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B.R.A.V.O.

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Table of Contents

Appendix B

1. Executive Summary

B.R.A.V.O. or "Bringing Reliability to Autonomous Vehicle Operation" is a fully autonomous vehicle that incorporates the use of an onboard image processing unit, onboard sensors to navigate a predetermined course, the ability to navigate alternate routes involving 90 degree turns and stop signs, detect potential collisions, and obeyed the basic "rules of the road." In an era where technology is increasing at an exponential rate, the conveniences provided by technology have also increased. From smart phones to navigation systems, technology has provided innumerable ways of reducing stress while improving safety in many aspects of everyday life. One specific aspect of everyday life that combines both large amounts of stress and safety concerns is the seemingly simple task of driving an automobile. According to the National Highway Traffic Safety Administration, over 840,000 injuries occur each year due to traffic accidents, a number which doesn't account for the total number of traffic accidents. This is an obvious area that technology has a potentially much larger role. If a vehicle were able to have the ability of self-navigation as well as collision detection capabilities, it would be safe to assume that the roads would become much safer. Computers do not panic, computers do not talk on their cell phones while driving, and computers do not drive while intoxicated. Computers lack the ability to be easily distracted as humans often are, making a self-driving or autonomous vehicle, ideal for today's roadways.

Because integrating this particular project into an actual vehicle would have been extremely costly as well as dangerous, the project focused on a smaller, less expensive platform that resembled an RC-type hobby car. This approach allowed the group to demonstrate a unique interpretation of an autonomous vehicle and provided the group with unique experience in designing, building, and testing an autonomous vehicle. The smaller scale of the vehicle also enabled the integration of B.R.A.V.O. into other technology fields that might require smaller and agile vehicles to accomplish a task such as search and rescue robots. The autonomous vehicle platform ultimately consisted of a hobby car chassis mounted with the necessary hardware that enabled the vehicle to accomplish its tasks without any external human influence, which highlighted the potential for this technology when integrated on a smaller scale.

Because the performance of this vehicle depended largely on its ability to process its surroundings through both a camera and a proximity sensor, the project designers found it necessary to incorporate the use of a remote image processing system. The image processing was dedicated to extracting and calculating the data from an onboard camera, sending that data to a remote computer which then processed the data into a relevant signal, and sent that signal to the motor controls. In order to add complexity and diversity to the project, the group chose to experiment with a second vehicle that also incorporated the use of a remote image processing unit that also interacted through a wireless communication system. Both vehicles beautifully exhibited autonomy when completing the challenges it faced and conformed to the requirements set forth by the group.

2. Project Motivation and Goals

As of September 2012, three states have passed legislation permitting the use of "driverless" cars, paving the way for the research and development of a potentially revolutionary technology. There also exists the well known "Google Driverless Car" project currently being developed and tested by Google. As these facts suggest, driverless cars are a rapidly emerging and important technology with the potential to impact the way future generations view automobile transportation. Though much smaller in scale and in scope, the group thought the idea of researching and creating a driverless car was a great opportunity to provide a unique perspective on a driverless car as well as acquire the knowledge of a broad range of engineering techniques that will benefit our individual members moving forward.

As the technology improves and advancements are made in image processing as well as sensor technology, so too will the reliability of driverless cars improve. Traffic jams will be a distant memory and so too will the headaches that accompanied them. Long and tedious trips will no longer involve sitting mindlessly at a wheel and fighting the urge to fall asleep. With driverless cars, driving a car will amount to sitting in a moving vehicle and entertaining yourself while the car navigates a route to take you to your destination. Imagine the thought of being able to sleep on a late night road trip, read a book while driving across town, or even make any last second changes to your appearance without endangering the lives of others.

This technology can also be used in a supporting role alongside the driver. The option for a safe driver to operate his or her own vehicle should always exist, but this technology can be applied in a multitude of ways that can improve the safety of the vehicle and its driver without restricting manual operation. Image sensing technology can be used to determine whether a person is staying safely within their own lane and can consequently help to deter intoxicated operation of a vehicle as well as drivers who are falling asleep at the wheel. Drivers with deficient skills at parallel parking or backing up are already reaping the benefits of cameras within their vehicle, as several cars possess the ability to parallel-park and many new cars possess rear cameras to assist a person in backing up. A camera system can also detect potential collisions within a driver's blind spot. A driverless car or at least a car equipped with an image processing system is a technology that has far reaching potential because it involves an activity that everyone participates in at some point in their lives.

As a senior design project, integration of a driverless system into an actual automobile was an intriguing idea, but the execution was limited by the enormous cost as well as safety concerns for demonstrating such technology. Faced with this reality, the group decided upon a more practical platform which still demonstrated the applicability of a driverless car system, albeit on a much smaller scale. As a group consisting of a computer engineer and three electrical engineers this project was attractive for several reasons: the obvious need for a large amount of image processing and coding, the importance of balancing the need for a consistent power supply against size constraints, the integration of electronic motors, the use of sensors, and the focus on choosing a powerful enough processor to integrate all the various parts of the project. The group felt that this project provided valuable experience in a wide array of topics that will not only broaden the knowledge of each individual engineer, but one which reinforced many of the concepts already encountered as an engineering student.

In order to accomplish these tasks, there were several goals that were absolutely essential to the overall success of the project. Both the hardware and software had specific objectives in mind, but there were several key components with important goals that determined how well the project worked.

2.1 Objectives

2.1.1 Autonomous Navigation

The vehicle would be able to navigate a pre-constructed course with various and diverse routes that would highlight the ability of the vehicle to not only follow a basic path, but to navigate alternate routes with sharp turns, 90 degree turns, and stop signs. Essential goal of the system was to be able to make apt decisions under different circumstances and recover from any potential errors and crashes without human intervention. The vehicle would also be able to sense other vehicles or obstacles in order to avoid any potential collisions while still operating within the “rules of the road.”

2.1.2 Line Tracking

The navigation system of the car would be dependent on data provided by the computer vision, line sensor array and proximity sensors. Key functionality requirement for the vehicle was to be able to track a line and follow it throughout its predetermined path. This function was one of the most crucial factors that requires real time processing capability and sustain precise maneuverability. To accomplish this, the team had considered different options for line tracking and object detection functions.

2.1.3 Sign Detection

The vehicle would need to obey all traffic rules that will be designated by color-coded signs and indicators. These include posted signs on the side of roadway as well as painted signals on the ground. For the purpose of sign detection and recognition the team used an onboard camera with a pattern recognition algorithm. Road signs were replicated by geometric shapes filled with solid colors. Initial idea was to design a text recognition program that would be able to convert human readable text into ASCII characters and utilize them throughout the course of the trip. Dependent upon the group’s knowledge of computer vision, all possible effort was put into practice in order to achieve top results.

2.1.4 Object ranging and Collision Avoidance

The vehicle would need to be able to differentiate physical objects on the road from painted signs, and avoid any collisions in its path. A proximity sensor was employed for detection purposes of nearby objects and vehicles. If an object was detected in vicinity over its threshold, the vehicle was to hold its position until the path was cleared since going around the obstacle would possibly lead the car to lose a visual of the painted lines and result in fatal errors within the navigation software. A proximity sensor also served as a distance ranging unit to maintain a safe distance with vehicles ahead. Minimum safe distance was determined and varied based on the speed the vehicle was traveling. Ideally, a vehicle would be able to react to changes in traffic flow instantly, although this proved much more difficult at sharp turns and intersections due to narrow scanning widths.

Ultimately for the on-board processing that was initially proposed, it was the goal of the group to incorporate only one microcontroller that would handle the task of processing all the required data, controlling the motors, and arbitrating any signal from the the proximity sensors. Because the group decided that a remote processing system was the most appropriate choice, only one microcontroller was chosen along with a robust motor controller system that will be discussed in subsequent pages.

2.1.6 Pre-Determined Routes

Various paths representing a roadway (Figure 2.2.1) were be drawn by white lines, while the starting positions of potential routes were indicated by the blue, red, green and yellow strips. There was a large outer circle with several “off” and “on” ramps that the autonomous vehicle would be able to use to access the inner road system consisting of a four-way stop, varied and challenging routes such as those involving 90 degree turns or where the path was temporarily unknown. The vehicle would finally be able to navigate the route back to the outer circle. The goal of this test track was to not only test the design’s ability to navigate a roadway, but to interact with other cars using a combination of proximity sensors and image processing integrated with a strong artificial intelligence framework. Below is a sample test track that the group used for the prototype. The track was drawn on a hard smooth dark colored surface using a white colored tape to represent the center-line of the roadway.

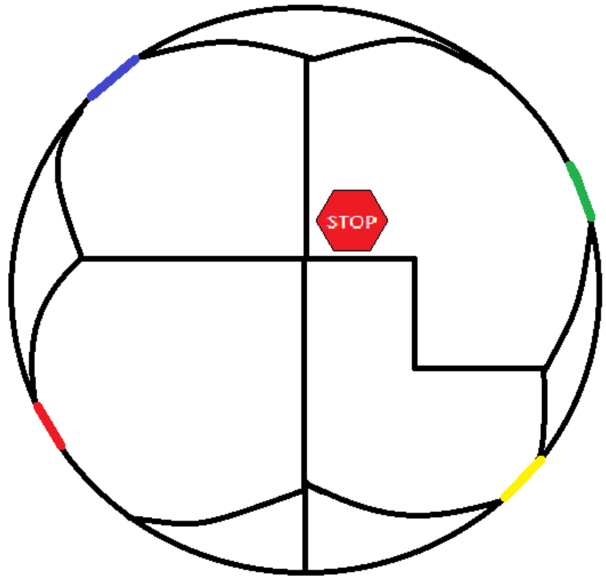


Figure 2.2.1 – Proposed Example Track

The goal of the pre-determined course was to provide a series of challenges that would test each component of the autonomous vehicle such as the image processing system, the proximity sensors, and the ability of the system to react. The course consisted of an outer path similar to that of an interstate bypass that might circle a large city. The outer loop had various “off-ramps” as well as “on-ramps” that were designated by different colors that represented the beginning of multiple and varied paths. The various paths consisted of challenges and obstacles that tested the ability of the autonomous vehicle such as 90 degree turns, stop signs, road obstacles, another car using the roadway, and path discontinuities.

Each particular path provided a unique challenge to the vehicle while each obstacle was designed to test specific aspects of the entire system. The 90 degree turns tested the ability of the image processing system to react to a sudden change in the path while the path discontinuities tested the A.I. software implementation of the system. If the vehicle temporarily lost the path, a routine enabled the car to eventually find the path again. The stop signs also tested the ability of the image processing system, as the system needed to recognize various shapes and colors. The obstacles tested system’s proximity sensors as well as the entire system’s ability to react to sudden changes and to compensate for those changes. The addition of a second car to the course challenged the vehicle to make quick decisions which is why the group chose to include the four-way stop. Though seemingly a simple task, a four-way stop represented a programming challenge that the A.I. of the system would have to account for. The colors representing the various paths also tested the programming of the vehicle and its ability to make decisions without external influence.

Once a path was completed the vehicle navigated back to the outer loop and made a decision on the next route to take. The final goal of this test track was to not only test the design's ability to navigate a roadway, but to interact with other cars using a combination of proximity sensors and image processing integrated with a strong artificial intelligence framework.

2.1.7 Computer Vision

In this project, a computer vision will serve as a vital data processing unit, providing input data to navigation system, contributing to decision making and safety functions. The team needs to ensure that the unit is capable of computing at relatively high rates with good precision and efficiency while possessing enough on-chip memory to reduce the latency in the transmission and calculation of any data. As the project relies so heavily on image processing, one of the primary goals for the hardware is to successfully mount and test a reliable camera atop the vehicle platform. The camera should be small, lightweight, relatively inexpensive, and should possess manageable processing specifications with regards to outgoing image size and communication protocols. Because image processing requires precision, the processor should be sufficiently fast enough to process the large amounts of data while still possessing enough on-chip memory to reduce the latency in the transmission and calculation of any data.

There is also a second vehicle that must manage the course using off-board image processing. To accomplish this goal, the group must be able to create a robust communication system to ensure the rapid transfer of data to the off-board processor which will be processed and sent back to the vehicle. Whether it is off-board or on-board processing, in order for the vehicle to move at a controlled pace and to smoothly navigate any type of turn, the camera needs to clearly capture and relay every image to the processor while the processor needs to be fast enough to evaluate each image and relay the corresponding signals to the motor controls.

2.1.8 Artificial Intelligence

Artificial intelligence software will be responsible to make all navigation decisions and resolve any road conflicts including handling interrupts, deadlocks, perform efficiently, ensure accurate calculations, maintain stable ride of the vehicle and regulate speed. AI needs to be composed of a robust structure and immune to any program crashes and errors, as well as avoid any potential dangers and damage to the system.

2.1.9 Power/Size Constraints

The hardware should also provide a suitable power source that will be able to provide sufficient voltage without being drained too quickly. To ensure this, the group must research and test every component and know its electrical characteristics. Ensuring the power requirements of all the components will allow the system to function within typical parameters which is ideal. All components that require a 3.3 voltage source should receive that amount. Failing to comply with the power constraints of the components in the system will result in the failure of the system. Having a suitable power source is an important goal, but the group must also account for size constraints as well. The group must account for vehicle platform space in every component that is selected which relates to the final goal of this section which is having all of the components including the PCB, servo motor controls, battery source, and camera should all fit onto one vehicle platform.

2.1.10 Peripheral Interfaces

Because there are several interacting peripherals for this project such as the camera, the motor controls, and the proximity sensor, creating a robust protocol through which they can communicate with the processor is an important goal. The camera-microcontroller interface will help to determine the rate at which the images are being received by the processor and consequently account for a portion of any lag in the system. This goal of this interface is to facilitate the rapid and smooth flow of information from the camera to the processor and also that the interface account for any discrepancies between the frequencies of the processor and the camera. For the sensor-microcontroller interface, the goal is to limit the amount of processing time that the interface uses so that the processor is able to focus primarily on image processing. To accommodate this goal, the proximity sensor relies on an interrupt based interface that allows the proximity sensor to communicate with the microcontroller when an object has been detected.

2.2 Project Requirements

2.2.1 Onboard Image Processing

The initial goal for this project was to use an onboard image processor that would perform all data extraction and calculations locally within the system platform. Advantages of this option included prevention of unnecessary time delay that can result in wireless data transmission, as well as lowering error rate and allowing for faster processing and higher throughput. The team was never able to implement the onboard system, and all line detection was performed by a line sensor array.

Had we implemented this technology, a camera would have been used to capture an image frame and save it to an image processing unit. An algorithm within the on-chip memory would then extract a set of coordinates of the centerline and the center of mass of the image frame. Extracted data would have been used to compare the coordinates of the centerline to the center of mass of the image frame which would have been horizontally aligned with the center of mass of the vehicle. If we were to implement this technology in the future for some reason, we would have to consider performance limitations of low level microcontrollers, and would need to implement separate subsystems for AI controls and image processing unit to supply sufficient computing power and memory capacity.

2.2.2 Remote Image Processing

To improve robustness of the vehicle, an alternate back-up system had been be implemented which consists of a remote image processing unit with a wireless data link. In this case, the team eliminated the need of high computing power from the local microcontroller, and instead used a remote PC based computer vision library to perform all image processing functions, simplifying the development process. With reduced complexity, the team faced some disadvantages that come from time delay of wireless data transmission and error correction. Remote Image Processor also performed the function of sign detection. Upon detecting a particular traffic sign designated by colors or shapes image processor notifies the AI with an interrupt signal. The navigation AI takes an appropriate action in response to the interrupt.

2.2.3 Alternate Line Detection Method

Another option for line detection was using a set of simple color sensor, such as a line sensor array, capable of distinguishing a line of certain color brightness from a relatively uniform solid colored background. Using this method, the vehicle was able to detect when it drifted away from the centerline of the path. The team designed a circuit of line scanner array for testing purposes that serves as a backup unit for line detection in case the primary line detector fails. In this case, the objective is to keep the car in motion and within its intended path. A discontinuity of line detection was a possible occurrence in utilization of a camera because there are many factors that affected the quality of an image and caused distortions.

2.2.4 Proximity Sensors

For object detection element, a proximity sensor has been utilized. The team has considered both infrared and ultrasonic sensors. From past experience, the capabilities and accurateness of ultrasonic sensors were found to be far more superior compared to infrared. A major constraint of this component was to be able to sense the obstacle in real time and calculate a precise distance to the object while the vehicle was in motion as well as other moving vehicles. This crucial component has been examined very carefully since it was responsible for avoiding collisions with any surrounding objects, maintaining a safe distance and preventing any damage to the vehicle and other fragile elements on the road.

2.2.5 On board Camera

As an embedded component of image processing unit, an onboard camera was supposed to capture mid-quality image frames with consistent resolution and store it on local memory or send it to a remote PC via wireless link for further processing and data extraction. The team needed to supply sufficient data storage available for a single image frame, since all data processing time is done in real time, therefore, old data will be overwritten with every consecutive image frame. Navigation system should have been based on color coded signs requiring the camera to be capable of distinguishing different colors. For accurate navigation an adequate frame rate needs to be supported. The vehicle had an anticipated speed of 3 kilometers per hour (32 inches per second), less than an average human speed of 5 kmph. Several tests have proven that providing a frame per inch would be sufficient and relatively accurate for a low level real time system. If the vehicle travels at 30 inches per second, providing a frame for every inch would mean 30 frames per second. In the end, due to extreme limitation of available hardware, the development of an on board image processor was abandoned.

2.2.6 Microcontroller

The microcontroller was the “heartbeat” of the entire project and therefore performed specific tasks and performed them in an efficient and timely manner. The MCU was also able to meet certain requirements that allowed the project to succeed. The microcontroller was able to perform the following tasks or possess the following requirements:

- Operated at a sufficient frequency to handle multiple peripherals and allowed the autonomous vehicle to travel at swift pace
- Met all the power and current demands of the motor controls, the camera, and the proximity sensors
- Possessed enough general purpose I/O pins to enable the connection between the various peripherals
- Possessed the capability for pulse width modulation on at least two pins and also generated “high” and “low” digital signals for the motor controls
- Possessed a serial interface for the camera with a relatively large baud rate to ensure quick data transfer
- Provided sufficient on-chip memory for the code as well as run-time variables
- Provided low-power modes for power efficiency
- Provided an external memory controller though the on-chip memory proved to be sufficient
- Provided an analog-to-digital converter for generation of digital signals as well as an digital-to-analog converter
- Provided an analog comparator for analog inputs
- Possessed both an internal and external interrupt controller

- Provided an efficient means of transferring data between the peripherals, the CPU, and memory
- Possessed necessary dimensions for the printed circuit board
- Relatively low cost and sufficient accessibility
- The manufacturer of the MCU provided all the necessary software libraries for all of the peripherals as well as an IDE to configure any written code

Though, there were a wide array of microcontrollers, the group required that the microcontroller range from 8-bit to 32-bit depending on the peripherals that were to be chosen to interface to the MCU. Should two microcontrollers share the same specifications, the deciding factor came down to cost, accessibility, and software/development support. These requirements were not overlooked as it was better to have a weaker MCU that is widely available than a powerful MCU with scarce availability.

2.2.7 RF Communications

The radio frequency communication module performs the function of sending a feedback to the vehicle indicating the detected signs. Theoretical calculations resulted in highest achievable data rate of 30 image frame per second available from RF modules. The sole purpose of the wireless module is to send the type of the detected signs. The team expected to be able to transfer at a baud rate of 9600 kbps within a distance of no more than 15 meters. Due to simplicity of application, no data encoding was required.

2.2.8 Power Supply

Considering a mobile platform, the power supply needs to provide sufficient power for a relatively long time, and have a recharging capability and occupy least amount of space possible. Power failure during an active navigation course may compromise the entire system if it stops in the middle of the road. With variety of subsystems that use different power ratings, teams needs to take all hardware safety precautions when designing a power system, including wiring, heat dissipation and oxidation.

3. Research

3.1 Reference Projects

The team had come across multiple projects of this nature performed by different groups and organizations in industry. Majority of them were implemented using similar systems and components to perform a line following function analogous to one the objectives described in this project. In the end of the research, it was realized that although past projects have successfully achieved their intended tasks, they lacked some of the functions this team anticipates implementing.
A group of engineering students from Cornell University had previously designed a project that consists of a vehicle that autonomously navigates through a road marked by 2 lanes avoiding a forward collision. Their solution to the problem was to use a CMOS image sensor to detect the borders of the road and navigating based on the data received from tracking device. This project gave some insight to the complexity and working principal of autonomous vehicles, and will be referenced throughout the development process.
Out of numerous projects observed, “The Driverless Car” of Google was found to be the most effective and capable in terms of performance and reliability. Due to monetary and time limitations, the team designed a system of a smaller scale with lower costs and reduced complexity in a timely manner. Instead of using real world objects and systems, the team built a model of a city road consisting of turns and intersection bound by a circular loop that will be used as a high speed freeway. There were physical objects on the roadway replicating obstacles and road signs.

3.2 Vehicle Platform (Chassis)

There were many factors that went into the process of selecting a technically competent and affordable vehicle platform to use. The starting point for the research of an autonomous vehicle platform revolved around remote control car models and related products. The primary reason for searching and investigating the remote control market was the diverse availability of vehicle platform types. The world-wide-web contains an abundance of sources for both professional and hobby enthusiasts. In the following pages, some of the autonomous vehicle platforms and their attributes which were investigated will be discussed. The platforms were primarily researched upon the following specifications:

- Price and availability
- Motor type (brushed or brushless)
- kv rating
- Steering servo
- Suspension
- Size
- Appearance

- Battery requirements
- ESC (electronic speed control)
- Ease of modification
- Drive type (2 or 4 wheel)

In addition to the previously mentioned specifications, the next several pages will highlight some commercially and financially viable chassis and platform options from which the team could have potentially built the autonomous vehicle project. By doing the research and highlighting and creating tables to compare the available platforms, this section can provide a resource for anyone reading this document or attempting to create a similar project for their own needs.
It is important as a designer or engineer in both educational and professional settings to take a broad approach at the beginning of a design project and implement broad brush strokes as the initial starting point for the project. This methodology created an environment that did an adequate job at preventing a closed-minded approach and helped the project designers and engineers explore options they may not have been considering. Some of the most costly mistakes made are those associated with lack of foresight and rushing to the design and build phase without properly conducting the applicable research as a whole. The market for remote control and hobby-type electronics is a multi-billion dollar industry and vendors are available in most developed countries as well as on the internet. This is an advantage when undertaking a project that has budget constraints because it can be found that, with a little modification, many commercially marketed products can be adapted to computer controlled autonomous vehicle designs and applications. In some cases, it may only require the removal of small amounts of parts and accessories to make room for the mounting of the needed control and computing circuitries to take advantage of pre-existing drive motors, steering servos, battery compartments and stable chassis designs.

3.2.1 Turnigy 1/16 Mini Rally Car

The Turnigy brand one-sixteenth size Mini Rally Car is four wheel drive vehicle platform that was researched for potential conversion to an autonomous vehicle. The vehicle has a sleek and aerodynamic body which could have been an aspect of the design that created a vehicle with well-rounded appeal which could complement the technological aspects of the total project (see **Figure 3.2.1**).
As noted, the vehicle is four wheel drive and accomplishes this via dual motors. On the front of the vehicle is an independent suspension system as well as steering rods connected to a centrally mounted servo. This turning and independent suspension configuration is very similar to real automobile that transport humans (**Figures 3.2.2 & 3.2.3**). In the rear of the vehicle is a fully adjustable suspension such as front toe in and out adjustable shock absorber locations, adjustable camber settings and adjustable drop height (**Figure 3.2.4**).
The Turnigy brand one-sixteenth size Mini Rally Car is an ideal platform to develop with. It provides an affordable cost and does not have any radio

frequency and motor driver circuitries included, thus the designer or engineer will not have needed to include the modification and/or removal of the types of components. It has parallel side step-like boards running along the sides of the chassis which can provide a place to mount spacers and threaded rods or similar products to attach the needed modifications such as microcontroller, motor controller and computer vision components.

Figure 3.2.1

Figure 3.2.2

Figure 3.2.3

Figure 3.2.4

(Permission granted from HobbyKing Support Team)

Another attribute which was considered was the fact that this is a four wheel drive platform. This can be an advantage when the need is power and stability. A small hobby car with four wheel drive is very similar to a full size automobile with regard to the physics of movement. It would have less hop and more control response for the vehicle as a whole when the power has a more equal distribution across the area of the vehicle.

It is also paramount that the designer or engineer is keenly aware that the power and motor control requirements are dramatically different from a vehicle with front or rear wheel drive. A motor control circuit with a single, low output current H-bridge could burn up if its ratings are not robust enough. A hypothetical configuration of four series connected double-A (AA) batteries can provide an average of 6 volts and 2000 mAh. This can equate to very little time available for experimentation and testing and can also provide and added expense.

Model	Turnigy 1/16 Mini Rally Car
Price	($) 50.00
Kv	2430-4800
Motor	Brushless Inrunner (B380)
ESC	25A Brushless 2~3S (with Reverse) (B1058)
Suspension	4-wheel independent
Servo	15g
Battery	2S 1300~1700mAh LiPo
Drive	4 wheel
Steering	Front

Figure 3.2.5 – Turnigy 1/16 Mini Rally Car Specifications

3.2.2 Schumacher Mi1 1/10 Electric Touring Car Kit

The Schumacher Mi1 1/10 Electric Touring Car (see **Figure 3.2.5**) was a high-end option to be used as an autonomous vehicle. It was reviewed to highlight some features and abilities that are generally only available in professional level cars that are beyond the hobby grade specifications.

Unlike most remote control cars, the Schumacher Mi1 is made to the highest standards. The vehicle features a frame made from aircraft quality machined aluminum. The platform has front and rear gearboxes but only requires a single drive engine which is mounted in the rear of the vehicle. A rubber, grooved drive belt links both gearboxes to provide all wheel drive performance and ability. It has authentic CNC machined alloy shocks which are fully adjustable.

Because this car is designed and marketed toward professional level enthusiasts, its performance and handling are precise and reliable. A project that has a low error tolerances and needs to be used for long-term applications would be well served by the Schumacher Mi1 1/10 Electric Touring Car. The Schumacher is an ideal starting point for a high budget, higher precision project. This platform would have been utilized if the team's budget was higher or sponsorship was helping supplement the cost.

Features:

- Limited slip ball differentials w/Tungsten Carbide balls
- composite chassis
- Rear in-board toe-in options
- Front in-board toe-out options
- Alloy shock absorbers
- Includes front differential for ease of use and transmission reliability
- Adjustable camber

- Dual belt transmission
- Alloy motor mount with heat sink
- Ball bearing steering joints
- Front and rear anti-roll bars

Figure 3.2.6

(Permission granted from HobbyKing Support Team)

Model	Schumacher Mi1 1/10 Electric Touring Car Kit
Price	($) 150.00
Kv	2430-4800 recommended
Motor	Brushless
ESC	30A recommended
Suspensio n	4-wheel independent
Servo	20-25g
Battery	LiPo
Drive	4 wheel
Steering	Front

Figure 3.2.7 – Schumacher Mi1 Specifications

3.2.3 Aluminum 4WD Robot Chassis

It was also a possibility to purchase chassis kits that are marketed toward electronics designers and hobbyists. The all aluminum 4WD Robot Chassis kit is a commonly used platform to achieve an autonomous vehicle and because it was designed specifically to be modified and it presented some attributes that are advantageous and worth highlighting:

- Easily Modifiable
- Affordable
- Aluminum 4WD Chassis

- 6x AA Battery Holder
- 4x Gear Motors
- 4x 65mm Wheels
- 8x DC Motor Connect Cable
- Battery charge Port
- Power Supply Switch

The images below, **Figure 3.2.8** and **Figure 3.2.9**, show the vehicle platform and the parts breakdown, respectively. Other dimensions and specifications are as follows:

- Length: 210mm
- Height: 66 mm
- Width: 202 mm
- Motor Voltage: 3V
- Motor Stall Current: 160 mA

Figure 3.2.8

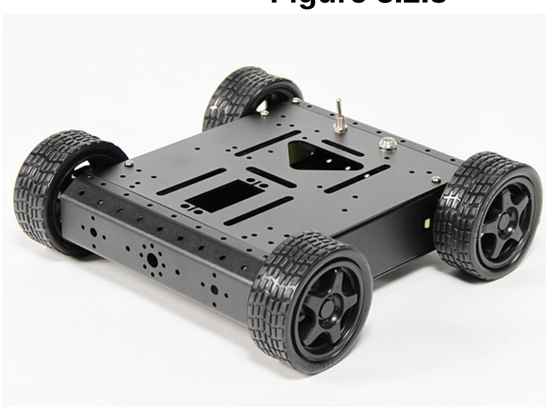


Figure 3.2.9

(Permission granted from HobbyKing Support Team)

3.3 Drive Motors

The selection of a direct current drive motor for the acceleration and deceleration of the wheels focused around two primary motor choices: brushed DC and brushless DC. Several factors influenced the decision between choosing a motor type and included cost, performance and available drive circuitry. Below, the two types will be described and the choice outlined. The motor was selected based upon the brushed or brushless criteria as well as the Kv rating (The RPM per volt specification at zero-load condition), the wattage and the operating voltage parameters.

3.3.1 Brushed Dc

A brushed DC (**Figure 3.3.1)** motor is the most commonly found director current motor and generates rotation through a stationary coil which generates a magnetic field when powered. This coil is surrounded by stationary or rotating magnets. Torque can then be supplied to a shaft from the force of the rotating armature.

The Lorentz force, named for the Dutch physicist who contributed much in the field of electromagnetism, is a principle that defines that any current carrying conduction that is embedded in an external electric field will undergo and accompanying force.

The primary advantages of a brushed DC motor include ease of procurement, low start-up cost, high reliability, and simplistic motor control options. Disadvantages are high maintenance and reduced longevity when used in high intensity environments such as applications that require continuous, uninterrupted use. The repairing and maintenance involves regularly replacing the brushes and springs which carry the electric current, as well as cleaning or replacing the commutator, which allows the current to be transferred to the different windings on the armature as it rotates The aforementioned components are the hardest working parts of the motor and are responsible for transferring electrical power from outside the motor to the spinning wire windings of the rotor inside the motor.

3.3.2 Brushless Dc

For the team engineers and designers, it was important to be able to visualize the differences in the motors. The illustrations below are an important part of this document because words often leave the reader some level of ambiguity and can be strategically complemented by graphic illustrations that show the distinct contrast. Unlike the brushed DC motor in (**Figure 3.3.1**), commonly produced brushless DC motors (**Figure 3.3.2)** use a rotating permanent magnet in the rotor, and stationary electrical current/coil magnets on the motor walls for the rotor. Within the brushless motor is an inverter which changes the DC current to an AC current and uses this changing waveform to power the motor. The use of this type of design facilitates a simpler solution to the need to change the DC polarity to provide continuous rotation in contrast to the changing electric fields. Some advantages of brushless DC motors can be extended life, low maintenance and operational costs and increased efficiency. Brushless DC motors are often the component of choice in high performance or sensitive operations because of their superior torque response and reduced noise. The absence of brushes used to create conductive contact really is a substantial issue and advantage that cannot be understated. If an engineer conducted a noise experiment between a brushed and brushless motor under the same conditions and load and measure the decibels of the motor after a year of operation the brushless motor would win hands-down. Notable disadvantages can been found in their higher cost and more complex motor drive circuitries. To properly operate a single brushless DC motor (also referred to as a stepper-motor) the drive circuitry requires a dual H-bridge motor driver.

The engineer or designer of any project often has to predict or forecast how the product will perform long-term and what associated maintenance may be required. The previously mentioned facts and information is presented not only as a resource for similar projects' needs, but also as a way to make this document a well-rounded resource that contains adequate material to support the hardware specifications that will be selected in the later chapters of this document.

Figure 3.3.1

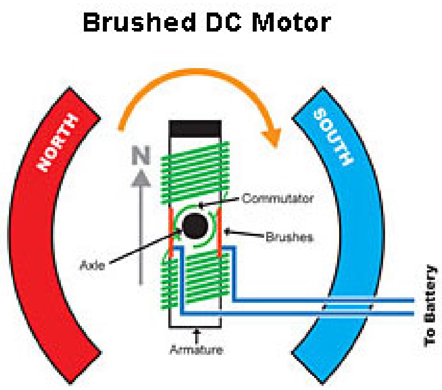
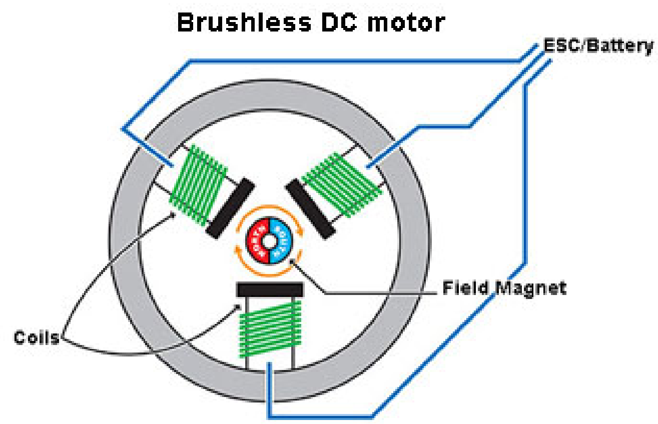


Figure 3.3.2



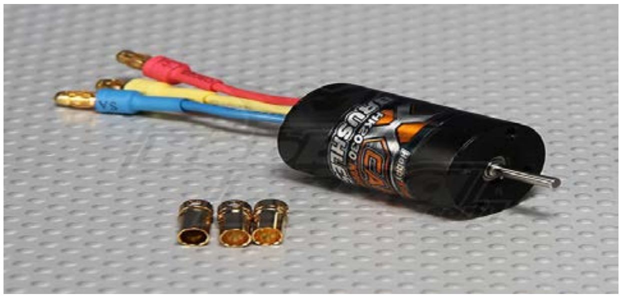
(Permission granted from* support@jpcommerce.com*)

In the following pages this document will highlight some motors that were commercially available and provide the literature and facts that were used in selection of the motor that best met the demands and specifications for the autonomous vehicle project. The information was focused on aftermarket motors that are designed to upgrade existing vehicles or for custom built applications. The featured models will provide a reference for the selection of the drive motor in later chapters and will focus on many of the attributes that are important in industrial or automotive applications such as power, shaft size, weight, dimensions and price.

3.3.3 Brushless In-runner (2030kv)

The image below (**Figure 3.3.3**) is an entry-level hobby-grade brushless motor. It has a standard 3-wire configuration, of which are each made of high quality bullet-type wire connectors and color coded insulation. When compared to a motor that is typically included as part of a ready-to-run configuration, this motor has superior manufacturing standards and will provide longer and more consistent performance over its life span. The data in (**Figure 3.3.4**) provides the manufacturers specifications.

Figure 3.3.3



(Permission granted from HobbyKing Support Team)

Figure 3.3.4 - In-runner specifications

3.3.4 Exceed RC 380 Brushed Motor

The image below (**Figure 1**) is an entry-level hobby-grade brushed Dc motor. It has a standard 2-wire configuration and solder-able terminals on the bottom of the housing case. When compared to a motor that is typically included as part of a ready-to-run configuration, this motor has superior manufacturing standards and will provide longer and more consistent performance over its life span. Aftermarket motors are considered an upgraded part and are considerably higher quality than the motors that often are included in a remote control car purchase. The data in (**Figure 2**) provides the available manufacturer's specifications.

It should be noted that brushed motors in the remote control car market are not considered to be a performance specification part and often include little or no data to identify the output capabilities. Brushless motors are the standard professional choice.

Figure 3.3.5 - Exceed RC 380

(Permission granted from HobbyKing Support Team)

Figure 3.3.6 - Exceed RC 380 specifications

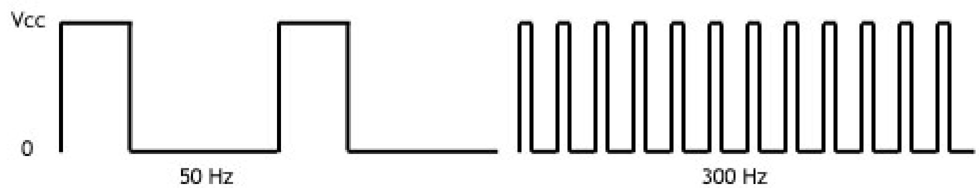
3.4 Steering Control

The most commonly mechanism for controlling the directional orientation of the front two wheels is a servo motor. The servo motor provides variable-angle control via pulse-width-modulation. A typical servo motor is connected with three wires. Two of the wires supply a positive and negative DC voltage and the third carries pulse-width-modulated signal.

To select a servo there are several considerations upon which to decide. Torque and reaction time are important depending on the size of the load and the application. A vehicle with large, heavy or aggressive wheels will need considerably more torque and holding power than a lightweight vehicle that travels at low speed on a surface with a small friction coefficient. Reaction time plays an important role in applications like aviation where the components that are specified are critical to successful operation.

An application can use an analog or a digital servo for its angular position control. Both servo types operate with similar principles with a three wire configuration. The difference, operationally, between the two is the frequency of the signal pulses. A standard analog servo pulse rate is approximately 30-50 square-wave pulses per second. A digital servo can achieve delivery rates of up to 300 square-waves per second. The digital servo’s dead band then becomes significantly smaller than the analog servo. This translates to faster reaction from signals as well as an increased ability to hold a position under stress. **Figure 3.4.1** illustrates the contrast in servo frequencies. The pulse width is decreased with respect to the period and allows digital servos deliver an equal amount of power as an analog servo whilst considerably improving the resolution of the signal. This allows for a much faster and more accurate response, as well as a smoother and more refined servo operation overall.

Figure 3.4.1 – Pulse Width of Analog and Digital Servos



A digital servo required a higher monetary investment because of their internal microprocessor and circuitry. The addition of a microprocessor and MOSFET amplifier within the control circuitry of digital servos adds this cost increase. Digital servos are externally programmable which allow the user to customize the parameters based on need or performance. This is an option that did not necessarily have to be utilized as most digital servos come pre-programmed with standard responses to pulses.

The operation of a digital servo is as follows: The 'minimum' pulse width that is capable of being generated will correspond to the counterclockwise extreme of the servo such as 270 degrees. 'Neutral' corresponds to the middle position at 135 degrees, while 'maximum' corresponds to the clockwise extreme such as 0 degrees. Giving a servo a PWM signal outside its recommended pulse width may cause the servo to exhibit jerk and otherwise undesirable characteristics.

3.4.1 Turnigy TGY-9025MG Metal Gear Servo

The Turnigy TGY-9025MG Metal Gear Servo is an affordable analog servo with an all metal internal gear and output cog.

Figure 3.4.2

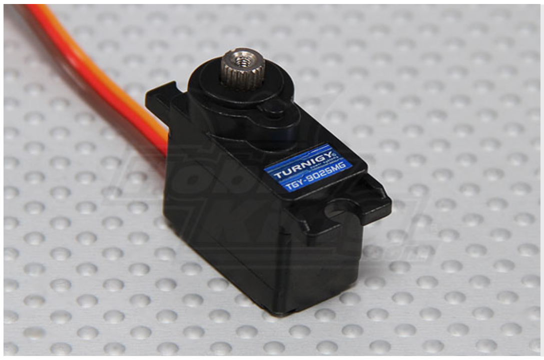
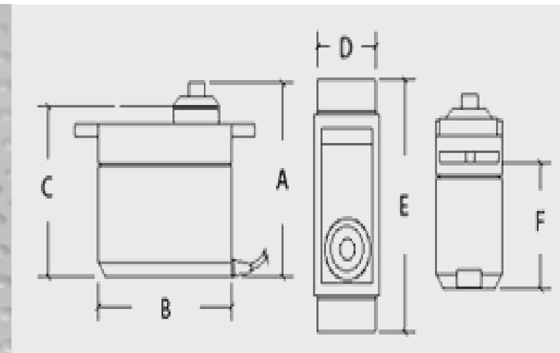


Figure 3.4.3



(Permission granted from HobbyKing Support Team)

Figure 3.4.4

Weight (g)	11
Torque (kg)	1.8
Speed (Sec/60deg)	0.09
A (mm)	29
B (mm)	23
C (mm)	26
D (mm)	12
E (mm)	32
F (mm)	16

3.4.2 Digital High Torque Bearing Servo

A digital servo is a strong addition to an autonomous vehicle project and can provide a real solution to inconsistencies and strength problems that can occur when testing a project. Often an analog servo is chosen early in a project because of the cost savings and availability but in the end a digital servo mechanism would have been the best choice in the first place.

It was important for the designers and engineers of the autonomous vehicle project to have a strong understanding of not only the operational characteristics of the servo mechanisms and how it will affect their goals but also what products were available to match the specifications of the project as closely as possible. A common problem designers and engineers encounter is a servo that has issues holding the exact angle that the pulse width modulation from the microcontroller is calling for. In an analog servo, the frequency rate of the pulse width often is inadequate for commercial duty applications.

Figure 3.4.7, above illustrates just how important a digital servo can be. If an autonomous vehicle is performing a turn and is undergoing excess stress do to road friction or sloped road angles, for example, an analog servo may have too much "dead time" in its signal which could likely facilitate slight or even large unwanted movements in the wheels' angular positions.

Figure 3.4.5

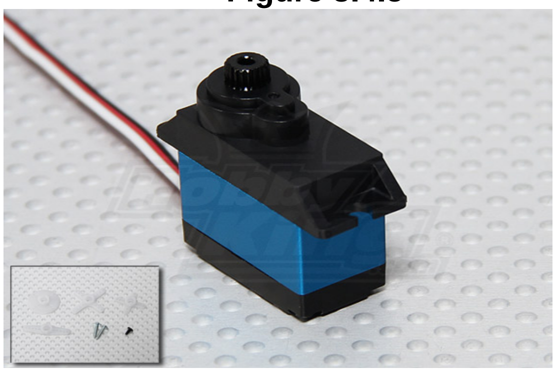
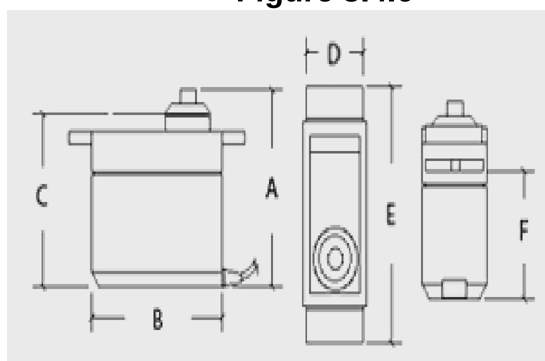


Figure 3.4.6



(Permission granted from HobbyKing Support Team)

Figure 3.4.7

3.5 Batteries

For our power supply we have chosen to use rechargeable batteries because of three reasons.

- Rechargeable batteries save money - While rechargeable batteries are more expensive, they can be reused as many times as needed. When used effectively they can last for years.

- Protect the Environment - Batteries contain very toxic materials and heavy metals. Their manufacture, transportation and disposal can impair human health and the environment. Rechargeable batteries greatly reduce the number of overall batteries required and disposed of.

- Conserve Resources, Prevent Waste – Because rechargeable batteries can be used time and time again, far less batteries need to be used than when using single-use disposable batteries.

There different types of rechargeable batteries that were considered for our device that may be used. The team chose to go with rechargeable batteries rather than use disposable batteries because the device will be used for an extended period of time. Disposable batteries may have a longer shelf life but they don't last as long as rechargeable batteries. The electrical components integrated on our autonomous RC vehicle demands for more power another reason why we chose the option of using rechargeable batteries. For the autonomous vehicle, a battery with high current measured in milliamps per hour (maH) will be chosen. Furthermore, disposable batteries would to be expensive due to the considerable amount we would have to use in order to keep our device running for a specified amount of time. Rechargeable batteries produce current through an electrochemical reaction that involves the anode, cathode, and the electrolyte where the reaction is reversible. Rechargeable batteries are also known as secondary cells because of this process. The process in Non-rechargeable batteries, also known as primary cells is irreversible. The rechargeable battery must undergo this reaction efficiently so that hundreds of recharging cycles are possible

Four different types of rechargeable batteries were researched upon. The four types of rechargeable batteries that we found most compatible and common for the autonomous vehicle are the Nickel Cadmium, Nickel Metal Hydride, Lithium Ion, and the Lithium Ion Polymer battery. The Nickel Cadmium and Nickel Metal Hydride battery will be compared first because of their similarities. The same will be done for the Lithium Ion and Lithium Ion Polymer battery. The rechargeable battery we will chose will be based on these criteria listed in order to choose one best fit for the BRAVO device. This criterion includes size of the battery, durability, the cost, charge capacity and safety use of the battery considering that batteries can be hazardous materials as well. Also a list of the advantages and disadvantages will be listed for each rechargeable battery. By applying this criterion for each battery we will have a strong and in depth insight on the rechargeable battery that is best suitable for the autonomous vehicle.

3.5.1 NiCd

The Nickel Cadmium battery is well known rechargeable battery that is composed of nickel oxide hydroxide and metallic cadmium. The process behind the recharging capabilities of the battery starts with oxidation which at the negative electrode equals the oxidation reduction at the positive electrode. This occurrence generates power within the battery. Nickel Cadmium batteries are for good use in devices such as alarm clocks and remote controls. The Nickel Cadmium battery is relatively inexpensive for low power devices. The Nickel Cadmium batteries were one of the first widely used rechargeable batteries. Nickel Cadmium batteries are available in a wide range of sizes. The Nickel Cadmium battery has a voltage during discharge of 1.2 Volts. Nickel Cadmium Batteries are characterized with wide temperature range operating in temperatures from -40 to 60 C, good electrical performance, and good resistance to overcharge.

Figure 3.5.1 shows the relationship of the cell voltage, pressure and temperature

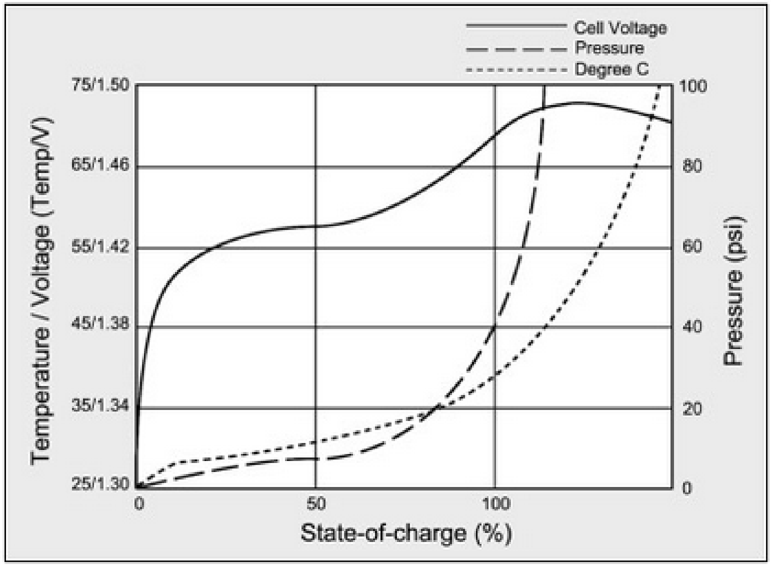


Figure 3.5.1
Pemission Pending from Batteryuniversity.com

Some of the benefits of the Nickel Cadmium battery are listed

- Can provide large currents, suitable for high-drain application
- Works well in cold weather
- Has a long shelf life
- Can withstand 400-1000 cycles with minimum capacity loss
- Can be stored discharged

Some of the disadvantages of the Nickel Cadmium batteries are

- They have a high self- discharge rate(20% or higher per month)
- Has low power to weight ratio compared to NiMH or Li-Ion
- Very toxic inside and has to be recycled
- Can develop internal shorts over time
- Has the memory effect

The concept of the “memory effect” is the idea that the battery loses its charge faster. If the Nickel Cadmium battery was not fully discharged it would lose its maximum capacity. What causes this defect is the formation of Cadmium crystals inside the battery. The metal Cadmium is a highly toxic element.

3.5.2 NiMH

The nickel metal Hydride battery is a rechargeable battery that is similar to the Nickel Cadmium batteries. Electrically, Nickel Metal Hydride batteries are similar to Nickel Cadmium batteries. A major difference between the two batteries is that the Ni negative electrodes use a hydrogen absorbing alloy. The electrolyte is alkaline potassium hydroxide which is able to transfer ion between the cathode and the anode. When a NiMH is charged electrons leave the positive electrode. This causes the nickel in the electrode to oxidize. During this process hydrogen atoms leave the positive electrode and react with the electrolyte. During the charge at the same time, electrons go into the negative electrode which causes a reduction reaction. This causes the electrode to absorb hydrogen from the electrolyte. This allows for the Nickel Metal Hydride battery to be used as many times as it is needed.

The Nickel Metal Hydride battery has a high electrolyte conductivity rate which allows for high power applications. The system of the battery system can be contained which reduces the maintenance and leakage issues. The NiMH batteries are great for high drain devices. High drain devices are those that need energy quickly like cameras. They are also used in high voltage automotive applications. They also have a much larger capacity than Nickel Cadmium batteries.

Some of the advantages of the Nickel metal hydride batteries are:

- They have a high energy compared to NiCd, up to 3600 maH per cell compared to 2400 in NiCd
- They are cheaper than Li-Ion
- They have a high shelf life
- Can withstand 500 cycles with minimum capacity loss

Some of the disadvantages are:

- They have a high self-discharge rate(30% or higher per month)
- They cannot provide as much current as NiCd (Nickel Cadmium)
- They cannot be charged fast without shortening cell life
- Must be stored charged

3.5.3 Nickel Cadmium vs. Nickel Metal Hydride

Though Nickel Cadmium batteries seem to be very reliable the Nickel Metal Hydride has a distinct advantage over the battery. **Figure 3.5.2** displays some of the characteristics.

	NiMH batteries' advantage over NiCd batteries
PERFORMANCE	NiMH batteries will greatly out-perform standard NiCd batteries in high-drain applications.
CAPACITY	The amount of energy stored by the battery. NiMH has more than twice the capacity of standard NiCd. **NiMH batteries have much longer runs times (hours played, number of pictures taken).**
MEMORY EFFECT	NiMH batteries can be charged or "topped-off" at any time without affecting battery life. In order to achieve optimum performance from NiCd batteries, they must be fully discharged before recharging. Unlike NiCd batteries, **NiMH has No Memory Effect**.
ENVIRONMENTALLY FRIENDLY	NiMH batteries have no Cadmium added. Cadmium is hazardous to the environment. **NiMH is much more environmentally friendly**
VOLTAGE	The power produced by the battery. Both NiMH and NiCd have virtually the same voltage.

Figure 3.5.2
Permission pending from All-Battery.com

As shown in **Figure 3.5.3** the Nickel Cadmium has greater service life and capacity in the AA and AAA batteries.

Comparison between NiMH and NiCd rechargeable batteries

AA Capacity (mAh)	600 - 800	1,800 – 2,000
AAA Capacity (mAh)	200	600 - 700
Service Life	Up to 750 cycles	Up to 1,000 cycles
Voltage	1.25V	1.25V

Figure - 3.5.3 Permission Pending from All-Battery.com

A downside for both batteries as listed in previous sections is that both cannot be overcharged which would to decreased capacity.
The Nickel Metal Hydride battery is superior to the Nickel Cadmium battery as described above. In terms of cost the Nickel Metal Hydride battery is also cheaper. Furthermore, the Nickel Metal Hydride is also less toxic. The Nickel Metal Hydride battery

3.5.4 Lithium Ion Battery

The Lithium Ion battery is a rechargeable battery where the electrodes are made up of lithium and carbon. The cathode is made up of lithium cobalt oxide and the anode is made up of carbon. When the battery charges up, the lithium based positive electrode releases some of its lithium ions which travels through the negative electrode and remains there. Energy built up and stored during this process. When no more ions flow the battery is fully charged. When the battery discharges, lithium ions move back to the positive electrode giving the power the battery needs. When all the ions have move back the battery is fully discharged and needs to be charged up again. The lithium ion battery is much lighter than other types because of its size. Lithium is a highly reactive element meaning that a lot of energy can be stored. Lithium batteries are very popular and are found in your everyday electronics such as Laptops, Ipods, cell phones and etc.

Some of the many advantages of the Lithium Ion battery include:

- Charge. A lithium-ion battery pack can lose only about five percent of its charge per month, compared to a 20 percent loss per month for NiMH batteries.
- Lithium-ion batteries do not a memory effect, you do not have to completely discharge them before recharging, as with some other battery chemistries
- Lithium-ion batteries can handle hundreds of charge/discharge cycles.

The Lithium Ion Battery is not without its disadvantages:

- They start degrading as soon as they leave the factory. They will only last two or three years from the date of manufacture whether you use them or not.
- They are extremely sensitive to high temperatures. Heat causes lithium-ion battery packs to degrade much faster than they normally would.
- If you completely discharge a lithium-ion battery, it is ruined.
- A lithium-ion battery pack must have an on-board computer to manage the battery. This makes them even more expensive than they already are.

3.5.5 Lithium Ion Polymer

Lithium polymer batteries are another form of rechargeable batteries (LiPo).They are composed of several identical cells in parallel addition which increases discharge current. A difference between Lithium polymer and lithium ion is that lithium polymer battery does not use a liquid electrolyte and instead uses a dry electrolyte polymer that resembles a thin plastic film. The film is smashed in between the anode and the cathode. Lithium polymer is considered to be an upgraded version of the lithium ion battery. **Figure 3.5.4** shows the relationship between the current and voltage of the Lithium ion battery

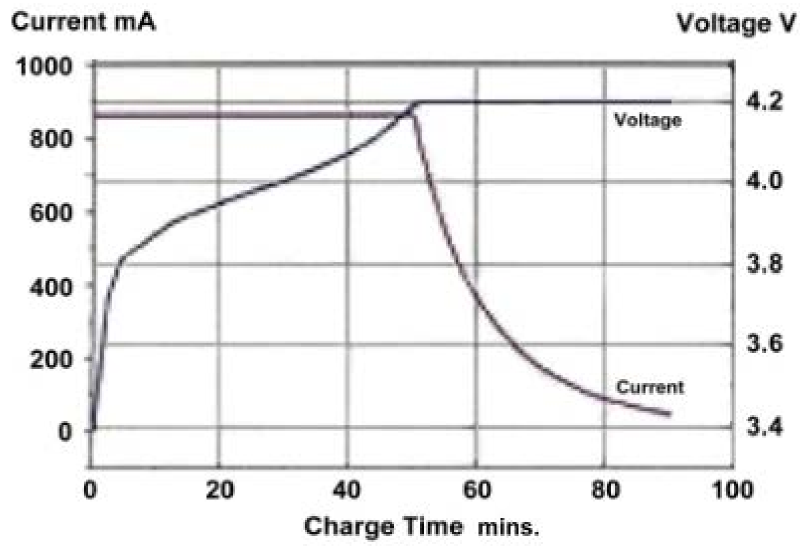


Figure 3.5.4
Pending permission from www.ibt-power.com

Some of the advantages of the Lithium Ion Polymer battery are

- Slim and able to be assembled into a credit card
- They can economically made a suitable size
- Light weight: battery used polymer electrolyte need not metal case as protection package
- Improved Safety; more stable overcharge and low rate of electrolyte Leakage
- More environmentally friendly

Some of the disadvantages include

- As opposed to lithium-ion battery, energy density and cycle times decrease
- There is a high manufacture cost for the Lithium Polymer battery
- Prices are more expensive than that of the lithium-ion battery
- No standard shape, mostly made for high capacity consumer market
- Not universally available
- Non-convertible/modifiable
- Chargers are not available in electronics stores

3.5.6 Lithium Ion vs. Lithium Ion Polymer

Although the lithium Ion polymer battery is smoother and thinner, lithium Ion batteries have a higher energy density and are less expensive to manufacture. **Figure 3.5.5** is comparison of the two batteries listing there characteristics

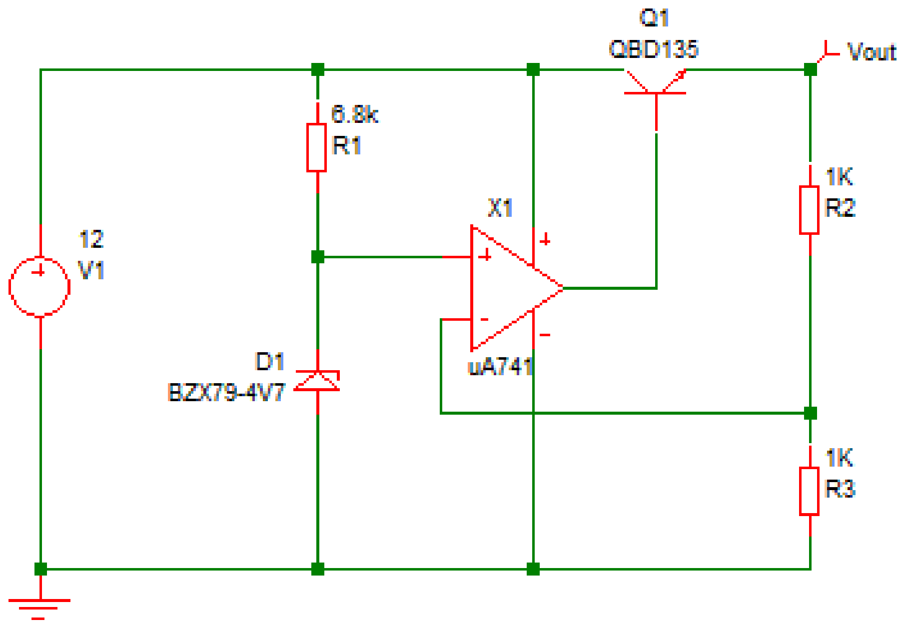
	Lithium Ion	Lithium Polymer
Type	Rechargeable	Rechargeable
Chemical Reaction	Depends on electrolyte	Depends on electrolyte
Temperature	4 to 140 degrees F	Better performance at high and low temperatures
Recommended For	Cell phones	Cell phones
Initial Voltage	3.6 and 7.2 Volts	3.6 and 7.2 Volts
Capacity	Two times the capacity	Surpasses the lithium ion
Discharge Rate	flat	flat
Recharge Life	300-400 cycles	300-400 cycles
Charging Temperature	32 to 140 degrees F	32 to 140 degrees F
Storage Life	Loses less than .1 % per month	Loses less than .1 % per month
Storage Temperature	-4 to 140 degrees F	Depends on electrolyte
Disposal	Can be recycled	Can be recycled

Figure 3.5.5

Lithium ion batteries have an overheating issue and require an active protection circuit which prevents overheating of the battery and bursting into flame whereas Lithium polymer batteries do not have to that protection circuit which makes its size smaller and easy to manufacture. Lithium ion batteries are susceptible to degrade at the point they are manufactured and become dead in two to three years if they are not used. Lithium ion batteries have leverage in size, weight, energy density, ability to work in wider temperature range and that they can be recharged before getting totally discharged which any effect on memory. Lithium ion batteries have a lot more energy capacity than that of Lithium polymer batteries so Lithium ion batteries are used in devices which have higher current requirement. Lithium polymer batteries are favorable because of the size which crucial considering the size of our autonomous vehicle. And when cost is considered, the Lithium ion battery is the choice as they are cheaper to manufacture than Lithium polymer battery.

3.5.7 Linear Regulators

Linear regulators were going to be considered for the cameras, proximity sensors, Line scanner and Bluetooth. Linear regulators are known for their simplicity and cost. Linear regulators are also building blocks for most power supplies used in electronics. Linear regulators regulate the voltage by dropping the voltage across the element and dissipate the power. This creates heat that can be removes using heat sink. **Figure 3.5.6** of the linear regulator circuit.

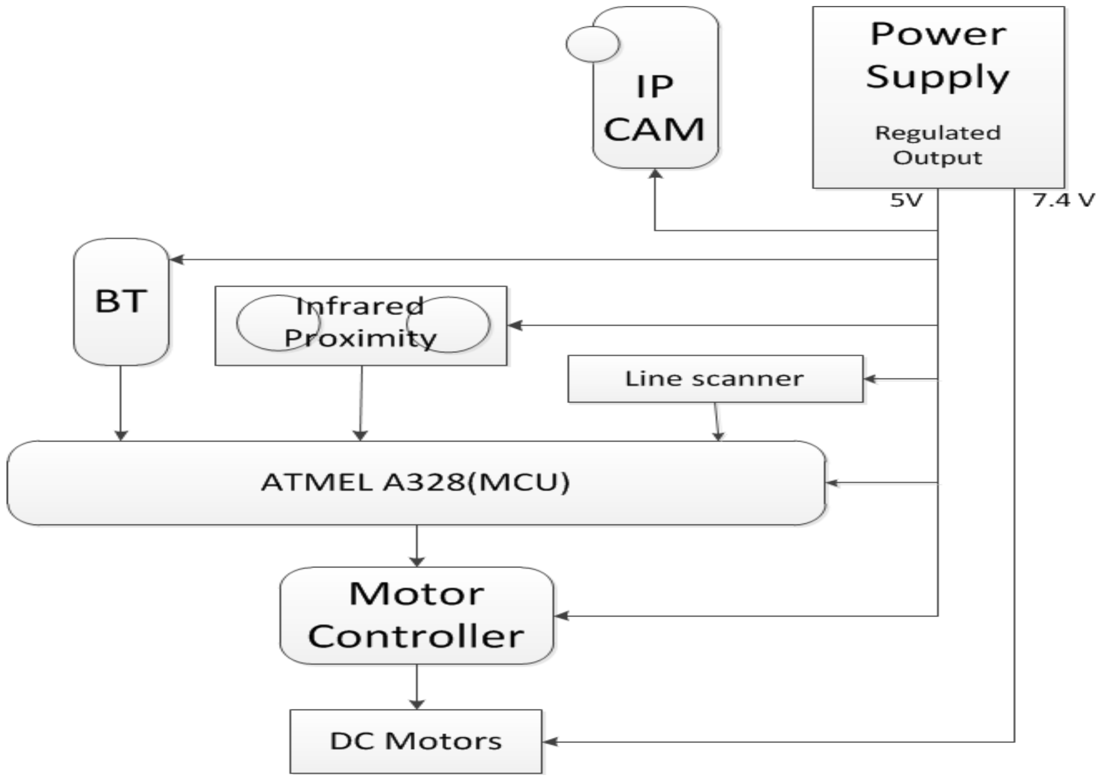


An example of the linear regulator circuits
Figure 3.5.6

3.5.8 Regulation of Power

The autonomous Bravo RC car will be powering multiple electronic components. There will be dc motors, motor controller, microcontroller, camera, along with image processing, proximity sensors, and a line scanner that will be competing for power. The power supply must last for a sufficient amount of time BRAVO time to complete its predetermined navigation route. In order to combat this issue a separate battery power source along with various regulators was considered to prevent any overloads or inconsistencies in the voltage.

In the following sections below different regulation devices were discussed in order to find the regulator or a combination of regulators that will best suit our autonomous vehicle. By integrating all the parts all the power will be distributed from two batteries. One battery will power the various components while the battery will power all other electrical components. A series of voltage regulators will be used to avoid any voltage irregularities and maintain a constant voltage.



Hardware Block Diagram
Figure 3.5.7

3.5.9 Switching Regulators

Switching regulators have the ability to take a higher voltage and it brings it down to a lower voltage. Also, a switching regulator is capable of transforming a lower voltage to a respective a higher voltage. Switching regulators are also highly efficient with regard to their power output to capacity ratio. Switching regulators also create very little heat when being used. The downsides of using the switching regulators are that they cost more and are little more complex. Furthermore, switching regulators can have a noise component associated with their operation which can discourage the application of them to more sensitive devices.

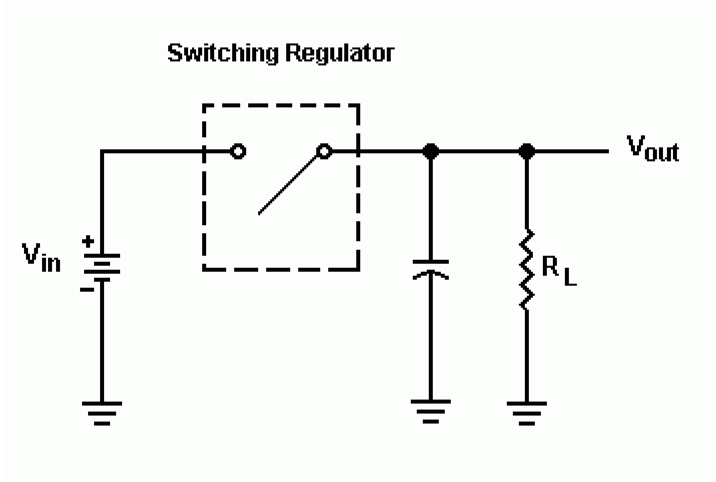


Figure 3.5.8 - Switching regulator circuit

In the table below it lists it compares different characteristics of each regulator

	Linear	Switching
Function	**Only steps down**; input voltage must be greater than output	**Steps up, steps down, or inverts**
Efficiency	**Low to medium,** but actual battery life depends on load current and battery voltage over time; **high** if V_{IN} - V_{OUT} difference is small	**High,** except at very low load currents (µA), where switch-mode quiescent current (I_Q) is usually higher
Waste Heat	**High,** if average load and/or input/output voltage difference are high	**Low,** as components usually run cool for power levels below 10W
Complexity	**Low,** which usually requires only the regulator and low-value bypass capacitors	**Medium to high,** which usually requires inductor, diode, and filter caps in addition to the IC; for high-power circuits, external FETs are needed
Size	**Small to medium** in portable designs, but may be larger if heatsinking is needed	Larger than linear at low power, but smaller at power levels for which linear requires a heat sink
Total Cost	**Low**	**Medium to high,** largely due to external components
Ripple/Noise	**Low**; no ripple, low noise, better noise rejection	**Medium to high,** due to ripple at switching rate

Figure 3.5.9
Permission accepted from Maxim Integrated

3.6 Motor Controls

For the velocity and directional control of the brushed DC motor, the circuit design primarily needed to be able to reverse polarity and limit the winding current. There are several different ways to achieve these requirements but the most common solution is the use of an H-bridge. The H-bridge consists of N-channel power MOSFET's at the outputs to drive the motor windings. The availability of commercially manufactured H-bridges is diverse and provided the team with many options. In the following section some of the features that were important to the selection of the appropriate motor control device are highlighted.

To complement the features section, several of the industry's more common integrated motor control microchips will be examined. As mentioned in previous sections, the ability to research and examine available options and technologies gave the engineering and design team an open-minded approach to both companies and niche-type features and accessories.

3.6.1 Current Control

One of the most important aspects in the selection of a motor controller for use in an autonomous vehicle application was the ability to limit the current through the motor windings. The engineering team needed to be able to adjust the movement to desired levels and it would not have been efficient to turn the motor off an on repeatedly in order to achieve a desired velocity or response. The current through the motor windings can be reduced or modulated via frequency pulse width modulation (PWM) current regulation. When used in DC motors, the current control feature is used to limit the start-up and stall current of the motor. For a brushless motor, current control is often used at all times. To operate with this feature, one output is enabled and the current will increase through the motor winding at a rate dependent on the DC voltage and inductance of the motor winding. If the current reaches the particular threshold of the desired level, the H-bridge will disable the current until the beginning of the next pulse width modulation cycle. This is the key factor the team utilized to be able to moderate the drive motor's output and thus slow the velocity of the wheels it is connected to.

3.6.2 Over-current Protection

Another important feature of a motor controller is the attribute of self protection. The construction, engineering and testing of an autonomous vehicle on a limited budget required that the components of the project be robust and not be susceptible to destruction if it overheats during the testing phase. Heat overloads, shorts and over-current faults can occur for a number of reasons and it's highly valuable to stop the motor controller before damage can be done to itself or the connected circuitry. The device must have current limits set on the internal field effect transistors. If a fault of any kind would have been detected, all of the field effect transistors inside the h-bridge would be disabled and the fault pin would be set to zero or low. This is how many manufacturers provide internal protection for motor controllers. The pin would have had to be reset to high before the device could be enabled again.

3.6.3 Sleep Functions

Many devices being manufactured in modern times have the ability to preserve battery life. As many consumers are acutely aware of, batteries are not only expensive if they are the replaceable type, but also have a propensity to have capacities that are quickly depleted. Because of these factors many industries have taken steps to meet consumer demands and need by manufacturing components that are able to enter a “sleep” mode to limit or reduce the number of devices that are consuming electrons. Modern cell phones are a sector where this technology is nearly universally implemented and this is because consumers want smaller phones and thus smaller batteries to accompany them. While battery technology is constantly evolving, the need for a device to turn off unneeded functions to preserve amp-hours is paramount.

To enable this function, many motor controllers simply need a small pull-up resistor added to the external circuitry to account for varying currents and the command from a microcontroller of either high or low, respectively. A user of a cellular phone may have a button that accomplishes this function and in reality are it is doing is sending a logic signal via a software interrupt and the device. For the autonomous vehicle application, this function could have been used when the vehicle was sitting idle for an extended period. It may seem like a small attempt to preserve battery life, but when a device or piece of equipment has long operation times, the need to extend the life of the battery and thus the product becomes more and more important.

3.6.4 ST Microelectronics L298n

Along with Texas Instruments, ST Microelectronics is the biggest player in the global construction and design of integrated circuit motor driver controls. ST Microelectronics offers an extensive line of motor controllers with various specifications that can meet most needs of an engineer or designer. The company has a strong customer support environment and offers free samples of many of their products, which is a strong asset for a team that has a limited budget.

The L298n is an integrated circuit in a package that features a multi-watt operating range which facilitates a broad range of power supply options. It can handle relatively high voltages and has a robust current handling capacity through its dual full-bridge driver and the transistor–transistor logic (TTL) is designed to accept standard TTL logic levels and control and drive inductive loads such as relays, solenoids, DC and stepping motors.
The L298n features two enable inputs which are provided to enable or disable the device independently of the input signals. The emitters of the respective lower transistors of each h-bridge are connected together and the corresponding external terminal can be used for the connection of external components such as a sensing resistor used for current measurements. An additional supply input is provided so that the logic works at a lower voltage.

Figure 3.6.1

	Manufacturer	ST Microelectronics
	Model	L298n
	Price ($)	Samples Available
PIN		**Function**
1	I-sense A	Sense resistor from pin1 to pin 8 to control current load
2	Output1	Outputs of the Bridge A; the current that flows through the load
3	Output 2	connected between these two pins is monitored at pin 1.
4	Supply Vs	Supply Voltage for the Power Output Stages.
5	Input 1	TTL Compatible Inputs of the Bridge A.
6	Enable A	TTL Compatible Enable Input: the L state disables the bridge A (enable A) and/or the bridge B (enable B).
7	Input 2	TTL Compatible Inputs of the Bridge A.
8	Ground	Common ground
9	Logic Supply Vss	Supply Voltage for the Logic Blocks
10	Input 3	TTL Compatible Inputs of the Bridge B.
11	Enable B	A logic input control for motor channel B
12	Input 4	TTL Compatible Inputs of the Bridge B.
13	Output 3	Outputs of the Bridge B. The current that flows through the load
14	Output 4	connected between these two pins is monitored at pin 15.
15	I-sense B	Sense resistor from pin15 to pin 8 to control current load

3.6.5 Texas Instruments DRV8833

The DRV8833 features a 4A peak output when configured in the parallel mode. The current limiting ability can be controlled with pulse-width modulation from the microcontroller. The motor power supply voltage range is 2.7 – 10.8 V which is ideal for RC-type motor conditions. The key features which make this H-bridge desirable to many others include:

- Pulse-width modulation winding current regulating/limiting
- Thermally enhanced surface mount package
- Wide power supply range (2.7 V – 10.8 V)
- The ability to obtain free samples from Texas Instruments
- Abundance of application support and literature
- Internal shut-down for heat, current and short-circuit protection
- Free samples available

Block Diagram

The block diagram in **Figure 3.6.2** shows a common configuration for the TI DRV8833.
The table of **Figure 3.6.3** describes all available DRV8833 pin functions.

Figure 3.6.2

Figure 3.6.3

3.7 Microcontroller (Image Processor)

Because image processing is a task that requires a large amount of resources, several necessary conditions were met in order for our vehicle to achieve its desired objectives:

- >= 32 KB of on-chip RAM
- >= 16 MHz Clock Frequency
- An external memory controller for off-chip memory access
- Two > 9600 baud rate serial interface
- Low power consumption
- Capability for Pulse Width Modulation (6 pins)
- IDE with Software library support

As displayed in figure 3.11.01, the processor was interfaced to several peripherals with potentially slower clock rates so the processor needed several asynchronous serial ports. The camera required a serial interface and because the group decided to implement a second vehicle with remote image processing, the microcontroller needed to have the capability to send and receive information via a wireless communication module. This enabled the processor to transmit and receive information without the trouble of synchronizing the respective data lines. As speed was initially thought to be an issue, it was deemed ideal to have on-chip memory that was large enough to store all of the program code. This reduced the number of clocks cycles as all memory accesses would occur on the chip without the need for external accesses. The processor also needed some sort of internal memory storage with a capacity greater than 300 KB or at least an external memory controller in order to store the received images from the camera.

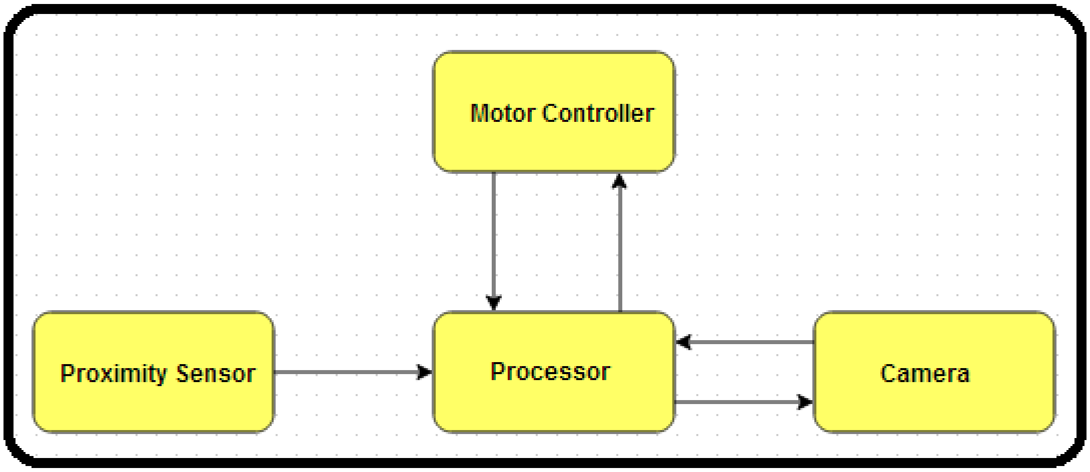


Figure 3.7.1

3.7.1 FreeScale Semiconductors - MCF52259 ColdFire

This particular microcontroller possessed several attractive features that were required for our project. This microcontroller is a 32-bit CPU reduced instruction set computing (RISC) style core with on-chip memory features including: up to 512 KB of flash memory and up to 64 KB of static RAM (SRAM). The microcontroller also contains an interrupt controller with the possibility for external interrupts with a peripheral bus operating at frequencies up to 40 MHz, three UARTs, one queued serial peripheral interface (SPI), one control area network (CAN) module, two inter-integrated circuit (IIC) modules, a four-channel direct memory access controller, and up to 123 configurable general purpose pins. The MCU offers multiple timers that are able to support pulse width modulation (PWM) signals as well as pulse code modulation (PCM). Because the vehicle relied heavily on image processing and the ability of a servo to deliver timely control commands, being able to support PWM was a very important aspect of our project. This particular PWM timer supports 8 channels with programmable duty cycle as well as programmable period. The microcontroller operates at speeds of up to 80 MHz and offers the option for low-power consumption and a JTAG debugging interface. Freescale offers sampling of their product as well as a free trial of their custom design suite called, “CodeWarrior.” The design suite contains all of the necessary libraries contained with the board support packages.

3.7.2 Atmel AT32UC3A

This microcontroller also has several features that met the minimum requirements set forth for this project. The Atmel AT32UC3A family are a 32-bit reduced instruction set computing (RISC) style microcontroller with both internal flash memory as well as internal SRAM. The internal flash ranges from 128K to 512K bytes of memory and the SRAM ranges from 32K to 64K bytes of memory. There is also pre-fetch buffering for the internal flash, a single precision floating point unit (FPU), and the processor supports byte and half-word data types without any penalty towards performance; all of which would have been beneficial in optimizing the code and also possibly beneficial in the speeding up of all the image calculations.

Another attractive feature is an external memory interface supporting both SRAM and synchronous dynamic RAM (SDRAM) with a 16-bit and 24-bit address bus which is beneficial for quick accessing and storing images from the CMOS camera should the internal memory prove to be insufficient. This microcontroller also contains an interrupt controller, a USB 2.0 interface, an ethernet EMAC (10/100 Mbps) interface, four UARTs, two master/slave SPI interfaces, one synchronous serial protocol controller, one 7-channel 16-bit pulse width modulation (PWM) controller and one master/slave TWI (IIC compatible). There is also a one 8-channel 10-bit analog-to-digital (ADC) converter if the project should require one. There are up to 109 general purpose I/O pins, on-chip debugging through a JTAG interface and the processor runs at up to frequencies of 66MHz.

One interesting feature of this processor is a peripheral direct memory access controller (PDCA) which allows the transfer of data between particular memories and peripherals without the use of the processor. Input voltage is recommended at around 3.3V. One feature that this processor does not possess, is cache. Though it was difficult to say whether cache would have had a significant effect with regards to speed or performance, especially with varying image files, the option would have been nice to have. Atmel features its own software library called the, “Atmel Software Framework,” and is free. The library is integrated into Atmel’s own IDE what is also free of charge.

3.7.3 STMicroelectronics - STM32F40xx

The STM32F405 is a 32-bit ARM Cortex RISC style CPU that comes with several attractive features such as a single precision floating point unit, internal Flash memory, SRAM, core couple memory data RAM, and up to 15 communication interfaces. The MCU family features frequencies that can reach up to 168 MHz while flash memory ranges up to 1 MB, the SRAM ranges as high 192 KB, and the core coupled memory data RAM is listed as high as 64 KB. These are particularly interesting memory features, as they would have allowed the group to be flexible with code optimization, while the images from the camera would have been able to be stored easily within the flash memory.

In conjunction with flash memory, the MCU offers an adaptive real-time memory accelerator (ART Accelerator), which implements a style of caching that able to increase the speed of the flash memory. For communication between peripherals and memory, the MCU features a direct memory access controller (DMA) that supports general-purpose dual port capability. This would not only allow two-way communication between peripherals and memory, it would allow memory-to-memory communication. The MCU also features an array of attractive communication interfaces including: three IIC interfaces,two USARTs,two UARTs, up to three SPIs, two CAN interfaces, 140 GPIO pins, an SDIO interface, a JTAG interface for debugging mode, USB 2.0, and 10/100 Ethernet EMAC. One particular feature of this processor that is very attractive is a FIFO camera interface for a CMOS sensor running on a bus at 168 MHz. The camera interface can achieve data rates as high as 54 MB/s at 54 MHz with 8 - 14 bit parallel communication capabilities. The processor also includes an external memory controller which would have been beneficial for accessing and storing any data that would not fit on the chip, though there appears to be more than enough on-chip flash memory.

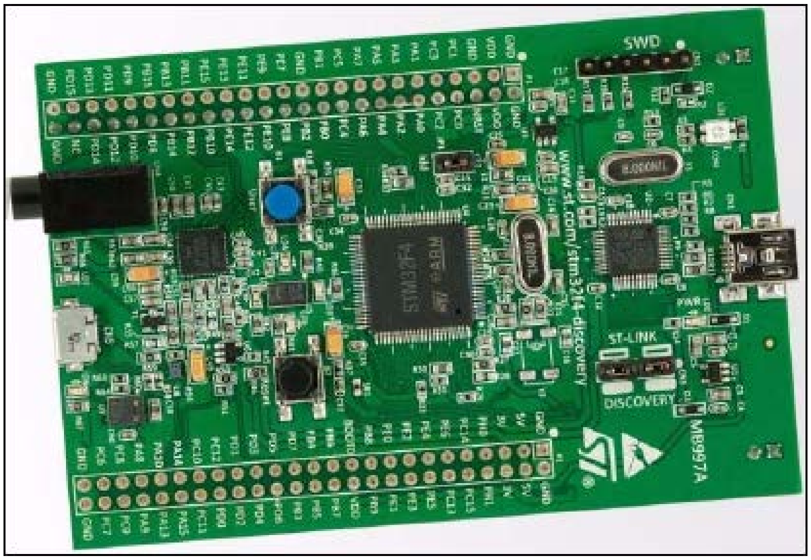


Figure 3.7.2
Permission Obtained from STMicroelectronics

STMicroelectronics also provides a free IDE along with a multitude of C compilers, libraries and development tools. Perhaps the most beneficial aspect of this microcontroller is that STMicroelectronics offers an inexpensive discovery board with the STM43F407 mounted onto the board. Priced at around $15.00, this board offered the unique ability to become acquainted with all of the microcontroller’s functions without the cost of purchasing an evaluation board that can sometimes run from hundreds of dollars to thousands of dollars. The board also comes with its own set of libraries and examples which allows the user to configure the processor in various ways that were not considered before. Another great advantage of having a discovery board is that the board offers the user the opportunity to make all of the physical connections by himself. This would have provided valuable experience with the microcontroller had we decided to use this microcontroller.

3.7.4 Silicon Labs SiM3C1xx

The SiM3C1xx is a 32-bit ARM cortex CPU that offers a maximum frequency of up to 80 MHz, internal flash that ranges from 32 KB to 256 Kb, SRAM that ranges from 8 KB to 32 KB, and an external bus interface that supports up to 16 MB of external memory which is important because this particular MCU did not have the necessary specifications for internal memory. This external interface allows for parallel asynchronous peripherals and provides memory-mapping for each peripheral. In order to minimize latency and wasted clock cycles, caching is enabled in the core along with prefetch buffering. For communication interfaces this CPU includes two USARTs, two UARTs, three SPIs,two IICs, and a 16-channel DMA controller that supports scatter-gather I/O. The timers support a 16-bit, 6-channel counter that can be used for PWM which was necessary for the motor controls. The CPU also features low power modes, multiple channels for analog-to-digital conversion or digital-to-analog, up to 65 GPIO pins, and a JTAG interface for debugging. Silicon Labs offers software support for all of their MCUs with a comprehensive software library as well as their own IDE, “Silicon Labs Precision32 IDE,” that is free of charge.

3.7.5 Analog Devices - SHARC Processor

This processor was very impressive due to its relatively high operating frequency coupled with its large amount of on-chip memory. Made by Analog Devices, this processor sat at the higher end of what the group had been researching and possesses many of the features that the group was looking for. The SHARC processor is a 32-bit single-precision floating-point Harvard Architecture processor with 625 KB of on-chip RAM and 500 KB of on-chip ROM.

The processor features bus widths that range as high 64-bits and support transfers between the core and memory at every cycle. There is an external memory controller that supports both an asynchronous memory interface (AMI) and SDRAM. The processor also has a Digital peripheral interface that includes two timers, two SPIs, a UART, a 2-wire interface (TWI), and the ability for pulse width modulation. This PWM module can generate both edge aligned and center aligned signals and contains four units of four PWM outputs with a total of sixteen PWM outputs. There are several other serial ports such as sample rate converters, an input data port with a multiplexed input of a 32x8 FIFO, and parallel interconnects, but in total the processor features eight serial ports.

Because of its bus architecture, the processor can fetch one instruction and four operands at the same time in a single clock cycle. Like many of the other MCUs, this processor possesses a DMA controller that allows the transfer of data from internal memory to the serial ports without eating up precious processor resources. This processor also features complete software support with hardware development tools and a development environment.

3.7.6 Texas Instruments - F28M35x (Concerto™) MCUs

The final microcontroller was another 32 bit ARM Cortex MCU that came with a good deal of attractive features. The makeup of the MCU itself, is one that includes an array of subsystems including: a master subsystem, a control subsystem, and an analog subsystem. The unique benefit of this is that each subsystem has dedicated memories as well as peripherals. As a result, these two subsystems are able to share data through the shared memories. The master subsystem clocks in at 100 MHz and has a diverse set of embedded memory options. There is up to 512KB of Flash, up to 32KB of RAM, and up to 64KB of shared RAM which relates to the Control subsystem. The master subsystem also features five UARTs, four SSI, an SPI, two IICs, two CANs, a 32-channel DMA, and an external peripheral interface.

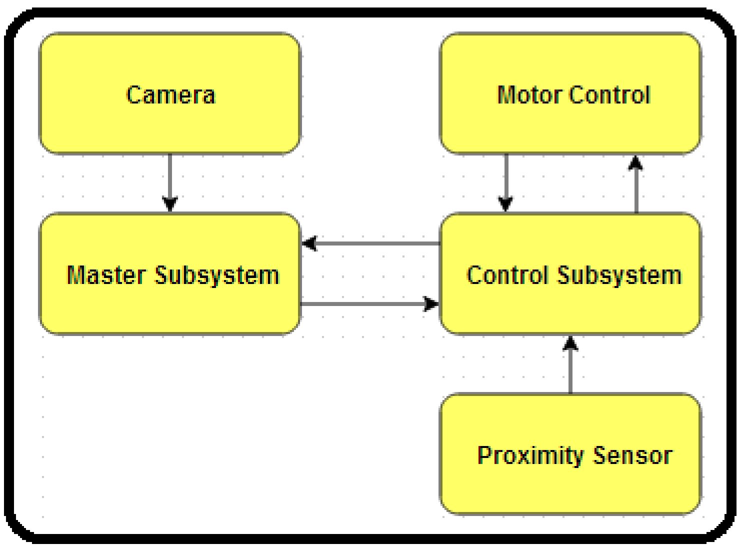


Figure 3.11.02

The Control subsystem clocks in at 150 MHz with embedded memory options of up to 512KB of Flash, 36KB of RAM, and up to 64KB of shared RAM. This subsystem features single precision FPU which would have aided in code optimization, three serial interfaces, a 6-channel DMA, nine ePWM modules, a multi-channel Buffered Serial port, and an external peripheral interface. As shown in figure 3.11.02, this particular MCU would have been able to simulate the advantage of having two separate processors or MCUs that were dedicated to separate tasks, but still able to communicate with each other. Including both subsystems, there are up to 74 MIO pins for general purpose. Not only does this MCU possess an enormous amount of beneficial features such as multiple serial ports and a sufficient clock speed, the MCU has two separate subsystems with their own dedicated memory. This feature would have been greatly beneficial in allowing one subsystem to focus on image processing while the other subsystem handled all of the motor controls and sensors. The MCU also includes 2KB of RAM for inter-subsystem communications. Another great feature of this MCU is that the price was relatively low considering its functionality. The TI website lists the most expensive version of this family of MCUs as only $15.65.

3.7.6 Microcontroller – Product Assessment

	MCF52259 ColdFire	Atmel AT32UC3A	STM32F40 xx	Silicon Labs SiM3C1xx	Analog Devices SHARC	TI Concerto
Clock Freq.	64 MHz	66 MHz	168 MHz	80 MHz	400 MHz	100 MHz / 150 MHz
OCM (RAM)	64 KB	64 KB	192 KB / 64 KB CCM	32 KB	625 KB	36 KB / 64 KB Shared
# of UARTs	3	4	4	2	2	5
# of Serial Interfaces	> 6	> 7	15	9	8	5
Internal Memory	512 KB	512 KB	1 MB Flash	256 KB Flash	500 KB ROM	512 KB Flash
External Memory Controller	Peripheral Bus	Yes	Yes	Yes	Yes	Yes
PWM	Yes	Yes (16 bit x 7 chan.)	Yes	Yes (16 bit x 6 chan.)	Yes (16)	Yes (9)
Software Library	Yes	Yes	Yes	Yes	Yes	Yes
Low Power Mode	Yes	Yes	Yes	Yes	Yes	Yes

3.8 Microcontroller (Motor Controls)

Had a single processor proved to be insufficient for the task of image processing as well as controlling the motors, then a second microcontroller would have become necessary to handle the responsibilities of controlling and driving the motors. The microcontroller was required to have the following specifications:

- > 16 KB on-chip RAM
- Preferable to have an instruction cache
- PWM module (6 pins)
- External Interrupt Capable
- Serial Interface

The MCU should have had enough on-chip memory to store any instruction code as well as an instruction cache which would have helped to reduce any delays in the processing of data or communication between peripherals. As displayed in figure 3.11.03, the MCU was interfaced with two peripherals: the motor controls that utilized PWM, and a proximity sensor that generated an external interrupt when an object was near. The MCU also needed to possess a serial interface for communication with the image processor. A serial wireless module handled the responsibility of communication protocols between the MCU and the image processor.

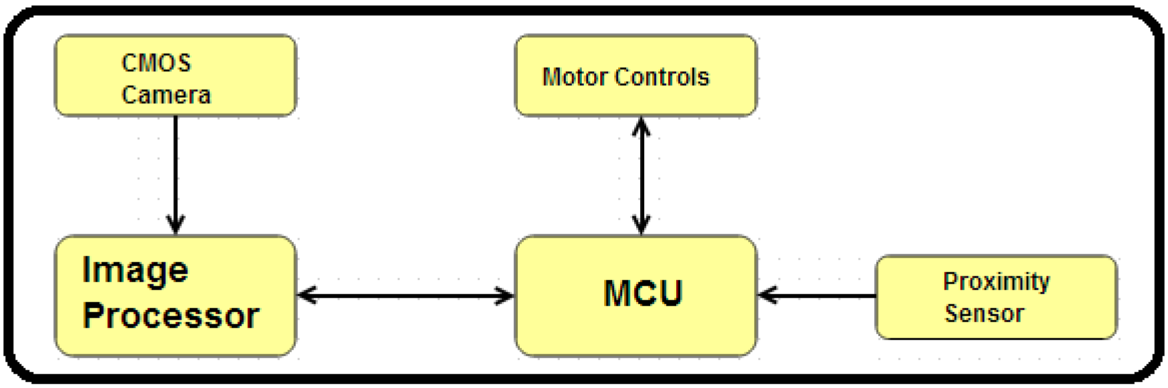


Figure 3.11.03

3.8.1 Atmel - ATmega328P

This MCU is a 8-bit low power AVR microcontroller with an advanced RISC architecture and 32 x 8 general purpose registers. Throughput is clocked at around 20 MHz while memory features up to 32 KB of programmable flash, 1 KB of EEPROM, and 2 KB of internal SRAM. Though there was much less capacity than a common 32-bit MCU, the program code would be much smaller than incorporating both image processing code and PWM control code which would have allowed for greater flexibility with the particular MCU. The controller has 6 PWM channels, 23 programmable I/O pins, one USART, a master/slave SPI module, and an IIC compatible interface. Both the SPI and the UART are connected through the 8-bit wide data bus as well as an interrupt unit so arbitration between various peripherals would have been able to be handled by priority and allowed the processor to process an instruction with the highest priority. This interrupt unit is also able to generate external interrupts which would have been beneficial with an external proximity sensor. As mentioned in section 3.11.1.02, Atmel offers support with their own software library as well as an IDE which makes integration of MCU much easier.

3.8.2 TI - MSP430

The MSP430 is a low power 16-bit RISC style architecture that features RAM as high as 4 KB and flash memory as high as 120 KB. The system frequency can reach as high as 16 MHz and is a direct result of the supply voltage. At 1.8 V the

MCU runs at around 4.15 MHz while at voltages greater than 3.3 V, the MCU runs at 16 MHz. The MCU possesses four serial communication interfaces with a UART, a synchronous SPI module, and an IIC module. There are 16 registers with four of the registers dedicated to the program counter, the stack point, the status register, and the constant generator. There are a total of 64 I/O pins and peripherals are able to be connected through the data, address, and control buses. There is a DMA controller that is able to bypass the CPU and move data from one memory location to another. The MSP430 offers two 16-bit timers with capture/compare registers that are also able to handle pulse width modulation with PWM outputs. The MSP430 offers the advantage of having extensive documentation for not only the MCU itself, but for software libraries as well. Texas Instruments also offers a free integrated development environment, “Code Composer,” that is able to integrate the software to the hardware with debugging modes through the JTAG interface.

3.8.3 Infineon XE161FU

The Infineon MCU is another 16-bit controller with a five-stage pipeline, up to 2 KB of on-chip dual port DPRAM, 2 KB of on-chip data SRAM, 4 KB of on-chip program and data SRAM, and up to 64 KB of on-chip flash memory. The CPU clock runs at around 66 MHz, has up to 33 I/O lines, and an interrupt system that contains 16 priority levels. Similar to the Atmel MCU, the Infineon is also able to generate external interrupts which will provide support for the external proximity sensor. The MCU offers two serial port interfaces that can be configured as a UART, LIN, SPI, IIC interface, or an IIS interface. With the on-chip peripheral module, the MCU offers PWM signal generation which could have been used for motor controls. The Infineon also features a capture/compare unit that offers two 16-bit timers that can be configured for pulse and waveform generation, and most importantly, pulse width modulation.

3.8.4 Product Assessment

	Atmel Atmega328P	**MSP430**	**Infineon**
Clock Frequency	20 MHz	16 MHz	66 MHz
On-Chip RAM	1 KB EEPROM / 2 KB SRAM	4 KB	Total of 8 KB
Other OCM	32 KB Flash	120 KB	64 KB Flash

PWM	Yes (6 Channels)	Yes (Two 16-bit modules)	Yes (Two 16-bit Modules)
Serial Interfaces	2	4	2
Interrupt Unit	Yes	Yes	Yes
Software Support	Yes	Yes	Yes

3.9 Wireless Transceivers

It was mentioned previously that application of computer vision library made the design process easier with elimination of need to implement image processing algorithms. The team anticipated to use OpenCV (Open Computer Vision) library to perform sign detection function remotely on a PC running a C++ code. Unfortunately, there are major limitations in application of wireless communication. It has been discovered that in order to maintain a consistent image processing speed, the wireless camera will be required to support a data rate of at least 2 Mbps kbps. In addition, most transceivers require a direct line-of-sight between communicating nodes. This can be problematic taking into account a constant movement of the vehicle.
There are many wireless transmission methods available that are widely commercialized in diverse fields of telecommunication industry. The team has considered designing a dedicated transceiver for wireless communications for this specific project, but due to time and monetary constraints it made more sense to make use of available equipment in the market. After several weeks of research, it was realized that some of the existing devices do not meet the project's requirements. A few industry professionals have advised that sending image frames at rates such as the project requires would be impracticable due to nature of wireless technology. Besides hardware capabilities, the team needed to obey all Federal Communications Commission's rules of radio frequency communication. In order to develop a dedicated transceiver, a license needed to be obtained as well as a purchase of designated frequency band. Such requirements would slow down the development process and it has been decided to take advantage of available equipment in the market instead. The following are the available peripherals from online electronics retailers:

3.9.1 HOPE RFM22B-S2 SMD

RFM22B is a transceiver supporting a wireless communication on 433 MHz, 470 MHz, 868 MHz and 915 MHz ISM radio bands. It operates on 1.8-3.6 V range with maximum output power of 100 mW (+20 dBm). Highest data rate achievable is 256 kbps which is equivalent to sending 1 picture frame a second over a range of up to 200 meters. The transmitter utilizes frequency shift keying, Gaussian frequency shift keying and On-off keying modulation schemes. Other useful features included are integrated voltage regulators, frequency hopping capability, on-chip crystal tuning, preamble detector, configurable packet handler, wake-up time, auto-frequency calibration, digital received signal strength indication and low battery detector. TX and RX pins transmit data by 64 bytes in first-in-first-out format. Power consumption is 18.5 mA to receiving and 30-80 mA for transmitting.

3.9.2 HOPE RFM12B-S2 SMD

This is a low cost high performance wireless transceiver comes with lower data rate. Maximum achievable rate is 115.2 kbps. It operates on 2.2-3.8V DC power with current consumption ranging between 15-26 mA depending on RX or TX modes, ¼ of current consumption for RFM22B. Modulation method used for this transmitter is frequency shift keying. Data is transmitted on 433 MHz, 868 MHz and 915 MHz frequency bands. Additional attributes include automatic antenna tuning, analog and digital signal strength indication outputs, wakeup timer, internal data filtering and clock recovery. The receiver bandwidth is programmable to 67-400 kHz bands and receives data by 16 bits in first-in-first-out order. Frequency deviation for the transmitter is programmable from 15 kHz to 240 kHz.

3.9.3 XBee Pro 60mW U.FL Connection - Series 1

This is a popular brand among many projects that have used wireless communications. XBee Pro 60mW operates on 3.3V consuming 215 mA of current. The maximum achievable data rate is 250 kbps. The transmission power is 60 mW (+18 dBm). Compared to the previous 2 devices, this module offers much wider range of 1 mile and transmits on 2.4 GHz band. On the security side, this module carries a 128 bit encryption. Considering the simplicity of this project, this function is not necessary and will most likely not be employed. The device can be reconfigured locally and wirelessly. This may be handy in case the team has to modify the settings while the vehicle is in motion. Extra features include 8 digital input/output pins, retransmission and acknowledged data exchange, direct sequence spread spectrum with 65000 unique network addresses. The most useful characteristic of this module is the relatively higher data rate compared to other options. The module supports a serial UART interface allowing a direct connection to the microcontroller.

3.9.4 XBee Pro 900 XSC RPSMA

XBee Pro 900 characteristics are somewhat unique compared to other XBee family transceivers. With transmission frequency of 900 Mhz this particular module is capable of connecting a high gain antenna and provides a maximum line-of-sight transmission range of 15 miles while significantly compromising the data rate. At a cost of wide transmission range, the maximum data range achievable is only 9.6 kbps, about 30 times slower than required. Reconfiguration can be done locally and wirelessly. It consumes 256 mA current operating at 3.3V with 100 mW(+20 dBm) output power. The input pins are also tolerant to 5V giving some flexibility to utilize multi voltage microcontrollers. Additional features include 7 channels, each supporting 65000 network addresses, support for multiple data formats such as parity and start/stop bits, reliable data delivery supported by retries and acknowledgements, point-to-point, peer-to-peer (unicast) and point-to-multipoint (broadcast) communications. Based on the locality of the project, it is clear that 15 miles of communication range will not be a valuable attribute for application in this project and neither will such a low data rate be effective. This module also supports a serial UART interface.

3.9.5 XBee 1mW Wire Antenna - Series 1

XBee module with a 1mW Wire Antenna is low output power wireless antenna. As one of the previous modules, it also transmits on 2.4 GHz band. Power consumption is 50 mA at 3.3 V with 1 mW (+0 dBm) of output power. Transmission range is 300 feet with 250 kbps rate. It utilizes 8 digital IO pins giving faster data processing. A security feature is included with 128 bit encryption, although it will not be necessary for this project. As described in other modules, it can be configured locally and wirelessly. Additional attributes include ensured data delivery with retries and acknowledgements, direct sequence spread spectrum, 65000 network addresses for every channel available, point-to-point (unicast) and point-to-multipoint (broadcast) communications. Among the modules listed above, XBee 1mW better meets the wireless communication requirements although does not maintain sufficient data rate. UART interface is supported as with previous modules.

3.9.6 Bluetooth Transceiver

An alternative to the previously mentioned devices would be a Bluetooth module that can operate within 30 feet of radius, consuming 40 mA of current at 5 V rating. UART interface simplifies the process of integrating it with MCU and other components.

3.9.**7** Wireless Transceivers - Product Assessment

The team carefully examined all characteristics from available products in order to decide on a module that more closely fits to project requirements set by the team. To facilitate selecting a proper match, a comparison table on the following page is presented.

Table 3.9.6 Wireless Transceivers

Product Name:	HOPE RFM22B-S2 SMD	HOPE RFM12B-S2 SMD	XBee Pro 60mW U.FL Series 1	XBee Pro 900 XSC RPSMA	XBee 1mW Wire Antenna
Frequency Bands Supported:	433, 470, 868, 915 (MHz)	433, 868, 915 (MHz)	2.4 GHz	900 MHz	2.4 GHz
Range:	200 m	200 m	1600 m	24100 m	91 m
Data rate	256 kbps	115.2 kbps	250 kbps	9.6 kbps	250 kbps
Power consumption	80 mA	26 mA	215 mA	256 mA	50 mA
Output power	100 mW	3 mW	60 mW	100 mW	1 mW
Supported Routing Methodology	Unicast, Multicast	Unicast, Multicast	Unicast, Multicast	Unicast, Multicast	Unicast, Multicast
Operating Voltage	3.6 V	3.8 V	3.3 V	3.3V	3.3 V

3.10 Proximity Sensors

Collision avoidance was one of the essential functions of the vehicle that was responsible for preventing physical damage. To provide the highest accuracy achievable, the team thought of multiple methods of object detection including RADAR, SONAR, LIDAR and computer vision. After some internal discussions it was been decided that using electromagnetic and mechanical waves would offer much higher level of precision and deliver better safety and reliability. Computer vision depends on virtual data and was potentially more vulnerable to erroneous results. Another reason for opting towards physical signals was the wide range of products available in the market, eliminating the need to design a self made object detection system which generally would require more time, a luxury the team didn't have.

3.10.1 Ultrasonic Sensors

Use of sound propagation in ultrasonic sensors was a key advantage on accuracy of distance over infrared sensors. Sound waves are capable of detecting an object regardless of the color. They are also immune to external disturbance such as vibration, infrared radiation and interference. Maintaining an immediate response to obstacles ahead was dependent on the response delay of the proximity sensor. There were different scenarios that needed to be addressed and resolved by the navigation system. For instance, if a vehicle ahead was traveling at a lower speed, local AI needed to adjust the speed of the vehicle instead of coming to rest altogether. SONAR emits echo sound that propagates through transmission medium (air) in initial direction. Upon contact with an object, the emitted signal is reflected back towards the sensor that listens for the reflected sound waves. Reflected signal carries information about direct distance to the object. This presented an ability to obtain almost instantaneous response to object detection. One of the shortcomings of ultrasonic sensors was the ghost echo, where the emitted sound could potentially bounce off of several obstacles and result in duplicate reflected waves with time interval delay. Additionally, sound absorbing objects could throw off the accuracy and lead to a crash; therefore, such objects were avoided during testing.

3.10.2 Infrared Sensors

In contrast with ultrasound, infrared sensors use electromagnetic waves instead of mechanical waves. Infrared emitters and detectors were found to be generally less expensive but are extremely sensitive to light and heat. Exposure to direct or indirect sunlight can drastically affect the performance. Infrared sensors apply the process of triangulation in distance calculation. A pulse of light is emitted and reflected by an immediate object. Reflected signal contains information such as the wavelength of the signal and an angle of the object with respect to the sensor. An exact distance can then be calculated based on the angle and the length of the wave. Accurate ranging can be challenging with infrared sensors due to physical properties of electromagnetic radiation. For testing purposes, the team conducted experiments using both ultrasonic and infrared sensors to verify predictions state above.

3.10.3 Sharp GP2Y0A21YK Infrared

Sharp GP2Y0A21YK is a mid range infrared proximity sensor. It outputs an analog signal ranging from 0.4V to 3.1V. Effective range for distances detected is between 10 and 80 cm. For convenience, it carries a solderless terminal connector. Operating voltage rating is 5 V with current consumption of 40 mA. This module more closely fit for the project requirement criteria and was considered for application.

3.10.4 Sharp GP2D120XJ00F Infrared

Sharp GP2D120XJ00F is a low range infrared proximity sensor. It outputs an analog signal ranging from 0.3V to 3.1V. Effective range for distances detected is between 3 and 30 cm. For convenience, it carries a solderless terminal connector. Operating voltage ratings are 4.5 and 5.5 volts with current consumption of 50 mA. This module more closely fit for the project requirement criteria and was considered for application.

3.10.5 Sharp GP2Y0A02YK0F Infrared

Sharp GP2Y0A02YK0F is a long range infrared proximity sensor. It outputs an analog signal ranging from 0.4V to 2.8V. Effective range for distances detected is between 15 cm and 150 cm. For convenience, it carries a solderless terminal connector. Operating voltage ratings are 4.5 and 5.5 volts with current consumption of 33 mA. Distance range of this module was a little too high for this particular application and therefore was considered as the last available option.

3.10.6 Maxbotix LV-EZ1 Ultrasonic

Maxbotix LV-EZ1 is a long range ultrasonic proximity sensor. It outputs analog, pulse width modulation and digital serial signals. One of the performance benefits that was absent in several of our researched infrared sensors was the ability to detect zero range objects. Data read frequency is 20 readings per second. Effective range for distances detected is between 0 cm and 647 cm. It uses an RS232 type serial interface with baud rate of 9600. Analog distance yields 10 mV/in and the PWM yields 147 µS/in. Emitted sound wave frequency is 42 kHz. Operating voltage range is 2.5 - 5.5 V with current consumption of 3 mA. This ultrasonic sensor carried much superior performance and offers additional useful features such as PWM output and zero range detection.

3.10.7 Maxbotix LV-EZ3 Ultrasonic

Maxbotix LV-EZ3 is a long range ultrasonic proximity sensor. It outputs analog, pulse width modulation and digital serial signals. Data read frequency is 20 readings per second. Effective range for distances detected is between 0 cm and 647 cm. It uses an RS232 type serial interface with baud rate of 9600. Analog distance yields 10 mV/in and the PWM yields 147 µS/in. Emitted sound wave frequency is 42 kHz. Operating voltage range is 2.5 - 5.5 volts with current consumption of 3 mA. According to data comparisons, this module carried the same characteristics as previous LV-EZ1 sensor except for a narrower beam of sound.

3.10.8 Maxbotix LV-EZ0 Ultrasonic

Maxbotix LV-EZ0 is a long range ultrasonic proximity sensor. It outputs analog, pulse width modulation and digital serial signals. Data read frequency is 20 readings per second. Effective range for distances detected is between 0 cm and 647 cm. It uses an RS232 type serial interface with baud rate of 9600. Analog distance yields 10 mV/in and the PWM yields 147 µS/in. Emitted sound wave frequency is 42 kHz. Operating voltage range is 2.5 - 5.5 volts with current consumption of 3 mA. Based on data comparison, this module carried the same characteristics as previous LV-EZ1 sensor, except for a wider beam of sound.

3.10.9 Hagisonc HG-B40C Ultrasonic

Hagisonc HG-B40C is a long range sensor with analog output of 2 - 5 volts. Detectable distances range from 400 cm to 600 cm. The device is interfaced with Serial TTL connection. Operating voltage rating ranges are 5V and 35V. Reading is triggered by a 100 – 500 μS PWM signal. Directivity of the sensor is 65 degrees. The sound frequency emitted is 40 kHz.

3.10.10 DFRobot URM04 v2.0 Ultrasonic

DFRobot URM04 is a long range sensor with digital PWM output. Detectable distances range from 4 to 500 cm. Input voltage is 5V with 20 mA current consumption. Echo sound frequency is 40 kHz. Supported interface is an RS486 BUS communication.

3.10.10 Proximity Sensor – Product Assessment

Figure 3.10.10 Proximity Sensors

Device Name	Operating Voltage	Distance range	Power consp.	Interface	Output signal	Sensor Type
Sharp GP2Y0A21YK	5V	10 – 80 cm	40 mA	Serial	Analog	Infrared
Sharp GP2D120XJ00F	4.5 – 5.5 V	3 – 30 cm	50 mA	Serial	Analog	Infrared
Sharp GP2Y0A02YK0F	4.5 – 5.5 V	15 – 150 cm	33 mA	Serial	Analog	Infrared
Maxbotix LV-EZ1	2.5 - 5.5 V	0 – 647 cm	3 mA	Serial	Analog, PWM	Ultrasonic
Maxbotix LV-EZ3	2.5 - 5.5 V	0 – 647 cm	3 mA	Serial	Analog, PWM	Ultrasonic
Maxbotix LV-EZ0	2.5 - 5.5 V	0 – 647 cm	3 mA	Serial	Analog, PWM	Ultrasonic
Hagisonc HG-B40C	5 V, 35 V	400 – 600 cm	Not Avail.	Serial	Analog	Ultrasonic

DFRobot URM04 v2.0	5 V	4 – 500 cm	20 mA	RS486 BUS	PWM	Ultrasonic

3.11 Camera

The team anticipates using a camera module with lowest possible resolution that can yield a consistent data for accurate navigation and reduced power consumption. After several days of research, a list of available technologies was composed to compare the advantages and disadvantages of all available technology.

3.11.1 CCD Camera (Charge-Coupled Device)

One of the technologies used in digital cameras are Charge Coupled Devices. This technology provides better light sensitivity to produce higher quality images and is less prone to noise. When exposed to light, CCD cameras build up charge proportional to the light's intensity on different sections of the charge-coupled device's surface that is made of photosensitive silicon. That charge is then measured to identify precisely how bright each pixel of the image should be. Due to uniform electronic shutter employed in CCD cameras, all pixel elements are registered concurrently allowing a more accurate image. This is one of the important factors that accounts to data extraction and processing and need to be considered during camera selection process. On the other hand, CCD cameras are potentially vulnerable to blooming effect where a high charge in one area can affect the adjacent pixels causing a distortion in the image. Such distortions may yield inaccurate data and lead to poor navigation.

The team discovered only a few online retailers have a limited amount of products related to CCD image sensors. They have similar characteristics in terms of built quality and performance, but there are also variations in technology used. CCDs generally require more complex manufacturing processes while offering better image quality.

3.11.2 CMOS Camera (Complimentary Metal-Oxide Semiconductor)

An alternate technology to CCD is the CMOS. A major advantage of CMOS sensor is the significantly low power consumption as well as low production cost. Considering the mobility of the vehicle, it will be an issue to supply uninterrupted power for a prolonged time; therefore, power efficiency plays a major role in the overall design of the system. These sensors utilize a built in circuit and a photodiode that convert incoming light into an electrical charge. A primary color filter is arranged over the image sensor so that each individual pixel corresponds with one of the colors: red, green or blue. The sensor then generates an electric

signal representing the brightness of each color. This electric signal is read as an analog signal and then converted into a digital data signal for storage.
In contrast to CCD, CMOS sensors do not suffer from blooming effect. On the other hand, taking a picture while in motion can result in skewed images where the image is curved in one direction. This is caused by a rolling electronic shutter, where the pixels are scanned and data is fetched row by row either vertically or horizontally. Such an effect can be a potential danger for the project since wrong data can contribute to even more errors throughout the data processing cycle. Quantum efficiency, given by the ratio of incoming light photons to number of electrons converted, is much higher in CMOS sensors than CCD sensors. Figure **Figure 3.10.3** illustrates the overall quantum efficiencies for both CMOS and CCD over the entire range of visible spectrum. This gives the team a more precise general idea of differences in efficiency between CCD and CMOS cameras. According to the figure shown below, the team anticipates choosing a CMOS camera over the CCD. This will be a useful contribution to solving a problem of low operational time and uninterrupted power supply. Due to lower production costs, many online retailers carry more supplies of CMOS cameras in comparison to CCD cameras.

Figure 3.10.3

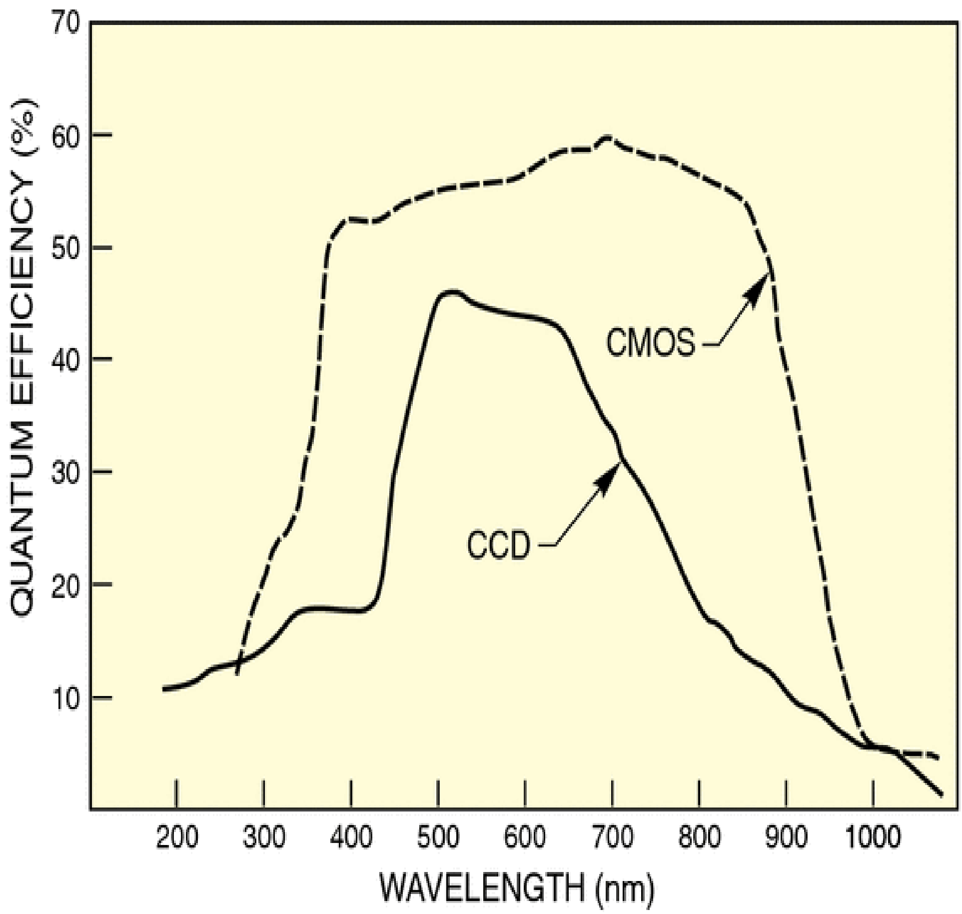


Figure 3.10.3 – Wavelength v. Quantum Efficiency

Sensor Comparisons

CCD vs. CMOS Sensors	CCD	CMOS
cost	expensive to produce because of special manufacturing methods employed	inexpensive due to variety of semiconductors devices that utilize CMOS wafers
power	consumes 100 times more power than CMOS	low power consumption
noise	High signal to noise ratio	vulnerable to noise
maturity	Have been produced for longer period; more pixels	less mature but equal in low and middle range resolutions to CCD
extended functionality	technically feasible; other chips are used	other circuitry easily incorporated on same chip
fill factor	High	low

Table 3.10.1 – CMOS and CCD comparison table

3.11.3 Toshiba CMOS TCM8230MD

Toshiba's TCM8230MD is a color sensor embedded in signal processing unit that outputs an image in VGA. This is a low resolution (640x480) mid quality camera with I^2C parallel BUS interface. Operating voltage rates are 2.6V for photodiode sensor and 1.5V for A/D converter. Current consumption peaks at 40 mA. It uses an RGB color filter and outputs image frames at rates up to 30 fps with automatic blemish correction, auto gain control and white balance. The negative side of this device is that it does not contain a signal processing unit and is designed to be an embedded part of a separate signal processor.

3.11.4 Omnivision OV7725

OV7725 Color CMOS VGA sensor is a low voltage, high performance camera incorporated in a single image processor. The device has high sensitivity for low-light conditions and supports various image sizes scaling down from CIF to 40x30. It uses a noise suppression technology to adjust automatically. Power consumption is very low ranging from 120 mW when active and <0.06mW in standby mode. The maximum effective resolution is 640x480 and capable of recording at a maximum rate of 60fps. It operates on 3.0 to 3.6 V and can sustain temperatures ranging -20C to +70C.

3.11.5 LinkSprite JPEG Color Camera

LinkSprite is a CMOS color camera with JPEG output format. With TTL serial connection interface it operates at 38400 symbols per second. Three modes of resolution are VGA(640x480), QVGA(320x120) and 160x120 pixels. The dimensions of the camera module are 32mm x 32mm. It runs on voltage ratings of 3.3V or 5V with current consumption of 80 - 100 milliamps. This specific camera is used for different applications such as image capture systems, environmental monitoring, industry monitoring, medical equipment, video phone systems, security systems and vehicle based GPS systems. This camera has caught the team's interest on account of flexibility of resolution, low power consumption and simple interface. This particular camera has been seen in use in one of the previous projects. Although it served a different purpose than our intentions, it did match to our specification requirements.

3.11.6 PTC08 TTL Serial camera module

PTC08 is a transistor-transistor logic serial interface camera. This camera takes pictures in 3 different resolution modes; VGA(640x480), QVGA(320x240) and 160x120 at a rate of 30 frames per second. The output format is a standard JPEG/M-JPEG. It has a signal to noise ratio of 45 dB, and offers features such as automatic white balance, automatic exposure and gain. The default baud rate is 38400 but can be increased to a maximum of 115200 symbols per second. Power ratings are 75 milliamps and 5 volts. The size of the module is 32mm x 32mm.

3.11.7 LinkSprite Color Serial JPEG Camera with Infrared

This LinkSprite Camera has an additional Infrared Sensor for low light conditions. Similar to previous devices, this camera also provides 3 different resolution modes VGA/QVGA/160*120. Current consumption is between 80-100 mA operating on 3.3 or 5 volt DC power supply. Image output interface is UART with capability extending to parallel interface. Image format is given in JPEG. The size of the camera is 32mm x 32mm.

3.11.8 FlyCamOne eco V2

This particular camera is specifically used in autonomous robots. With an integrated module it can record and store video images on a microSD card. Another useful feature is the ability to send control commands though an open channel with a wireless transceiver. The camera's housing provides a flexible mounting and can be positioned to view at different angles and rotate in different orientations. The module supports up to 8 GB of memory card. Output resolution is 720x480 at 30 frames per second. This could affect the processing time and create issues in data storage. Power requirements are somewhat unique for this device. According to the manufacturer's specifications the team will need to provide a Lithium-Polymer battery with 3.7 volts of DC power, as well as 6 volts for the RC receiver. There's also an on-board mini-USB port for easy access to the memory unit. One extra feature that is absent in other cameras is the ability to record sound as well. The device has an embedded microphone with a status LED.

3.11.9 D-LINK Cloud Camera

Unlike previously mentioned devices, this camera comes with embedded wireless image transfer functionality and supports multiple transmission schemes. At a frame rate of 30 fps and variable resolution, it perfectly fits the needs of the project. Power consumption for this device is 1.2 A @ 5V.

3.11.9 Cameras - Product Assessment

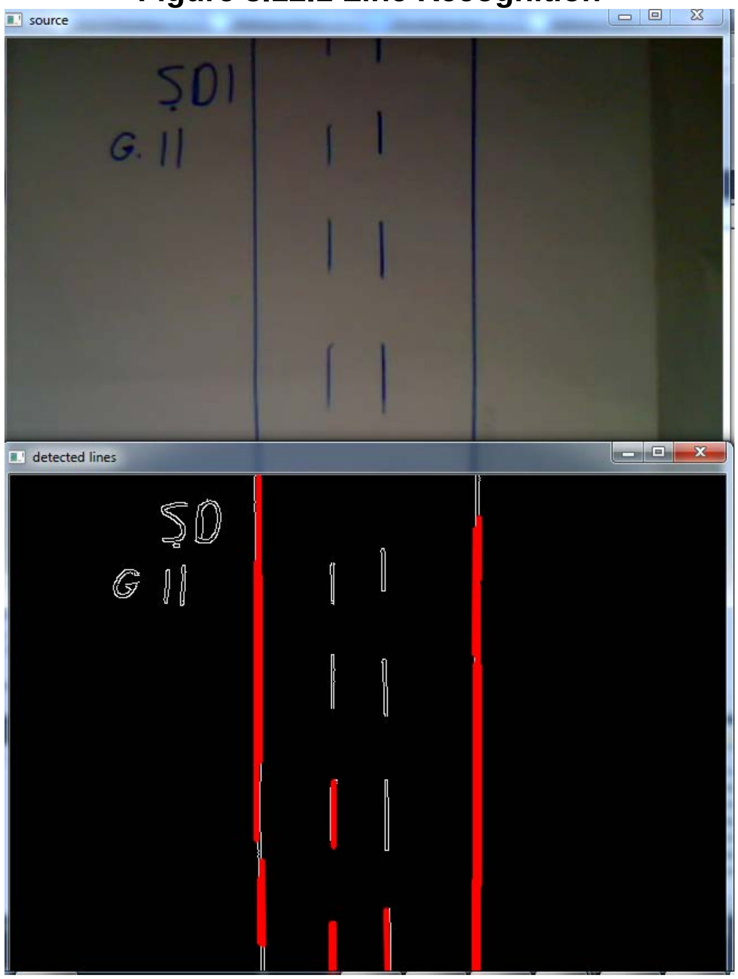
Name	Resolution	Power Consumption	Operating Voltage	Interface	Frame Rate
Toshiba CMOS TCM8230MD	640x480	40 mA	2.6 V	I^2C BUS	30 fps
Omnivision OV7725	640x480	36 mA	3.0-3.6 V	Serial	60 fps
LinkSprite JPEG Color	640x480, 320x120, 160x120	100 mA	3.3 V, 5 V	TTL Serial	30 fps
PTC08 TTL	640x480, 320x120, 160x120	75 mA	5 V	TTL Serial	30 fps
LinkSprite Color with Infrared	640x480, 320x120, 160x120	100 mA	3.3 V, 5 V	TTL Serial	30 fps
FlyCamOne eco V2	720x480	220 mA	3.7 V	USB	30 fps

3.12 Pattern recognition

Throughout the research process of the project, the team had been studying possible image processing algorithms that are available in computer vision area. We have consulted with a few faculty members who have expertise in this area, and they have suggested looking into OpenCV library that has a wide range of computer vision functions available for object detection and pattern recognition. Several online tutorials have been reviewed about application of OpenCV in object detection and tracking. We have implemented multiple minor test programs to verify that OpenCV supports necessary functions for this particular project. We have successfully achieved a program for line detection and tracking that can be embedded into the main software module. The two key elements of

OpenCV will be employed by the team are the Hough Line Transform and the Hough Circle Transform. Image below demonstrates an example of line detection performed by the team.

Figure 3.12.1 Line Recognition



3.12.1 Hough Line Transform

Hough Transform is a method of extracting simple shapes/forms such as a line, a circle, etc. The algorithm is implemented using an array with a length equal to the number of unknown parameters. For implementation purposes, polar coordinates were be employed where points are represented by parameters ‘r’ and ‘θ’. In this case, a line is given by following equation:

For point (a_0, b_0), a set of lines that go through this point can be determined using the following formula.

This yields a set of pairs (r, θ) that represent every line that goes through points (a_0, b_0). Plotting a family of lines that go through (a_0, b_0) results in a sinusoid wave. Same procedure is repeated for all points in the frame. If an intersection is detected between the curves of 2 different points in the plane that indicates that these 2 points belong to the same line. With this method, Hough Transform can effectively detect all intersection between points. For more precision, a threshold can be set to indicate a minimum number of intersections needed to detect a line in an image frame. But for the purpose of the project, the algorithm will be limited to detect only the lines on the road based on its color, and ignore any additional detected lines.

3.12.2 Hough Circle Transform

Unlike line detection, circle detection relies of 3 parameters: a_0, b_0, r_0, representing the center of the circle and the radius respectively. Using “Canny” edge detector operator, an image is pre-processed to detect all edges that are present in the frame. For every point that lies on the edge, a circle is plotted around that point, making it the center with radius r. An array is used as an accumulator to increment the radius until a desired value equal to r_0 is achieved. Another accumulator counts the number of circles that pass through each edge point. At the end, the highest count is selected. Center coordinates of circles with the highest count in the image frame are presented as detected circles.

3.13 Line Sensor Array

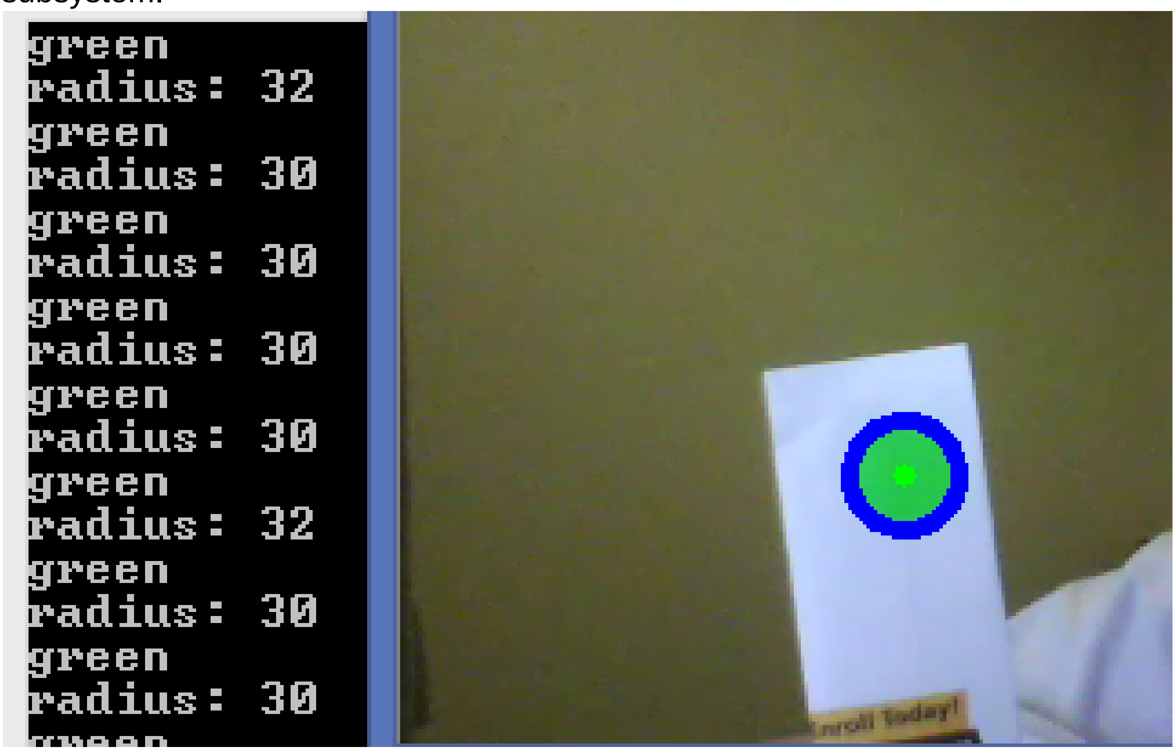
For an alternate line tracking module, the team have considered designing a custom Line Sensor Array. The module was made up of Infrared Rx and Tx LED pairs. Operating scheme will be as follows: Tx emits an infrared radiation towards the ground. Reflected rays will be scanned by the Rx receiver indicating the color beneath. For instance, if the line beneath an LED is white, a value higher a certain threshold will be returned. Likewise, if the color beneath an LED is dark, a value smaller than the specified threshold will be returned. Using a series of such LED pairs would permit detecting in which direction the vehicle is drifting away from the centerline.

4. Hardware and Software Specifications

With diversity implementation methods of autonomous agents, this team experimented with multiple techniques on 2 vehicles to perform identical functions. This was in anticipation of taking on different challenges, as well as assessing our knowledge on different levels. In particular, we initially wanted to design two different image processing units and test them on 2 different vehicles jointly in the same environment and scenario.

4.1 Image Processing

Before starting the design process, a theoretical hardware performance analysis had been done. The team established detailed hardware requirements as well as specified capabilities and characteristics for all devices and subcomponents. They will be addressed throughout the hardware design section within every subsystem.



4.1.1 Camera Selection

Data rate calculations based on multiple minor tests have revealed that in order to maintain a consistent real time processing, a camera needs to supply a data rate between 20-30 fps. Calculations shown in project requirements section indicate that a picture per inch is sufficient for this type of application. Important factors such as low resolution, high frame rate and low power consumption are taken into consideration. Looking through the list of available products, the team has decided to choose the DLINK Cloud Camera. The reason for favoring this camera over the rest is flexibility of resolution mode. It can take pictures at 160x120 requiring less space and reduced processing delay. Power consumption is within a tolerable range, although it has been anticipated to use a camera with lowest possible current consumption. Embedded wireless capability will simplify the interface between the car and the remote computer.

4.1.3 Line Detection Algorithm

Images generated by the camera will be stored on a microcontroller where a line detection algorithm will be utilized to extract the data. Due to redundancy of entire picture frame, the team will only utilize a portion of the image to detect the line. The algorithm will scan through the midpoint row of the binary 2-d array representation of the picture until it encounters a white colored element which will indicate the left edge of the line of a fixed width. Detected element's index will be used as a reference point indicating the position of the line in the frame with respect to the left edge of the frame. Returned index will be compared to the value of the midpoint element to generate the offset between the centroid of the car and the line. We anticipate using a white colored tape to draw the lines on a dark surface.

4.1.4 Mounting

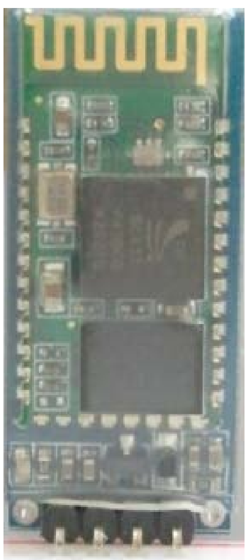
The Camera was placed on top of the vehicle and strapped with duct tape. It communicated with the remote PC via a WI-Fi router that had established a static IP with the camera and the PC.

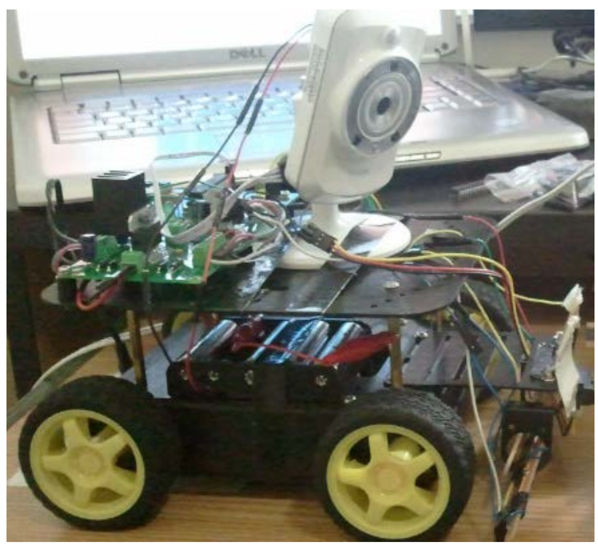
4.2 Remote Image Processing

Remote image processing unit served as a primary means of sign detection and a secondary method of line detection. Implementation complexity of shape detection algorithm led the team to decide on using an OpenCV Library for this purpose. At a lower rate, it was possible to transmit images at 1 image per second. Although this was not a satisfactory for line tracking, resulting time delay allowed an effective speed for sign detection since they did not occur as frequently, therefore, need not be scanned as frequently.

4.2.1 Wireless Transceiver

Among the selected products, the best choice turned out to the a Bluetooth module with simple UART communication protocol. It simplified the process of connecting the module to the MCU and programming it to maintain a stable communication with remote PC. Additionally, compared to other devices, the Bluetooth module cost the team less and consumed significantly less power.





4.2.2 Wireless Communication and Data Extraction

A remote PC computer runs a c++ code in Visual Studio IDE. Due to the nature of the software component, there’s no need to develop a graphical user interface. Upon the start of test runs, image processing code will be running and scanning for input data. The program will listen to the serial port for incoming image data. Image transfer will be initiated by the microcontroller which will send an interrupt signal to the PC through a Bluetooth module indicating its intention to send the images. Once the image is transferred, the microcontroller listens to a response signal from the PC. Image processing program applies all necessary algorithms such as Canny, Hough Line Transform and Hough Circle transform and return output data for navigation AI. Upon extraction of coordinates of the line and identification of detected signs, remote PC sends this data back to the microcontroller.

4.3 Proximity Sensor

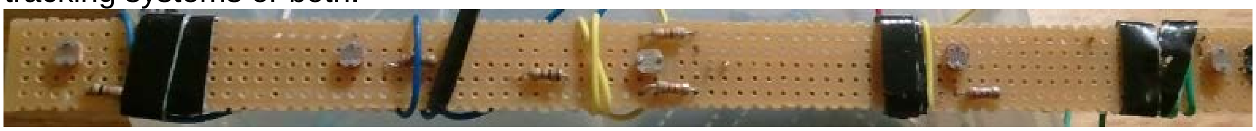
Operational procedure of a proximity sensor was relatively simple. The navigation software continuously listen to sensor ports and compare the returned value to the threshold value identifying whether an object is present on current path.

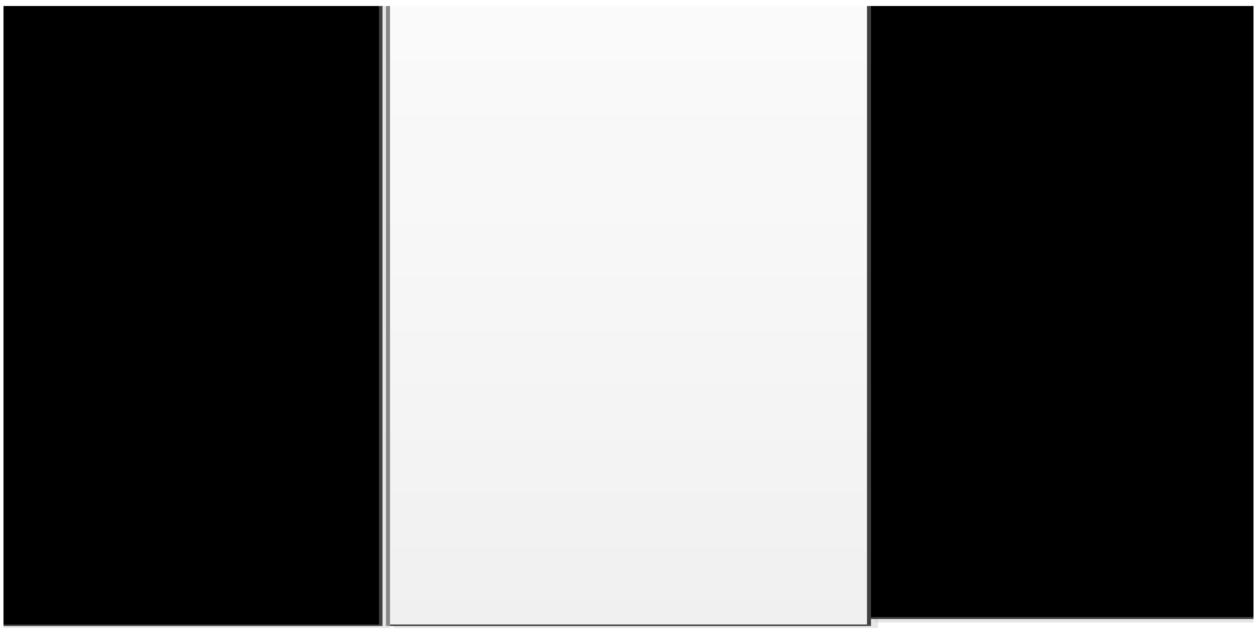
4.3.1 Product Selection

The scale size of the vehicle played a major role on selecting a proximity sensor with respect to the effective measurable distance. Initial approximations were between 3 inches minimum and 1 car length maximum. Additional factors that influenced the team’s preference were maximum and minimum travel speeds, stopping distances, power consumption, light sensitivity, heat and noise. The comparison table was referenced to determine the best available option and the team selected Sharp IR analog proximity sensor due to its low power, low dead-zone distance detection capability, and analog output signal. Among the list of ultrasonic sensors it had a major advantage over infrared sensors in terms of output signal type, immunity to noise, accuracy and power consumption.

4.4 Line Sensor Array

During the testing phase of the project, the team will enable both the line sensor array and an on board image processing unit on one vehicle and a remote image processing unit on the other. AI will reference data from both the line sensor array and image processors and compare them for consistency. Depending on the results of the test, the team will modify the AI to rely on one of the two line tracking systems or both.





The line sensor array consists of a prototype board with hand soldered circuitry and screwed in underneath the vehicle on the front side. Image above shows a rough sketch of the device attached to the car.

4.5 Software Design

4.5.1 Microprocessor Software

One of the benefits of the using the ATMega328P MCU was the enormous amounts of documentation and resources that were available free of charge. Atmel provides several libraries pertaining to a multitude of peripherals that allows users to implement their designs without the headache of searching the internet for a snippet of code. It is important to note that though we used the ATMega328P with a custom printed circuit board, we made use of the

ATMega328P that been instantiated with the Arduino bootloader. By using this bootloader, the group was able to program the chip using the Arduino Uno board using the provided scipts, remove the chip from the Arduino board and place the chip in the custom board. This was not only extremely convenient in terms of downloading a program onto the board, it also helped to provide a streamlined version of C through scripts that made programming very easy.

4.5.5 Main Code

The main job of the CPU when using the line sensor array was be to find what is called the, “center line.” For example, if the user is looking for a particular color and is receiving values ranging from 0 - 255 from the camera, instead of evaluating the block of pixels or the entire resolution, the user can simply choose a middle line or what will be referred to as a, “scanline.”

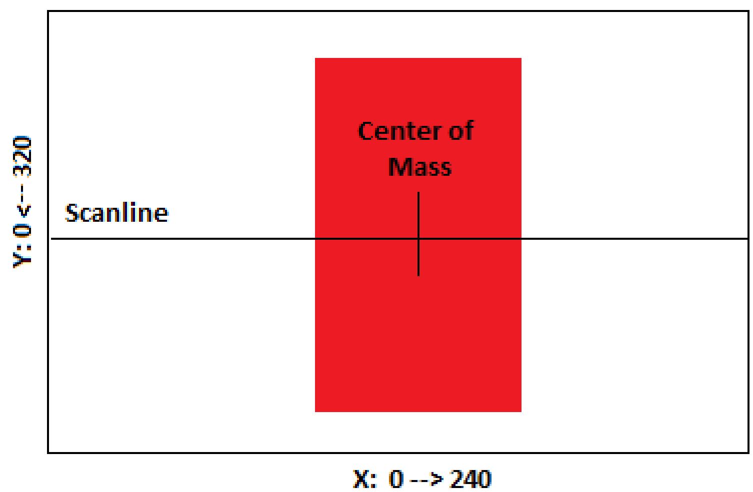


Figure 4.2.2.04

As shown in figure **4.2.2.04**, the scanline represents a middle point on the y-axis so if the user is using a 240 x 320 resolution, then the y-scanline will be around 160. The user would then sum all of the pixel values from x = 0, to x = 240. Because certain colors represent certain values on the RGB scale for pixel values, the user would then divide the total sum of all the pixel values on the scanline by the x-axis values that were within a particular threshold that represented the color that the user was searching for. This number is the center of mass or the centroid of the colored object the camera will be sending back. The deviation of this centroid from the middle of the x-axis determined the amount the wheels needed to be turned and consequently, the width of the pulse.

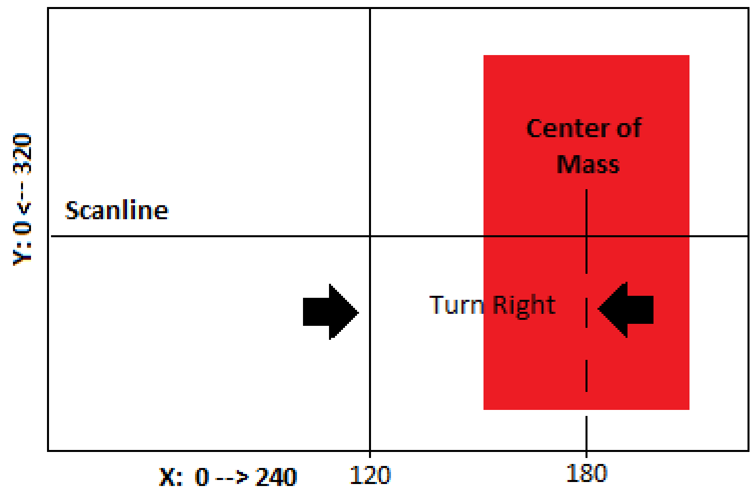


Figure 4.2.2.05

This process was achieved by several line sensor evaluations, which returned a number indicating to the CPU the deviation of the centroid of the detected image from the center of the X-axis. From figure 4.2.2.05, the center line is X = 120, so in this image if the center of mass is X = 180, the function will return 60. Because the line sensor array was constantly returning new data and in order to ensure a smooth transition back to the centerline, the algorithm could not simply account for the change from the center line, but had to take the previous deviation into account. This allowed for the vehicle to gradually return to the line and avoid any jerky movements. The next step was to convert this number into a useable signal which was simply achieved though software, and consequently an appropriate value was sent to the pulse width modulated pins.

In the main part of the code, several libraries had to be called for the initialization of that particular hardware component. The library for the USART or the SPI, the GPIO pins, the PWM module, the DMA, the A/D converter, the external and internal interrupt controller, and the flash libraries will all have to be defined and initialized within main(). As shown in figure 4.4.2.01, the general layout for main() is relatively straightforward and after all of the hardware components are initialized, the USART will receive data from the camera with the function, USART_ReceiveData() which takes in a pointer to the instance of the USART that is being used and passes back an unsigned word. It seems likely that the processor will be processing image data, so the image data received from the USART will need to be placed in either RAM or flash memory where it will wait until the processor is ready. The function that writes to flash is FLASH_ProgramWord() and takes in two unsigned words, one representing the address to be written to, and one representing the data.

From here the data will be sent to one of the external pins for pulse width modulation, but the CPU will have to determine several values such as duty cycle, pulse, polarity, and so on. At any time during these processes, there remains the possibility of an external interrupt being generated which must be dealt with quickly. As noted in the proximity sensor section, the sensor can either use a simple digital pulse to trigger the interrupt or the interrupt can be generated through the use of the analog comparator. Whichever strategy is chosen, the library for the external interrupt controller is very detailed and contains an initialization function, EXTI_Init(), that determines whether the selected pin will be used as an interrupt or an event, and specifies the specific trigger that will create an interrupt. The triggers are edge rising, edge falling, or both rising and falling edges.

Figure 4.2.2.06 Code Functions

Function	**Return Type**	**Description**
initPeripherals()	void	A general function to initialize all the peripherals
getDeviation()	Float	Find distance from center
getPulseWidth()	Float	Calculate pulse to send to the motor controls

In the next two figures**: figure 4.4.2.06 and 4.4.2.07**, a general layout of all the peripheral functions are organized into block diagram as well as the overall goal for the flow of the software. This will provide a helpful reference from which to work as well as understand the basic flow of the program.

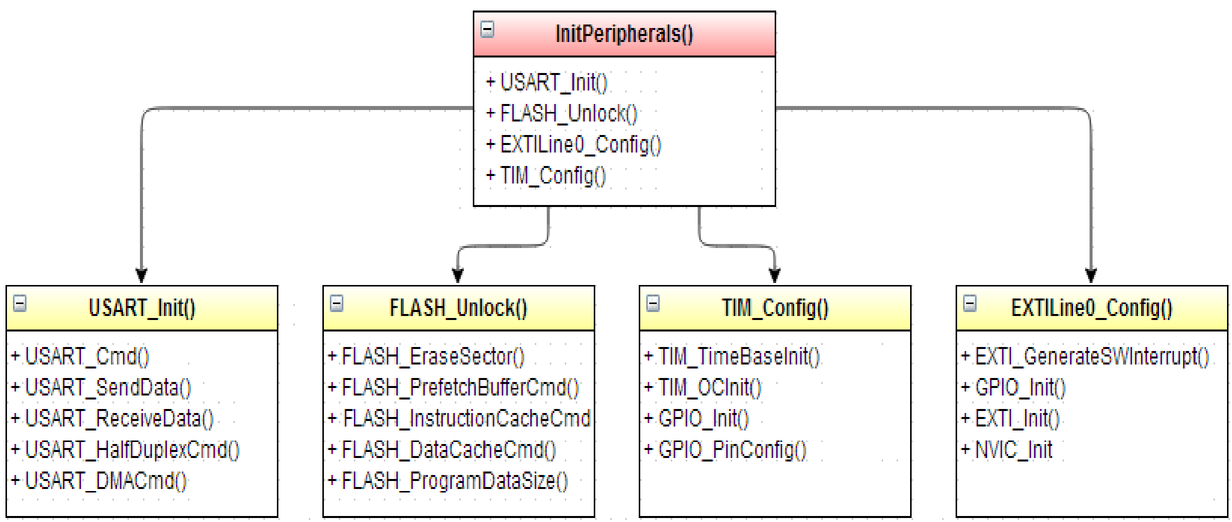


Figure 4.4.2.06

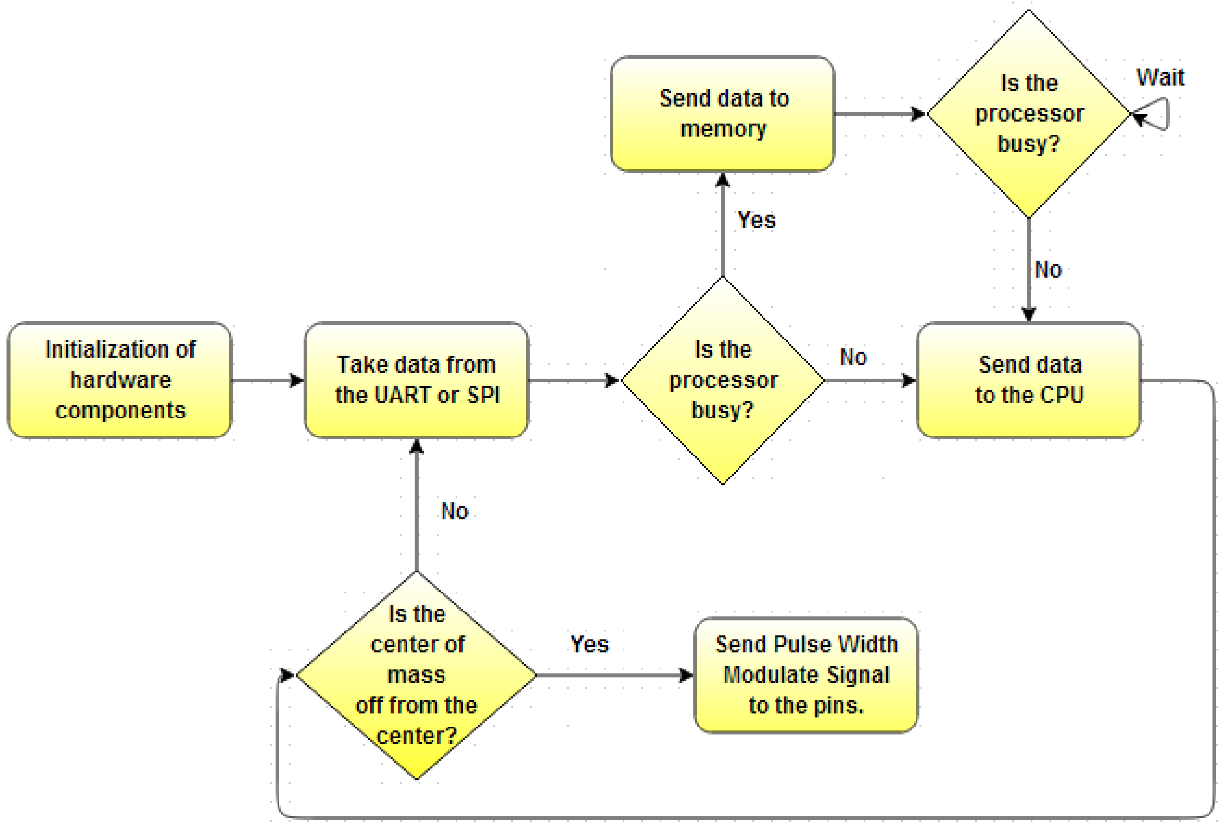


Figure 4.4.2.07

4.6 Microcontroller

Taking into consideration all of the requirements for the various peripherals and objectives of the project, the microcontroller that best suited the needs of the project was the Atmel ATMega family of microcontrollers. This particular MCU possessed a wide array of features including:

- 168 MHz CPU Clock
- Up to 192 KB of SRAM and 64 KB of CCM
- Up to 1 MB of flash memory
- Flexible Memory Controller
- Multiple A/D converters as well as D/A converters
- Multiple channels for Pulse Width Modulation
- Up to 15 Serial Interfaces
- External Interrupt/event controller

After wading through large amounts of documentation and similar examples, it was discovered that the ATMega328P MCU provided a solid hardware platform that would not only be able to handle the rigors of processing the signals from the image processing unit, it also possessed the capability of interfacing to the motor controls as well as the external proximity sensor. Atmel also has extensive software libraries that not only detail the process of programming their microcontrollers, but software and examples for various peripherals and internal hardware components like flash. As seen in figure 4.2.1.01, there were three peripherals that needed to be accounted for and a corresponding interface that will be addressed in the following sections in conjunction with the MCU specifications.

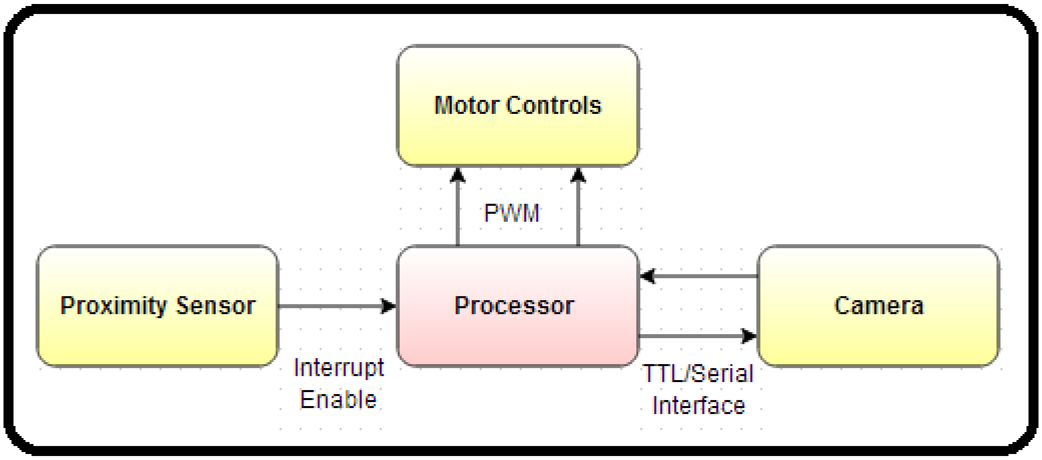


Figure 4.2.1.01

4.7 Hardware Interface

4.7.1 Camera Interface

The wireless interface as well as the camera interface required a TTL/Serial interface with two pins for receive (Rx) and transmit (Tx). The MCU provided multiple serial interfaces such as a USART and a serial peripheral interface (SPI) module that enabled the required serial interface to the camera. The USART interfaces were able to support communication speeds of up to 10.5 Mbit/s while the SPI was able to support suitable communication speeds between the MCU and the wireless module. It was initially thought that the serial communication could be controlled by the direct memory access (DMA) controller. The use of the DMA would be able to provide several benefits for the project as the DMA allowed for dedicated FIFO transfers for all peripherals connected through the advanced peripheral bus (APB) as well as memory-to-memory transfers, memory-to-peripherals transfers, and peripheral-to-memory transfers.

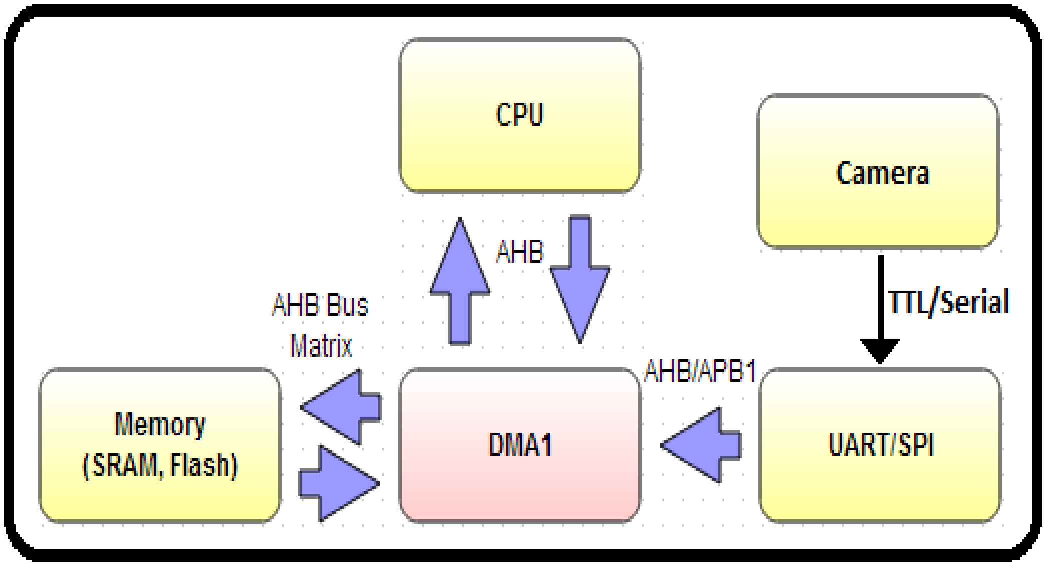


Figure 4.2.1.02

As seen in figure 4.2.1.02, the DMA would have allowed for several options and flexibility. First, the CPU would receive data from the UART through the DMA and perform any calculations pertaining to the image data while the next stream of data would be sent to memory. The memory would store the data until the CPU was done with the previous stream and then transfer its contents to the CPU and await the next stream of data. Initially this was thought to be a suitable strategy for the transfer of data, but after subsequent tests it was found that use of the DMA was not needed. Because the images from the camera were being sent to an external computer for processing, serial communication did not require any special use of the chip's resources, rather the on-chip RAM was sufficient memory for any necessary variables,

4.7.2 Controls Interface

Because this project required the use of a digital servo, pulse width modulation was required to send the necessary signals to the servo. Our project required the use of six pins for PWM and the MCU provided the sufficient amount as well as timers, each with pulse width modulation modules. The timers were able to support both edge and center aligned pulse width modulated signals and the timers also supported the ability for programmable dead times.

When the external CPU was done processing the image data from the camera, the calculated signal was sent back through the wireless communication module where the signal was processed and sent to the motor controls to make any compensations.

4.7.3 Proximity Sensor Interface

Because the processor was largely consumed by processing the image data, it was necessary to provide a simple, low cost, solution for interfacing a proximity sensor to the processor. This would allow the CPU to halt its current operation and deal with the signal from the proximity sensor that would represent the threat of a collision. The solution to deal with this was through the use of an interrupt controller or an external interrupt controller that would signal the CPU to stop its current operation and deal with the interrupt. Versatility of the microcontroller allowed for the use of both analog and digital interrupts to be used which was beneficial.

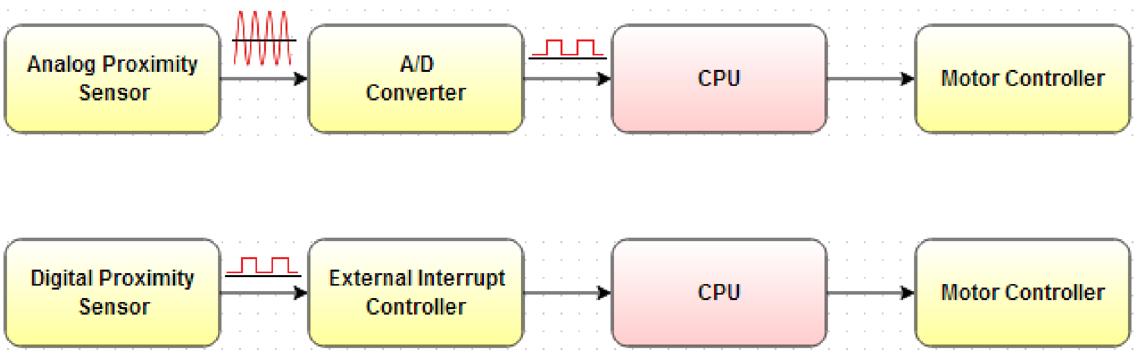


Figure 4.2.1.04

If the output signal from the proximity sensor was a digital signal, the processor offered up to 6 GPIO pins that were able to be connected to 2 external interrupt lines. Whenever the sensor sent back a digital signal, the external interrupt line would generate a high priority interrupt which the processor then dealt with. Because the sensor we were using output an analog signal, the approach was similar, but the sensor needed to be interfaced through one of the 6 analog channels that made use of the A/D converter which was triggered by one of provided timers.

Listed below (Figure 4.2.1.05a) is table with a reference to all of the pin connections, their number, the peripheral they connect to, and their particular function.

Pin Connection (Number)	Peripheral Connection	Description
PB6 (pin 92)	Camera	USART1_Tx (Transmit)
PB7 (pin 93)	Camera	USART1_Rx (Receive)
PA2 (pin 25)	LV-EZ1 Sensor	USART2_Tx
PA3 (pin 26)	LV-EZ1 Sensor	USART2_Rx
PB11 (pin 48)	LV-EZ1 Sensor	TIM2_CH4 (PWM)
PA6 (pin 31)	DRV 8833 Motor Controller	TIM3_CH1 (PWM)
PA7 (pin 32)	DRV 8833 Motor Controller	TIM3_CH2 (PWM)
PC6 (pin 63)	DRV 8833 Motor Controller	TIM8_CH1 (PWM)

PC7 (pin 64)	DRV 8833 Motor Controller	TIM8_CH2 (PWM)
Vss (pins 27, 99)	All peripherals	Ground
Vdd (pins 50, 100)	Power In	Voltage in

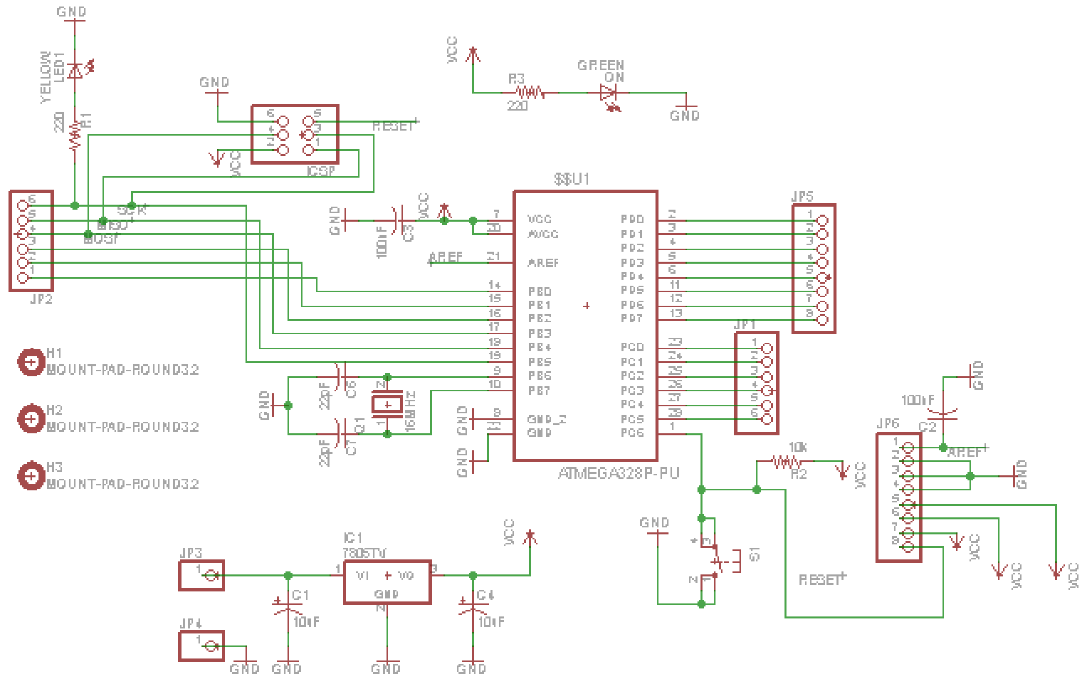


Figure 4.2.1.05b – Atmega328P Pinout

Hardware Mounting - Mounting of this particular microcontroller was done by the group itself. Because the board was created through the Eagle CAD software using through-hole components, all soldering and maintenance was performed by the group.

4.8 Vehicle Platform

4.8.1 Selection

The selection of parts and platforms quickly became a cumbersome undertaking when the decisions could only be made from statistics and pictures available on the internet. If the design team consisted of hobbyists with a wealth of experience in the remote control realm then it would have been less difficult to design a completely custom autonomous vehicle by each individual part. For the team, the decision was more practical to modify an existing platform to achieve the project goals.

Though the aftermarket arena for hobby grade parts is large, technical references on the processes of selecting the proper components and associated documentation of doing so is mostly anecdotal excerpts from individuals' projects. A considerable amount of monetary and time risk could have been involved in trying to simply replicate a project that is written about online. The claims associated with performance and reliability generally are not scientific and therefore were not going to be appropriate for a senior design level autonomous vehicle project.

To avoid unnecessary costs and errors, for the scope of this endeavor a vehicle would only be chosen that is commercially available and one that was made of reasonable quality. Once a good understanding of the theory of component operation and interaction was gathered, a vehicle platform to adapt those ideas and specifications could be selected.

The main purpose of the research in the earlier sections involving various motors, solenoids and platforms was to have a broad canvas of ideas and begin to make decisions on how particular parts may or may have fit into the evolving idea and premise of the autonomous vehicle as a whole. An engineer or designer could simply have made decision to find a car and then immediately began to design the project and go to work. If that was the methodology then important ideas and technologies could have easily been hidden or missed completely.

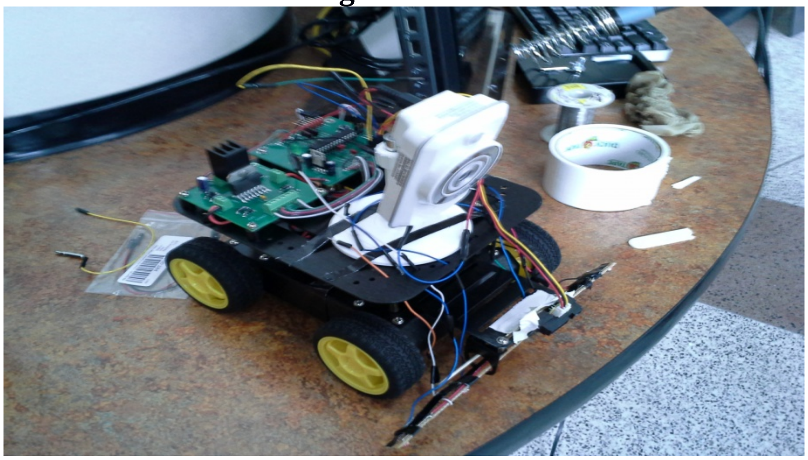
For the budget minded autonomous vehicle designer, the decision that most intelligently reflected the need for performance and financial boundaries is the selection of DF Robot 4WD Platform. Ultimately, the design for the vehicle platform mirrored one of the researched models with an aluminum body and a four-motor design. Two DF-Robot 4WD Mobile Platform kits, shown completed in **Figure 4.8.2.1,** were purchased from RobotShop.com for a price of $55 each.

Figure 4.8.2.1

Figure 4.8.2.2

They required assembly, as shown in the **Figure 4.8.2.2**, and took approximately 1.5 hours to assemble. The assembly consists of mounting all of the parts together as well as making soldered connections for all four motors and the control switch. This platform was ideal for many reasons. It has a robust, aluminum body and frame which was sturdy and was well-suited for the team's needs such as being drilled for mounting sensors and circuit boards. **Figure 4.8.2.3** shows the vehicle in complete operating form.

Figure 4.8.2.3



4.9 Motor Control

The L298n motor controller from ST Microelectronics is the product that best met the requirements for the autonomous vehicle which were based on the following specifications:

- Affordability/Free Samples
- Dual H-bridge
- Merge-able bridge
- High noise resistance; L298n can handle logic 0 to 1.5 volts
- 2 Amps/H-bridge or 4A total
- External Heat Sink Terminal
- Test-board style pin construction
- Vs (motor supply) rated at 3-50 Volts; allows for flexible motor options

The L298n is a tried-and-true motor controller and is very common among electronics enthusiasts. **Figure 4.9.1** shows the 2-dimensional representation of the L298n. It has a fifteen-pin configuration as well as a vertical dome on the top of the chip to attach an external heat sink. This is one the exceptional features of the device and by having the exposed heat sink terminal, the engineering and design team was able to compensate for increased heat loads which occurred during the testing and evaluation phases of the project.

Figure 4.9.1

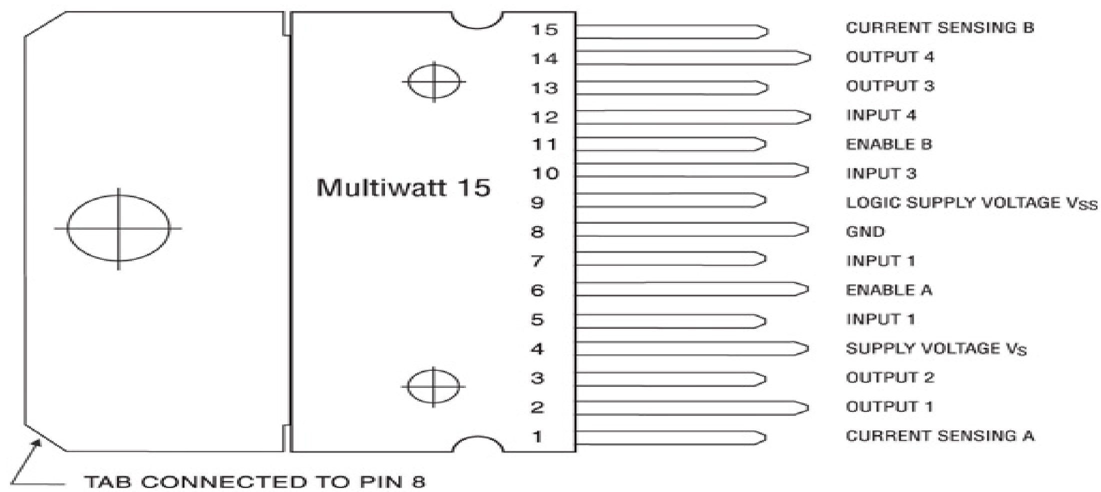
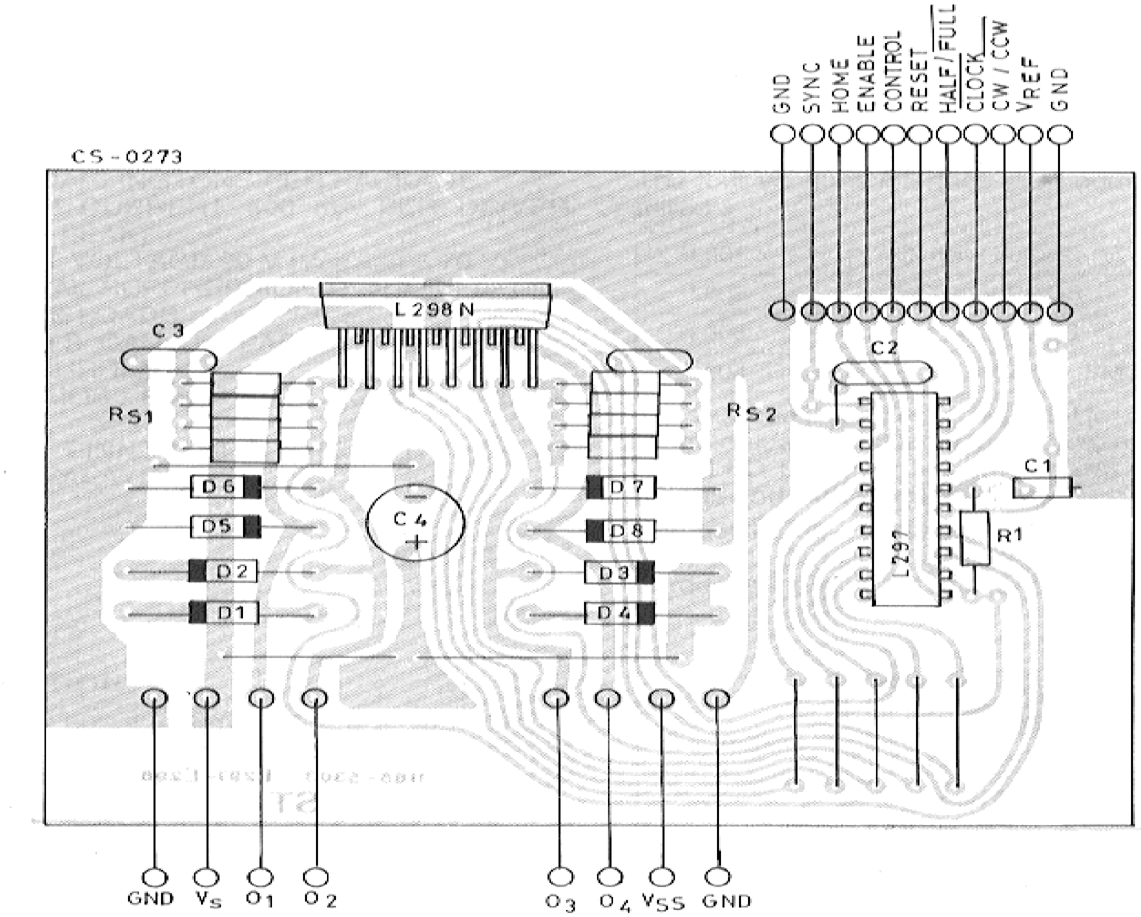


Figure 4.9.2 is an important image for the scope of this design document. This is the recommended circuit board lay-out which was consulted and utilized in the design of the autonomous vehicle. While some small differences occurred in the final design, it was important for the designers and engineers to pay close attention to the board arrangements and spacing. ST Microelectronics is a global company and their expertise in mounting and testing should not be ignored. The L298n package configuration is unique in the fact that it can be inserted in a bread-board for testing and does not require a through-hole mount to be used. For a team with limited resources and budgets, this was a very attractive feature. Also seen in the 2-dimensional image is the metal heat-sink attachment to the entire gray area of the board. This method of PCB design is an excellent choice for the safety of the sensitive semiconductor components built within the microchip. This is connected to the common ground of the microchip and with an external sink with cooling fins it will do an excellent job of drawing heat away from the internal components.

Figure 4.9.2

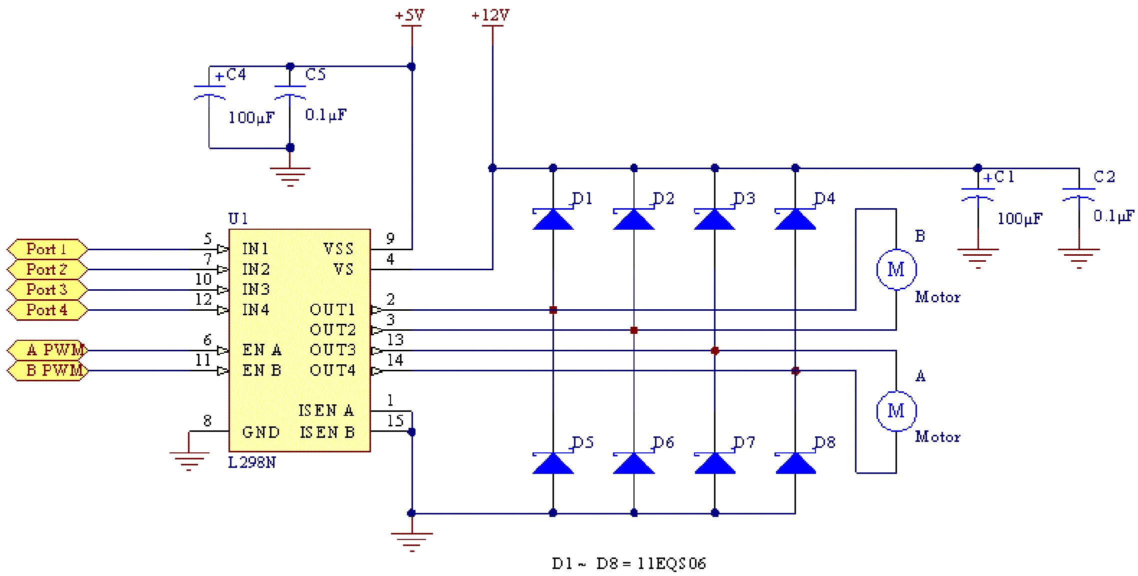


(Permission granted from ST Microelectronics)

4.9.1 Motor Controller Schematic

The schematic in **Figure 4.9.1.1** shows how the L298n was connected and configured in the design of the autonomous vehicle. The square, yellowish rectangle is the L298n and its fifteen output and input pins are labeled. In this design, a 12 volt supply **(Vs)** was connected via externally mounted rechargeable NiCad batteries. This is the power source that exclusively is used for the needs of the drive motors. A 5 volt supply to **VSS** from the microcontroller was used to connect to **Pin 9.**

Figure 4.9.1.1



Four 11EQS06 low forward voltage drop diodes (**1, 2, 3, 4)** were connected from the supply **(Vs)** to their respective cathodes and with each individual anode connected to pins **2, 3, 13 and 14**, respectively.

Diodes **(5, 6, 7, 8)** had their respective cathodes connected to the opposing individual anodes. Their respective anodes were all then be connected to the grounded terminal **15. Port 1 and Port 2** are the high and low pins for **Motor A. Port 3 and Port 4** are the high and low pins for **Motor B. Figure 4.9.1.2** describes their functions.

Figure 4.9.1.2

Motor	Port	State	Rotation
A	1	High	CW
A	2	Low	CCW
B	3	High	CW
B	4	Low	CCW

Port A and **Port B** are the pulse width modulation (PWM) connections from the microcontroller which were used to regulate and control the respective motors' speed and outputs. The pulse width modulation directly related to the power output and served as a current limiting action to control the RPM's of the drive motor's shaft. On the supply **VSS** two capacitors were wired in parallel to facilitate quality voltage supply. Additionally, two capacitors were needed on the **Vs** supply side to ensure quality power conditioning. **Pin 8** is the common ground terminal and was connected to both supply grounds and the ground terminals of all associated components such as the microcontroller.

The current sensing **Pin 1 and Pin 15** could have been used to detect the real time output of the devices connected to it. This is very important and utilized for several reasons:

- Motor amperage measurements
- Formulas to relate data to RPM or angular measurements
- Supervisory systems such as an LED that signals the use of the device
- Power management calculations.

4.9.2 Motor Controller Mounting and Wiring

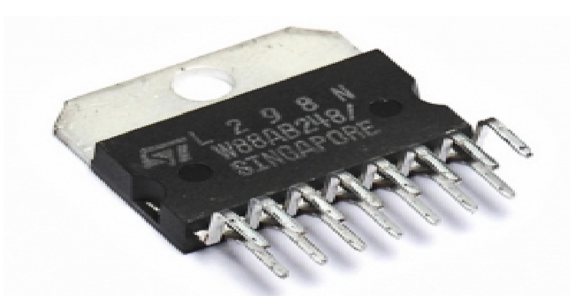
Once the L298n-based PCB fabricated it was ready to be mounted to the chassis of the autonomous vehicle platform. The following steps describe the process used to prepare and mount the printed circuit board to the autonomous vehicle chassis.

Hardware, wires and fittings needed.

1) (4) 2.125" long x 0.25" diameter hex aluminum standoffs. F-F, 6-32 thread.
2) (8) 0.25"long aluminum Phillips head screws. F-F, 6-32 thread.
3) Soldering iron
4) Lead-free electronics solder
5) 20 AWG copper wire
6) Insulated 20 AWG wire crimps

Procedure:

1) Drill 4 four 1/8" holes in the vehicle chassis aligned with the four PCB holes.
2) Attach 4 6-32 screws to the bottom of the stand-offs and through the drilled holes.
3) Align the PCB to the opposite end of the stand-offs and attach the remaining 4 screws.
4) The 20 AWG wire should be used connect the microcontroller, motors and batteries to the motor controller as directed by **Figure 4.9.1.1** in this section.



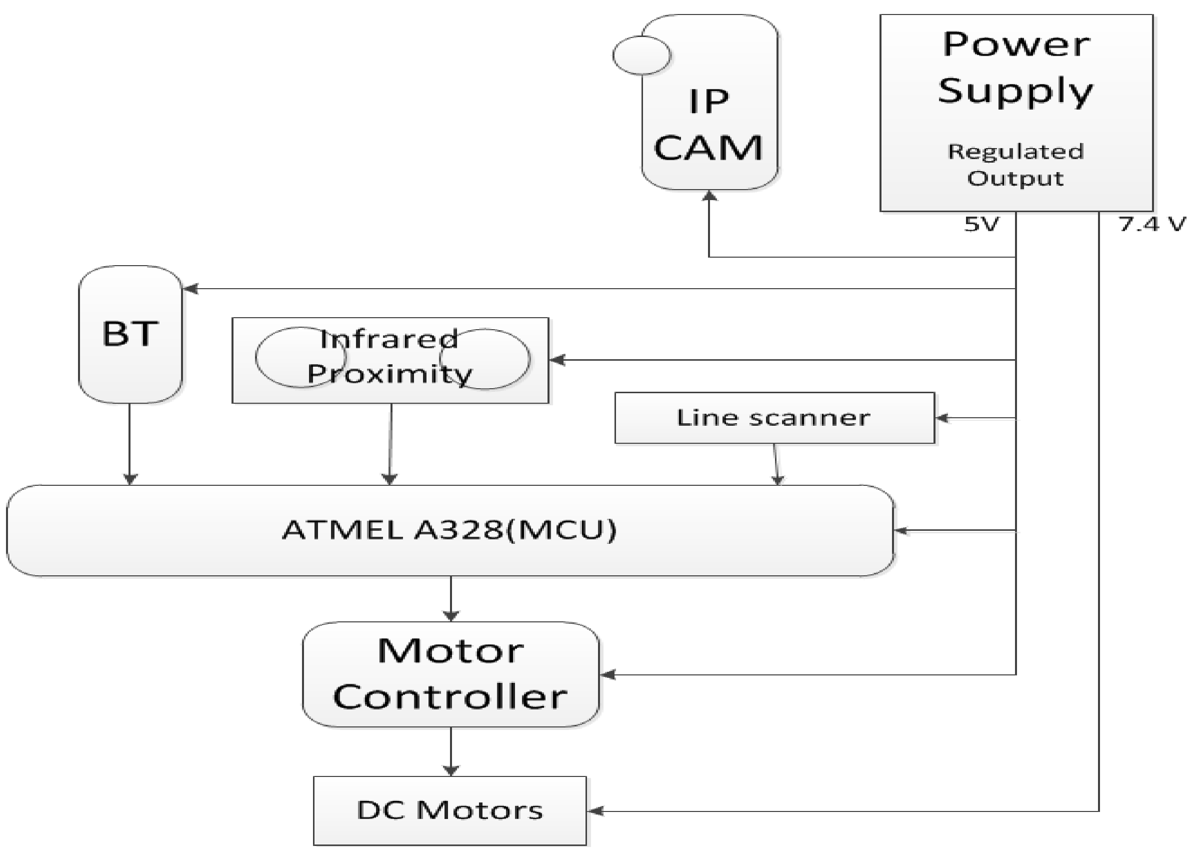
4.10 Power System

4.10.1 Power Specifications

The diagrams below show the distribution of power of the BRAVO vehicle.

Figure 4.10.1.1

Device	Voltage	Current
DC Motors	7.4 V	2 A
AtMega328	4.5-5 V	200mA
Motor Controller	5 V	25 mA
IP Camera	5 V	1.2 A
Bluetooth	5 V	8mA
Infrared Proximity Sensors	5 V	30 mA
Line Scanner	5 V	40mA



The two main voltage sources will be a 7.4V Lithium Polymer Battery rated at 1600 mAh and a four pack of AA NiMh batteries rated at 4.8 V in series. The Lithium battery will power the DC Motors, Atmega 328, motor Controller, Bluetooth, and proximity sensors. The Camera will be powered by the AA batteries.

4.10.2 Power Systems Hardware Selection

The BRAVO requires 7.4V, 5V ,5V, 5V,5V and 5V. After researching the different lithium polymer batteries that we could use it was decided for the BRAVO vehicles that we use the Turnigy Li-Po 1600 mah battery and set of four AA Energizer NiMh battery pack. (**Figure 4.10.2)**. We used one Lithium battery battery per vehicle and one AA pack per vehicle to provide us efficient amount of voltage to supply power for our vehicles.

Figure 4.10.2.1

(Permission granted from HobbyKing Support Team)

Spec.
Minimum Capacity: **1600mAh**
Configuration: **2S1P / 7.4v / 2Cell**
Constant Discharge: **20C**
Peak Discharge (10sec): **30C**
Pack Weight: **97g**
Pack Size: **106 x 32 x 13mm**
Charge Plug: **JST-XH**
Discharge plug: **XT60**

Energizer NiMH Batteries

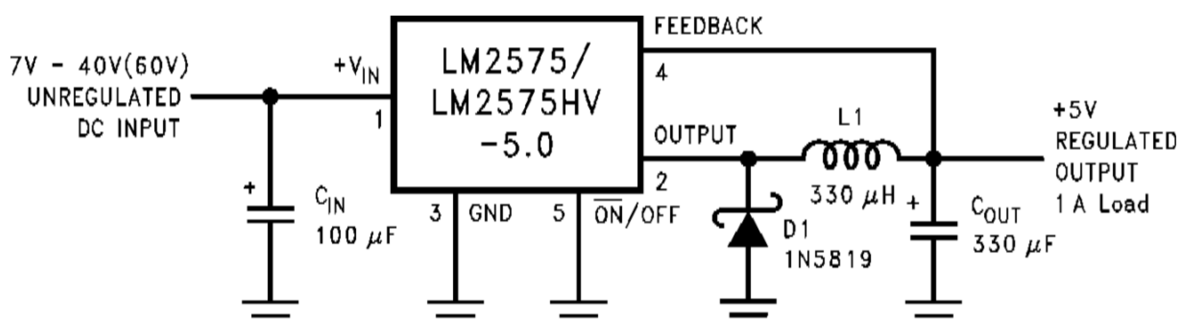
We will use the Turnigy Balance Charger Direct 110/240V input to charge our batteries.

Figure 4.10.2.2 Battery Charger

(Permission granted from HobbyKing Support Team)

Battery Charger Specifications

Input: 110v or 240v A/C (50/60Hz)
Output: 650mA per cell
CE, FCC Certified.



Picture of the LM22575 circuit

5. Design Summary

5.1 Process Sequence

The project will consist of two vehicles BRAVO One and BRAVO Two. Each of the two vehicles will contain differently implemented autonomous navigation units that will perform identical functions and posses same behaviors. The systems will follow a series of sequential input readings from 3 devices: camera, an ultrasonic proximity sensor and a line sensor array. Data will be fetched and processed by the microcontroller and the remote PC. Processed data will be sent to the navigation AI which based on preset parameters will give an appropriate command to the motor and steering controller board. Subsequently, the motor controller will regulate power of the drive motor and the steering servo in order to perform accurate maneuvers and continuously adjust the speed accordingly. Vehicles will be preprogrammed with a certain route to follow, indicated by the amount of signs and turns encountered. For instance, the team will determine the starting and ending points of the route on the map and count the number signs that fall within that route. This data will then be stored in memory of the microcontroller unit. Once a start command is given, the vehicle will begin its journey and keep track of signs detected. Upon accounting for all anticipated signs, the vehicle will know the destination is reached and come to a stop.

5.2 Input Devices

5.2.1 Camera

As the main input data source, the camera will be mounted on the front side of the vehicle facing in forward direction. Its sole job is to capture and send low resolution image frames to the microcontroller at a specified rate of 30 frames per second. Selected product is theDLINK Cloud Camera. The quality of captured images will be relatively low in terms of color depth, sharpness and clarity. However, for the purpose of this project, it will be sufficient for data processing and extraction in terms of quantity and accuracy of information fetched.

Figure 5.2.1.1

5.2.2 Line Sensor Array

The line sensor array will be embedded as a backup line tracking device. There is a potential risk of failure of the image processor in low light and low visibility conditions. Under these circumstances, the navigation system may return an error terminating its operation and leaving the vehicle immobilized in the middle of a road creating traffic congestions. Should such failures occur, the navigation AI will temporarily seize its communication with the camera module and refer to the line sensor array as an input source for navigation purposes.

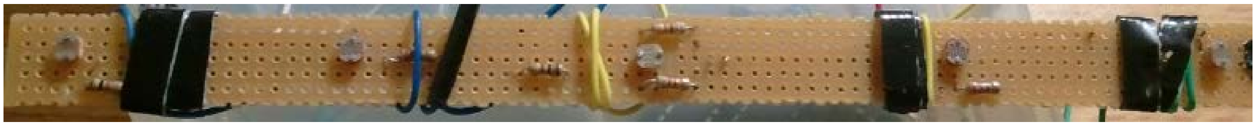


Figure 5.2.2.1

5.2.3 Proximity Sensor

Each vehicle will utilize only one proximity sensor attached on the front side of the vehicle scanning at a maximum rate of 20 readings per second and transmitting the result to the microcontroller. Based on the distance measured the vehicle will take an appropriate action by reducing the speed or coming to a complete stop. Connection pins are described in Hardware Design section of this report. Image (**Figure 5.2.3.1)**below illustrates how the module will be mounted to the vehicle chassis.

Figure 5.2.3.1

5.3 Processing Units

5.3.1 Microcontroller (Navigation AI)

Navigation unit be taking multiple simultaneous readings from all input devices at different rates. Input data is sent to appropriate processing elements for data extraction. Once raw data is processed into useful information, a series of logical operations and mathematical approximations are computed to generate control signals.

Both cars employ a remote image processing. A C++ code runs on a Visual Studio IDE that will listen to the serial port (wireless Bluetooth), when the camera transmits an image, the program performs a Hough Line Transform and a Hough Circle Transform Algorithms to identify any detected signs. Extracted data is sent back to the on board microcontroller for further navigation processing. Image below (**Figure 5.3.3.1)** demonstrates how the circle is detected by the program visually, although for navigation purposes, only a set of integers representing the type of sign within the image array is relayed back to the vehicle.

Figure 5.3.3.1

5.4 Battery Summary

Four different rechargeable batteries were research upon in order to find the best one suitable for our autonomous vehicles. The following batteries were the Nickel Cadmium, Nickel Metal Hydride, Lithium Ion and the Lithium Polymer. For each battery the advantages and disadvantages was documented and criteria was formed in order compare and contrast each rechargeable battery. The criteria for the rechargeable batteries were size of the battery durability, charge capacity, cost and safety.

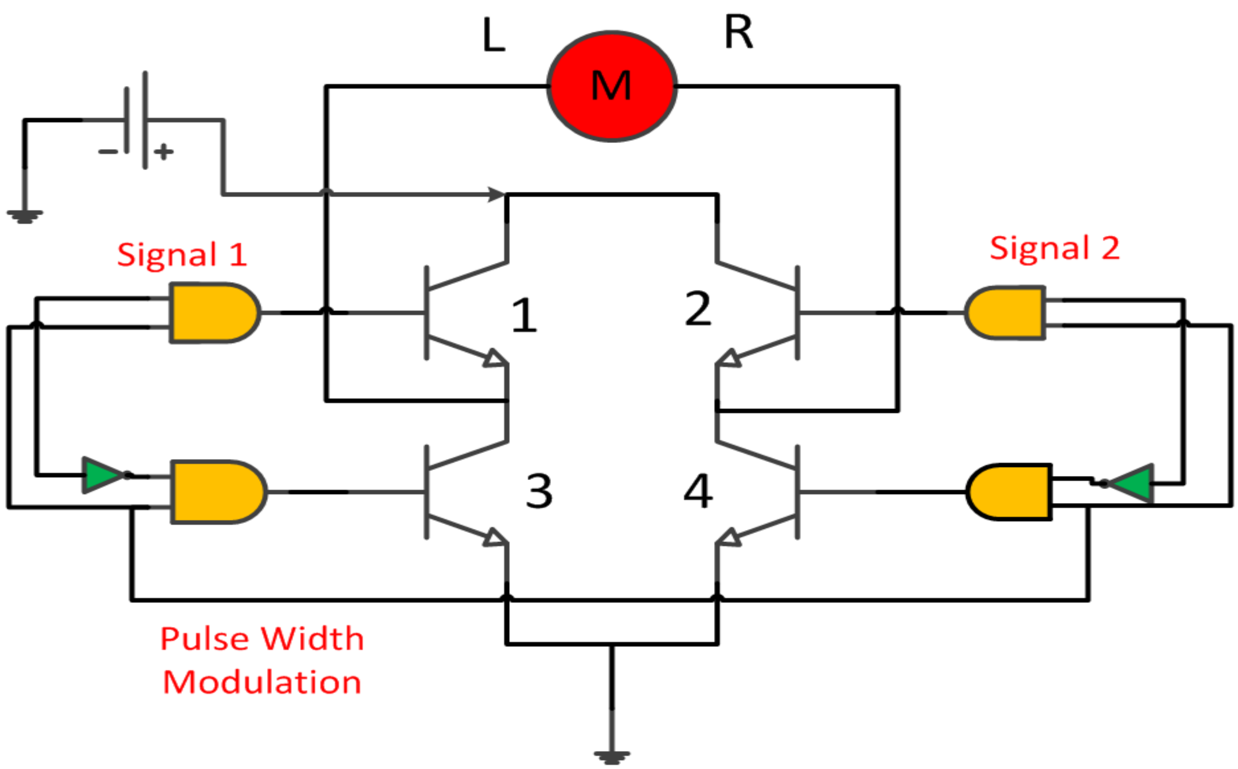
Based on the criteria the best battery suitable for the autonomous vehicles will be the Lithium Polymer battery. The Lithium Polymer battery is the most advanced, weighs less and produces a lot more energy than the Nickel Cadmium and the Nickel Metal Hydride battery. Moreover the Lithium Polymer battery has less internal resistance than both batteries. Though the Lithium Polymer Battery is more expensive it has improved safety over both batteries as well.

The Lithium Ion battery is very similar to the Lithium Polymer battery. Where the Lithium polymer has the advantage over the Lithium Ion battery is its durable slim size. They can be manufactured to the size of a credit card. The overheating issues in the Lithium polymer battery is a drawback.

5.5 Vehicle Design Summary

The BRAVO project ultimately used two identical DF-Robot 4WD vehicles as the platforms from which to develop on. They were mechanically capable, well-built and affordable and were capable of being transformed into autonomous vehicles capable of demonstrating intelligent behavior.

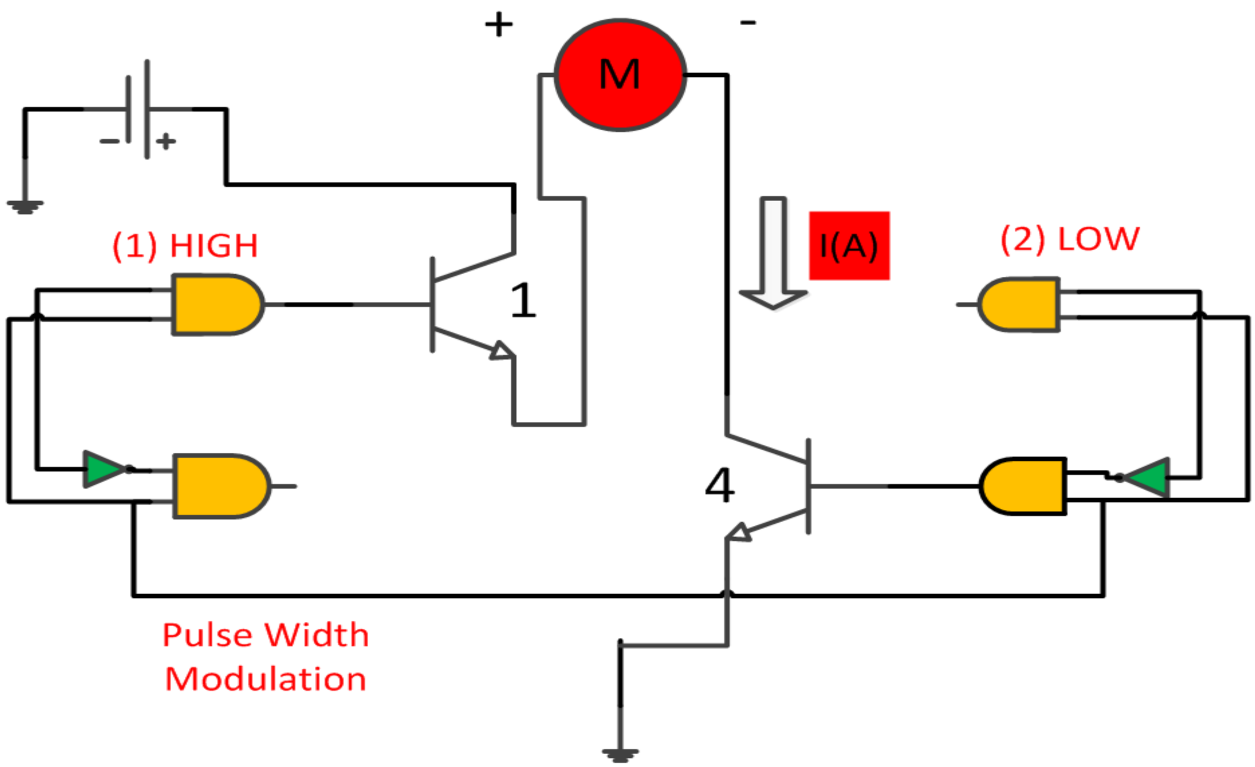
The DF-Robot 4WD vehicle came without radio control devices or control circuitry which was ideal because these parts would not have been needed for the conversion to an autonomous vehicle. The modification to a custom vehicle began with the addition of top mounted stand-offs to mount the custom designed motor control circuitry. Once the mounting platforms were securely placed, the control circuitry was attached and interfaced (wired) to the drive motors that came pre-equipped with the vehicle.



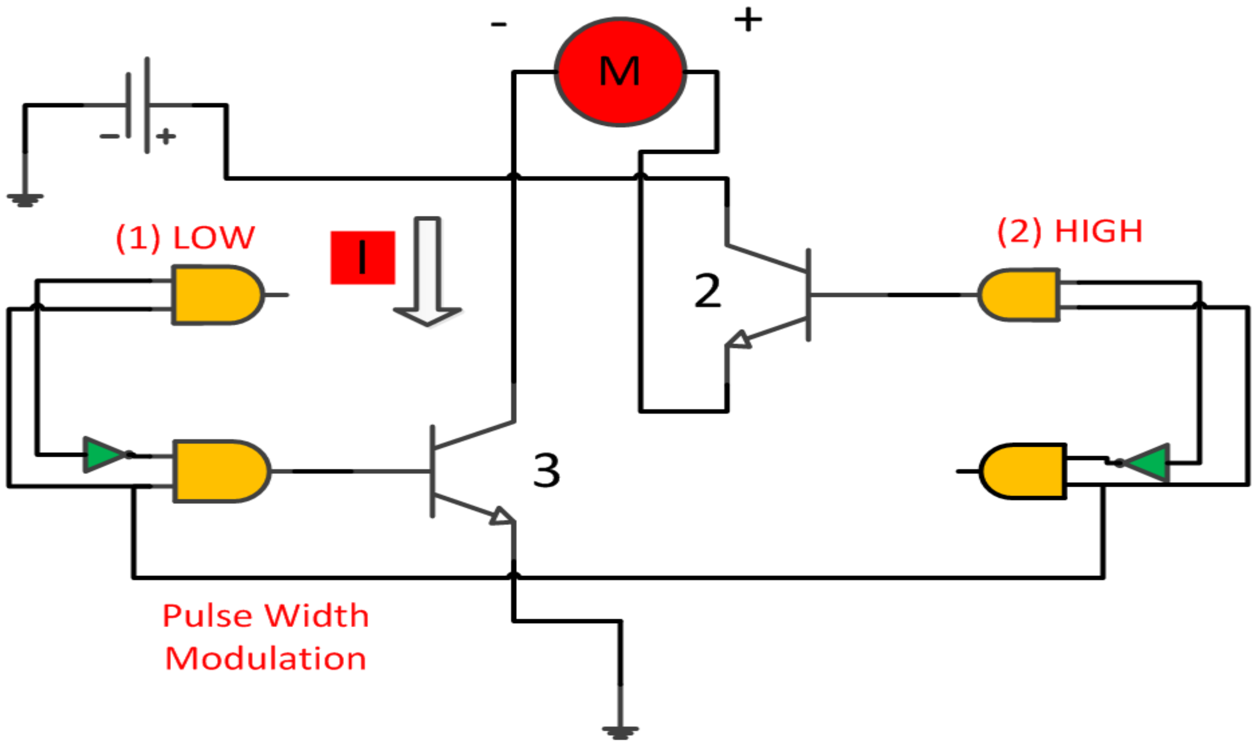
The motors were controlled with digital logic voltages and pulse-width-modulations sent from the microcontroller to the L298n integrated circuit motor controller manufactured by ST Microelectronics. The L298n is a tried-and-true motor controller and had the ability to reverse polarity for directional control of the drive motors as well as the appropriate internal logic gates to facilitate the pulse-width-modulation for current control.

The vehicle platform and motor control were similar to the human body and its limbs. The ‘body’ and ‘limbs’ are meant to be strong and functional with the ability to exhibit quick and consistent responses to the commands from the signals that the brain (microcontroller) transmits to them. The microcontroller will make decisions to accelerate, decelerate or turn based on signals from its other sensory components.

As a whole, the moving parts of the BRAVO project were an avenue to demonstrate computer intelligence and autonomous decision making. The entire platform behaved as feedback system, like the human body, reacting to problems and delivering solutions. The simple act of sending a few digital signals doesn't have much of an impact unless the feedback control system is well coded and tested.



To demonstrate a smoothly operating feedback loop, the control circuitry needed to be quick and svelte. The DF-Robot 4WD vehicle had high quality motors and the L298n is a fine complementary device to provide crisp movement. This was the goal of the platform of the BRAVO project. A smooth platform was the best way to demonstrate the quality of the software coding and computer vision, and the platform described above proved be the tool to do so. For more specifics, and detailed specifications of the motors and circuitry, right down to the transistor, the appropriate sections and chapters are provided in their respective locations throughout this document. Likewise, this document provides software simulations of the functions of the drive circuitry to illustrate the relationship between the 'limbs' and the 'brain' of the project.


-
M
+
(1) LOW
I
2
(2) HIGH
3
Pulse Width
Modulation

5.6 Hardware Diagram

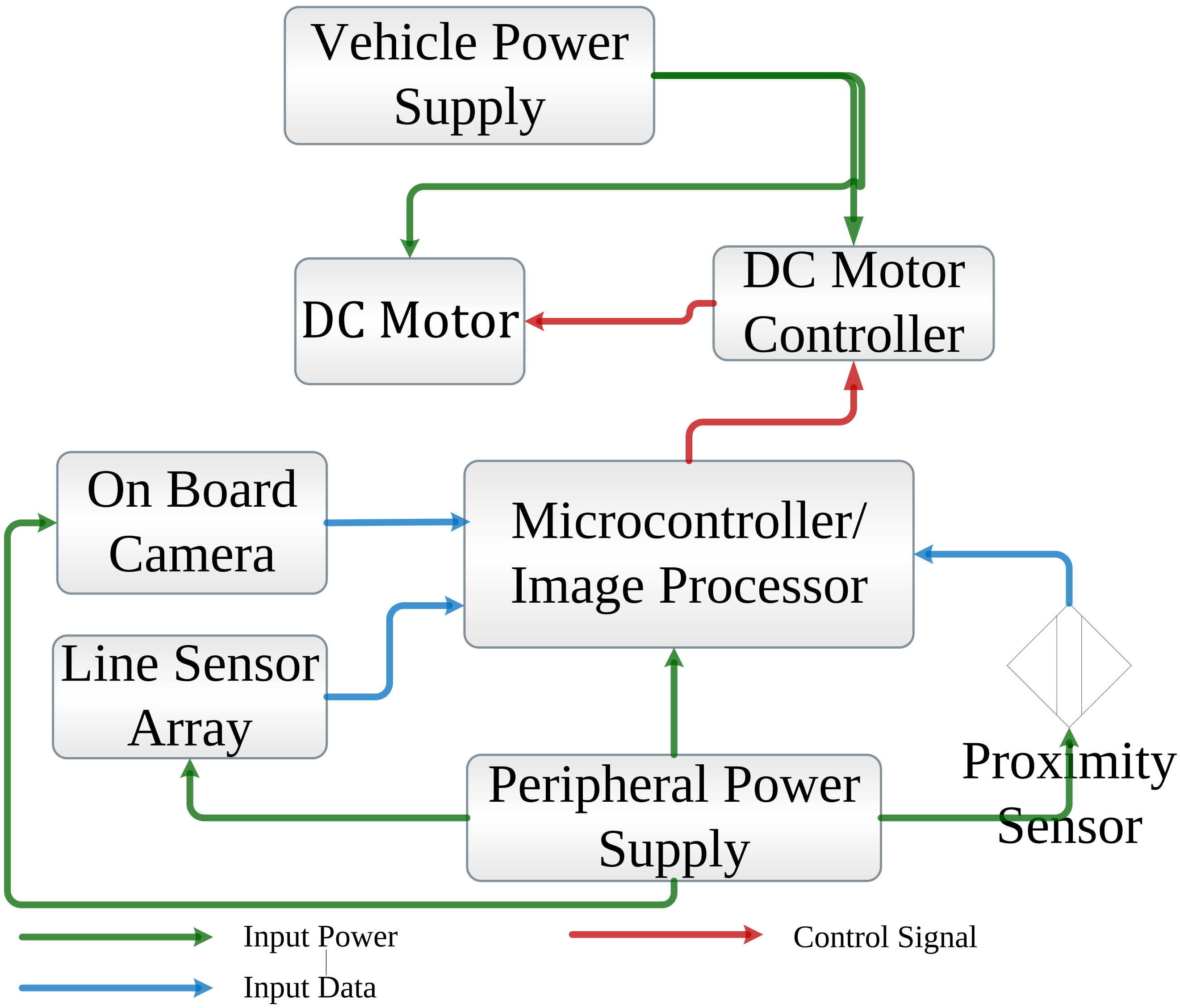


Figure 5.6.1

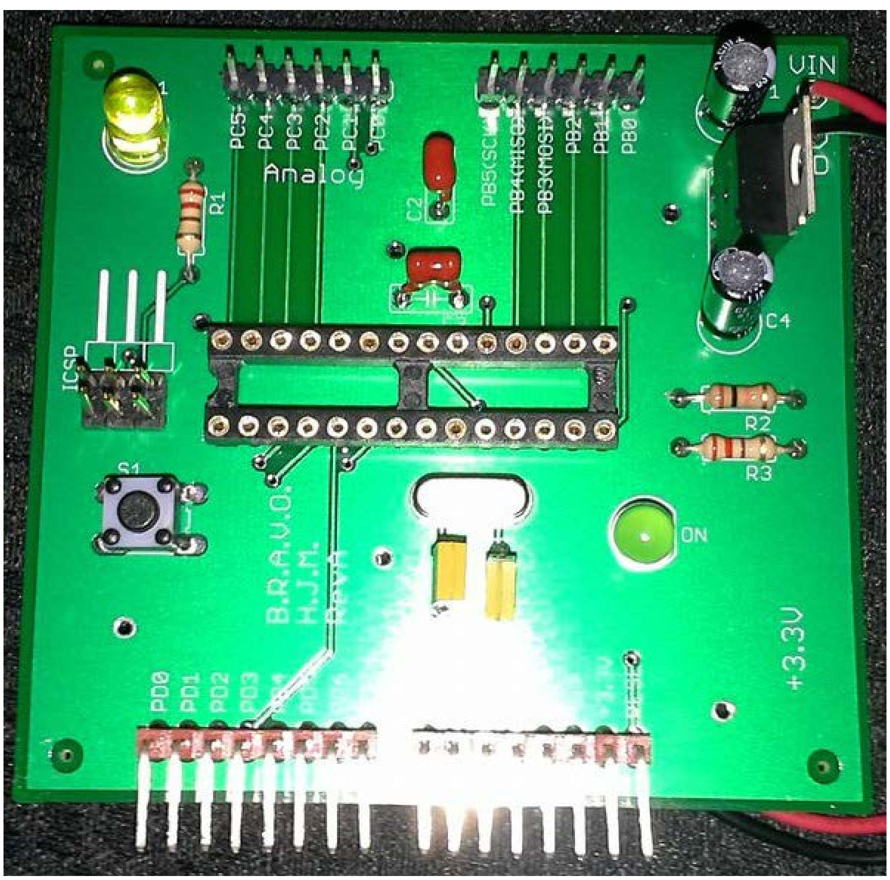
5.8 Course Summary

The pre-determined course was meant to provide a significant challenge for the autonomous vehicle while providing an array of engineering challenges such as image detection and processing, digital servo control, embedded systems, PCB design, and power systems design. The goal was for the course to incorporate a large outer loop, similar to a large one-way interstate bypass that surrounds an entire city. From this outer loop, the vehicles were able to enter and exit, simulating the way a car would enter or exit an interstate. Inside the outer loop was a series of routes that tested the overall functionality of the autonomous car. The vehicle was ultimately given a program to determine when to initiate a particular route and when the vehicle was ready to initiate a route, the route was identified by a specific line color. Several routes existed within the loop, each corresponding to a particular color and each route presented its own distinct challenge. Some routes incorporated a sharp turn or a stop sign and some routes incorporated hazards where the vehicle had to navigate its way around the hazard. A successful project was required to demonstrate a robust autonomous vehicle that was able to navigate and complete all of these challenges without external assistance which we believe we accomplished.

5.9 MCU Summary

The microcontroller that the group chose was the Atmel Atmega328P microcontroller. The group initially decided on this microcontroller because it possessed the necessary requirements set forth in the microcontroller requirements in section 2.3.6. The microcontroller is a 8-bit ARM MCU that operates at frequencies of up to 16 MHz. The microcontroller also possesses an abundance of on-chip memory such as up to 32 KB of flash memory, up to 1 KB of SRAM, and an external memory controller should the existing memory specifications prove to be insufficient.

The microcontroller also provided several features that were necessary to the project such as universal asynchronous receiver/transmitter, general purpose I/O pins, and timers that were able to be configured for pulse width modulation. Perhaps the most attractive feature of the microcontroller was the reference or discovery board provided by the Arduino Uno. The discovery board was an inexpensive, yet valuable tool that allowed the group to uncover any flaws or miscalculations that might have been previously overlooked. The board also allowed the group to optimize and become familiar with both the electrical characteristics of the system and the software as well, giving the group a headstart on the project that ran several months.

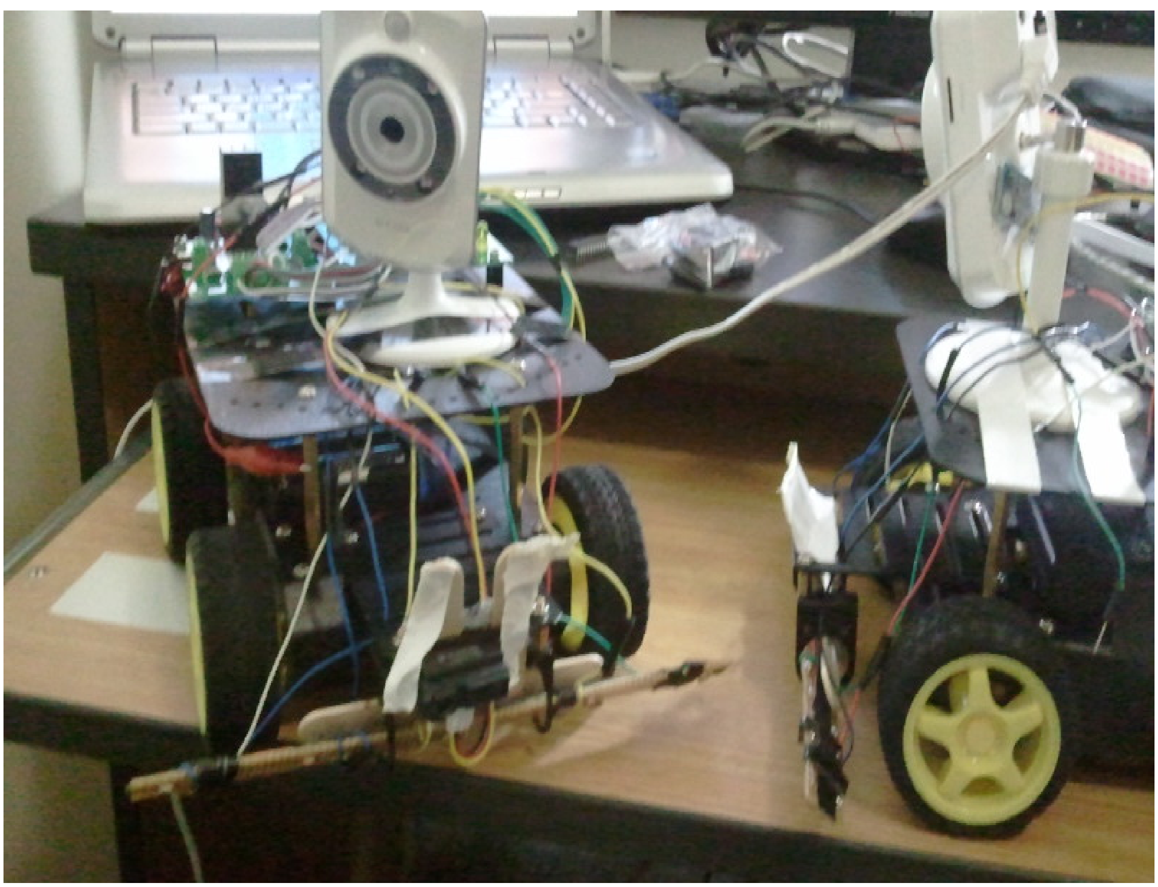


5.10 Overview of system

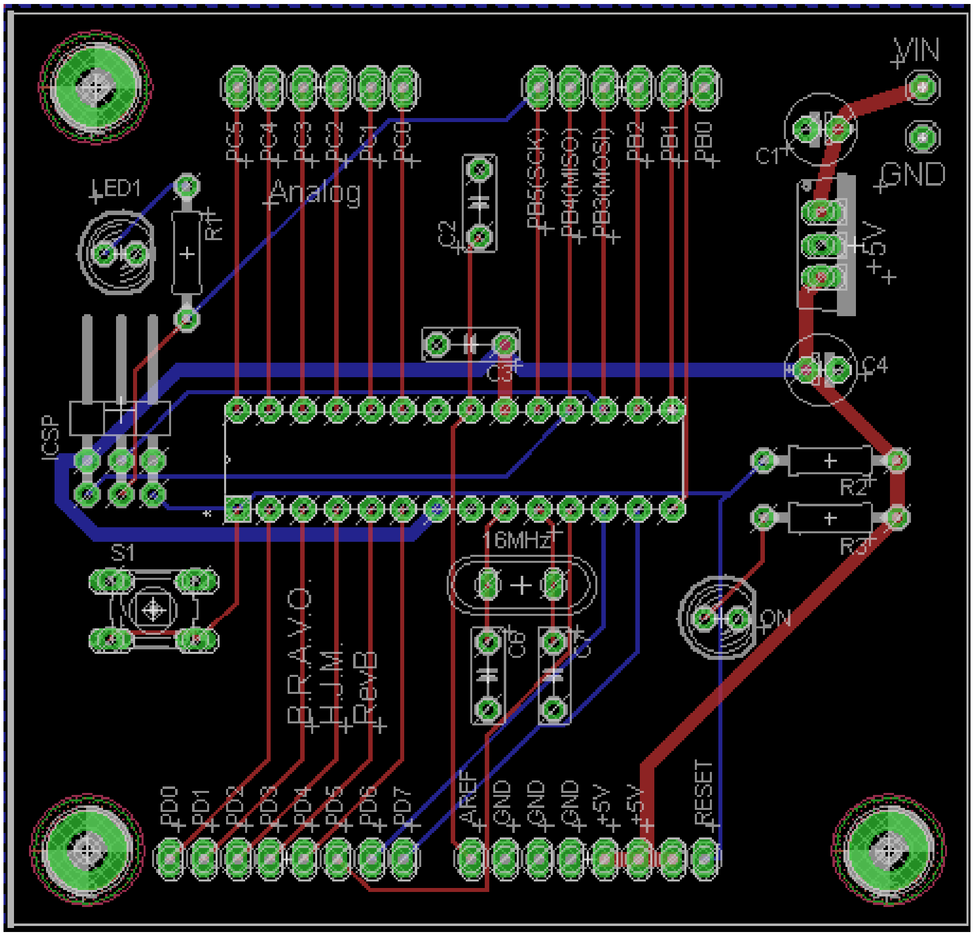
The overall system consisted of an RC hobby car platform mounted with a printed circuit board, motor controls, an onboard camera, and the power source. The vehicle was fully autonomous, incorporating all the necessary hardware and programming to navigate the course without human assistance. The camera was mounted to the front of the vehicle, continuously took images and sent those images to the external processor via the wireless module connected to the microcontroller.

Because timing was critical to avoid the “bottleneck” of incoming data, the microcontroller had to possess the necessary memory requirements and processing speed to ensure that the data was being processed and routed to the motor controls before the next set of data was able to overwrite any current data in memory.

Problems such as these could have proven to be disastrous in navigating the course and could have caused the robot to exhibit “jerky” motions or veer off the current route altogether. Once the data was ready for processing, the external processor made use of efficient image processing algorithms to determine objects and sent this data back to the MCU to take the necessary actions. The MCU then translated this action into a pulse width modulated signal and sent the signal out to the external pin for the motor controls to interpret and react.



Due to the fact that the project made use of a digital servo in the motor control system, a pulse width modulated signal had to be sent to the output pin which was used to determine the action that the digital servo took and consequently, determined the direction of the vehicle. As shown in **Figure 5.11.1**, the general strategy for system was to receive an image, process the data if the CPU was ready, and send out the appropriate signal to the motor controller.



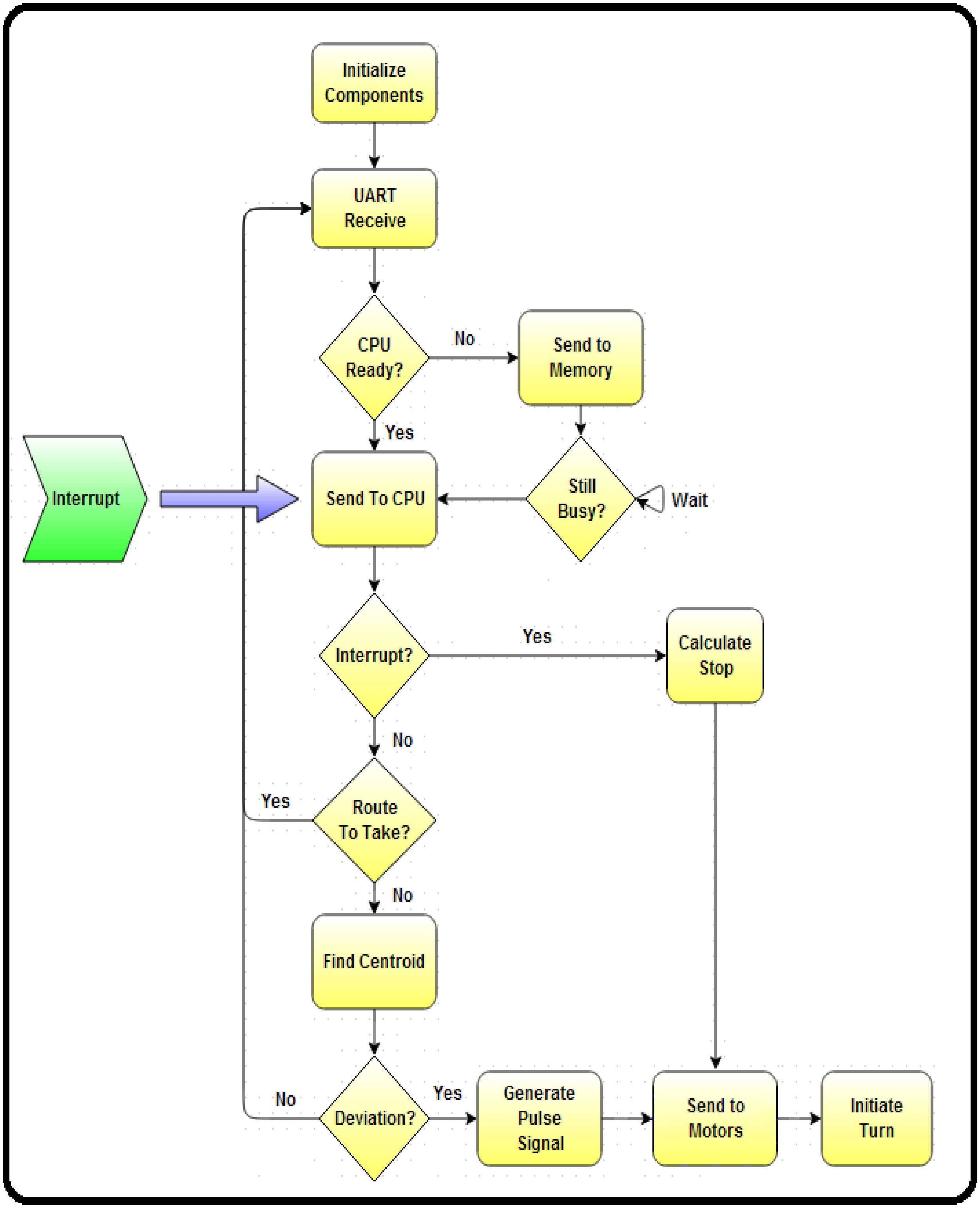


Figure 5.11.1 – System Process Diagram

5.11 Interface to interrupt

The project also made use of an external proximity sensor, which was an infrared proximity sensor that output an analog signal. Because we used the IR sensor, the microcontroller had to provide an interface that was able to interpret the analog signal and take the appropriate action. Because detecting a collision was outlined as a requirement of this project and was of the utmost importance, a high priority interrupt was generated when the proximity sensor detected an object in its path. Had the signal been digital, an external interrupt would have been configured for one of the general purpose I/O pins which the central processing unit would have immediately dealt with and commanded the vehicle to slow or stop, thus avoiding a collision with the object. Because signal was analog, the microcontroller made use of the analog comparator to detect the amplitude of the incoming signal, converted the signal to a digital signal, generated an interrupt, and allowed the processor to take the appropriate action. Though components and strategies were subject to change up until actual testing began, this system allowed the autonomous vehicle to follow along its chosen route while avoiding obstacles and meet the requirements of the project.

5.12 Software Interface

Once the implementation for the hardware was completed, there still remained the arduous task of providing an optimized and reliable software interface. Simple navigation of the course required a robust line detection algorithm that not only sensed a deviation from the route, but corrected the deviation without overcompensating or undercompensating. Initially the algorithm made use of a line following technique that records and sums the pixel values that were within a particular color threshold across an appropriately placed Y-scanline. The algorithm then divided this number by the X-values that corresponded to the numbers that were within the particular color threshold, generating a centroid of the line that the vehicle wished to follow. The algorithm then took this number and found the deviation from the center line or where X was equal to the middle pixel. Once this deviation was discovered, the algorithm could then compute the appropriate pulse width modulated signal to send to the motor controls for course correction. The computation of the signal had to be exact, else the motors may have overcompensated and displayed jerky movements or even undercompensated and lost the line altogether. For more complex shapes and turns, the external or remote processor made use of more robust algorithms such as the Hough Line Transform. With this algorithm, the vehicle was better able to detect sharper turns and stop signs. Though beneficial, the group had to be diligent and fully optimize their code by avoiding higher math functions if possible. There was inherent latency in all function calls, especially in general functions and it was quicker to use custom definitions instead.

To satisfy the requirements of the autonomous vehicle, the software had to implement an algorithm that allowed the vehicle to decide when and what routes to follow. Colors that corresponded to specific routes were pre-programmed into memory. Because various colors appeared throughout the course, the vehicle had to know when to follow a specific route as well as the route itself. The choice of the route was easily determined by associating signs and numbers. Any time a sign was encountered, a counter was incremented and if the counter was a particular number, a certain decision was made. In order to avoid adding any unnecessary latency to the processing unit, the timing of when to follow a specific route was determined by whenever the route is first encountered.

In order for the project to integrate both the hardware and the software, the group made use of the multitude of libraries and development tools provided by Atmel. Because the project depended on the speed and direction of the flow of data, the group had to take great care in the selection of microcontroller components. For example, the direct memory access may have provided a great tool for directing the flow of traffic within the microcontroller, but with each added component comes the price of latency and the group had to ensure that each selected component wass the most efficient means of configuring the microcontroller.

5.13 Part and Price Chart

Figure 5.13 represents all parts and prices for the design summary. This is a best-effort estimate of the needed products to complete the autonomous vehicle.

Figure 5.13

	Item	Qty.	Price($)
1	1/16 Mini Rally Car/Platform	1	59.99
2	Motor Controller	1	FREE
3	2.125" ALUMINUM HEX SPACER, F-F, 6-32	12	7.8
4	6/32x.25" Button Socket Head Screws (25 pk)	8	.69
5	20 AWG Solid Wire Orange-25'	1	3.26
6	20 AWG Solid Wire Gey-25'	1	3.26
7	20 AWG Solid Wire Brown-25'	1	3.26
8	BUTT CONNECTOR, RED-(50 pk)	1	3.05
9	Solder	1	2.35
10	Printed Circuit Board	1	33.05
11	Miscellaneous Electrical Parts (diodes,	TBD	<20
	heat sinks, terminal block, LED's)		
12	1700mAh 2S 20C Lipo Battery	2	15.6
13	2S 3S Balance Charger. Direct 110/240v	1	11.44
14	XBee 1mW U.FL Connection - Series 1 (802.15.4)	1	22.95

15	Ultrasonic Range Finder - Maxbotix LV-EZ1	1	25.95
16	LinkSprite JPEG Color Camera TTL Interface	1	44.95
17	Infrared Emitters and Detectors	1	1.95
18	STM32407xx	1	15.00
19	Turnigy 1700mah Lipo Pack	2	7.80
20	Turnigy Balance Charger	1	11.44
	TOTAL COST		322.36

6. Prototype and Testing

To ensure the system met all performance requirements every subsystem was tested separately by each member of the team responsible for that particular module. The team developed a systematic approach for testing. A set of criteria was composed for every hardware and software component of each vehicle. The team then prototyped all the hardware and software designs and performed test runs on every component or a device and checked whether the performance results satisfied the preset criteria. Any failures were analyzed for errors and mistakes, modified accordingly and tested again. This process continued until every system passed all of the test runs. Once the team was certain that every component was working properly, they were merged together and embedded into a single platform. The final phase of the test involved a full test run under different circumstances that evaluated precision and overall performance of the autonomous vehicles.

6.1 Image Processing

6.1.1 Camera

A serial camera was connected to a computer via a wifi router. The function of the code is to read the incoming video feed and capture image frames. Person responsible for image processing unit checked the format, resolution, color intensity, and overall quality of an image taken. The output image needed to be of a JPEG format with 160x120 resolution and color pixels. If any of these criteria are not met, the team analyzed the camera rerun the test. Next, the 2-D byte array representation of the image was analyzed for consistency with visual picture taken. Possible faulty results include improper wiring; erroneous test code and manufacturing defects were also checked. Any issues encountered were addressed until the problem was resolved.

6.1.2 Wireless Transceiver Module

Subsequently, the team tested the wireless communication and wireless data transfer capabilities of the Bluetooth module. One of the nodes was directly connected to the microcontroller, and the other one connected to a remote PC via a serial USB connection. The team attempted to set up a connection between the microcontroller and the PC sending data back and forth. Once a connection was established, data rate was measured by sending large amounts of random data and calculating time delay. Passing criteria was to be able to transfer 9600 bits in a second. The team attempted to send a start command wirelessly and verify a successful transmission. Possible reasons for failure were obstruction of direct line-of-sight, improper wiring, manufacturing defects and faulty code.

6.1.3 Data Extraction Program

Once the images are successfully captured and saved, team proceeded with image processing and data extraction program tests. For this part of the test, a picture of an actual sign was saved on a remote PC. An on board image processor was evaluated with prototype code implemented using methods and algorithms mentioned in Research section of this report. Passing criteria for the test was to be able to identify road signs based on color and shape. Possible reasons for failure were erroneous code and defective or incomplete input data.

6.2 Proximity Sensor

The proximity sensor was one of the simplest devices utilized in this project, although it played an important role in the safety of the vehicle. The selected IR sensor was connected to the microcontroller unit in a way described in the Hardware Design section of this report. The device needed to be tested for time delay, accurate measurements and false readings. An object was placed in front of the sensor with a known distance in between. The testing person then sent a trigger signal to the sensor and read the response signal. If the returned signal carried an accurate data, the first phase would be completed. The team repeated this procedure with objects at different angles and distances. Issues that arose were noise, faulty wiring and manufacturing defects. Passing criteria for this test were precise measurements in a timely manner.

6.3 Line Sensor Array

The line scanner array's operating principle was the simplest out of all subsystems contained in the vehicles. It consisted of an array of IR Tx and Rx pairs that emitted and detected reflected electromagnetic waves. This device did not require a trigger signal and operated by emitting and detecting IR rays continuously. The team connected it directly to the microcontroller and passed it over different colored surfaces, specifically white and black. IR sensors were constantly passed over the colored surfaces changing position from one color to another while the output data was simultaneously read on the microcontroller. If the output value varied with change of color, the test was passed successfully. In this case passing criteria for line scanner array test was to be able to differentiate colors and instant detection of color change. Considering the fact that this device was completely prototyped by the team, attention needed to be paid to proper design and connections. Possible reasons for faulty results included incorrect design, improper wiring, thermal noise and other electromagnetic interference. The team ran these test procedures under different lightning conditions to verify sufficient accuracy of the line scanner array.

6.4 Microcontroller

As has been previously stated, the microcontroller was the medium through which all of the peripherals were interfaced and as such, the MCU was able to perform a multitude of tests. As with most larger systems that are made up of several smaller systems, each individual smaller system should have been able to perform on its own before being integrated into the larger system. This was the approach when testing and configuring the microcontroller. A large amount of the testing was devoted to timing and power constraints to make sure the microcontroller was able to avoid "bottlenecking" when processing the image data; the microcontroller also needed to stay within the recommended voltage or current levels when pushing the maximum frequency threshold. We also needed to test these constraints at each level because when a new interface was added to the whole system, new strains emerged and were put upon the processor. Testing occured on both the software and hardware levels, so a JTAG interface as well an integrated development environment was needed for debugging.

As mentioned previously, a great benefit of the Atmega328P microcontroller was that Atmel offered a discovery board that offered the inexpensive use of the microcontroller with very little added features and also enabled the user to become familiar with all of the systems and functions of the microcontroller. The discovery board is similar to an evaluation board, but without several features that will be unnecessary for this particular stage. The board also comes without the hefty price tag that accompanies many evaluation boards. This board was a great help in not only interfacing the various peripherals, but also in helping to optimize the entire system from the timing parameters to electrical characteristics.

Because testing of the microcontroller for this project involved verifying data transmission and reception, pulse width modulated signal output, and the detection of external interrupt lines, much of the testing was done with a JTAG interface and a multimeter until the group was ready to start the integration of peripherals. The JTAG interface was used to debug all of the code and the multimeter was used to initially test individual pins to make sure the firmware was correctly interfaced with the software and to the corresponding hardware components. The first test involved the reception of data from the camera via the UART. To run this test the group needed to make the proper connections between the UART interface of the microcontroller to the camera. The camera and the microcontroller were then turned on and the camera was given a command to start receiving images. In order to be considered successful, the microcontroller needed to demonstrate:

- Clean reception of image data without corruption
- Successful calculation of image data
- Successful ordering of data in memory while CPU is busy
- Transmission of data to an external pin.
- Avoid bottlenecking of image data and allow for maximum throughput. More specifically, operate at a speeds that allows the camera to send images at the rate of 30 frames per second

Though data output was not necessarily a high priority at this stage, it was beneficial to see the timing effects of sending a pulse to an outside pin while new data was being transferred within the CPU. This test was also be applied to the remote image processing vehicle. The next test consisted of sending a pulse width modulated signal to an external pin that was properly connected to the motor controller. The most important part of this stage was being able to accurately control the servo motor by sending a precise pulse width modulated signal. The group then used the actual vehicle for this test and attempted to steer the car in a precise direction, making note of each calibration as the test progressed. This test was straightforward as it mostly involved firmware and was deemed successful when the CPU correctly and accurately controled the motors using the correct pulse width modulated signal. The third test was to determine the effectiveness of the proximity sensor. The proximity sensor needed to be connected to the proper pins and the pins needed to have their external interrupts enabled for this test. An observable reaction also needed to be created as the test should reveal if the sensor was detecting an object and generating an interrupt; the test should also reveal if the proper action was being taken to deal with the interrupt. One of the group members simulated a hazard or object by simply waving a hand in front of the sensor and observed the response. When sensor detected an object, the LED blinked to indicate success. For this initial test, the group blinked an LED while an object was present in the sensor’s range. As a more complex test, when the sensor was able to detect the range of the object, the LED blinking rate was then increased or decreased for variable distances.

Once these initial tests were complete the group then began the integration of the peripherals. The motor controls were integrated with the image processing system and testing began with simple line-following and evolved into more complex tasks such as shape detection. To demonstrate a successful image processing system, the microcontroller had to:

- Successfully receive a stream of images from the UART
- Take appropriate and swift actions when the image wass received by either immediately processing the data or placing the data into memory for later usage
- Process the data and send a pulse width modulated signal to the motor controls
- Sustain a throughput that was able to support 30 frames/s
- Detect various objects and colors

The final set of tests involved the integration of all three peripherals. This set of tests was also straightforward, because testing entailed introducing the vehicle to challenges it was able to see in the course. Successful testing included:

- Navigation of 90 degree turns
- Recognition and appropriate reaction to a stop sign
- Recognition of a hazard followed by an appropriate reaction
- Continuous selection and recognition of routes within the course
- Strict adherence to the road or line
- Smooth and quick reaction to any deviations from the line
- Appropriate reaction when path discontinuities occur
- Operation of all peripherals within recommended electrical characteristics

A successful test of the microcontroller in this instance was a successful test of the entire system, because the microcontroller had to account for the performance of all the peripherals.

6.5 Power Supply

6.5 1 Interface

The goal of the project is to have the BRAVO vehicles are able to run for an extended period of time on a single charge while navigating through its pre-determined route. The integrated battery source that will be incorporated will extend the run time of the BRAVO vehicles and prevent voltage drops and electrical noise from affecting various components. A 7.4V Lithium Polymer Turnigy battery will be powering the RC vehicle along with the DC motors. Another 7.4V Lithium Polymer Battery will be used to power the camera, proximity sensors, IR LEDs, line sensor arrays, and the microcontroller. The first phase of the test will take place in the lab under ideal conditions. The run time for the autonomous vehicles is about an hour with the two 1700 mAh batteries on

board the vehicle for an extended time. The next part of testing will take place on the track where all of the hardware and software components will be incorporated on the vehicle platform. Once that is done we will have a better indication of the run time. Other factors that will affect the power supply include the obstacle avoidance and image processing.
Power delivery to a number of individual components will need to be tested to ensure the vehicles will run smoothly without errors or problems. The components are listed below.

1. **DC Brushless Motors**
   Test the motors to make sure they run correctly

2. **Proximity Sensors**
   We will test the accuracy of the sensors to ensure the device works for time delay, precise measurements and errors.

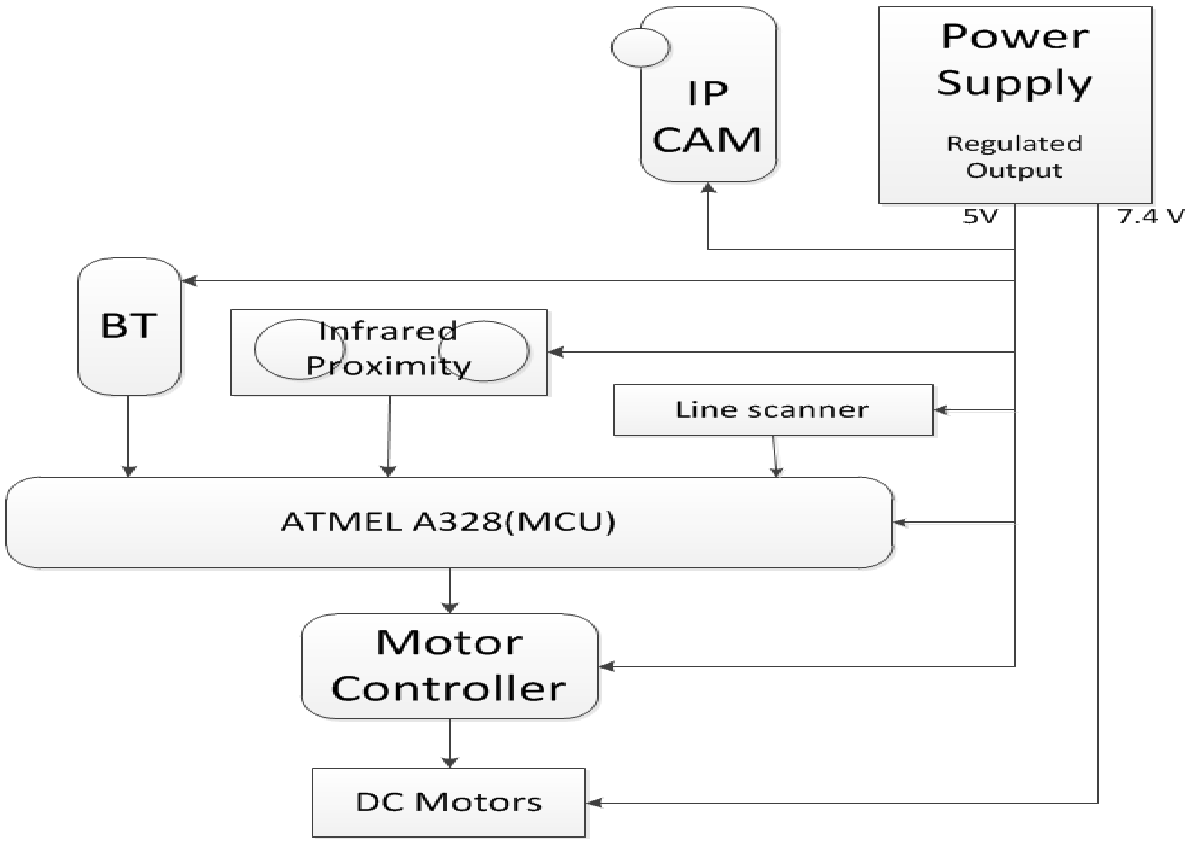
3. **Camera**
   We will test the camera for recording as it travels on the vehicles through its navigation to see if functions properly. Also to make sure the image functionality is working.

4. **Wireless Transmitter Receiver**
   We will test the power of the wireless transmitter receiver make sure the wireless transfer functions are up to speed

5. **5V Power System**
   Test the regulated voltage with a multi-meter for IR LEDS and the Line Sensing Array

6.5.2 Voltage Regulation

The voltage regulation is important to make the components on BRAVO vehicles run as they should without having problems or issues. It is expected that that voltage drops will regularly occur when traveling on its pre-determined route because of all of electrical components present on BRAVO. It will be pivotal that as we begin connecting the electrical components that they receive the proper voltage is ensure nothing goes wrong during navigation. Different components will be tested and voltages tested on the multi meter. Once this is done the power will be distributed to the different components for the BRAVO vehicles and then we can begin integrating all the component on to the vehicle platform

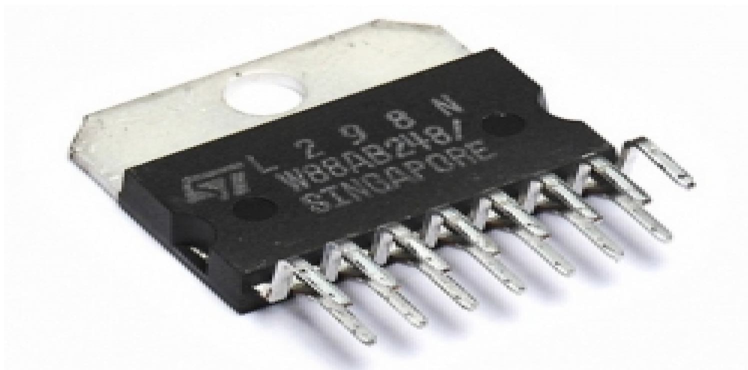


6.6 Motor Control

6.6.1 Hardware Testing

The testing of operational hardware is a critically important stage for any engineering project. Without thorough testing, the product is nearly worthless regardless of the source of its origination. Likewise, the most credible and prestigious corporations, manufacturers and university inventors implement rigorous testing and quality control procedures. There many factors that influence the rigorous testing and authentication that professionals include in their decision making processes and, though the scope of this autonomous vehicle project is intended for senior level university students, the motivations for delivering a quality product mirror those of industry giants like Texas Instruments, ST Microelectronics and Linear Technologies.

Reputations can quickly be made, both negatively and positively, on the outcome and presentation of a body of work. Whether it's a university level senior design project or a new line of microcontrollers by Texas Instruments or even a new car from Chevrolet or any other car maker, if the end product turns out to be full of problems, the professor or consumer will be lead to the idea that there were flaw in the testing procedures.



6.6.2 Requirements and Standards

To ensure that the *BRAVO* project met high standards and had operational integrity, the hardware was to be tested to meet the following guidelines:

- **a)** The motor controller shall recognize and respond to the input power VSS.
- **b)** The motor controller shall recognize and respond to the motor power VS.
- **c)** There shall be no visible signs of a short or malfunction such as smoke or sparking.
- **d)** The motor controller shall demonstrate the ability to operate the drive motor in the clockwise direction.
- **e)** The motor controller shall demonstrate the ability to operate the drive motor in the counter-clockwise direction.
- **f)** The motor controller shall demonstrate the ability to brake/stop the drive motor.
- **g)** The motor controller shall demonstrate the ability to provide DC polarity to the servo motor and demonstrate the changing of angular position from 0°-180° through pulse-width-modulation.
- **h)** The motor control controller shall effectively control the drive motor and servo motor simultaneously under load without malfunction.
- **i)** The motor controller shall effectively dissipate heat generated by an increased, but reasonable operating load, and not trigger the bridge disable function.
- **j)** The motor controller shall demonstrate standards **(a – i)** in a reliable and efficient manner. The command response shall be measurably finite.

6.6.3 Testing Procedures

It is important for engineers and designers, to not only devise and recommend rigorous standards and procedures to ensure that their products and devices perform, but to prove and authenticate those directives set forth in the **Requirements and Standards** section.

Within a professional design and manufacturing environment, with modern technology, the desire to model a product and simulate its functions with software prior to any physical developmental stage is highly paramount. There are many free, and highly expensive, simulation software programs that help to avoid costly mistakes and accidents that can occur when humans are involved.

For the scope of this project, the *BRAVO* team will also implement software to help strengthen the integrity of the project. In the pages below, the software part of the **Requirements and Standards** section will be demonstrated with the use of LTspice IV simulation software from linear technologies. This section will help to complement the written methods for adhering to, and completing the parts **a-j,** where it is possible to do so with software.

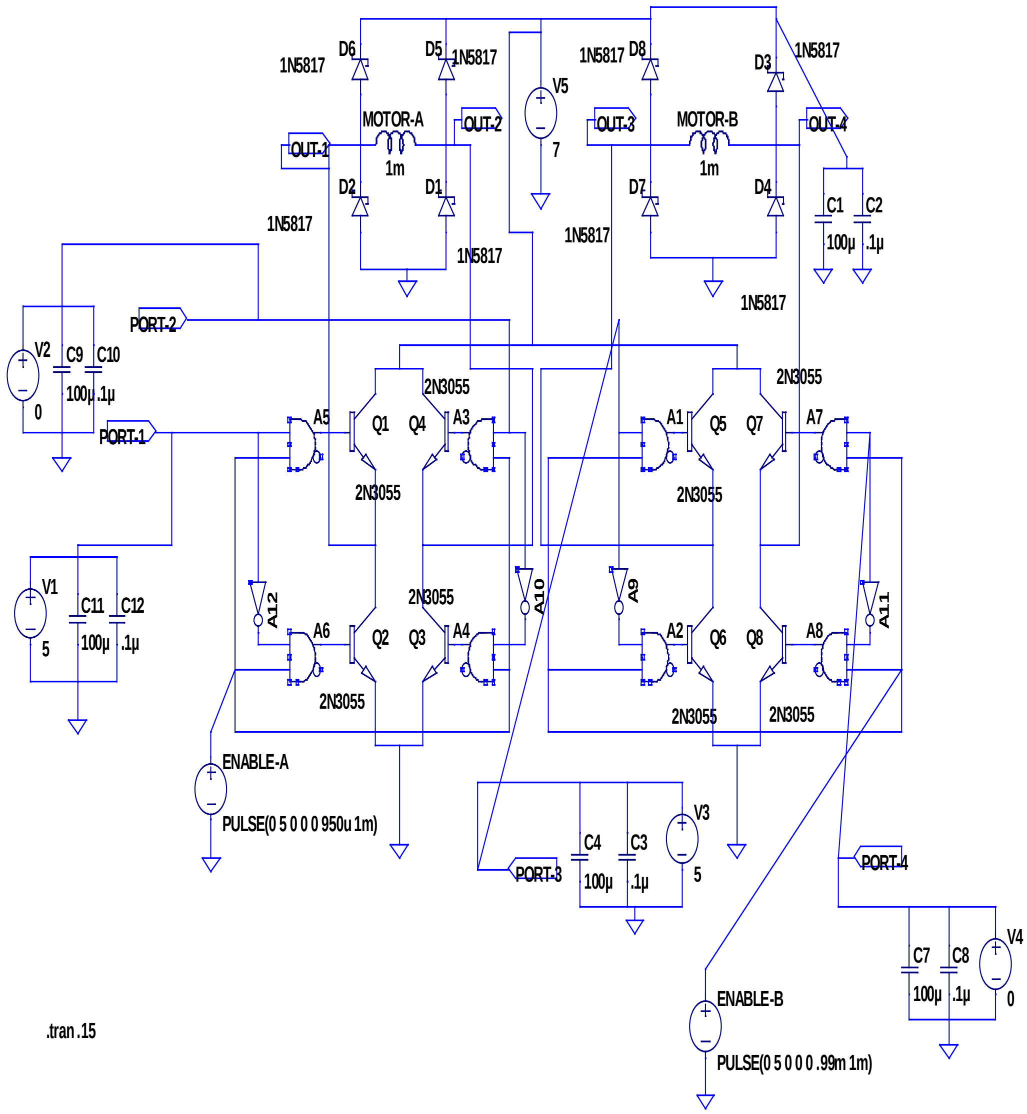
6.6.4 Software Simulations

Linear Technologies does not manufacture a dual H-bridge motor controller, and therefore the model for one does not exist in the product database. In order to simulate the L298n, the transistor and diode integrated circuit had to be represented as a whole.

The model in **Figure 6.6.4.1**, below, was constructed in LTspice IV and represents the L298n. This was be used to simulate the effects of pulse width modulation and also the digital input scenarios from **Ports 1 – 4**. The **Enable A and B** sources are the pulse width modulation generators and are meant to represent those which will be supplied from a microcontroller. This complex integrated circuit functions well and serves as a tool for testing device currents, pulse width modulation parameters and voltage drops across transistors. It was imperative to be able to obtain this data for calculating specifications such as total heat production and estimated amp- ratings for the entire device. Important figures in the schematic are the following:

- Motors A and B
- 1N5817 Schottky Diodes (1A, 20V breakdown)
- 2N3055 NPN transistors, ST Micro, Vceo 60V, Ic 10A
- 7 Volts source (Labeled V5)
- AND gates, Inverters
- Architecture of inputs and outputs
- Enable locations which represent digital inputs

Figure 6.6.4.1



The image in **figure 6.6.4.2** represented the maximum current through motor B. This was obtained by applying the pulse width modulated signal represented in **Figure 6.6.4.3.** The 5 volt pulses are 1ms in length with a period of 1.01ms. This is essentially the repeated pulse with little time down-time and forces the current to its peak through the induction motor.

Figure 6.6.4.2

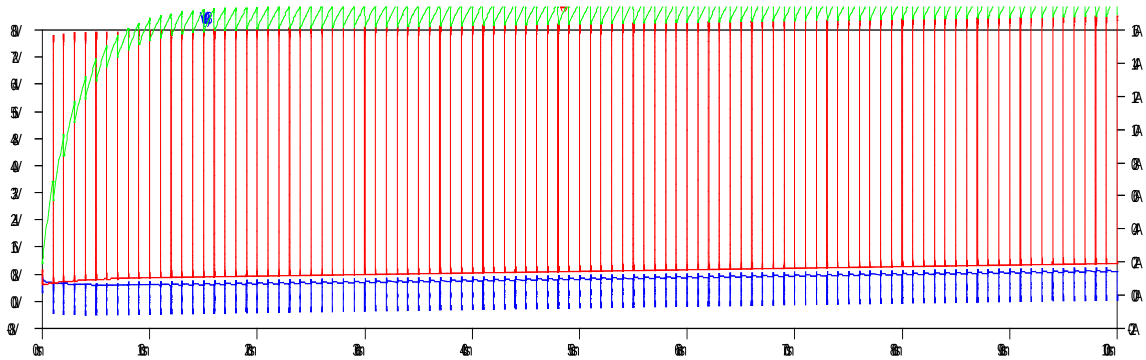


Figure 6.6.4.3

Figure 6.6.4.4 showed the ability of the L298n architecture to limit or chop the current through the motor windings through pulse width modulation. Without the pulsing from the enable inputs, the motor would simply be in clockwise, counter-clockwise or in the brake (off) mode. This would be fine for an application that is constantly on at full power, such as an exhaust fan motor, but for an autonomous vehicle the need to slow or modulate speeds is paramount. **Figure 6.6.4.4** shows an output of approximate 0.5 amps. Notice that the voltage levels at the windings are still at **Vs**, but the amperage level has dropped due to a shorter pulse width and period. **Figure 6.6.4.5** illustrates the input pulse width modulation with a 600µs pulse width recurring on a 650µs period.

Figure 6.6.4.4

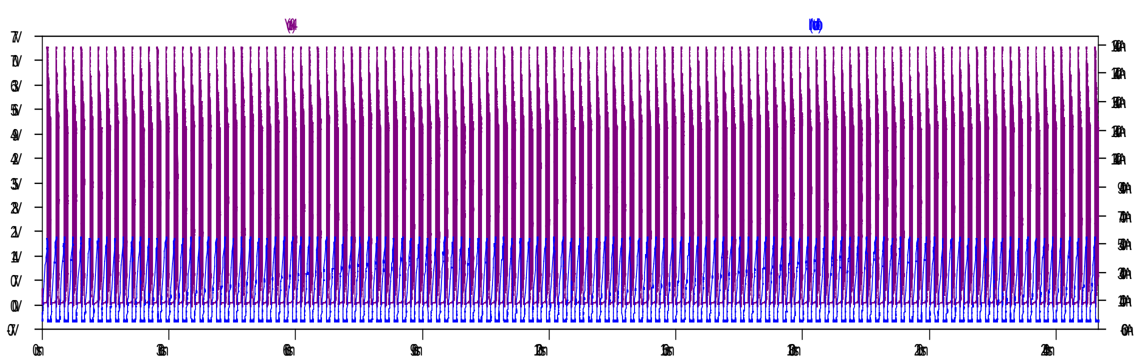


Figure 6.6.4.5

Both figures showed the consistent results and responses that the design team expected from a properly configured motor controller. It is shown that with longer pulse widths the motor is subjected to the supply voltage for longer periods and reaches higher current levels. Conversely, a short pulse in the micro-second range would have chopped the current to a reduced level and as a result the motor would have turned wheels with less power and less RPM's.
Another observation that was made from the images is that when the pulses are long enough to allow full motor output, the current steadily increased until it peaked and then remained constant. When the motor controller was configured to this output, the models showed the current had less modulation and had a smoother distribution. This effect would have produced less noise because the motor controller would not be in a constant mode of regulation and chopping. When the motor controller is highly regulating the motor's output, a noticeable noise will emit from the device because it is resisting the motor's desire to reach full current.
These effects of noise and vibration are normal when using motor controllers. There are more advanced, and expensive, motor controllers that can be purchased that have very smooth current delivery through the entire power spectrum, but for an senior-design level autonomous vehicle the L298n was very acceptable and ultimately performed quite well.

6.6.5 Physical Testing

In this section the testing procedures to meet the criteria of **a-f** will be outlined. These steps were part of the process of preparing the prototype for operations and autonomous demonstrations. The following guidelines were met with certainty before the prototype was cleared for reliability and the final presentation stage.

a) ***The motor controller shall recognize and respond to the input power VSS.***
To confirm the motor controller is fully connected to **VSS**, a visual confirmation of supervisory LED shall be made and a multi-meter shall be connected to the **Input 9** and show a voltage of approximately **5 volts.**

b) ***The motor controller shall recognize and respond to the motor power VSS.***
To confirm the motor controller is fully connected to **VS**, a visual confirmation of supervisory LED shall be made and a multi-meter shall be connected to the **Input 4** and show a voltage of approximately **7 volts.**

c) ***There shall be no visible signs of a short or malfunction such as smoke or sparking.***

With the respective motor and device power sources connected, the engineering shall take care to check for smoke or sparking and, using an infrared thermometer, monitor the heat distribution and ensure that the temperature does not stay contant.

d) ***The motor controller shall demonstrate the ability to operate the drive motor in the clockwise direction.***
The engineer shall send a high signal to **Port 1** and a low signal to **Port 2** and confirm the clockwise rotation of the drive motor.

e) ***The motor controller shall demonstrate the ability to operate the drive motor in the counter-clockwise direction.***
The engineer shall send a high signal to **Port 2** and a low signal to **Port 1** and confirm the counter-clockwise rotation of the drive motor.

f) ***The motor controller shall demonstrate the ability to brake/stop the drive motor.***
The engineer shall send a low signal to **Port 2** and a low signal to **Port 1** in a very short pulse while the motor is rotating clockwise. The reverse procedure can be by sending a brief pulse containing a high signal to **Port 2** and a low signal to **Port 1** while in the counter-clockwise operation. A successful test will bring the motor shaft to a quick stop. Adjusting the pulse time may be necessary to achieve the desire braking distance.

g) ***The motor controller shall demonstrate the ability to provide DC polarity to the servo motor and demonstrate the changing of angular position from 0°-180° through pulse-width-modulation.***
The engineer shall send a high signal to **Port 3** and a low signal to **Port 4** and transmit a series of 1ms – 2ms pulse-width-modulated signals to the **Enable 2** port and achieve rotation of the wheels. The engineer will have to calibrate the pulses to formulate desired angles.

h) ***The motor control controller shall effectively control the drive motor and servo motor simultaneously under load without malfunction.***
To meet the standards in this step, the engineer shall combine steps **d, e, f** and **g** in sufficient combinations and scenarios to ensure a good-faith attempt at full and vigorous functionality.

i) ***The motor controller shall effectively dissipate heat generated by an increased, but reasonable operating load, and not trigger the bridge disable function.***
To complete this step, the vehicle will be tested under load. To sufficiently meet the full load criteria, the assembled vehicle will undergo simulations similar to the routes that are described in the project testing section.

j) ***The motor controller shall demonstrate standards (a – i) in a reliable and efficient manner. The command response shall be measurably finite.***

It is the responsibility of the engineer to show prudence in completing the preceding steps and use integrity and sound judgment before giving the end-product the proverbial stamp-of-approval. The engineer shall complete the steps with the motivation of establishing their reputation of a designer and tester as being credible and respected.

7. Administrative Content

7.1 Milestone Discussion

The milestone chart was very critical to the senior design project as it kept our group on schedule to finish documentation. The milestone was a reminder of letting the group what and when specific tasks had to be completed. As a group of four our different schedules often conflicted with one another so it was imperative that we create the milestone chart. The milestone helped us to be organized and we act cordially to the schedule. Without the milestone our team would have in been in confusion and in dysfunction as we would not be prepared to meet the deadlines of each task

The idea of the project being RC autonomous vehicles was decided as soon as the group was formed. The group decided to meet roughly every two weeks to talk about ideas, concepts, and progress on research of the report. Most of our meetings were productive and much was accomplished during that time. Starting the research proved not to be an easy task as initially thought. Very much thought, detail, and organization had to be put to make sure the research documentation was complete and meet the standards and necessary requirements.

The overall schedule for the two semesters is laid out in the two tables below. The first semester was focused mainly on investigating and incorporating the research we acquired into documentation. The second semester was geared towards integrating the electrical components onto the vehicle platform and implementing the software as well. The first task took place not long after we returned from the break. It was important for us to order some of the parts over the break to help avoid any delays during the semester.

The next task we started the software portion of the project by beginning to write the code and run simulations. Further by middle of February we began testing the hardware and software components along with integrating our PCB design. Moreover, we assembled the components onto the vehicle and began test runs. This part of the semester was critical to the success of our project. The team started fast and aggressively to meet expectations and deadlines.

7.2 Senior Design I

TASKS	DATE	OBEJECTIVE
1	9/11/2012	Project Proposal
2	9/26/2012	Broke down the project into sections

3	10/02/2012	Began research on each section
4	10/18/2012	Turned in Table of contents
5	10/30/2012	Began Individual documentation
6	11/27/2012	Group meeting - progress report
7	12/02/2012	Final Rough Draft
8	12/06/2012	Submitted Senior Design I Documentation
9	12/17/2012	Order Hardware components

7.3 Senior Design II

TASKS	DATE	OBJECTIVE
1	1/8/2013	Begin to write coding
2	2/15/2013	Create PCB Design
3	2/22/2013	Begin testing /debugging of hardware and software components
4	3/16/2013	Assemble components onto vehicle platform
5	3/18/2013	Test run of vehicles
6	3/28/2013	Final Test Run
7	4/29/2013	Submit in Final Documentation

7.4 Project Budget and Financing

For budget and financing we aimed to be as cost efficient as possible and not put so much a financial burden on the group. We were not able to find a sponsor for our project and paid the expenses for the items out of pocket. Below is a list of items for the project. Respective costs were taking from the manufacturer.

	Item	Qty.	Price($)
1	Vehicle Platform	2	105.98
2	Motor Controller	2	5.99
3	2.125" ALUMINUM HEX SPACER, F-F, 6-32	24	7.8
4	6/32x.25" Button Socket Head Screws (25 pk)	16	11.04
5	20 AWG Solid Wires (Different Colors) 25'	6	9.78
6	BUTT CONNECTOR, RED-(50 pk)	2	3.05
7	Printed Circuit Board/Motor Control	2	105.00
8	Miscellaneous Electrical Parts (diodes,capacitors etc)	1	60.00
9	1600mAh 2S 20C Lipo Battery	2	8.05
10	2S 3S Balance Charger. Direct 110/240v	1	11.61
11	JY-MCU Bluetooth Module	2	20.99
12	Infrared Proximity Sensor	2	25.95
13	DSL Wireless IP camera	2	230.35
14	Photoresistors	10	16.22
15	Microcontroller PCB	2	86.00
16	Voltage Regulators	2	3.00
	TOTAL COST		763.81

8. PCB Designs

8.1 Motor Controller

The motor controller PCB, which was focused around the L298n from St Micro, was designed using Eagle. Pictured below are the schematic in **Figure 8.1** and the Gerber file representation in **Figure 8.2**.

Figure 8.1.1

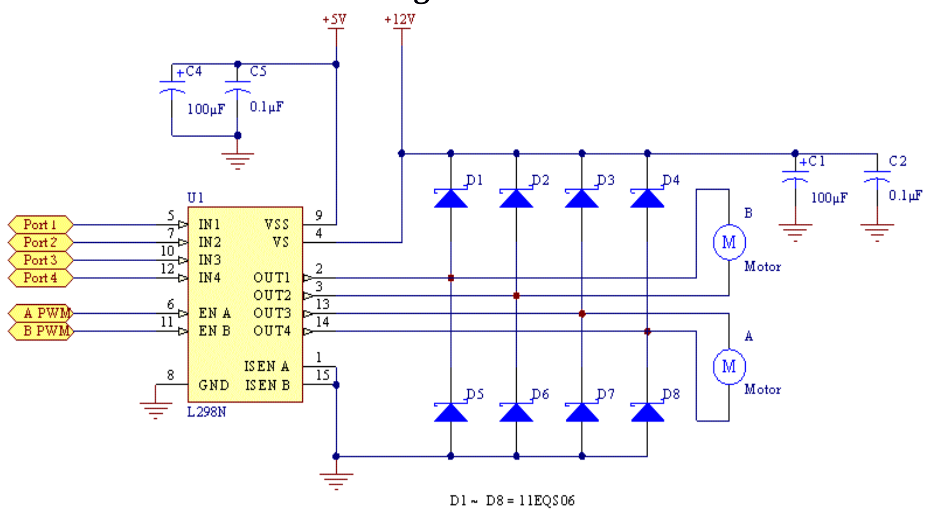
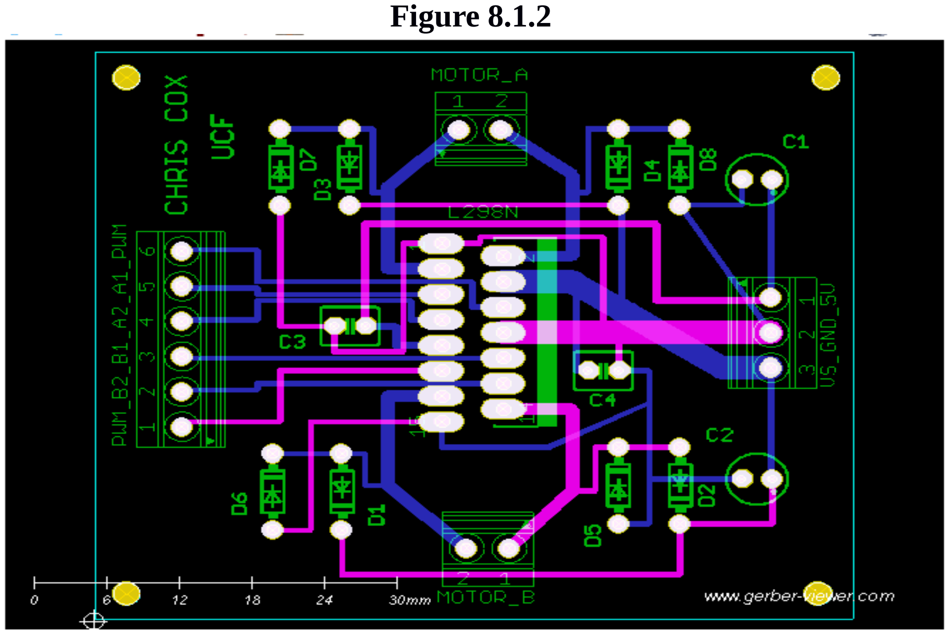


Figure 8.1.2



The design was sent to 4PCB for construction and the cost for 2 boards and shipping was $105. The parts for the construction of the PCB were purchased from Digi-Key for a total cost of $48. The parts breakdown is shown in **Figure 8.1.3**. The PCB was hand soldered using all through-hole parts.

Figure 8.1.3

Idx	*Box*	*Ordered*	*Cancelled*	*Shipped*	*Item Number/Description*	*Back Order*	*Unit Price US $*	*Amount US $*
1	1	18	0	18	1N5818DICT-ND DIODE SCHOTTKY 30V 1A DO41 HTSUS: 8541.10.0080 ECCN: EAR99 LEAD: LEAD BYEX ROHS: ROHS COMP REACH: REACH UNAFFECTED COUNTRY/ORIGIN: TAIWAN CAGE: 12060		.31100	5.60 T JUN-2012
2	1	2	0	2	277-5779-ND CONN TERM BLOCK 6POS 3.5MM HTSUS: 8536.69.4040 ECCN: EAR99 LEAD: LEAD FREE ROHS: ROHS COMP REACH: REACH UNAFFECTED COUNTRY/ORIGIN: GERMANY CAGE: 5Y407		2.89000	5.78 T OCT-2011
3	1	4	0	4	277-5719-ND CONN TERM BLOCK 2POS 3.5MM HTSUS: 8536.69.4040 ECCN: EAR99 LEAD: LEAD FREE ROHS: ROHS COMP REACH: REACH UNAFFECTED COUNTRY/ORIGIN: GERMANY CAGE: 5Y407		.96000	3.84 T OCT-2011
4	1	2	0	2	277-5749-ND CONN TERM BLOCK 3POS 3.5MM HTSUS: 8536.69.4040 ECCN: EAR99 LEAD: LEAD FREE ROHS: ROHS COMP REACH: REACH UNAFFECTED COUNTRY/ORIGIN: GERMANY CAGE: 5Y407		1.45000	2.90 T OCT-2011
3	1	4	0	4	277-5719-ND CONN TERM BLOCK 2POS 3.5MM HTSUS: 8536.69.4040 ECCN: EAR99 LEAD: LEAD FREE ROHS: ROHS COMP REACH: REACH UNAFFECTED COUNTRY/ORIGIN: GERMANY CAGE: 5Y407		.96000	3.84 T OCT-2011
4	1	2	0	2	277-5749-ND CONN TERM BLOCK 3POS 3.5MM HTSUS: 8536.69.4040 ECCN: EAR99 LEAD: LEAD FREE ROHS: ROHS COMP REACH: REACH UNAFFECTED COUNTRY/ORIGIN: GERMANY CAGE: 5Y407		1.45000	2.90 T OCT-2011
5	1	2	0	2	497-1395-5-ND IC DRIVER FULL DUAL 15MULTIWATT HTSUS: 8542.39.0000 ECCN: EAR99 LEAD: LEAD FREE ROHS: ROHS COMP REACH: REACH UNAFFECTED COUNTRY/ORIGIN: MALAYSIA CAGE: 50088		4.67000	9.34 T JUL-2011
6	1	6	0	6	BC1084CT-ND CAP CER 0.1UF 50V 10% RADIAL HTSUS: 8532.24.0060 ECCN: EAR99 LEAD: LEAD FREE ROHS: ROHS COMP REACH: REACH UNAFFECTED COUNTRY/ORIGIN: CHINA CAGE: 56699		.36000	2.16 T JUN-2011
8	1	2	0	2	493-1269-ND CAP ALUM 470UF 10V 20% RADIAL HTSUS: 8532.22.0020 ECCN: EAR99 LEAD: LEAD FREE ROHS: ROHS COMP REACH: REACH UNAFFECTED COUNTRY/ORIGIN: JAPAN CAGE: 55680		.32000	.64 T JUN-2012
9	1	2	0	2	HS300-ND HEATSINK TO-220 4.3W H=1.0 BLK HTSUS: 8473.30.5100 ECCN: EAR99 LEAD: LEAD FREE ROHS: ROHS COMP REACH: REACH UNAFFECTED COUNTRY/ORIGIN: CHINA CAGE: 1N6F3		1.94000	3.88 T NOV-2011
					BOX 1 SHIPPED XGT WEIGHT 0 LBS 8 OZS BOX ID 012606073755219			
					TOTAL INVOICED SHIPPING CHARGES APPLIED ** CHARGES SUBTOTAL ** SALES TAX (T INDICATES TAXABLE AMOUNTS) TOTAL CHARGED TO CREDIT CARD			35.64 10.36 46.00 2.14 48.14

Figures 8.1.4 and **8.1.5** show the PCB before and after assembly.

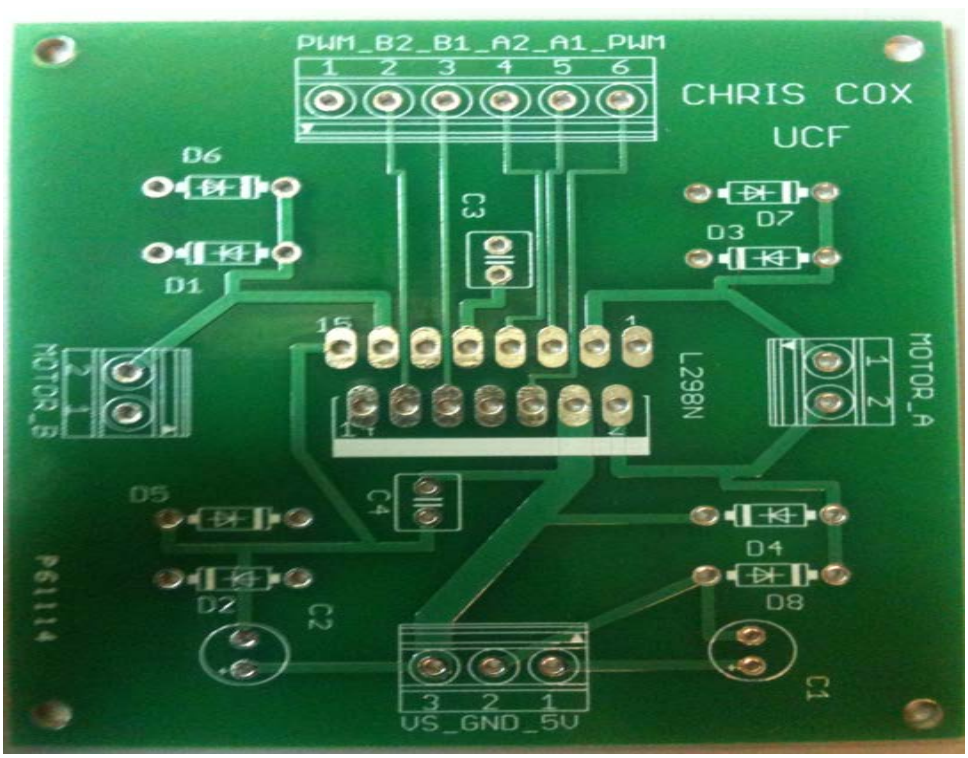


Figure 8.2.02 – Eagle Layout

Section 8.2 Microcontroller

The design of the microcontroller was based off of the Arduino Uno reference. One-to-one pinouts were used for both the analog and digital outputs. A tactile switch was used draw current from the active low reset pin. The input voltage was stepped down from a 7.4V input to a fixed 5V output using an LM7805 voltage regulator with a 2V dropout voltage and a 1A max output. The board also used a 16MHz oscillator for timer purposes, possessed the capability for in-chip serial programming (ICSP), contained a green "on" LED, and contained various capacitors and resistors for filtering input current, limiting the current to an LED, etc...

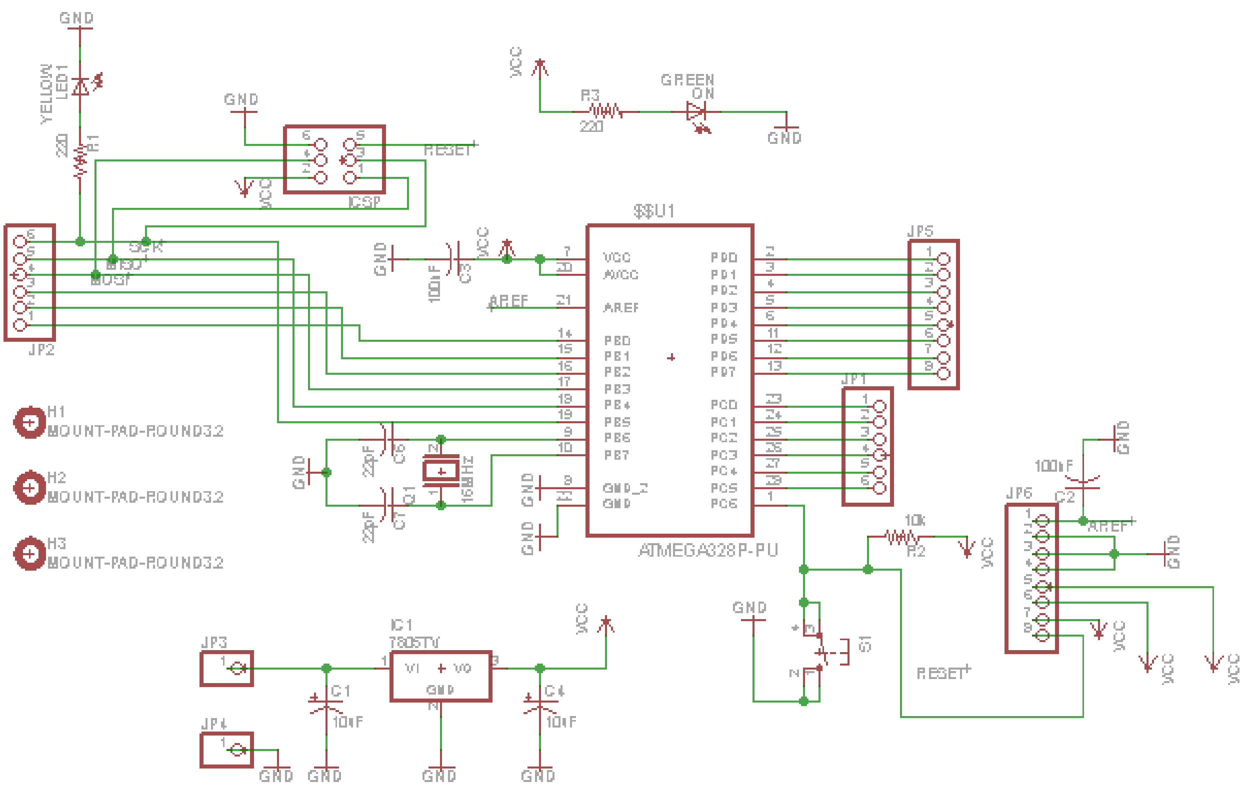


Figure 8.2.01 – PCB Schematic

9. Project Operation

The following procedures explain the steps of operating the prototype and observe the performance of the vehicles.

1) Turn on the wireless cameras and wait for a few minutes until the connection is established with the router.

2) Turn on the main power on the vehicle and check to see if all modules are powered up (blinking LEDs).

3) Scan and find the COM port used by for the Bluetooth communication on the remote PC.

4) Scan and find the IP address by the wireless camera.

5) Open the Image Processing program and enter the specific COM port for Serial Communication over Bluetooth as well as the IP address of the wireless camera.

6) Make sure that the connection is established between the Cloud Camera and the PC. Run the program.

7) The LED on the Bluetooth module on the vehicle will stop blinking and stay lit once a connection is established with the remote PC.

8) Upon a successful connection, the vehicle will be given an “initialize” command by the image processing program and the vehicle will start navigating through the course.

9) The remote PC will continuously scan for road signs using the video feed from the on board camera and upon detecting one, send a character byte to the vehicle AI over Bluetooth serial port.

10) The vehicle takes an appropriate action in response to the detected sign, and continues its navigation until it reaches the final destination.

11) Avoid physically moving the vehicle off the track.

12) To interrupt the navigation and halt the car, carefully press on the reset button located on top of the microcontroller board.

13) In order to start another run, stop debugging the image processing program and start from step 6.

10. Summary

B.R.A.V.O. or “Bringing Reliability to Autonomous Vehicle Operation,” is fully autonomous vehicle that has the ability to navigate a pre-determined course using image processing technology and navigate sub-routes as chosen by the group to demonstrate a wide array of line-following techniques such as sharp turns, stop signs and intersections. The vehicle also displayed collision detection abilities through the use of proximity sensors while maintaining control of the vehicle and finished the chosen route for the vehicle. For complexity, the group added a second autonomous vehicle that relied on an off-board image processor that processed all the necessary image data for the vehicle, while completing all of the required challenges set forth for the first autonomous vehicle.

The idea for the autonomous vehicle was inspired by the emergence of driverless cars over the last decade and though the task of incorporating this technology onto a larger scale was the initial goal, cost and safety concerns were the deciding factors in choosing another route. Driverless or autonomous cars have enormous potential when considering the future of individual transportation. From avoiding hazardous driving situations such as a sleepy or intoxicated driver, to optimizing traffic flow in rush hour traffic, a driverless car that is able to detect potential collisions while safely navigating a pre-determined route is beneficial for the safety of all drivers.

B.R.A.V.O. was a project that the group has derived both joy and frustration while designing, building, testing, and showcasing for the Spring of 2013. It was a project that was diverse in its respective components, combining the skills and knowledge of both electrical and computer engineering. From embedded systems and servo controls to image processing and artificial intelligence design, the project has allowed the group members to expand their knowledge of engineering by taking the learned concepts of the classroom and applying those concepts to the actual experience of building and testing a working project.

The project has also demonstrated to the group members the valuable experience of working as team to accomplish a common task. As engineers, problems often arise that require the expertise and knowledge of more than one individual. The group has taken pleasure in the challenges and experiences that this project has provided and is satisfied with our work in that we have provided a unique perspective on the autonomous vehicle.

Appendix A:

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Actions
To:
christopher_cox@knights.ucf.edu
The following is a record of your online chat.

General Info	
Chat start time	Nov 29, 2012 6:02:12 PM EST
Chat end time	Nov 29, 2012 6:08:10 PM EST
Duration (actual chatting time)	00:05:57
Operator	Michele

Chat Transcript

info: Please wait for a site operator to respond.
info: You are now chatting with 'Michele'
Michele: Hello, how can I help you today?
you: Hi Michele, I am a university student in electrical engineering and am doing research on adapting remote control type cars to computer controlled platforms. Do I need permission to use any pictures from your website?
Michele: Our website only has remote control helicopters. Which photos are you trying to use?
you: The photos of the brushed and brushless motors
Michele: One moment. Let me check for you.
you: they are the colored drawings, not actual photographs
Michele: You don't need permission. You can use any photos you choose.
you: Ok thanks Michele
Michele: No problem.
info: Your chat transcript will be sent to christopher_cox@knights.ucf.edu at the end of your chat.

HobbyKing Permission

nreply@live2support.com

Actions
To:
christopher_cox@knights.ucf.edu

You are now chatting with : Cheryl (Customer Service)

Cheryl:	Thank you for contacting the HobbyKing Support Team. How may I help you?
You:	Hi Cheryl, I am a university student in electrical engineering and I am doing research on vehicle platforms to be modified for use in computer controlled applications. Do I need permission to use any pictures or car data from HobbyKing's website?
Cheryl:	let me check for you
You:	ok
Cheryl:	i have checked
Cheryl:	the photos can be used, but you are required to cover the logo on the product
You:	ok thank you very much

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Appendix B

Data Sheets

DRV8833 Motor Controller:
http://www.ti.com/lit/ds/symlink/drv8833.pdf

L298n Motor Controller:
http://www.sparkfun.com/datasheets/Robotics/L298_H_Bridge.pdf

http://www.st.com/internet/com/TECHNICAL_RESOURCES/TECHNICAL_LITERATURE/DATASHEET/DM00037051.pdf

http://www.ti.com/lit/ds/symlink/f28m35h52c.pdf

http://cache.freescale.com/files/32bit/doc/data_sheet/MCF52259.pdf

http://www.atmel.com/Images/doc32058.pdf

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http://www.atmel.com/Images/doc8161.pdf

http://www.ti.com/lit/ds/slas700a/slas700a.pdf

http://www.infineon.com/dgdl/xe161fu_ds_v1.2_2012_07.pdf?folderId=db3a3043156fd5730115b3a665650d23&fileId=db3a30432e398416012e4d7b0ca95d84&sId=db3a30443b360d0e013b6a2ef8744ac2

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