travel to the midpoints, it should efficiently disperse the water in the area. The performance testing will examine all these mentioned requirement to validate that the vehicle will deliver correct amount of water. Also, the following test cases will be executed to verify the obstacle avoidance functionality.

- Check the autonomous irrigation vehicle properly connected the retractable tether hose
- Monitor the program to check if the vehicle turn on the sprinkler at the correct place.
- Check if the sensor send the signal at the right time.
- Monitor the program to check, after it turned off the sprinkler the autonomous irrigation vehicle is traveling to the correct next destination midpoint.

These test plans will be executed to check the water allocation requirements. If the vehicle does not satisfy any of the requirements we will follow the testing failure process flowchart to fix the problem and make sure the system performs its function as per the customer requirements.

10.2.5 Backtracking Testing

This section explains the backtracking testing of the autonomous irrigation vehicle.
Here are some of the requirements that the autonomous irrigation vehicle shall be able perform.

- The autonomous irrigation vehicle should be able to backtrack to reach its home station (charging station)
- If the vehicle run out of battery on its way, it shall be able to backtrack to reach its charging station to recharge it.

There will be two ultrasonic sensors attached in the back of the autonomous irrigation vehicle to detects any objects when it back tracking. Since the vehicle is backtracking in the same way it travel to reach its destinations, we assume there should not be any problem to backtrack even if there is any objects on its way, the ultrasonic sensor will detects that and updates the map. The performance testing will examine all these requirements to check the backtracking functionality of the irrigation vehicle. Also, the following test cases will be executed to verify the backtracking functionality.

- Check if the ultrasonic sensor mounted at correct angle on the back of the autonomous irrigation vehicle
- Run the backtracking algorithm to check if its works as per the requirement

These test plans will be executed to check the backtracking requirements. If the vehicle does not satisfy any of the requirements we will follow the testing failure process flowchart to fix the problem and make sure the system performs its function as per the customer requirements.

10.2.6 Communication Testing

This section explains the communication testing of the autonomous irrigation vehicle. Here are the some requirements that the autonomous irrigation vehicle shall be able perform.

- The autonomous irrigation vehicle shall be able to communicate with mesh network to receive sensor data
- the autonomous irrigation vehicle shall be able to communicate with the microcontroller raspberry pi
- The Lidar and ultrasonic sensors shall to able to communicate effectively to share data
- The raspberry pi shall be able to communicate with other components over the wireless

These test plans will be executed to check the communication testing requirements. If the vehicle does not satisfy any of the requirements we will follow the testing failure process flowchart to fix the problem and make sure the system performs its function as per the customer requirements.

10.3 Software Failure Process

Testing is significant part of the software development. All those different types testing will be performed to check the all functional and nonfunctional requirements of the autonomous irrigation vehicle. Although we perform all the test, its not guarantee that the test plan will pass all the requirements, few test cases might fail. If the test plan fails we will follow the testing failure process flowchart to make sure that the function have been fixed. Testing failure process flowchart shown in Figure 47.

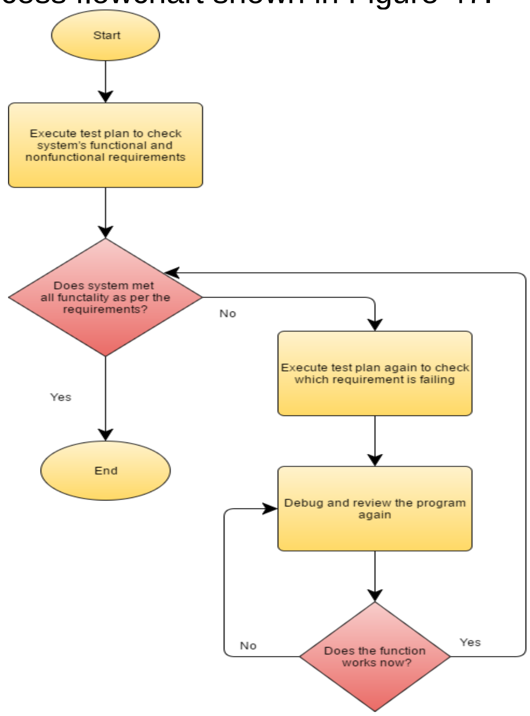


Figure 47: Testing failure process flowchart

In the flowchart at first the test plans are executed to check if the system's functional and nonfunctional requirements are met and is met by as per the customer requirements. If it does met all requirements then the system is ready to perform acceptance testing. If it does not meet the requirement then the test plan will be executed again to check exactly which requirement is failing. Moreover, the specific component would be debugged and reviewed and tested again. If does produce any other error the debug process continues until the it gets fixed. If it does not produce any other error then it continue to the acceptance test.

11. Administrative Content

The group has come to a clear and genuine understanding of how each other will operate, conduct themselves, and coordinate with one another. This collaboration is needed for the proper and successful execution of the autonomous irrigation vehicle. As such, there have been milestones put in place in order for the group to remain on schedule. Along with an appropriate scheduling of tasks to complete, there has also been a plan of financing that has been discussed and agreed upon. With all of the aforementioned steps, the group has a clear and steady path to research, document, develop, and finally prototype the autonomous irrigation vehicle.

11.1 Milestone Discussion

Listed below is Table 4 which lays out an approximate estimation of deadlines the team has set out for itself. The purpose of aiming for an approximate deadline prior the actual deadline gives the team time to make final overlooked errors, incorrect data, and deal with extraordinary circumstance that may occur. By taking into account of the final revision and random events that could arise, the group has spare time to make the proper adjustments that are needed. As such, achieving each milestone within a reasonable timing window is a critical step in the successful completion of the autonomous irrigation vehicle.

The Senior Design 1 Milestones outlines a set of estimated completion dates as previously aforementioned. The estimated completion dates for the Documentation section allow the team to correct any errors or faults that may occur. Research completion dates are listed as such as to allow the team to collect the proper amount of data in order to obtain the precise information while also staying within a reasonable timeline to complete an item from the Documentation section. The biggest hurdle the group faces whilst writing the final documentation is proper formatting and documentation which could hold back the initial stages of development for the autonomous irrigation vehicle.

#	Task	Estimated Completion	Completion Date	Assignee
	Senior Design 1			
1	Project Selection	January 18, 2018	January 16, 2918	All Members
2	Assignment of Roles	January 31, 2018	January 24, 2018	All Members
	Documentation			
3	Initial Project Document - Divide & Conquer	February 9, 2018	January 28, 2	All Members
4	Updated Divide & Conquer Document	March 6, 2018	March 8, 2018	All Members
5	60pg Draft Senior Design 1 Documentation	March 23, 2018		All Members
6	Final Documentation	April 26, 2018		All Members
	Research			
7	List of peripherals & sensors to be used	February 7, 2018		All Members
8	Ideal Microcontroller Unit (MCU)	February 12, 2018		CpE Members

9	Machine Learning Algorithms	February 16, 2018		CpE Members
10	Circuit Schematics	March 9, 2018		EE Members
11	Methodology to Interface MCU with PCB & peripherals	March 16, 2018		CpE Members
12	Robot Vision Algorithms	March 16, 2018		All Members
13	Finalize Research & Acquisition of Items	April 20, 2018		All Members

Table 4: Senior Design 1 Milestones

With the given Milestones set from Table 4, the team has used the given dates to address and also estimate the completion dates of assignments, requirements, and the presentations that will be due for the following semester within the class of Senior Design 2. As the estimations are to be completed a few days prior to the actual given deadlines within Table 4, Table 5 will also be constructed in an identical fashion as Senior Design Milestones 1. In Table 5, Senior Design 2 Milestones, there has been a numerous amount of new elements that have been included such as proper testing of components, ensuring efficient coding, and building of proposed circuit schematic as well as to begin prototyping. The group's aim is to complete each of the given tasks on time so as to make any last minute changes and corrections for items that have been overlooked during the entire process.

The initial printed circuit board design and autonomous irrigation vehicle design will need to be completed by the 11th of May, 2018, preferably by the end of April, 2018. Once the designs have been polished and carefully analyzed, acquisition of items will begin. With the items and components in hand, then begins building and putting together the circuit on a breadboard for further analysis and tests. As the circuit is being built, the programming of the selected microcontroller unit will have also begun along it. At a later date, proper interfacing of the printed circuit board and microcontroller unit will be performed for efficient data acquisition. Final testing of both the printed circuit board and microcontroller unit builds will then allow the group to construct a working prototype.

#	Task	Estimated Completion	Completion Date	Assignee
Senior Design 2				
	Development			
15	Initial PCB Design	May 11, 2018		EE Members
16	Initial Vehicle Design	May 11, 2018		All Members
17	Testing of Acquired Items	May 18, 2018		EE Members
18	Build proposed Circuit Schematic on Breadboard	May 24, 2018		EE Members
19	Build & Test proposed design of PCB	June 8, 2018		EE Members
20	Program MCU w/ appropriate functions	June 8, 2018		CpE Members

21	Design PCB Revision 1	June 22, 2018		All Members
22	Interface MCU & PCB	June 29, 2018		All Members
23	Interfacing & debugging of MCU	June 29, 2018		All Members
24	Build Prototype Unit	July 6, 2018		All Members
25	Finalization of Prototype	July 19, 2018		All Members
	Presentation			
26	Peer Review Presentation	July 21, 2018		All Members
27	Final Report	July 26, 2018		All Members
28	Final Presentation	July 28, 2018		All Members

Table 5: Senior Design 2 Milestones

Within a course of two weeks, a finalized prototype of the autonomous irrigation vehicle will have been constructed. Once the prototype of the autonomous irrigation vehicle has been constructed, final testing will commence to ensure quality has been met. Once all of the testing of the autonomous irrigation vehicle prototype has been completed, work on the final presentation will commence. The final presentation will encompass all of the group's research, documentation, and work of the autonomous irrigation vehicle over the past two semesters.

11.2 Budget and Finance Discussion

After careful consideration, our team has come to the conclusion of obtaining a couple of items in order for the autonomous irrigation vehicle to operate autonomously and safely. Throughout the research process, the autonomous irrigation vehicle has undergone multiple revisions. As such, the autonomous irrigation vehicle has discontinued the usage and implementation of certain components. Due to the revisions and the desired successful operation of the autonomous irrigation vehicle, the following items are required:

List of Items

- LIDAR
    - Allows autonomous irrigation vehicle to detect obstacles within its path
- Battery
    - Drives motors, sensors, and other applications
- Printed Circuit Board
    - Used to allow autonomous irrigation vehicle to communicate with LIDAR and other electronic components
- Microcontroller

- Extracts data from LIDAR and mesh network of sensors
  - Analyzes and interprets extracted data
  - Operates motors
- Circuit Elements
  - Used in printed circuit board

The LIDAR will be taking in data from the vehicle's surrounding area which will be used in conjunction with the vehicle vision and machine learning algorithms that will be incorporated to allow the vehicle to move autonomously. Solar panels will be installed at the home base which will allow the vehicle to recharge its battery as well as refill its water tank from the home base's reservoir tank. The 12V battery will provide the current based on the vehicle's power demand which is dependent on the amount of water the vehicle is carrying. The microcontroller will be used to control all operations of the vehicle. PCB provides communication between the LIDAR and microcontroller. Below isTable 6 which lays out all of the financial issues that need to be addressed before the autonomous irrigation vehicle can begin its construction. Some items are subjected to change at the will of the sponsor.

Items	Price Per Unit (Low)	Price Per Unit (High)
LIDAR	$199.00	$349.00
Ultasonic Range Finder	$.250	$16.00
Battery Management Sensor	$19.95	$190.95
Battery	$36.67	$259.00
Raspberry Pi	$35.00	$40.00
PCB	$5.18	$10.00
Circuit Elements	$25.00	$50.00
Servo	$11.49	$50.59
Servo Brackets	$11.95	$12.90
LIDAR Brackets	$4.95	$5.95
Microcontroller	$2.28	$3.99
Power Distribution Boards	$1.95	$6.99
Buttons & Switches	$1.05	$5.85
Wiring Harness	$3.95	$4.95
Terminal & Headers	$0.58	$1.50
Total	**$589.72**	**$973.59**

Table 6: Project Budget

Given the high costs of the items needed to obtain the desired results of the autonomous vehicle, even when going with the economical purchases, we as a team seek out sponsorship that can provide financial aid with item procurement. Without sponsorship, we as a team propose self financing with each member paying a distributed portion in order to obtain all items on the budget list. By splitting the costs between the team members, acquirement of the needed components becomes a feasible possibility.

Summary

Current irrigation systems are seriously flawed in regard to being invasive to install, prone to frequent user error, require frequent maintenance, and expensive to install and maintain. Traditional irrigations systems also produce enormous amounts of water waste, and for all these reasons there is obvious room for improvement. Overall the goal of the autonomous irrigation vehicle is to provide water to dry regions of an area only when those regions need it to reduce water and energy consumption and waste through monitoring the soil. The autonomous irrigation vehicle will be designed to be user friendly, durable, and autonomous with obstacle avoidance capabilities to reduce repairs and maintenance. The water and energy savings coupled together with the reduced maintenance and repair costs will save the customer to which the autonomous irrigation vehicle will be used by a substantial amount of money. This project is built upon soil moisture sensors that were developed during a previous senior design project by a team of mechanical engineers who were sponsored by Guard Dog Valves, who decided to move forward with future projects to develop future water conservation technologies due to its success. The autonomous irrigation vehicle is currently being developed by three teams for senior design who are all sponsored by Guard Dog Valves.

The first team is made up of three mechanical engineers who a developing the physical structure of the autonomous irrigation vehicle. They plan to build it with four wheel drive to handle difficult terrain, which it could come across on all the various areas it may be deployed. The autonomous irrigation vehicle will also be designed with a water proof shell so that its water delivery system down not cause any water damage to any of the electronic systems that it depends upon for its software to find the most efficient path for it to travel to provide water to all the dry regions that need it. They will also design the autonomous irrigation vehicle with a rechargeable battery and a retractable water supply tether to supply it with water and power. In addition, they are also responsible for the development of a charging station for the autonomous irrigation vehicle to dock at in order for it to recharge its battery. The charging station will also provide the water source for the retractable water supply tether controlled by a shut off valve and will also include a reeling system to collect portions of the water supply tether as the autonomous irrigation vehicle travels back to the charging station to dock to remove any excess slack that could result in tangles that would impede upon the autonomous irrigation vehicle’s ability to perform its intended water delivery duties. They are looking at the Traxxas Summit 1/10th Scale as a potential design to work with.

The second team is made up of a computer engineer, an electrical engineer, and another electrical engineer who has a computer science minor. Their contribution is the development of the wireless mesh network made up of moisture sensors to act as nodes within their network. Their moisture sensor nodes are an improvement upon the previous moisture sensor developed. They aim to include features for moisture detection, as well as humidity and temperature sensor within their sensor nodes as well as a durable protective enclosure to keep them safe from the elements and reduce maintenance, repair, and replacement labor and costs. Each sensor node within the wireless mesh network will be solar powered with excess energy stored in batteries to remove the need of invasive wires and improve the self-sustainability of the system with renewable energy, meeting one of the goals to be as eco-friendly as possible. The mesh network itself will include all of its senor nodes, the autonomous irrigation vehicle traveling around the area of the wireless mesh network, and mesh gateway to manage the network. The wireless mesh network will be scalable enough to cover very large areas and reliable to where if a node fails, the communications path between the nodes in the network can reroute to maintain the integrity of the network. They also plan to include a mobile web app to allow the user to have access to moisture readings and determine if manual watering is needed through an easy user friendly interface they can access though a smart phone or any device that can connect to the internet.

The third team is made up of two electrical engineers and two computer engineers who are developing the electronic systems and software for the autonomous irrigation vehicle to plot a course to traverse a landscape to provide water to all the regions that need it in the shortest and safest path possible. The electronic systems onboard the autonomous irrigation vehicle will be made up of a Raspberry Pi as a computer to analyze and processed received data to adjust its path and direction and an ATMEGA32P-PU microcontroller to provide communication to sensors and other onboard electronics as well as providing control for its servos and sensors. The autonomous irrigation vehicle will communicate to the wireless mesh network using the E01-ML01PX chip that uses the 802.15 Standard protocol due to its low cost, low power consumption, and wireless personal area network capabilities. While the autonomous irrigation vehicle is traveling around the area watering the areas that the wireless mesh network's sensors determines needs it, it will be detecting obstacles along its course for it to avoid and prevent structural damage and course impedance that would result in an unhappy user with maintenance costs or a dehydrated lawn. The obstacle will be detected using ultrasonic sensors and a LIDAR system that has been weather proofed and attached to a servo for one-hundred-and-eighty-degree movement where it scans the area in front of it and sends bac the data of the locations of the obstacles detected to the Raspberry Pi to label on its map with the number nine and all locations adjacent to them with the number of their adjacent obstacles. The autonomous irrigation vehicle will also include a battery management system that utilize a voltage divider integrated onto a printed PCB circuit to ensure the most efficient energy use within all the electronic systems as possible. The autonomous irrigation vehicle will map out the locations of the moisture sensors from the wireless mesh network and calculate then plot the midpoints between them onto a two-dimensional integer array map. From its current location, the autonomous irrigation vehicle will look to the midpoints between the sensors to its left and right and travel to whichever has the most dry sensor readings, if the both have the same number of dry sensors that is not zero, it will travel straight ahead to the center midpoint, if none of the midpoints around it have dry senor readings but the mesh network still has dry sensors in it, the autonomous irrigation vehicle will employ the nearest neighbor algorithm to find the closest midpoint with dry sensor readings for it to travel to. If it detects multiple midpoints equal distance away with the same number of dry sensor readings, the algorithm will branch to both and look for the next one from there and overall choose the one with the shortest and safest path. It will build its path from one location to another location it will utilize a breadth first search algorithm.

APPENDICES

Appendix A – Reference

[1] Ackerman, Evan. Guizzo, Erico. "*iRobot Brings Visual Mapping and Navigation to the Roomba 980."* IEEE SPECTRUM, September 2015, www.spectrum. ieee. org /automaton/robotics/home-robots/irobot-brings-visual-mapping-and-navigation-to-the-roomba-980. Accessed 14 March 2018.

[2] Alex. "*Power Distribution Boards - How to choose the right one."* DroneTest, September 2015, https://www.dronetrest.com/t/power-distribution-boards-how-to-choose-the-right-one/1259. Accessed 9 April 2018.

[3] Anderson, Mickie "*Soil-moisture Sensors May Produce Big Water Savings for Homeowners, UF Study Shows" Institute of Food and Agricultural Sciences and University Of Folrida, www.blogs.ifas.ufl.edu/news/2007/11/13/soil-moisture-sensors-may-produce-big-water-savings-for-homeowners-uf-study-shows/.* Accessed 2 April 2018.

[4] *"AVR-ATmega32A_Datasheet-Summary.*" Atmel Corporation, August 2016, ww1 .micro chip.com/downloads/en/DeviceDoc /Atmel-8155-8-bit-Microcontroller-AVR-ATmega32A_Datasheet-Summary.pdf. Accessed 14 March 2018.

[5] "*Beginner's guide to ultrasonic level transmitter."* Coulton, www.coulton .com/beginners_guide_to_ultrasonic_level_transmitters.html. Accessed 9 April 2018.

[6]Cochrum, Andrew., Corteo, Joseph., Oppel, Jason. Seth, Matthew." *The Manscaper Autonomous Lawn Mower*." University of Central Florida, 2013 PDF file.

[7]Darbyshire, Paul. Granda, Alice. Halterman, Brandon. Torres, Yahsiel. Ravenswaay van, Zavanio. Sookdeo, Jonathan. "*Integrated Water Monitoring System*" University of Central Florida, 2017 PDF file

[8] "*Droplet is a reinvention of the way plants get water."* Droplet Inc, www. smartdroplet.com. Accessed 14 March 2018.

[9] "*Edward H. Adelson*." Edited by Elmer, People/Adelson.txt, 22 Sept. 2017, persci.mit.edu/people/adelson.

[10] "*The Floridan Aquifer"*. The Florida Springs Institute, Floridasprings institute.org/ floridan-aquifer. Accessed 14 March 2018.

[11] Grumney, Dave. "*Ultrasonic Transmitters vs. Guided-Wave Radar for Level Measurement*." Questex LLC, March 2011. www.sensorsmag .com/components / ultrasonic-transmitters-vs-guided-wave-radar-for-level-measurement. Accessed 9 April 2018.

[12] Huang, T. Computer Vision: Evolution and Promise(PDF). 19th CERN School of Computing. Geneva: CERN. pp. 21-25. http://cds.cern.ch/record/400313/files/p21.pdf

[13] IEEE Standards Association Family of Sites. IEEE, 2018, standards.ieee.org/ Accessed 2 April 2018

[14] "*I2C*". SparkFun Electronics, www.learn.sparkfun.com/tutorials/i2c. Accessed 9 April 2018.

[15] Jackson, Jonathan., Velasco, Alejandro., Oppel, Jason. Wilson, Christopher.*" F.A.R.M. (Fundamental Agriculture Resource Monitor)*." University of Central Florida, 2015 PDF file.

[16] King, Austin., Plaza, Kevin., Baumgartner, Adam., Hromada, Ryan. "*Military Surveillance Robotic Vehicle*." University of Central Florida, 2016. PDF file.

[17] *"LIDAR-Lite v3."* GARMIN, www.buy.garmin.com/en-US/US/p/557294#overview. Accessed 9 April 2018.

[18] "*Meet the Roomba® family of vacuuming robo*ts." iRobot Corporation, www.irobot.com/For-the-Home/Vacuuming/Roomba.aspx. Accessed 14 March 2018.

[19] Minesweeper. Curt Johnson. Microsoft, 1990. Microsoft Windows.

[20] Olson, Tim. "*How Level Measurement With Pressure Sensors Works*" Automation Products Group, August 2015, www.apgsensors.com/about-us/blog/how-level-measurement-with-pressure-sensors-works. Accessed 9 April 2018.

[21] Parent-Charette, Sébastien. "*LIDAR-Lite Laser Rangefinder – Simple Arduino Sketch of a 180 Degree "Radar".*" RobotShop Inc., April 2015, www.robotshop.com/blog/en/LIDAR-lite-laser-rangefinder-simple-arduino-sketch-of-a-180-degree-radar-15284. Accessed 9 April 2018.

[22] Parent-Charette, Sébastien. "*LIDAR-Lite v3 – Available for pre-order."* RobotShop Inc., September 2016, www.robotshop.com/blog/en/LIDAR-lite-v3-available-for-pre-order-19202. Accessed 9 April 2018.

[23] Pfleeger, Shari Lawrence., Atlee.M, Jonne. *Software Engineering Theory and practice*. Pearson education, 2010.

[24] Prathik, A., et al. "*An Overview of Application of Graph Theory*." International Journal of ChemTech Research, vol. 9, no. 2, 2016, pp. 242–248., www.sphinxsai.com/2016/ch_vol9_no2/1/(242-248)V9N2CT.pdf.

[25] "*RPLIDAR A1M8*". Slamtec. https://www.robotshop.com/media/files/pdf/rpLIDAR-a1m8-360-degree-laser-sca1nner-development-kit-datasheet-1.pdf Accessed 7 Apr. 2018.

[26] Russell, Stuart J., and Peter Norvig. *Artificial Intelligence A Modern Approach*. Prentice-Hall, 2010.

[27] Sam Travarca. *"Reason for an Development integrated dvelopment environment"*. Vantageone Software, http://vantageonesoftware.com/reasons-integrated-development-environment/. Accessed 8 Apr. 2018.

[28] *"SCHEMATICS - BATTERY MONITOR CIRCUIT"*, Society of Robots, www. society ofrobots.com/schematics_batterymonitor.shtml. Accessed 14 March 2018.

[29] "*Summit.*", Traxxas. www.traxxas.com/products/models/electric/summit. Accessed 14 March 2018.
[30] "*Water Level Sensors*". RS Hydro, http://www.rshydro.co.uk/water-level-sensors/. Accessed 9 April 2018.

[31] "*When it's Hot."* U.S. Environmental Protection Agency, www.epa.gov/watersense/when-its-hot. Accessed 2 April 2018.

[32] "Why learn C++". Codementor. http://www.bestprogramminglanguagefor.me/why-learn-c-plus-plus Accessed 7 Apr. 2018.

[33] Zhang, Qian. Zhang, Young-Fei, Qin, Shi-Yin, " *Modeling and Analysis for Obstacle Avoidance of a Behaviour-Based Robot with Objected oriented methods.*" Journel of computers, Vol .4, No. 4 (2009).

Appendix B - Copyrights Permissions

Alexandre (RobotShop)
Apr 10, 09:16 EDT

Hi Parameswari,

Thank you for contacting Robotshop. You can use that image and table data without any problem.

Please let us know if you have any other questions.

Regards,

Alexandre
RobotShop inc.
RobotShop.com
Putting Robotics at your service!™

Parameswari Chandrasekar
Apr 9, 19:31 EDT

I'm a Computer Engineering student at University of Central Florida. I would like to request permission to use the image of "PRLIDAR A1m8" model that you have listed at https://www.robotshop.com/en/rplidar-a1m8-360-degree-laser-scanner-development-kit.html and the measurement performance table data that is associated with the PRLIDAR A1m8 model
If permission is granted, the image and the table will be used in a senior design paper.

Thank you,
Parameswari

Figure 48: Permission for PRLidar A1M8 Model

Permission to use image

Roberto Santos
Fri 4/20, 11:05 PM
OnlineSupportUS@Avnet.com

Reply all

Hello, my name is Roberto Santos I am an electrical engineering senior and would like to ask for permission in using the front view picture of your LIDAR anywhere in a project I am doing for the University of Central Florida. This Project is posted on you website https://www.hackster.io/.

Thank you,

Roberto

Figure 49: Waterproofing Permission

Request Permission

Roberto Santos
Tue 4/3, 8:07 PM

Terri,

Thank you. The project is a autonomous lawn irrigation vehicle.

Sincerely,

Roberto

Terri.Thill@ocfl.net
Tue 4/3, 2:05 PM

Sure

What is your project about? April is Water Conservation Month

https://www.sjrwmd.com/water-conservation/

Terri Thill
Orange County Utilities Water Division
9150 Curry Ford Road
Orlando, FL 32825
407-254-9602

Roberto Santos
Mon 4/2, 10:30 AM
Water.Division@ocfl.net

Reply all

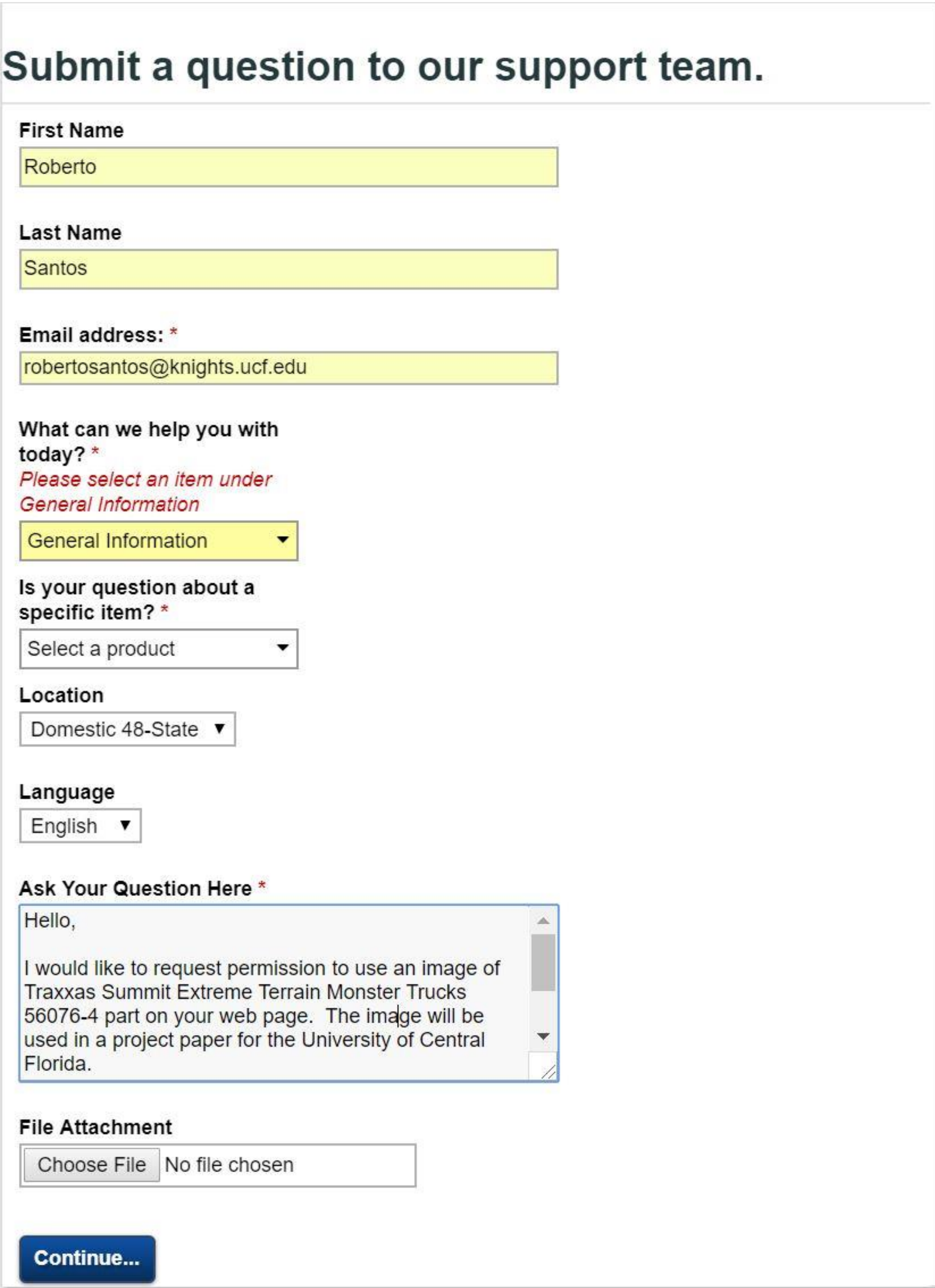
Hello,

I would like to request permission to use an image of the table in the Watering Restrictions part of your web page. The image will be used in a project paper for the University of Central Florida.

Thank you,

Roberto Santos

Figure 50: OUC Permission



Submit a question to our support team.

First Name

Roberto

Last Name

Santos

Email address: *

robertosantos@knights.ucf.edu

What can we help you with today? *

Please select an item under General Information

General Information

Is your question about a specific item? *

Select a product

Location

Domestic 48-State

Language

English

Ask Your Question Here *

Hello,

I would like to request permission to use an image of Traxxas Summit Extreme Terrain Monster Trucks 56076-4 part on your web page. The image will be used in a project paper for the University of Central Florida.

File Attachment

Choose File No file chosen

Continue...

Figure 51: Traxxas Permission

Appendix C - Datasheets

Test	Test description	Test condition	Expected results	Results (pass/fail)
PathFinding test	listed in Pathfinding test	The test will be performed in the environment	Should pass pathfinding test	
Obstacle Avoidance test	Listed in Obstacle avoidance test	The test will be performed in the environment	Should pass obstacle avoidance test	
Mapping test	Listed in map testing	The test will be performed in the environment	Should pass mapping test	
Water allocation test	listed in water allocation testing section	The test will be performed in the environment	Should pass water allocation test	
Backtracking testing	listed in backtracking testing section	The test will be performed in the environment	Should pass backtracking test	

Table 7: Test Plan for Performance Testing