1 - Executive Summary

The purpose of this project is to fabricate an apparatus which controls an external vehicle's every movement. The apparatus, here on referred to as the Cockpit, will transmit information via a wireless transceiver to an external vehicle, here on referred to as the RC Car. The Cockpit will provide driving direction controls as well as regulate the speed and acceleration of the RC Car.

The RC Car will consist of a store bought radio controlled vehicle equipped with a high grade analog camera fastened to the front and will stream real time video to the Cockpit display screen. The driver will use the video feed to navigate the RC Car through a prefabricated course or have free reign to roam the terrain. The RC Car will also have a series of potentiometers and an accelerometer that will send information to the Cockpit regarding the pitch and acceleration of the RC Car which will be accurately recreated by a series of three actuators attached under the driver's seat.

Using the video information seen on the Cockpit's display monitor the user will press the accelerator or brake pedal to control the speed. In addition, a steering wheel will be used to turn the RC Car. The pedals and the steering wheel are spring loaded to ensure the driver experiences slight resistance while operating the simulator. The pedals and steering wheel also contain potentiometers that are realized by the RC Car and act accordingly. There will be adjustable components on the Cockpit meant to allow rider's of various size to operate the RC Car comfortably in a seated position.

2 - Project Description

2.1: Motivation and Goals

When taking on a project such as this, a clear set of motivations as to why the project is being pursued should be outlined. Some primary motivations for the project are to learn about working in a team environment with collaborative constructive brainstorming, to solidify the knowledge attained of electrical engineering, to learn more about mechanical and computer engineering, to get involved in an in depth challenging project, and to create an interactive realistic experience for the user of the product.

When analyzing different project ideas, it became readily apparent that a project such as this would provide more than adequate design to understand a variety of interesting topics. This is important because the primary goal of this project is to learn about relevant technologies in the electrical engineering field. Some of the topics that will be understood by the completion of this project are software and hardware interfacing, precision control of analog devices by way of digital output from an MCU, analog and digital RF communications and interfacing, and data packing and transportation protocols.

2.2: Objectives

RC Ghost Rider must be a realistic simulator that actualizes motion from an RC Car. The user should be able to use the vehicle with very little extra knowledge other than very basic understanding about vehicle operation, simple fundamentals of batteries, and the safety protocol of operation. The cockpit must accommodate people of varying sizes and weights. Safety protocol must be established and accommodated, as safety is the greatest concern in all product usage. It must be dynamic, and adjust based on intense and thorough testing procedures.

The RC Car must be wirelessly controlled, and thus, must have the longest lasting battery life possible. Also, the RC Car must be able to travel as far away from the Cockpit as possible, with little interference. This distance must be limited (or even correspond) by the distance of the camera's transmission. Also, the RC car must be durable, as to be able withstand the obstacles that it encounters. The RC car must have a functioning camera, also with extensive battery life. A clear and detailed dynamic image must be displayed in the weakest delay of real time as possible. Wide angle of vision must be displayed to give a greater awareness of surrounding area to the operator. The Camera must also transmit sounds taking place around the RC car to the user.

The Cockpit must be safe, and must achieve the most realistic simulations possible. It must tilt based on forward and backward acceleration, and left and right based on turning. Also, vibrations from the RC car must be wirelessly transferred to the cockpit to simulate realistic obstacle encounters such as bumps and dips. All motion must take place in the weakest delay of real time as possible.

2.3: Requirements and Specifications

Technically speaking, the vehicle will need to be small. That being said, it cannot be too small as it will need to house a variety of pieces in order to function as intended. It will need to house one accelerometer, four potentiometers, a DC drive motor, a DC servo motor, two batteries, many small DC voltage regulators ranging between 5 and 10 volts, an MCU, a transceiver and a transmitter. The potentiometers will need to be small, accurate and relatively inexpensive. The will also need to fluctuate resistance by a large margin in order to compute with reasonable accuracy the current disposition of the vehicle. Ideally they will be passive components with a resistance of about 10K ohms.

The accelerometer will need to measure at least 2g in order to sufficiently complete it’s task, and thus will not be as inexpensive as desired. It will also need to be at least a two axis accelerometer (preferably three) that has a digital output mode. In addition it will have to have a sampling frequency of at least a few hundred samples per second. To fit in the amount of space allotted to entire packaging of the device will need to be less than one square centimeter. The voltage that will be used by it should be no more than 5 volts.

The four potentiometers will be housed at each of the wheels on the vehicle. The will be used to determine how much stress the vehicle is under due to turning and gradients of the ground. These four potentiometers should be small enough to be housed in the space between the wheels and the chassis. They should also have a fairly significant variation in resistance in order to accurately judge their position. They should have a spring coefficient that allows for them to be partially compressed when in their rest state.

The DC motor should have a max spin speed of at least a few thousand RPM's. It should take in a variable DC voltage as its driving force. It should be small enough to comfortably house on the back of the vehicle, light enough as to not over encumber the vehicle, and strong enough to move the vehicle at an acceptable speed. The variable DC voltage should be within the range of 0-9V.

The batteries will need to have a voltage output of at least 9V each (preferably 12V) in order to properly power the DC motor that will be moving the car. In addition it will need to be at least 1000mA/H in order to give the experimenter a reasonable amount of time to test the vehicles operation. It should be fairly small, and have approximately the same proportions as a toy RC car battery.

Three voltage regulators will need to be used in order to properly power the MCU and the DC motor. The MCU will need a stable power supply of between 2 and 5 volts (depending on the MCU of choice). The next regulator will be responsible for the variable voltage of the DC motor. This regulator should be able to fluctuate from 0-9V and be controlled by a serial digital output from the MCU that will give it a signal to drive the motor. The last voltage regulator will control the behavior of the DC servo motor and must be able to fluctuate from 0 to 5 volts to decide whether the vehicle will turn and to what extent.

The MCU on the vehicle will need to be a small unit that uses a very small amount of power. It will need to have an operating frequency of over 10 MHz and power consumption under load of less than 2W. It will be used to receive information from the components and relay this information to the transceiver to be sent to the cockpit. In order to send the required information of at least 20 packets of 20 bytes each, the transceiver will need to relay information at a rate of over 1kBps in order to have a channel in which to move all the information that will need to be moved, at a rate that will be observed as real time to a person that is identifying the information coming in. Ideally the information will be moved much faster and thus the transceiver in question should transmit at a rate of greater than 5kBps. The range of the transceiver should sufficient to test the remotely controlled device and thus should be over 50 feet indoors and over 150 feet outdoors.

The transmitter will need to operate on a frequency that is free to use, as to not violate any laws instituted by the FCC. The possible frequencies are 900MHz and 2.4GHz. Regardless of what transmission frequency is used it is necessary to implement a receiver on the vehicle that corresponds to the chosen frequency. The transmitter that is received must be able to send an analog video signal, and thus will need to occupy a bandwidth of at least 50MHz. In addition the transmitter should have a range that is higher than the range of the transceiver that will be used.

The Cockpit will need to have a comfortable chair equipped with a restraint harness, an adjustable steering column, adjustable foot pedals, a mounted flat screen TV, (that will be used for the incoming video transmission) and a receiver. All of this will be mounted to the bottom of the chair onto a metal platform. On the bottom of the chair, it will be mounted to three linear actuators, and a shock absorbing central pivot point that uses a ball and socket joint, as to not obstruct the actuators movement, but to give a fair amount of stability to the device while in motion. This pivot joint will also need to absorb possible shock and should have either a hydraulic or spring-loaded piston. The actuators will move up and down at a rate greater than one and a half inches per second under a load of at minimum 350 pounds per actuator. Using these standards, it can be said that the apparatus will move enough to offer an enjoyable simulation experience.

The comfortable chair should ideally be the seat from a Nissan 240sx. It should be equipped with a five point harness in order to ensure the safety of the rider. The seat will be in relatively good condition without any rust or structural damage. The harness should be fastened to a metal mounting bracket that will be fastened to the back of the seat.

The adjustable steering column should sit at approximately the same level as one would be assume it to be when driving a vehicle. It will have a pivot joint in order to allow it to pitch up and down as a normal steering column would. It should also be able to move closer to, and further from the seat, as the seats position will be fixed. The control system for the steering column will consist of a wheel retraction mechanism (which will bring the wheel back to center) as well as a potentiometer that will measure the difference in the wheels spin, relative to the zero position. This potentiometer must be very sensitive in order to properly account for the minuscule changes in the system. In addition the wheel retraction mechanism must be fast, and slightly over-damped. This way when the user lets go of the wheel, it will return to center for a more realistic user experience.

The adjustable foot pedals will need to be mounted to the platform that extends from the chair. They will need to be at a distance away from the user, such that it feels akin to riding in a vehicle. In addition the pedals will need potentiometers in order to judge the movement of the pedals. That being said, the pedals will also need to be spring-loaded. The purpose of this is to allow the pedals to spring back to their upright position after they have been depressed. Since the position of the seat is static, the pedals will also need to be adjusted in order to accommodate a person of larger or smaller stature.

The linear actuators will be controlled by PWM to DC output networks that will receive its control input from the Cockpit's MCU. This voltage regular must be able to sync a maximum of 20 amps of current at a voltage of at least 24 volts. There will need to be one voltage regulator per actuator The MCU will deliver a pulse width modulated voltage signal with a duty cycle between 0% and 100% that will need to then be translated to a reasonable voltage by the regulator, to the actuators. Because there are three actuators there will need to be one PWM to DC output network per actuator.

All of the readings will be taken in by the MCU located on the cockpit and converted into usable information. The readings will be read one at a time, and three readings will need to be stored in memory as an array. These three readings will be averaged to calculate the average value of the voltage and eliminate possible noise. The receiver that is used by the cockpit should likewise operate on the same frequency that is picked for the transmitter on the vehicle. This receiver should be able to accept the input and output the information to the display unit that will be located on the cockpit.

3 - Research Related to Project

3.1: Similar Products

When designing project RC Ghost Rider, two similar products were used as the basis of the cockpit design. They were the *Blue Tiger Motion Simulator* and the *Force Dynamics 401 Racing Simulator*. While no specific part of RC Ghost Rider was specifically mirrored or mimicked, some design features from each of the aforementioned products were used as a starting point during the cockpit design portion. These products have been thoroughly tested for efficiency and safety; however, given the lack of research resources and development time for this project in comparison to these products, it would be wise to compare & contrast these products to determine which attributes will best suit the project. When using these products as benchmarks and references, extreme care went into ensuring that RC Ghost Rider is distinctly off design but shared similar qualities. The products listed above are strictly racing and flight game simulators, whereas the RC Ghost Rider cockpit gives users control of an external remote controlled vehicle. The largest difference in this project versus similar products is that it simulates the movements of another physically moving object, where the other two are virtual reality simulators.

Blue Tiger Motion Simulator

The Blue Tiger Motion Simulator seems to be the cream of the crop when it comes to prefabricated simulators. It appears to have the most aesthetically pleasing appearance and uses the highest quality parts. Its three monitor visual display unit incorporates state of the art monitors with high resolution and refresh rate (120 Hz). The material used to construct the simulator is comprised of high grade steel, fiberglass, and plastic. The body is concept design with jet fighters and formula cars as the inspiration.

The base of the simulator houses the power supply, control electronics, actuators, and motors. The body is the part of the simulator that moves and is attached to the top of the base and actuators. There is nylon material between the base and body to protect the actuators from dust and debris. The base also uses outriggers which can be bolted on for added stability.

This simulator uses am unknown amount and type of actuators to control the body. The actuators are located directly under the center of the seat with a rubber and plastic casing around them providing both a base and also to keep the actuator assembly hidden. It uses a combination of fast and slow frequency of movements proportional to the action in the games to convince the rider that they are experiencing both the dynamic forces of acceleration and braking. The actuators also move the body into the same physical position that one would expect to be in if they were inclining and declining on a hill or slope. There was also care taken to provide a variety of special effects such as engine vibrations, road surface texture, and minute and frequent bumps in the road. This is achieved by the actuator control circuit just as the RC Ghost Rider is. The Blue Tiger's maximum weight payload that the actuators can properly function concerning both the rider and accessories is 350 lbs. The actuators can also provide is positive or negative 20 degrees of independent pitch (tilting the body left and right) and positive or negative 20 degrees of independent roll (inclining and declining the body forwards and backwards), and an 8 inch sway (moving the seat forwards and back on the lateral plane). The RC Ghost Rider will not be capable of this movement given its' motion is around a central ball joint.

The body is comprised of lightweight fiberglass, where-as the RC Ghost Rider is fabricated using 4340 Chromoly. The Blue Tiger is a comprised of two pieces, a one-piece chassis around the seat and footwell, and a one-piece front cowling, monitor enclosure, and dashboard. There are two prefabricated bodies available and there is also an option for the buyer to help design a custom one off version.

One glaring difference between this product and RC Ghost Rider is that there are various components that can be added to the simulator to enhance the user's experience. Blue Tiger offers a variety of seat, steering wheels, and joysticks available to consumers. Project RC Ghost Rider offers no upgradeable components or modes. This is due to the predetermined budget and also that RC Ghost Rider is not a consumer grade product with no immediate plans to recreate and redistribute for financial gain. Another is that three monitors can be integrated, equally distributing the image into thirds, with each screen displaying its corresponding portion. This option is designed so the driver can easily view the video game. The Blue Tiger is designed to accommodate up to three 42 inch flat screen televisions or monitors. Another is that the Blue Tiger Motion Simulator is both a racing and flight simulator. The company is currently working to make PC and internet games compatible with the simulator. The Blue Tiger offers either 2 or 3 pedal assemblies with the latter including a clutch pedal. This is not needed in RC Ghost Rider due to the fact that it will be controlling an electric remote controlled vehicle with no transmission. They do however both feature pedal assemblies that can be adjusted forwards and back for user comfort. Also, The power consumption of the Blue Tiger is much lower than RC Ghost Rider, with a 700 watt maximum load drain and a 200 watt no load drain.

There are also many similarities between these two products though. One is that both will be completely electric to create a quiet and clean user experience. Both can be operated from standard wall sockets. Both simulators offer a 3 point harness system to keep riders placed firmly, comfortably, and safely in the drivers seat. It should also be noted that RC Ghost rider's 20 degree pitch and roll standard is based on the Blue Tiger.

Force Dynamics 401 Racing Simulator

The Force Dynamics 401 Racing Simulator is more closely related to the RC Ghost Rider. The 401 implements a three actuator system with a series of ball and hinge joints used to connect them to the body of the simulator and recreate the forces and movements felt by the car in the video game. Just as the Blue Tiger, this product uses the highest grade components available to create a realistic driving experience. It is however, another video game simulator not a mechanism used to remotely control an external vehicle.

The 401 Racing Simulator provides four-axis motion that utilizes pitch, roll, yaw, and heave. The 401 has the most unique design with regards to the motion of the body. All movement is based off the driver's shoulders as being the relative center of mass. The roll axis is located around the shoulder level on the driver's plane of symmetry. This plane of symmetry cannot be precisely located given the varying sizes of the simulator operator. The pitch axis is located somewhere around 4 inches forwards of the driver's shoulders again, but perpendicular to the driver's estimated plane of symmetry. The yaw axis is based off the vertical plane and uses the driver's symmetry, it is approximately 20 inches forward of the rider's shoulders. For RC Ghost Rider the center of mass is assumed to be around the driver's waist/hip area.

The one glaring draw back to the 401 when compared to the other two simulators is the maximum load the actuators can handle to efficiently operate. The maximum passenger weight is 280 lbs and the maximum passenger weight for full performance is only 220 lbs. Project RC Ghost Rider is designed to comfortably handle a maximum full performance load of 400 lbs.

The linear thrust actuators can provide is positive or negative 30 degrees of independent pitch and positive or negative 30 degrees of independent roll,positive or negative 90 degree of yaw, and 8 inches of sway just as with the Blue Tiger. These are very good statistics considering RC Ghost Rider boasts dynamic performance values of positive or negative 20 degrees of independent pitch and positive or negative 30 degrees of independent roll. RC Ghost Rider lacks in the area of sway with its measuring at a constant 0 degrees of sway due to the presence of the center ball and socket joint located under the cockpit seat.

Another unique design aspect of the 401 is how the images and video is displayed to the display screen. The screen consists of a powder coated aluminum sheet surrounded by a steel frame. It is a neutral gray color to enhance contrast with brighter ambient light. The Blue Tiger and RC Ghost Rider both use mass produced monitors to display video, the 401 uses a projection system. This feature separates the 401 from the other two simulators and also shows another level of sophistication and uniqueness in the 401's design. This ensures that the video display unit is free from all problems associated with vibrations, but adds a dimension of new problems in that the projection lens must be at the perfect angle at all times and that nothing can obstruct its projection path.

The power supply of the 401 is compatible with a standard wall socket, but in an added design enhancement it can be used in not only North American wall sockets, but in many European wall sockets as well. It is equipped with an isolation transformer and can be used with common non-polarized outlets found throughout the world. There are many safety precautions taken in the 401, one being that it contains a relay with self-checking contacts, as well as software monitoring contacts. There is also a separate manual reset function to make sure that if any malfunctions or anomalous behavior occurs it can be manually shut off by someone other than the driver. Located on the body of the 401 there is another emergency stop switch within close range of the driver. The seat belt and door both have monitored locks that place the machine in pause mode when they are not in the locked position. The RC Ghost Rider has also taken extensive measures to ensure driver and simulator safety by also placing a power on/off switch withing arms length of the driver, as well as the type of harness used to secure the driver in cockpit seat.

The body of the 401 is closer in material used to the material used for the construction of the RC Ghost Rider than the Blue Tiger. The strut tubes are comprised of 4140 steel. The frame is fabricated from low-carbon steel and a textured polyester powder coating used to combat erosion. There are also various aluminum parts used to construct other components on the body. The electrical components are mounted in a separate structure fabricated from Galvalume. This structure contains a series of fans to keep circuitry cool. There is a 25 Amp single pole circuit breaker that is used to protect the circuit in case it is connected to an unfused power source or a power surge is experienced. The RC Ghost Rider will house all of its cockpit electrical circuits in a housing not directly mounted to the cockpit to ensure that there is no noise or vibration interference caused by the actuators felt upon the circuitry. Just as with the Blue Tiger, the 401 comes available with a 2 or 3 pedal system and a transmission shifter. The RC Ghost Rider is again only available in one model and it has a 2 pedal system. The RC car that will be controlled does not contain a transmission so no clutch pedal is required.

The 401 adds a dimension to its simulator that neither of the other simulators does, audio system. The 401 utilizes a brand name five-way speaker system with two being located on the side and one on top of the screen, and two located behind the driver's head. A sub-woofer located in the base just below the rider.

3.2: Relevant Technologies - RC Car

3.2.1: Battery and Power

In order to adequately power the various components that are to be used on the vehicle, it will be necessary to have two 12V battery packs as well as multiple voltage regulators. The two 12V battery packs are Ni-MH battery packs that are rated 1000mAH. The current rating of the batteries was of paramount concern as it is very important that the RC Ghost rider can be run for at least a half hour continuously. The dimensions of the batteries are .5” X 3.8” X 2.8”. The batteries will be wired in series, and the common node that will be used for the entire circuit will be the node where the positive of one battery meets the negative of the other. Because there are so many components that will run off of the positive components, it will be necessary to run the drive and the servo motors off of the negative voltage. Doing so will ensure that the other systems remain active even when the battery for the control of the vehicle has been depleted.

In addition to the battery power that will be used for the system, there will also need to be a voltage regulators used that will control the supply voltage to the various circuit components. As all of these voltages will be designed to fall between 5 and 12 volts the LM7805 will be used. Their will need to be various LM7805’s with different output supply voltages in order to power all of the subsystems that will be needed to complete a project of this magnitude.

3.2.2: RC Car and Accessories

To begin conceptualization of the vehicle and its various accessories it is necessary to pick a remote controlled car. The car chosen for this project is the “Bright Black Ram”. This car was primarily chosen because of its price, weight, and size. The car is a 1/10 scale with dimensions of 18 inches wide, 10.125 inches wide and 10 inches tall. The vehicle weighs approximately 4lbs. In addition the vehicle cost of $25 fits nicely into the stringent budget.

The servo motor that comes will the car will be exchanged with a HI-TEC HS-55 DC servo motor. This servo motor has been selected because of its input voltage, price, speed and total angular movement. The voltage range of operation is 4.8V to 6V. This voltage coincides nicely with the output voltage from the LM7805. In addition the price point of $12 fell within the range that was to be expected. Likewise the speed of motor is a surprising 438 degrees per second, which works out to a speed of 71 RPM. This speed of motion is more than adequate for the purposes of controlling the vehicle, considering that the motor has a maximum angular displacement of 40 degrees. In addition, a separate drive motor must be selected, because the speed of the vehicle with its current motor is unacceptable. For that purpose a GWS RS-777 DC motor has been selected. This motor operates at 7.2V and thus a circuit must be devised to properly control it. Under no load the current draw of the motor is 700mA and the speed of the motor is 16,000 RPM. The motor has a stall torque of 836 g/cm with a stall current of 21.2A. For the purposes of this project, these values should never be necessary, and to ensure this point does not get reached a 15A fuse will be placed on the motor drive voltage input.

3.2.3: Processing Platform

When searching for a micro-controller to be used on the vehicle, there we many factors that needed to be taken into account. Among those factors was the units price, size, power consumption, processing abilities, and analog to digital inputs. When weighing all of the potential prospects for this type of application, it was decided that the MSP-430 would be the best fit for this particular situation. When concerned with the price, the Launchpad version (a small all in one development solution) of the MSP-430 seemed to fit well within the constructs of the design specifications. The processor meets both the size constraints that have been put in place, as well as the speed constraint. The competitors could not match the price-point of $4.30. That begin said, there are some drawbacks to the selection of this version of the MSP-430 but to the projects specifications, these drawbacks should not be an issue.

Based on the scope of the project at hand, the main functions of this micro-controller unit will be to take voltage readings from the digital and analog components (accelerometers, potentiometers) and relay that information to a transceiver that will move the information from the vehicle to the cockpit. For this functionality the MSP-430 should work swimmingly, as it will only need to take in a few hundred readings per second, and relay the information it takes in. Even though it only had 128B of RAM, this shouldn't be a problem, as most all operations should take less than 50B, none of the information needs to be stored and can easily be overwritten and disregarded.

With the extremely low power consumption of the device, the mobility of the vehicle shouldn't be dramatically affected by its power usage (compared to the vehicles motor, servos, etc). When operating at 1 million instructions per second (MIPS Active) the device uses approximately 220uA. With an input voltage of 2.2 volts this means that the power consumption of the device under a considerable load would be about .5 mW. Considering the specifications of the parts the car will be using and their power consumption, this small number is practically negligible. The mention of the MIPS Active rating was a very high approximation of the actual power consumption of the micro-controller, because the design specs would allow the controller to use significantly less power, based on the fact that it will be preforming far less calculations than this rating is intended for.

The size of the parts in question is also another determining factor in what type of MCU (micro-controlling Unit) will be used for the design. It is very important that the unit is small and can be mounted relatively easily to a remote controlled vehicle. Taking these specifications into consideration, there was yet again another reason to use the MSP-430. With the size of the components and the varying packaging arrangements available, there will be no problem getting a solution that meets the requirements for space in question.

This micro-controller's input pins will be used to take the information from the active/passive circuit components used to measure the vehicles disposition. Because of the fast clock rate (25 MHz) there will be no problem reading all of this information. In addition to reading the information the MCU will be making calculations on the data being sampled in order to verify the legitimacy of the received signal. This can be done by taking multiple samples of one circuit elements voltage output and averaging them over time. For instance in taking 45 samples from the accelerometer each second, the programming that will be need to take in three samples at a time into an array and use the average of the three samples, then after computing the average of these samples, they will need to store the last average in a variable so that it can be compared to the new average, in order to get the change in how gravity is acting on the part. This derivation in gravity can then be used to get an approximate acceleration. The acceleration will be fine-tuned by adding into the equation the difference in the potentiometers that are attached at the four wheels.

3.2.4: Sensors

There are various sensors that need to be implemented and retrofitted onto the RC car. Among those sensors are the accelerometer and the potentiometers. These sensors will take information and relay that information to the MCU so that it can be used by the cockpit to determine how to adjust accordingly. The potentiometers that will be used must be small in size and relatively inexpensive. In this area it’s quite hard to find a product with both specifications. The product selected for the four linear potentiometers on the vehicle is the Bourns PSM01. This particular model is a 10K ohm linear potentiometer with a price point of $15 each. The entire length of the device is just under four inches, which is a bit larger than anticipated, however will not hinder the operation of the vehicle.

Likewise an accelerometer must be selected. In the case of the accelerometer it has been stated that it should be very small, low power, at least two axes, sensitive to two times the force of gravity, and have a digital output. The accelerometer that was chosen is the AIS326DQ. This accelerometer has been chosen because it meets all of the criteria above. In addition to meeting the above criteria, this accelerometer was also marginally cheaper than the others researched.

3.3: Relevant Technologies - Cockpit

3.3.1: Power

The Cockpit apparatus will be supplied power using two DuraComm RM-5024 power supplies. These can operate using a wall socket connection (120V, 60Hz). RM-5024 can supply 23-29 volts DC at 50A, so 100A can be supplied using a parallel connection in using two. Approximately 100A is required. In the worst case scenario approximately 90A will be drawn from the power supply. This is a switching power supply, so efficiency in power delivery takes place. Also, this quality provides that the power supply is small, and light-weight. A 12V supply is not a sufficient supply for the cockpit operation, as a 12V supply would not reliably deliver 12V to the actuators when required. If the average operation of a 12V supply is 12V, then it will almost never be able to supply 12V to an actuator (as some voltage is dissipated by the source follower in the PWM to DC output stage) limiting extension speed. It should also be noted that this is a non-isolated power-source, so supplying negative voltage is not an option.

All of the cockpit will be supplied power using this power supply, aside from the visual interface and the -5.1V DC power supply. However, not all components powered by the power supply require 24V to be powered, so LM-78XX series voltage regulators will be used between the power supply connections to the devices that require DC power. Note that all schematics assume a24V DC power will be supplied; However, voltage fluctuations are bound to happen. Therefore, an LM-7824 will be used on all 24V connections where another voltage regulator is not used.

The DuraComm RM 5024 is typically used in communications, and is typically valued new at $737.33. However, two of these power supplies have been obtained, and are available for use. Commonly these are used on rack mounts, making it simple to mount to any housing apparatus. It is 3.3” deep, 5.95” wide, 5.5” tall, and weighs 6.5lbs. Due to such specifications, transportation of the apparatus is made easier.

The display and 900MHz receiver will be supplied power indirectly from a wall socket, as it was previously designed to do so. There is no reason to bypass this specification and power the display from the power supply, as it would likely cause an issue in maintaining the reliability of the display. Also, it would cause unnecessary current drain from the power supply. Subsequently, the power supply, the-5.1V power supply, the display, and the display’s receiver will be powered using a power strip (obviously connected to a wall socket) mounted in the housing made for the circuitry.

The -5.1V supply used will be a 5.1V, 800mA cell phone charger. This is necessary for variable power delivered to an actuator. This is isolated, so when connected in an inverted configuration can supply -5.1V. The use of this will be more closely examined in the design summary section (5.3.2).

Due to the price of high current DC power supplies, it should be noted that all designs were made around the basis that only positive voltage will be supplied to components and devices that require high current. Thus, adjustments have been made to accommodate requirements for actuator retraction.

3.3.2: Cockpit Processing Platform

To choose a processing platform one must consider cost, reliability, performance, and ease of use. Many different processing platforms were considered for this part project, such as the TI Piccolo board (which was much too expensive, though the specs were better), and some 16-bit processors such as the Arduino and the MSP 430 (both of which are not powerful enough to process the information required for the project). Ultimately, it was decided that a 32-bit processor which was affordable and open source would be the best option. The Netduino, currently, is the best processing platform balancing all of those things.

The Netduino is available at $34.95. This is a major benefit, as many 32-bit electronics platforms are more expensive. Comparable platforms range from $70 to $120. All accessories necessary for programming the platform are also included. This product is available for purchase on-line consistently.

The micro-controller to be used in the operations of the cockpit unit will be the Netduino. This is an Atmel 32-bit micro-controller that operates at 48MHz. The code storage is 128 KB, and consists of 60 KB of RAM. The processing speed will be sufficient to perform the tasks required; the 128KB of code storage is certainly more than sufficient to store the code necessary for the RC Ghost Rider cockpit; the 60KB of RAM is much more than necessary, as the most of the stored elements of the code will be replaced very shortly after execution.

The I/O features include 20 analog and digital I/O pins. 14 of which are digital I/O pins, and 6 are analog inputs which can also act as digital I/O pins. All 20 pins are General Purpose I/O. The pins have a variety of specific uses; however, not all will be used for the purposes of this project. Pins 5, 6, and 9 will be utilized for their PWM capabilities; 6 analog input pins will be utilized as intended, and 4 other pins will be utilized for GPIO utility. This was a major reason to choose this board, as the abundance of I/O pins is necessary to meet the goals and specifications designated.

The input required is 7.5-12.0 VDC, or USB powered. The output voltage is 5 VDC and 3.3 VDC regulated. The analog reference is 2.6 – 3.3 VDC, but only required when using analog features. Max current is 8mA per pin (Digital pins 2, 3, 7: 16mA per pin; analog pins 0-3: 2mA per pin; micro-controller max current 200mA). Digital I/O pins are 3.3 V, but 5 V tolerant. Default pulse width modulation frequency is 10 kHz, but it is most probable that 1 kHz will be utilized. The operating temperature is within the range of 0 - 70 °C (32 - 158 °F). These specs are standard for electronic devices comparable to the Netduino, but are necessary to perform actions such as PWM and controls. It should be noted that the electrical design of this project should not be taken lightly, as nearly 100 times the current tolerance is may be used to power the linear actuators. This issue would not have been avoidable had any other processing platform been utilized.

Design files and source are easily available, as the Netduino is an open source electronics platform. This is a major benefit to using this particular platform, as the code and files are easily and immediately available, and completely free. The support for the product is the community that uses it. Hobbyists make use of open source platforms such as the Netduino and the Arduino to perform a multitude of tasks which include electromechanical designs like this one, so it is optimal for use in this project.

3.3.3: Actuators

The most vital and essential components of the cockpit, and possibly the project are the actuators. The actuators that were chosen recreate the movement of the RC car were linear thrust actuators. These are screw driven actuators and were chosen for their simplicity and strength. They don't require a large cumbersome compressed air tanks like pneumatic actuators and they don't use messy and expensive fluid where- as hydraulic actuators do. These screw driven actuators operate under the principle of the simple screw machine and do not implement a vast amount of moving parts. This greatly decreases the chances of the internal actuator components malfunctioning. This feature ties into cost efficiency theme of the project.

The actuators will be controlled by the cockpit design circuitry and will use the information sent from the potentiometers to accurately recreate the motion of the RC car. The actuators feature a built in wiring for potentiometers, this is extremely beneficial given the nature of what these actuators will be required to do. The RC car will send information regarding terrain, turning, and gradients. This in conjunction to the visual display should yield and enjoyable and realistic driving experience.

The actuators that will be used in this project are three, 12 Volt thrust linear actuators manufactured by Servo City. The operating voltage range of the actuators is 6 to 12 volts DC. As mentioned before these actuators are powered by electricity. This feature was desirable given the nature of the project and behavior of linear actuators. The behavior of these actuators is that the experience identical behavior when extending and retracting. By simply changing the polarity of the voltage applied to each actuator they will extend and retract accordingly. This aspect made the programming and fabrication of the control circuitry of the actuators relatively simple and attractive to use for this project. This property of electric linear thrust actuators made them an obvious choice when compared to the pneumatic and hydraulic varieties.

The actuators are composed of aluminum frames with high grade plastic gear housing which should translate into high durability and low risk of corrosion. The extension shaft is 1.125 inches in diameter and is also made of high grade aluminum. The combination of quality grade materials and material thickness will be more than adequate to yield a dependable product with great response. There is a 0.5 inch diameter mounting hole located on the bottom of the gear housing, this be connected to the circular cockpit base for each the three actuators. Each one will be connected to the Cockpit via a Heim joint at both the top and bottom of the actuator.

Each actuator is capable of efficiently moving a maximum load of 450 lbs while generating repeatable and dependable results. This aspect of the actuators made them the ideal choice to be used the the three actuator design this project is implementing. Some of the driver and cockpit load will be dispersed across the center ball joint located under the seat, so there is not foreseeable instance or situation where each actuator will have to move the maximum load by itself. The heaviest load all three are expected operate under is 450 lbs combined. Since combined they will normally be working within a range of 20% to 35% of their maximum load, this should be a relatively moderate work environment and should lengthen the life of the actuators.

They also boast a 6 inch stroke length. This length was chosen to make certain that the cockpit feels a pitch or roll of plus or minus 20 degrees. Though they are capable of 6 inches, due to programming and a desire to keep them from operating at any maximum specification they will only be implemented to reach a length of 5 inches. This keeps them from operating under too much stress, putting too much stress on the cockpit and driver, and also to ensure that the cockpit can reach maximum pitch or roll in under two seconds. Since all motion is designed to occur are the central joint, the extension had to be tailored so that neither the actuator nor joints ever rub or come in contact with the frame.

Another crucial aspect of the actuators is the speed at which extension and retraction occur. They operate at 2.9 inches per second under no load and 1.89 inches under maximum load (450 lbs). These specifications were vital in choosing the actuators since the response must be quick enough that the driver experiences a realistic simulation without any lag. The actuators must extend or retract to an exact position and then change position again in a fraction of a second hundreds of times during any given simulation. This implies that the response time must be fast enough that it can keep stride with the vast amount of continuous information being sent from the RC car. This is achievable given that the actuators will typically extend and retract at a range between 2 and 2.6 inches per second. Therefor in less than two seconds the actuators will be able to reach the maximum extension length that the programming will allow them to reach.

The actuators have a full retraction length of 17.72 inches and full extension length of 23.72 inches. When the cockpit is off the actuators will be at the full retraction length so they don't feel the static force of the cockpit when it's not in operation. When the cockpit is on, but not in use they will remain at a stable length of 20 inches until the RC car is in motion. This will ensure that when the cockpit is on that each actuator receives a steady supply of voltage until the potentiometers send information. This is an essential feature to better protect thee actuators and as a measure to make sure that there will be no need to replace any of them.

3.3.4: Body Composition and Joints

The cockpit will be solely constructed of 4340 (Chromoly) Normalized Alloy Steel. The square tubing will be 1.25 inches in both length and width, where-as the circular tubing will have a diameter of 1.25 inches. The square tubing used to construct the frame of the cockpit will have a wall thickness .120 inches. The base of the Cockpit will be comprised of the same material and material thickness, but will be in sheet metal form to create the raised platform needed to make sure that the body of the cockpit is raised high enough so that the bottom of the floorboard and the ground never meet.

4340 Chromoly was chosen for its high ultimate tensile strength, yield strength, and rockwell hardness. This material is easily welded and considerably stronger and more durable than most steel and aluminum tubing. It is not as lightweight as aluminum, but given this project's budget and the negligible weight difference in the two materials, the high performance actuators will be more than adequate enough to handle the weight of this material. It is more susceptible to rust and corrosion than other more expensive materials, but given this will be in a closed environment with minimal moisture that was not a great concern.

One reason square tubing was chosen to fabricate the cockpit frame was the fact that its easier to cut and weld a straight line. This will make the welds under the seat, for the floor board, the video display unit, and steering column more structurally secure and safe when the cockpit is in operation. Also through considerable research it was found that since all portions of the cockpit frame will be straight portions of material they won't require there to be any bending or shaping of the tubing, thus making square tubing ideal. There will also be considerable lateral, sheer, and moment forces placed on the framing while the cockpit's in use due to the shift in center of gravity (of the operator in conjunction with the platform), the square tubing will be more resilient to warping, bending, and stretching.

The pedal platform will connect to the bottom of both the base and brake pedals using a hinge joint for each. The hinge joint allows the pedal to move in a radial manner and eliminate shaky lateral movement. One flat brace will be glued to the platform and opened to mount to the pedals. A spring will be mounted between the top of the pedal and platform and will create resistance in hinge joint aided pedal movement, as well limit the range in which the pedals can move.

The base of the cockpit will be fabricated from 4340 Chromoly sheet metal. The base will be a cylinder with a radius of 2.5 feet and a height of 6 inches. The height must be 6 inches so that the floorboard will never hit the ground while the cockpit is in operation. The sheet metal will be cut into two identical circles and then a strip will be cut to close off the cylinder. Inside there will be a series of 4340 Chromoly trusses to provide additional support. An undetermined number of rubber floor stops will be placed on the bottom the cockpit base using an industrial strength glue or epoxy. The floor stops will give the base traction to grip the floor surface and prevent any sort of sliding or moving to take place while the actuators are thrusting.

To securely attach both ends of the actuators to the cockpit a heim joint, also known as a rod end bearing joint, will be used (which is shown above). This joint type will be bought not be fabricated and it will be again made of 4340 Chromoly. This particular joint is an extremely strong and durable join used in a wide variety of applications, but most often used as control rods, steering links, and tie rods in vehicles. Heim joints are precision articulating joints consisting of 3 parts. The first is a ball swivel which allows the joint to move in any direction on the three axes with almost 340 degree range. This portion of the joint is a hollow circle which allows a bolt or many other connecting devices to pass though and attach to the heim joint. This portion of the joint will create a secure connection of the actuator and frame underneath the seat. The will be three of these joints connected to the frame under the seat and three connected to the base, two for each actuator. The next is the housing, a circular casing that the ball swivel is encompassed by and its function is to hold the ball swivel in place and is the rigid part of the heim joint. The housing will need to have lubrication applied to it approximately every other use to be sure the joint won't seize up during operation which would put additional lateral force on the joint, the framing, and the actuator .The final part of the joint is the threaded shaft. This is connected to the casing and acts as the anchoring part of the joint. The thread can be either left or right hand threaded and allows it to be screwed or bolted into various materials (mostly metals). The threading will attach to the frame and base to the cockpit directly in the center of the welded joint. This will not compromise the joints integrity in any way. And given that the frame and the joint are made of the same material, the will not be stripped due to a difference in the density or hardness of the metals.

This joint will allow each actuator to move in the desired directions without fear of rubbing, forced over/under extension, and will provide a solid connection to avoid slipping. The base of the Cockpit which touches the floor will considerable "wider" than the seat, underneath where the front two actuators will be mounted. This will allow all three of the actuators to be angled in approximately 15 degrees. This angle is needed since the movement of the Cockpit is effected by the ball joint and is now dynamic with both X, Y, and Z movements on each actuator.

There will also be a ball joint located under the cockpit seat. The ball and housing will be bought or fabricated of 4340 Chromoly as well. The material used in this joint is not as important as with the heim joints for structural integrity so much as it is for cohesion reasons. The same material must be used to the ball, the ball housing, and the square tubing located under the seat. This has to do with the metallurgical properties that are specific to each alloy. It is not advisable to attempt to weld different metals together due to the difference in heating and melting points. This could cause a severe decline in the structural stability if the frame of ball joint is heated so that they become brittle or more malleable. The ball joint will be approximately 3 inches in radius so that motion of the actuators is not inhibited and also to make sure the ball joint is capable of dissipating some of the driver's weight. The fitting between the ball and housing must be considerably tighter than most. This is to help decrease excessive slipping of the cockpit which would put added lateral force on the actuators that could cause them to have to be replaced. The ball joint will by systematically greased or lubricated so that motion is possible and there is not so much friction that it binds up and again puts the actuators in a compromised position where they would have to be replaced. There may be hole drilled into the upper corner of the housing so that the lubrication is distributed on the entire surface of the ball.

To ensure that the Chromoly tubing of the Cockpit is connected safe and securely a Metal Inert Gas (MIG) weld will be used to create every joint on the frame and to create the base. MIG welding, also known as Gas Metal ARC welding is a process developed specifically for welding aluminum and other non-ferrous metal (which is what the 4340 Chromoly is). This weld will securely connect all portions of tubing together without heating the Chromoly too much causing the end pieces to loose structural integrity and become brittle.

One advantage of MIG welding is that it allows metal to be welded much more quickly and efficiently than other more traditional methods. This makes it ideal for welding softer metals such as again, aluminum. Another advantage of MIG welding is that it can produce long, continuous welds much faster than traditional methods. This specific welding process will help cut down on the time spent fabricating the cockpit and base so that this projects is completed by the date listed in the Milestone section. The shielding gas used during the welding process helps to protect the welding aRC and also produces a clean weld with minimal splatter.

There are very few drawbacks that may be encountered when performing this type of weld. The equipment for this is considerably complex. This means that when outsourcing this portion of the project the welder that is selected must be extremely well versed in this form of welding. Given that this type of welding is somewhat of a specialty, the fabrication may cost a little more than previously expected. Another disadvantage is that since there is a need for an inert gas shield, this weld cannot be performed in an open area where wind would be a problem destroying the gas shield, so a backyard welder is not an option.

3.3.5: Display

For the cockpits display a Video Display Unit (VDU) with reasonably high specifications will be needed. The video feed from the RC car will be displayed on the cockpit via a 22 inch Samsung television. This television boasts a flat screen with a 1080p resolution Liquid Crystal Display (LCD). This screen is very high quality and will display the live video feed from the vehicle with sharp, vibrant, clear images. It has a 5 millisecond maximum response time meaning that as long as the transceivers and moving data at an adequate rate the monitor will not experience any sort of lag or distortions. It has a 60 Hertz standard refresh rate which is among the industry standard so that the driver can be sure all cockpit components are of the highest quality. The Standby Power Consumption (the amount of power the television will draw while it’s plugged in but not in use) is 290 mW, while the Operating Power Consumption is 47 W. These values are not important however since the monitor will be plugged in directly to the wall to minimize the amount of voltage and current the power supply needs to power the cockpit. This monitor will receive its display information from transceivers that are connected to it and the RC cars digital camera. The digital camera being used has a reasonably high resolution so it will capture information with enough detail that there won’t be any portion of the video that the monitor displays hazy, blurry or pixelated. The transceiver will stream the footage fast enough and the televisions specifications are high enough, that the user should experience little to no lag or delay with the images. The display also has to be prompt and crisp to stay in synchronization with the movement of the actuators. The LCD type television also has a horizontal and vertical viewing angle (over 170 degrees) such that no matter the user’s position in the seat, a clean and crisp picture will always be viewable. This is one reason an LCD display was chosen because since the monitor permanently secured in the cockpit it will be viewed at different angles given the heights of the drivers. Each driver should easily be able to see the screen and view the footage captured by the vehicle.

3.4 RF Technologies and Camera

Two sets of RF transmitters/receiver sets will be implemented, one for video transmission/reception, and another for data. It should be noted that both the video communication, and the transceivers used must have corresponding transmission distances. Thus, the XBee 1mW will be used for data exchange, and a wireless surveillance camera with receiver set will be used for video transmission. Both operate at 2.4GHz, and have an estimated maximum range of 150ft-300ft (depending on obstacles). It is very important that not only do these signals have corresponding ranges, but also that they have a similar SNR at a distance from the cockpit. These details will be further discussed later, in the *RF Discussion* section.

Two XBee will be utilized for communication between the cockpit and the RC car. The antennas available are PCB or wire antenna, thus the wire antenna will be used. The transmit power of this transceiver is 1mW, with a receiver sensitivity of -92dBm. The features include adjustable power, 3.3V CMOST UART, API or AT commands, 7 10-bit ADC Inputs, and 8 digital I/O. The supply voltage required is 2.8V-3.4V, with a transmit current of 45mA and a receive current of 50mA. It costs about $30, well within the price range allocated in the budget.

KY-2.4GR01+C-203A is a camera/receiver set that functions in 2.4GHz frequency, with a transmission power of 10mW. The miniature color camera is of suitable dimensions to be mounted on the RC Car. The camera has a built in transmitter, built-in rechargeable Li-Battery that operates for 3 hours continuously, and includes a built in microphone, which will also be implemented for use with the display. The camera has a horizontal resolution of 380, a viewing angle of 62 degrees, a bandwidth of 18MHz, and a consumption current of 80mAh. The receiver has 4 channels, is supplied by an AC/DC adaptor (12V, 500mA), and a consumption current of .3W. The receiver has RCA outputs, which can very easily be utilized with the display. With a value of $32.99, all visual and audio goals are satisfied for use in the RC ghost rider.

3.5 Ergonomics

The cockpit is designed to be as ergonomic as possible. Since the cockpit will be simulating a driving experience it was decided to use a seat from a car, a 1992 Nissan 240 SX driver’s seat specifically. This seat was designed and tested vigorously by Nissan before being used in their cars with comfort and safety in mind. Also by using the driver seat from a car the rider should be in a comfortable upright seating position so that when the actuators thrust there won't be any discomfort felt in the upper or lower back. The 240 SX seat has an added luxury or being able to increase or decrease lower lumber support with the turn of a knob to generate a more comfortable and stable feel. Given that the floor board will be mounted right beneath the seat, the 7 inch thickness will provide enough distance between the bottom of the user and the top of the floorboard. And given that this seat is normally seen in a sleek sports car it is designed for a vehicle in which the drivers feet extend forward and not down as compared to someone who operates a truck's are. This property again adds to the ergonomic feel of the cockpit. The bottom padding thickness of the seat also helps ensure that the user's back side does not feel the metal ball joint located under the center of the user's seat.

The seat will also have a 3 point harness connected to a metal rod running up the back of the seat. The vertical metal rod will connected to a horizontal piece tubing to form a “T” shape. The metal rod will not inhibit the back of the seat to be angled forwards of back. The 3 point harness was chosen for its comfort and safety since many drivers complain about the traditional single over the shoulder belt, saying it is uncomfortable and cuts into their neck. It will also allow children to operate the vehicle without the advent of a booster seat. This will serve to safely hold the rider in place and give them an added sense of security and stability while the cockpit is in operation. The fastener of the harness is more reliable than a traditional belt since they are designed to raving vehicles and made of higher grade materials.

The floorboard of the cockpit is where the pedal platform will be mounted. The platform will have both a gas and brake pedal with a spring attached between the back of the pedal and the top of the pedal platform. This will create the resistance and movement that is normally felt when operating any vehicle for an added sense of realism. The platform will be angled to 135 degrees and the pedals to 115 degrees. This is the measurement found to best recreate that of an actual vehicle. Understanding that all drivers are of different body height and different leg length the pedal platform cannot remain in a fixed position. The floorboard will be exactly 36 inches in length from the front of the seat to the end. At distances of 18, 24, 30, and 35 inches from the front edge of the seat there will be a series of corresponding pilot holes drilled on the outer ends on the top of the floorboard. By being able to move the platform to a comfortable distance there should be no chance of the operator experiencing ankle, leg, or hip pain for the constant thrusting of the cockpit. The pedal platform will connect to the floorboard via a spring-loaded pin system or a cotter pin and bolt system. The connection of the pedal platform and floorboard must be secure enough so that the vibrations of the cockpit don't cause them to back out or become loose while it is in motion. The movable pedal platform feature will allow the drivers to extend and retract it to ensure that no driver is in a compromising or uncomfortable position while the cockpit is operating. This again should increase driver comfort.

The cockpit display will be firmly mounted. There will be a layer of foam and other vibration dampening material so that the monitor will move with the driver, but it won't bounce and vibrate. Small sharp vibrations or disturbances of the screen could case added strain to the driver's eyes causing fatigue, dizziness, or disorientation while operating. The dampening material should eliminate such a problem. It should and help to make sure that there is no chance of it moving and possibly obstructing the driver. Another precaution taken since the display would remain stationary was to utilize a high quality monitor so that any driver, regardless of height would be able to easily see the screen. That is why that specific LCD monitor was chosen. It was a viewing angle of 170 degrees and any driver able to reach the pedals and steering wheel will be able to view all images with ease.

The steering wheel will be mounted horizontally to the vertical structure supporting the television. It was be approximately 18 inches in length and will be able to move forwards and backwards just like the pedal platform. The steering wheel will also utilize a spring-loaded pin or a bolt and cotter pint design. By designing the steering column capable of moving forward and backward the driver will be able to easily operate the cockpit at comfortable arm position. This should alleviate any chance of the driver experiencing pain in their wrists, arms, shoulders, or neck while in operation. The actual steering wheel will again be from a 1992 Nissan 240 SX. Once again extensive amounts of man hours were put into the research, design, and testing of this product to make sure that it was ergonomically satisfactory. The steering wheel is slender with a relatively narrow diameter to accommodate drivers of larger girth. The steering wheel will also be connected with a spring so that the driver feels the expected resistance that they would if they were actually driving a vehicle. The air bag will be taken out to ensure there are no injuries due to malfunction. The steering wheel will be connected to the steering column utilizing a ball bearing. The bearing will allow the steering wheel operate in the circular motion that is expected when operating a vehicle. A spring will be connected to the back of the steering wheel and the front of the steering column. This feature will be provide many uses. The spring will be wound around the ball bearing so that the driver feels the resistance provided by the spring. This will, again, help create a more realistic experience. It will also reset the steering back to the centered position. The final use for the spring is to protect the driver from injury. If the steering wheel were capable of uninhibited movement the when the cockpit was in operation controlling the RC car would be nearly impossible and it will prevent quick jerking movements. These movements, when amplified by the ever changing pitch and roll of the cockpit could put added strain on the driver and ultimately result in an injury.

3.6: PCB

Two PCB boards will be used in the RC Ghost Rider: one for the Cockpit, and another for the RC Car. These will be two layer boards, and will cost $61.10
for each board from PCBFabExpress.com. Eagle software will be used to digitally construct the PCB board, and then it will be sent to the designers in 10 days after being submitted to PCBFabExpress.

4 – Project Hardware and Software Design Details

4.1: RC Car

4.1.1: RC Car Hardware Design Overview

Concerning the electrical design of the car, it is first necessary to identify the basic structure of the system in question. The MCU will need to accept input from the accelerometers, potentiometers, and the transceiver. That input will need to be interpreted and either used to control the vehicle or sent to the cockpit so that it can be processed at the cockpit's MCU. The control input will be used to control the car by way of its DC servo motor for turning or DC drive motor for moving. In addition there will be another subsystem of the car that is used to send data, however this system will not utilize the MCU because the video transmission would put too much stress on the processor. The following block diagram depicts the basic electrical subsystem structure of the vehicle.

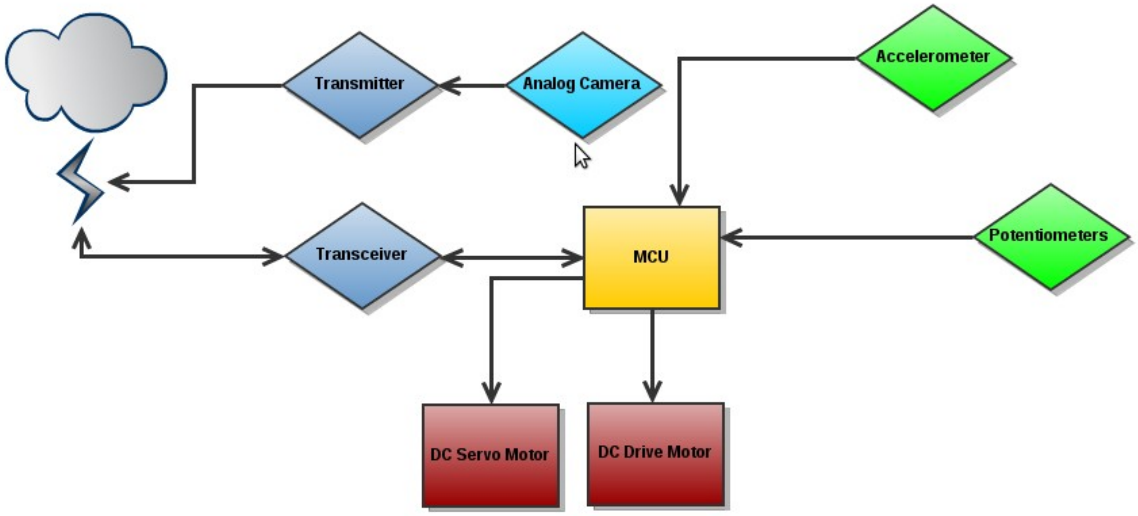


Figure 4.1: Electrical Overview

To be more specific, coming from the battery there will need to be three voltage regulators. One of the voltage regulators will be used to step the voltage down so that the MCU can operate. This voltage regulator should be relatively simple. The second voltage regulator is marginally more complex. It will go from the battery to the DC drive motor and will need to vary based on an input from the MCU. The final voltage regulator will control the DC servo motor.

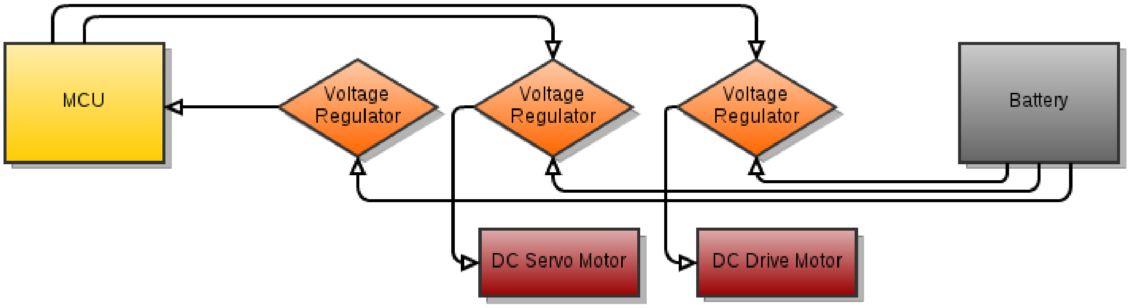


Figure 4.2: Power System Overview

In addition to this, the accelerometer and the potentiometers will also need to be interfaced with the battery and the MCU. The power system for the MCU, potentiometers, accelerometer, and two DC motors will be two batteries wired together in order to achieve a positive and negative voltage. This interfacing is relatively trivial and can be accomplished in the manner outlined by the following block diagram.

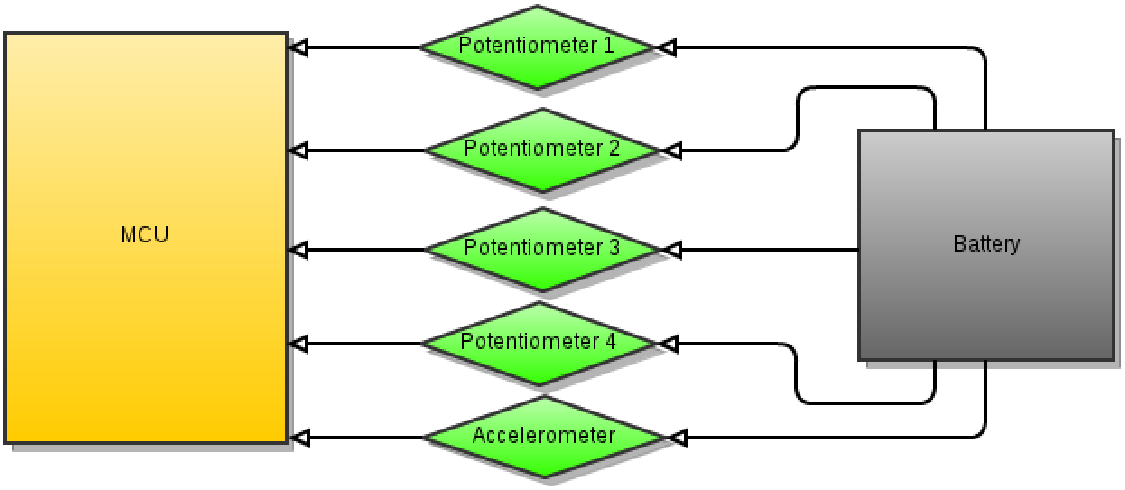


Figure 4.3: Sensor to MCU interfacing

Following this basic structural design, the power that will be used for the RF communications will be a different battery. This is so because of the massive amount of current draw, and the fact that it will vary in time because of the amplitude modulated signal that is being transmitted. This design was instituted in order to minimize possible anomalous behavior of the system due to various current draws. The following block diagram illustrated how the RF components are to be integrated.

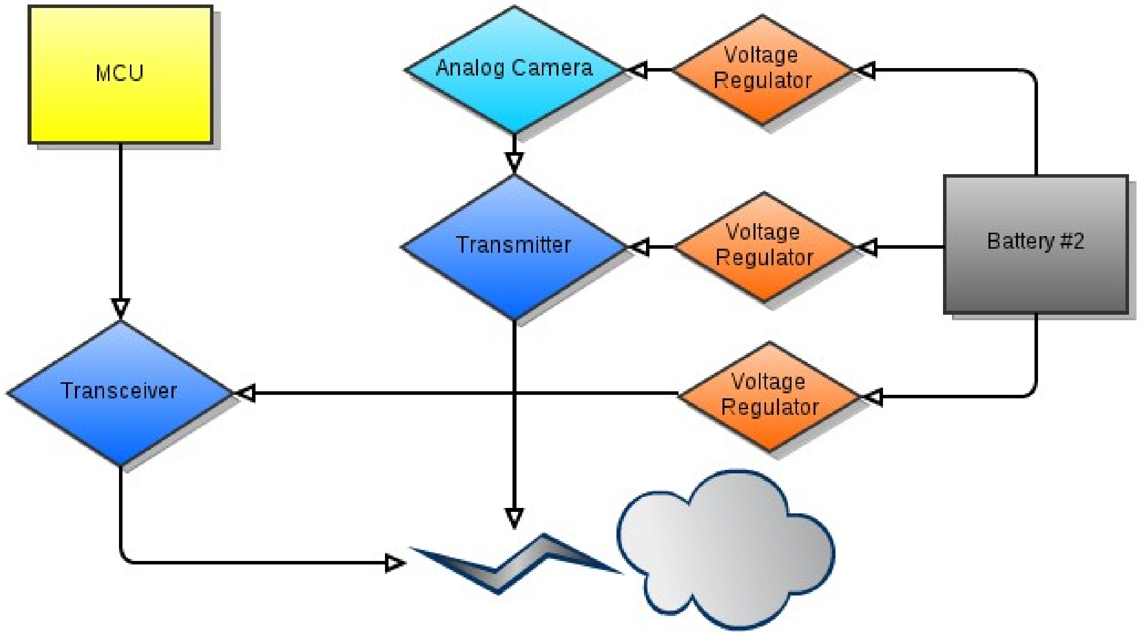


Figure 4.4: Transmission Subsytem

4.1.2: RC Car Software Design Overview

In regards to the structure of the programming the MCU is to collect the data from the potentiometers and the accelerometer. Following this collection it is necessary to analyze the data and determine whether any of the information is significantly different enough to change. If the information in question is significant enough to change, the output buffer must be populated with the new information that was received from the peripherals. When either the output buffer has been changed, or the information was not significant enough to change the output buffer, the collection of transmission data must be begin. This data must be compared to the old data to determine whether or not it is significantly different. In the case that the information received is important, control changes must be made before the data located within the output buffer is to be transmitted. Otherwise the control change step can be skipped and the data can immediately be transmitted. The last step of the programming will be to update and destroy the necessary information. The following flowchart depicts the basic program flow for the vehicle.

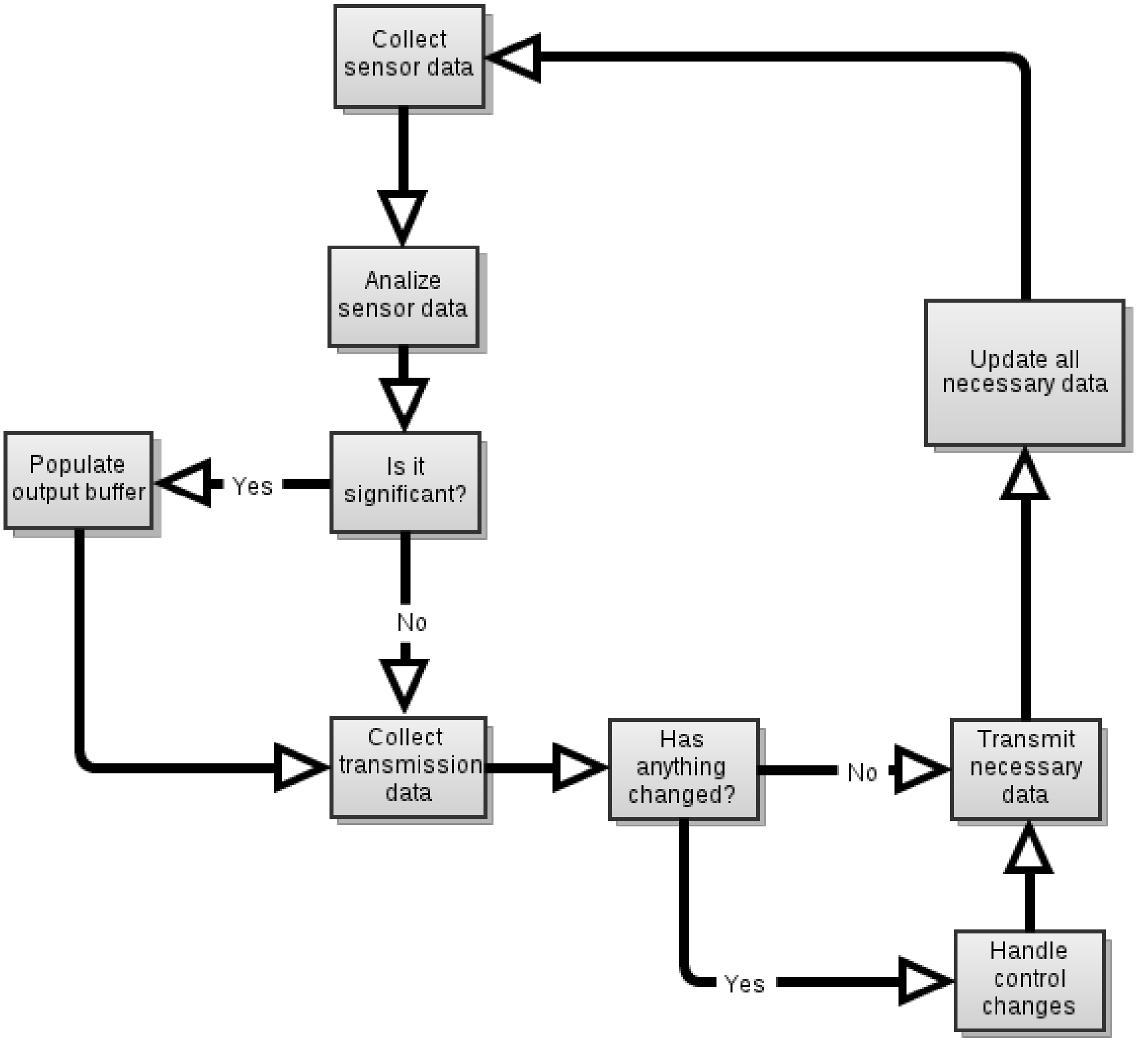


Figure 4.5: Program Flow Overview

4.2 Cockpit

4.2.1: Cockpit Hardware Design Overview

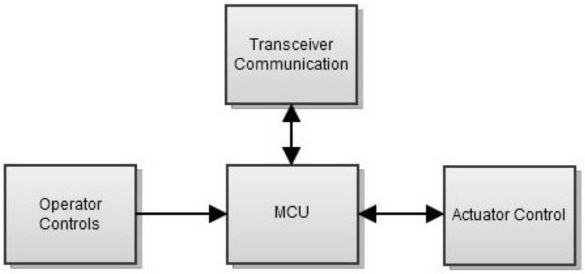


Figure 4.6: Block Diagram of MCU Data Exchange

The MCU receives information systematically from the Operator Controls, the Transceiver, and the Actuator Control. Separately, the MCU transmits information to the transceiver, and the actuator controls. The Operator Controls, Transceiver Communication, and Actuator Controls blocks are all summarized below, displaying their connections to the pins on the Netduino. Note that pins with suffix “D” are digital pins, and pins with suffix “A” are analog pins.

Flow Chart Color Key: Purple - Sub-Circuit, Green – Netduino Input/Output Pin, Blue - Circuit Input/Output, Red - Hardware Input/Output, Yellow - Decision, Orange - Process.

Operator controls

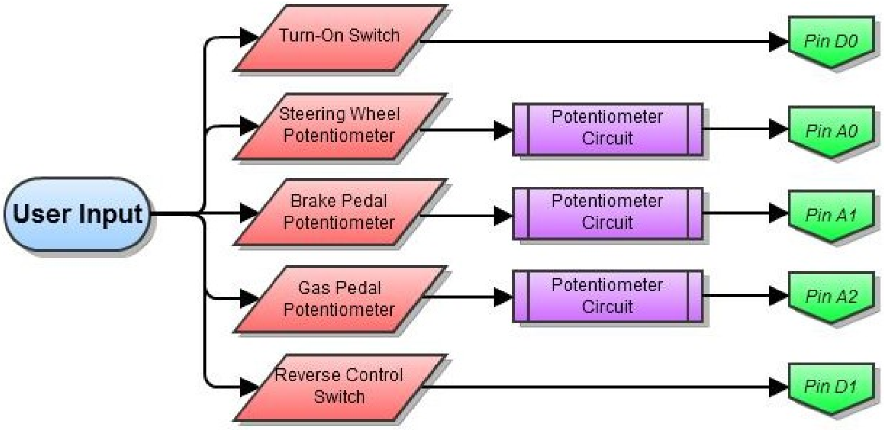


Figure 4.7: Operator Controls Block

User input operates all controls, which include the turn on switch, the steering wheel, the brake pedal, the gas pedal, and the reverse switch. The turn-on and reverse control are both connected directly to pins D0 and D1 (respectively). However, the steering wheel, brake pedal, and gas pedal potentiometers are each connected using a potentiometer circuit due to their continuous variation. Their analog inputs to the Netduino at analog pins A0, A1, and A2, respectively.

Transceiver Communication

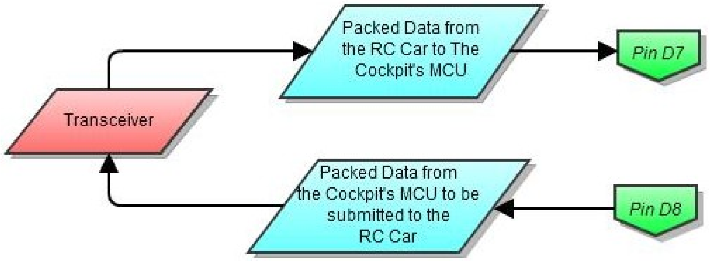


Figure 4.8: Transceiver Communication Block

The transceiver is, very simply, connected to pins D7 and D8. D7 will receive the packed data from the RC Car, and D8 will transmit packed data from the Netduino to the transceiver, which is to transmit data to the RC Car. 5 bytes of serial data are to be transmitted to D7, and 5 bytes of serial data are to be transmitted from D8. These “packed bytes” are described in the RF sections.

Actuator Control

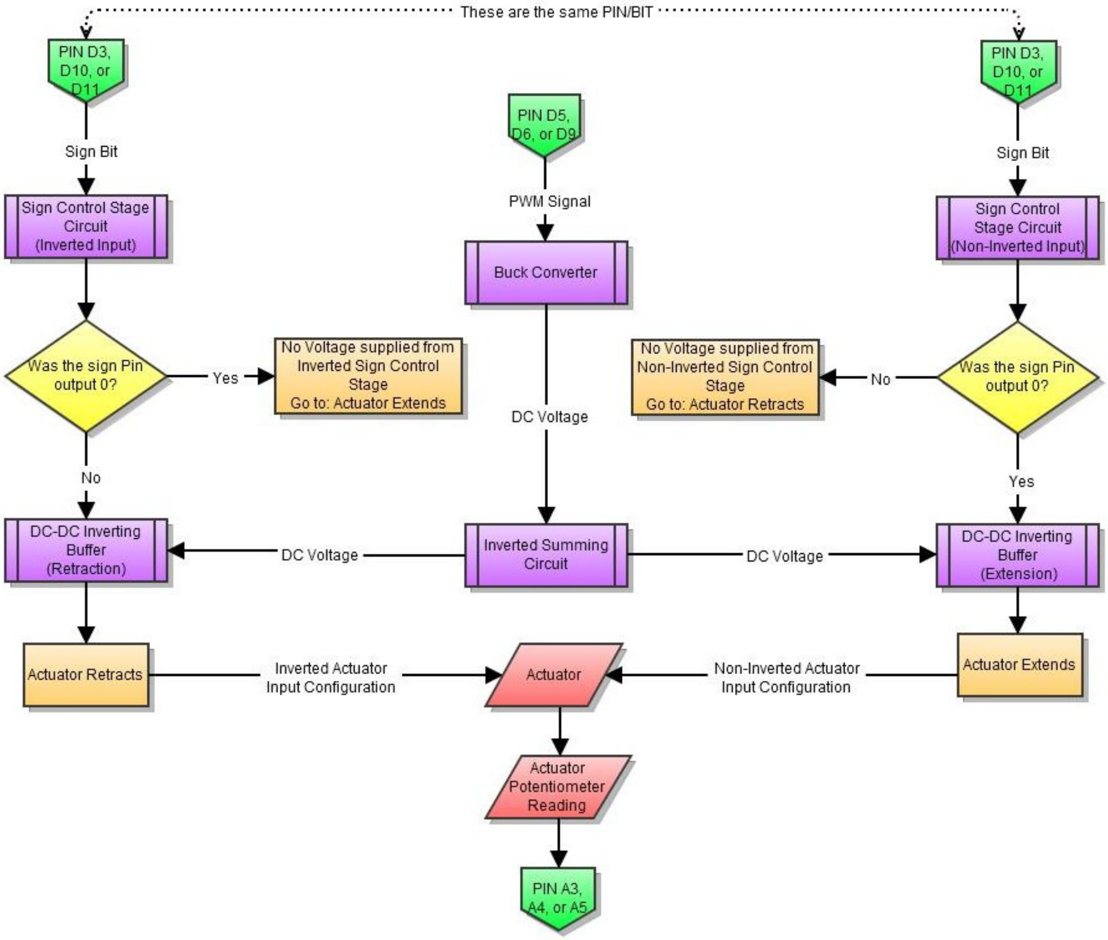


Figure 4.9: Actuator Control Block

The Actuator Control circuitry is the bulk of the cockpit circuitry, using a buck converter and inverted summing circuit for each actuator, and two sign control stage circuits for each actuator. A Sign Bit from Pin D3 and PWM signal from D5 will correspond to the circuit input to Actuator 1, (Sign Bit) D10 and (PWM) D6 will correspond to Actuator 2, and (Sign Bit) D11 and (PWM) D9 will correspond to Actuator 3. The sign pin will choose which circuit is used to activate retraction or extension, 0 corresponding to extension, or 1(3.3V) corresponding to Retraction. If the appropriate value of the pin is not the one necessary to turn on the Sign Control Stage, no voltage will be submitted to the actuator from the DC-

DC step-up buffer. The buck converter receives the PWM signal, and converts it to a DC Voltage with some negligible ripple current and voltage, and then the signal is added to be input to 2 DC-DC Step-up inverting buffers, but only the signal with the “Sign Control” stage activated will turn on. Detailed descriptions of these blocks are further enhanced in the Hardware Design Summary section.

4.2.2: Cockpit Software Design Overview

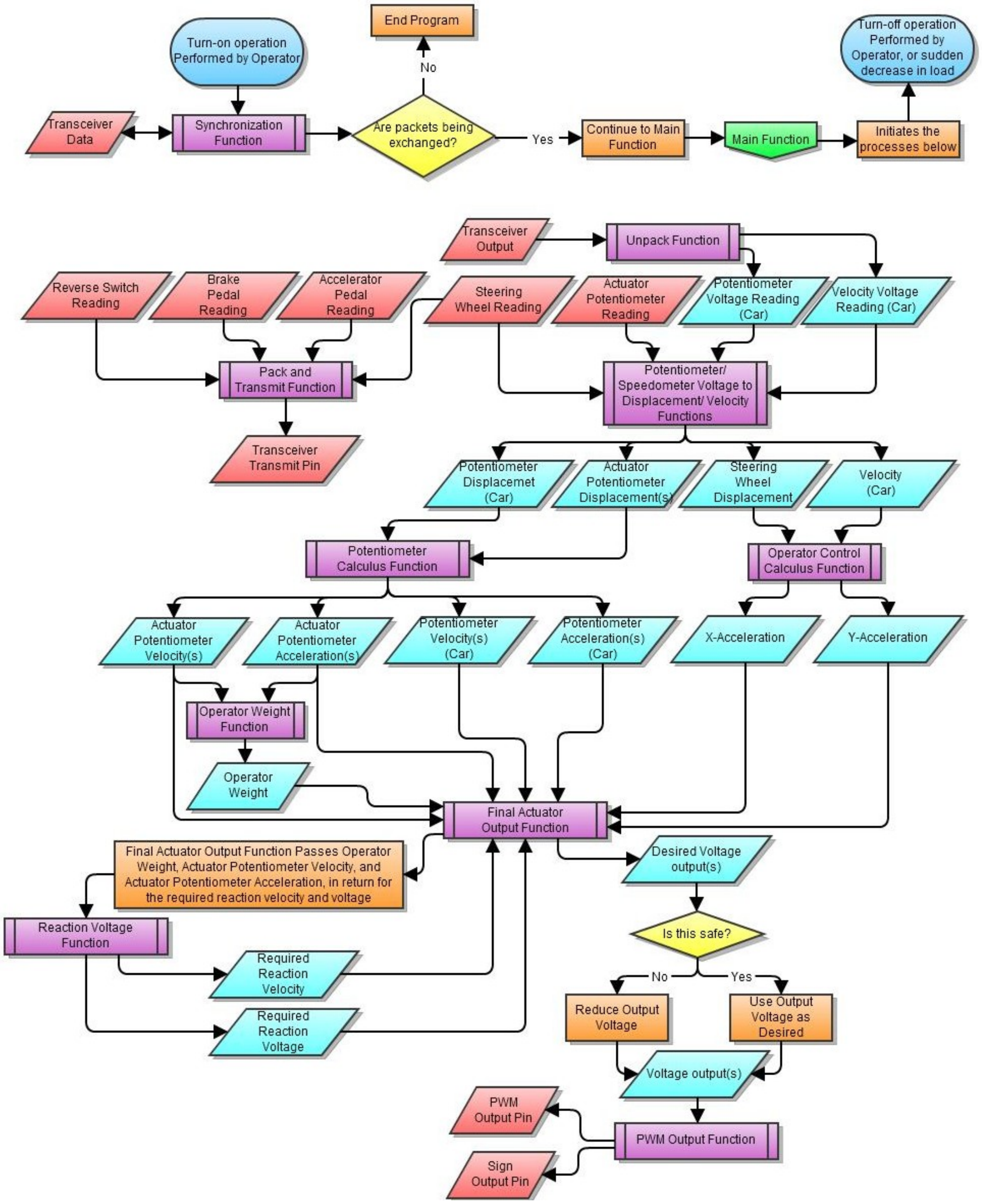


Figure 4.10: Block Diagram of Cockpit Program Operations

Above is a block diagram describing the programming operation of the Netduino. The I/O connections are as described in 4.2.1.

Flow Chart Color Key: Red - Hardware Input/Output, Blue - Functional Input/Output to be used for another function, Purple - Predefined Function, Green - Output that initializes, Orange - Process, Yellow - Decision

The turn on switch initializes the *Synchronization Function*, which determines whether or not the RC Car's transceiver and the Cockpit are able to transmit packed information between each other. The turn on switch also acts as a "turn off" switch once the program is initialized, thus whenever it is pressed, the program will end, and the cockpit will stop all motion, and move back to base level. If the *Synchronization Function* determines that data packets cannot be exchanged, then the program ends. Then, the main loop begins, and ends execution under particular conditions to be determined in testing, along with when the "turn off" is switched.

Once synchronization has taken place, the cockpit will weigh the operator, as discussed in 5.3.2, using the *Operator Weight Function*. Data from the operator controls will be taken in, and converted into percent displacements, and submitted to the *Pack and Transmit Function*. The output of such action is then submitted to the transceiver pin to control the car. Then, data received from the transceiver will be received and unpacked using the *Unpack Function*, which outputs voltage readings from the car's potentiometers and the voltage reading across the motor.

The values output from the *Unpack Function*, the steering wheel reading, and the actuator potentiometer reading will be converted to their actualized displacements and velocities by their respective *Potentiometer/Speedometer Voltage to Displacement/Speed Functions.* The actualised values are then changed into their average velocities and accelerations over sample times and are input into the *Final Actuator Output Function*. In the *Final Actuator Output Function*, a voltage will be chosen to apply to the actuators, and a duration of that voltage, given that it is safe. If it is not safe, the voltage will be reduced. Within the *Final Actuator Output Function*, retraction voltages will be chosen using the *Reaction Voltage Function*, which also output reaction velocity using operator weight, actuator velocities and actuator accelerations. Then, the values will be output to the PWM output function, which will output the digital output for either extension or retraction, and the PWM signal for the given desired voltage output.

5 – Design Summary of Hardware and Software

5.1: RF Discussion

General environmental issues in RF communication revolve heavily around noise, as well as other uncontrollable concerns like heat, weather, signal obstruction, ect. However, weather is not of tremendous concern (Who is going to drive an RC car in the rain? Or possibly more-so, who is going to operate a simulator in the rain?), heat should not be a problem, so long as both the RC Car and Cockpit are circulated/insulated properly. It is impossible to eliminate noise, or avoid obstruction of the signal; however, the specifications of the XBee, and the Camera and its corresponding receiver were prebuilt to help reduce these issues. Thus, it is at some point the responsibility of the operator to use the RC Ghost rider within the range specifications listed.

Using only one transceiver set to establish all RF communication would be insufficient in practice (for the particular set of processors used in this project). No transceiver that transmits data, video, and audio feed would have the proper range of communication, and would cause too much delay in execution of commands set by the MPU's. Therefore, two separate sets of RF communication devices would best be utilized for the purpose of this project. To design either of these devices would be impractical, as it would be more expensive, and more time consuming while sacrificing power efficiency, range, size, and range. Thus, a black-box approach was utilized.

Camera-to-Display communications are of priority over XBee data transmission, as it would be impossible to observe obstacles while driving the vehicle. Although operator safety is the most dominant concern, preservation of RC Ghost Rider shortly follows. It is the responsibility of the operator to not use the RC Ghost Rider if a visual feed cannot be established.

Synchronization must take place to ensure that communication between the XBee devices is effective. Each XBee must be awaiting the moment when it is to submit data, the data it is to receive, and they must also know exactly how much data they are about to receive. This will be accounted for in the process of its integration with its respective processing platform. Given that synchronization is not able to take place due to an issue with blocked transmission, significant RC car to Cockpit displacement, or lack of battery power to the RC car, a connection cannot be established and control operations cannot executed.

Data Communication implemented between the RC car and the cockpit will take place by making packets of information to be transmitted and received by their respective XBee's. The XBee receives data, and transmits it in a serial fashion. The RC car will transfer 15 bytes of allocated packed data, and the Cockpit will transmit 15 bytes of allocated packed data as well. The RC car will transmit 3 bytes for a voltage reading from each of the three potentiometers, 3 bytes corresponding to the voltage reading across the motor, and 3 bytes for a voltage reading for the battery power of the power source operating the controls of the RC car. The Cockpit will submit 3 bytes for the voltage reading from the steering wheel potentiometer, 3 bytes for the voltage reading from the gas pedal, 3 bytes for a voltage reading from the brake pedal voltage reading, 3 bytes for the reverse switch, and 3 bytes for the on/off switch. 3 bytes is more than sufficient for each voltage reading, as then the voltage reading can be represented by 512 unique values.

5.2: RC Car Design

5.2.1: Structural Modification

Because the RC car that will be used will be purchased, structural modifications will need to take place in order to properly fasten all necessary components. The linear potentiometers that will be used to sense the disposition of the vehicle will need to be attached to the vehicle where the shocks for the vehicle are located. Rather than dramatically change the structure of the vehicle, the current shocks will now have the linear potentiometers mounted to them. The top of the potentiometer will be mounted at the top of the shock, and likewise the bottom. Likewise the plastic body of the car that actually makes it look like a car will need to be detached in order to mount the MCU, accelerometer, and batteries. Because the vehicle was purchased already manufactured, the positions of the DC drive motor and the DC servo motor should not need to modified, however the actual motors as well as the associated wire will. The accelerometer will need to be mounted on the top of the vehicle in the very center, 8.85 inches from the top and 4.85 inches from the right.

In addition the PCB for the DC drive and DC servo motor should be mounted a few inches away from these motors to damped possible feedback. There will need to be two holes drilled into the top of the plastic body of the vehicle in order to allow both the transmitter antenna and the receiver antenna to be in optimal placement to receive and transmit the necessary RF communications. The MCU should be placed as far from the DC motors as possible in order to minimize possible interference. Likewise it should be as close to the edge as possible in order to quickly and easily interface the MCU with a computer via the USB cable without having to remove the plastic body when in the testing phase. There will need to be some extra space hollowed out in the body of the vehicle to accommodate the extra battery, as well as the newer higher powered battery. The battery cavity will need to be substantially hollowed out as the space to accommodate the new batteries will be

5.2.2: Hardware Design

The hardware design for the vehicle can be somewhat complicated when it comes to the DC drive motor. In order to adequately control the vehicle there will need to be a system devised in which to control the DC drive motor as well as the DC servo motor. In order to explain the circuit diagram, it will first be necessary to mention that an eight bit serial to parallel converter will be used. This part will be used to control the circuit corresponding to the DC drive motor. The part is produced by Texas Instruments and the part number is 74LV8153N. It is more than sufficient enough for the purposes of this design as it can move 24kbps. Since the DC drive motor is a 7.6V motor it will be necessary to create a circuit that has an output of 7.6V in order to get the most out of the motor. A diagram of the circuit is as follows.

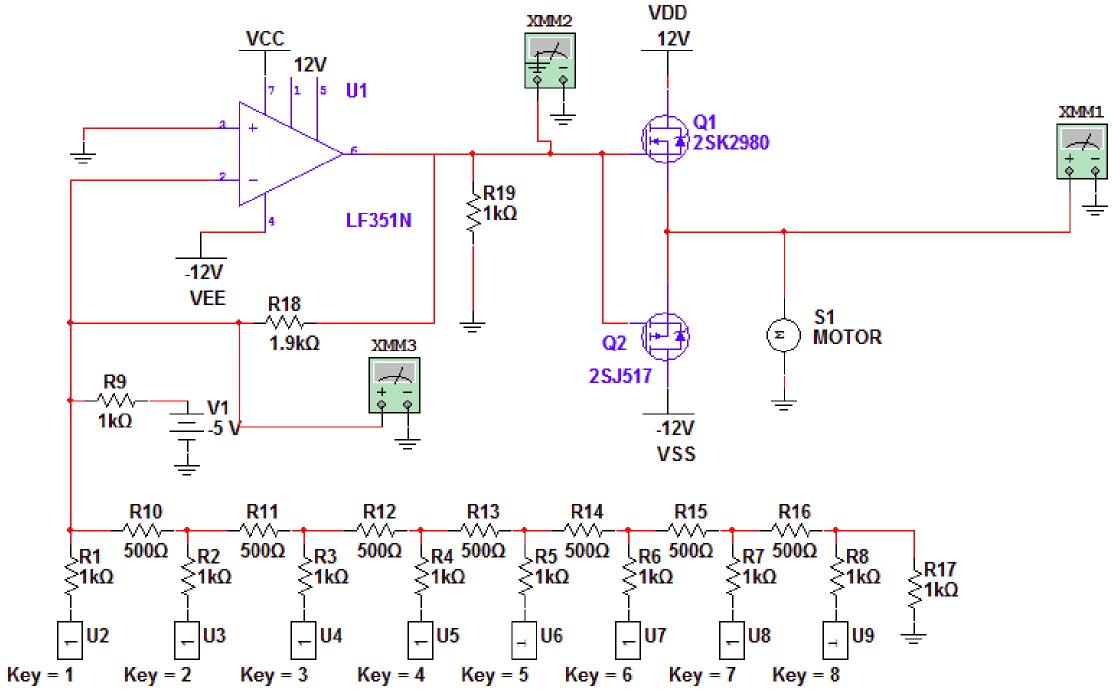


Figure 5.1: DC Drive motor controller schematic

The input to the circuit is a parallel binary signal that will come from the MCU and will need to be realized via a serial to parallel converter in order to get this information from the MCU. This binary signal is then weighted as a binary signal and a negative DC offset is applied. This offset allows for the realization of both the positive and negative values. The output is then multiplied by 1.9 in order to get the highest possible output of the circuit while still remaining in the relatively linear region of the power MOSFET's. This voltage is used to bias the power MOSFET's and a push pull output stage allows for a varying applied voltage to the DC servo motor. The final varying voltage range for the above circuit is -7.6V to 7.2V. This will allow the vehicle to operate both in forward and in reverse.

In order to supply the negative DC offset voltage the eighth bit of the parallel output will be used as the negative offset for the op-amp. This will allow for the circuit to zero out at both “00000000” and “11111111”. Even though this design will only allow for 128 various voltage outputs, this amount of values will be plenty sufficient for the control purposes of the motor. Most significant volt will be used to determine whether or not the output voltage is to be negative. In the case where the input is “10000000” the maximum positive value of 7.2 volts is realized. Preforming the one’s compliment on the seven bit number will give the current representation for the voltage value relative to its maximum. Likewise in the case when the input is “01111111” the maximum negative output is realized. Once again this binary representation can be manipulated and the voltage reading across the motor will change accordingly.

For the aforementioned circuit the 12V and -12V inputs will be supplied by using the two supply batteries connected in parallel. The ground node that will be used for the circuit will be the connection point of the two 12 volt batteries. In addition the 12V power supply will need to be used to power all of the voltage regulators needed in the circuit, as well as the potentiometers and the accelerometer. There will need to be multiple LM7805’s to control the 5V inputs on accelerometer, transceiver, transmitter and analog camera. In addition there will need to be another LM7805 that is configured with an output voltage of 10V in order to power the potentiometers.

The DC servo motor control is relatively trivial, especially compared to the control circuitry for the drive motor. One of the LM7805’s with the 5V output will need to be connected as the power source for the motor. In addition one of the GPIO’s from the MSP-430 will need to be configured in software to use a PWM signal with a 50Hz output. In order to control the motor the active high will need to be one from between 1ms and 2ms. Any value less than 1.5ms will cause the servo to spin counter-clockwise, while any value longer will cause the motor to spin clockwise.

5.2.3: Processing Platform: Structure and Duty

When designing the software necessary for the collect, transmission and acquisition of data, it is very important to understand the complexity of such a system. Likewise one must understand the steps needed to accomplish such a task. The first order of business is to layout the components needed in order to complete such a task. To begin it will be necessary to have location in memory at which the data is to be stored. In this case, there will need to be an array of length three for each of the potentiometers readings as well as each of the motors (both drive and servo). In addition there will need to be a three by three array for the accelerometers values to hold the information pertaining to the changes along each axis. It will also be necessary to have two more locations in memory for each of the aforementioned arrays. (and three for the accelerometer)

One of these locations will store the computed average value and the other will store the old computed average value. Also, there will need to be two more arrays that hold the information for the control of the vehicle. These arrays will have two elements, the first being the newest received value, and the second being the old value. The final memory elements will be a buffer that is used to send data to the cockpit via the transceiver, as well as a buffer that will receive input from the cockpit.

In addition to having these memory locations, there will also need to be a set of functions that are to be called along the way in order to break this seemingly daunting task into small, accomplish-able tasks. There will need to be a function called “Collect_Data”. Collect data will read the sensor values, as well as compute the average. It will also compare the new average data that has been collected to the last average data. It should return a Boolean that will let us know if the information is different enough from the old data to cause something to happen

In order for the “Collect_Data” function to accurately measure the voltages across any sensor it will be necessary to take multiple consecutive readings of said voltages. In this case, there will need to be three consecutive voltage readings. The readings across any one part should not be directly consecutive in time. Consider the case where the potentiometers readings are named PFR,PFL,PBL,PBR and the accelerometer readings are named AY,AX,AZ. The readings should take place in that order three times.

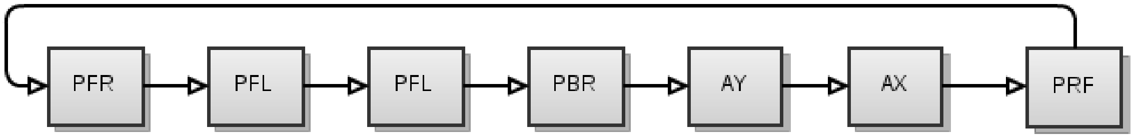


Figure 5.2: Receiving order of information

After the readings have been taken and the new information has been stored in the memory locations, it will then be necessary to analyze the data. This analysis will consist of taking the average of the new three readings in each section. These new averages will be compared against each of the old averages to see if there is a difference in magnitude greater than 4%. In the case that any one value has that difference, all of the new averages will be used to populate the output buffer. In the case that the values are all below the threshold, there will be no change to the output buffer, and the previous values will not be altered. The follow block diagram illustrates the basic flow of the function.

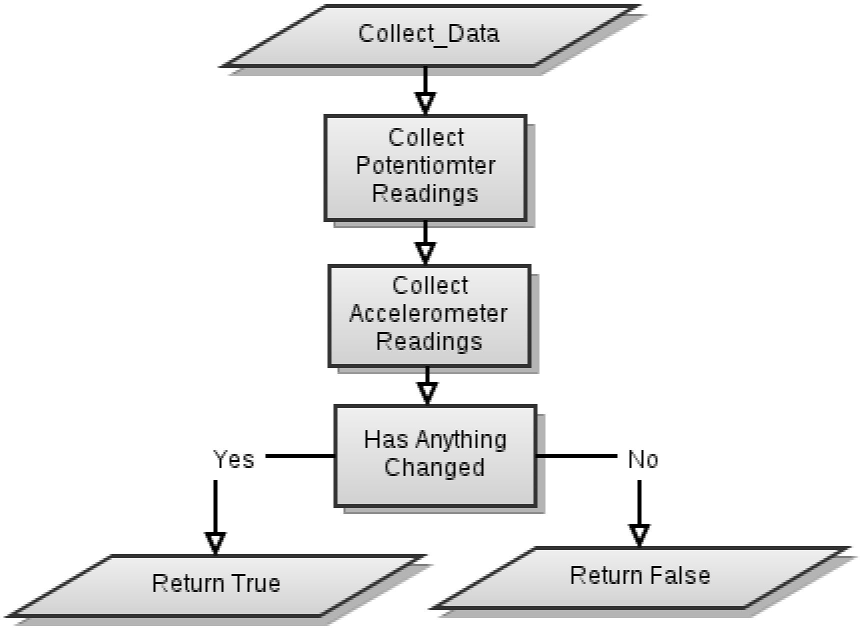


Figure 5.3: Data Collection Function

The next import piece of code that will be used in the programming for the MCU on the vehicle will be the “Receive_TX” function. This function will be relatively simple and will be used to receive the information that is being sent from the cockpit. The information that will be coming in will contain the current control values for the DC drive motor as well as the DC servo motor. These values will be compared to the old values that were received from the prior transmission. In the case that nothing has changed, the “Receive_TX” function will return a false Boolean value to the main program. This will signify that there has been no change and the program will then hand control over to the “Send_TX” function. Otherwise in the case that something has changed regarding the control of the vehicle, the program flow will be passed to a function that will be called “Control_Car” and the values within memory that contain the information pertaining to the control of the car are to be updated.

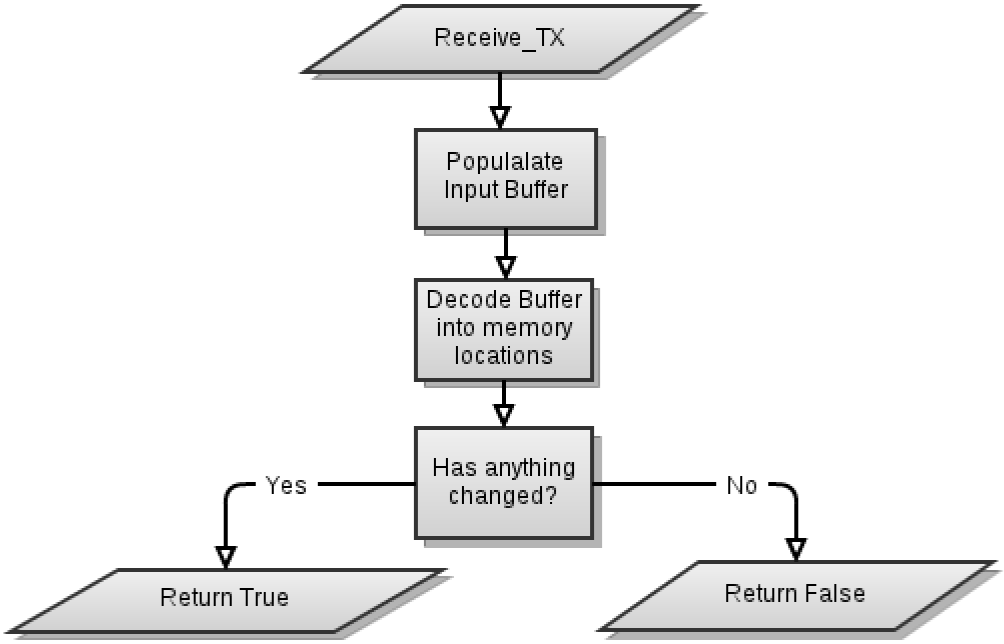


Figure 5.4: Receive Information Function

The function “Control_Car” will be responsible for handling all changed values. If this segment of code is being executed, there are differences in the control values for one, or more of the vehicles controlling components. The values that are held in memory that contain the new drive information will be written to the digital output ports that pertain to each of the motors. At this point the program control will then be passing to the “Update” function.

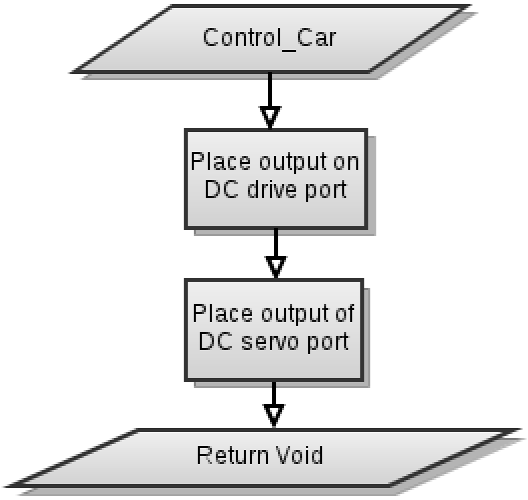


Figure 5.5: Vehicle Control Function

The function “Send_TX” will be used to actually send the necessary information to the cockpit. When this function is called all the values that have been stored into the output buffer will be sent, by giving the transceiver the input it expects to actually send the data. After this function has been successfully executed the “Update” function will be called.

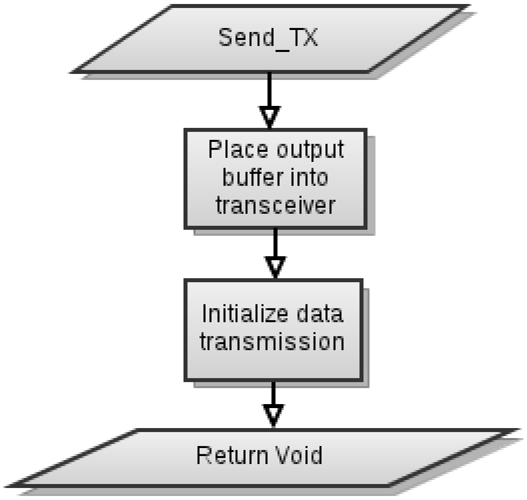


Figure 5.6: Send Information Function

The “Update” function is the final step of the programming before everything is started over. This function will be used to move all of the readings that are in the “new” spots in memory to the places that contain the “old” information. In addition the output buffer as well as the input buffer will be purged of all information and stored will zero's. This will be done so the “Cockpit” will be able to easily assess the situation where nothing has changed.

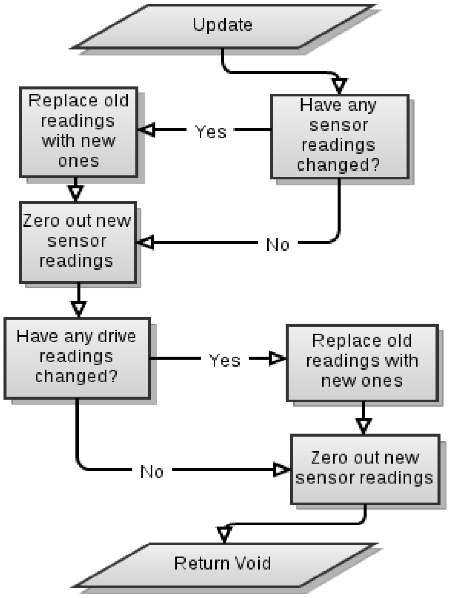


Figure 5.7: Update Information Function

5.3: Cockpit Design

In the design of the cockpit, there are recurring relations pertaining to the motion of the cockpit. The geometry of the apparatus requires that not only is the behavior known, but it also requires that it is regulated. Capital letters denote constants. Let H be the height of the central ball and socket joint relative to the bottom of the apparatus, W be the horizontal distance of the bottom of any actuator from the central ball and socket, R be the distance of the top of any actuator from the origin in which rotation takes place, θ_1 be the angle made between the top of the actuator to the to the central ball and socket (relative to being set completely horizontally), θ_2 be the angle made by the bottom of an actuator to the top of an actuator (relative to the normal axis from the ground plane), L be the fully retracted length of the actuator, and ℓ be the length of extension by the actuator. Then, the system can be modeled as follows:

(5.1)

$$\begin{aligned} W &= (L+\ell)\sin(\theta_2) + R\cos(\theta_1) \\ H &= (L+\ell)\cos(\theta_2) - R\cos(\theta_2) \end{aligned}$$

Which implies, by setting both equations equal to θ_2 (due to θ_2 as an element between 0 and 90 degrees):

(5.2)

$$\chi = \frac{1}{2R}[(L+\ell)^2 - H^2 - W^2 - R^2] = H\sin(\theta_1) - W\cos(\theta_1)$$

Using χ for simplicity, and reuse. Thus, θ_1 can be found in relation to χ (Due to θ_1 being a positive or negative number in the 1st or 4th quadrant):

(5.3)

$$\theta_1 = \pm\arccos\left(\frac{\sqrt{H^4 + H^2W^2 - H^2\chi^2} - W\chi}{H^2 + W^2}\right)$$

Note that positive sign will be used when the top of the actuator is above the ball and socket joint, and negative if the case would be in the contrary. In addition, taking the derivative relative to time it can be found that:

(5.4)

$$\frac{d\theta_1}{dt} = \pm\frac{d\chi}{dt}\left(\frac{H^2\chi + W\sqrt{H^4 + H^2W^2 - H^2\chi^2}}{(H^2+W^2)\sqrt{H^4 + H^2W^2 - H^2\chi^2}}\right)\left[1 - \left(\frac{\sqrt{H^4 + H^2W^2 - H^2\chi^2} - W\chi}{H^2 + W^2}\right)^2\right]^{-\frac{1}{2}}$$

Where

$$\frac{d\chi}{dt} = \frac{d\ell}{dt}\left(\frac{L+\ell}{R}\right)$$

$d\ell / dt$ is the rate of extension of the actuator, $d\theta_1 / dt$ is the rate of change of the angle made by the platform. The negative case takes place is in the cases when the top of the actuator is below the ball and socket joint, in the retraction phase and when the top of the actuator is above the ball and socket joint in the extension phase.

For programming purposes, it is necessary (5.2) to solve for ℓ in terms of θ_1:

(5.5)

$$\ell = \sqrt{2R[H\sin(\theta_1) - W\cos(\theta_1)] + H^2 + W^2 + R^2} - L$$

Then, in differentiation:

$$\frac{d\ell}{dt} = \frac{d\theta_1}{dt}[RH\cos(\theta_1) + RW\sin(\theta_1)]\left(2R[H\sin(\theta_1) - W\cos(\theta_1)] + H^2 + W^2 + R^2\right)^{-\frac{1}{2}} \tag{5.6}$$

It is extremely important to understand that any actuator will extend at a rate slower than one which is retracting in this design for two dominant reasons: an actuator fighting against gravity will have a harder time in extension than one which is working with gravity, and the geometry of the project provides that the actuator with the lowest angle made by the actuators and the axis normal to the ground plane will have a greater component of acceleration in that direction. Potentiometer readings from the reference on the actuators can be used to find the instantaneous value of the extension, denoted as ℓ.

It should also be noted, that θ_2 can be found in terms of θ_1 as follows:

$$\theta_2 = \arctan\left(\frac{H + R\sin(\theta_1)}{W - R\cos(\theta_1)}\right) \tag{5.7}$$

And thus,

$$\frac{d\theta_2}{dt} = -\frac{d\theta_1}{dt}\left(\frac{R(H\sin(\theta_1) + R - W\cos(\theta_1))}{H^2 + 2HR\sin(\theta_1) + R^2 - 2RW\cos(\theta_1) + W^2}\right) \tag{5.8}$$

5.3.1: Body and Physical Design

For the physical design of the cockpit simplicity, functionality, and safety were the goals. Given the limited amount of time to complete the design and fabrication of the cockpit a no frills design was needed to ensure that the milestones dates were met. The cockpit was however designed to keep the driver in the most comfortable and ergonomic position possible when operating the simulator.

When designing the framework simplicity was again the goal. The square tubing used to fabricate it cannot be bent or shaped into any sort of curvature. This means that the framing is comprised of only straight segments of tubing welded to other straight segments of tubing ensuring a proper seal and connection. The framework was designed around the central ball joint. The ball joint will be 30 inches from the ground to the highest point on the ball. The ball will be 6 inches in diameter and sit upon a hollow cylinder of diameter 23 inches in height. The hollow cylinder will not be welded to the ball; its function is to act as a housing for the nitrogen filled shock that connects to the bottom of the ball. The nitrogen filled shock will be mounted to the bottom of the ball and extend to the ground. The shock will be used to disperse some of the driver's weight which will take some pressure and force away from each of the three actuators. One advantage of the shock is that the nitrogen can be bled or added as needed to extend and retract the length of the shock. It will also be used to dampen the vibrations felt by the user of the cockpit. The housing cannot be welded to the ball to allow for easy access to the shock for maintenance or repair. All the motion of the cockpit is designed to be centered on the ball joint. This portion of the cockpit acts as the hub of the whole design in that every aspect was designed with some relation to the center ball joint.

Surrounding the center ball joint will be a wide cylinder shaped base. The base will act as a platform to help some user's up into the cockpit seat. The base's primary function it to raise the entire cockpit height enough so that while the cockpit is in motion the floor board will never come in contact with the ground. To make sure of this the platform will have a height of 8 inches. This will allow for the platform to reinforce the central ball joint as well as help stabilize the cockpit during movement. Attached to the bottom of the platform will be a series of rubber stoppers. The stoppers will be used to prevent the whole cockpit assembly from sliding and shifting across the floor. The base of the platform is also where the bottom of the three actuators will connect. The figure below shows the actuator place relative to the base of the cockpit.

The base will be constructed of 4340 Chromoly to make sure there is cohesion in the materials being used in the cockpit. The base will be cut and shaped from a piece of sheet metal with a thickness. 120 inches, equal to that of the square tubing. Inside the base there will be a series of trusses and supports that will be used to support the weight of the entire weight of the cockpit and driver. This portion will incorporate a combination of square tubing and sheet metal to stabilize the cockpit while it is in motion and exerting a barrage of forces on the base. For the purposes of welding all of these components in place, it is necessary to use the same materials.

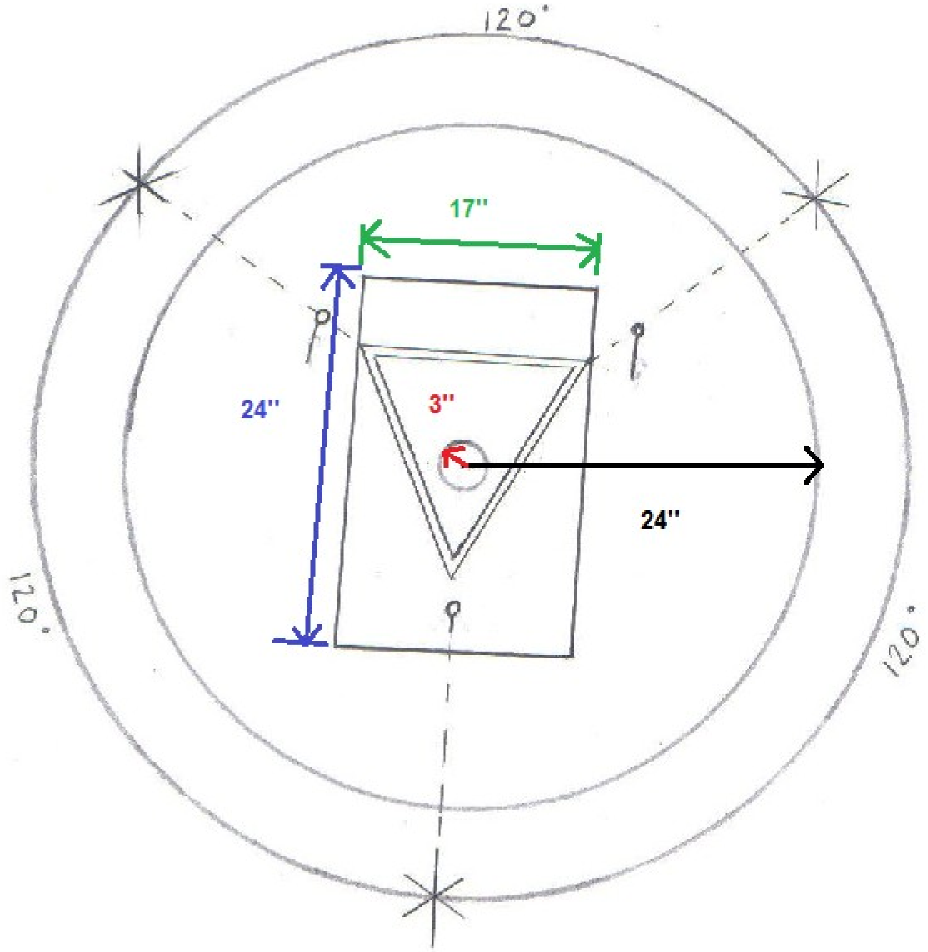
The hollow cylinder used that connects to the central ball joint and houses the nitrogen shock will pass through the center of the base. This means that a portion of the base, 5 inches in diameter, in the center of the base will be removed to the housing can securely fit inside. For this section of the base there will be no wall, it will use the housing as a shield so no debris can settle in the base. Since the base will not house any electric circuitry there is no need to completely seal it.

The diameter of the circle is much larger than the side lengths triangle that the seat is mounted on. The cockpit was designed in this manner for adequate actuator movement with minimal lateral force felt on them. The top view of the cockpit base is shown below with the seat, triangle bracing, and heim joint location.

Figure 5.8: Cockpit Base Top View

The actuators will connect both the base and the the triangle/seat apparatus. With the implementation of the central oversized ball joint, it is necessary to place the actuators on an angle to accommodate the dynamic movement (in both X,Y,and Z directions) simultaneously. The desired in incline angle was derived to be 75 degrees on every actuator. This will allow for less stress and force on anyone single actuator at any given time, and allow one to act inversely from another in most cases (turning, grade change, etc.).

The actuators will act in one of three manners. The first is that the two front actuators will be asked to move proportionally inverse from one another in many applications. Thus even though there are there actuators, they will be asking as though there are only two in the dynamic side to side movement. Assuming the RC car is a solid one piece axle, the distance one side moves, the other side must move an equal distance in the opposite direction. To achieve this one actuator will thrust while the other retracts to the same length, but the retracting actuator must move at a speed approximately 95% of the extrneding actuator. This will more aptly simulate a vehicle turning. This will be simulated in various turning situations, grade changes, and in certain terrain. While the front two actuators are working inversely proportional to one another the back actuator will more than likely be stationary and by virtue of the heim joint act as a “spit in a barbeque” or the center lateral rotating point. Utilizing the cockpit design the user with experience the same change in degree about their center of mass while only two of the actuators are actually extending or retracting.



5.9 Cockpit Base Design

The second manner the actuators will work in is when both the left and right front actuators are working together performing identical movements while the back actuator is working inversely proportional. Again even though there are three actuators, the movement preformed will only be 2 dimensional (front to back with no side to side lateral movement). This will mainly happen when the RC car experiences an inclining or declining plane. To achieve a real life simulation or recreation the front actuators will receive precisely the same amount of voltage applied at the exact same time for the same duration.

The final manner in which the actuators will be asked to work is when all three actuators are in motion providing front to back and side to side movement simultaneously. This will be the most challenging movement to mimic. The three RC car potentiometers will be sending information at the same time so each actuator will be working independently or one another.

The spacing of the actuators is set at the above mentioned dimensions to provide a total of 20 degrees of lateral pitch, and would provide a maximum angle in the most extreme case of extension vs. retraction of the actuators (one of the front actuators fully extended [retracted], the rear actuator fully extended [retracted], and the remaining front actuator fully retracted [extended]) of 4 inches (safely) will be required for planar movement relative to the angle made by the actuators. At a maximum, 6 inches in the back, relative to the ground plane, will be required to account for movement of the top of the seat while in use. At maximum, 6 inches will be required in the front, relative to the ground plane, to account for movement of the extended platform. The maximum extension speed of the actuators is 1.89 inches per second at maximum load capacity. Thus, there is either a clockwise or counter clockwise rotation caused by the extreme case of an actuator extending, and another retracting.

The actuators will be spaced 120 degrees in either direction of each other. The placement of the actuators must be exactly 120 degrees about so that they can sufficiently angle the cockpit and achieve the desired experience. The separation is also necessary so that there is never surge of lateral or sheer forces exerted on the actuators. The actuators and heim joints will allow for the cockpit seat to roll lateral at a maximum pitch of 20 degrees, this is the maximum pitch that the RC car will ever encounter, therefore the cockpit was designed to achieve such angle specification. As shown in the side view below.

The design of the actuator connections were figures with the prone length being 20 inches, not the fully retracted length of 17.72 inches. This will place a constant or static load on the actuators while they are non-operational. This was a desirable feature of the cockpit design because it will help ensure a long actuator life. To achieve this the cockpit control circuitry was designed to always send a constant base voltage to each actuator while it is non operational, but still on.

At each corner of the triangle will be a heim joint to which the actuators will mount. The jointing will act as the insertion point of the actuators to both the cockpit framing and the base. These joints will allow the actuators to extend and retract with having the motion causing the actuators to feel the full lateral force. They have many of the same attributes of a ball joint with the enhancement of added strength. They will be fastened to the cockpit frame and base using the threaded end section of the heim. The bearing inside the joint will allow for the actuators to connect to the joint using the prefabricated mounting holes at the top of the rod and the bottom of the housing. The side view of the seat, ball joint, actuators, and cockpit base is as shown below.

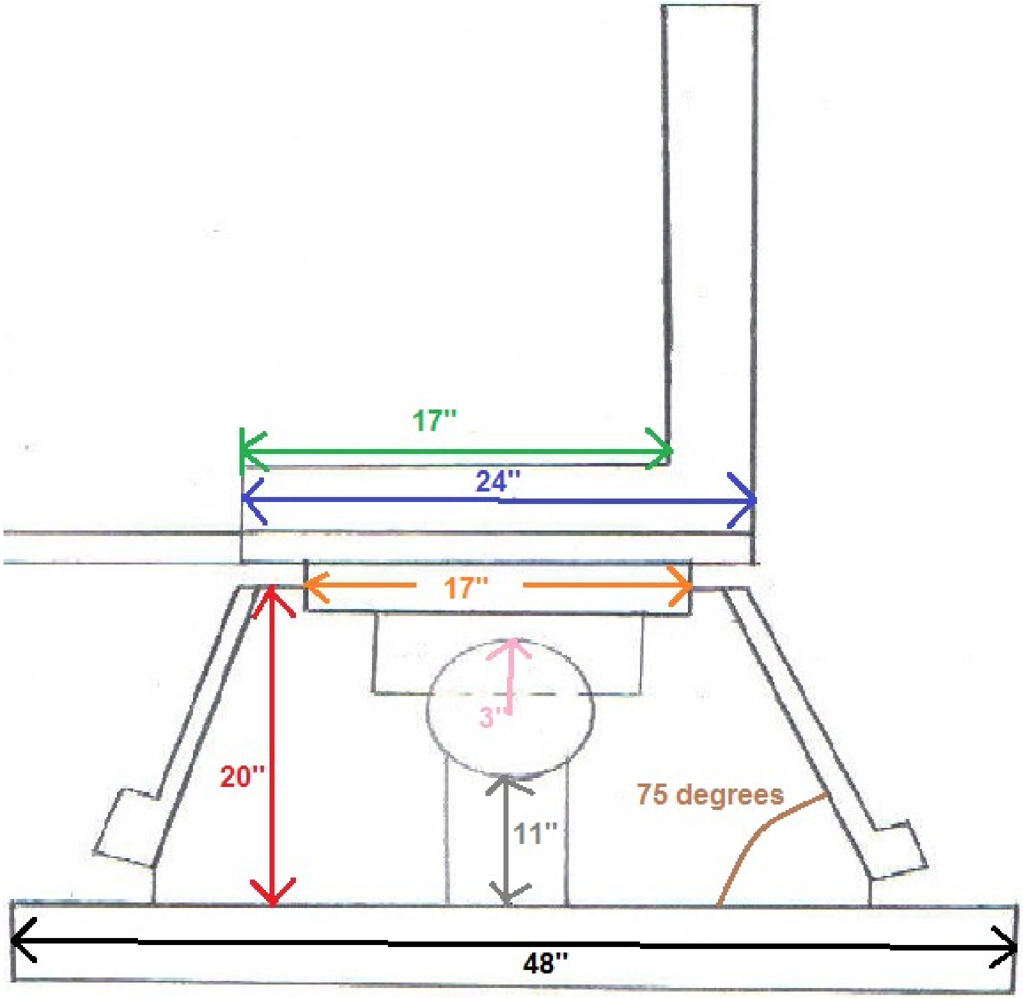


Figure 5.10: Central Cockpit Side View

The seat of the cockpit will be the driver’s seat from a 1992 Nissan 240 SX. This seat was chosen due to its comfort and design. In this design the driver's leg extend forward and away from the body as in a sports car, not down as someone driving a truck would experience, so a sports car seat was a feasible option. The seat has a bottom cushion thickness of 7 inches when the driver is not sitting in it. This thickness will provide sufficient backside support. The seat will remain in a fixed position once welded to the cockpit frame. This measure is taken to guarantee that the operator is safely attached to the cockpit. A piece of 34 inch long square tubing will be inserted from the bottom of the seat up through the top of the headrest. At the top of the tube another 6 inch long piece of will be welded horizontal forming a “T” shape. Connected to the top of this structure will be where the 3 point harness is bolstered.

The harness is an aftermarket modified racing harness. It has two straps which connect to the end of the “T” structure and will be pulled down over the user's shoulders. The bottom portion of the harness will fasten directly to the frame under the front edge of the seat. When fastened together properly they should connect in the navel region. This type of seat belt was chosen due to its increased restraining power and to make it a more universal fit. This type would also provide a more accommodating fit if a child or person of smaller stature was operating the cockpit since there would be a series of three belts to adjust as opposed to the traditional one. A standard seat belt would require an area where the unused would be housed and also a complete redesign of the cockpit frame so the above the riders left should there would be a spot for the belt to mount. The floor mounting bracket on the seat is made of a high grade steel and will salvaged to mount the seat above the central ball and socket joint.

The seat will mount to a portion of the frame shaped as an equilateral triangle with equal side lengths of 17 inches. The triangle will be oriented such that the base of the triangle will be parallel to the front edge of the seat and the peak of the triangle with split the back of the seat down the center. The triangle will be fabricated using the 4340 Chromoly described in the Body Composition portion. Welded to the top of the triangle will be a piece of sheet metal cut to the same dimensions of the triangle. This flat surface is what the seat will mount on top of. This is a vital portion of the cockpit was was designed to alleviate as much of the lateral force as possible from the actuators. Since the triangle will be where the top of the actuators connect to the cockpit, it must be structurally stable enough that it will not warp, twist, or be altered in any way while the cockpit is in use. This could could result in a changing of the pitch in the actuators which would inhibit the motion of the cockpit during the simulations.

Welded to the front side of the triangle under the seat is where the floorboard will connect to the frame. The floorboard will measure 36 inches in length from where it is welded to the triangular bracing to the end where the driver's feet will be. It will be fabricated using a single 36 inch length of square tubing and two 36 by 15.75 inch sheets of metal. These materials will consist of 4340 Chromoly and will measure .120 inch in thickness. The square tubing will be cut down the center line using a plasma cutter. Then the two portions of tubing will form a set of parallel lines that measure 17 inches from end farthest edge of each. The square tubing will be fastened so that the cut line faces in. This means that there will be 15.75 inches in between both pieces of tubing and that is where the portions of sheet metal will be welded. Once these sections are welded together they will form a hollow rectangular box. Given the dimensions of the floor board “box”, the end that is welded to the triangular bracing should be of the same height and wall thickness assuring an air tight seal. This will help keep the floorboard and bracing keep a very tight connection over extended periods of the simulator's thrusting and moving. Starting 20 inches from the weld connecting the floorboard to the triangular bracing a series of holes will be drilled. Each series of holes will be 4 inches in distance from the previous set of holes. The holes will be on the top of the floorboard 1 inch from the the center of the hole to the outer edge. The radius of the holes are both .125 inch. These holes will allow the pedal platform assembly to move closer or farther away from the driver operating the cockpit. The top view of the floorboard is show below with the pedal plastform assembly shown and the tree mount cut out.

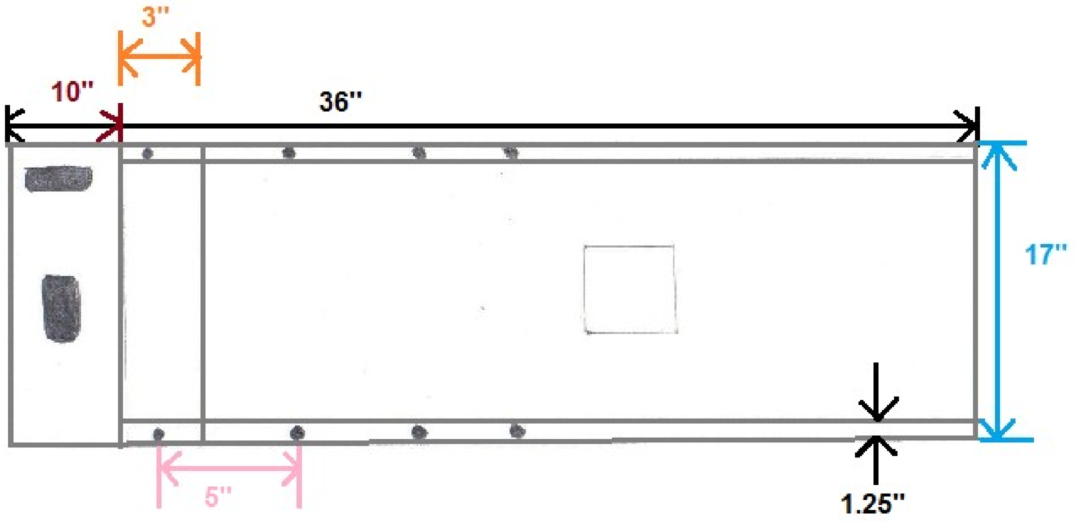


Figure 5.11: Top View Floorboard

The pedal platform will also be constructed of 4340 Chromoly sheet metal. The dimensions of the sheet metal will be 17 inches wide to correspond to the width of the floorboard, and 18 inches in length. The floorboard will have to be machined to create an angle of 30 degrees. There will be a 3 inch portion , or tongue, that will sit flat atop the floorboard and from there the platform will raise to the 45 degree incline. The tongue will also have 2 hole drilled in it measuring 1 inch from the center of the hole to the outer edge and 1.5 inches from the center of the hole to either the inclined portion of the platform the edge closest to the driver. These hole will have the same radius as the holes in the floorboard. The platform holes need to match the floorboard holes so that when a driver moves the platform there is a secure connection between both sets.

The pedal platform must also contain, pedals. A gas and brake pedal will be mounted to the platform and when pressed will correlate to acceleration of the RC car. The pedals will consist of a set of pedals from a 1992 Nissan 240 SX and will be oriented with the gas pedal on the right side of the brake pedal. The gas pedal measures 3 inches wide and 6 inches tall and the break pedal is 5 inches wide by 4 inches tall. The pedals will be spaced so that there is 2 inches in between them and 3.5 inches from the outer edge of each pedal to the outer edge of the platform.

The pedals will connect to the the platform by a hinge joint. The hinge joint will be screwed to the platform and glued to each pedal with an industrial strength quick drying epoxy. The reason quick drying epoxy is used is over a screw or bolt fastening is because exposed bolts increase the possibility of a driver injuring their foot when pressing the pedal. The epoxy is quick drying so that if any must be reapplied the cockpit won't be nonoperational for a long period of time, or any, while the epoxy is drying. The hinge joint will be connected to the to the pedals at the bottom of each and will let the pedals be fully pressed to the platform yet eliminate lateral movements. The movement of the pedals will mirror the movement experienced when operating an automotive vehicle.

In between each pedal and the angled portion of the platform will be a spring. The spring will be fastened to the bottom of each pedal and to the edge opposite of the hinge joint. The springs will be fastened to the bottom of the pedal by using a core out drill bit going about .375 inches deep. The core out drill bit hole will be the same diameter of the spring so that the top of the spring fits inside of the drilled hole. The spring and pedal connection will also be glued using the same quick drying epoxy as before. The bottom of the spring will connect to the platform by drilling the smallest possible hole in the platform and threading about 20% of the prone length of the spring though. Given the design of a spring by threading it through the platform the is effectively no chance of the spring ever backing out of the hole and if it does it will take no time to fix the problem. The spring-loaded pedals will right themselves and extend to a predetermined distance when each pedal is not being used just as in an automobile. The spring will also generate a resistance that mimics those of automobiles and the farther the pedals are pressed the more resistance that is felt by the driver just as expected. Potentiometers will be located under the pedals and will send data to the RC will be used to control the acceleration of it.

The pedals will operate within a range of 45 degrees. This measurement in addition to the angle of the cockpit means that a fully pressed pedal will still feel a 30 degree angle and when prone will be on a 75 degree angle (both relative to 0 degrees/the floor). This element was designed to be as close to actual operating ranges of automotive pedal as possible, but given the need for design simplicity and efficiency and cost effectiveness some dissimilarities are present. They are however vastly ergonomic with the pedals operating in a manner closely mirrored to the foot movement preformed while it stretches when pressing the pedal decreasing stress on the on the foot and ankle joint. The angling of the platform and pedals also put the driver's feet in a comfortable position which was necessary given the constant motion of the cockpit. The side view of the floorboard and pedal assembly is shown below.

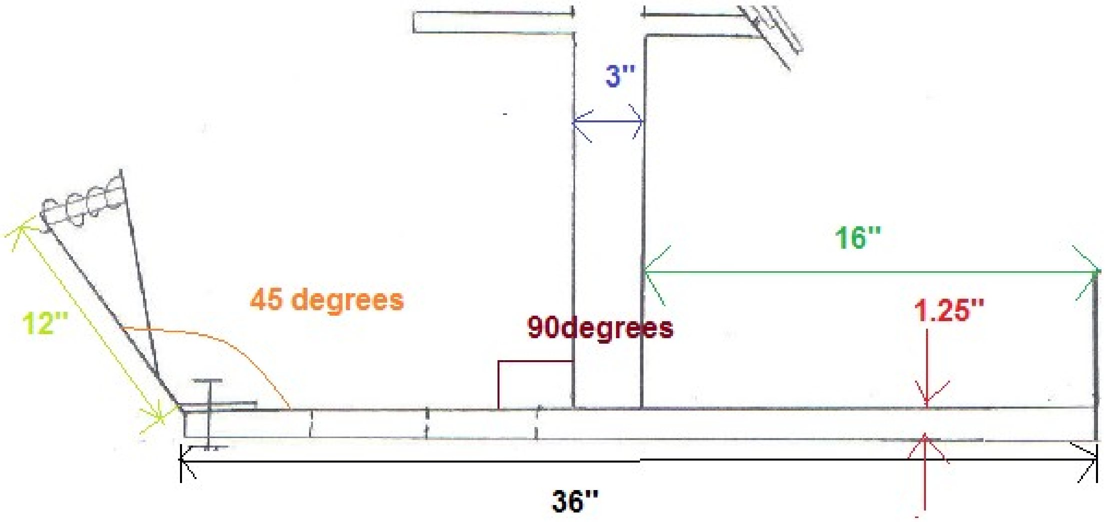


Figure 5.12: Pedal Assembly and Floorboard Side View

Extending 90 degrees up from the floor board and approximately 18 inches from either end is where the television tree mount and corresponding steering wheel portion will be located. The television tree mount will once again be created using 4340 Chromoly square tubing. This is the only place where the square tubing will not be 1.25 inches in side length. The television tree mount will have a side length of 3 inches. The reasoning will be explained in the steering column discussion. Square tubing will extend 19 inches up from the floor board upon which shaped sheet metal will be welded to form a rectangular cuboid of 21”x 20” x 4” dimensions. This is where the television display will be housed.

The backside (from the vantage point of the seated driver) of the cuboid will be fully closed off. The front side of the cuboid where the image will show on the display screen will have a portion cut out that is equal in dimensions to the the display screen. By not fully removing the cuboid side entirely the chance that the screen coming loose and striking the driver is eliminated.

The top side of the cuboid will also be removed. This will allow the television to be inserted into and taken out to perform any repairs that must be made and removed when the cockpit is being moved from one location to another. The power cord which will be powered by the wall socket via an extension cord will be run through the top as well. If it was not run through the top portion the plug of the power cord would not allow the television to be moved unless a large hole was drilled into one of the remaining sides. This option was not chosen for aesthetic reasons and also because it would weaken the structural integrity of the side wall in which the hole was drilled.

To dampen the vibrations and absorb the shock the television will experience due to the thrusting of the actuators the inner walls of the cuboid will be feature a layer of foam. The foam will also act as a buffer between the plastic shell of the television and the hard Chromoly walls of the cuboid. If the plastic shell were to hit a wall with enough force this could result in a crack on the shell or even worse irreparable damage that would require buying another television. The foam layer will also help prevent shaking any inner circuitry loose which would also result in needing to replace the television.

The height of the television mount was measured so that television will be positioned with the center of the viewing screen located at the eye level of the expected “average” driver. This design will allow the drivers to be in a comfortable viewing position in most cases. This will reduce stress on the neck of the driver and not cause soreness or stiffness in the driver’s neck. On the right side of the mount is where the power switch will be located. The switch will be comprised of a household light switch and will act as an user controlled power switch within reach of the driver. This will allow a driver or spectator to power off the simulator if any mechanical problems occur or when the simulator is not in use.

Down the television tree is where the steering column will be placed. The steering column will be mounted horizontally inside of the the 3 inch wide television tree square tubing creating a 90 degree angle. This is the reason that the television tree had to have a side length greater than that of the standard 1.25 inch Chromoly square tubing used for the rest of the project. The size of the tubing was chosen so that the structural integrity of the tree was not compromised when square hole of 1.25 inch width and height was cut through both the front and back sides (relative to the seat driver). The steering column hole will be located approximately 15 inches above the floor board. This is believed be at a comfortable height for the drivers. The steering column will be 20 inches in length and have a series of holes .5 inches in diameter drilled through the right and left side. The center of the holes will .625 inches from the top or bottom of the 1.25 inch tubing. There will be a series of 4 hole drilled into the columns all 3 inches away from the previous series of holes. The holes will be at lengths of 1, 4, 7, and 10 inches away from the back end of the steering column. This will allow the steering column to be moved towards or away from the driver at their discretion.

There will be a hole drilled though the television tree congruent in height and area to those in the steering column. This allows the steering column to be positioned securely in place once the driver has moved it to a comfortable length. To securely position the steering column a bolt and cotter key will be used. A bolt and cotter key consists of a bolt with a small hole drilled through the shaft of it. The cotter key is a piece of bent metal circular tubing that is shaped so that when it is inserted into the bolt it is almost impossible for it to back out. This type of fastening is ideal since the television tree will be in almost constant motion while the cockpit is in operation. A Side view of the steering column should below.

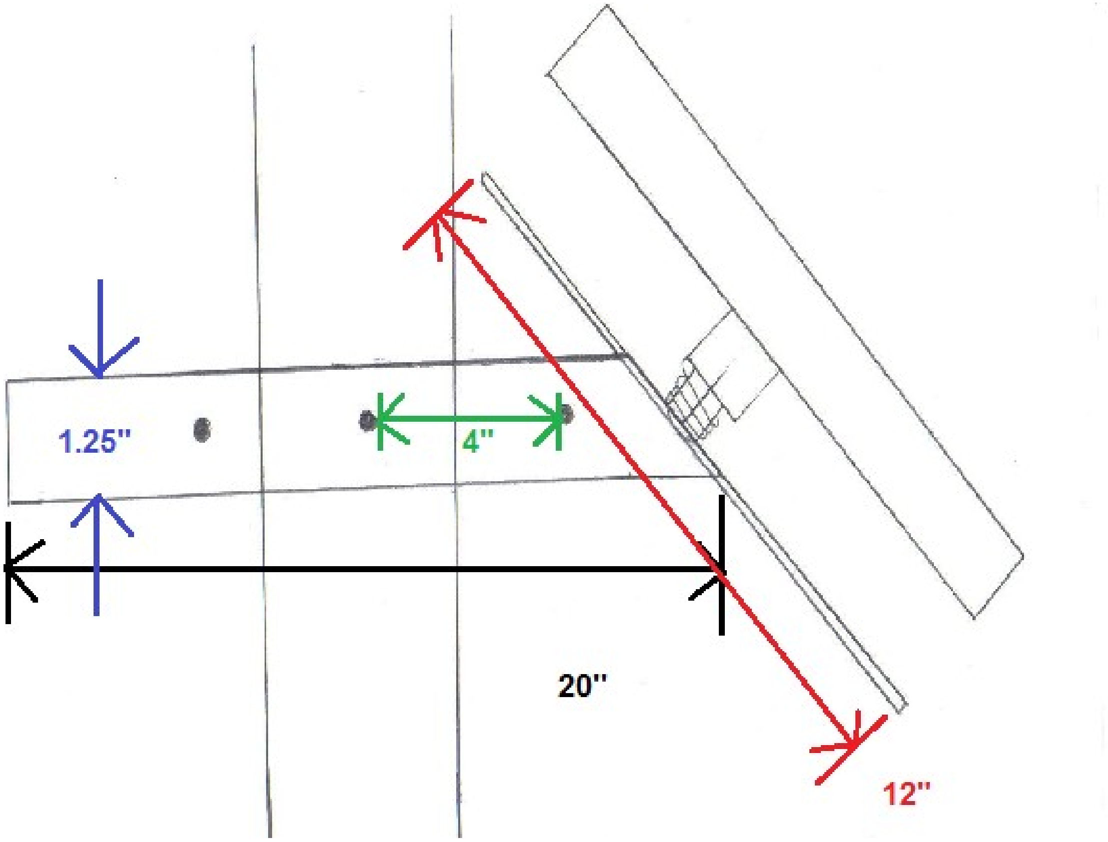


Figure 5.13: Steering Column Side View

The front end of the steering column will be flush cut at an angle of 15 degrees. To this a flat piece of 4340 Chromoly sheet metal will be welded. The sheet metal will be 6 inches by 6 inches. In the center of this section a solid steel rod of length 2 inches and a diameter of .5 inches will be welded. Around this a ball bearing housing will be mounted, this is where the steering wheel will connect. The steering wheel will have a hole cut in the center of it that mirror that of the solid steel rod. The wheel will sit on top of the rod so that the steering housing is not readily seen by the driver. A spring will be used in to provide resistance and right the steering wheel in the same manner as with the pedals. The steering wheel that will be used is again from a 1992 Nissan 240 SX.

5.3.2 Cockpit Hardware Design

A.) Hardware of D/A: PWM to Actuator- Output Phase

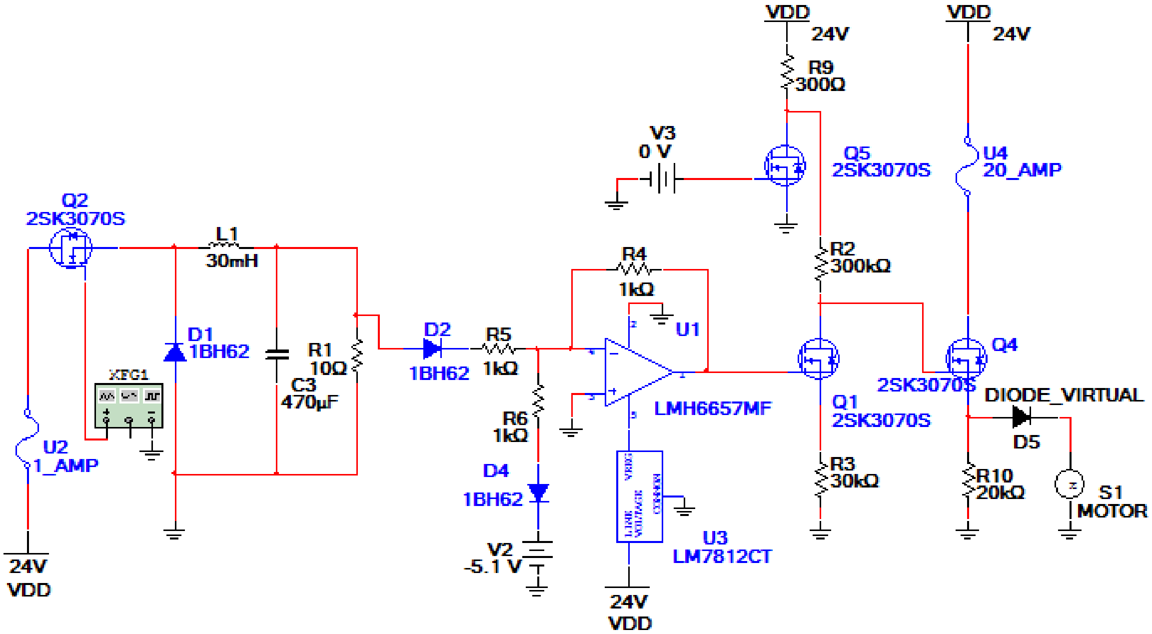


Figure 5.14: PWM to DC Voltage to Actuator Output Phase-Extension

Located above is the circuit that will be used to convert the PWM signal to a DC 2-12V. It can be broken into three stages: To the left of D2 is a Buck Converter, and to the right of D2 is DC to DC step-up output, and the stage corresponding to Q5 is a turn on or off based on the sign pin. The relationship between the duty cycle (D) and the output voltage (V_{od}) when $.04 \le D \le .22$ and $1.83m \le V_{od} \le 12.07$ (V) was found to be given by the regression $V_{od} = 69.184D - 2.6199$ (V), with a statistical r value of r=0.998. This range is sufficient, as 828mV is not enough to turn on the actuators (and if it is not, no duty cycle can be applied if desired), and are tolerant to approximately 1V above 12V, though not recommended. Simulations were done using MultiSim 11.0. Note that the N-MOS transistors used are Hitachi 2SK3070S, which are in the linear region $\sim 2V \le V_{Gs} \le 4V$, with an $R_{DS} \approx 0.0045\Omega$ and is tolerant to 75A and 40V. It is not necessarily the case that this exact transistor will be used; however, one with the same (if not similar) specifications will be used. The same MOSFETs are used for the Cockpit electrical design, for cost reasons (discount on quantity), for accessibility (if one is to burn out, it is easily replaced by the bank of them possessed), for compatibility, and for ease of reference. The desired output voltage takes place in approximately 150ms (when outputting 12.07V), and can discharge in less than 100ms (more than sufficient for the tasks of this project). Also, this circuit is designed to work for a PWM output frequency anywhere between 1kHz and 10kHz. This range is necessary, as 10kHz is the maximum (and default) output frequency of the PWM, but less may be used because tasks to be performed by the Netduino may be too abundant to perform this task effectively. This circuit is rated for 1kHz, as it is the most likely frequency to be based on the previous facts.

Three circuits applied to the gate of Q1 (*Buck Converter* and *Inverting Summer*) will be used, as only three are necessary. However, six of the circuits (two for each actuator) beginning at Q1 (*Sign Control Stage* and *Inverted High Gain Buffer With Source Follower*) will be present in the cockpit. One will be connected for extension (positive to positive, ground to ground), and the other will be connected for retraction (positive to ground, ground to positive). To switch between these, the sign pins will be utilized. 0 will be used to activate the extension circuit, and 1 will be used to activate the retraction circuit. It is clear that the high current diode is required between the circuit output and the actuator to ensure that voltage will not be provided to the immediately unused circuit's NMOS drain from the circuit in operation. If the signed bit is 0, no voltage will be delivered to the retraction circuit from the power supply. The contrary would also be the case. It is necessary to perform this operation in this way, as the power supply available is unipolar. In no situation do those this circuit exceed 25A, and thus all circuits in operation will never exceed 75A (very safely stated).

1.) *Sign Control Stage*

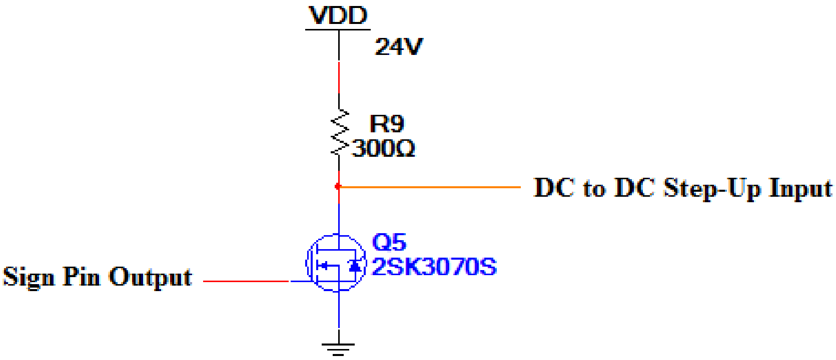


Figure 5.15: Sign Control Stage Circuit

This is the sign controller for the circuit, as one of these will be activated by the sign pin output of the Netduino. Either 0, or 3.3V will be transmitted to this circuit, which will turn the transistor on or off. For the retraction circuit, a digital inverter will be placed at the sign pin output, so that the DC/DC step-up converter will be turned on when 3.3V is received. Thus, in the event 0V is applied at the gate of the MOSFET (in common source configuration), the appropriate voltage will be applied to the DC to DC step-up converter, and when 3.3V is applied, the voltage will not be applied to the DC to DC step-up converter. The maximum current supplied by the power source is 80mA, in the situation when Q5 is turned on, and no voltage is applied to the step-up converter.

2.) Buck Converter

A Buck Converter is ideal for this scenario, as the power applied to the actuators must have a quick reaction. It is not sufficient to use a standard Boost converter, as the charge time is too extensive, and the required transistors for such operation are not tolerant enough to the specifications for the actuators.

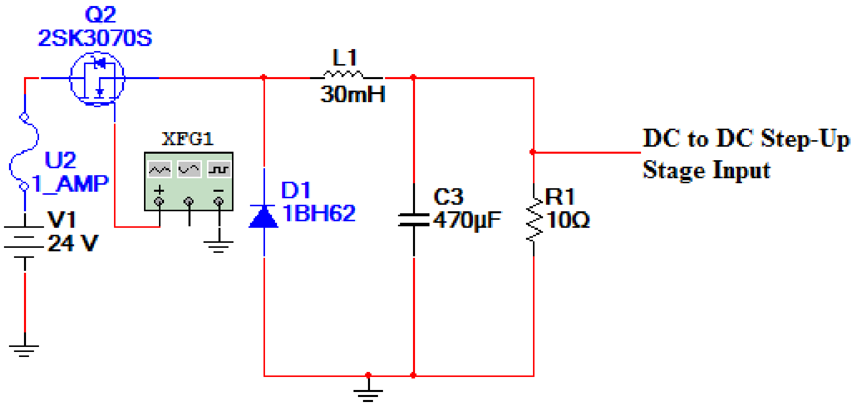


Figure 5.16: Buck Converter Circuit

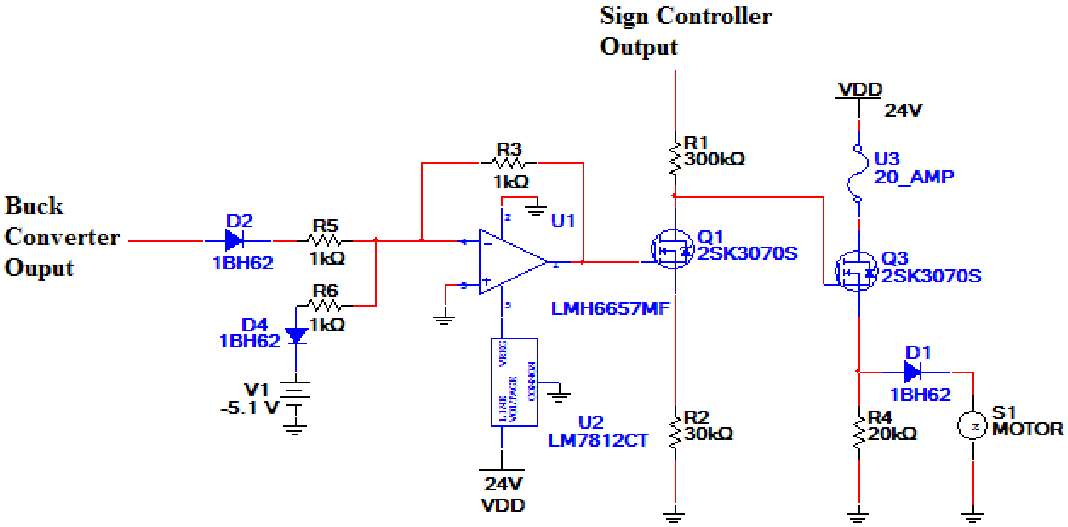
The Buck Converter is of the standard design, using a 24V input voltage, 30mH inductor, a 470uF capacitor, a max 0.7V drop diode, a $10\,\Omega$ resistor (required for the situation when the output voltage is not high enough to turn on the diode on the DC-DC output stage input, and in discharge while not in use), with an enhanced mode power NMOS for switching. XFG in this simulation picture represents the output of the PWM pins of the MCU. The maximum current applied by the MCU is approximately 1mA, well within the proper range specified. The inductor used will be PLA10AN3030R4R2, rated for 400mA, 300V while in common mode with a leakage of 2.7Ω. The max voltage applied at any given time to this inductor is approximately 5V, and the maximum current across it is approximately 225mA (well within range of its specifications). It is essential to have a 1A fuse between the power supply and the drain of Q3; if there was a situation in which the active components were to fail in this circuit, the diode can fail to short, causing damage to the circuit, or in the situation that the MOSFET is to fail, a temporary short will take place, applying too much voltage to the MPU. The intended maximum output voltage is 2.205V (to be explained in the inverting buffer section). This circuit achieves such at 22% duty cycle. Through simulation inspection, a sufficient linear regression was found between .04 and .22 duty cycle (D), ranging between approximately 0 and 2.205V (V_{buck}), with a value r=.995: $V_{buck} = 8.967D + 0.3148$ (V)

3.) DC to DC Step-Up Output Stage

The requirement for 2.2V is within the requirements of the “DC/DC” increase. 2.1-4.2V was found to be needed to step up the voltage at Q1. The sign control stage output must be activated for this circuit to produce an output of any significant voltage. The Diode ensures the voltage from this portion of the output circuit doesn’t leak into the Buck Converter. The power NMOS must be in the linear region to achieve a variable voltage based on an input. This NMOS had to be tolerant to 20A, 24V, and had to have a low R_{DS} .

i.) Inverting Summer

Noting that an inverting buffer is in use for large gain, a summer with all resistor values 1K, with an input of -5.1V (which will be supplied by the 5.1V, 800mA power supply, yet again, as the 24V power supply is uni-polar and non-isolated) followed by a diode (pointing toward the power source, dropping the voltage to be summed to -4.4V) to differ from the output of the Buck Converter, to keep the output low until the Buck Converter outputs the required voltage to take the Power NMOS into the linear region. The operational amplifier used will be uni-polar, thus making the low current negative power supply a requirement, as negative voltage cannot be delivered from the operational amplifier.



5.17: Inverting summer (Left of Q1) with Inverting Buffer (on right, starting with Q1)

The Op-amp used will be a LMH6657MF, as it has preferred use in uni-polar configuration. The LM7812 will be used, connected between the power supply, ground, and turn on terminal of the OP-Amp, so that voltage spikes in operation of the motor will never disrupt operations, or damage active components. The maximum current delivered by the operational amplifier is approximately 1mA, and the maximum voltage applied to Q1 is 4.4V. In no particular scenario does the current delivered (to one circuit) by the -5.1V power supply exceed 4.5mA, and thus in the worst scenario, will never exceed even 13.5mA for all three circuits.

ii.) Inverting High Gain Buffer with Source Follower

An inverting buffer (common source) at Q1 then follows, giving gain to the DC voltage at the gate. The output from the drain is then received by Q3, a source follower, so that the output resistance is not affected by operation of the actuator. This source follower must have a 20A Fuse at the power source, as it is recommended while using the actuators. This is the point in which an actuator will most directly draw current from the power source, so this is essential in operation. That being stated, it is of great importance that Q3 be mounted to a heat sink. The output of the source is then followed by a 20A tolerant diode (.7V drop), making the max voltage applied to the actuators 12.07V. The output of the DC/DC stage also had a sufficiently linear regression for the input voltage between 0.574V and 2.205V (V_{buck}), and the output voltage between 1.83mV and 12.07V (V_{od}), with a value r = .9987: $V_{od} = 7.684V_{buck} - 5.002$ (V). If, for any reason, the buck converter output is to exceed 2.205V, the input of the actuator will not exceed 12.9V, as the MOSFET is in saturation at that point. Although the actuators are not specified to 12.9V, they can operate without difficulty or harm at this voltage. However, it is unwise to operate the actuators at more than 14V.

B.) Netduino Power

The Netduino will be regulated by an LM7812 (12V voltage regulator mounted to a heat sink), to protect it from voltage fluctuation. It is very common in DC motor operation that the power source is likely fluctuations in Voltage output. This can cause the Netduino to reset itself, or in the worst case scenario, be destroyed. Though this is not likely an immediate concern to the operator, it is essential for the RC Ghost Rider to not destroy itself.

C.) Potentiometer Circuits

All potentiometers used in the cockpit will be 10k pots, exactly as displayed above. This can be used for the steering mechanism, the break mechanism, the acceleration mechanism, and the potentiometer readings from the actuators (as they are designed with 10k potentiometers). This will range values between 2.7V and 3.2V (as these are safely within the 2.6V to 3.3 V range of the analog inputs of the Netduino). As all other things connected directly to the MCU, a voltage regulator will be used instead of a voltage divider so that no excess voltage in operation will damage the MPU, or ruin the integrity of the readings. In this case, a LM7805 (5V regulator) will be used.

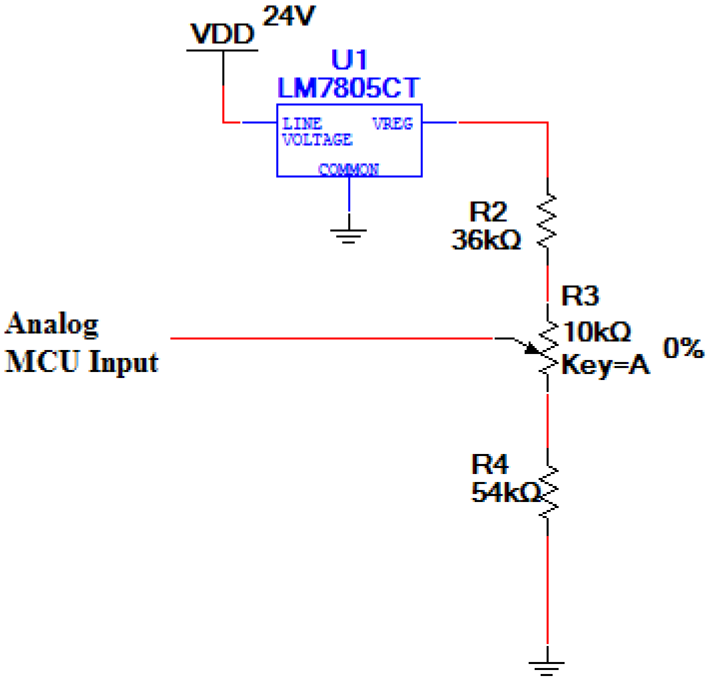


Figure 5.18: Potentiometer Circuit

D.) Transceiver Power

The XBee® will operate at 3.3V DC to maximize the distance in which the hardware from the Cockpit can communicate with the RC Car. That being said, The XBee will require approximately 45mA in transmission, and 50mA in reception phase, with a power-down current of less than 10uA at 25 degrees Celsius. To accommodate the requirements to supply the XBee with 3.4V, an LM7805 will be used with a simple voltage divider between the voltage regulator output and the XBee supply port.

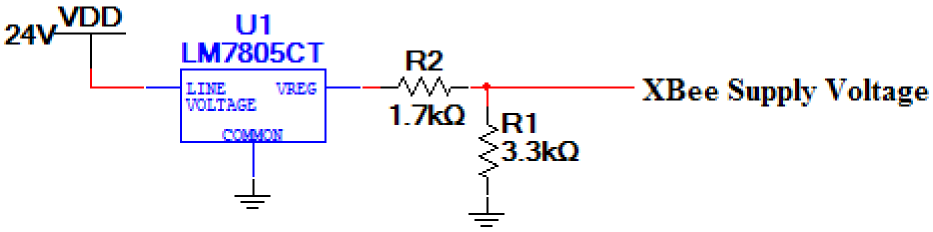


Figure 5.19: Transceiver Power Connection

E.) Power Delivery

It is clearly evident that all the parts chosen for the hardware design require no more than 24V (with exception to the -5.1V DC power supply); However, current delivery is quite essential in this scenario. The PWM to DC output stage while in connection to the actuators, and while rapidly changing between extension and retraction stages (stepping swiftly between 12V DC and -12V DC) received no more than 75A from the power supply in simulation. This situation causes a drain from the power supply at slightly more than 22A delivered to each actuator, noted as a much more than worst case scenario for this design, as the 20A fuse at the placement of the Drain of the voltage follower is present. Also, note that it the leakage of the motor was assumed to be abnormally low for these power distribution simulations (0.6 Ohms).

That being said, the XBee requires no more than 50mA, and the potentiometer circuits each drew less than 5mA. Assume, for the purpose of this discussion on power delivery, that the Netduino is delivered its maximum current of 200mA, which, due to testing in programming and careful construction, will not happen unless a manufacturing error takes place. This would bring the total current delivered by the power supply to 75.255A. This is well within the range of the specifications stated in the “Relevant Technologies” section, and thus, has further verified the selection of the power supply.

5.3.3: Cockpit – Processor Platform Programming: Structure and Duty

The Netduino is to be connected at analog pin 0 to the steering wheel, analog pin 1 to the brakes (through D/A), and analog pin 2 to the accelerator pedal. Digital Pin 0 will be used for the turn-on operation. Pin 1 will be utilized for the reverse switch. Digital pin 7 is to receive the signal from the transceiver that is transmitted from the RC car to detect vibrations. Digital pin 8 will transmit a data signal to the transceiver so the cockpit can control the car’s motion. Pins 5, 6, and 9 will be used to transmit the signal to the buck converter, then to the DC to DC converter which controls the actuators, as they are PWM output terminals which can be used for D/A conversion. Pins 3, 10, and 11 (from now on referred to as “sign pins”) will be used for switching between positive and negative D/A conversion networks. Analog pins 3, 4, and 5 will be used to for potentiometer readings from the actuators.

The program is to be initiated by a button found in the cockpit. If a person is not in the seat, then no signal will be sent to the actuators. Given an appropriate weight is detected; this value will be stored for later use in the program. If a person in conjunction with the weight of the apparatus is deemed too heavy for operation, no signal will be sent to the actuators. This will be discussed again later in this section.

The main loop will begin following the reception of the above mentioned value, and the program will stop once a person pushes the off button, which is found on the steering wheel, thus ending the program. This, mind you, is the same button that initiates the main loop.

Flow Chart Color Key: Red - Hardware Input/Output, Blue - Functional Input/Output to be used for another function, Purple - Predefined Function, Green - output that initializes, Orange - Process, Yellow - Decision

Synchronization Function:

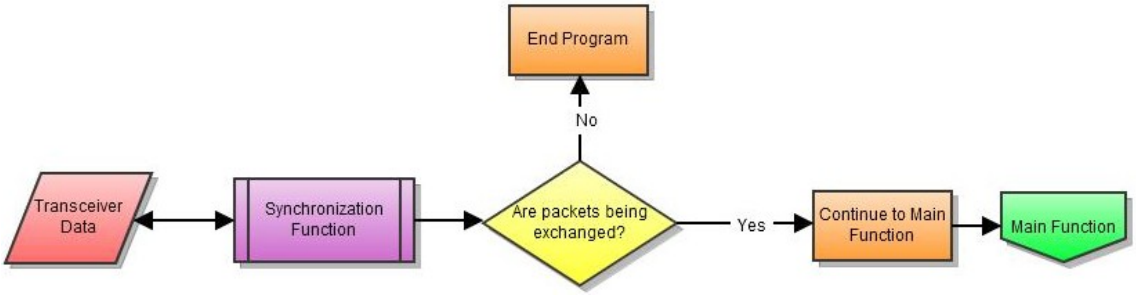


Figure 5.20: Block diagram of Synchronization function

This function will begin the operation of the car from the cockpit as it will detect that the car is on, and then synchronize so that the data signal will be unpacked properly.

Unpack Function(s): The signal received from the car at pin 7 will decoded in software to separate into four separate values for each of the four potentiometers from the car and the speedometer.

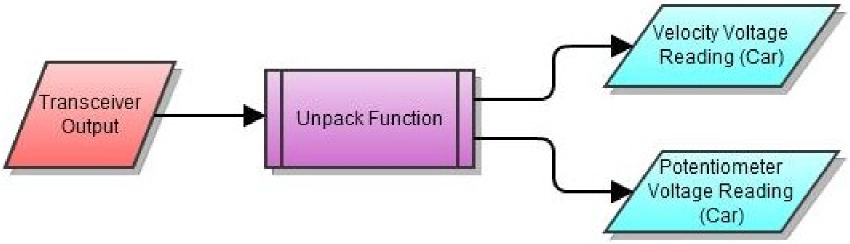


Figure 5.21: Block Diagram of Unpack Function

Potentiometer/Speedometer Voltage to Displacement/Speed Conversion Functions:

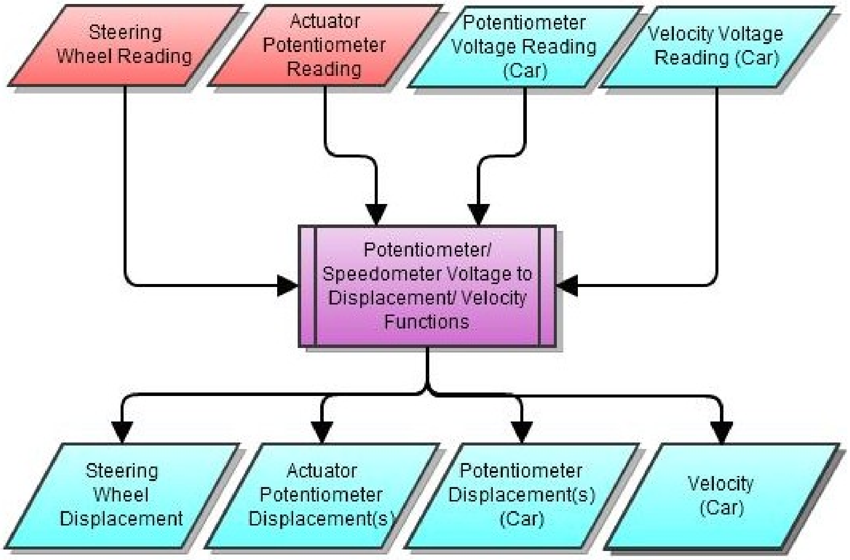
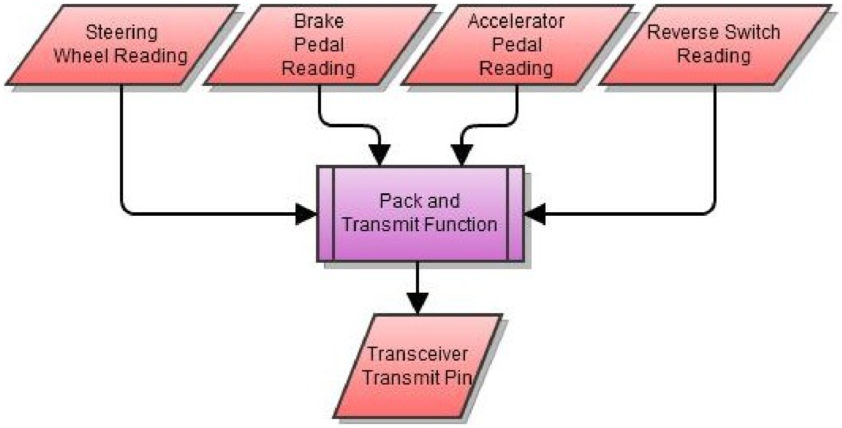


Figure 5.22: Block Diagram of Potentiometer/Speedometer Voltage to Displacement/Speed Conversion Functions

This function will take in one of the voltage values from the Unpack Function, the steering wheel, the accelerator pedal, and the brake pedal and convert it back to the displacement of the potentiometer, and the measured speed from the speedometer. Then, displacement and speed will be scaled depending on the proportions of the dimensions of the cockpit, to the dimensions of the car. This function will also convert the potentiometer readings from the actuators to displacements. The voltage read will be transmitted as a value between 2.7V and 3.2V, as these are within the specs of the analog input of the Netduino. The value of the potentiometer reading the steering displacement will note that anything less than 2.95V is a negative displacement, any value greater than such as positive, and any value nearly equal to will be exactly equal to 2.95V as 0 displacement.

Pack and Transmit Function: The signal from the steering wheel, brakes, and accelerator pedal (here after deemed operator controls) will be taken to, so that they can be transmitted to control the car using pin 8. The steering wheel signal will be interpreted to be passed later by the *Operator Control Calculus Function*

. **Figure 5.23: Block Diagram of Pack and Transmit Function**



Operator Control Calculus Function(s):

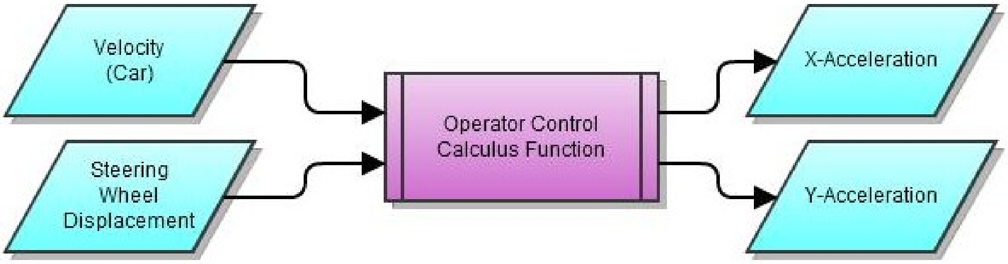


Figure 5.24: Block Diagram of Operator Control Calculus Function

Two functions will be created to pass three variables, which are the values submitted from the steering wheel and two which are the velocities of the car from the *Speedometer Voltage to Displacement Conversion Function* sampled at a time spacing of t_s. Each of these functions will output the net acceleration applied in two dimensions. Let x denote the function pertaining to the dimension left and right of the car, where left is negative and right is positive. Let y denote the function pertaining to the dimension relative to the front and back of the car, where toward the front is positive, and toward the back is negative. Let s be the percent of application applied to the steering wheel, where s when negative is left, and when positive is right (s is a decimal value). If $s \neq 0$, let the resulting radius from turning be denoted by $r_c = r_{\min} / s$, where $r_{\min}$ is the smallest turning radius possibly made by the RC car. For the "y" function: Let v_{c1} and v_{c2} be the sampled velocities, respective to sample order. Then the acceleration of the car over the duration of sampling can be found as follows:

$$a_{cy} = \frac{v_{c2} - v_{c1}}{t_s}$$

For the "x" function: if $s = 0$, then the acceleration $a_{cx} = 0$.

If $s \neq 0$, then $a_{cx} = -\frac{v_{c2}^2}{r_c}$.

Note that the direction is determined by the sign. If the car is turning left, the car's motion from the top will be counter-clockwise, thus the feeling will be rightward. The contrary would be true, given the car is turning right.

Potentiometer Calculus Function:

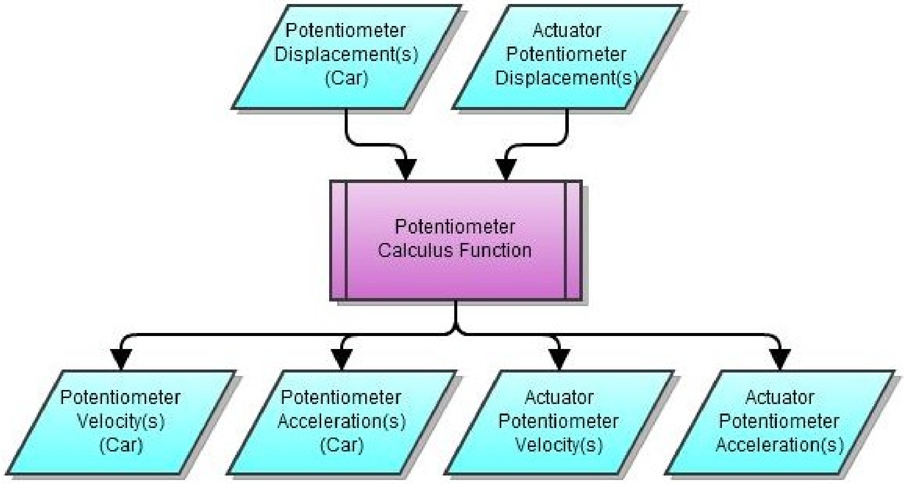


Figure 5.25: Block diagram of Potentiometer Calculus Function

This function passes one value from the *Potentiometer Voltage to Displacement Conversion Function* to determine the amount of force to be applied in the vertical direction by the actuators. Three samples from the signal are to be taken at a time, corresponding to three separate, evenly timed, values measured from the potentiometers, as at least three samples are required to sample to find acceleration based on displacement. These values will be d_n, d_{n+1} and d_{n+2}, while t will be the time between measured samples. Thus, the average velocity between d_n and d_{n+1} will be v_n, and the average velocity between d_{n+1} and d_{n+2} will be v_n, and the average acceleration over the range of the three samples will be noted as a_n. Thus the following will be the mathematical framework of this particular function is:

$$v_n = \frac{d_{n+1} - d_n}{t} \quad \text{and} \quad a_n = \frac{v_{n+1} - v_n}{2t}$$

This function will return both v_n and a_n.

Operator Weight Function:

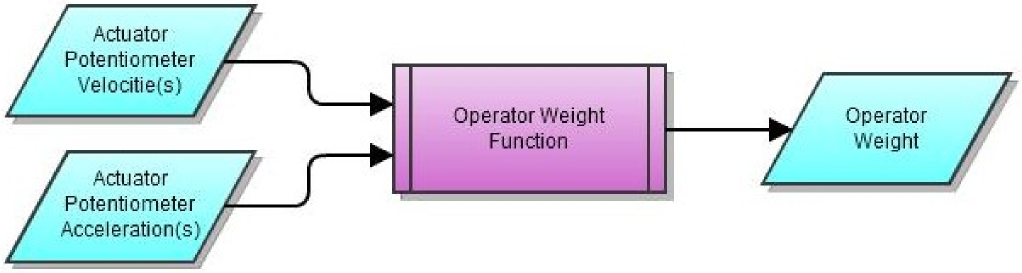


Figure 5.26: Block Diagram of Operator Weight Function

This function will determine the operators weight based on the *Potentiometer Calculus Function*. Upon turning on the cockpit, and once synchronization has taken place, the rates will be noted by the MCU in which the force applied on the actuator will determine the weight of a person. If the actuators move slower at a set voltage, relative to software testing results, the person is heavier. The contrary would also be true.

Final Actuator Output Function:

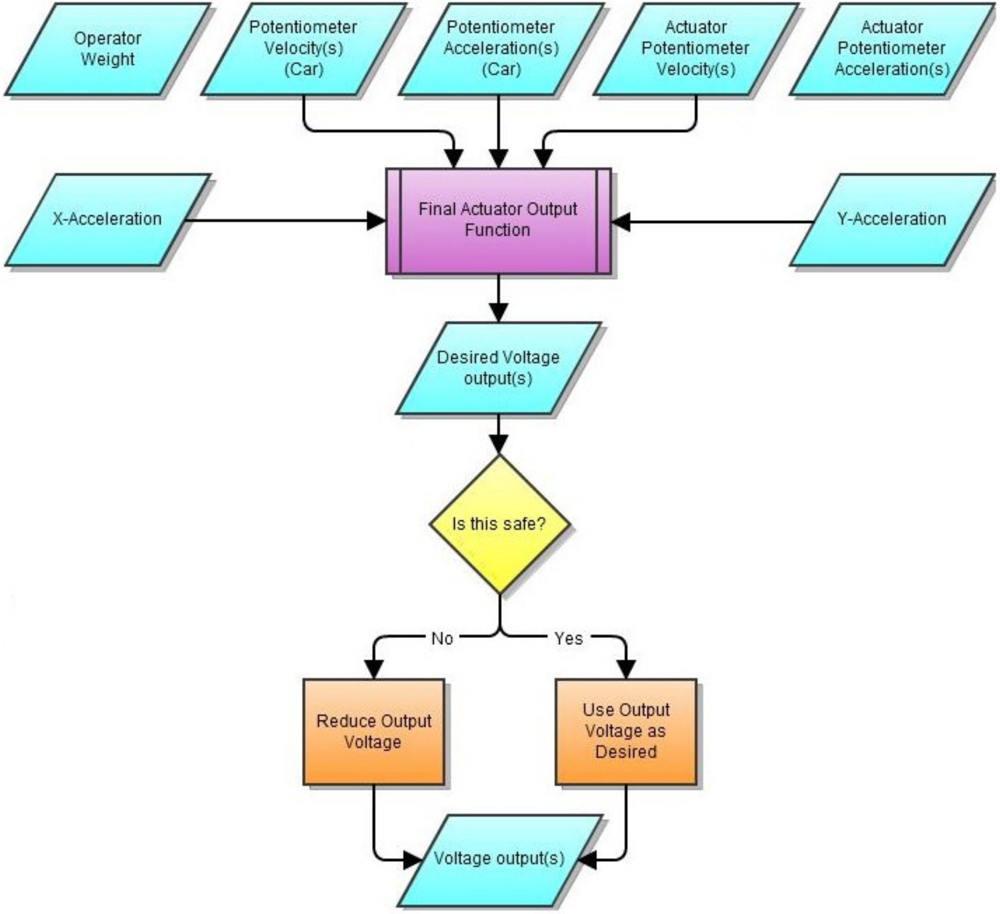


Figure 5.27: Block Diagram of Final Actuator Output Function

A function will be created to pass the following variables: the weight of the person with the apparatus, the values taken from the actuator potentiometer reference, the values taken from the *Operator Control Calculation Functions*, and one *the Potentiometer Force Functions*. This function will determine if the applied force from the actuators will be safe for the vehicle, and most importantly, safe for the operator. This will be set by a threshold, to be determined in construction of the vehicle. Then, the function will apply the input values to determine how much voltage is to be output to an individual actuator. The output of *Final Actuator Output Function* is to be modulated, and output through pin 5, 6, or 10, based on the corresponding actuator. Given that the actuators extend a total of 6 inches, 5 inches of motion will be dedicated to the output of a_{tot}, where the other inch will, roughly be dedicated to the potentiometer motion on the front actuators. When the car is at rest and synchronized to the cockpit, the cockpit will be lifted 3 inches in the front, 3 inches in the back, and will retract and extend in the range of d_r,the maximum range of motion allowed from the center point (or "base" level) of the actuator. This value, d_r, is allowed 2.5 inches swing in both the upward and downward direction. These voltages are to be applied for a time-duration so that those actuators will be adjusted to the desired height. Mind that these displacements are to be kept for the next loop-through of the function, and these values will be adjusted to account for changes in acceleration. The mathematical framework of this function will be as follows: Let a_{tot} be the total force, also accounting for direction (in radians). Let $a_{x\max}$ be the maximum acceleration as calculated in the x dimension, and $a_{y\max}$ be the maximum acceleration as calculated in the y dimension (both with margin of error fully considered). Mind that $a_{y\max}$ will be the stopping acceleration, calculated by $a_{y\max} = v_{\max} / t_{stop}$, with $v_{\max}$ as the maximum speed of the RC car and t_{stop} as the time required to bring the car to a full stop from maximum velocity. These are scaled for ease of calculation, and to make a more enjoyable, rather than a necessarily more "realistic" experience, as turning intensity would be greater in more frequent circumstances. Then, let $a_x = a_{cx} / a_{x\max}$ and $a_y = a_{cy} / a_{y\max}$, and let the angle of the acceleration be θ.

If $a_x = 0$, then

$$a_{tot} = \begin{cases} |a_y|, \theta = \dfrac{\pi}{2} & \text{If } a_y \geq 0 \\ |a_y|, \theta = \dfrac{3\pi}{2} & \text{If } a_y < 0 \end{cases}$$

If $a_x \neq 0$, then the total acceleration $a_{tot} = \sqrt{a_x^2 + a_y^2}$ at an angle of

$$\theta = \begin{cases} \arctan\left|\dfrac{a_y}{a_x}\right|, & \text{If } a_x > 0 \text{ and } a_y \geq 0 \\ -\arctan\left|\dfrac{a_y}{a_x}\right| + \pi, & \text{If } a_x < 0 \text{ and } a_y \geq 0 \\ \arctan\left|\dfrac{a_y}{a_x}\right| + 2\pi, & \text{If } a_x > 0 \text{ and } a_y < 0 \\ -\arctan\left|\dfrac{a_y}{a_x}\right| + 2\pi, & \text{If } a_x < 0 \text{ and } a_y < 0 \end{cases}$$

Let V_{motion} be the (variable) greatest scaled voltage submitted from the Netduino to the actuators for acceleration transmission to the cockpit to allow for comfort of the operator, applied as a ratio of the current acceleration against the largest acceleration in a two-dimensional direction. This particular value will be found in the ongoing testing phase. Then, let V_{react} be the voltage required to react to make a change in angle that is the negative of V_{motion}. This can be found by multiplying a constant (to be verified and found in testing and construction) to the result of Equation 5.7. If $0 < \theta < \pi / 2$, then V_{motion} will be noted to be assigned to the pin corresponding to the rear actuator, and V_{react} will be noted to be assigned to the front-right actuator. If $\pi / 2 < \theta < \pi$, then V_{motion} will be noted to be assigned to the pin corresponding to the rear actuator and V_{react} will be noted to be assigned to the pin corresponding to the front-left actuator. If $\pi < \theta < 3\pi / 2$, then V_{motion} will be noted to be assigned to the pin corresponding to the front-right actuator and V_{react} will be noted to be assigned to the pin corresponding to the pin corresponding to the rear actuator. If $3\pi / 2 < \theta < 2\pi$, then V_{motion} will be noted to be assigned to the pin corresponding to the front-left actuator and V_{react} will be noted to be assigned to the pin corresponding to the pin corresponding to the rear actuator. If $\theta = 0$, then V_{motion} will be applied to the pin corresponding to the front-left actuator and V_{react} will be applied to the pin corresponding to the front-right actuator, while the rear actuator is set to the “base level”. If $\theta = \pi$, then V_{motion} will be applied to the pin corresponding to the front-right actuator and V_{react} will be applied to the pin corresponding to the front-left actuator, while the rear actuator is set to the “base level”. If $\theta = 3\pi / 2$, then V_{motion} will be applied to pins corresponding to the rear actuator and V_{react} will be applied to the pin corresponding to both of the front actuators. If $\theta = 5\pi / 2$, then V_{motion} will be applied to pins corresponding to both front actuators and V_{react} will be applied to the pin corresponding to the rear actuator.

Then, the values from the *Potentiometer Calculus Function* will be applied using the values received from the potentiometer readings from the car. The voltage, V_{Pot}, corresponding to the velocity, v_{n+1}, will be applied for the sampled duration t. V_{Pot} = αv_{n+1} is the relationship between V_{Pot} and v_{n+1}. The constant, α, will be experimentally found and verified in the building and testing procedures. The displacement of the front actuator will be stored for the next loop through, as this displacement is $d = v_{n+1}t$. This displacement will be restricted by the 5 inch total range of motion discussed earlier for potentiometer control of the cockpit. Thus the swing of motion will be 6 inches on the varying actuator axes in both directions. The greatest acceleration will be used from the potentiometers, and applied to front actuators, V_{Pot} at the pin corresponding to the side with the greatest acceleration and $V_{Potreact}$ (from equations 5.4 and 5.6) at the pin corresponding to the side with lesser acceleration. In the event that all potentiometers are at full extension (for example, if one was to propel the RC car off a ramp) the only voltage to be applied to the actuators would be the voltage required to keep the actuators at the level of extension they were in prior to the time in which the RC car was momentarily a projectile. This voltage will be further determined by the weight of the person.

Once the acceleration in any planar direction is decreased, or decreasing, the cockpit will steadily make its way back to base position. Once the acceleration in any one planar direction is zero, the cockpit should already be placed back at base level.

Reaction voltage:

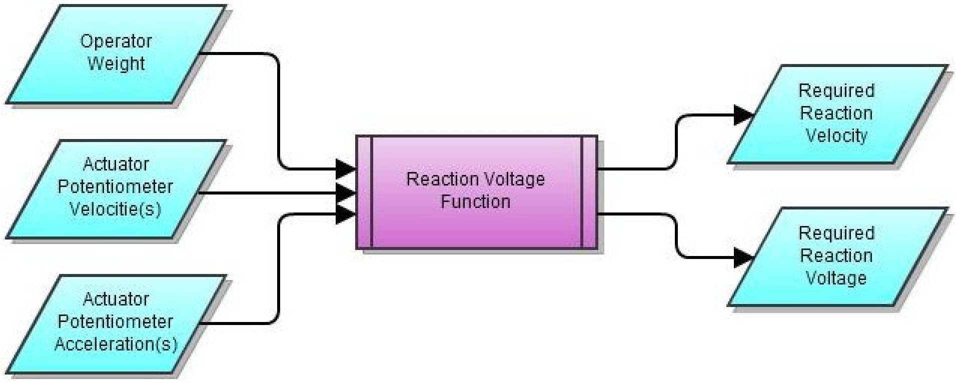


Figure 5.28: Block Diagram of Reaction Voltage Function

The reaction voltage, $V_{Potreact}$, found by scaling equations 5.4 and 5.6, will be calculated by the processor using the values from the *Potentiometer Calculus Function* after passing the values calculated from extending actuators to solve for $d\ell / dt$ (the velocity function output). The value of the change of angle of the retracting actuator(s) must be the additive inverse of the change of angle of the extending actuator(s). This is absolutely necessary, as not all people have the same center of gravity or weight. Safety is of the greatest concern, and so is stability in this project.

PWM Output Function:

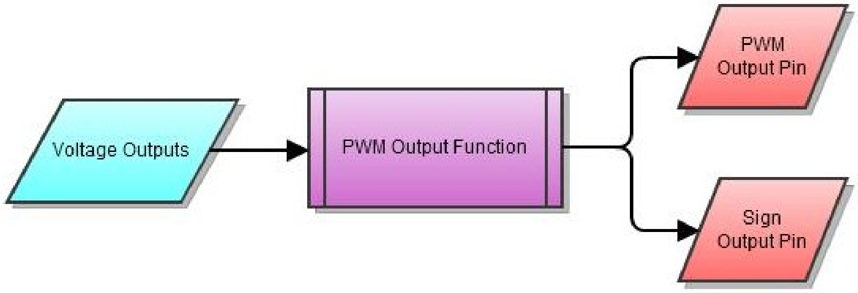


Figure 5.29: Block Diagram of PWM Output Function

The PWM will be adjusted through programming and output from the designated PWM pins. For the duty cycle, D, and the desired output voltage, v_o, $D = (v_o + 11.46) / 69.184$ in decimal form (Based on simulation, not necessarily true to actualization of the circuit). The sign of the voltage will be transmitted as the output of the sign pins to choose which D/A conversion network to use. In the event of a nearly immediate sign change in the direction of the actuator, the PWM signal must be delayed for approximately 0.08 of a second, to discharge the previous signal. If this step is not taken, motion will be jerky, and the actuator will likely draw current succeeding 20A, breaking a fuse in operation.

6 – Prototype Construction and Coding

6.1) Structural Modification: Process

In order to adequately secure the various components to the vehicle, proper precautions must be taken. The linear motion actuators will need to be mounted to both the top and the bottom in order to ensure stability. For this purpose a set of small hinge joints will be used in order to account for the various motions the actuator will encounter. The part of the actuator from which the wires extend must be at the top of the shock in order to ensure that the wires involved do not become tangled unnecessarily. In addition the accelerometer will need to be securely fastened to the frame of the vehicle. This will be a relatively simple accomplishment as the accelerometer will be directly mounted to the PCB board. Four small screws will be used to fasten the PCB board to the frame of the vehicle to ensure stability.

In addition the MOSFET's that are to power to motor also need to be securely fastened. A hear sink for each of the MOSFET's will be mounted to the vehicle's chassis by way of four small screws. The MOSFET's will then be mounted to the heat sink by way of the single screw located on them. The batteries that will be used for the cars motion will also need to be securely mounted. As stated before a cavity was hollowed out in order to accommodate the new batteries. The batteries will be stacked into the cavity and sealed in place with a small piece of Plexiglas. Likewise the transceiver, transmitter and camera will also need to be securely mounted.

The transceiver will be soldered onto a small board that will be mounted to the back right of the vehicle, and thus should be very securely mounted. The transmitter will need to be mounted closely to the rear of the vehicle, this time on the back left. A small cavity will be made in the vehicle in order to accommodate the transmitter. This cavity will be covered with a small piece of Plexiglas that is screwed into place to secure the transmitter. There will need to be a hole in the Plexiglas to allow for the antenna connected to the transmitter to stick out of the top. In addition two holes will need to be put into the plastic body of the car to accommodate the antennas. A small metal rod will be mounted to the front of the vehicle sticking straight up in the Z direction. On top of this rod will be a small platform for the camera to rest upon. On the platform will be four holes to allow the camera to be mounted.

6.2) Programming RC Car Processor Platform: Process

In order to program the MSP-430, there will need to be an environment in which to program in. For the purposes outlined in this project, it has been decided that the “C” programming language will be used rather than “Assembly Language”. This has been decided because of the amount of time and effort that will need to be spent debugging assembly code does not outweigh the subtle performance drawbacks of writing in “C”. In order to get started with the programming process, the Texas Instruments Code Composer Studio v4 must be installed on the machine that will be used for development purposes. The next step in the programming process will be the step in which the user gets familiarized with the interface that will be used. At this point the programming for the vehicle can commence.

In order to adequately test various parts of the structure of the program, it will be necessary to complete the subroutines in a specific order. Doing so will allow for the proper testing of each routine before another routine is written. This will lead to greater confidence that the overall program will function as intended when the code writing has finished. Because it will be necessary to use the values that are read in from the input pins on the board, the collection of data should be the first routine that is written. When this routine has been written it should be tested as the software testing portion of the paper dictates. After the acquisition of data has been handled, the routine that decides the importance of the data acquired should be coded. This portion of programming must be done after the program has received data, because in order to test the data for validity, there must first be data to be tested. Likewise, the manipulation of the output buffer should happen after the check for significance of the data in question.

The next step in the process is where the MCU receives the data from the transceiver. In order to write the software portion necessary for this, there must also be software for the cockpit's MCU that will transmit data, unless a dummy signal will be routed directly in through the transceivers input/output ports. Using the dummy signal will allow the user to separate the cockpit and the vehicle when it comes to data transmission, while the software is being written. The next piece of code that will need to be handled will involve the control signal that will be sent to the output pins. This will need to be written after data has been received because in order to test the data to see if anything has changed, there will need to be data in the first place. The next portion of the program to be written is that in which the MCU actually transmits the data to the cockpit will need to be implemented. This portion should be written after the portion about collection data from the sensors, because in order to send off the data, there must first be data to be sent. In order to create this program given the set of functions that need to be written, it is easy to see that a simple flowchart can depict what portions of code need to be written in what order. The two separate flow trees show that both trees can be simultaneously accomplished without the other tree.

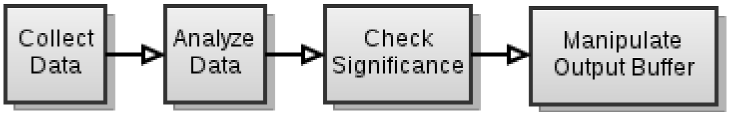


Figure 6.1: Order of program creation #1

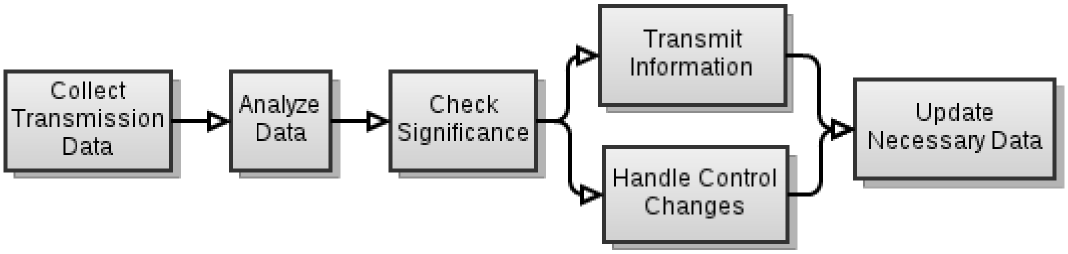


Figure 6.2: Order of program creation #2

6.3 Construction of Cockpit

The first step in the construction is to buy all of the prefabricated components of the cockpit which include: three actuators, driver's seat, 3 point harness, steering wheel, pedals, nitrogen filled shock, ball joint, six heim joints and television. It is paramount that the actuators be purchased as early as possible to ensure there is adequate time to test and analyze the movements of each independently. During the period of time the actuators are being tested the first portions of Chromoly material will bought. These portions will be used to create the cockpit base and the nitrogen filled shock housing. The cockpit base will be fabricated from two pieces of sheet metal by first cutting two circles of radius 2 feet that will act as the top and bottom sides of the cylinder. Next each portion will need to have a circle of radius 2.5 inches to be cut from the center. This section is removed to accommodate the nitrogen filled shock housing. Then two strips of the Chromoly sheet metal must be cut with the first measuring 8 inches in width and 12.57 feet in length and the second measuring 8 inches in width and 19.635 inches in length.   These two strips of sheet metal will be welded to the inner and outer sides of the cylinder base at a 90 degree angle and give it the 8 inch height that is required. For all welding purposes a MIG weld will be used. Both strips will have to be formed into a semi circular shape to make welding them easier. Before the top side is welded on to finish the fabrication of the base, a series of trusses and supports will be connected inside the cylinder to help support the combined weight of the cockpit and driver. Once the supports are welded into place the top will be welded creating a 90 degree angle with the sides of the cylinder. After this is done the cockpit cylinder base and shock housing portion is completed. During this time the actuator testing should be completed and to make sure they are suitable for use.

The next purchase of materials will be of Chromoly square tubing and sheet metal as well as the six heim joints, one ball joint, and the 3 point harness. All the Chromoly material will be 0.120 inches in wall thickness and except for the vertical portion of the television tree mount which will be 3 inches in side length, all square tubing will be 1.25 inches in side length. The sheet metal will be cut to form a cube of length, width, and height of 5 inches that will act as the upper housing of the ball joint. The bottom portion of the cube will need to be shaped such that it can accept the top half of the 5 inch diameter ball. This section of the cockpit will be the focal point of all movement and support most of the weight of the driver. The square tubing will be cut into three pieces each 17 inches in length with the end being but at a 45 degree angle. This angle will allow there to be a larger surface area for the weld which substantially increases its strength. The bottom side of the triangle will be welded to the top side of the ball joint housing. At the center point of each corner of the triangle a heim joint will be fastened. There will also be corresponding heim joints attached to the cockpit base and the actuators will be mounted to both sets of heim joints. The bottom heim joints must located 5.176 inches outside of the ones connected to the triangle to put the actuators on and 75 degree tilt. On top of the triangle a rectangular piece of sheet metal cut to 17 inches wide by 24 inches long will be welded. The width of this section was selected to match the side length of the equilateral triangle and the length to be equal to the seat mounting bracket on the bottom of the driver's seat. The seat will sit atop this structure and attach to it using the bottom brackets and bracing that are already on the seat. A 40 inch long piece of square tubing will be needed after the seat is successfully secured to the cockpit. The square tubing will be cut into two pieces of length 6 and 34 inches. The 34 inch portion will be inserted through the mid-point of the seat back from the bottom through the top where the 6 inch section will be welded to it horizontally to form a “T” shape. At the upper ends to the top of the “T” is where the two vertical straps of the 3 point harness will be mounted. The bottom strap of the harness will be connected to the center of the front side of the triangle support under the seat.

The floor board is the next part of the cockpit to be fabricated. This entails buying a 36 inch length of square tubing, two pieces of sheet metal that measure 36 inches in length and 15.75 inches in width. The square tubing will be cut down the center line for the entire length. The two halves will be separated and welded to the two pieces of sheet metal to form the rectangular box that will act as the floorboard. The front side of the floorboard will be welded to the triangular bracing under the seat to secure it to the cockpit. Starting 20 inches from the weld connecting the floorboard to the triangular bracing a series of holes will be drilled. Each series of holes will be 4 inches in distance from the previous set of holes. The holes will be on the top of the floorboard and 1 inch from the center of the hole to the outer edge. The holes with both have a radius of 0.125 inches. These holes will allow the pedal platform to be moved to a comfortable position by the driver.

The next step in construction is to build the pedal platform. This will require sheet metal to be bought and cut to 17 inches wide to match the width of the floorboard, and 18 inches in length. The platform will have to be shaped to create an angle of 30 degrees. There will be a 3 inch section that will sit flat atop the floorboard and from there the platform will raise 30 degrees. The 3 inch section will also have 2 hole drilled in it measuring 1 inch from the center of the hole to the outer edge and 1.5 inches from the center of the hole to both the inclined section of the platform to the edge of the platform closest to the driver. The holes on the floorboard and the platform will have the same radius . The platform holes need to match the floorboard holes so that when a driver moves the platform so there is a secure connection. To connect the two structures a bolt and cotter key will be implemented. The pedals will connect to the platform using a hinge joint, spring, and epoxy. The epoxy that will be used to connect the hinge joint to the platform and pedals is quick drying, and industrial strength. The spring will be connected to the pedal with the aid of a core out drill bit will create a circle about 0.375 inches deep into the back of each pedal. The circular drill bit and the spring will have the same diameter so that the top of the spring fits in place securely. The bottom of the spring will connect to the platform by drilling the hole in the platform equal to the thickness of the spring and about 20% of the prone length of the spring will be threaded though. Due to the spring's design, threading it through the platform is effective was to connect the spring to the platform. Potentiometers will be located inside of the springs.

The television mount is the next section that will be fabricated. An 19inch length of square tubing will be bought and mounted with it directly on the center point of the floorboard (relative to both the width and the length) at a 90 degree angle. A square hole will be drilled through both the front and back side of the television column with its center located 15 inches from the floorboard and 1.5 inches from the left of right side. This is where the steering column will attach. It will have side lengths of 1.25 inches to match the dimensions of the steering column. The steering column will be fabricated using a 20 inch length of square tubing. It will have a series of holes that measure 0.5 inches in diameter drilled through the right and left side. The center of the holes will be a distance of 0.625 inches from the top or bottom of the 1.25 inch tubing. There will be a series of four holes drilled into the steering column all 3 inches away from the previous series of holes. The holes will be at lengths of 1, 4, 7, and 10 inches away from the back end of the steering column. There will be an equivalent hole drilled though the television tree, this will allow the steering column to be moved by the driver to a comfortable position. A bolt and cotter key will again be used and it will keep the steering column static once the driver has moved it to comfortable position. The front end of the steering column will be cut at an angle of 15 degrees and 6 inch square of sheet metal will be welded to it with the center of the square sheet metal and square tubing being in the same position for both. Around the center of the square section of sheet metal, a ball-bearing housing will be mounted. The steering wheel will connect to the bearing by a solid steel rod of length 2 inches and a diameter of .5 inches that will be welded to the center of the square. The steering wheel will need to have a hole cut in the center of it that mirrors the dimensions of the steel rod. The steering wheel will be place atop the solid steel rod. A spring will be attached to the back of the steering wheel and the rod will be placed inside the spring. This spring will connect to the square in the same manner the springs are connected to the pedal platform.

The final section of the cockpit construction is the building of the television housing. The housing will be welded the top of the vertical tubing that connects to the floorboard. It will consist of 5 sections of sheet metal cut to form a rectangular cuboid of 21 inches x 2 inches x 4 inches dimensions. The back, left, and right sides will be fully closed off. The front side of the cuboid will have a 20 inch by 20 inch square portion cut out so the screen of the television is not obstructed.

6.4: Programming Cockpit Processor Platform and Circuitry Construction: Process

It should be noted that testing in this project is an ongoing procedure, as testing is necessary to ensure safety and proper operation without destroying the apparatus. Programming the platform will begin by ensuring that imaginary input values are accepted as predicted, and assure they are converted properly using the given functions. Following such action, inputs will be placed for operator controls, and output values from the converting functions will be found. Voltage values and processor function outputs will be documented until acceptable results are found. Then, pulse width modulation outputs will be tested with the PWM to DC circuitry, to ensure that the proper DC voltages are output.

Though hardware testing on the non-moving circuitry would be considered physical construction, the circuitry is heavily dependent on the processing platform’s performance. Circuitry will be tested using the collected components and required components. First, the buck converter will be constructed and tested for a desirable range of voltages, corresponding to the simulated design. Once a desirable range of voltages can be found on the output of the buck converter, a regression will be formed to suit the response of an output voltage due to the duty cycle. This can vary, as other stages may require that this output vary differently in a real-world environment.

The sign-selector circuit along with the DC to DC step up function will be tested simultaneously, as resistor values on the drain of the sign selector circuit can produce undesirable results, as it is a common-source buffer. A regression will be formed based on output voltages versus input voltages (where the buck converter is to be connected) once adequate results are achieved. Then, a reverse in polarity test will take place to determine that second-circuit inversion of the voltage applied to the actuators will work as predicted. In this “inversion testing” process, things such as current applied to the unused circuit will be tested. Given that the prior takes place, the circuit will be connected in its entirety, and verification will take place to ensure that interfacing all three circuits yields desirable results. Finally, a duty cycle to final output regression will be constructed to be used in programming. Discharge times of the circuit will also need to be documented.

The process of programming the Netduino will be heavily dependent on hardware testing. Once the prior steps are taken, the complete circuit will be applied to an actuator to determine the actuator’s response to varying loads. In this process, it can be determined how displacement, velocity, and acceleration are effected by active loads, which will lead to a significantly safer operation. Documenting such things will determine the total force applied by the actuators, which will be used in computing the weight of a person. The proportional change in weight will vary actuator extension, and a regression will be established. Also, this will determine specific factors about live load that effect lateral forces on the actuator, to help deem variables which can cause unsafe operation. A regression establishing a connection between weight and velocity of response in both extension and retraction will need to be documented. Potentiometer readings are essential in such action, and will be received by the MPU and processed to find the velocities using the functions established in the *Cockpit Processor Platform: Structure and Duty* section.

The prior step will be applied to programming, adjusting factors for the response voltage for retraction vs. the extension of actuators. All will be tested, to ensure that changes in angle are cohesive allowing that smooth pivoting around a central point are correlated. Likely, this will be tested with two actuators first, bottom portion affixed to the lower platform of the prototyped cockpit without the seating apparatus affixed, with a flat surface (such as a wooden board) balanced on a pivotal axis attached to the top. Then, varying loads will be added, and results will be documented using potentiometer readings. Then, virtually the same procedure will be performed using all 3 actuators. Adjustments will be made in programming until acceptable results are found.

Interfacing the previous steps will allow that the structural construction of the cockpit can take place, and then the previous tests will be performed on the fully constructed prototype. Varying tests described in the testing section will take place at this phase. Then, RF interfacing will take place to wirelessly connect the cockpit to the car, and prioritization testing will take place to determine how long and how frequently command execution is to take place. This part of programming will likely take place until completion of the project.

After meeting a significant milestone of the prioritization phase, examination of forces applied to the car will be tested based on motion will take place. Using output data from the USB port of the Netduino, without load or connection to the actuators, response due to X-Y acceleration will be documented. Once deemed desirable, the same will take place, using no applied load, to document actuator response to such values. Then, once desirable response is achieved, a load may be applied, and the same procedure will take place.

Once a desirable acceleration response, potentiometer readings from the car will be examined independently of acceleration response in the same manner, first using no load and only USB readings, then using no load and actuator response, and finally using a load. Once independent potentiometer readings are adjusted and verified, prioritization phase will take place again, and potentiometer readings will be integrated with acceleration calculations to give realistic response. Given that there is enough time, the same procedure will be done using an accelerometer to detect the pitch and roll (relative to the force of gravity) exerted on the car. Once these take place, will be needed.

7 - Project Prototype Testing

7.1: Hardware Test Environment

Testing the hardware is a very important phase of the project. There will need to be multiple configurations in which the hardware on the vehicle is tested in order to ensure the proper functionality of the hardware when the software is interfaces with it. The first and most basic set of information is the testing of each component by itself and collection the data needed to preform later tests. The battery will need to be completely charged and completely drained and the data concerning it must be logged. There will be a constant load applied at first and then after those statistics are logged the load will change and statistics will be gathered for the changed load. This test will need to be performed for both batteries involved.

Likewise the potentiometers must be tested on both extremes of their operation. With a constant voltage applied they will be extended and the compressed. The information concerning their whereabouts will be logged everywhere in between in order to adequately understand the readings that are to be expected with various distances of contraction and expansion. Another caveat to the potentiometers is the fact that they are also to be used as shocks for the vehicle. In that way it would be ideal if the potentiometers were partially compressed when they are only under the weight of the vehicle. The idea behind this would be to allow the potentiometers to react to the change in gravity acting on the vehicle based on the acceleration that the potentiometers are be influenced by After understanding the potentiometers the accelerometer will need to be understood. The accelerometer will be tested similarly to the potentiometers, however since the accelerometer changes based on orientation rather than a difference in length, there will need to be a system devised in which the orient the accelerometer and take readings. Because the accelerometer readings will not matter beyond a grade of 20 degrees, a simple platform that can be rotated about the accelerometer will work just fine. The accelerometer should be mounted to this platform, and rotated in order to receive various voltage readings. When the accelerometer is to be attached to the vehicle, it will be necessary for it to be oriented in such a way that the force acting on it due to gravity is only acting on one axis.

The transceiver will be mounted to the top of the vehicle at its highest point. This will be done in order to reduce possible noise that could be introduced by the various electrical components that will be used to operate the vehicle. In addition it will be wired up to the MCU in order to send and receive data. It will be tested by hard wiring a set of data into the input line and verifying that the output of the transceiver is that which was wired into it. The DC servo motor that will be used to control the vehicle when in motion will need to be securely mounted to the vehicle so that when activated the wheels can pivot in order to allow for radial motion when the vehicle is in motion. This motor will be tested by using a variable voltage DC power supply and applying various voltages across the servo. For the servo to be functioning correctly, it should move when the various voltages are applied. The DC drive motor will need to be mounted to the rear axle in order to allow the vehicle to be put into motion. This motor will also be connected to the variable DC power supply for testing purposes. Based on the voltage applied as well as the load, changes in RPM can be seen and should be noted.

After the vehicle is assembled in this manner it will be necessary to test the components with the MCU. This can be started by focusing on the potentiometers. With the MCU plugged into a computer, the necessary information can easily be extrapolated as seen fit by the individuals testing the system. The vehicle should be depressed all the way parallel to the two front wheels in order to fully depress the potentiometers. Assuming the readings are valid the vehicle can then be depressed on the back. The same can be done to the left and right sides of the vehicle. All information from the potentiometers should correlate with the information previously taken. Assuming this is the case the vehicle should then be manipulated in a similar fashion, however this time the vehicle is to be lifted, and the potentiometers are to be depressed, rather than compressed. This set of tests should give accurate information in regards to the potentiometer.

Concerning the next phase in the hardware test environment, the readings from the accelerometer should be taken. These readings can be measured relative to the compression and depression of the side of the vehicle. These results should closely coincide with those assessed previously concerning the accelerometer, and the approximate potentiometer readings should be able to be deduced based on this information. Just as before the servo motor and the DC drive motor must also be tested with the MCU. At this point the circuitry concerning the voltage regulation of the drive motor and the servo motor should be in place and the MCU should be able to control both motors.

In addition to testing all of these pieces and parts the transmitter and the receiver for the video feed will also need to be tested. The analog video feed should be connected into the transmitter and the receiver on the other end must be connected to a display unit. To ensure that this hardware is function as is to be expected, there should be a video feed that coincides with the position of the analog camera on the display unit. Verifying this will mean that the units are functioning in perfect harmony.

After the rigorous testing of the hardware for the vehicle it is now necessary to run through similar tests concerning the hardware that will be used for the cockpit. The voltage regulators that were designed for this purpose will be rigorously tested to ensure the proper functionality. In order to verify their functionality there will be a PWM signal applied via a function generator with a varying duty cycle. This duty cycle will need to be changed and the output of the regulator should be validated. After the validation of said regulators, it will be necessary to test the actuators that will be used on the cockpit. The actuators must be tested with and without the voltage regulators, and thus it should be easier to test the actuators after the voltage regulators have been tested. In order to test the actuators, in the first case they should be wired directly to a DC voltage supply. The speed and disposition of the actuators should be noted. The DC supply should be changed and the speed of the actuators under varying voltages should also be noted. Likewise after this has been accomplished for the actuator in the case where the voltage regulator is not tied into the system, it will also need to be tested in that case. Here the actuator will be the load that is applied across the voltage regulator that was designed for this case. The voltage regulator will be controlled with a PWM signal as it has been in the past and this information will be compared against the expected results that were obtained previously.

After the testing of the hardware components for this subsystem, the potentiometers that will be used on the cockpit will need to be tested. The cockpit will use both radial and linear potentiometers. The radial potentiometer will be used within the steering wheel. This potentiometer will need to be tested by changing the degree of rotation of the dial upon the potentiometer. The voltage readings will need to be taken in order to get an accurate idea of what range of rotation the potentiometer allows for. After the radial potentiometer has been tested it is now necessary to account for the linear potentiometers that will be used for the gas and brake pedals. The potentiometer will need to be tested with a voltage applied across the at their most and least compressed positions. As the potentiometers for the vehicle, they will also need to be thoroughly tested for the ranges in between. After the potentiometers have been tested and verified it will now be necessary to mount them to their desired locations and test the range of values that will be used. For the radial potentiometer it will need to be mounted at the base of the steering column to the rotating shaft that is connected to the steering wheel.

Just as the potentiometer was previously tested, it will need to be tested again. This time the testing will not be done by turning the dial, but by actually rotating the steering wheel. The values that are received from the maximum clockwise and counter clockwise rotations will be adjusted so that the center point of the turning lies at the center point of the resting steering wheel. Once this can been accomplished the brake and gas pedals will need to be manipulated. The pedals will need to be mounted where the potentiometer on the pedal will depress based on the pressing of the pedal. The readings will have to be logged at the maximum and minimum depression of the pedal as well as many points in between. This process should take place for both pedals.

After the pedals have been in place it will be necessary to mount the seat. The seat will sit upon a ball joint at its center that is connected to a spring loaded piston. The center point should be partially depressed at the mounting of the actuators. The actuators should be mounted at the positions specified previously. The actuators are not to be mounted until the software they are to be using is functioning as intended. At this point the actuators can be mounted and the hardware design of the seat can be tested. The software should cause the seat to move about the center point and the seat at any given point in time ideally should not be displaced along the Z axis. The software will vary the movement speeds as well as positions and measurements will be taken of the center pistons displacement. After verifying that the seat is functioning as is to be expected, the display unit should be mounted to the bracket located above the steering column. The display should mount appropriately and should be very secure. The display position will need to be logged and the comfort of the rider will be assessed at various display positions.

After each of the hardware components have been tested individually it will be important to test them as a system. This system for testing the hardware will need to be put into place after the software has been verified so that the idea of potentially breaking pieces of the hardware is not an issue. At this time the actuators will be connected to the MPU and the movement of the actuators will be closely analyzed.

7.2: Hardware Specific Testing

In order to adequately test the hardware on the vehicle, there will need to be a system of testing procedures devised on each subsystem, as well as each individual component, due to subtle changed in component specifications. To get an accurate metric of all the outliers the potentiometers, accelerometer, battery, DC drive motor, DC servo motors, voltage regulators, camera and transceiver must all be thoroughly tested.

In order to test everything thoroughly, the battery must be the first item to be tested. It will be ran through 5 full charge and discharge cycles with a constant draw of approximately 2 watts. This test will allow to verify the validity of capacity of the battery. After these cycles there will be a more realistic scenario and the power output of the battery will vary between less than 1 watt and 15 watts. This test will also be ran 5 times and the results will be recorded. Likewise the same set of tests will need to be conducted for the second battery. Assuming the batteries live up to the specifications given as per the manufacturer, the next steps can then be started.

The voltage regulator that will be used to control the DC drive motor of the vehicle will be a binary eight bit input for its values. This input will be changed for each of the 256 possible values and the output voltage readings will be recorded. For a number of intermediate values the output voltage will be zero. The readings for each intermediate point will be compared with the results obtained from the simulation and as long as the readings are correct it will be time to move on. The next voltage regulator will be the one that actually powers the MCU. As can be seen from section 4.1, this circuit has an output voltage of 3.3V. Because resistors in the real world have a variable tolerance, it may be necessary to slightly adjust the value of the load resistor in order to more accurately receive the 3.3V that is intended. The three voltage regulators that will be used for the transceiver, transmitter, and analog camera will all be black boxed, and thus will just need to be connected to a power source and verified.

The measurement of the potentiometers is very important. Now that the power supply for the potentiometers has been accounted for, these components can be tested. This test will be somewhat rigorous, as a thorough understanding of the restrictions of the part is very important. For each of the four individual components, the voltage across the potentiometer at the output current node will be measured. The maximum difference in position of the potentiometer will need to be divided by 20, as there will need to be many measurements between the max and minimum output reading. For each of these measurements the output voltage will need to be graphed with respect to the position of the potentiometer. This graph will need to be created for each potentiometer to ensure linearity and consistency. In addition these measurements are very important because the potentiometers difference in position will be sending a measurement to the Cockpit, so each set of measurements will need to be specific to each individual potentiometer.

Next on the docket is the measurement that is read from the accelerometer. The accelerometer in question has three axes, and therefore each axis will need rigorous testing. The accelerometer will need to be temporarily mounted to a platform whose, angle can be adjusted. The device will be test thought the extremes. In other words, the device will be position in such a way that the -Z axis will receive all of the force of gravity. The device will then be turned 30 degrees at a time about the X axis until it is once again resting at the -Z origin. The same process will be repeated about the Y axis. After this test the device will be placed with -Y as the origin and rotated about the Z axis for completeness. All of this information will then be used to formulate a table, so that the disposition of the vehicle can be determined by voltage output of the accelerometer.

The DC servo motor that will be used to control the turning of the vehicle will need to be tested next. As per their nature, they move a certain amount depending on the voltage applied. A voltage regulator will need to be used in order to control this part. To get an accurate understanding of the part, the off center angle of the motors spindle will need to be measured 20 times. These measurements will begin at the minimum possible input voltage and end at the maximum possible voltage. There center point will be the middle point of rotation, not in voltage, but in position. Ideally they will be very close.

The next order of business will be to test the MCU. It is very important that the MCU will properly interface will all of the parts in question. The first thing to do with the MCU is to become acquainted with all of the possible inputs and outputs. This will be accomplished by using the board to supply outputs and measuring said outputs. After becoming familiar with the ways in which the board outputs information it will be necessary to learn the idiosyncrasies with doing this. In addition this process will need to be repeated for inputs to the board. After becoming familiar with the board it will be necessary to wire up the transceiver.

In order to adequately test the transceiver there will need to be a sending and receiving board. After properly wiring up the boards to host the transceivers a sequence of binary digits will be sent from one board to another to ensure the proper functionality of the transceiver. In the case of the analog transmitter/receiver that will be used to transmit the data from the camera to the an off-vehicle display, it may be easier to test them synonymously. The transmitter will be wired up to the analog video camera, so that it will transmit its data over the air. The receive will be wired to a display unit. After tweaking the broadcasting frequencies a signal should be acquired at the display unit, allowing for the transmission of an analog video signal over the air.

The DC drive motor will be tested next. In order to test this, the voltage regulator discussed above will be used. The RPM of the motor will be graphed as a function of the voltage being supplied to the motor by the voltage regulator. This information will need to be taken after the vehicle is assembled because the stress put on the motor by the weight of the vehicle will drastically impact the graph. After the vehicle is assembled and running it will be necessary to take another assessment. This assessment will once again be base don the RPM of the motor in order to get an understanding of the upper and lower bounds of what this motors capabilities are.

Another sequence of test procedures will need to be run on each component of the Cockpit. This would include testing voltage regulators, actuators, potentiometers, the MCU and the transceivers. The voltage regulators that will be used in this case will be more heavy duty than those previously tested as they have been designed to sync 20 amps of surge current. Because of the amperage that needs to be synced through these devices it is very important to be careful when testing them. As an initial test, a simple resistive system will be used in order to verify the regulators function as intended. A PWM signal of 100% duty cycle will be used to begin with. Because of the design of the regulators, at this percentage of duty cycle the output of the system should be zero volts. The duty cycle will then be changed between 0% and 99% and the various output voltages will be logged. After this test, a single actuator will be connected to the regulator. The voltage will be changed and based on the load applied by the actuators, a graph can be formed to show the linearity of the system. There will need to be multiple graphs created that show the movement of the actuators over time relative to the voltage applied to them as well as the load applied. These graphs will be used later on in the process of programming the actuators.

The potentiometers that will be used for the steering wheel as well as the gas and brake pedals will be tested. The potentiometer used for the steering wheel will be a dial in which the variable resistance depends on the angular change of the device. This can be tested by starting at the lowest extreme. The potentiometer will be followed by a resistor to ground and then set at it lowest position. A constant voltage will be applied to the other end of the potentiometer and it will be rotated about its axis and the voltage on the node where the current leaves the potentiometer will be measured. There will need to be twenty measurements taken at increments of 12 degrees along the turning of the potentiometer. This information will be used later to determine the total amount the steering column is turned, based on the change in voltage across the potentiometer.

The potentiometers that will be used on the pedals will be slightly different. These parts will be linear potentiometers rather than angular ones. A similar approach will be used to find the extremes of this part. In this case however, the potentiometer will sit in its rest position which will be fully extended. The maximum change of distance of the potentiometer will be measured and the voltage across will once again be measured incrementally in order to find the range of the part.

After the steering column has been assembled and the radial potentiometer is mounted to the base of the column, the above measurements must be taken again. The angle at which the potentiometer will need to be adjusted so that the center part of the steering wheel lies on where it is to be expected. There should be at least twenty measurements taken from the steering wheel. Ten of those measurements should take place on the counter clockwise rotation, while the other ten should take place on the clockwise rotation. The information will need to be stored and the voltage reading that represents the center point should be taken into account as zero.

Just as the potentiometer for the steering column will need to be calibrated after it has been mounted, so will the potentiometers that are located on the brake and the gas pedals. After the pedals are mounted with the potentiometers in place, the pedals will need to be adjusted from the highest point in which there is no depression applied to them, to the lowest point where they are compressed as far as the user can push them.

In addition it will also be necessary to verify that the spring loaded pedal returns to the position of least compression. This simple task can be accomplished by reading the potentiometer then compressing the pedal. The pedal will then be released and the potentiometer should be read again. The final output voltage should match the initial output voltage. Now the display unit should be mounted to the brackets that have been designed to hold it. This unit should be securely mounted with no possibility of falling. This will need to be further tested when the cockpit is completely assembled.

After getting familiar with the MCU located on the cockpit, measurements and conversions will be necessary to account for inputs in a way that will be usable. As the MCU has already been tested sufficiently in the software portion, the hardware portion will be analyzing the control of the seat. It is very important that the the maximum angles in all possible situation are assessed. The most important components to test while the cockpit is in motion are the displacement of the actuators as well as the displacement of the center ball and socket joint that is upon the spring-loaded shock. With the current design it is very important that the actuator displacement causes a negligible change in the displacement of the center connection. This is because the center joint was not designed to actually displace, but rather to accommodate for any programming error in a way that will minimize the structural damage. The center joint should really just take the brunt force in the plane that is parallel to the ground.

7.3: Software Test Environment

In order to adequately test the software, it is necessary to create a hardware test environment that will allow for managed testing of the software. Going through the programming process for the vehicle step by step with altered hardware will allow for this. In the beginning stages of the programming process it is necessary to collect various data from the analog input pins. To test this portion of the software it will be essential to isolate these pins and to ensure they receive a structured input. In order to do this there must be a variable voltage DC power supply that will be tied to the input pins. The following diagram illustrates how this environment should generally be set up.

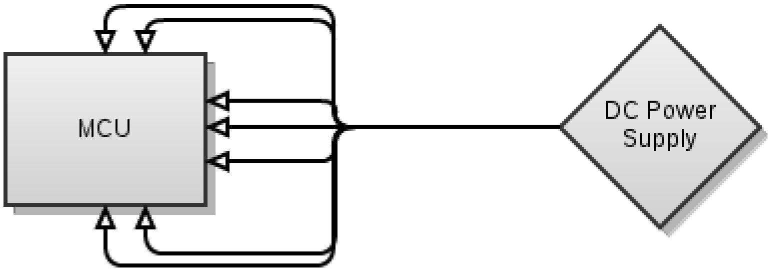


Figure 7.3.1: Input voltage software test environment

The same DC supply will be used for all of the inputs. This environment should allow for rigorous testing of the sensory collection data. The analysis of the data collected will need to be tested after the collection of data. That being said the same structure that has been described above will be used to test this section of code. Next on the chopping block will be the collection of data from the transceiver. This testing environment will be quite different from that which was written about above. It will be necessary to interface the MCU and the transceiver with another MCU and transceiver in order to adequately test the collection of data. This testing environment should consist of two MCU's, two transceivers, and an over the air connection between them both. The following diagram illustrates the environment.

Figure 7.3.2: Data Transmission Test Environment

This specific test environment comes in very handy because it doubles as an environment for the second MCU that will be used to control the cockpit. This environment can be used to not only test the software that deals with data coming in, but also to test the transmission of data. Another test environment that will need to be used in order to thoroughly understand how the MCU and the software is operating is the output of the device. This environment will need to consist of the MCU, two eight bit serial to parallel integrated circuits, two resistors, and sixteen LED's. Two of the digital outputs of the MCU will be attached to the serial to parallel converters. The LED's will be linked up to the eight outputs of each of the converters. The LED's will then be wired into a resistor that is then grounded. This system will allow for adequate testing of the output by changing the value to be written at each of the two pins.

In addition to testing the programming for the MCU on the vehicle, it will also be necessary to test the MCU on the cockpit. The MCU on the cockpit will receive input from a button that the user will press to initiate a program. Thereafter it will check potentiometer readings from the actuators, analyze the data received from the potentiometers, receive data from the vehicle, process this information, issue voltage commands to the actuators, make necessary data changes, and if the button is still active it will continue these operations indefinitely.

The environment that will allow for the testing of the button will be relatively simple, and should be the first testing environment that is created for the cockpit. One of the analog input pins will have the button wired to it, and then to a voltage. This will allow the user to test the software interface with the hardware in the event that the button is pressed.

After it is ensured that the button is working properly, it is now necessary to move on to the reading of the potentiometer values from the actuators. This testing environment will involve receiving readings from the potentiometers. These readings will be the voltage values across the potentiometers. In order to test these adequately it will be necessary to wire the MCU to a variable DC power supply. This testing environment will be the same process outlined above concerning the MCU on the vehicle, only this time the Netduino will be used instead of the MSP-430. As previously stated, the testing environment will mimic that of the MCU on the vehicle. Concerning the data that will be received from the MCU on vehicle, the transmission of data will need to be tested next. Once again the process for testing this data is as stated in the previous section and the transmission testing can be accomplished simultaneously.

When testing PWM signal that will be used at the output to control the actuators the use of an oscilloscope will be necessary. Unlike the analog to digital converter that will be used on the vehicle, this signal will be used to determine the voltage output based on the duty cycle of the waveform.

It will be necessary to take readings of the output and measure the duty cycle in order to conclude that the software is functioning as intended. After these measurements have been taken it will then be necessary to connect the MCU to the regulator that will be used to drive the actuators. The voltage outputs will be collected as a function of duty cycle and time and a representation of what the voltages will be to drive the actuators can be assessed. Assuming that the voltage readings that were gathered coincide with what is to be expected, an actuator can then be connected to the system

7.4: Software Specific Testing

In order to test the adequately test the MCU on the vehicle and the associated software, the test environment must be implemented. The first order of business is to incorporate the DC supply that was specified in section 7.3. The variable DC supply should be connected and give a voltage reading to the analog input of 6 volts. This 6 volt input should be taken in by the software and the values in memory should all be changed to 6 volts. In the case that any one value is not what to be expected, that portion of the software must be manipulated. After it has been seen that the values that are being taken in by the software are what is to be expected, the 6 volts must vary by +-1% until the value that is stored in memory changes to the new value. As stated previously this should take place at both plus and minus 4%. At the point in which the values change, the stored memory value should be approximately 5.76 for the minus 4% and the 6.24 for the case in which the voltage has gone up 4%. It should be checked that all of the locations in memory appropriately change based on the percentage change in the voltage at the input pins. Assuming these cases function as intended, the voltages should be varied between 3 volts and 9 volts and the places in memory where the information is stored should be logged with each changing value. The places where the voltages change should be logged in order to further investigate the behavior of the software. Likewise, all of the inputs should be disconnected and each individual input port should now be tested one at a time. When the values from this test are what is to be expected, it can be said with relative confidence that the software is functioning as intended.

After this information is validated it will be necessary to manipulate the output buffer to ensure that the information to be sent is what is to be expected. As the information is read, so shall it also be sent. Concerning the buffer the information should be stored as first the potentiometer in the front right (PFR) followed by the potentiometer in the front left (PFL) followed by the back two (PBR,PBL). The buffer should then contain the accelerometers readings from the Y,X and Z axis. (in that order) After validating this buffer by checking it for each of the changes listed in the above paragraph, the software is functional.

The next environment where testing is vitally important is the case in which the transceivers are used for input to the MCU and output to the MCU on the vehicle. In this testing environment it will be necessary to fill the output buffer with information that is meaningful to the programing. While the information will, in fact, be “dummy” information it must be in the format in which it is to be expected. This packet of information will be sent from the transceiver holding the information about the potentiometer sensors, as well as the information pertaining to the accelerometers current disposition. This information will be sent via the transceiver to the MCU located at the cockpit. After the information is interpolated at the cockpit and determined to be correct, nine more sets of different dummy information will be sent in order to ensure the correctness and stability of the connection. Likewise the MCU at the cockpit will now need to send information to the MCU on the vehicle. There will be ten different sets of information sent to the vehicle to once again ensure the reliability and stability of the system.

After the testing for the transceiver's has been completed, it will then be necessary to link the testing of the transceivers with the testing of the collection of the input. The input will now be collected from the variable DC power supply and placed into the buffer, at which point it will be transmitted to the MCU that is to be located on the cockpit. The DC supply should be individually connected to pins and their values changed in order to verify the validity of the output. In addition all the pins should be connected to the supply in another test instance to see that all the information does in fact change. The time delay that is noticed from the collection to the reception of data should be below 100ms. In the case that the delay is greater will mean that adjustments will need to be made to the transceiver, and the buffer may need to be filled with zero's in order to transmit the data as soon as possible.

The following test will need to be performed in order to test the control signals that will be used on the DC motors. As outlined in the test environment section, the output pins must be wired to a serial to parallel converter. The parallel outputs must be connected to LED's and resisted to ground. This will allow the user to put an output on a specific pin and verify its value by the illuminated LED's. A set of dummy information will be passed to the output for the first cases. The values between 0 and 256 will be placed on the output pin and the user will verify that the pins are illuminated correctly. Upon validation of this fact the user will then attempt to use the values that will be sent from the MCU on the cockpit. The software will now replace the dummy input with the input that is taken from the cockpit. Once again a large variety of values should be tested to ensure that the circuit is functioning as intended.

Following the testing of the software on the vehicle, it will be pertinent to test the software on the cockpit. As stated in the testing environment section the first and simplest task will be to attach a button to one of the input pins that is tied to a DC voltage. The program will start when the button is depressed and a voltage is applied to the pin. In order to test this, the user must press the button multiple times and ensure that when it is depressed the first time the program begins, and when it is pressed again the program ends. After the user is confident in the functionality of the button there will need to be tests performed on the actuator input. The readings from the potentiometers on the actuators vary rather significantly, and thus there must be a rigorous testing over broad voltage ranges. As stated the potentiometers will all be wired up to the analog input pins on the Netduino. In order to ensure the functionality the DC voltage should be varied from 0-12V. The program should read the values and place them in memory. Therefore this portion of the program should be considered valid if the values are properly stored in memory.

Following the testing of the input readings from the actuators, it will then be necessary to test the transceiver. The steps for this testing should mirror those above concerning the MCU on the vehicle. After confidence is ensure in both the potentiometer readings coming in, and the data coming from the transceiver, it will be evident that the actuator control programming need to be tested. The circuit that has been designed to convert the PWM signal to an output voltage will need to be used in this section on three different output ports.

Under normal circumstances the information from the potentiometers will actually be the information that is sent to the cockpit. However because this is the testing phase it will be necessary to send mock information to the cockpit. The MCU on the vehicle will be connected to a computer and the information for the potentiometers will be manually input. This will allow for changes to the actuators based on our user input, and thus allow for testing. Extremes, such as the front potentiometers completely depressed and the rear completely compressed will need to be taken. This information will be sent through the software on the MCU of the cockpit and the output should be as desired. The information sent from the vehicle to the cockpit in this phase should contain all extreme cases, as well as may more normal cases.

After testing the potentiometers it will be necessary to test the movement of the car. It is important for the software that controls the vehicles movement to work as anticipated. In this case the MCU on the cockpit will be connected to the computer and mock information will be sent to the vehicle. The information that will be sent should be based on the information that can be read from the radial potentiometer that will be housed within the steering wheel on the cockpit. This mock information will be sent to the vehicle and the DC servo motor that actuates the wheels on the front of the vehicle should pivot. The measurements of the pivoting of these wheels should be the same angular offset in both directions relative to the center point.

Since it has been ensured that the vehicle can turn, it will now be necessary to test the DC drive motor. At this point, the necessary information will be sent from the cockpit to the vehicle by way of a mock up program. The processor on the vehicle will need to receive this information and interpret it as intended by converting the information

7.5: Stress Testing

After performing the basic structural and software testing, it will be necessary to perform a set of stress tests on the system. These tests will include stressing both the cockpit and the vehicle. Concerning the stress test for the vehicle, it will be pertinent to control the vehicle as erratically as possible. Since the car has been tested in a controlled environment where the inputs are precise and expected, a more real world situation will need to be tested. The car should start from a stop and accelerate as fast as possible. After this test the car should once again start from a stop and accelerate as fast as possible, only this time the vehicle should turn. The vehicle should accelerate and decelerate as much as possible, as well as turn erratically in order to test a real world situation. All the while the movements should be recorded and they should coincide with the information that is being transmitted concerning the disposition of the vehicle. After it can be said with confidence that the vehicle behaves as intended with unexpected user input it will be necessary to then stress test the software and hardware that controls the cockpit.

The stress testing of the cockpit should be a rigorous time consuming process, as there will be people sitting in it and the safety of the occupant is of the highest priority. The cockpit should first begin with no load on the seat, and the input that should be given to the cockpit should erratic. The information that was collected from the vehicle should be streamed to the cockpit and the movements of the cockpit should mimic the movements that should be expected based on the vehicle behavior. After this basic test has been performed and it has been noted that the cockpit is functioning correctly, weights must be added to the cockpit. These weights will be added in increments of 50lbs until the 450lb total weight limit is reached. For each individual section in which weight is added the behavior of the cockpit should be analyzed to ensure that it is functioning as intended. One specific diagnostic to focus on will be the speed in which the cockpit is moving. Based on the programming for the control of the actuators on the cockpit, it is to be expected that the cockpit should move at the same speed regardless of whether or not there is a user, thus the cockpit should move the same speed when there are weights as it does when it is empty. These tests should be run for over thirty minutes in order to ensure that the cockpit does what is to be expected on a long simulation. After stressfully testing this portion of the project and verifying that the data collected coincides with the hypothetical data that has been established it can be said that the cockpit is functioning correctly.

Another factor to take into account is the stability of the display. The display should be fastened into place using lock washers in order to ensure that it should not be loosened during use. The bolts on the stand should be fastened securely before the following test. The cockpit should have no load on the seat and it should be taken through the tests previously outlined. After the test it should be ensured that the display is securely mounted. The information that was previously taken from the vehicles erratic behavior should be looped into the cockpit and the cockpit should run for ten minutes. After the ten minutes are completed the display mounting should be checked to ensure that it is still securely fastened. The next test should be thirty minutes of simulation. The final test for the display unit will be to have the simulation play for an hour at a time and be monitored.

The actuator control for the cockpit will now be temporarily disabled in order to allow for the control of the vehicle by way of the cockpit. The potentiometer readings from the pedals and the steering wheel will be transmitted to the vehicle and the vehicle will be controlled by these readings. The speed of data transport will be analyzed and assessed and assuming that the transmission time is adequate, this portion will be considered a success. The next stage of testing will be the stage that tests the real time simulation capabilities of the design as it pertains to the cockpit. The vehicle will be synchronized with the cockpit and the information that is sent from the vehicle will control the cockpit. The information that will be used to control the vehicle will be sent via a connection with a computer rather than directly from the cockpit in this testing phase. The motion of the cockpit should coincide to the motion of the vehicle.

Assuming the last test succeeded, it will be necessary to test the end-state in which an occupant of the cockpit actually controls the vehicle and experiences the feedback provided by the actuators. In this state the user will sit within the cockpit and control the vehicle. The feedback received from the vehicle should be experienced in a timely manner. In this testing phase there will need to be a wide range in weight of the riders in order to test the cockpit under various load conditions. After the variety of riders have completed their thorough testing of the cockpit and the information pertaining to each ride has been analyzed, if the information is what is to be expected than it can be said with confidence that the RC Ghost Rider is a success.

8 – Administrative Content

8.1 Milestone Discussion

To ensure this project is completed in a timely manner and to keep all members of the group informed of upcoming goal dates a “Milestones” chart is much needed. The first grouping of dates correspond with ordering, testing, and building the vehicle portion of the project.The first thing to be accomplished is to finish the project write up by December 2nd, this will allow for sufficient proof reading and binding time. The next is to submit the final edited copy by 12:00 pm on December 5th. The next is ordering all parts for the RC car and including the RC car. The transceivers and cockpits MCU will also be ordered at this time. On January 30th the testing of all parts will begin being logged to ensure components work as specified and expected and also as another faction of ensuring safety. February 5th is when the project starts to take form, that is when the RC car begins being assembled. The final date in the staging process is on February 15th when the actuators and other cockpit components are ordered. Below is the first grouping of dates important to making sure that the hardware is ordered and tested sufficiently before being integrated into the Cockpit and RC car.

•12-2-11 – Complete the documentation

•12-5-11 – Submit the final copy of the documentation

•1-1-12 – Order all necessary parts for the car, as well as the transceivers and the cockpit's MCU
•1-30-12 – Test all of the parts and log the info

•2-5-12 – Begin assembling and testing our design

•2-12-12 – Order the actuators and the various cockpit components

The next grouping of dates is geared towards fabrication of the cockpit and cockpit circuitry. On February 18th the car's circuitry will be finalized and either physically created or sent to be fabricated on a PCB. A week after that, the cockpit actuators will be tested in a controlled environment to once again ensure that they preform as expected under various loads. On the 28th of February the design circuitry for the cockpit will be tested under different loads making sure that they yield the expected/simulated outputs. Given that all circuitry performs as expected, on March 5th after extensive testing, the design circuitry for the cockpit will be finalized. On March 25th all testing on the singular components of the cockpit should be completed, compiled, and analyzed so that an end-state circuit board for the cockpit should be fabricated.

•2-18-12 – Confirm the layout of the car's circuitry, and get the PCB fabrication started.
•2-25-12 – Test all of the cockpit components and log the necessary information
•2-28-12 – Test the design circuitry for the cockpit
•3-15-12 – Finalize the design circuity for the cockpit
•3-25-12 – Create an end-state circuit board for the cockpit

The final grouping of milestones are primarily to ensure that the cockpit and RC car are properly interfaced and work well in conjunction with each other. On April 4th interfacing the cockpit and RC car will commence. Given that all components act as designed and interface with one another properly on April 15th, after two weeks of testing, there will only be fine tuning needed to ensure the cockpit acts as expected. During this portion, run time behavior will be logged and anomalous behavior will be identified, if there is any. During the week of April 20th said behavior will be identified and eliminated. The last week will be dedicated to adding the “finishing touches” to the project, ensuring it is aesthetically pleasing.
•4-5-12 – Properly interface the cockpit with the vehicle

•4-10-12 – Fine tune the cockpit to operate as intended

•4-15-12 – Log run time statistics and search for anomalous behavior

•4-20-12 – Track down and eliminate said behavior

•4-25-12 – Add finishing aesthetic touches

8.2 Budget and Finance Discussion

The budget is split into two portions, the RC Car and the Cockpit. The budget for this project is turning out to be somewhat of a hassle to stay within as is the case with virtually any project. It is crucial to stay within the milestones time line to make sure this project gets done in a timely manner. It is important to keep to the budget plan as close as possible so that there is no negligent spending which could inhibit buying all of the parts needed to complete the project Another concern is destroying or damaging parts such that replacement components must be bought. This could again impede the acquisition of parts needed to complete the project.

The portion of the budget concerning the RC car should be considerably easier to stay within compared to the cockpit. The RC car will not require a large amount of outsourced work to be done on it, while most of the cockpits construction will be done by a professional The most expensive portion of the RC car will be the PCB board fabrication which has an allotment of $100.00. The budget was created with the belief that the RC car would be built, but given recent developments will now be a store bought manufactured model. This means that the money intended for: 1 DC motor, 2 batteries, 4 wheels, 2 turning servos, and 1 chassis is equal which were all going to be implemented to build a one of a kind RC car will now be used to purchased prefabricated model. The total cost of the above listed parts is equal to $241.00 and it is expected that the RC chosen to buy will not be anywhere close to that value. This means that there is now more money available in the budget that can be used to buy higher quality components for the project or to buy back up ones with the notion that some will be damaged beyond repair and need replacement.

This project also requires one accelerometer expected to cost $5.00. The accelerometer will be mounted to the RC car and send information to the cockpit that is necessary for the actuator movement. Some of the unused money in the budget may go to buying the best accelerometer available. This may exceed the $5.00 stipend, but thanks to possible over estimations this may be a viable situation.

The information from the potentiometers and accelerometer will be sent to the cockpit by a transceiver. The transceiver in the budget was of mediocre quality and initially thought to cost $45.00. With the recent loss of a group member means this portion will now be black boxed so a set of previously made transceivers will be used and comes with a price tag of $90.00. The total amount for transceivers in both the cockpit and RC car portions of the budget was $90.00 ($45.00 for each). This will not create skewing of the budget however.

Another component of the RC car parts list is the camera. This project requires an analog camera of moderately high specifications. The camera should have a high resolution since the television monitor in the cockpit will be displaying the video captured by the camera and if there is low quality or grainy images it will dilute the simulation experience. The must also high a high transmission rate. If the camera doesn't then the driver will experience a lag in the video feed which would make the RC car harder to operate due to the video to not matching the actuator movement to be out of synchronization, which is the main focus of the project. The camera stipend is $20.The RC car budget is as shown below in figure 8.1.

RC Car

Parts	**Quantity**	**Price**	**Total**
Accelerometer	1	$5.00	$5.00
Potentiometers	4	$10.00	$40.00
Turning Servo	1	$20.00	$10.00
DC Motor	1	$40.00	$40.00
Battery	2	$65.00	$130.00
Voltage Regulators	3	$5.00	$15.00
RC Car	1	$35.00	$35.00

Mounting Brackets	5	$5.00	$25.00
MCU and Components	1	$30.00	$30.00
Transceiver	1	$45.00	$45.00
PCB Fabrication	1	$100.00	$100.00
Misc. Parts	1	$100.00	$100.00
Camera	1	$20.00	$20.00
		Subtotal	**$681.00**

Figure 8.1: RC Car Budget

There is a section of the budget titled miscellaneous parts and $100.00 is set aside for it. This was put in when the RC car was going to be built not store bought. Therefore from over estimations there is $125.00 or so that can be used for the project in any manner desired. The RC car portion of the budget is shown below to easier see that parts needed, quantity, price, and subtotal cost.

The cockpit portion of the project is where most of the worries lye with the budget. This is due to components necessary to complete the project design. Given the expensive nature of all the components and the limited budget the project must be completed on, there is no room to replace and part on the cockpit price list. In this section there is also some discrepancies with the parts needed in the list and the actual parts needed. This is again due to the budget being based on a previous cockpit design.

The budget calls for 10 ball and socket joints. It was previously thought that there would be five actuators that would move the cockpit, but the current design calls for only three. That means there only needs to be six of the same specifications, two per actuator and one over sized ball joint that s located under the cockpit seat. The six joints that are implemented in the current design are now heim joints as well. A quality heim joint made of 4340 Chromoly cost anywhere between $15.00 to $20.00. The means that the six heim joints will cost a total of between $90.00 to $120.00. The center ball joint will cost $75.00 That means the total cost of all the joints ranges between $165.00 and $205.00. Since there was $500.00 (10 joints at $50.00 a piece) in the budget there a sizable difference in the budget putting the project around $300.00 or so further in the black.

In the budget it states there is $1,000.00 that will be used to buy four linear actuators each costing $225.00 each. The current design only uses three actuators, so they are of higher power and this drove the cost up. The Servo City actuators that will now be used have a hefty price tag of $399.99, this means that the total cost of the actuators is $1,200.00. This is the only known under estimation in the budget and means somehow $200.00 has to be freed up to afford the new stronger actuators.

In this the biggest problem with the budget is that a slight oversight was made and there is no allotment for the 4340 needed to build the cockpit frame or any to pay the entity that cuts/welds/fabricates the cockpit. It is estimated to cost upwards of $1,200.00 and it would be impossible to build this project as described given the current budget. Amendments are being made so a new updated budget can be submitted to Workforce Central Florida in the hopes that they will give more funding than previously thought necessary to help complete the project. Below is the cockpit subtotal of the budget and the total price of the project. The cockpit budget and total cost is shown below.

Cockpit

Parts	**Quantity**	**Price**	**Total**
Seat	1	$95.00	$95.00
Pedals	2	$50.00	$100.00
Display	1	$100.00	$100.00
Adjustable Seat Platform & Mounting Brackets	2	$100.00	$200.00
Potentiometers	6	$8.00	$48.00
Steering Wheel	1	$45.00	$45.00
Ball and Socket Joints	10	$50.00	$500.00
Platform	1	$50.00	$50.00
Linear Actuators	3	$400.00	$1,200.00
Raised Platform	1	$95.00	$95.00
Transceiver	1	$45.00	$45.00
Fabrication	1	$200.00	$200.00
MCU	1	$80.00	$80.00
Misc. Parts	1	$100.00	$100.00
		Subtotal	**$2,858.00**
		Total	**$3,500.00**

Figure 8.2: Cockpit and Total Cost

8.3 Safety Discussion

A.) User Safety

In the interest of protecting irreplaceable assets, user safety is of primary concern in design of the RC Ghost Rider. Certain protocol will be strictly adhered to in all testing and leisure use of the apparatus. The rotational velocity of the cockpit will be adjusted by the MCU to ensure that no excess force will be applied on the operator, so that injury to the user by impaction due to the apparatus, or so that the user is not propelled out of the cockpit through thorough testing. The suspension from the ground on the cockpit will not be excessive, thus if the operator is to exit the cockpit, possible injury is minimal. Electrical components will be placed distant from the apparatus to ensure no accidental electrical discharge is to affect the operator, as it is a high current application. All wire is to be properly shielded to protect the user from electrical discharge. The electrical housing for the cockpit will be locked, so that the user cannot access it inadvertently. A three-point harness will be implemented in order to adequately restrain the user under stressful operating conditions. Persons under the age of 18 operating will provided with a helmet to wear.

It is the responsibility of the user to not wear loose fitting clothes or jewelry. Pregnant persons, people with high blood pressure, back problems, or are otherwise not medically clear to undergo heightened stressful situations are advised to not operate, and to do so take on all risks and liabilities associated with injury. Users under the influence of drugs or alcohol are strictly prohibited from use. Users are responsible for fastening the seatbelt, and persons under the age of 18 must wear a helmet in operation. People weighing more than are strictly prohibited 400 lbs, or less than 75 lbs risk injury. A person cannot comfortably fit in the seat, or the three point harness should not ride the vehicle, as they will risk injury. Persons over the height limit should not operate the vehicle, and persons under the height requirement probably can’t operate the vehicle anyway. Observers must stand a safe distance of 10 feet from the cockpit apparatus.

B.) Construction Safety

When working with high current applications, fuses will be used. Fire safety utilities will be on hand during all testing phases. Complete care and standard protocol in handling electrical components will be executed. The touching of high current components and wire will be strictly prohibited when voltage is applied. No operator will sit upon the actuators until extensive documented testing takes place, as discussed in the stress testing section (7.5).