University of Illinois at Urbana - Champaign
Department of Electrical and Computer Engineering

Green Retrievers

Final Report

Team 20

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Abstract

The goal of our project was to create an autonomous robotic vehicle that retrieves golf balls and is solar powered. The robot uses a front mounted camera to retrieve images up to 5 feet in front of the robot. The image is processed using a compact vision processor (NI CVS) and it identifies the nearest golf ball to the robot. Based on the position, the CVS outputs pulse width modulation (PWM) signals to two Hbridges which directs two front mounted motors to the ball. The entire system is powered via two 12V batteries. One battery is charged by a 5W PV panel while the other provides power to the robot. A power management circuit controlled by an Arduino switches the batteries when the one powering the system begins to run out of energy. We have succeeded in constructing all modules of the robot and met all of our initial requirements.

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1. Introduction

1.1 Motivation

Currently, most driving ranges implement multiple car sized vehicles that pick up golf balls on the range. There are three main disadvantages to this design. The first is that these vehicles are costly, usually at least $10,000. These vehicles are also gas powered and pollute the driving range which can cause discomfort for golfers. Finally, these vehicles require an operator to control. Our project was to construct a robot that addresses these three disadvantages

1.2 Objective

The goal of our project is to build a solar powered autonomous robot that picks up and stores golf balls. This robot would be used on golf courses and driving ranges. Our robot will use a camera that connects to a controller. The controller will identify the location of the nearest ball and direct two front motors to it. The ball will be picked up by a rotating wheel and stored in a container on the robot. This gives the added benefit of nonstop golf ball retrieval. The power system will have two batteries, one charging via solar panel and the other powering the system. A power management circuit will switch between the batteries when one is low without disrupting the power supply to the system. Another feature added to this robot is a ball counting sensor which detects the number of balls that have been collected and halts the robot once a specified number has been reached. Finally we have a manual disable switch that turns off both motors when toggled.

The benefits include ease to use, just flip a switch to begin retrieval. Many hours are saved due to autonomous retrieval. The robot is completely powered by green energy. The wear on the grass is also reduced due to using a much lighter vehicle. The robot also is able to retrieve balls in compact locations where a normal vehicle may not be able to reach. Finally, the robot will have a much less initial capital cost than current models.

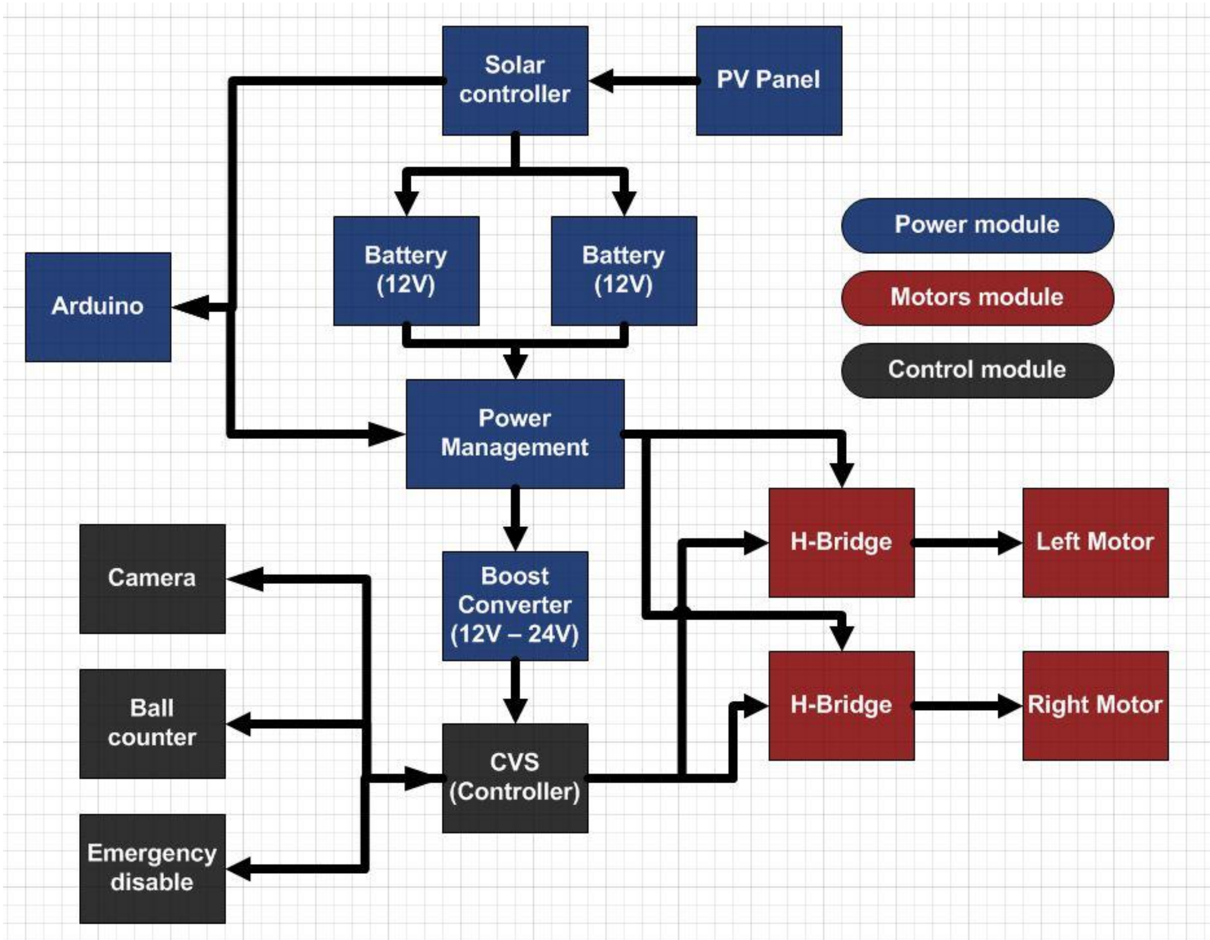


Figure 1 : Block diagram of electrical system

2. Design

The robot can be broken into four main modules. The mechanics module includes the chassis of the robot and the design of the pickup wheel and container. The control module includes the compact vision system which acts as the main decision maker in our robot. The controls module also includes the camera, ball counter and disable switch. The next module is the motor module. This includes the design of the 2 Hbridges and motors. Finally, the power module contains the solar panel, batteries, power management circuit and the arduino which controls the system power.

2.1 Mechanics module

2.1.1 Robot structure

Originally we planned to build this robot completely out of plastic, specifically high density polyethylene (HDPE). This would provide a high strength to weight ratio and the pieces can be easily machined. The preliminary 3D CAD model is shown in Figure A.1. Ultimately we decided that wood would be a better alternative, this is because wood is more easily machined, not as brittle, and can be bought at a much cheaper price. Figure A.2 shows the initial wood model with two levels of wood. This was to provide a larger area for placing components but we decided it was unnecessary and too complex. The final wooden model is shown in Figure A.3. This provides enough area to fit all the electronic components and is very simple to construct. Another benefit is that the container is next to the pickup wheel where the balls come out. The structure was built with help from the machine shop and the product is shown in Figure A.4. Initially we went with a three wheel design, the 2 wheels in front would be powered by 2 motors and we would use differential steering to maneuver. The third wheel in back would pick up the golf balls while the robot is moving. When we finally tested this design, we quickly found out that the robot was unable to turn without the pickup wheel slipping. We decided to add two castor wheels to the back of the robot while positioning the pickup wheel about a centimeter off the ground. This would prevent the pickup wheel from contacting the ground. To rotate the wheel we decided to drive it using a sprocket driven chain drive that connects to the front right motor. This kept the wheel turning whenever the robot was in motion and allowed for it to maneuver much easier. The final design is shown in Figure 2.

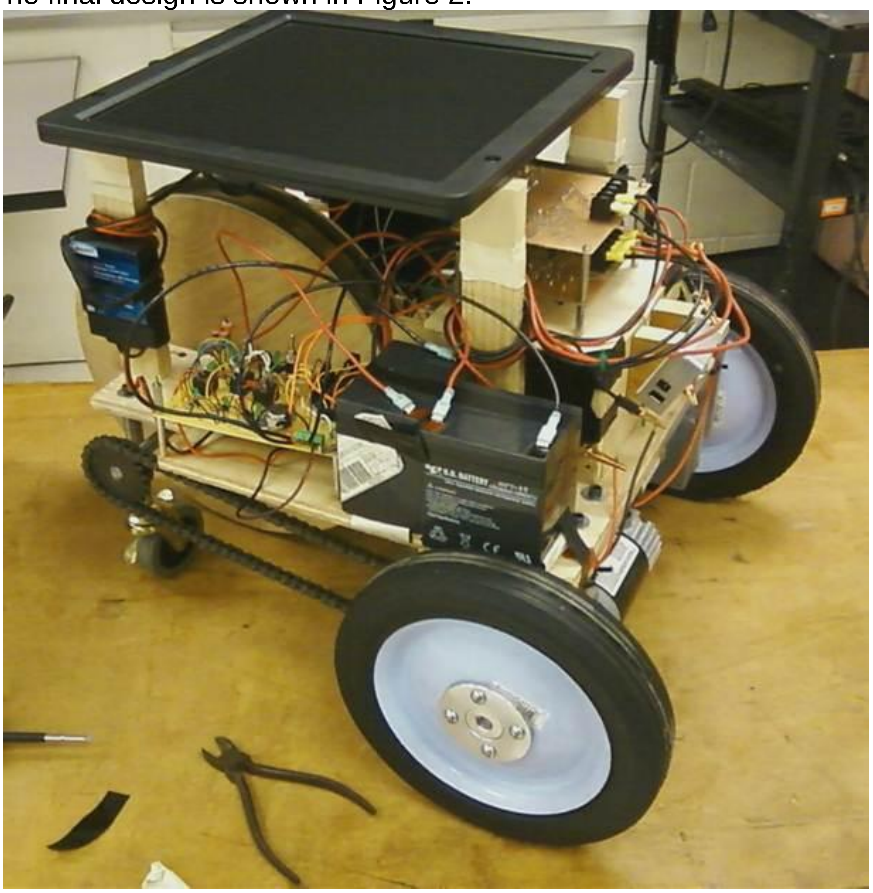


Figure 2 : Final mechanical design

2.1.2 Pickup Wheel

The CAD model for the pickup wheel is shown in Figure A.5 and the wooden structure is shown in Figure 3 below. The distance between the two wooden wheels is 2 inches which provides enough clearance for golf balls(1.68” diameter) and the diameter of the wheels are 14”. Surrounding the inner circumference of the wheels is a thin flexible film where the golf balls fit through when they are rolled over. There are 6 L shaped brackets positioned in the inner radius of the wheels which are used to lift the golf balls up while it rotates. When at the top of the wheel, the golf balls land on a thin inclined surface protruding into the wheel. The golf balls are then pushed through the flexible film via the L brackets intersecting with the inclined surface. Once out, the golf balls roll down the inclined surface, over the ball counter and into the container.

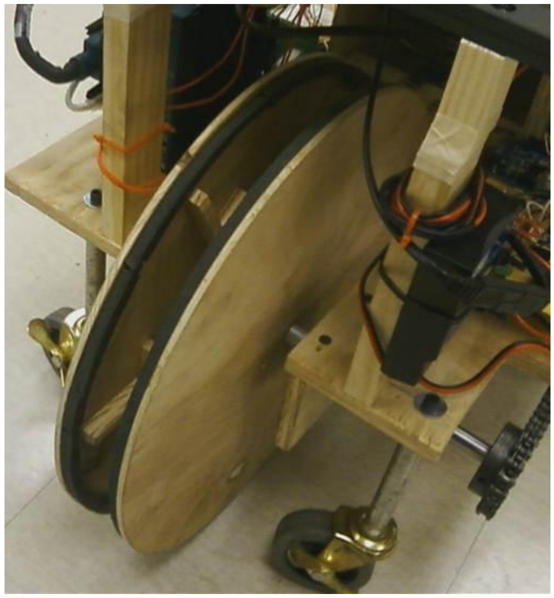


Figure 3 : wooden pickup wheel

2.2 Controller Module

2.2.1 Camera

The camera purchased is a Fire-i digital camera. It has a max fps of 30 and a resolution of 640x480. The camera communicates with the CVS (compact vision system) via a FireWire connection. It is positioned at the front of the robot about 10 inches off the ground and at a 60 degree angle w.r.t the horizontal plane. The camera can locate balls between 6” and 60” in front of the robot.

2.2.2 CVS (main controller)

The CVS (compact vision system) acts as the main controller to the robot. It retrieves the image from the Fire-i camera and processes the image to determine where the nearest ball is. It then outputs two PWM signals to the two Hbridges of the front motors. It also receives data from the push button ball counter and counts the number of balls that have been collected. Finally, the CVS receives an input from the manual disable switch indicating to shut off the motors.

The image processing flowchart is shown in Figure 4 below. The image processing is done through LabVIEW vision assistant. The image received from the camera is a 640 x 480 grayscale image. By not using a color image, the fps can be increased from 2.5 to 5. Next, a threshold grey scale value from 0 to 255 was used to split the image into binary. This will split the image into a red/black image shown in Figure 4 step 2, the black image is the background and the red images are the golf balls and unwanted noise. The final step is to fill in gaps and holes within the circles and to filter out all blobs with areas greater than the maximum ball area and areas smaller than the minimum ball area. Next, the centroids for the remaining shapes are found and the pixel coordinates for each object is outputted as a matrix. The closest ball corresponds to the centroid with the lowest horizontal pixel based on the orientation of the camera. Once the nearest ball location has been identified the x coordinate is used to decide which direction to move the robot. Initially the direction algorithm was very complex and changed with every different x and y location. This was an unnecessary complexity as it can work just as well with 4 distinct states. The first state is HALT, this sets the PWM for both motors to 0%. This state is triggered when the disable switch is flipped or if the maximum number of balls stored has been reached. The second state is to go straight which sets both PWMs to the same value. This occurs when either no ball is found or if a ball resides in the middle half of the image. The third and fourth states are turn left and turn right respectively. This is achieved by setting one PWM higher than the other depending on which way you want to turn. When the ball is in the left quarter of the screen the robot turns left and vice versa for the right quarter. This code was implemented in LabVIEW using the function block shown in Figure B.1. The input signals are shown on the left and the output signals are on the right, Table B.2 explains these signals in more detail.

Figure 4 : Image processing flowchart

2.2.3 Ball Counter Sensor

The ball counter sensor was placed in the storage container after the inclined ramp from the pickup wheel. Figure B.3 shows the design with the push button under the plastic panel. one side of the push button was connected to a +5 voltage output from the CVS and the other was connected to a TTL(Transistor Transistor Logic) input of the CVS. When a ball rolls over the button it completes the circuit and causes a high signal to go into the TTL input. This is read by the CVS and increments a counter. When the counter reaches the maximum number of balls, the HALT state is triggered. Detailed LabVIEW code is shown in B.1 and B.2.

2.2.4 Disable switch

The disable switch is simply a toggle switch with one side connected to a +5V output from the CVS and the other side connected to the second TTL input of the CVS. The signal is read from the input and the HALT state is triggered when the switch is toggled. Disabling the robot also causes the ball counter to reset. Detailed LabVIEW code is shown in B.1 and B.2.

2.3 Motors module

2.3.1 Hbridge

The Hbridge is necessary in order to interface the microcontroller with the motors. This is done in order to isolate the controls from the consumption of the power. In order to take the signals from the controller and adapt them such that they are usable by our power bridge we will use a HIP4081A. The HIP4081A is a high frequency full bridge n-channel fet driver. This allows for the power mosfets in the power bridge to be correctly bootstrapped and adds an extra element of protection to ensure that the power bridge does not create any shorting conditions (shoot-through conditions). Going from the fet driver to the power bridge as seen in the wire schematics in Appendix C.2 it is clear that the system is designed with a modular interface in mind. The Hbridge and motor control system is able to take in PWM signals which can range from 3-12V (Modified TTL) and allows for future expansion and the ability to use a range of logic voltages. The design of this Hbridge also allows us to have varied battery voltages if different motor conditions were chosen. As stated in [4] the HIP4081A can source approximately 1A from each pin there are measures taken in order to limit the current by use of a gate resistor. This reduces the heating of the chip and limits the gate current to something more reasonable. One large issue with motor controller design is flyback voltage from repeated cycling of voltage to the motor. To help with this issue of large negative flyback voltages at the motor terminals flyback diodes are attached to clip the voltages and protect the mosfet reverse voltage threshold.

The actual control of the motor is done in a way as described by Table 1. This method allows us to implement the functions of Forward, Reverse, and Disable for each of the motors. This paired with the concept of PWM and duty cycle we are able to effectively control speed, direction, and braking.

Table 1 : Control Signals

CONTROL SIGNALS					
	AHI	**BHI**	**ALI**	**BLI**	**DISABLE**
FORWARD	PWM	0	0	1	0
BACKWARD	0	PWM	1	0	0
DISABLE	X	X	X	X	1

We have specified that the Hbridge should be able to operate at full 100% duty cycle without causing harm to the motor or heating beyond 40^{o}C. Duty cycle is the ratio of the duration of the event to the total period.

The mosfet driver circuit has been created as a schematic then tested on a protoboard. The mosfet driver and header schematics shown in Appendix C.3-4 appropriately bias the driver for the PWM function. The mosfet driver must be given 12Vdc to be able to output the correct signals to the power bridge and to correctly bias the mosfets within the power bridge. These diagrams also have other safety features to limit the current being drawn from the drivers as well as the inputs to the circuit. The schematics were put into effect in the creation of the PCB's(Printed Circuit Boards).

The schematics were compiled to create a condensed version of each Hbridge into one PCB layout. These layouts were done in Eagle and were designed to simplify and maximize the efficiency in wiring. The boards were laid out on the computer and manufactured to create two identical Hbridge units to be used on the left and right motors. The Appendix C.10 shows the PCB layout schematics.

2.3.2 Motors

A weight and torque investigation were completed in appendix C.9 such that we were able to accurately define what motors were necessary for this application. Luckily the Dayton Motors (1LPV3A x2) from the laboratory perfectly fit the requirements in which we had laid out. The motors take in 12 Vdc which aligns well with the available sources of power. Other options were pursued however from the weight investigation and speed of the motors the motors proved to be an ideal fit for this unit.

Figure 5 : DC Motor Specs

The voltage of the motor coincides well with the standard value of lead-acid battery that will be necessary as well as the standard PV (Photovoltaic) voltage increments on the market.

2.4 Power module

2.4.1 PV panel

The PV solar panel is a 5 watt trickle charger solar panel, the main factors for choosing this panel is directly related to the physical real estate of our robotic unit. The 14'' x 13.1'' solar panel will match the basic size of the chassis. It is the core element for our green energy source of our project. Considering the portability of the vehicle, a bigger solar panels will not match our system while a smaller panel will not allow for the power generation necessary to charge the system. Therefore, we found a balance between those two considerations.

2.4.2 12V battery

Two 12V rechargeable sealed lead acid batteries will be used in this project. The batteries will be the power source for the entire system. They will be able to be recharged through the use of the solar cells as well as through a power outlet. Since a battery cannot be charged and used at the same time, we require at least 2 batteries, one to power the system and one to receive power from the solar panel.

2.4.3 Battery Controller

The battery controller works functionally as a protector, it regulates the voltage from the solar panel to protect the battery from being overcharged.

2.4.4 Power management Circuit

SPDT Dual Relay

A relay is an electrically operated switch used to isolate one electrical circuit from another. In its simplest form, a relay consists of a coil used as an electromagnet which opens or closes switch-contacts. Since the two circuits are isolated from one another, a lower voltage circuit can be used to trip a relay, which will control a separate circuit that requires a higher voltage or amperage. Relays can be found in early telephone exchange equipment, in industrial control circuits, in car audio systems, in automobiles, on water pumps, in high-power audio amplifiers and as protection devices [5].

NPN β=100 Transistor

The transistor will manipulate the relay's function, and it is controlled by the Arduino microcontroller. When we want a relay on, the arduino outputs a "High" signal to the BJT, which is five volts in our design. Then the current flowing through the coil within the relay would be seen when the BJT's input is high. The relay would be completely controlled by the arduino microcontroller which could be pre-programmed.

Voltage Regulator

The Arduino microcontroller works on 5 Volts; therefore, we need a voltage regulator which could output 5 volts continuously when its input is the 12 volts from the batteries.

Current Sensor

A low current sensor is used in our system. It measures the current flowing from solar panel to the battery which would be charged. Since we used a 5W, 12V solar panel, the current flowing from it is smaller than 1 Amp , therefore, a low current sensor would bring us more accurate results. Since the arduino analog input could only measure the voltage signal, this device converts the current signal into a voltage signal which perfectly matches our requirement. Meanwhile, a voltage measurement would also be applied in the charging battery side such that we could obtain the power charging data easily.

Circuit explanation

The power management circuit is shown in Appendix D.1. We assume battery one is being charging by the solar panel, and battery two is used for the system initially. Since the relay "COM" terminal would be initially connected to "Normally connected" (NC). And when the coil of relay is applied by 12 Volts, the "COM" terminal would be connect to "Normally opened" (NO).

Table 2 : Relay operations steps

	Relay operation steps				
Battery on Low Battery two High	Relay 4 on	Relay 3 on	Relay 1 on	Relay 2 on	Relay 4 off
Battery on Low Battery two High	Relay 4 on	Relay 2 on	Relay 1 on	Relay 3 on	Relay 4 off
Battery on Low Battery two High	Shut down the system and wait for battery to be charged by the solar panel				

When the robot is working, we don't want the system to shut down when the relay switches between the two terminals. As the relay operation steps shown in Table 2 are implemented, the battery that is charging would then be connected into the circuit first, then the solar panel would be switched to another battery to start charging, which is controlled by relay 1. Finally, the battery used would be removed from the circuit. By this design, both batteries would be connected into the circuit in a moment to avoid a system shut down situation.

We could notice that relay 4 would be connected into the system before each case of the switching operation, there are two diode connected after the current following from the relay 4. The reason we put the diodes here is because in the switching operation, when the two batteries are connected into the circuit,and if the two diode are not connected into circuit, the current would flow from the battery with higher energy into the one which is of lesser energy. The diodes consume power, so we would short it when the switching operation is not being implemented.

2.4.5 Arduino UNO

The arduino is the brain of the entire power management system. It is powered by 5 volts from the voltage regulator, and the analog input can measure the voltage condition of the battery which is being used for the system. It means the battery powering the system without extra source for arduino. We set the lowest voltage limit of switching implementation to 10.5 volts, which is the safest value for different current situations. It is known that if the voltage of the battery drops below 10.5 volts, the battery may only have a few minutes of battery life left. When the arduino senses the system voltage hit the limit, then it would implement the switching operations as shown in Table 2.

3. Verification

3.1 Testing Procedure and Quantitative results

3.1.1 CVS

Testing the CVS was done through LabVIEW. A laptop connected to the CVS via an ethernet cord and LabVIEW code was transferred to the CVS to run. The front panel labVIEW display shown in B.4 could be seen through the laptop and showed the calculations made by the CVS. The first requirement was to locate 90% of the balls in the FOV. This was achieved by placing multiple balls in front of the camera. The number of balls was then displayed on the front panel under the “number of balls” label in B.4.

The next requirement was to locate the nearest ball 100% of the time. This was done by placing the balls in different locations and observing the change in the “x” and “y” labels on the front panel. These gave the pixel locations of the closest ball and we verified that these values correctly identified the closest ball.

The CVS was also tested to output the correct PWM signal to the Hbridges. This was done by observing the values of the “Ld,Lw,Rd,Rw” which correspond to the width and delay of the left and right motors. We placed a ball on the left side of the camera and observed Ld increase and Lw decrease while Rw increased and Rd decreased. This meant that the PWM being sent was moving the right motor faster then the left which indicates a left turn. The same was done by placing a ball in front of the camera and to the right.

The final test was trying to increase the fps until it reached 5. The fps can also be seen in the front panel under “frame rate”. By using the grayscale image from the camera instead of a color image, we managed to double the fps from 2.5 to just above 5 which satisfied the requirement.

One set of requirements that was removed from the design was the transfer of power data through an RS232 from the Arduino to the CVS. Ultimately we determined that this was unnecessary because we were not going to display the power data on an LCD screen. The arduino was also capable of handling the power management decisions on its own without the need to interact with the CVS.

3.1.2 Sensors

A requirement/verification that was added since the design review was the two sensors, the ball counter and the disable switch. The disable switch was tested by hooking up the switch to the CVS, the LED labeled disable on the front panel turned on when the switch was toggled and the PWM outputs measured from an oscilloscope went to 0V. The counter was tested by pressing the push button switch and observing the “ball count” display on the labVIEW front panel. By pressing the push button multiple times we observed the ball count number grow. When it reached the maximum ball count, the PWM’s measured by an oscilloscope went to 0V. An important note is that we were unable to get the golf balls to trigger the push button when it rolls over it. Despite this mechanical problem, the push button still worked as intended.

3.1.3 Battery controller and power management

To validate the charge controller functionality, we measured the voltage output and compared this to the requirements which is between 11.8V and 12.2 V. Then, we added LEDs in series with the Ic on each BJT to test if the switch works when 5V inputs is given to the BJT.

To test if the switching operation functions correctly, we connected the Battery terminals to power supply and adjusted voltage input from 12 Volts to 10.5 Volts. In response we see the LEDs on or off as described in table 2. If the switching operation works correctly, we know requirements for “circuit maintains the voltage to the system while the switching implementation happens”. All the voltage sensor values and current sensor values could be viewed from arduino software on the computer display. We could save those values for future work. When we connected all the rest parts to the power management circuit, if the motors move, both the arduino and boost converter power LED is on, we know the circuit give correct voltages to the rest of the robotic unit.

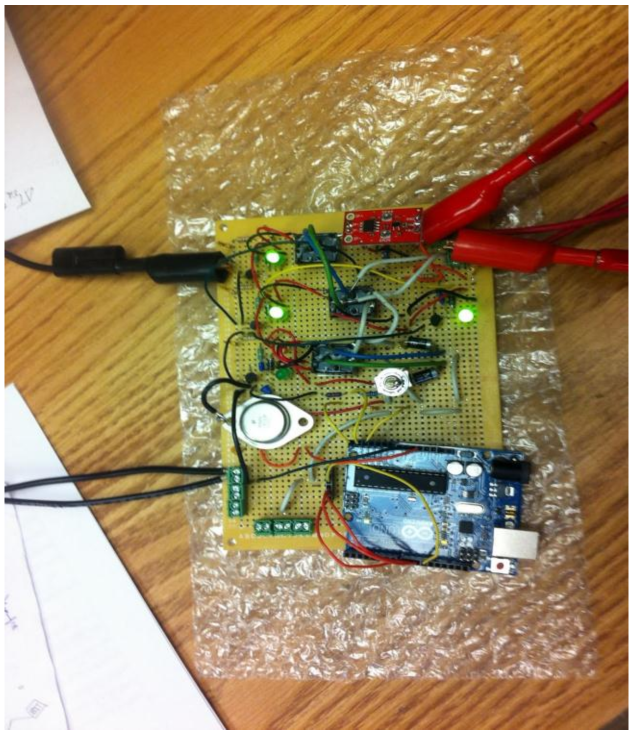


Figure 6 : Power Management Testing

3.1.4 Motors and Hbridge

Power Bridge Construction
Construction of the power bridge was a step in the verification so that the prototype and PCB layout of the Hbridge were found to be logically equivalent. The inputs and outputs were tested with continuity tests and input-output logic.

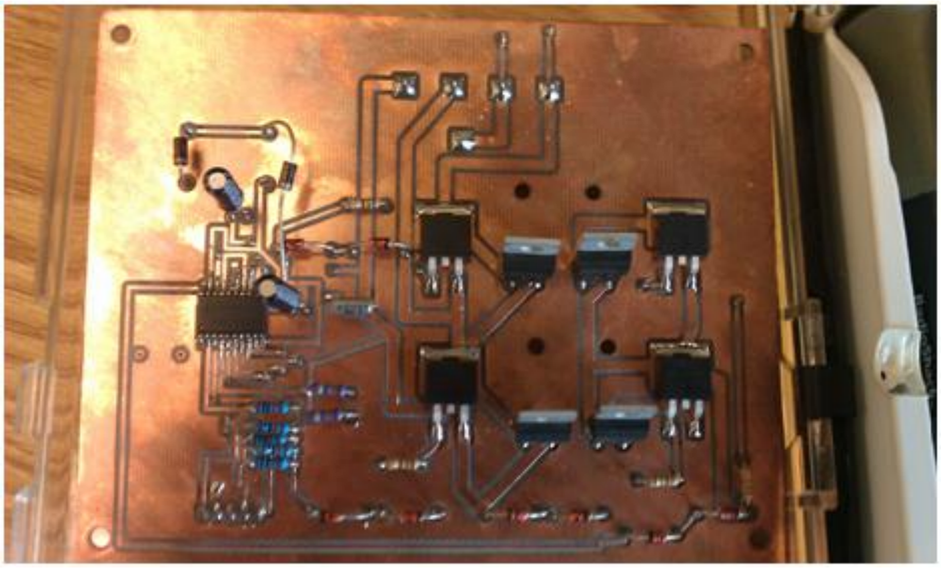


Figure 7 : HBridge Construction

DC Motor Temperature Testing

Testing has been completed on the motor to validate the requirement 4d in Apendix E.1 such that the motors do not heat to above 40^{o}C compared to ambient temperature. In order to complete this testing we used a thermocouple attached to the motor casing as shown in Appendix C.6. Data was taken from this testing and is shown in Table C.1. and plotted in Figure C.7. The temperature of the room was 22.3 ^{o}C taken previous to the experiment. The maximum temperature in testing was 31.90 ^{o}C. This is well within the 40^{o}C above ambient requirement.

PWM Hbridge Testing

Testing was completed to determine the best operational frequency to determine the characteristic of the CVS output waveforms. The Hbridge was set up to receive inputs of 12Vdc and the signals were set that the motor was in the forward orientation. The AHI signal was fed PWM from the function generator and the BLI was given 5Vdc. The output waveforms were determined audibly and through the oscilloscope. The output is given in the figure 8 below. We found that 1Khz was an acceptable frequency that could be output from the CVS and safely operated on the Hbridges. This is the frequency used for all subsequent testing and demonstration work. The temperature for the motors and Hbridge were determined quantitatively to be within scope (nominal heating) and the ripple was determined to be acceptable in terms of actual motor performance.

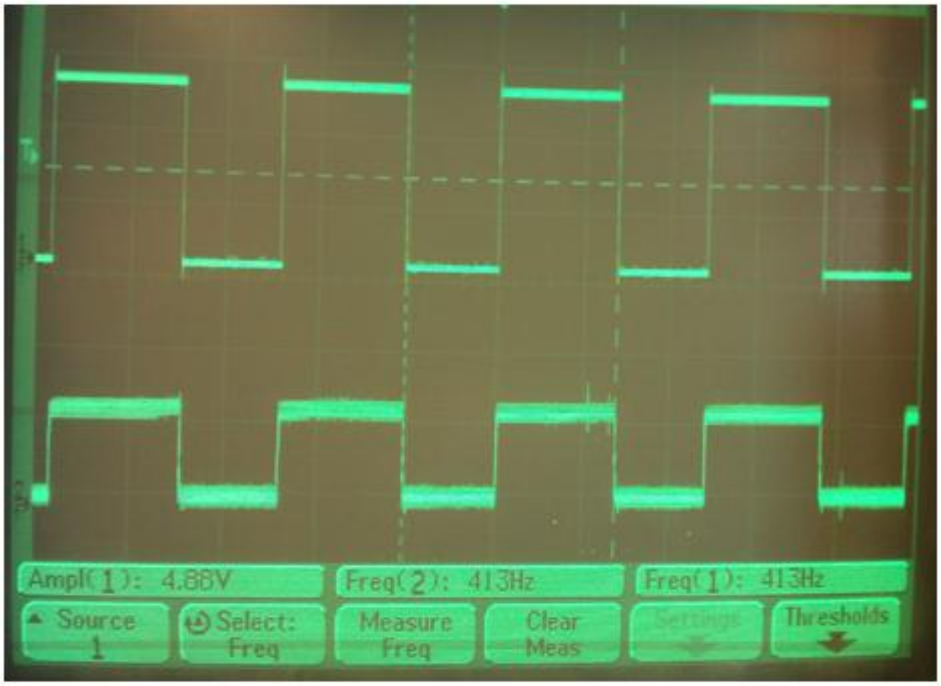


Figure 8 : PWM output waveform

3.2 Discussion of Results and Failed Verifications

All of our requirements and verifications passed when tested. Since all individual modules passed, we were able to test the system as a whole. We placed balls on the ground and the robot was able to navigate to them and pick them up. While in operation it also switched batteries when the one powering the system was low. The success of the system as a whole indicated the success of all modules

4. Costs

4.1 Parts Cost

Table 3: Main parts list

Part	Quantity	Unit Cost ($)	Total ($)
NI CVS 1456	1	4409.00	4409.00
Fire-i digital camera	1	98.00	98.00
Golf Balls	30	0.75	22.50
Wheels and Hubs	2	25.00	50.00
Motor Coupling	2	20.00	40.00

Wooden Frame/Parts	1	90.00	90.00
Solar Panel 5W	1	50.00	50.00
Charge Controller	1	20.00	20.00
12 V Battery 5AH	2	20.00	40.00
Boost Converter(12V-24V)	1	24.00	24.00
Arduino	1	30.00	30.00
		Total:	4873.50

Table 4: power management circuit parts list

Name (Part No.)	Description	Quantity	Price/unit ($/unit)	Price $
255-1852-ND	SPDT Dual Relay	3	$5.12	$15.36
6.62Kohm Resistor	Resistor	4	$0.10	$0.40
5 Kohm Resistor	Resistor	2	$0.10	$0.20
10Kohm Resistor	Resistor	2	$0.40	$0.80
1N5820	Diode	2	$0.30	$0.60
LM323K	Linear Regulator	1	$0.50	$0.50
.1uf 50V Cap	Voltage Regulator Cap.	1	$0.50	$0.50
NPN Transistor	BJT	4	$0.50	$2.00
			Total	$20.36

Table 5: Hbridge parts list

Name (Part No.)	Description	Quantity	Price/unit ($/unit)	Price $
Dayton 1LPV3A	DC Motor	2	$208.00	$416.00
HIP4081A	Fet Driver	2	$3.50	$7.00
Power Mosfet	PowerFet	8	$2.50	$20.00
Zener Diode 15V	Zener	16	$0.15	$2.40

1A 100V Diode	Source Return Diode	4	$0.80	$3.20
1N3661	Silicon Power Rectifier	8	$0.30	$2.40
1.0uF 50V Cap	Source Return Cap.	6	$0.50	$3.00
.47uf 50V Cap	Voltage Regulator Cap.	2	$0.63	$1.26
10kohm Resistor	Resistor	12	$0.04	$0.48
14kohm Resistor	Resistor	2	$0.10	$0.20
90.9kohm Resistor	Resistor	2	$0.10	$0.20
150ohm Resistor	Resistor	8	$0.10	$0.80
249kohm Resistor	Resistor	4	$0.10	$0.40
Board-misc		1	$8.00	$8.00
Terminal connectors		2	$1.00	$2.00
Headers		2	$1.00	$2.00
			Total	$469.34

4.2 Labor Cost and Total Cost

Table 6: Labor Cost

Name	Rate	Hours	Hours*2.5	Total ($)
Jonathan Hall	$35.00/hr	240	600	$21,000
Diyang Qiu	$35.00/hr	240	600	$21,000
Kevin Dluzen	$35.00/hr	240	600	$21,000
			Total:	$63,000

Total cost = Labor + Parts = $63,000 + $5363.20 = $68363.20

5. Conclusion

5.1 Accomplishments

The product of the months of work and effort has allowed this project to satisfy all requirements set out at the beginning of the semester. This robot is able to correctly identify golf balls in its FOV, determine a path to the ball through the CVS and correctly output PWM signals to the 2 Hbridges. The Hbridges send the correct power to the motors based on these PWM signal and don't overheat. The motors themselves navigate through different terrains including short grass and tile floors. The structure of the robot can support the weight of all components and has enough space to place all components comfortably. The pickup wheel was also a success in that it could pick up most balls in its path. Finally, the solar panel and power management circuit correctly routes the power to the system and switches batteries without interrupting operations. All in all our project for a prototype of a pv autonomous golf ball retrieving robot has been accomplished.

5.2 Uncertainties

There are a few uncertainties with the final working prototype of our project. There is much work to be done to refine the golf ball counting mechanism. Also, the accuracy and algorithm of output pwm to motors must be refined to correctly pick up the ball with the highest efficiency. We were also unable to have our robot move accurately in tall grass. In order to improve this, more powerful motors could be used and the weight of the system could be reduced significantly by optimizing all our components.

5.3 Ethical Issues

Ethics is an important concern when designing an autonomous robot. As stated in the IEEE code of ethics[3] engineers must "accept responsibility in making decisions consistent with the safety, health, and welfare of the public". Our device has an emergency disable switch that halts the motors in emergency cases. However, because our vehicle is autonomous, there is no human supervision. Our robot is not able to detect humans or animals and currently has no way of stopping when it collides with a large object. From our calculations, we have determined that the maximum momentum of our robot will not harm or knock down the average human adult. This study was furthered by investigating the pressure needed in order to puncture the average human skin, which was found to be approximately 450 psi. Using the assumed weight calculations in Appendix C and the puncture threshold previously stated, it would take 450 lb of force on a contact area of approximately 1 square inch. Given the shape of the robot and the maximum speed of approximately .5 mph this cannot be achieved (given that extra care is given such that the contact area remains at an acceptable level by using rounded edges and beveling).

5.4 Future work

Many improvements can be made to the search algorithm of the robot. It can be made to only search in a designated area or it can circle around if no ball has been detected for a period of time. Also, a ball collector station can be constructed where the robot goes to dump a full container of balls instead of just stopping. Obstacle avoidance is another improvement that could be made in order to make the robot safer in public areas. Also, as stated earlier, by reducing the weight and using better motors we would be able to run the robot in different terrain environments including sand and grass. Using this robot underwater could also help in retrieving golf balls hit in lakes. This would require a water resistant casing to protect the circuits and the addition of propellers to navigate the lake floor. We may also require defenses to protect against large fish.

6. Citations

[1] Wxman81. "Lawn Care Forum." Web. 21 Feb. 2012. <http://forums2.gardenweb.com/forums/load/lawns/msg0800293317869.html>.

[2] Lloyd, Sonny, Matt McFadden, Don Jennings, and Robert Doerr. *OSMC Project Documentation V4 25*. Xtreme Motor Control, 30 Mar. 2002. PDF.

[3] "IEEE Code of Ethics." *7.8 IEEE Code of Ethics*. IEEE. Web. 26 Feb. 2012. <www.ieee.org/>.

[4] *HIP4081A*. Intersil, July 2004. PDF.

[5] Dan Keen. "How does SPDT relay work?". eHow. [Online]. Available: <http://www.ehow.com/how-does_4911787_spdt-relay-work.html>

7. Appendices

A. Mechanical design

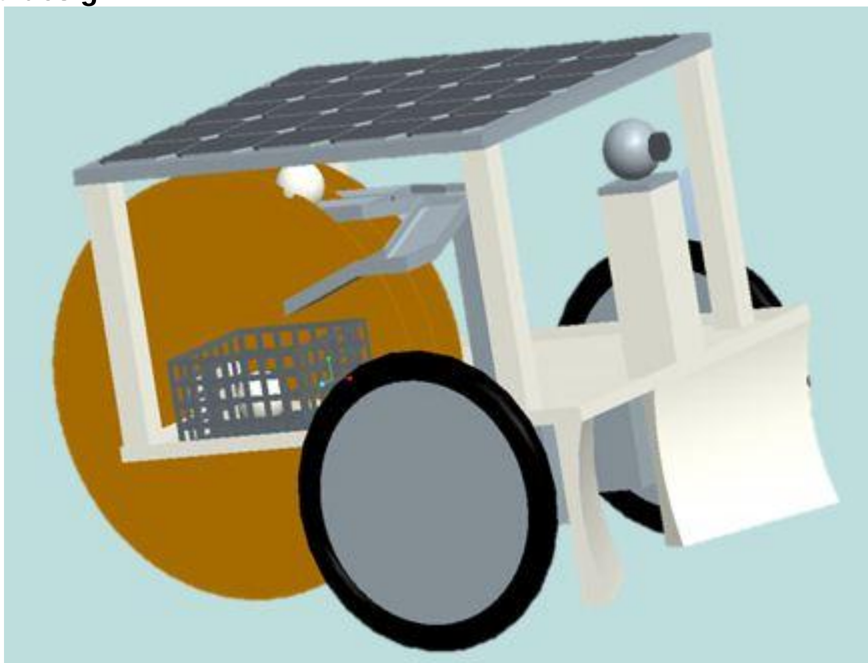


Figure A.1 : HDPE CAD model

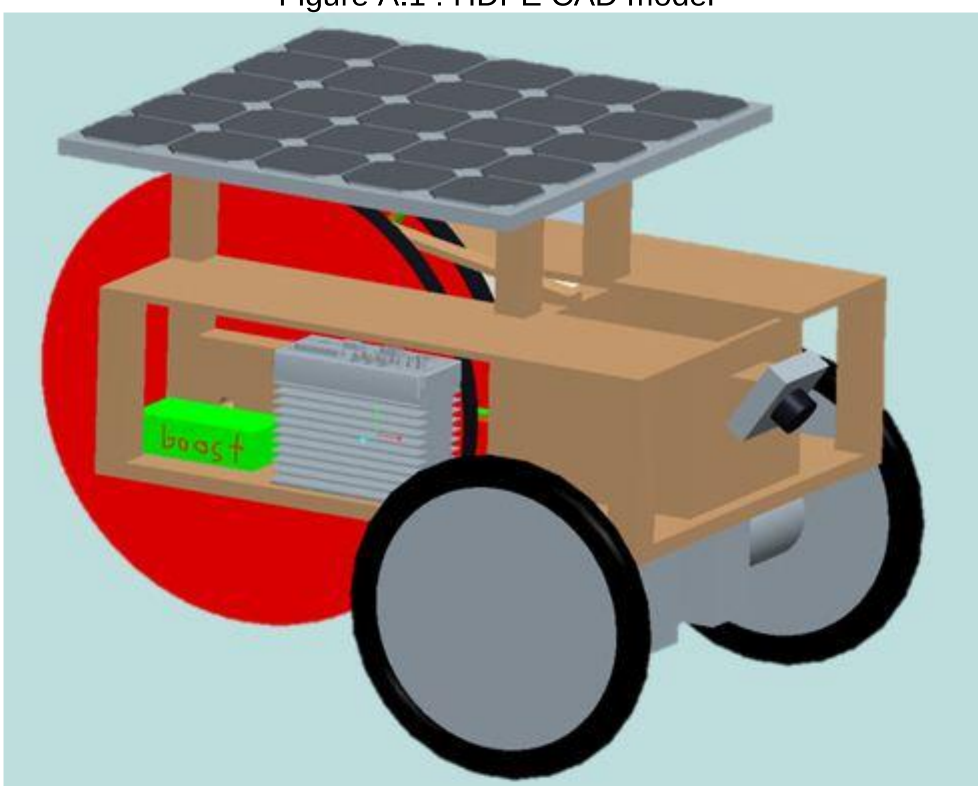


Figure A.2 : initial wooden model

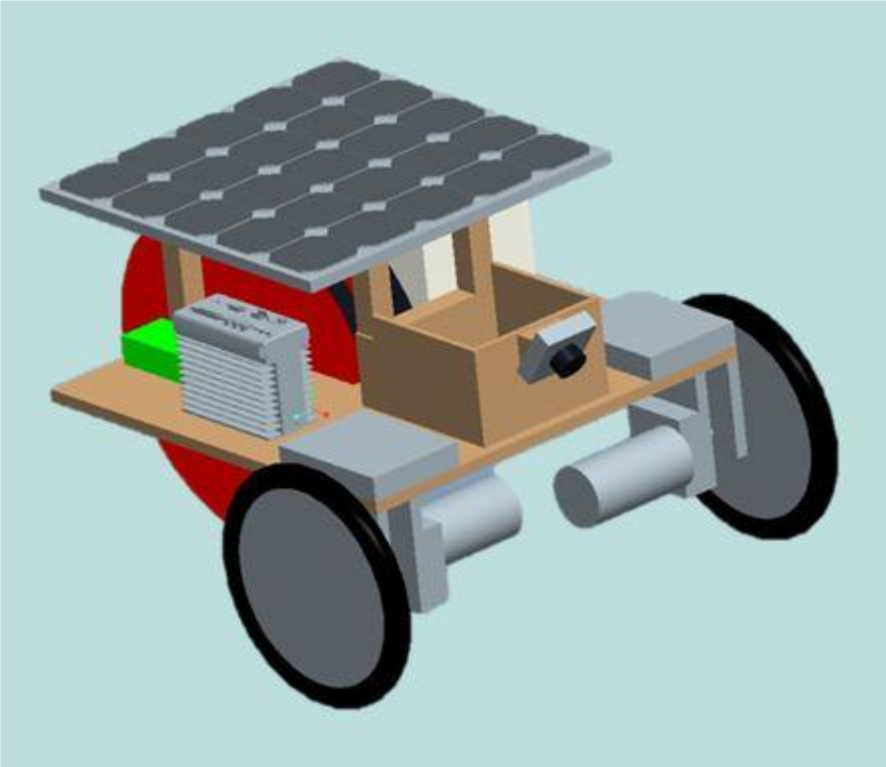


Figure A.3 : Final wooden CAD model

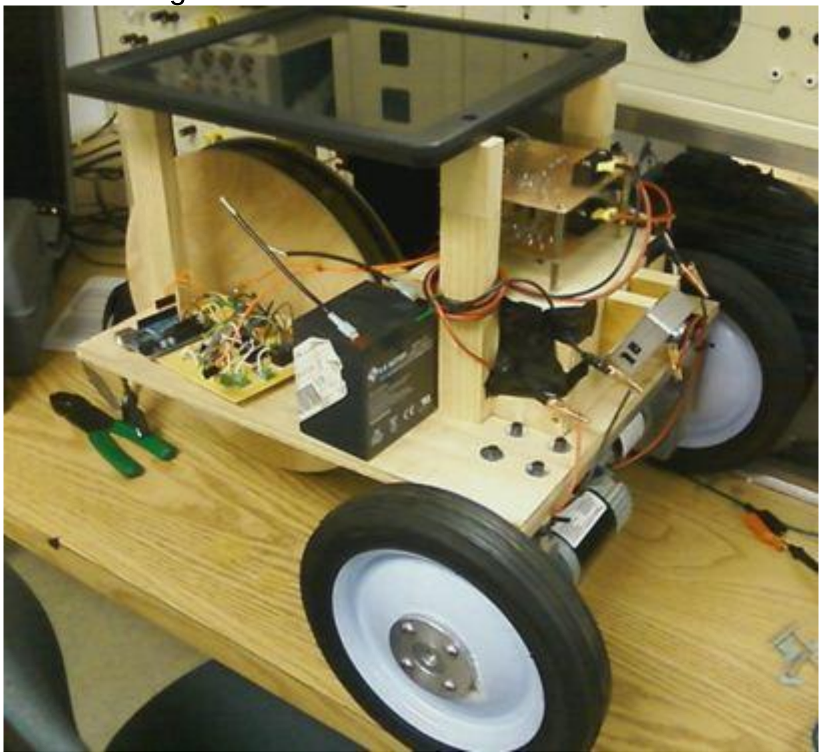


Figure A.4 : constructed 3 wheel robot

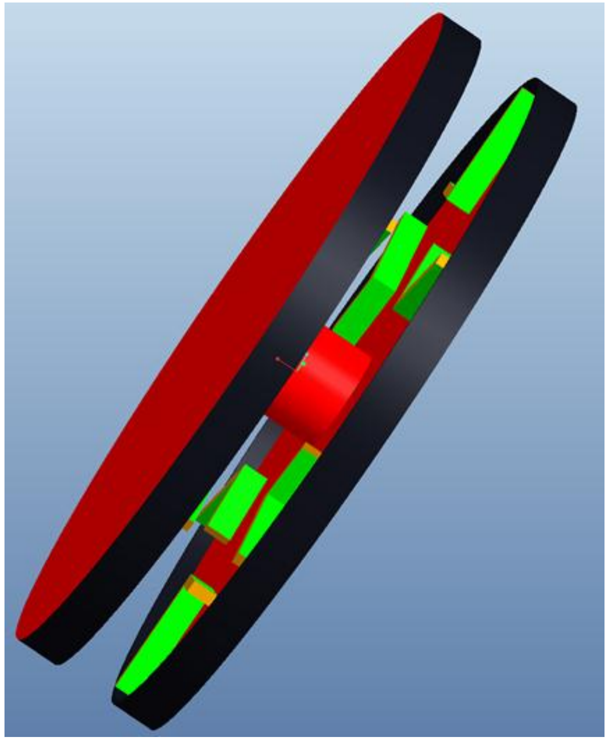


Figure A.5 : Pickup wheel CAD model

B. Control Module

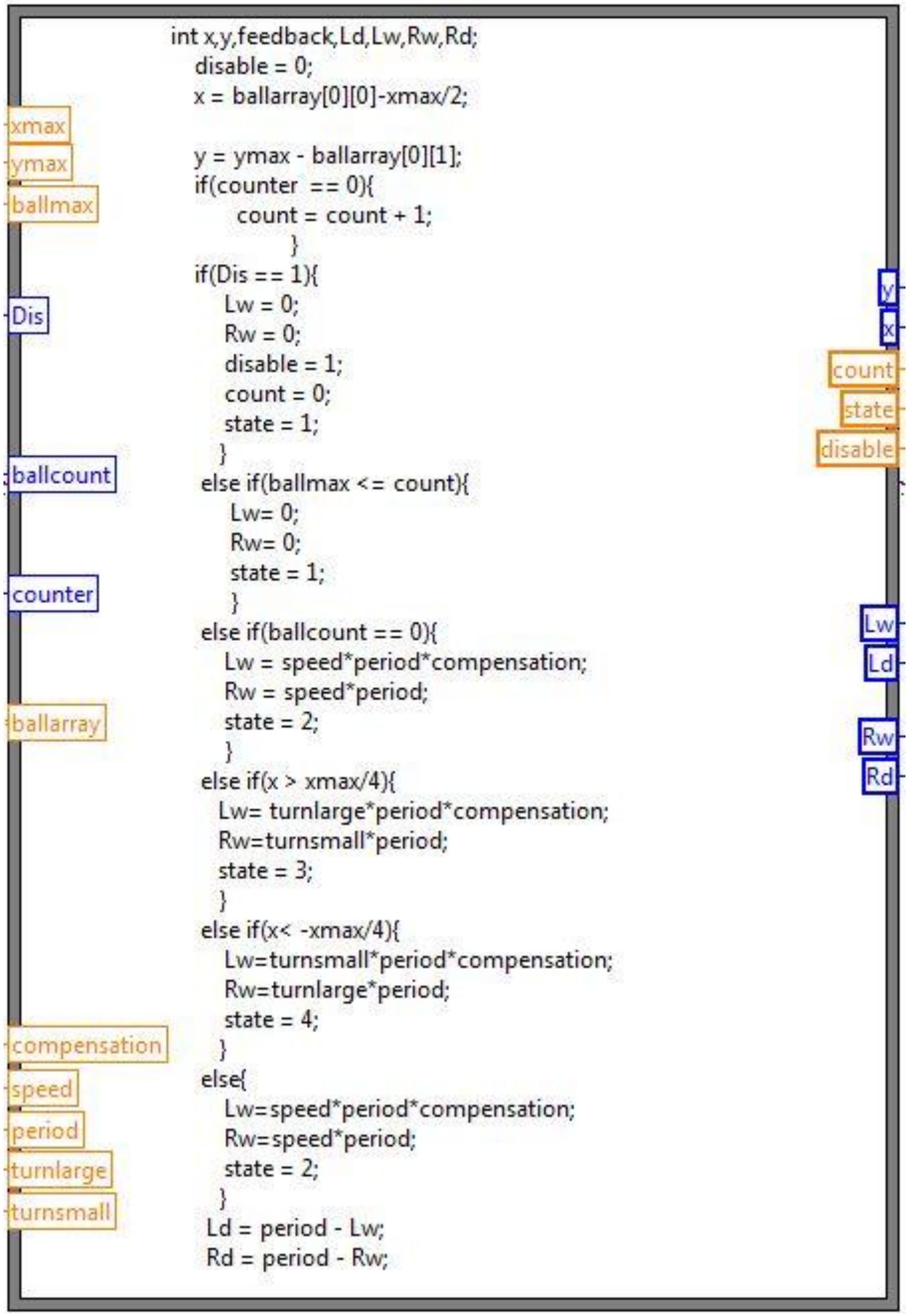


Figure B.1 : LabVIEW formula block code

Table B.2 : input/output signals

input signal	**Use**
xmax	resolution of camera in x direction (640 for Fire-i)
ymax	resolution of camera in y direction (480 for Fire-i)
ballmax	maximum number of balls to collect (typical = 4)
Dis	input from disable switch (TTL input 0)
ballcount	number of balls detected from vision assistant
counter	input from counter push button (TTL input 1)
ballarray	2x1 array of x and y position of closest ball
compensation	factor to reduce PWM on left motor (usually .9)
speed	percent of width of PWM when going straight (typical=.7)
period	period of PWM signal (typical = 1ms)
turnlarge	percent of width of PWM for faster wheel when turning (typical=.7)
turnsmall	percent of width of PWM for slower wheel when turning(typical=.4)
Output signal	**Use**
y	y position of nearest ball shown on front panel (0-480)
x	x position of nearest ball shown on front panel (0-640)
count	current number of balls collected shown on front panel(0- ballmax)
state	current state of robot shown on front panel (1-4)
disable	LED on front panel shows whether disable is on
Lw	time of width for left motor PWM (ms)
Ld	time of delay for left motor PWM (ms)
Rw	time of width for right motor PWM (ms)
Rd	time of delay for right motor PWM (ms)

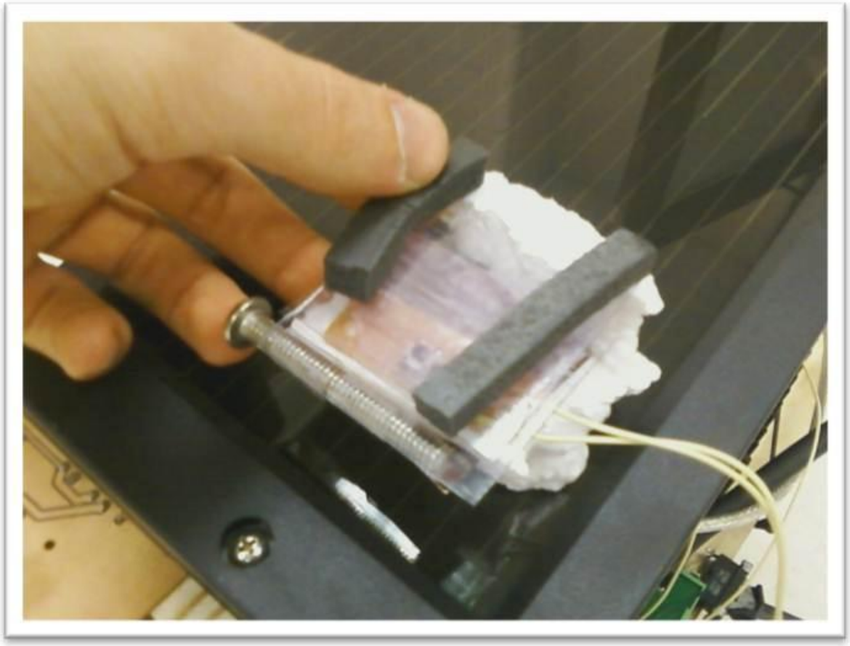


Figure B.3 : push button ball counter

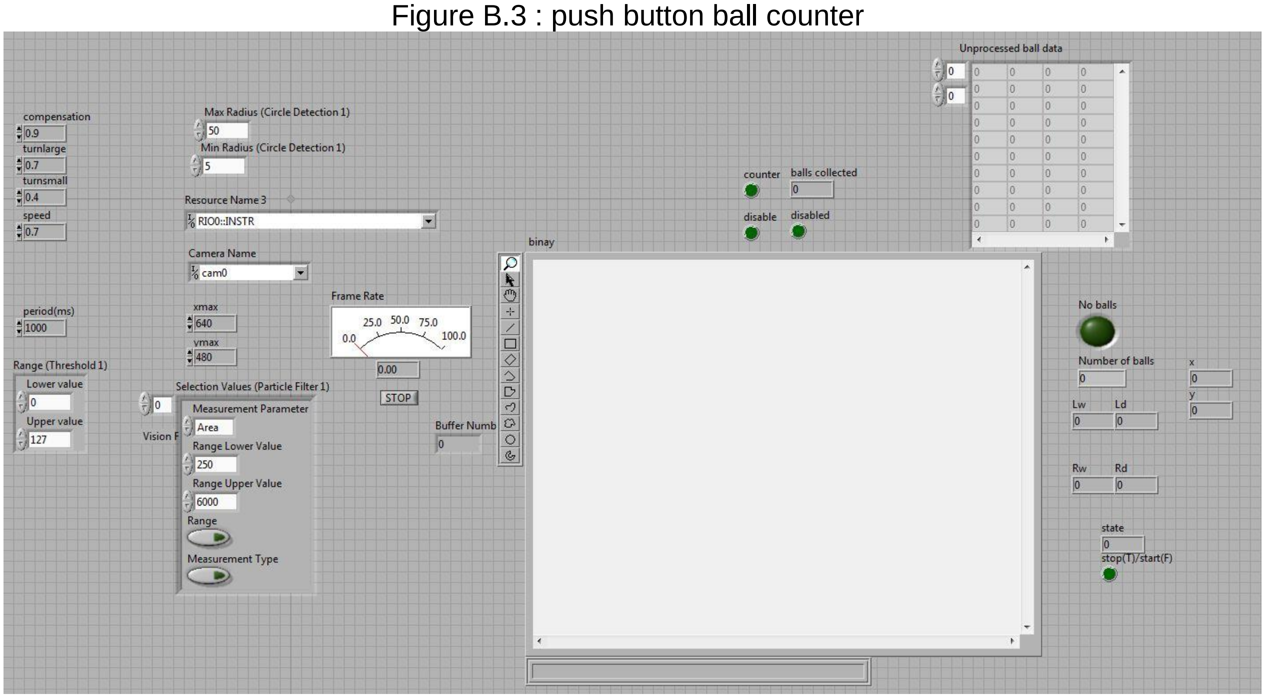


Figure B.4 : LabVIEW front panel display

C: Motor Module

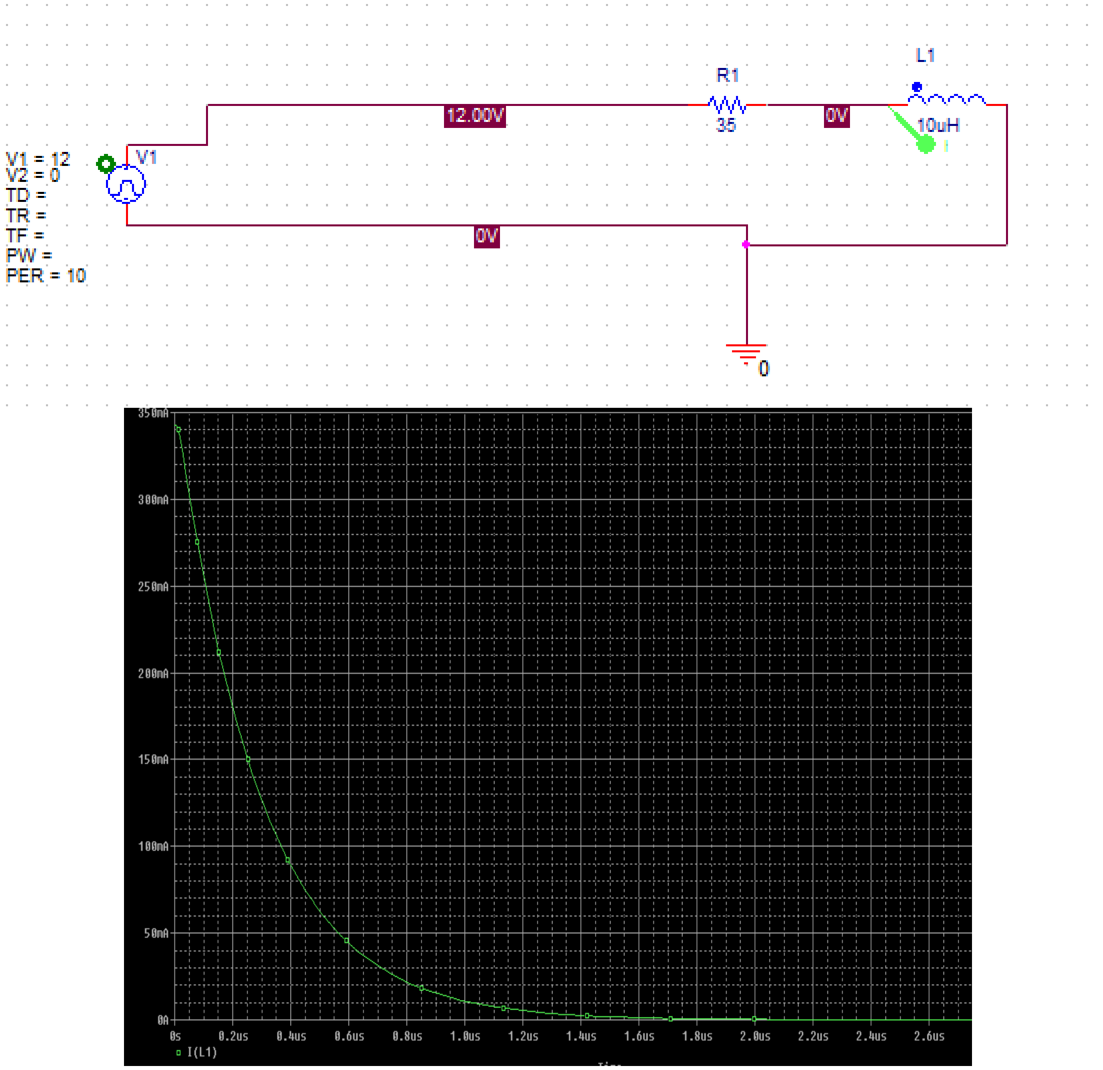


Figure C.1 : Pspice Simulation

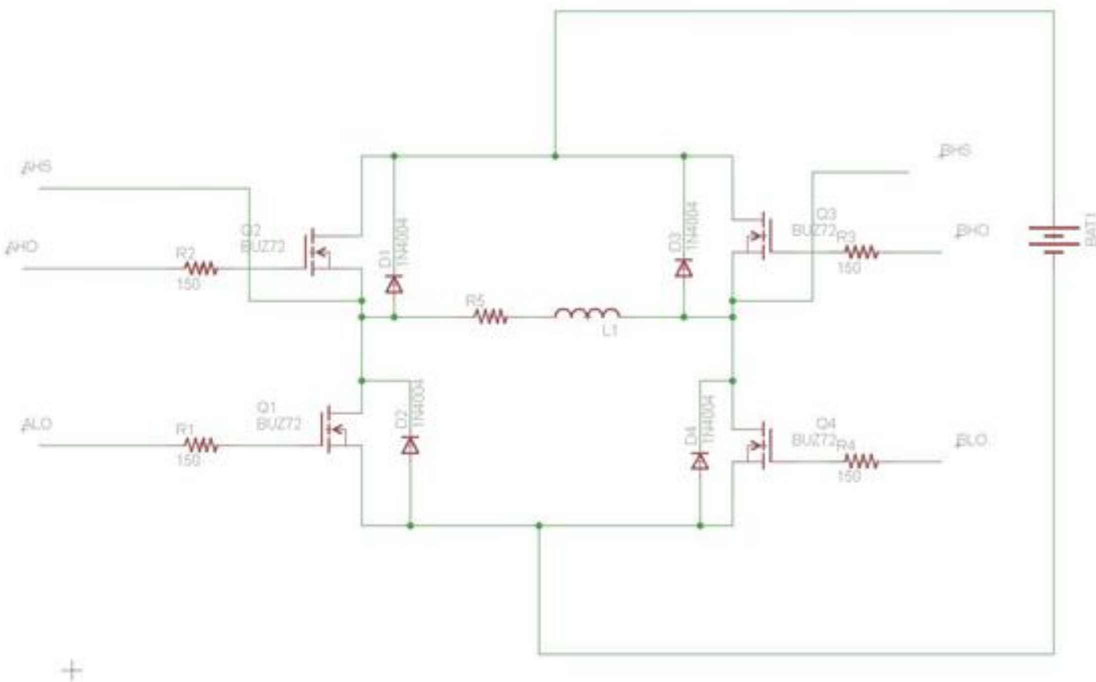


Figure C.2 : Hbridge Schematic

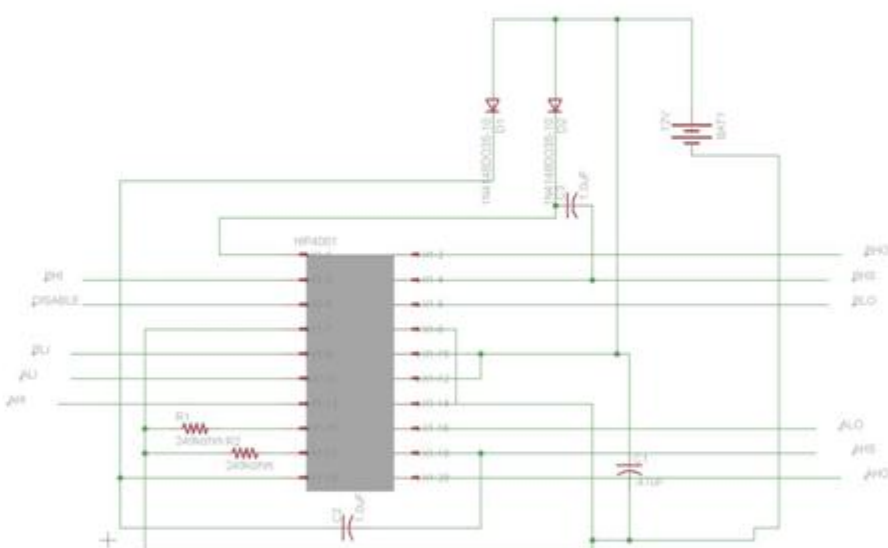


Figure C.3 : Mosfet Driver Schematic

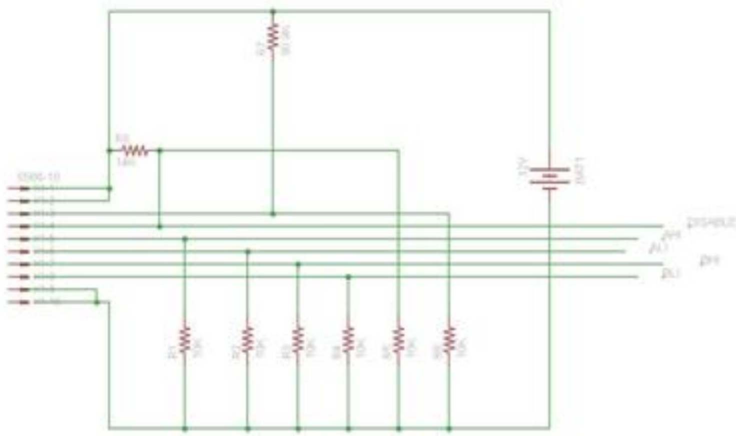


Figure C.4 : Header Schematic

Figure C.5 : Thermocouple Display

Figure C.6 : Motor and Thermocouple Placement

Table C.1 : Temperature Testing Data

Time (min)	Temperature (Deg C)	Fahrenheit
0.0	23.20	73.76
0.5	23.20	73.76
1.0	23.10	73.58
1.5	23.10	73.58
2.0	23.00	73.40
2.5	23.00	73.40
3.0	22.90	73.22
3.5	22.90	73.22
4.0	26.80	80.24
4.5	26.80	80.24
5.0	26.90	80.42
5.5	27.00	80.60
6.0	27.00	80.60

6.5	27.10	80.78
7.0	31.90	89.42
7.5	27.30	81.14
8.0	27.10	80.78
8.5	27.00	80.60
9.0	26.70	80.06
9.5	26.70	80.06
10.0	26.80	80.24
10.5	27.50	81.50
11.0	28.60	83.48
11.5	28.90	84.02
12.0	28.90	84.02
12.5	28.60	83.48
13.0	28.90	84.02
13.5	28.60	83.48
14.0	28.60	83.48

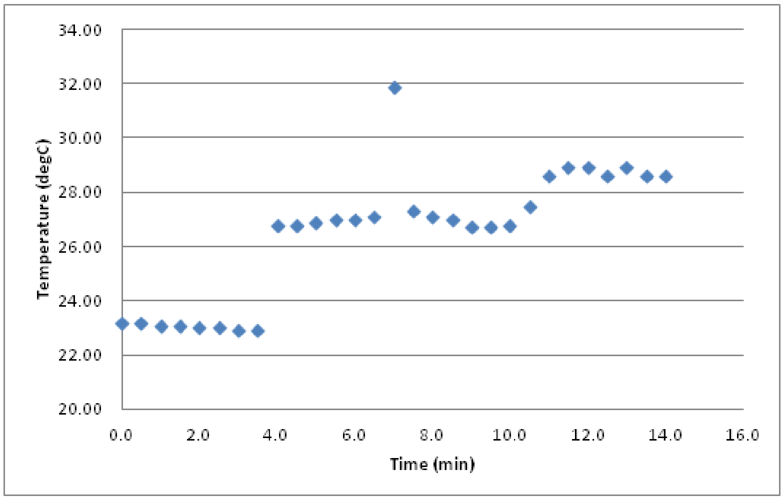


Figure C.7 : Temperature Testing Data

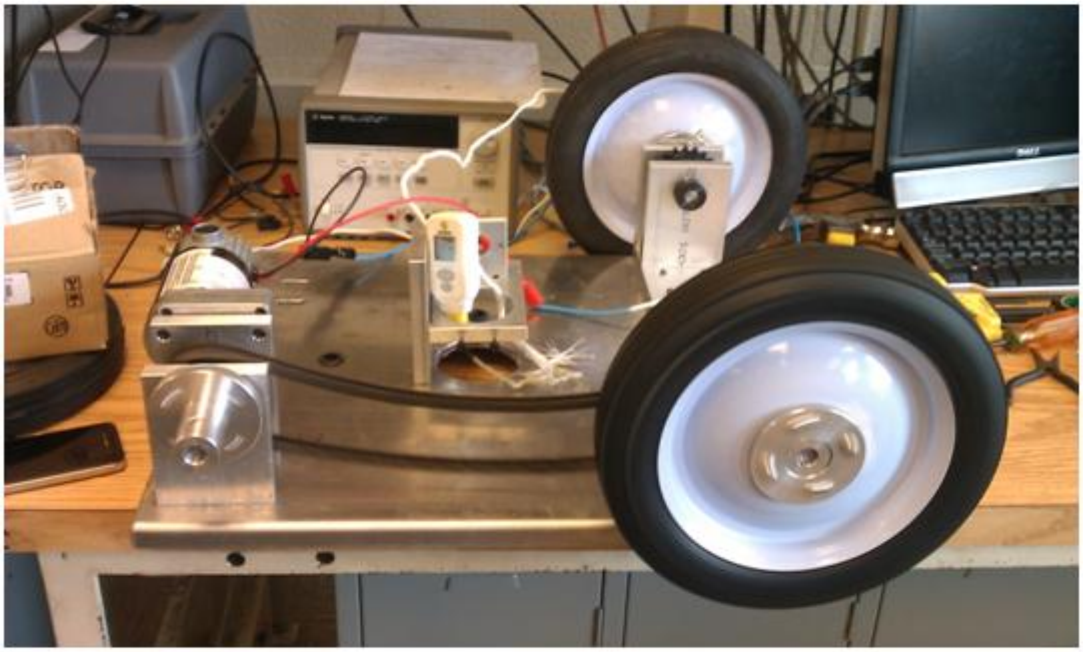


Figure C.8 : Motor Control Testing Layout

Motor Control Module Fermi Calculations

Note: For these calculations we will take three different loading scenarios using different values for the weight of the robotic unit. This will serve as a guiding investigation to the general size of the robotic unit. We will take a scenario to have the minimal specs to meet the requirements for the project. Another scenario will be at the top end of the spectrum giving us more range and weight than necessary and the mid range will be right in the middle.

Weight Investigation						
Item	Weight A (lb)	Note A	Weight B (lb)	Note B	Weight C (lb)	Note
Battery	6	12 V from lab	6	12 V from lab	12	2x 12V from lab
Motors	4	Small 4lb	10	2x 5 lb from lab	20	2 x 10lb from lab
Balls	3.0375	30 golf balls	5.0625	20 golf balls	10.125	100 golf balls
Chassis/Wheels	3	Light	5	Medium	10	Heavy
Ball Retreival Mech.	1	Smaller system	2	large system	3	Longer Pickup
Solar Panel	7	Tiny Solar Panel	14	Half size Coleman	28	Coleman SP
TOTALS	24.0375		42.0625		83.125	whoa

DC Motor Specs

$$F = MA$$

$$A = \frac{2\,ft}{s^2} = \frac{.66096m}{s^2}$$

$$F_a = 10.903kg * \frac{.66096m}{s^2} = 7.206N$$

$$F_b = 19.079kg * \frac{.66096m}{s^2} = 12.610N$$

$$F_c = 37.704kg * \frac{.66096m}{s^2} = 24.920N$$

$$F_a = 3.603N$$

$$F_b = 6.305N$$

$$F_c = 12.460N$$

$$Torque = FxD$$

$$R_{wheel} = 5" = 0.127m$$

$$T_a = 3.603 * .127 = .4576Nm = 4.050 in - lbs$$

$$T_b = 6.305 * .127 = .800735Nm = 7.0871 in - lbs$$

$$T_c = 12.46 * .127 = 1.58242Nm = 14.006 in - lbs$$

$$V = RPS * 2\pi R$$

$$1\frac{ft}{s} = 0.30475\frac{m}{s}$$

$$0.30475 = RPS * .798$$

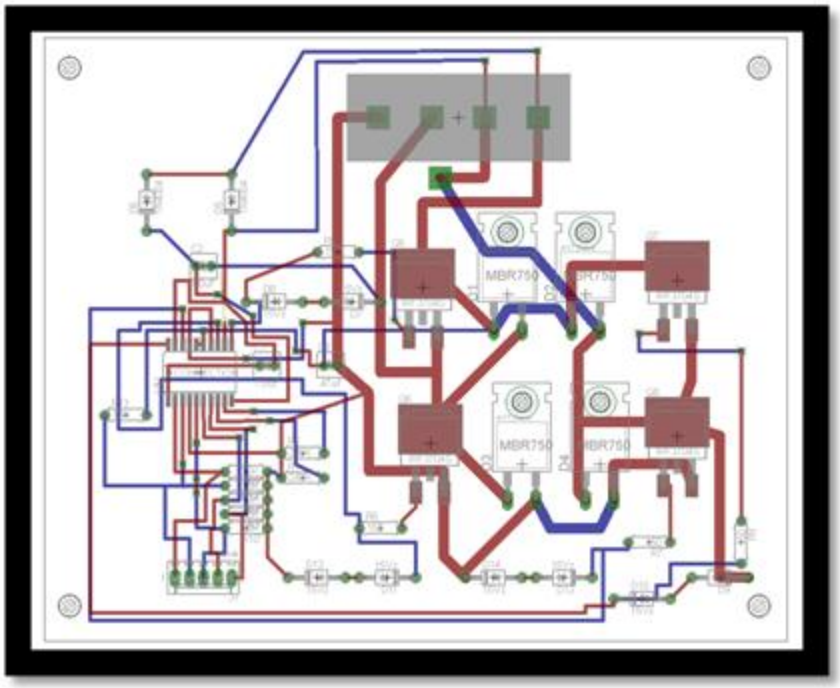
$$RPS = .3819$$

$$RPM = 22.915$$

$$SuppliedV = 12V$$

$$OutputTorque = InputTorque * GearReduction * TransmissionEfficiency$$

Figure C.9 : Weight Torque Analysis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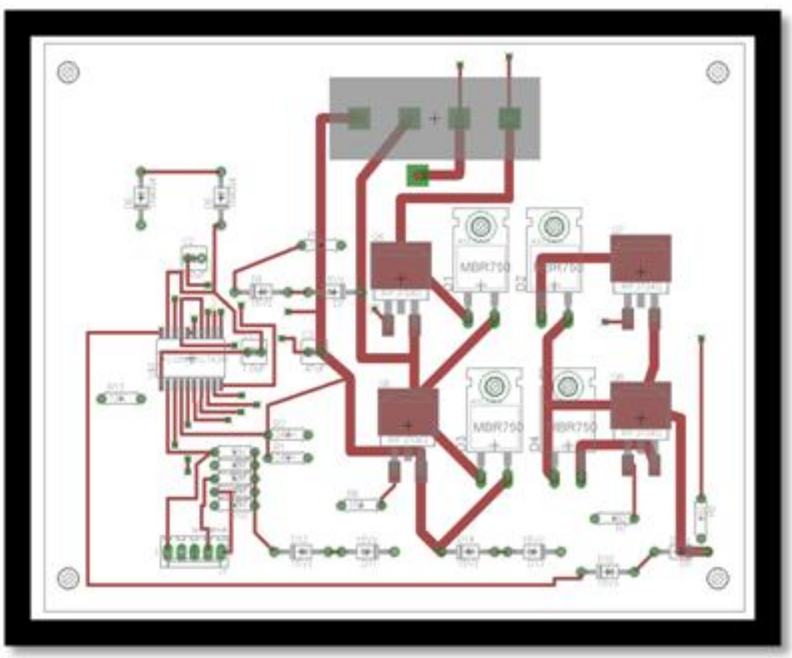
MBR750
MBR750
MBR750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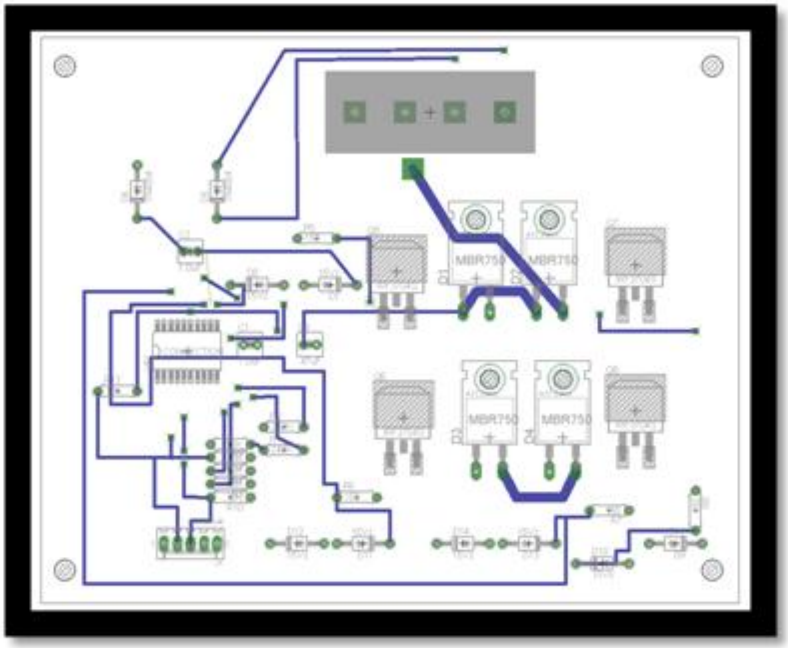


Figure C.10 : PCB Layout Schematics

D: Power

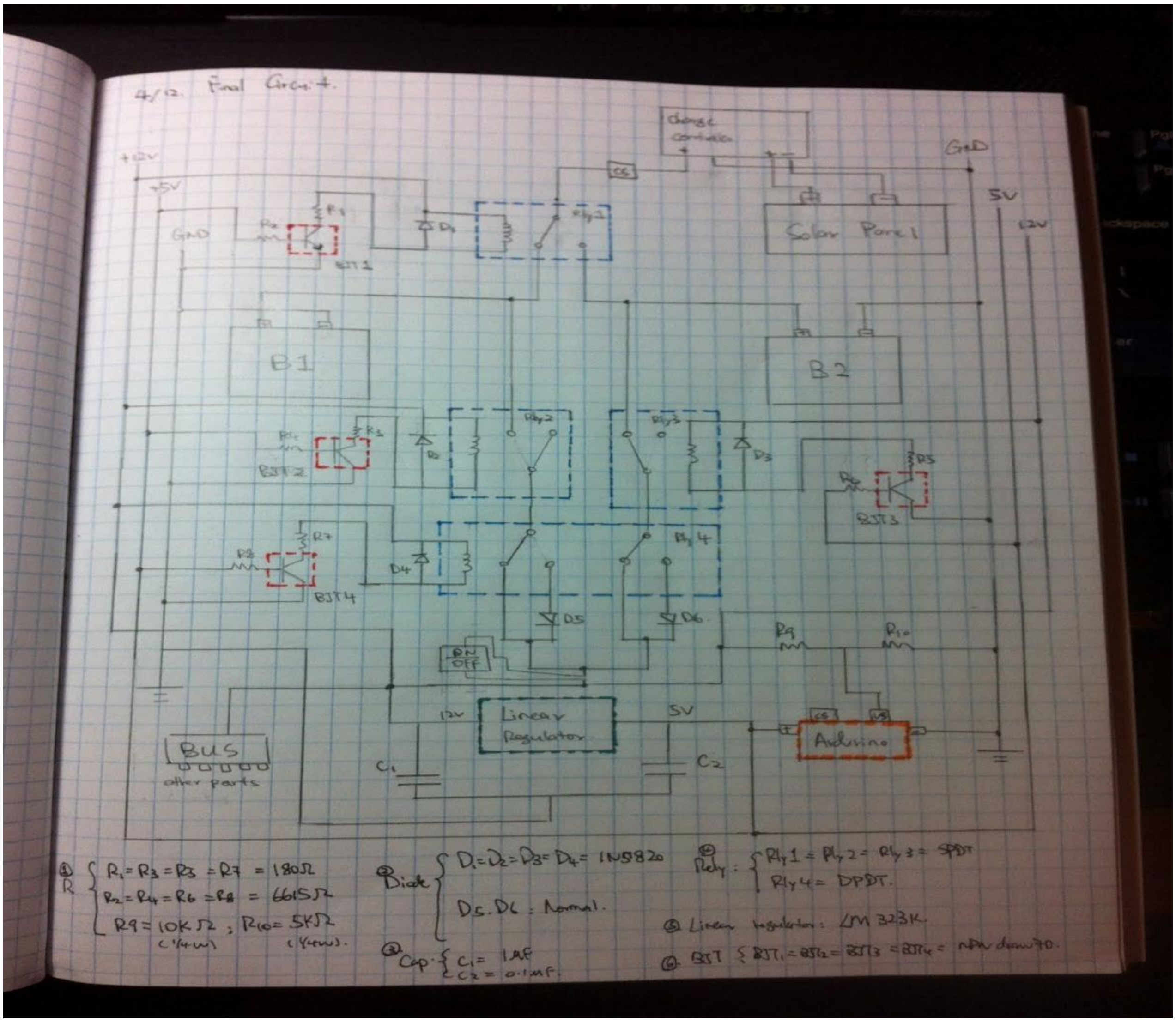
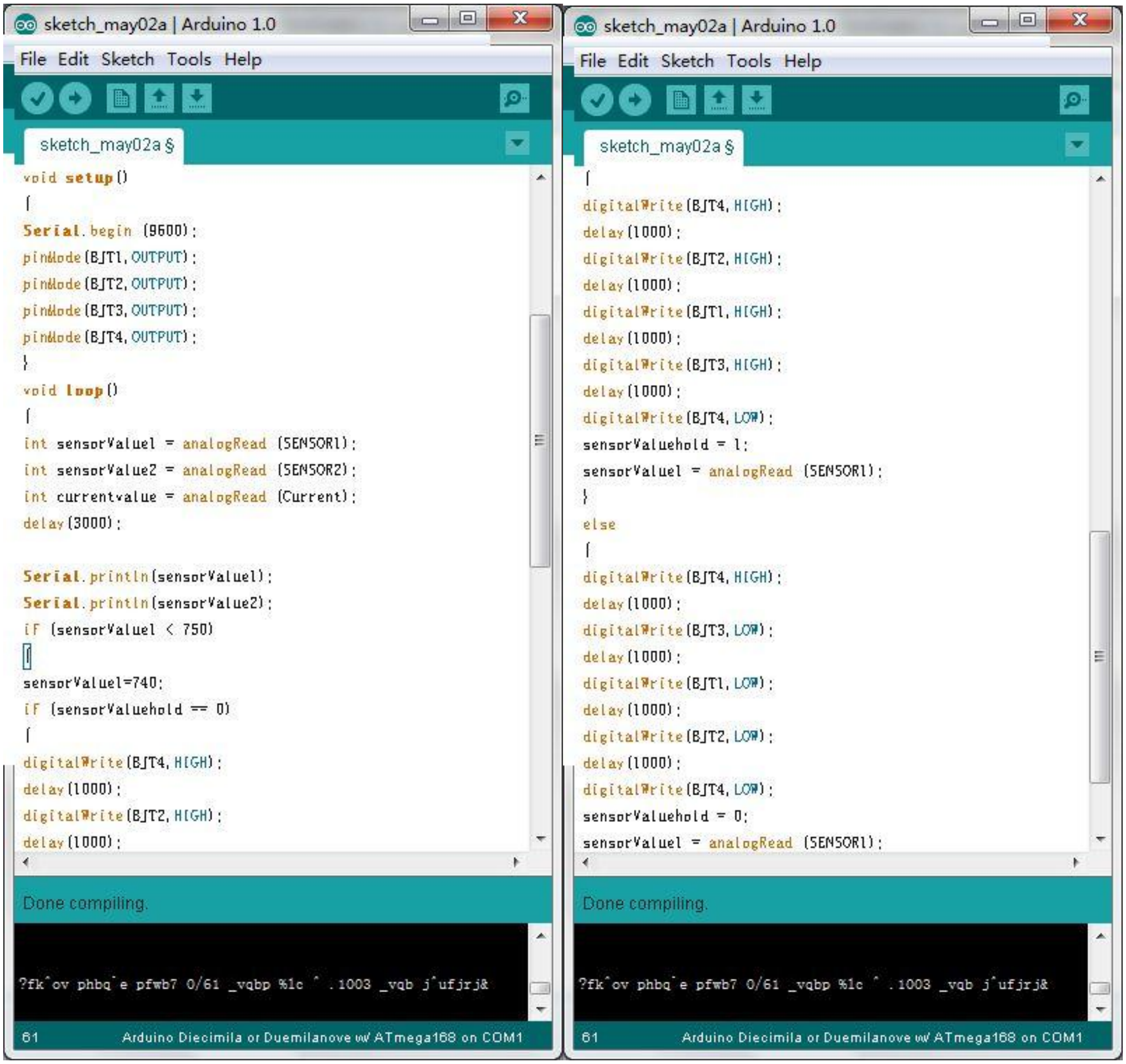


Figure D.1 : power management circuit



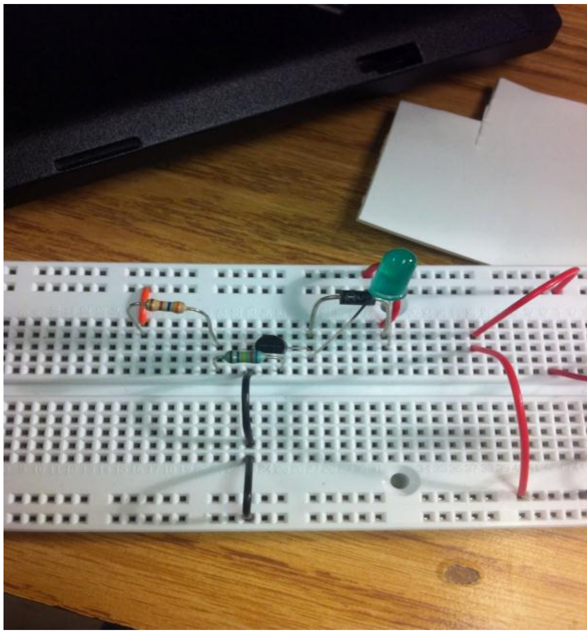
```
void setup()
{
Serial.begin (9600);
pinMode(BJT1,OUTPUT);
pinMode(BJT2,OUTPUT);
pinMode(BJT3,OUTPUT);
pinMode(BJT4,OUTPUT);
}
void loop()
{
int sensorValue1 = analogRead (SENSOR1);
int sensorValue2 = analogRead (SENSOR2);
int currentvalue = analogRead (Current);
delay(3000);

Serial.println(sensorValue1);
Serial.println(sensorValue2);
if (sensorValue1 < 750)
{
sensorValue1=740;
if (sensorValuehold == 0)
{
digitalWrite(BJT4,HIGH);
delay(1000);
digitalWrite(BJT2,HIGH);
delay(1000);
```

```
{
digitalWrite(BJT4,HIGH);
delay(1000);
digitalWrite(BJT2,HIGH);
delay(1000);
digitalWrite(BJT1,HIGH);
delay(1000);
digitalWrite(BJT3,HIGH);
delay(1000);
digitalWrite(BJT4,LOW);
sensorValuehold = 1;
sensorValue1 = analogRead (SENSOR1);
}
else
{
digitalWrite(BJT4,HIGH);
delay(1000);
digitalWrite(BJT3,LOW);
delay(1000);
digitalWrite(BJT1,LOW);
delay(1000);
digitalWrite(BJT2,LOW);
delay(1000);
digitalWrite(BJT4,LOW);
sensorValuehold = 0;
sensorValue1 = analogRead (SENSOR1);
```

Figure D.2 : Arduino code

Figure D.3 : panel power tracking test



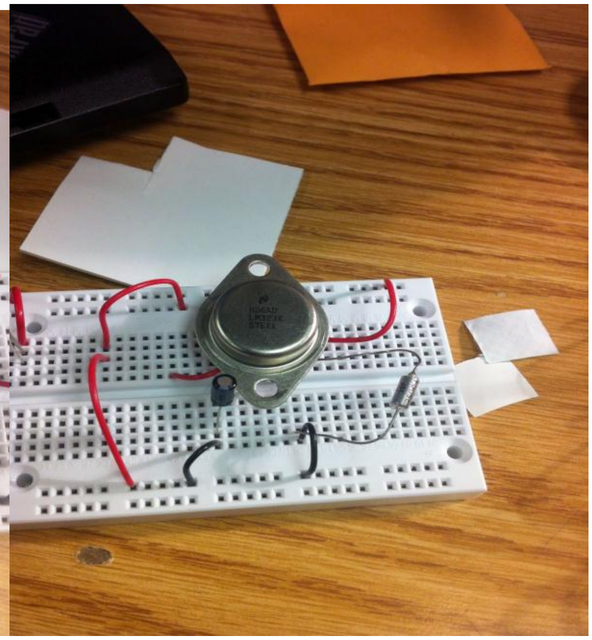


Figure D.4 : BJT circuit test   Figure D.5 : Voltage regulator test

E: Requirement and Verification table

Requirement	Verification
1. CVS (controller) outputs PWM to motors corresponding to the location of nearest ball. a. The CVS will locate 90% of balls within the camera's FOV b. The CVS will accurately identify the nearest ball 100% of the time c. The CVS will accurately output the PWM needed for each motor d. Camera will not go below 5 fps	1. The camera must be hooked to the CVS and be oriented as it would be on the robot. Balls will be placed within the camera's FOV on a piece of turf or outside in the grass. An oscilloscope will connect to the PWM outputs of the CVS. a. Connect a monitor to the CVS and determine which balls have been identified and which were missed. Also look at how many fps the camera is outputting and reduce code length if fps is too low b. From the monitor output, the nearest ball will have a crosshair placed over it and pixel location shown. We will determine whether the ball identified is indeed the closest ball. c. Example pixel values will be coded into the CVS and we will measure the corresponding output from the CVS using an oscilloscope and determine whether the PWM is accurate. d. Find the fps from the monitor and reduce code length/complexity if average fps is lower than 5.
2. Sensors: Disable switch turns off motors and ball counter sensor counts the number of balls stored. a. Disable switch can completely turn on and off the motors while not interrupting anything else b. Counter sensor counts the number of balls going into container and stops the robot when the maximum number is reached	2. Disable switch turned on and off while robot moves and golf balls are rolled down into the container and counted. a. allow robot to go straight, after a few seconds, flip the disable switch. When the robot has stopped moving, flip the disable switch again to continue task. b. unplug or lift up the motors in order to keep the robot stationary. slowly add golf balls onto the ramp that leads to the container. Set the maximum golf balls to 4, once this number has been reached, ensure that the motors shut off immediately.
3. The battery controller will charge the lower voltage battery via the PV panel and direct the higher voltage battery to power the robot a. The output voltage from the solar panel must be between 11.8V and 12.2V b. The controller switches the output mode if the robot battery is less than 10.5V c.. The battery controller will maintain the voltage to the system	3. The battery controller will connect to both batteries and be able to switch between the two based on the voltage signal from the robot battery and via microcontroller to manufacture the switch action. a. A discharged battery will connect to the PV panel and solar controller and the microcontroller will measure the voltage from the solar panel through a voltage divider schematic. b. The controller senses voltage of the robot battery by a voltage divider schematic and by implementing four relays to achieve a switch network which are supplied by 5V signals fed into BJT’s which control the 12V across

while the switch implementation happens. d. The battery controller would obtain power information of the solar panel.	the coil of the relay. c. A “make before break” design will make sure both batteries are connected into circuit at the moment of the switch happens. d. Both voltage sensor and current sensor would be implemented when the battery is charging. And power characteristic of the solar panel would be record from the two values.
4. The battery controller would be able to manufacture different voltage requirement for the components in the system. a. Be able to supply 12V to the H-bridge. b. Be able to supply 5V to the arduino microcontroller. c. Be able to supply 24V to the CVS system.	4. There are many components in the robot system, they are working under the different voltages, we need to make sure all of them working in the correct mode. a. Both H-bridges will be fed 12V directly from the battery. b. The arduino will be fed 5V from the battery through a voltage regulator which ensures the arduino and all the BJT will work correctly c. The CVS will be fed 24V from the battery though a boost converter which input voltage is 12V.
5. Motor Delivers Torque to wheels to successfully pick up balls a. H-bridge accepts input PWM values from 3-12V logic b. The Controller must output PWM suitable for the FET driver (3-12V) c. Motor must not overheat (40°C) d. Must operate continuously at 90% duty cycle for 30 minutes	5. This results from several moments of stress testing on the motor and motor drive components. 10-13V will be applied to battery terminals of the power bridge and the microcontroller will be set to a particular Duty cycle a. The power bridge will be tested with 3-12V logic to ensure that it does indeed provide the correct conductive path necessary for motor control signals b. The controller will be tested using the power bridge and detecting the output waveforms on the oscilloscope. The output waveforms must produce a PWM with ranges of 10-13V and within +- 5% duty cycle. c. The motor will not be attached to the motor control unit (while loaded) and will be run continuously at 100% for 10 mins and temperature and results will be taken d. Again, the above test will be taken yet again but for longer durations and with a 90% duty load