Mr. Clean Board

ECE 445 Fall 2018

Design Document

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1 Introduction

1.1 Objective

In many of today's academic and professional settings, whiteboards and blackboards are commonly used. In collegiate environments, professors write their lecture notes on these boards. During class time, the professors must balance their time between writing notes on the board as well as addressing the class directly. Often, the board space is limited causing the professor to take time out of the lecture to erase the board. Furthermore, it is a common courtesy that the board is cleaned at the end of class. Sometimes, the professor overlooks cleaning the board because they are caught up interacting with their students at the end of class. Leaving the board not erased is often a minor inconvenience for the next class to use the room.

To address the minor inconvenience of erasing the board, we propose a small robot named Mr. Clean Board. This robot's sole function will be to erase any whiteboard or chalkboard quickly and efficiently. This robot will allow the professor to simply push a button during class to erase the board while they address students or check their notes. After class, the professor merely hits the start button and the board will be erased. Ultimately, this robot will be a convenience for the professors by allowing them to give more time during lectures to their students.

1.2 Background

As students at the University of Illinois at Urbana Champaign, we have attended hundreds of lectures and discussions in our time as undergraduate students. During this time, we have seen professors inconvenienced many times: erasing the board before class, erasing the board two to three times during class, getting chalk dust all over one's hands and clothes, and, although uncommon, professors covering their mouths to avoid breathing in the dust. While solutions exist for automatically erasing a whiteboard, most of these solutions use two rails mounted to the board with a big eraser that slides back and forth across the board. Our proposed solution would magnetically attach to the board allowing for greater flexibility and a more straightforward setup while still erasing the board efficiently.

1.3 High-Level Requirements

- The robot must be able to erase a 6' by 4' board in two and a half minutes or less.
- The robot must be able to detect the edges of the board by working with the IR lighthouses.
- The robot must be able to clean the whiteboard or blackboard within one or two passes.

2 Design

The robot has four main systems necessary for the design to work: a power supply, a control unit, a motor control unit, and a physical component. The power supply will power the motors, sensors, and the microcontroller. The power supply unit will also feature a USB charging module. The control unit will consist of an accelerometer, IR sensors, motor controller, and microcontroller and will be responsible for ensuring the car erases the board correctly and stays on track. The control unit will work with the IR lighthouses which will aid the robot in ensuring it has erased the whole board and that it will return to its proper starting point. The physical component consists of a chassis that will hold the PCB, motors, eraser, and magnets. Several components must be selected carefully to ensure that the robot can erase the board in time and do within two passes; however, we will be aiming for a completion in a single pass. The magnetic properties of the robot and lighthouses will make the design easily transportable to a different board and a simple switch of erasers will allow compatibility with either a whiteboard or blackboard. The block diagram is shown in Figure 1.

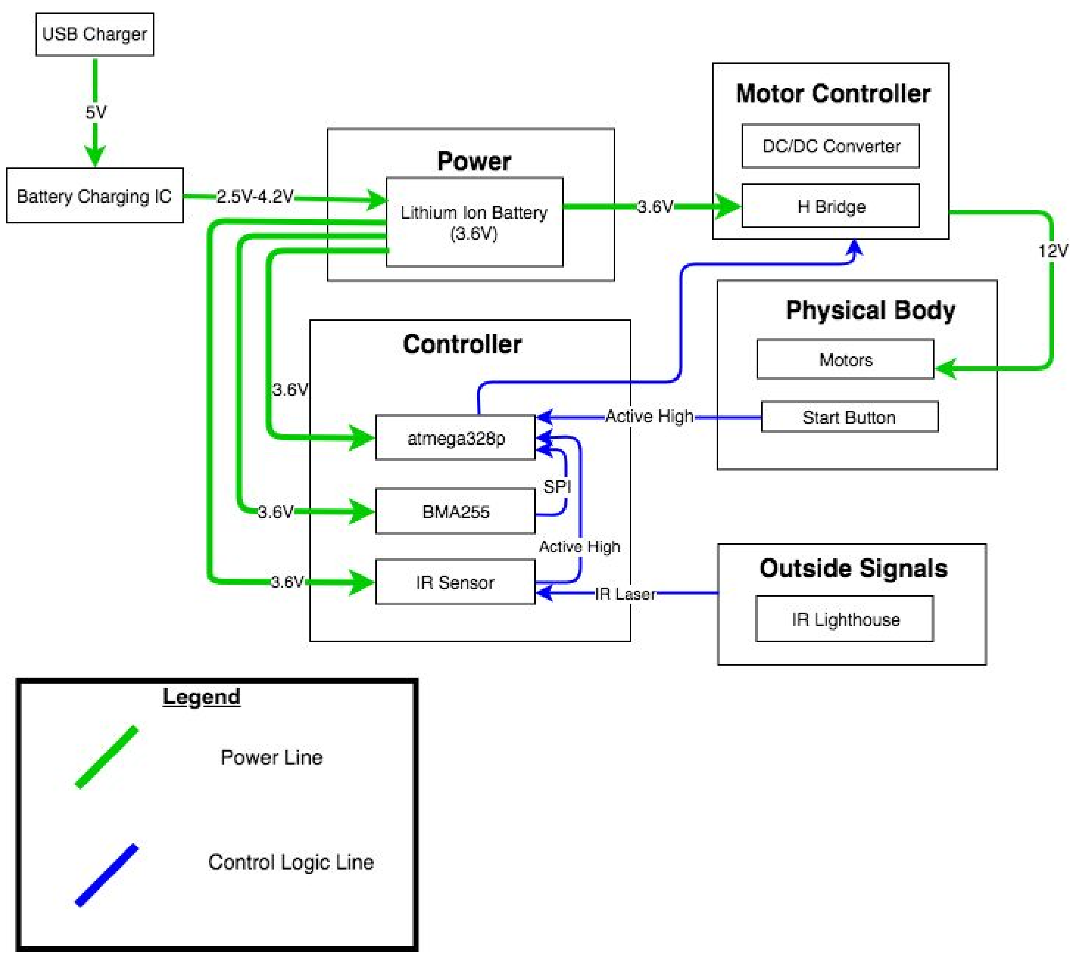

Figure 1. Block Diagram

The physical layout, as shown in Figure 2, of the design consists of two wheels located in the rear with the eraser located at the front providing the swivel point for the car. There will be 2-4 bar magnets located underneath as well to provide the attaching mechanism to the board. The battery and PCB will be mounted on top of the chassis or in the remaining space in the middle underneath the chassis. The start button will be located on the top of the chassis to allow for easy user interface with the car. The exact number and placements for the magnets and erasers may be subject to change as we test out which combinations yield the best grip and erasing results.

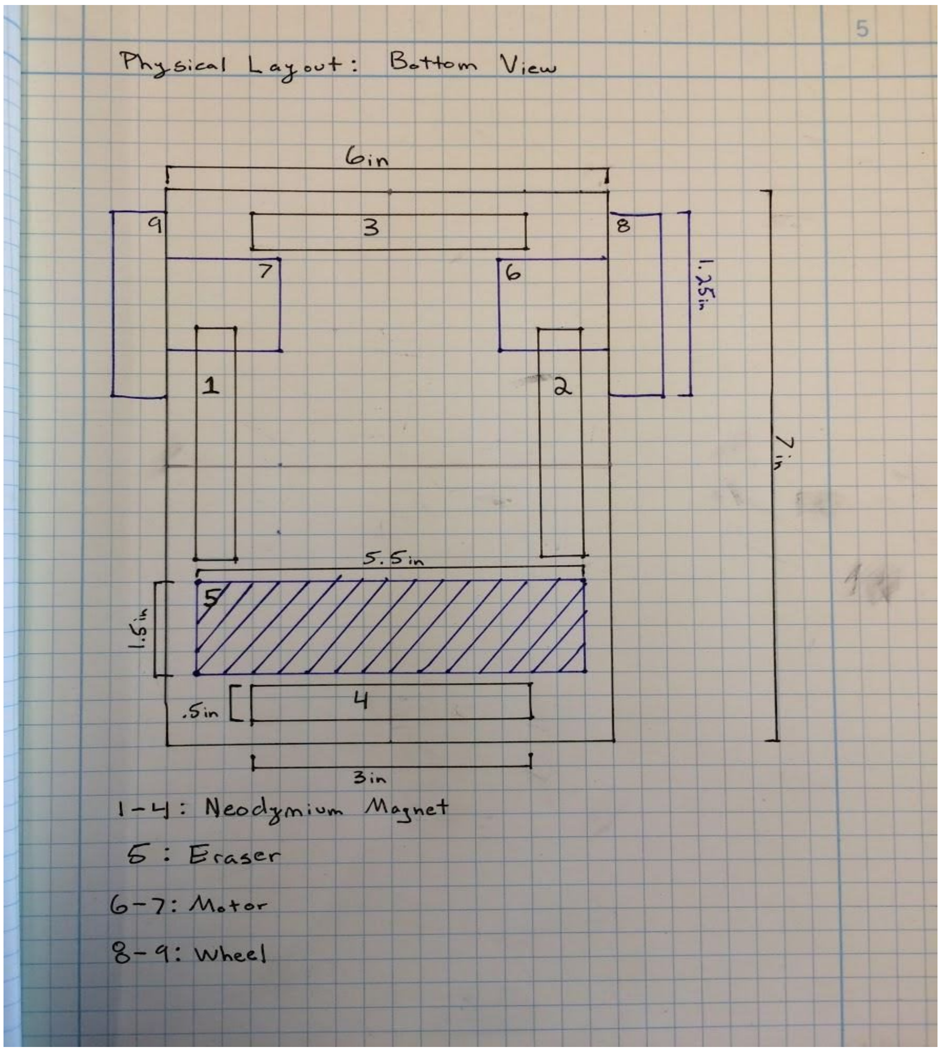

Figure 2. Physical Body Diagram (Bottom View)

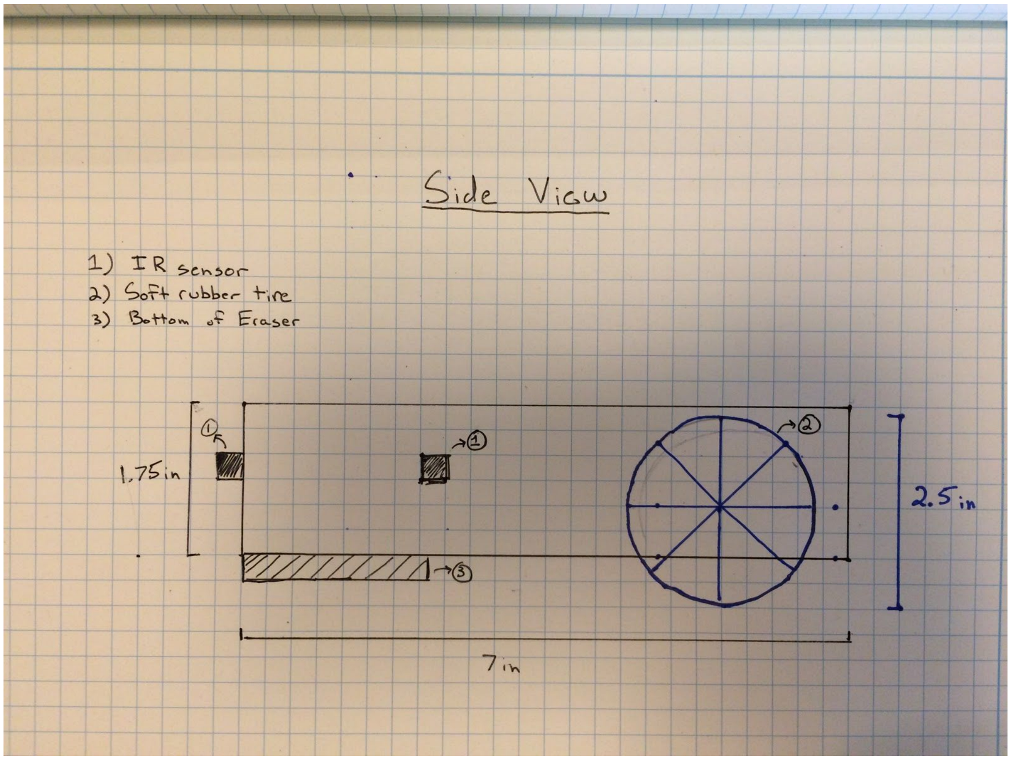

Figure 3. Physical Body Diagram (Side view)

2.1 Power Supply

The power supply will consist of a lithium-ion battery and a charging circuit. The charging circuit will allow for the robot to be continuously operational and easily recharged once the battery is depleted.

2.1.1 Lithium-Ion Battery

We will use the LGDBHE41865 lithium-ion battery to power the motors and circuitry. The battery must be able to power the car with about two hours of continuous use. It will also have a resting lifetime of over a month. The battery is rated to 2500 mAh, we believe this rating will be enough for our desired run time.

Requirement	Verification
1. The battery must produce 1.5A of current while operating at 2.8V – 4.2V. 2. The battery must be able to provide two hours of continuous use.	1. Attach the motors to the battery and monitor the current and voltage levels with a multimeter. 2. Attach the motors directly to a fully charged battery and make sure the run time of both motors is at least two hours.

2.1.2 USB Charger

The USB charger will be able to work with any device with USB ports. The charging cable will have a standard USB port on one side and a micro USB on the other side. The charger will be passed into the battery charging IC via the micro USB port.

Requirement	Verification
1. The USB charger must produce between 4.4V - 5.25V. This is the USB 2.0 standard power range.	1. Probe the power power pins of the USB cable with a multimeter and verify that the output voltages are between 4.4V and 5.25V.

2.1.3 Battery Charging IC

We will use the Sparkfun PRT-10217. It will take the USB-C from the USB charger as an input and will charge the lithium-ion battery. The IC will have a positive and negative terminal output that connects with the housing of the battery when charging. The battery charges based on a constant voltage and constant current scheme which is what the IC will provide to the battery. The schematic is shown in Figure 4 [1].

Requirement	Verification
1. The IC must be able to fully charge the battery in 5 hours.	1. Deplete the battery while testing the run time and then time how long the battery takes to get back to full capacity using a multimeter.

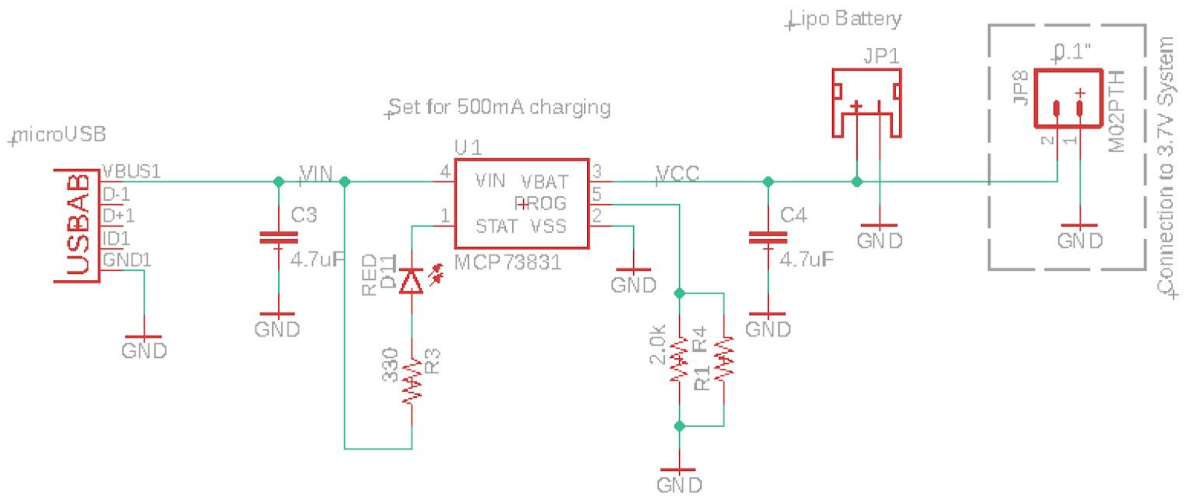

Figure 4: Battery Charging IC Schematic

2.2 Controller

The controller is responsible for taking in all the sensory input and then processing this data to send output signals to the motor controller.

2.2.1 Atmega328p

The Atmega328p is the microcontroller that will monitor and respond to the input from the sensors. The accelerometer, IR sensor, and start button will be all the inputs into the microcontroller. The accelerometer will communicate by an SPI link while the IR sensor and push buttons will be active high signals. The microcontroller will drive the motor controller which then controls the wheels. The schematic is shown in Figure 5. The control logic is shown below in Figure 6.

Requirement	Verification
1. The logic in the microcontroller must operate with a supply voltage of 2.5V - 4.2V.	1. After programming basic logic in the controller, connect the motors to the battery and verify the logic works properly. Also, check the Vin pin to the chip using a multimeter.
2. The microcontroller must read the data from the accelerometer at a rate of 9600 bits per second.	2. Program the microcontroller to pull the accelerometer for a 1 second interval. Then, report the number of reads that it accomplished.

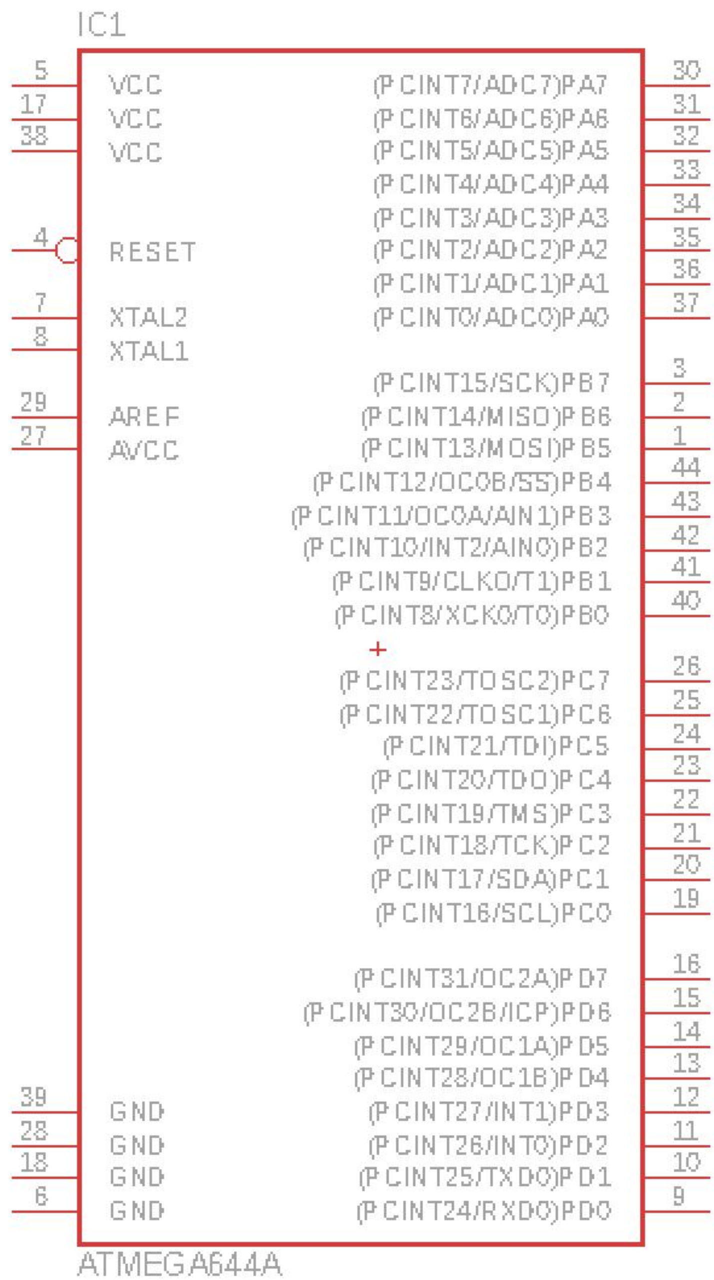

Figure 5: Atmega328p

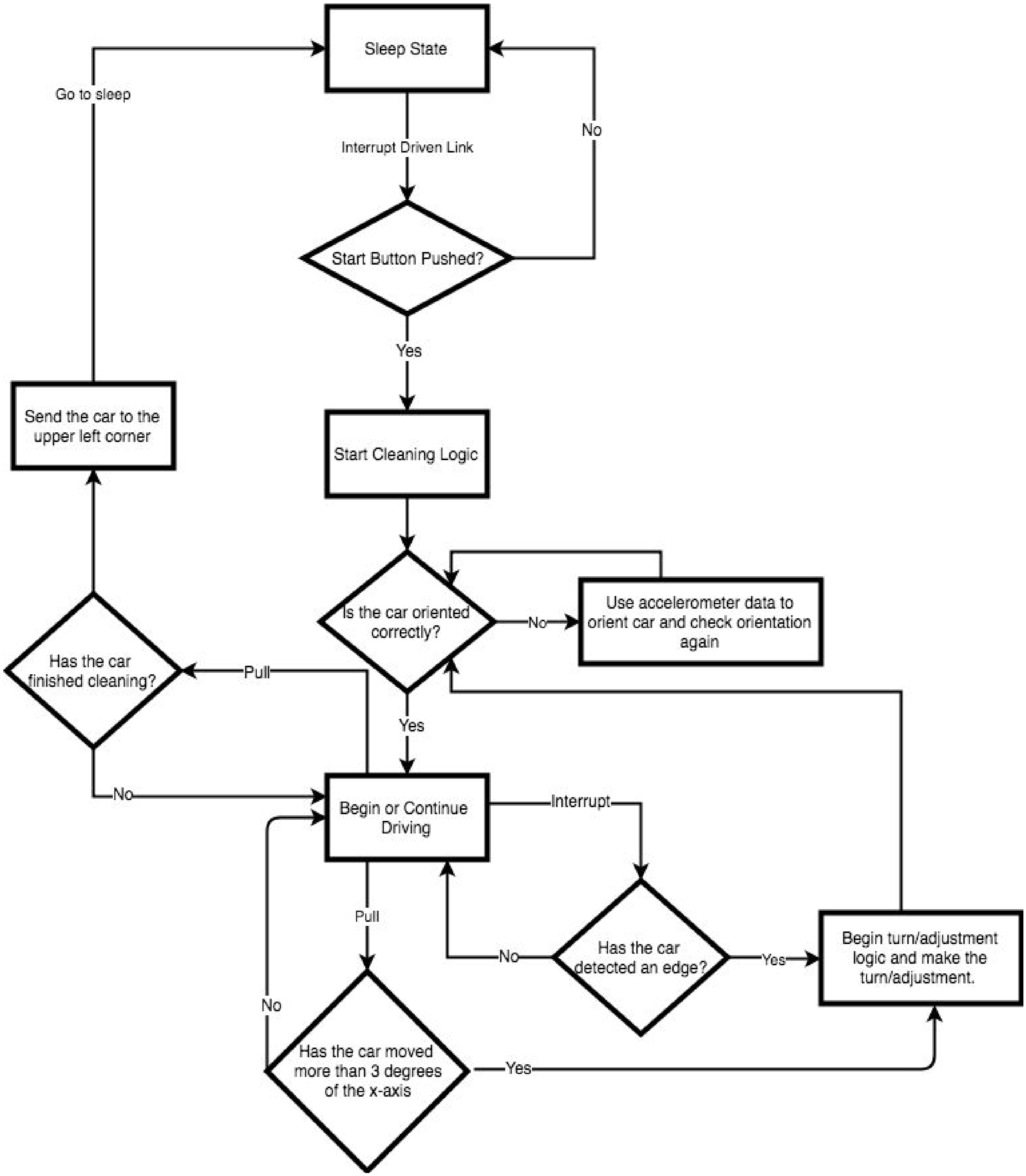

Figure 6: Software Flowchart

2.2.2 BMA255

The BMA255 is the Bosch accelerometer that will always be monitoring the x-axis and y-axis positions of the car along with the orientation of the car so that the car will always be able to drive in straight lines. This chip is only connected to the microcontroller through an SPI link.

Requirement	Verification
1. The chip must detect when the car has moved 3 degrees of the x-axis of the board.	1. Attach the BMA255 to the microcontroller and have the microcontroller turn on a LED when the accelerometer is rotated more than 3 degrees of the x-axis.
2. The chip must report the rotation degree off the x-axis to the tenths place.	2. Have the BMA255 send the chip data to microcontroller which processes the data. Then, the microcontroller sends the data to the PC which displays on a serial port terminal the rotational axis values.

2.2.3 IR Receiver

The robot will have an array of 1 - 4 TSOP38238 receiver diodes. These receivers will be placed around the robot, so the robot will be able to pick up any of the signals from the IR lighthouse. When a receiver picks up the signal, the robot will know that it has reached the edge of the board so that it can turn around. The receiver will be connected directly to an I/O pin on the microcontroller. We are still considering different models. A schematic is shown in Figure 7.

Requirement	Verification
1. The IR receiver must be able to receive at least a 700 nm wave from 2 meters away. 2. The IR receiver must work with a supply voltage of 2.5V - 4.2V.	1. Power the receiver attached to a breadboard which has a LED that the receiver will turn on when it receives the correct wavelength. Set the receiver at least two meters away from the laser and observe the LED turns on when hit. 2. Change the supply voltage to 2.5V and redo Verification 1. Then change the supply voltage to 4.2V and redo Verification 1.

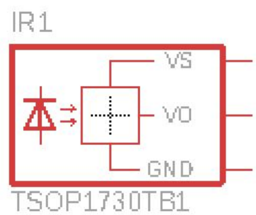

Figure 7: IR receiver circuit

2.3 Motor Controller

The motor controller is responsible for receiving data from the controller and to drive the motors to control the robot's traversal.

2.3.1 H Bridge

For the first part of the motor controller, we will use the TB6612FNG H Bridge chip. This chip will oversee controlling the direction of movement of each wheel. The control signals to drive this chip will come from the microcontroller. This chip will pass the output of the DC to DC converter to the motors in a controlled manner.

Requirement	Verification
1. This chip must work with a 60 kHz PWM generated by the microcontroller.	1. Program the microcontroller to produce a 60 kHz PWM that is tied to simple motor control logic that tests both motors. Verify the desired motor functionality is produced.

2.3.2 DC to DC converter

The DC to DC converter will be inserted between the battery and the motors. It will take in the 3.6V from the battery and increase it to 12V with a loss of current. The converter is tunable, so we will test a range of values to find the best performance for our design. The output of the converter will be given to the H-Bridge where it will be used to power the motors.

Requirement	Verification
1. The converter must take the 2.5V - 4.2V produced by the battery and increase it to 12V plus or minus 1 volt.	1. Attach the battery to the DC to DC converter and probe the output pins with a multimeter to verify that the output voltage is between 11V and 13V. This will be tested on 4 varying battery capacity levels.

2.4 Physical Body

The physical body is the housing for all the components and will consist of the magnets that hold the chassis to the board.

2.4.1 Start Button

The start button will rest on the top of the car. When this button is pushed, the car will begin its cleaning sequence. For the button, we will use a standard push button. The push button will be routed to the microcontroller which will control the start logic.

Requirement	Verification
1. The push button must turn on the robot to start the cleaning sequence.	1. Have the start button connect to the microcontroller which will monitor the pin and light up a LED when the button is pressed signaling the start of the cleaning sequence.

2.4.2 Motor

For the motors, we will use the RioRand 60 RPM high torque motor. We need to go with a high torque motor to overcome the frictional forces of the magnets and wheels. The motors will get their power from the H bridge and use it to spin the wheels.

Requirement	Verification
1. The current draw of spinning the wheels under no load must be less than on average 200mA. 2. The motor must be a high torque motor that produces around 60 RPM when driven.	1. Use multimeter to monitor the current draw under a no load condition and verify that the current draw is below 200mA. 2. Power the motors directly with the battery and count the number of rotations of the wheel by eye.

2.4.3 Magnets

The magnets will be used to hold the chassis to the board. The exact magnets have not been determined but will most likely be neodymium bar magnets.

Requirement	Verification
1. The magnets must be able to hold the 3lb car to the board while still giving maneuverability to the car.	1. Attach the magnets to the car and then put the car on the board to verify that the magnets will hold the car up. Then, hook up the battery to the motors and see if the car is capable of moving in straight lines on the board.

2.4.4 Eraser

The eraser will be mounted under the chassis and will be the primary method for erasing the board.

Requirement	Verification
1. The quality of the eraser should be high enough to erase the board in no more than two passes. 2. The user must be able to swap the erasers out without any additional tools other than their hands.	1. Write on a whiteboard varying lines of different thicknesses and have the car drive in a straight line over them once or twice. After this, verify that the line can be erased fully after the first or second pass. 2. Have someone not familiar with our project attempt the swap out the erasers.

2.5 Outside Signal

2.5.1 IR Lighthouse

To help sense the edge of the board, we will have four IR lighthouses. These lighthouses emit an IR wave which the robot will receive. Each lighthouse will be individually attached to the board magnetically. Each lighthouse will also have its own power supply. The lighthouses will require a one time set up when the robot is applied to a new board.

Requirement	Verification
1. The lighthouse must produce at least a 850 nm wave that can be detected at a distance of 2 meters.	1. Purchase a IR receiver that works with the same spectrum and have the receiver drive a LED when hit with the laser. Vary the distance between the laser and receiver to ensure the lighthouse meets the 2 meter requirement.

2.6 Tolerance Analysis

The most important tolerance for our project is the ability of the car to detect the edges of the board that are outlined by the IR lasers. If this is not possible, the car would drive off the board rendering it useless. The target sensing distance we want is two meters. This means that the signal generated by the IR lighthouses is able to trigger the IR receiver at a distance of two meters. The IR lighthouses must have a narrow enough half intensity angle so that the IR receiver does not get triggered to early and fail to erase large parts of the board.

The difference in half intensity angles is crucial if the half radiant intensity is still large enough to trigger the receiver. Since intensity falls of as $1/r^2$, when the robot is around 6 feet away from the lighthouse picking up half intensity strong enough to trigger the receiver will not pose to be a huge problem. However, as the robot gets closer to the IR lighthouse this could become an issue. The comparison of two different half angle intensity IR emitters is shown below.

For a half intensity angle of 17° (shown in Figure 8 [2]) and a height of 1 feet:

$$tan(\theta) = \frac{x}{y} \Rightarrow ytan(\theta) = x = .30573\,ft \cdot \frac{12\ in}{1\ ft} = 3.67in$$

For a half intensity angle of 17° (shown in Figure 8) and a height of 3 feet:

$$tan(\theta) = \frac{x}{3y} \Rightarrow 3ytan(\theta) = x = .91719\,ft \cdot \frac{12\ in}{1\ ft} = 11in$$

For a half intensity angle of 5° (shown in Figure 9 [3]) and a height of 1 feet:

$$tan(\theta) = \frac{x}{y} \Rightarrow ytan(\theta) = x = .087\,ft \cdot \frac{12\ in}{1\ ft} = 1.04in$$

For a half intensity angle of 5° (shown in Figure 9) and a height of 3 feet:

$$tan(\theta) = \frac{x}{3y} \Rightarrow 3ytan(\theta) = x = .262\,ft \cdot \frac{12\ in}{1\ ft} = 3.15in$$

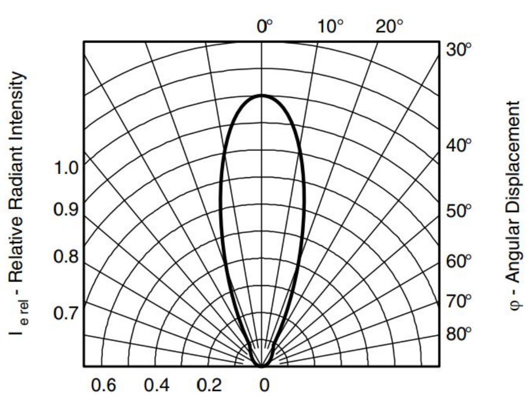

Figure 8

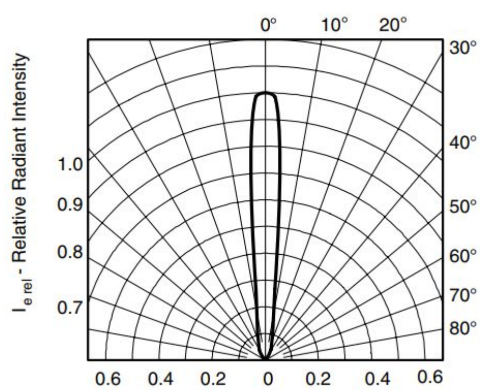

Figure 9

To test and verify this behavior, we will use the TSOP38438 IR receiver and the TSTS7100 IR laser. The IR receiver will be connected to a LED which will provide us a visual signal when the IR receiver picks up the correct light. We will position the laser so that it emits in a straight line with no obstacles in the beam path. Starting with the receiver three centimeters from laser, we will slowly move the receiver farther and farther away. We will note the distance the receiver is no longer able to detect the laser and verify that it is more than two meters.

3 Cost and Schedule

3.1 Cost Analysis

3.1.1 Labor Analysis

For this project we have two types of cost: cost of labor and the cost of parts. The cost for labor is calculated based on the average starting salary for students graduating with a bachelor's degree in computer engineering and electrical engineering. The average starting salaries are those reported in 2016 - 2017 by UIUC graduates [4]. The calculation is also based on working 10 hours per week for 13 weeks, which is the number of weeks from the projects approval until its required completion. The calculation is performed below:

$$\left(\frac{\$96{,}518\ /yr}{52\ wks/yr} \cdot \frac{1\ wk}{40\ hrs} \cdot \frac{10hrs}{1\ wk} \cdot 13wks\right) + \left(\frac{\$71{,}166\ /yr}{52\ wks/yr} \cdot \frac{1\ wk}{40\ hrs} \cdot \frac{10hrs}{1\ wk} \cdot 13wks\right) = \$10,480$$

3.1.2 Part Analysis

The part analysis is shown in the table below:

Description	Manufacturer	Part #	Quantity	Cost
Lithium-Ion Battery 3.6 V, 2.5 AH	LG	LGDBHE41865	1	$4.79
Battery Charging IC	Sparkfun	PRT-10217	1	$7.95
Microcontroller	Microchip	Atmega328p	1	$1.46
Accelerometer	Bosch	BMA255	1	$1.37
IR Receiver	Vishay Semiconductor	TSOP38438	2	$2.16
IR Emitter	Vishay Semiconductor	TSTS7100	4	$11.50
H-Bridge	Sparkfun	TB6612FNG H	1	$5.95
DC-DC Converter Module	Sunkee	Lm2577	1	$6.95
Start Button	Sparkfun	COM-09190	1	$.50
Motors	RioRand	N/A	2	$26
Wheels	Shaluoman	N/A	2	$7.00
Magnets	x-bet Magnets	N/A	2	$13.99
Eraser	Expo	N/A	1	$3.20
Total				$92.82

The grand total of this project including labor and parts is $10,572.82 plus whatever it takes to build the chassis if the machine shop is used.

3.2 Schedule

Week	Task	Person
10/8/2018	Rough test of magnets on model car.	Jimmy
	Order IR receivers and transmitters.	Thomas
10/15/2018	Talk to machine shop with updated spec. Teamwork evaluation.	Both
	Test receiver and transmitter distances.	Thomas
10/22/2018	Work on PCB design.	Both
	Order the rest of the materials.	Jimmy
10/29/2018	Program microcontroller with I/O and motor control logic.	Thomas.
	Begin soldering with the first revision of the PCB.	Jimmy
11/5/2018	Have chassis of car to begin mounting wheels and motors.	Jimmy
	Attach sensors and have fully programmed microcontroller.	Thomas
11/12/2018	Begin designing the second version of the PCB.	Both
	Debug motor control logic.	Both
11/19/2018	Solder the second revision of the PCB.	Jimmy
	Enjoy Thanksgiving break.	Both
11/26/2018	Put the car together and double check every functionally.	Thomas
	Get ready for mock presentation.	Both
12/3/2018	Get ready for actual presentation.	Both
	Begin final paper.	Both

4 Safety and Ethics

4.1 Safety

This project contains a few potential safety hazards. The first of these being the use of Lithium ion battery. Lithium ion batteries can explode especially if they experience thermal runaway. The more energy the cell has stored the more energetic the resulting thermal runaway. The most severe thermal runaway results when the cell is at full electrical capacity or is overcharged [5]. Our design will prevent this because the USB charging IC has built in regulators to ensure the battery does not get overcharged. The DC to DC converter will also regulate the output side of the battery. The converter will also assist with controlling any odd voltage and current outputs the battery may have.

Another safety hazard could be skin-damaging effects caused by IR light exposure; however, it has also been found that low energy exposure to near-infrared light can be beneficial to humans. [6]. Our design will alleviate any potential issues since the IR emitters being used would be low power and in the near infrared range (approximately 940nm). None of the emitters will be pointed in the direction of people, but instead will be forming a square around the board. The IR emitters and detectors will be very similar to ones used for things like wireless remotes and other everyday applications.

4.2 Ethics

Potential ethical concerns follows the ninth code in the IEEE Code of Ethics: "to avoid injuring others, their property, reputation, or employment by false or malicious action" [7]. This project could possibly injure others in a couple scenarios. If the robot loses traction to the board and falls to the ground the robot could potentially injure the foot. Since it is a moving object, it could also collide with the user's hand while they are writing on the board. These injury concerns are easily avoided since the robot must be lightweight to stick to the board. The robot's weight will not be substantial enough to cause sufficient injury to the user. In addition, since the robot is lightweight and will not be moving that fast, the momentum it possesses will not be enough to injure a hand. It is more likely that the robot will be stopped by the hand and just remain in place as it attempts to move forward.

5 References

[1]Seidle, N. "SparkFun_Lipo_Charger_Basic-microUSB_v10." *Sparkfun*, 2015, cdn.sparkfun.com/datasheets/Prototyping/SparkFun_Lipo_Charger_Basic-microUSB_v10.pdf.

[2] "High Power Infrared Emitting Diode, 940 Nm, GaAlAs, MQW." *Vishay Semiconductor*, 8 Feb. 2017, www.vishay.com/docs/81010/tsal6200.pdf.

[3] "Infrared Emitting Diode, RoHS Compliant, 950 Nm, GaAs." *Vishay*, Vishay Semiconductor, 2017, www.vishay.com/docs/81047/tsts7100.pdf.

[4] Services, Engineering IT Shared. "Undergraduate Degree History." *Fields of Specialization :: ECE ILLINOIS*, 2018, ece.illinois.edu/about/degree-history.asp.

[5] Long, Thomas R., and Michael Kahn. "Lithium-Ion Battery Hazards ." *Effectiveness and Reliability of Fire Protection Systems - SFPE*, SFPE, www.sfpe.org/page/2012_Q4_2/Lithium-Ion-Battery-Hazards.htm

[6] Barolet, Daniel, et al. "Infrared and Skin: Friend or Foe." *Current Neurology and Neuroscience Reports.*, U.S. National Library of Medicine, Feb. 2016, www.ncbi.nlm.nih.gov/pmc/articles/PMC4745411/.

[7] "IEEE Code of Ethics." *IEEE - Advancing Technology for Humanity*, Ieee, www.ieee.org/about/corporate/governance/p7-8.html.