Design Project Report

EECE 401 Senior Design I
Department of Electrical and Computer Engineering
Howard University

MEMORANDUM

04/21/2009

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SUBJECT: Design Project Report Submission

This project report is submitted for partial fulfillment of the Senior Design course describing the design and implementation of our project

SUBMISSION AND APPROVAL

This project report is submitted for partial fulfillment of the Senior Design course describing the design and implementation of our project.

Name **Signature** **Date**

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I approve this project report is an accurate representation of the Project and I approve it

Advisor's Name **Signature** **Date**

Executive Summary

The focus of the AMF project was to design a completely autonomous map following vehicle in order to decrease car collisions due to human error. By completely autonomous, it is meant that the given user inside the AMF vehicle simply has to specify their desired destination into a user-computer interface and the vehicle will calculate the best possible route, automatically drive the user to said destination, and alert the user upon arrival. Various methods were researched and analyzed in a arriving at the final solution utilized a GPS guided. A scaled prototype of the system was built using the P3-AT robot as a vehicle. The project team was successful in completing the project according to the design requirements and constraints and the final solution was evaluated against the requirements.

Table of Content

1. **Introduction**

The objective of this project was to design a system that allows a vehicle to drive autonomously from one destination to another. Car systems have evolved to include a number of functions which permit safer driving and allow drivers to also navigate destination routes a lot easier. One of the proposed developments to further ensure safety in the road would be to allow for driver-less vehicles which are better able to methodically assess driving conditions in order to quickly adapt to an adverse conditions in the surrounding environment. By replacing the human driver with a system that can autonomously drive the vehicle, it is likely that driving can be made safer for both commuters and pedestrians.

The project designed a scaled version of the prototype which mirrored the full functionality of the design. In order to deliver this finished product within the allotted time of 8 months, the team completed the tasks of design selection and approval, testing and simulation, building of product and final testing to ensure the product performed as expected.

In developing a solution for an Autonomous Map follower, several engineering courses and skills covered by the engineering curriculum were employed. A good knowledge of circuit analysis covered in Network Analysis lectures and labs was essential in analyzing circuit schemes for achieving the desired system. Also, a working knowledge in micro computing was required in working with the processors which was a core part of the design implementation. Other Engineering courses which were applied include Signals Processing, Electronics, Energy Conversion, Programming, as well as the various lab classes. These courses were essential in developing the design solution and implementing it with an actual prototype.

This project was an initiative of, and also sponsored by Chrysler LLC, the American car manufacturer. Chrysler is at the forefront of developing auto vehicles that will improve safety on the roads. The company partnered with the Howard University Engineering department to provide students with real-world design experience by giving the students an opportunity to work on projects that are relevant to the current auto industry. Chrysler funded the project and also served as a resource to the students throughout the projects duration. A Chrysler employee also served as a mentor to the students.

2. **Problem Definition**

The problem we were faced with was to design a system that allows a vehicle to drive autonomously from a start location to a desired destination which is pre-determined by the vehicle operator. The development of this system was focused on making certain that both safety and convenience were priorities when traveling. By taking human error out of the equation, the Autonomous Map Follower can provide less hazardous travel situations and lower accident occurrences. As such a scaled prototype was to be designed and created to test and replicate these desired results. The autonomous vehicle system, and prototype, would be able to do the following:

- Calculate and drive a route in a controlled environment
- Stop within 3 meters of destination
- Alert the user upon arrival at destination
- Allow the user to abort on-going destination navigation
- Change desired destination during on-going navigation
- Automatically calculate and return to departure location
- Turn off remotely

3. **Current Status of Art**

In reviewing the various technologies which could be used in designing the system, the focus was on identifying technologies that enable location mapping of vehicles. A processor was used in controlling the steering and acceleration of the vehicle, and the processor was also able to determine the car's correct position in order to issue the right instruction to turn right or left towards the intended destination. As such, a reliable means of pin-pointing the cars actual position is critical to this project. Current technologies which are available and have been successfully used in location mapping include the following:

GPS

Systems using GPS have been employed in various location mapping devices. It is used in a lot of vehicles today in determining location on a map. The GPS system has also been successfully utilized in developing autonomous vehicles as displayed in the DARPA competition. The Urban Challenge sponsored by the U.S. Defense Advanced Research Projects Agency (DARPA) is a competition which has produced vehicles utilizing a robot system navigating a determined path using GPS coordinates. A key advantage of utilizing the GPS system is that it is a proven system that can be employed at low costs. Integrating the GPS with a controller for manipulating the cars driving components will serve the purpose of making the car system autonomous. However, one requirement of utilizing this technology is that the system will have to be integrated within the vehicle components and as such cannot be an add-on system. Another weakness is that error of margin of GPS systems which typically range between 3-5 feet. This means that the vehicle's position cannot be exactly determined and is thus prone to error. The weakness of this design would be that the map follower could not be an independent part of the vehicle and it must be integrated with other components in the vehicle for it to successfully drive autonomously from a start destination to a final destination. For the best possible solution, GPS was used because it can be integrated with a processor to be the secondary source of navigation for the vehicle to reach the final destination.

Multilateration

Multilateration is another technology which is currently used to track the location of different types of vehicles by using RF transponders. Multilateration, also known as hyperbolic positioning, is the process of locating an object by accurately computing the time difference of arrival (TDOA) of a signal emitted from the object to three or more receivers. It also refers to the case of locating a receiver by measuring the TDOA of a signal transmitted from three or more synchronized transmitters. One weakness of this technology is that it requires the presence of external antennas which may not always be present. It is also prone to interference. For an optimal solution, Multilateration could be used as a form of tracking the vehicle to ensure that it is following the correct course to its predetermined destination. With the accuracy of Multilateration, if the vehicle strays from its intended route then the user can be notified and make the proper adjustments.

Electric Compass

The electric compass is a dead-reckoning sensor based on terrestrial magnetism. With an electronic map system with coordinates, the system can utilize readings from the electric compass to navigate from a starting point to the destination, provided the coordinates of the end point are initially identified. The major weakness in utilizing the electric compass is its sensitivity to external interferences of the magnetic field. The electric compass is based off the magnetic north which leaves error because of interference from steel or other metal buildings which can interfere with the accuracy of the compass. To address the inexactness of the electric compass, the use of two electric compasses integrated into one robust electric compass will efficiently cancel out the low-frequency interferences. This use of the technology would be sufficient and it is proven to work. To include the electric compass in the optimal solution would add another dimension of accuracy and it would serve as an assisted GPS to the primary GPS. The electric compass can assist in areas where the GPS signal may not be strong based on certain interferences that could arise from tall buildings or bad reception depending on the quality of the GPS system.

4. Design Requirements

The following design requirements and constraints were drawn up to guide the design of the system

- Calculate a route within 1 minute of input and automatically drive the route to a destination determined by the user
- Stop at said destination without any user input after the initial destination determination within 5% error margin
- Alert the user by way of sound or signal upon arrival at said destination within 10 seconds of arrival
- Allow the user to abort on-going destination navigation within 1 minute of notification

Additional requirements of the autonomous vehicle and prototype include:

- The user may be allowed to change their desired destination during the on-going navigation within 10 seconds of notification
- Automatically calculate and return to their departure location
- Stop at destinations along the original destination route without hampering/interfering with the original final destination
- Turn off remotely

The following constraints were also considered when developing the system prototype:

- System should be developed within the 8 month time period allotted for the project
- Cost of the entire system must be less than $1500

The automated map following vehicle and prototype would also have to adhere to the following safety standards:

- The IEEE 802.11 standard for information technology, telecommunications and information exchange between systems (local and metropolitan area networks)
- The FCC standard CFR 47 part 15 in regards to unlicensed transmission IEC 61108-1 Standard for Global positioning system (GPS) Receiver equipment

5. Solution Generation

Preferred Solution

The challenge in creating a fully autonomous system was how to triangulate the location of the vehicle and the position of the users' destination. Thanks to Global Position System (GPS), we can always find the location of a vehicle through the help of satellites. Modern GPS uses a combination of GPS and Geographic Information System (GIS). With these two systems we were given the tools to calculate positions as well as routes. The problem arose in how to translate the instructions that are created by the GPS instruction to drive a system that would control the car.

In primary approach to the problem we planned on using a system which contained a computer, and two microcontrollers. One microcontroller was to be in charge of receiving, interpreting GPS signal and then transmitting the GPS coordinates to a computer. The computer would contain our GIS as well as the coordinates of destinations. The computer was to be the core part of the system that would interpret, plan, and translate given instructions into a language that could be interpreted by the second microcontroller. The final microcontroller would be in charge of the motors and would move the vehicle. This microcontroller was to act as a failsafe that would be able to calculate motor speed, and distance to be used in error correction to check errors transmitted from the GPS. These checks would be sent back to the computer to correct errors in routes, and give feedback information to the user.

In our pursuit of a solution, we used our knowledge in microcontroller, programming, and signal processing to help aid us. At the end of this project we hoped to learn more about embedded systems, and how to construct and program across many different electronics to be able to work as one.

Alternative Solution 1

An alternative design solution would be the use of Multilateration to determine the location of the vehicle by computing the time-difference of arrival of a signal emitted from the object to three or more receivers. Multilateration allows for multiple transmitter/receiver locations to overlap for a stronger and more optimal signal strength area. The vehicle would be located and guided, using an RF transponder communicating with signals emitted from multiple towers or locations, through the route predetermined by the user. The location information was to be passed on to a processor which would then send directional instructions to actuators connected to the mechanical parts of the vehicle. The processor would also receive information regarding distance travelled from sensors connected to the vehicle. Due to the relative local position of the transmitter/receivers used in this method, the accuracy is much higher than the popular GPS. Unfortunately this is also its down fall as these transmitter/receivers are not common in all areas and would cost a great deal to install across the nation.

Alternative Solution 2

Another design option would entail the input of line by line directions by the user. The directions will then be sent to a central processing unit which would be connected to an electric compass. That way the user may enter the street names and allow the in system map to judge its position and heading by using azimuths and distances. This system required the user to know the exact position of their starting point, as well as their ending point. The location device would be connected to a processor which would send directional instructions to actuators connected to the mechanical parts of the vehicle. The processor would also receive information regarding distance travelled from sensors connected to the vehicle. The benefit of the compass is that the user doesn't need to know the exact angles to turn at every corner. The internal map would have all this information inside it and would check it with the compass. Even with the compass, however, this system leaves too much room for user error. In a real world scenario the risk of the user entering an incorrect initial or final position would cause numerous uncorrectable issues. This system simple does not have the proper checks and balances.

Decision Matrix

After coming up with three different design solutions for the project, we used a decision matrix to assess each one in other to determine a preferred choice. Some of the design attributes we considered for the matrix include:

- **Price**: we considered price because we were working with a budget constraint as determined by the ECE department. We attributed price a weight of 20
- **Safety**: this was also an important attribute for us to consider in making a decision and so we gave it a weight of 30
- **Ease of Use:** this was one of the most important factors we considered as it would determine how user friendly the design solution was. We attributed this factor a weight of 35.
- **Accuracy**: this was also one of the most important factors in choosing a design as it was directly related to the function of the system in moving the vehicle from one location to another. We attributed accuracy a weight of 35.

		DECISION MATRIX					
		Solution 1 GPS Guided System		Solution 2 Triangulation System		Solution 3 Electric Compass System	
Selection Criteria	**Weight**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Ease of Use	35	7	2.04	6	1.75	4	1.17
Accuracy	35	8	2.33	6	1.75	5	1.46
Safety	30	8	2.00	6	1.50	6	1.50
Price	20	8	1.33	7	1.17	7	1.17
Total Score			**7.7**		**6.2**		**5.3**
Rank			**1**		**2**		**3**

Based on the decision matrix, the preferred solution design was the GPS guided system. The next step was to design a prototype for the selected solution. We came up with 3 designs for a prototype and also applied the same decision matrix to select a preferred prototype design

Prototype 1: RC Car with a GRID and Infra-Red Sensors

In this solution there would be the use of a remote controlled car that would be reconfigured to be able to drive autonomously following a predetermined grid layout. The remote controlled car or R/C car would be rewired so the use of the controller would not be needed to direct the car. A program must be written in order to apply the appropriate commands to the car such as when to move forward and when to turn left or right. The program could be written from Matlab Simulink and the schematics of the circuit could be drawn using Pspice. In order for the car to be autonomous, it would need a map with destinations to follow. Since the car would be on a small scale and for the sake of better accuracy, the destinations would be predetermined in the programming. One way to form a grid would be the use of infrared (IR) Light Emitting Diode (LED) to plot out destinations. The IR LED’s would be stationed in specific locations in the desired area. On top of the R/C Car we would need a hobby servo and two IR sensors to pick up the signals from the IR LED’s.

We would need IR LEDs and IR sensors that pick up signals from 38 kHz – 40 kHz range, and could be used in all lighting conditions. We could use two IR receiver modules that would be more then capable of receiving the signals. The IR receivers would be connected to a PIC which would also control the hobby servo. The two IR receiver modules would be positioned on the hobby servo so that when they are rotating they can have a wider range and pick up the signal transmitting from the LEDs. The vehicle would then be programmed to go to the LED, which would be lit. We the programmers can chose a destination for the vehicle to go by feeding the IR sensors' signals. The drawback to this design would be the amount of IR LED's to light a given path and the fact that the signals must be within a certain range for the sensors to pick them up. The type of sensors we would use would mirror that of a television sensor for a remote control, so the constraint of the signals distance could be an issue.

The programming would be very tedious and challenging to interpret all of the necessary information to successfully integrate the R/C car controls with the IR sensor. Based off of an expert opinion from Carl Cooper an Electrical Engineer who works for the United States Postal Service as a Plant Supervisor, the use of IR Beacons coupled with IR sensors would need to be precise in placement. The Plant where he works uses autonomous vehicles to carry large amounts of mail to various locations in the plant. There are different IR beacons which would be our LED's on a smaller scale set up in destinations for the vehicle to move to. The autonomous vehicles were manufactured from Northrop Grumman.

<u>Protoype 2: P3-AT Robot with GPS</u>

In this solution we thought of replacing the RC car with a sophisticated robot. The idea of using the Pioneer 3-AT was brought to us from head of the Electrical and Computer Engineering department, Dr. Choukiha. This robot is very expensive and cost up to $4,000, luckily there was one on campus and we were given permission to use it.

There were many benefits to using this robot and was very advantageous to our project. First, the robot could be linked with Matlab to simulate different behaviors it may encounter in real life scenarios. This helped alleviate stress caused by unforeseen variables when attaching a GPS, peripherals and other sensors. These attachments will require extensive testing to verify components will work properly before assembly.

One of the major difficulties when using GPS was how to use a system in combination with a Geographic Information System (GIS). Creating a GIS could have been tricky especially if there are obstacles involved. Each object must be measured, scaled and mapped to a Graphical User Interface (GUI) that can be recognized by both the user and microcontroller. Each pixel of each object needed to be accurately mapped to a corresponding GPS position in order to provide an accurate map. The Pioneer 3-AT could be programmed to map a surrounding and create a map for a user. This took away some of the time for programming and allowed us to focus on other areas and constraints within our design.

By using the robot instead of an RC car, we could take time from building a prototype to programming it to react to different scenarios. We planned on attaching sensors to the prototype to allow it the ability to react to changes in the environment such as moving objects, stop signs, and changes in the maps. Programming was still required as the robot still received its instructions from a computer source. In that regard, we would still need to program the behaviors of the robot as well as the guidance system of the map.

Prototype 3: RC and GPS

The RC car and GPS unit solution consisted of an Electrical/Regular RC car, PIC microprocessor(s), a compatible GPS unit (HCS12X MCU Family processing unit), and a GIS unit. The purpose of the GPS and GIS systems were to allow a predetermined grid system to be mapped out and followed by the RC car.

An RC car with GPS satisfied our design problem of making an autonomous vehicle similarly to the way the Lego Mindstorm would in that the car is to receive line-by-line instructions from a user. These line-by-line instructions were then transferred to a PIC microcontroller which was placed on the RC car, by way of Bluetooth technology, and used to guide the car through the given obstacle course. The PIC microprocessors was seen as the “new brain” of the RC car in that they would hold a digital signal from a computer (user input) and translate that signal into an instruction set of directions for the car to follow.

A GPS device, which would be designed and programmed, using an HCS12X processing unit, would be attached to the car to simulate a mapping system for an autonomous vehicle to navigate with. This mapping system would be designed using a grid-mapping technique to be the means for the RC car to navigate from a starting point to an end location. Since there was a grid system in play, if the car were to receive a new desired location en-route to a previously input location, it would need to reach its initially input location before it moves toward the newly input destination.

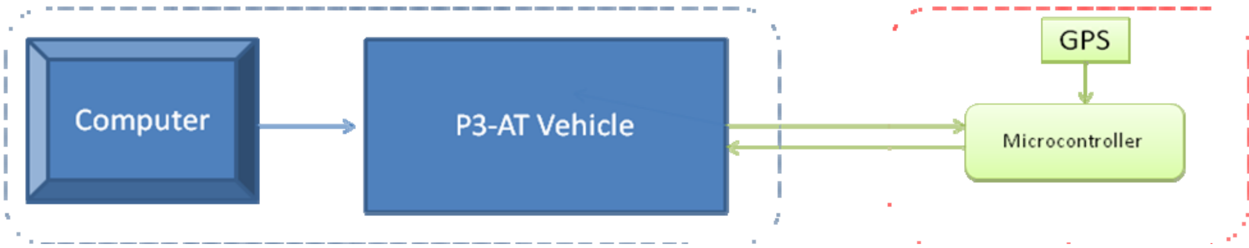
A GIS would relatively determine and keep track of the location of the car in reference to the user’s original input and grid-mapping system. When a desired destination was determined through line-by-line user instructions, the RC car would move based on coordinates given compared to coordinates from the GPS unit, navigate with GIS assistance, and move autonomously either until other instructions were given or the desired destination was reached.

	PROTOYPE DECISION MATRIX						
		Solution 1		Solution 2		Solution 3	
		RC/Grid/IR		Robot/GPS		RC/GPS	
Selection Criteria	**Weight**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Accuracy	35	4	1.65	7	2.88	7	2.88
Safety	30	8	2.82	8	2.82	8	2.82
Price	20	8	1.88	9	2.12	7	1.65
Total Score			**6.35**		**7.82**		**7.35**
Rank			**3**		**1**		**2**

Based on the decision matrix, we decided to implement the project using the P3-AT robot and a GPS system.

6. Implementation

Prototype Design



In order to implement a prototype of our design solution, we split the project into two distinct modules. The first module was the work of programming and building the subroutines to guide the vehicle's navigation while the second module was the work of programming the external microcontroller which receives the GPS signal and passes it on to the vehicle's microcontroller. Upon completion of both modules, we completed the prototype with its functionality mirroring the functionality of the design solution

Module 1

This module involved programming on the vehicle's microprocessor so that it can autonomously issue navigation commands to a selected destination with the use of waypoint (latitude and longitude coordinates) to calculate the distance between each waypoint and then make the correct turnings. The vehicle issues a notification of arrival upon getting to its destination. Work on this module involved

- Learning ARIA, an object-oriented, robot control applications-programming interface for MobileRobots (and ActivMedia) intelligent mobile robots. Written in the C++ language, ARIA is client-side software for easy, high-performance access to and management of the robot, as well as to the many accessory robot sensors and effectors. Build

Subroutines for the various functions to enable navigation. The subroutines are as follows:

- Destination_ Select: this function would handle the user input destination and also receive the latitude and longitude of the vehicles present location from the external microprocessor connected to the vehicle's processor. It would also pass the waypoint longitude and latitudes to the Distance_Calc function.
- Distance_Calc: this function would calculate the distance between the waypoints into meters and pass it on to the Navigate_Route.
- Navigate_Route: this function would receive the distance information and issue turn by turn directions. This part of the program was implemented in two ways. The first was an algorithm which had a list of routes to various destinations. The user would the input the desired destination and based on the input the related route would by the vehicle in navigating to the intended destination. The second navigation algorithm was more intelligent as the route selection was carried out by the code. The user would only have to input the destination and the algorithm would run a search of the map to find the most optimal path. This path would then be used to navigate to the destination. The search algorithm which was implemented was the A-star algorithm which is widely employed in route selection programs.
- Notification_Arrival: this function would check to see if the vehicle's location is the intended destination and print a message to show that the vehicle arrived.

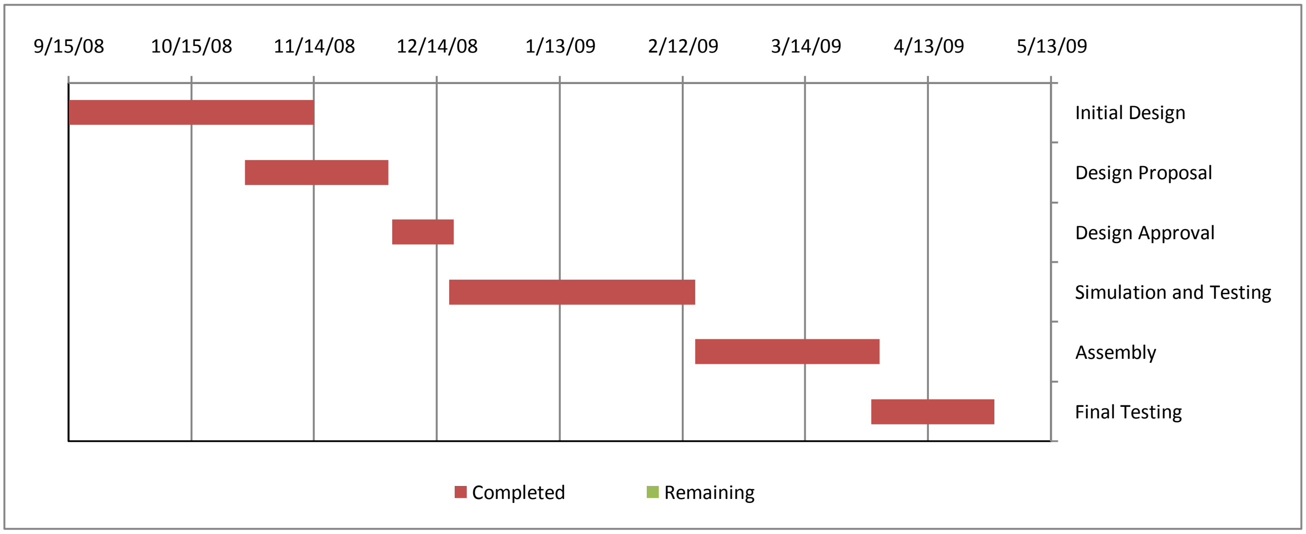
Module 2

This module involved programming the external microcontroller to accept GPS signals and relay them to the processor in the vehicle. The processor which we intended to use was the Freescale MC9S12XDP512 with the SK-S12XDP512- starter kit. Using this board cuts down on costs and it enabled flexibility in designing our GPS module. We decided to use the Garmin GPS 18 GPS PC/Serial Interface Sensor for OEM Clients. This type of GPS module used a RS-232 connector that connected directly to our board. Using the RS-232 connector gave us the freedom to use the USB connector to communicate between our GPS unit and the P3-AT robot. Some of the tasks involved in designing this module were:

- Learning the NMEA(National Marine Electronics Association) protocols for GPS and developing an algorithm to convert NMEA 0183 signals into longitude and latitude coordinates
- Learn and configure communication between host (P3-AT) and device (GPS module) to allow for adequate date transfer.

Upon implementation of the HCS12X microcontroller and the GPS, we discovered major latency and baud rate inconstancy between the two devices. In the end, we decided to move away from the HCS12X microcontroller. We connected the GPS directly to the P3-AT robot where we had to reconfigure both the device and robot. We changed the baud rate to 38400 bps as well as configured the robot to take the NMEA strings from the GPS through COM port 3. In order to get a better fix on position we modified the GPS module to have an update rate of 2Hz as well as extracted specifics strings from the module (GGA, RMC, GSA, and GSV). This strings allowed for allowed us to extract specific information such as latitude and longitude coordinates, satellites position and acquisition information. To reduce the error associated with our GPS, we decide to reprogram it to all for DPGS from Wide Area Augmentation Satellites (WAAS), this reduced our error of accuracy from 3.3m to 2.5m

Timeline for project completion



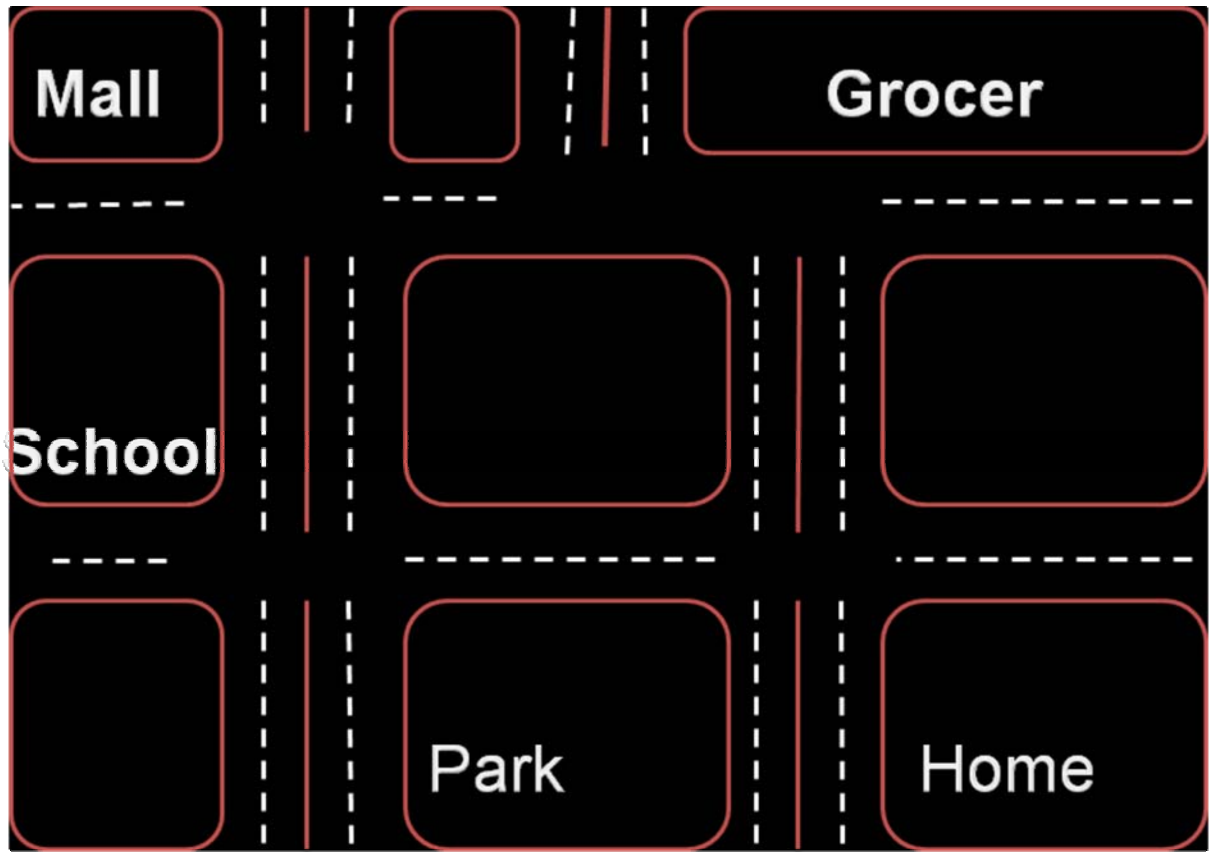
Budget

No	Item	Qty	Unit Price	Total Price
1	SANAV FV-M8 (EB-85A) 5Hz GPS Engine Module	1	$81.95	$86.06
2	GPS-08334 GPS Evaluation Board	1	$39.95	$46.90
3	Coin Cell Battery - 12mm	3	$1.95	4.85

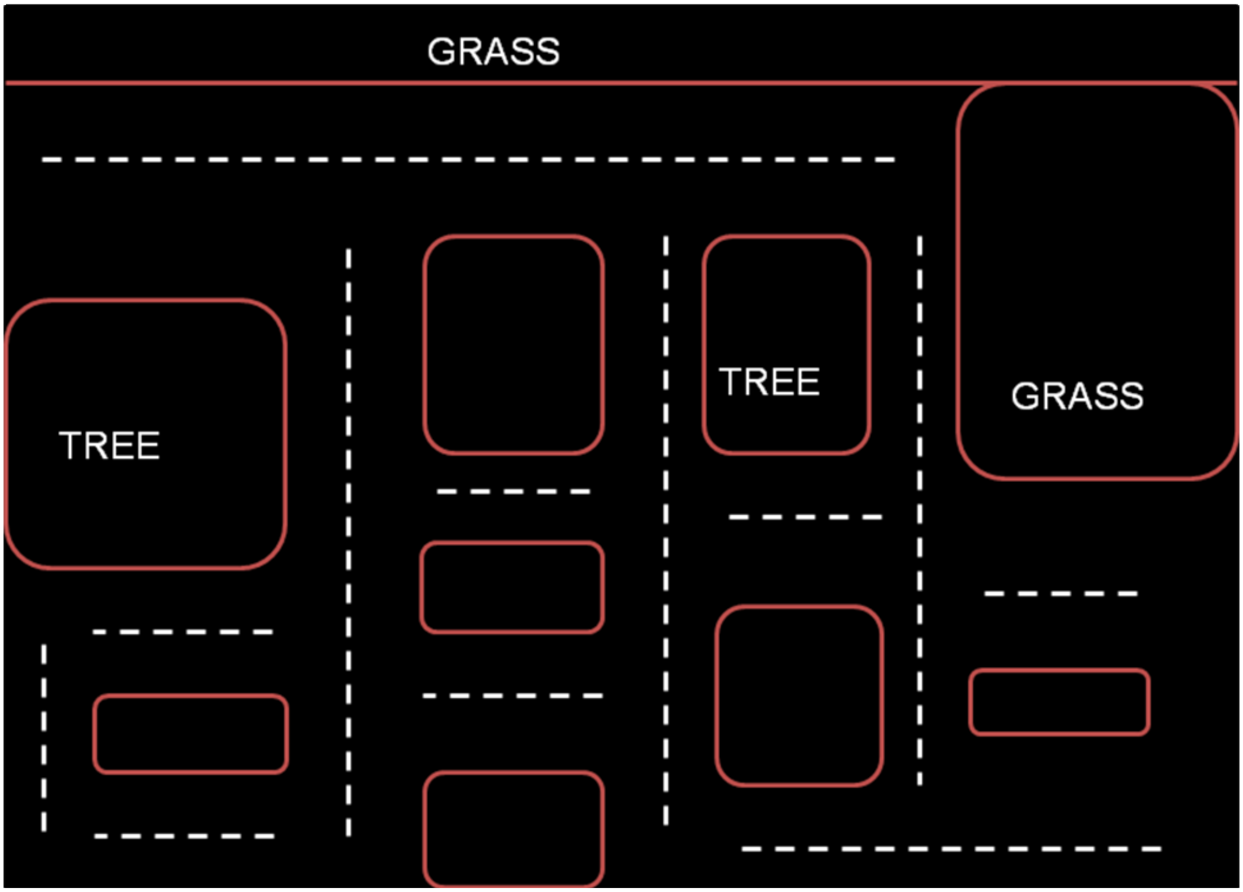
7. Performance Analysis and Evaluation

Evaluation Plan

The project was tested against the initial design requirements to ensure accurate functionality. Two maps were created based on the two algorithms to test the vehicle's accuracy and. The first test was based on the map with pre-determined routes. A map was created with specific destinations and routes to each destination.



A second map was also used to evaluate the system running the A-star route planning algorithm.



Our project was tested in an open area. The results were measured against the initial design requirements.

- *Calculate a route within 1 minute of input and automatically drive the route to a destination determined by the user*

Result: The system was able to calculate an optimal route within 15 seconds of destination input

- *Stop at said destination without any user input after the initial destination determination within 5% error margin*

Result: Based on the map distance, the vehicle was able to arrive at the precise destination. Initial tests with the GPS system showed greater errors due to the small scale of the prototype. As a result the GPS system was used as a secondary system for finding location, while the internal map memory was employed as the primary means of determining position.

- *Alert the user by way of sound or signal upon arrival at said destination within 10 seconds of arrival*

Result: Upon arrival at the intended destination, the user is notified within 2 seconds by a notice displayed on the user interface.

- *Allow the user to abort on-going destination navigation within 1 minute of notification*

Result: The user was also able to terminate the on-going destination within 5 seconds if need be.

- *The user may be allowed to change their desired destination during the on-going navigation within 10 seconds of notification*

Result: The user was able to redirect the vehicle after arriving at its previous destination. The use of the GPS system would have allowed the vehicle to

- *Automatically calculate and return to their departure location*

Result: The vehicle was able to automatically calculate an optimal route and drive to that location when the desired destination was entered by the user, therefore it could navigate automatically to its departure location if prompted

- *The IEEE 802.11 standard for information technology, telecommunications and information exchange between systems (local and metropolitan area networks); The FCC standard CFR 47* *part 15 in regards to unlicensed transmission IEC 61108-1 Standard for Global positioning system (GPS) Receiver equipment*

Result: The specifications of all components of the prototype adhered to the relevant IEEE and FCC standards.

8. Conclusion

The project was successful in developing a system which allows a vehicle to autonomously navigate from one point to a determined destination. At the end of the 8 month period, the team intends to deliver a scaled prototype reflecting the full functionality of the design. The project initially intended to utilize the GPS tracking system with an external processor to obtain location coordinates which the vehicle will follow. However, latency problems were encountered when the processor was used and so the GPS system was connected directly to the vehicle. In order to navigate the route, A-star algorithm was implemented. In executing the project a timeline will be adhered to for completing the various phases of design proposal and approval, simulation and testing, building and assembly, and final testing The system was tested against the design requirements and constraints and the performance measures were met. Facilities which were utilized include the Mobile Studio Lab, FPGA boards, as well as other testing equipment in the Electrical Engineering Lab. The total design and implementation of the project cost approximately $500. The project was sponsored by Chrysler and a company employee served as a mentor to the team for the duration of the project.

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9. Recommendations

- Implementation of lane departure warning system to enable vehicle remain within lane. It was observed that the vehicle drifted across lanes when driving over a long distance. As such a lane departure warning system would be effective in enabling the vehicle correct its direction so that it remains within its lane en-route the intended destination.

- Addition of obstacle detection system to enable vehicle operate outside controlled environment. In this project, it was assumed that the vehicle would operate in a controlled environment with the absence of moving objects. However, for the system to function in the real world, it would have to be equipped with an obstacle detection system so that moving objects can be detected and avoided.

- Addition of Assisted GPS system to ensure better location accuracy. Using an Assisted GPS system would enable better accuracy for the vehicle as it would not always be dependent on satellites in orbit but would also be able to locate itself using ground stations. This would eliminate the error which resulted from loss of GPS signals from the satellite.

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11. Attachment:
a. Final Design Requirement Form
b. Source Code Listing
c. Resumes of all team members