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A Low-Cost Implementation of Vehicular Platooning Using PIC Microcontroller and Diversified Sensors

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Abstract

Collision avoidance systems have been developed and implemented in diverse ways. A result of collision avoidance technology is the development of a capability known as platooning. Platooning is the idea that one vehicle tracks and follows the movements of another. A major consideration in the implementation of platooning is the cost. In this project, a low-cost, but efficient implementation of a platooning system is designed and implemented using PIC18 microcontroller and various sensor technologies. Results from previous studies show that multiple types of sensors are far superior to using a single sensor in both the reliability and the cost. Therefore, ultrasonic sensors, IR, and RF sensors work independently in tracking the turns and distance, and then compete with each other to reach more accurate driving decisions. Low-cost PIC microcontrollers are selected as the major computing units. The experiments were performed on two microcontroller cars in a controlled laboratory environment. This low-cost implementation of vehicle platooning can make the future of platooning vehicles on the highway more efficient and cost-effective. Also, the simplicity and ease of installation makes this system a good candidate for use in factories or other applications where it is beneficial for one machine to follow another.

Introduction

In today's society, the use of technology to make life easier for humans is a very popular concept. One of the things that people feel is a waste of time is sitting in the car, especially in traffic or when waiting for red lights. Consequently, people use their time in the car to eat breakfast, put on their make-up, and talk on the phone. These distractions create an unsafe driving environment. An additional concern is the increase in traffic jams and air pollution. Out of these concerns, the concept of vehicular platooning arose. Vehicular platooning is the idea that one car follows another car. This allows the "driver" of the second car to be completely free of the need to focus on his driving.

The idea that platoons will make a safer driving environment extends all the way to the European Commission. They decided to fund the SATRE (Safe Road Trains for the Environment); "Systems will be developed in prototype form that will facilitate the safe adoption of road trains on un-modified public highways with full interaction with non-platoon vehicles"[12]. This project was completed in September of 2012, but included numerous high-cost materials. In fact, almost every implementation of platooning involves expensive equipment, which makes its wide-spread implementation limited and unlikely.

However, a simplified version of vehicular platooning can be created using just a few simple sensors and a PIC microcontroller. In this way, it becomes a more cost-effective project that can be used in applications like mobile robot platoons in factories, parades, and other small-scale systems. Also, with a few adjustments, like better sensors, the use of the PIC microcontroller to synthesize the data can still be used to lower the cost of production.

One complaint and argument against the use of a PIC microcontroller for vehicular platooning is the limited memory and speed needed for computations. However, the PIC microcontroller is more robust than is first expected, and is more than capable of producing a platooning system.

Literature Review

A considerable amount of research has been done in the area of collision avoidance systems and vehicular platooning. A big part of vehicular platooning is avoiding a collision if the lead car stops. Basically, half of the challenge of vehicular platooning is rooted in collision avoidance systems. Collision avoidance is a highly researched topic. The major issues that arise when discussing collision avoidance systems is being able to detect how close the follow car can chase the lead car without getting into a crisis situation. Unfortunately, the line between being a safe distance, and being too far away for effective vehicular platooning is fuzzy. Therefore, various collision avoidance algorithms that match specific applications and situations have been developed. One of those algorithms by a group from MIT discusses avoiding collisions in an environment of a roundabout or merging on the freeway[1]. Their set-up uses intra-vehicular communication, which means that the two vehicles communicate with each other about their relative positions and both respond to the movements of the other to avoid collision. They use set theory to make decisions based upon the likelihood of a collision. This is one method in a large subset of intra-vehicular communication in collision avoidance and platooning.

Mazda[2], Honda[3], Berekley[4], and NHTSA[5] have all developed algorithms that calculate the last possible second to brake without collision and implement it at that time. The Berkeley and NHTSA algorithms provide visual warnings when the driver should implement braking before overriding and breaking by itself. Zhang, Antonsson, and Grote[5] developed their own algorithm that is non-linear, since danger of collision is also non-linear. They used a measure they defined, which they called the time-to-last-second-breaking to determine when the car should brake in spite of driver decisions. It quantifiably makes decisions in the dynamic situation, and responds accordingly. This dynamic response is exactly what we are looking for in a platooning situation.

A second concern in platooning is the type and use of sensors. An article by Amditis et. Al[7] discusses sensor fusion and the importance of using more than one type of sensor. It talks about how visual sensors (like IR and cameras) are sensitive to the environment and can easily become not useful. Electromagnetic sensors work well in many environments, but their cost is relatively high. Ultrasonic sensors have good resolution, but only work for shorter distances. They propose that the best option for a holistic approach to various environments is a fusion of multiple types of sensors. A team from California Polytechnic University[8] came to a similar conclusion as they used magneto-resistive, ultrasonic, and radar sensors in their low-cost collision avoidance system for trucks. A type of sensor that is often used alone not in sensor fusion is that of 3D-LIDAR[9]. With LIDAR, it is possible to generate a 3D map of the area in front of the sensor. This makes it a good candidate for collision avoidance and platooning. LIDAR can accurately and quickly map an area and can detect changes.

Implementations of platooning itself have been completed in a variety of ways. Almost every type includes multiple sensors, which requires a significant amount of computations. A group from UC Berkeley[10] designed a platooning system using sensor fusion, intra-vehicular communication, and roadside sensors. They did not test their data, rather just developed a model to be used in the future. They included the issue of having multiple platoons on the road, and how to communicate with them. Basically, one car would read in its sensor data, and combine that with the data being communicated to it by the other cars and the other platoons and then it would respond accordingly.

Another implementation of platooning was developed by a group from the Universiti Kebangsaan Malaysia[11]. This implementation uses active RFID, infrared sensors, and a CMOS camera in order to detect the necessary information. It uses an on-board computer to process the images, and a PIC microcontroller to process the rest of the data. The RFID is used to communicate that a platoon would like to be formed, and then once formed; the cars rely on the infrared sensors and the CMOS camera in order to follow correctly. The data collected by the sensors is also sent to the front car.

Another implementation of platooning is that which was developed by the SARTRE project as explained above[11]. This project resulted in a working prototype that worked with multiple vehicles that all communicated together and back to the head car. It also worked fine with cars nearby moving vehicles that were not members of the platoon. To do this, they extended the camera, laser, and radar technology that was already in the Volvo's back-up camera, blind-spot detectors, and cruise control. Adding a touch-screen HMI and prototype vehicle communication, the project was tested and it worked as expected.

A final example of platooning involves a project that was created for one tractor to follow another tractor given a certain offset[12]. This project considered objects as well as turning at the end of the field. It used RTK GPS and curve-fitting systems in order to have the tractors drive appropriately. They did not employ any other sensors than the computers, modems, and GPS system. The application was significantly different than the others, but it follows the same basic principle of having one vehicle respond to the actions of another vehicle.

While the algorithms explained above provide a very holistic and accurate avoidance of collisions, they all have the same drawbacks: complicated algorithms that were used are not efficient for simple and small platoon systems. Also, the high cost of implementation makes it not available to some budget-restricted applications.

Implementations

This simple implementation of vehicular platooning was done using two of SparkFun's Magicians Chassis. These chassis come complete with two working DC motors. Therefore, implementation was accomplished by adding Toshiba's TB6612FNG Dual Motor Driver on Pololu's development board. The motor driver was pulsed using two PWM Modules on a

PIC18F45K22 microcontroller. The DC level input pins required for forward, reverse, and stop motion are also driven by the PIC. This PIC controller is also responsible for the entire sensor reading, computations, and decision-making in this platooning scenario. The lead car is driven using a SaberTooth controller and a RC remote.

Sensors

The sensors employed in a platooning scenario are important. Because of the studies outlined above, multiple types of sensors are adopted in this project. Using a fusion of diverse types of sensors provides a more reliable approach to platooning. However, as noted above, using multiple types of sensors usually calls for large amounts of computations. Because of this, almost every type of system shown below is using a computer to process the data[7, 8, 11]. LIDAR sensors, while accurate, are very expensive (a couple thousand dollars for middle-of-the-road quality) and require a large amount of processing. Because part of the purpose of this project is to keep the cost low, three low-cost sensors IR, RF and ultrasonic sensor are used, with the data processed by a PIC Microcontroller. This means that our cost is greatly reduced. A computer itself costs more than this entire system.

This system works by having the transmitters of each type mounted on the back of the lead vehicle, allowing the driver of the lead vehicle to have the ability to "turn off" platooning. In this way, it is up to the lead car to decide if platooning is allowed. These transmitters had to be both conditioned as well as mounted on the vehicle. Below is a diagram of the layout of the lead car and the follow car, as well as a diagram describing the circuits.

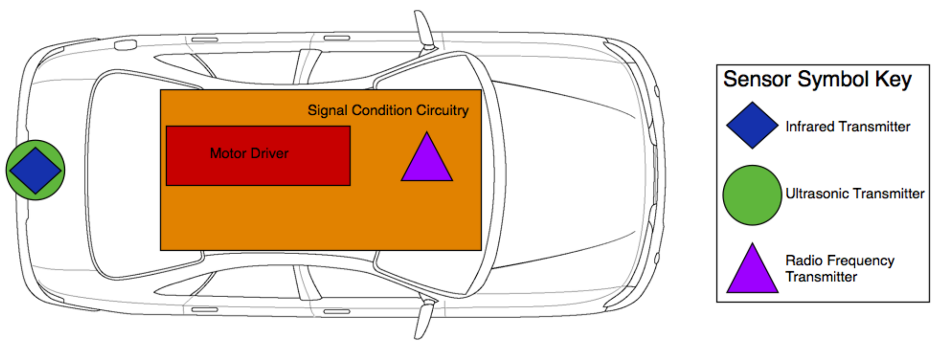

Figure 1. Lead Car Layout

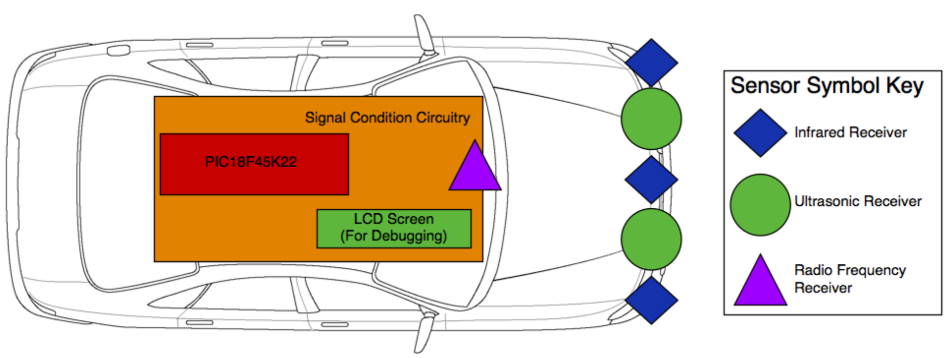

Figure 2. Follow Car Layout

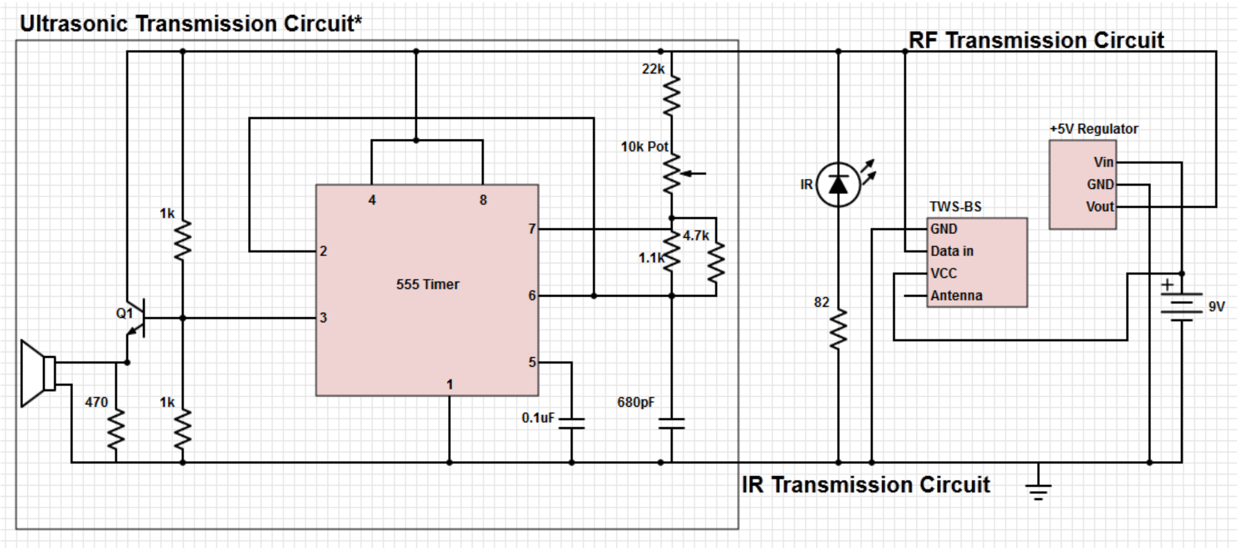

Figure 3. Signal Transmission Circuits (*Ultrasonic adapted from reference 14)

The ultrasonic transmitter is driven by a basic 555 timer circuit that is biased for a 40kHz signal. The potentiometer is present in order to tune the circuit to obtain a perfect 40kHz signal. The IR signal is transmitted with a simple IR LED biased with a resistor. The RF signal is transmitted using SparkFun's 434MHz RF Link Transmitter.

The receiver sensors are mounted on the front of the follow car. There is only one transmitter for multiple receivers. This means that the follow car can triangulate its position based upon the strength of the relative signal it is receiving. Also, if multiple sensors are obtaining a signal that is too strong, the car knows to slow down. If it is receiving a signal that is too weak, it knows to speed up. These sensors had to be configured in order to achieve maximum sensitivity. The following figures show the layout of the follow car, as well as the various signal conditioning components.

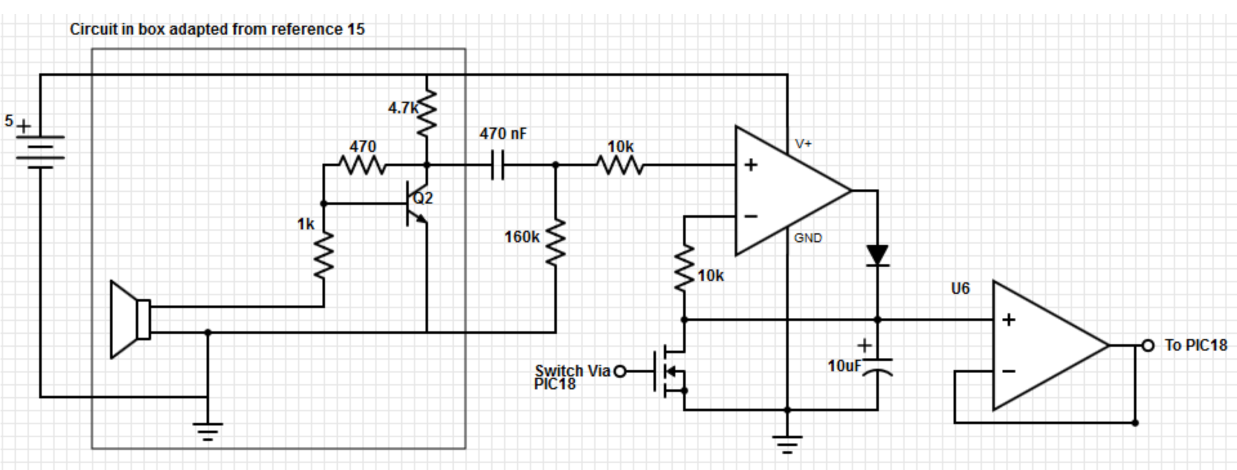

Figure 4-1. Ultrasonic Sensor Signal Conditioning Circuit

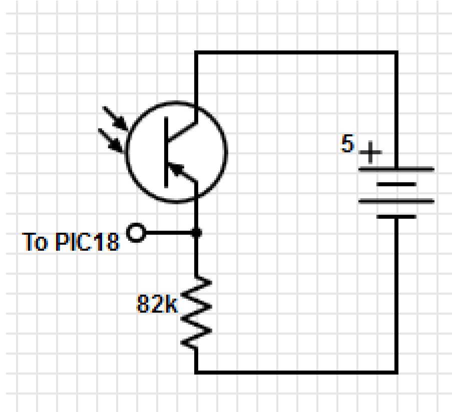

Figure 4-2   IR Sensor Signal Conditioning Circuit

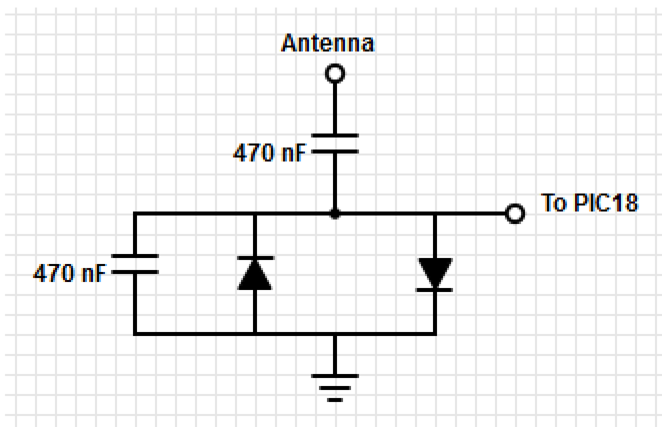

Figure 4-3 RF Sensor Signal Conditioning Circuit[16]

The ultrasonic receivers pass the received signal through a BJT common-emitter amplifier, which then passes it through a low-pass filter to remove the DC offset. Then, the signal travels through a peak detection circuit. This peak detection circuit's switch is a MOSFET, which is pulsed high by the microcontroller after the analog-to-digital conversion is complete. This causes the capacitor to drain and the peak detection circuit to begin again. The RF receiver is simply two germanium diodes, and a capacitor. Because the antenna is not tuned to any specific frequency, it was important to make sure that the antenna length corresponded to a quarter wavelength of the transmitted frequency. Since the transmitter was transmitting a 434 mHz signal, the antenna wires were cut to 6.8 inches.

The sensors were placed based on an attempt to find the maximum range between the sensors at any given point that they are apart. This means that the IR sensors are placed as far apart as possible. Because there are three sensors, priority of placement was given to them. For the ultrasonic sensors, maximum spacing between the two was also important, but they remain slightly inside of the IR sensors. The RF sensor is mounted on top of the car causing it to be able to receive better data.

The final layout of the car, including component location, can be seen in the following images. In the images, there are two layers of circuitry. The bottom layer contains the majority of signal receiving and conditioning. This data is then passed to the top panel where the microcontroller and motor controller are located. The exception to this rule is the RF transmitter and detector circuit, both of which are on the top panel. The robots are each powered by two 9V batteries.

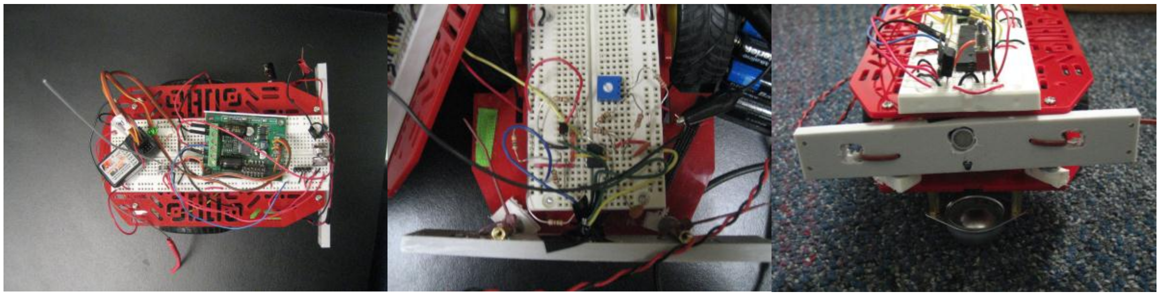

Image 1-1. Lead Car’s Top Panel, Bottom Panel, and Sensor Panel

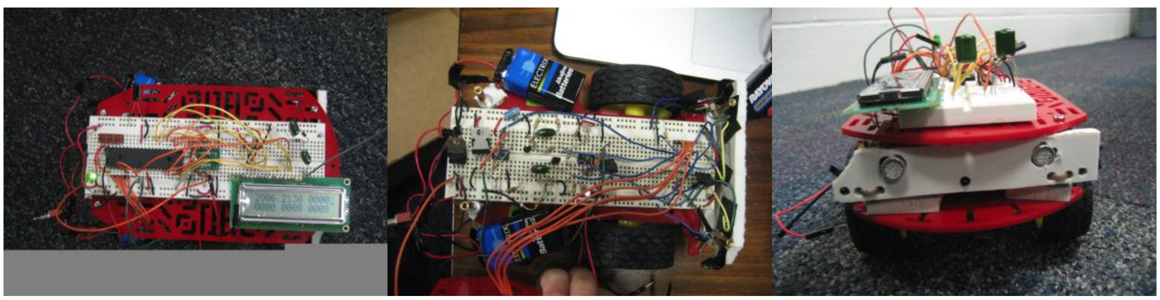

Image 2. Follow Car’s Top Panel, Bottom Panel, and Sensor Panel

Analysis

The various sensor data is then analyzed based upon its effective values. Tests in the lab produce information as to the different sensitivity levels of the sensors. Since the sensor system is responding with a DC voltage that varies based on signal strength, the following plots show distance versus the sensor sensitivity in volts. Due to the oversensitivity in the current configuration of RF sensor, data is given in two forms: one of the distance between the two cars, one in the distance between the two sensors. Both are shown on the same plot.

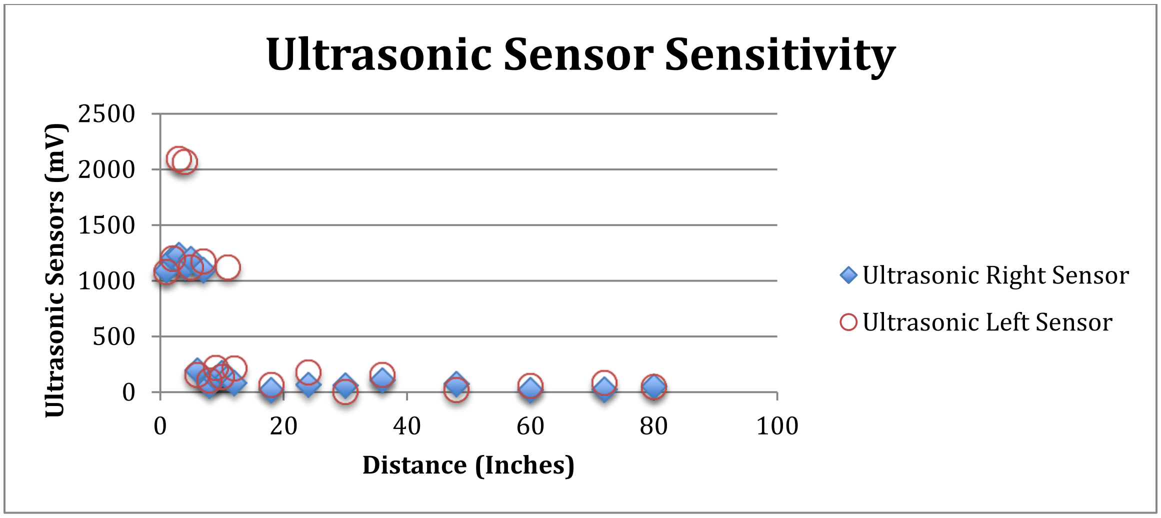

Figure 5-1 Ultrasonic Sensitivity

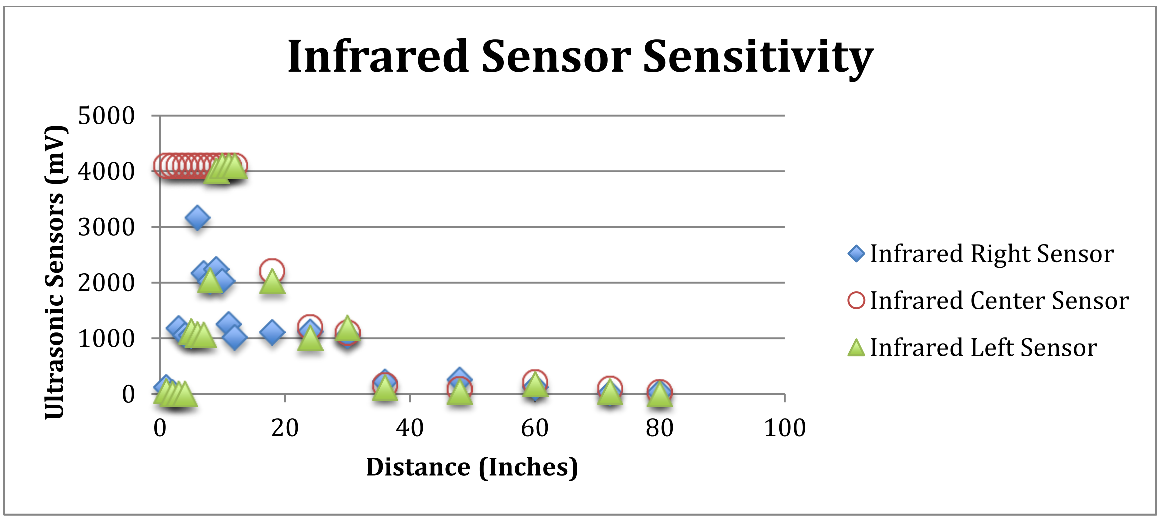

Figure 5-2 Infrared Sensitivity

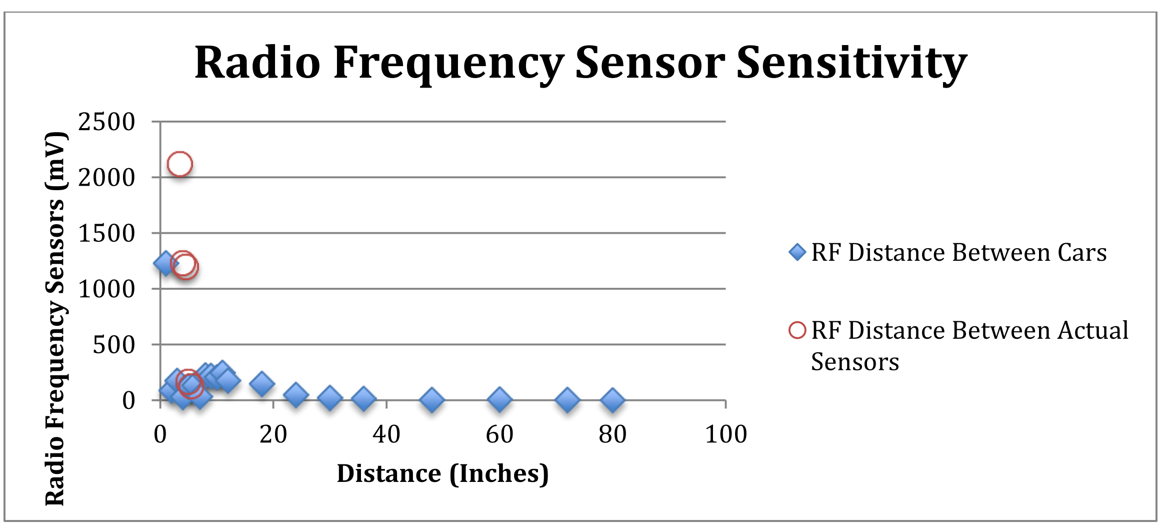

Figure 5-3 Radio Frequency Sensitivity

From this data, a determination regarding the effectiveness of the sensors at a given distance is possible. This allows for ranges to be set regarding the validity and strength of the signals for use in the decision-making algorithm. Based on these numbers, the decision was made to use ultrasonic at short range, IR at medium range, and RF at long range. The reason for the selection of RF at long range is the fact that there is little or no noise in the RF signal in the lab setting. This means that it is more reliable at long distances. Also, it is difficult and somewhat impossible to triangulate with an RF signal; therefore, only one RF receiver is used. This means it will be ineffective as anything other than a beacon from long distances.

Interestingly enough, the magnitude of the sensors produces data that is not linearly related to their distance away. Below is a plot that shows the magnitude of the combination of all IR and ultrasonic sensors. These magnitudes were found by taking the square root of the squares.

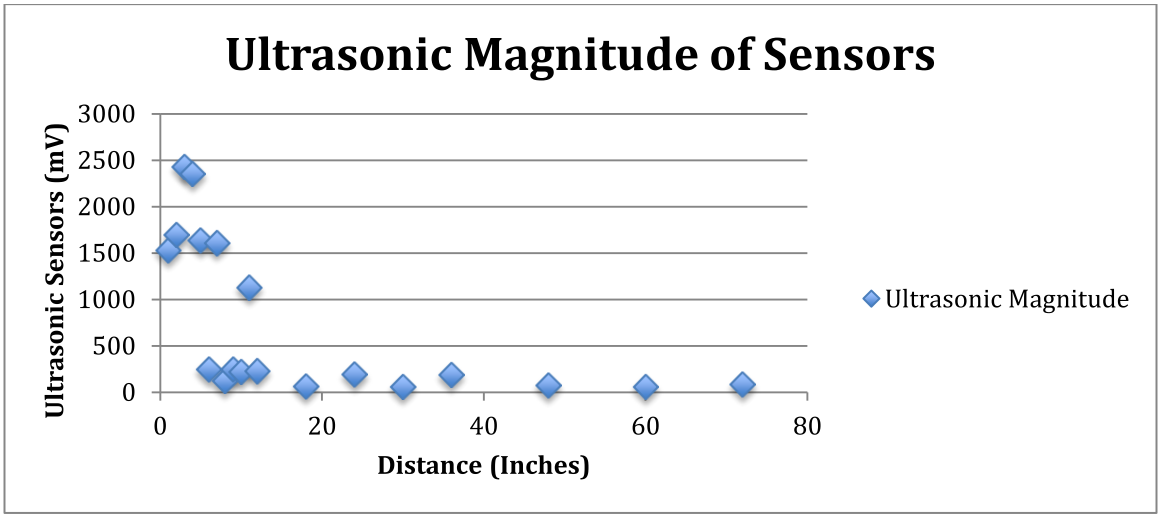

Figure 6-1. Ultrasonic Magnitude Sensitivity

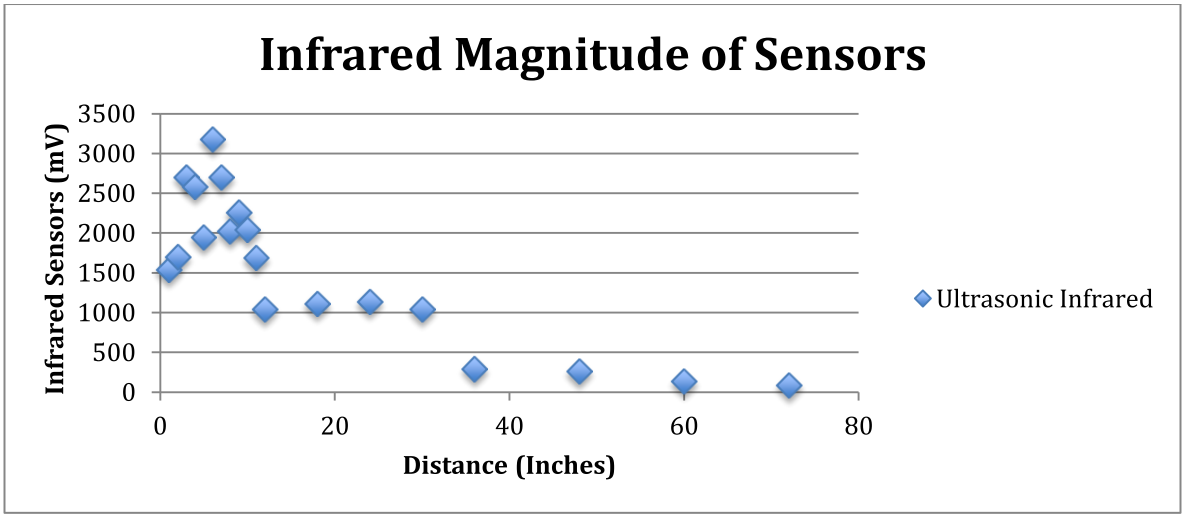

Figure 6-2. Infrared Magnitude Sensitivity

The algorithm is basing its decisions on the magnitude of the sensor values. Because the sensors peak and then decrease, it is important to pick the range that the car will remain in an area that will cause minimal sensor distortion. In order to do this, a horizontal line was drawn through each graph. This allowed for both sides of the peak to be taken into consideration. Two lines were drawn on each graph to represent the three levels that the sensor values could end up in. The first line for ultrasonic was drawn at around 2300mV. So, if the sensors are reading in a value whose magnitude is over about 2300mV, the system responds by stopping immediately. If the data is in between approximately 2300mV and the second level of near 1600mV, the car should respond by slowing down. Finally, if the data is less than approximately 1600mV, the car should increase its speed. Taking values when the transmission circuits were turned off allowed the establishment of a “data valid” category as well. If the ultrasonic sensor value is less than about 250mV, it is considered invalid and is not used.

The infrared sensor data is handled in almost the exact same way. For IR, valid data was considered anything above about 30mV. The stop level is set at any magnitude of IR values that are in the range of 2700mV. Then, if the magnitude is valid and below the stop level, it will slow down. It will continue to be in the slow-down zone until it drops below a value near 2000mV. Here the car will speed up.

For the RF data, the only threshold set is to speed up if the voltage is lower than about 100mV, and slow down if it is greater than around 100mV. This is because in its current configuration, the RF signal is not strong enough to provide greater accuracy, especially at close range. Therefore, the RF sensors are used only if the other two can’t be found. After driving toward the lead car, the IR and ultrasonic sensors should become in the valid level and take over for the RF sensors.

A similar procedure was done to find and analyze the turn data. First, using the data in the plots above, the difference between each sensor when the car is in straight-line motion is calculated and plotted. This allows for the creation of a baseline value of which the definition for a turn value can be found.

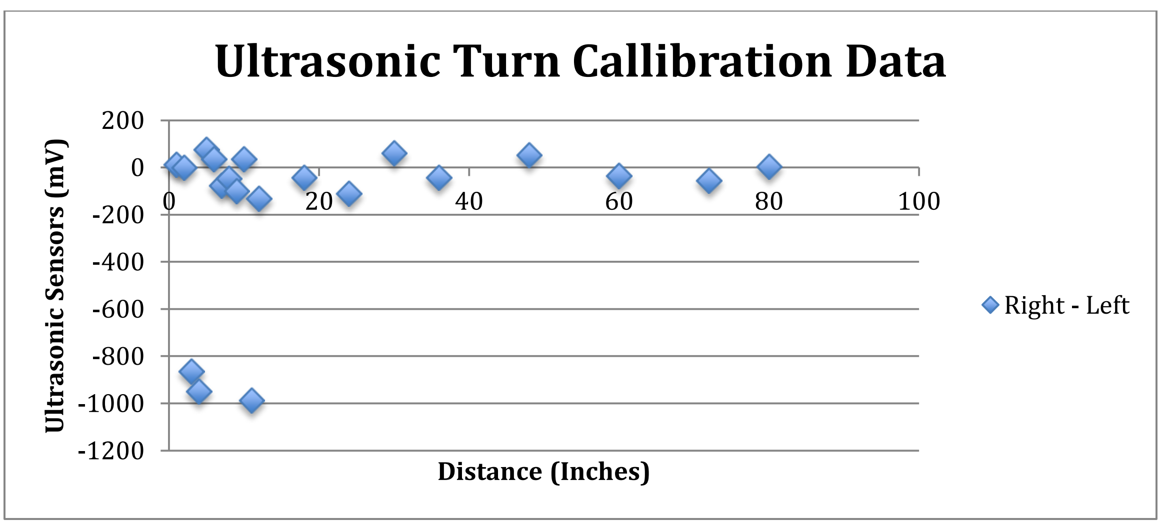

Figure 7-1. Ultrasonic Turn Calibration Data

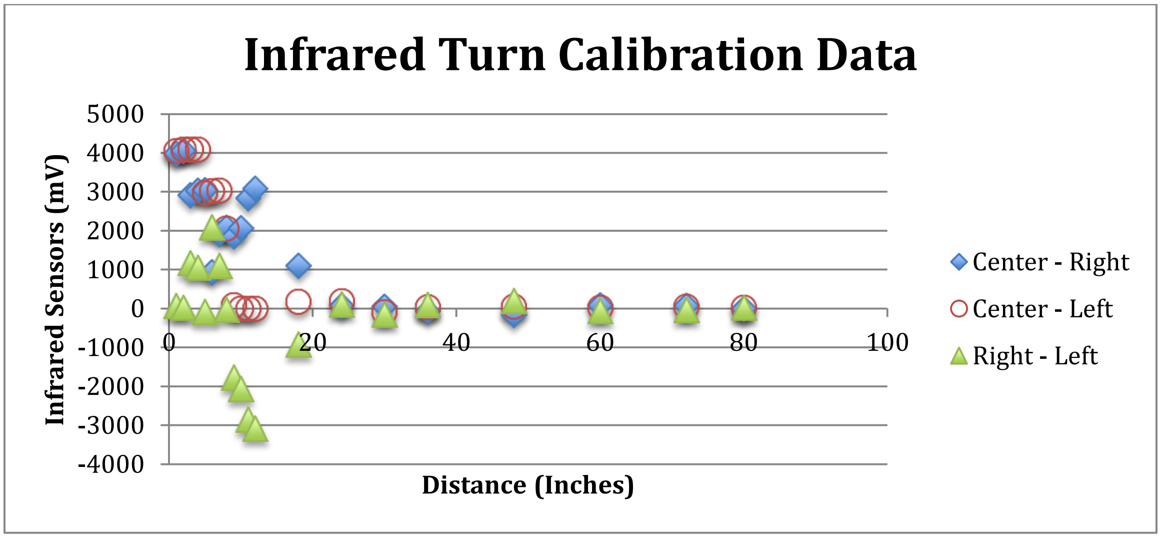

Figure 7-2. Infrared Turn Calibration Data

The car keeps track of the amount of change between the two sensors as an unsigned character. Then, if the difference is big enough, it finds out of the left or the right sensor value is greater, then responds accordingly. At this time, the center IR sensor is not being used to calculate the turns. If the ultrasonic difference is greater than about 250mV, or the infrared difference is greater than around 1000mV in either direction, a turn sequence is started. This turn sequence causes one motor to decrease, and the other increase for four instruction cycles of the PIC. Then, the values return to their previous speeds, and the loop starts over.

Due to the nature of the PIC microcontroller's A/D, the values given above are approximate. When the PIC displays the voltages on the LCD, they are truncated and rounded in order to provide a visible value. However, the PIC's 10 bit A/D converter provides more resolution. Therefore, when programming, the debug feature on the PIC will be useful. The data levels are set based upon the more specific A/D conversion results.

Algorithm

In this project a simple algorithm is used to keep the leading car and following car within an acceptable distance range. The sensor data is read in and processed. Then, both the magnitude and the difference between the sensors are calculated. If the sensor data falls within the valid range, the program proceeds to analyze it. It uses the values outlined above in the sensor discussion in order to base its decisions. To find the necessary sensor value, a debugger was implemented and the maximum of 10 values was used as the zone line. This allowed for more precision than the signal that is outputted on the LCD.

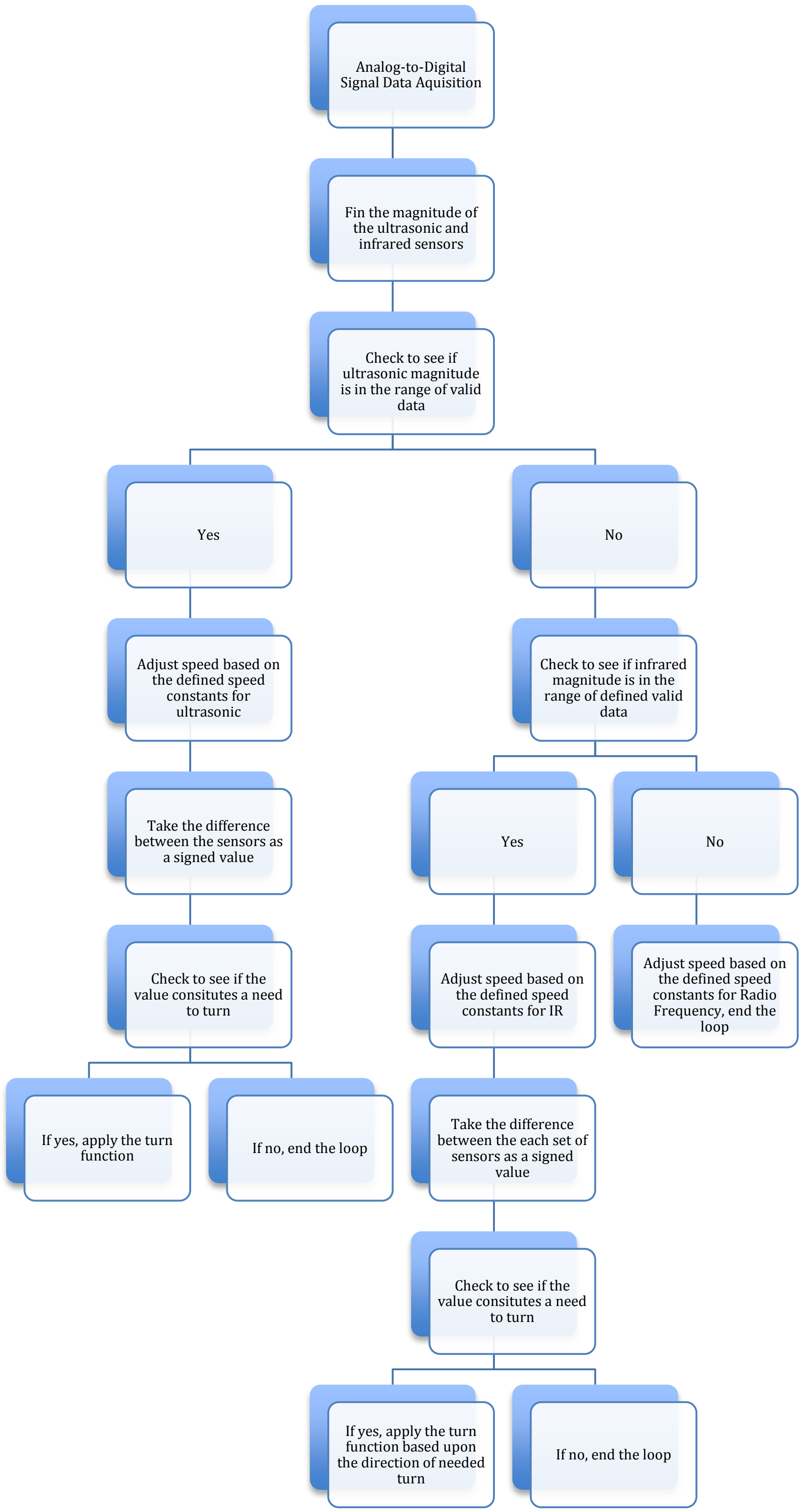

Figure 8. Algorithm Flow Chart

Results

Using this configuration, the follow car can successfully follow the lead car in a laboratory environment. The follow car was able to track and correct, or angle offsets of up to 45 degrees. Also, the follow car is capable of stopping at a safe distance when the lead car is stationary.

Because the purpose of this project was to create a low-cost vehicular platooning system, the vehicles not only needed to be able to complete the task, but also do it with minimal cost. The following is a list of parts used in the data transmission and acquisition circuits, as well as the decision-making circuits. The parts that constitute the actual vehicle, motors, motor driver, etc. are not included in this list.

Part Titles and Numbers		Quantity	Cost per Unit	Cost
Item	Part number			
Microcontroller	PIC18F45K22	1	$3.05	$3.05
555 Timer	LM555	1	$1.99	$1.99
Op Amp	LM1458	2	$4.00	$8.00
Transistor	2N2222A	3	$0.10	$0.30
Ultrasonic Transmitter	40T-10AW	1	$3.98	$3.98
Ultrasonic Reciever	40R-10AW	2	$3.98	$7.95
IR Transmitter	Everlight IR333-A	1	$0.17	$0.17
IR Reciever	Lite-On LTR-4206E	3	$0.13	$0.39
RF Transmitter	TWS-BS-3	1	$3.95	$3.95
Germanium Diodes	IN34A	2	$1.50	$3.00
Diodes	1N4001	2	$0.14	$0.28
Resistors	Various Resistors	25	$0.10	$2.50
Capacitors	Various Ceramic	5	$0.10	$0.50
Capacitors	Various Electrolytic	2	$0.10	$0.20
		Approximate Total Cost:		$36.25

Note: These are approximate costs. Exact values are similar, but may not be exact

Figure 9. Cost of Building

From the above list, it can be seen that the total cost of this modular vehicular platooning system is significantly less than a computer, not to mention the expensive sensors needed in most platooning systems. However, it can also be seen that the data processing in our algorithm is relatively simple. If a more robust design is required, better sensors and more data processing would be necessary. It should also be noted that in our implementation, we did not use all of the memory in the PIC. Below is an image of the memory usage gauge of this program, showing that it still has processing room for improvement. It also shows that the PIC microcontroller does contain the processing speed and space necessary to be used in a vehicular platooning system.

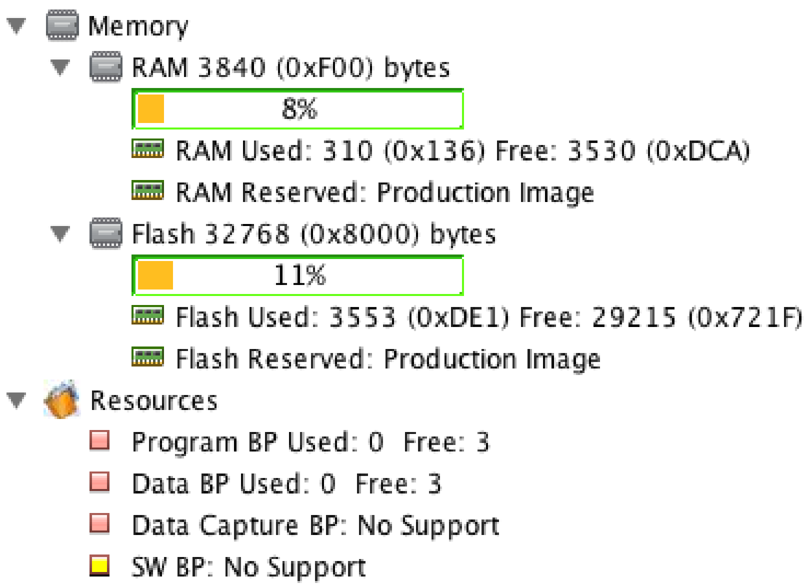

Figure 10. Memory Usage Gauge

Conclusion

Given the simplistic nature of this project, it worked as expected. Improvements can be made to the system to allow greater reliability and flexibility. First, because IR sensors can experience large amounts of noise outside, pulsing them at a given frequency, and then using a high-pass filter on the receiver side can cause only the desired signal to be received. Further, the RF receiver circuit can be improved for a clean, long distance signal. Another practical improvement that can be made is the use of intravehicular communication. If the lead car communicated data, like speed and direction, it can be as useful as the sensors.

After additional testing and small improvements, this project still retains the applications of any type of vehicular platooning. That is, it can be used in cars, parades, or in factories. Its modular nature makes it possible to quickly attach and remove from vehicles. This makes it easily implemented in temporary situations. Also, it remains low-cost which makes it preferable for applications in which cost is a deciding factor. The extra room in the PIC memory also allows for greater improvement in algorithm and sensors.

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Biographical Information

Growing up in Santa Barbara, CA, my homeschooled education provided me with the flexibility to pursue the topics that interested me. I spent hours reading and researching whatever caught my interest. I also loved team sports, of which soccer and outrigger canoeing were favorites. Upon high school graduation, I opted to move far from home in order to attend Cedarville University. Because of my wide variety of interests, I explored various academic disciplines before I chose a major. Looking for a challenge, I decided to try some engineering classes. It didn't take long for me to declare electrical engineering as my primary course of study. Over the past few years, I have been part of Cedarville University's robotics team, which competes in an event sponsored by ASEE, as well as the Supermileage team that competes in the Shell Eco-marathon. Through my numerous class projects, competition teams, and internships, I have become certain that I will enjoy my future career in the field of electrical engineering.