SMART BLACK/WHITEBOARD

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Abstract

Although PowerPoint and electronic boards are widely used in presentation nowadays, black/whiteboards are still not replaceable in some situations. Yet cleaning the board could be time consuming and troublesome. We present a low cost smart black/whiteboard cleaning system to release presenters from the trouble of cleaning the boards. In this paper, we focus on design, implementation, and verification of our smart black/whiteboard cleaning project. A brief discussion on cost, ethical considerations, and future work is followed.

Contents

1. Introduction

1.1 Purpose

Cleaning boards seems like a trivial problem to some of us. However, this is often an irritating problem to presenters. This “trivial problem” could break up presenter’s train of thought or lose the audience. We aim to present a smart cleaning system to take care of this problem. Furthermore, we aim to interface the system in an elegant user-friendly way. Fumbling with remote control or buttons could be as or even more distracting than erasing board.

1.2 Features

- Commanding eraser by selecting erasing function from console.
- Partial erasing by boxing the desired erasing area.
- Emergency shutdown switch to turn off the entire system.
- Handwriting interaction with the system.

2 Design

2.1 Design Breakdown

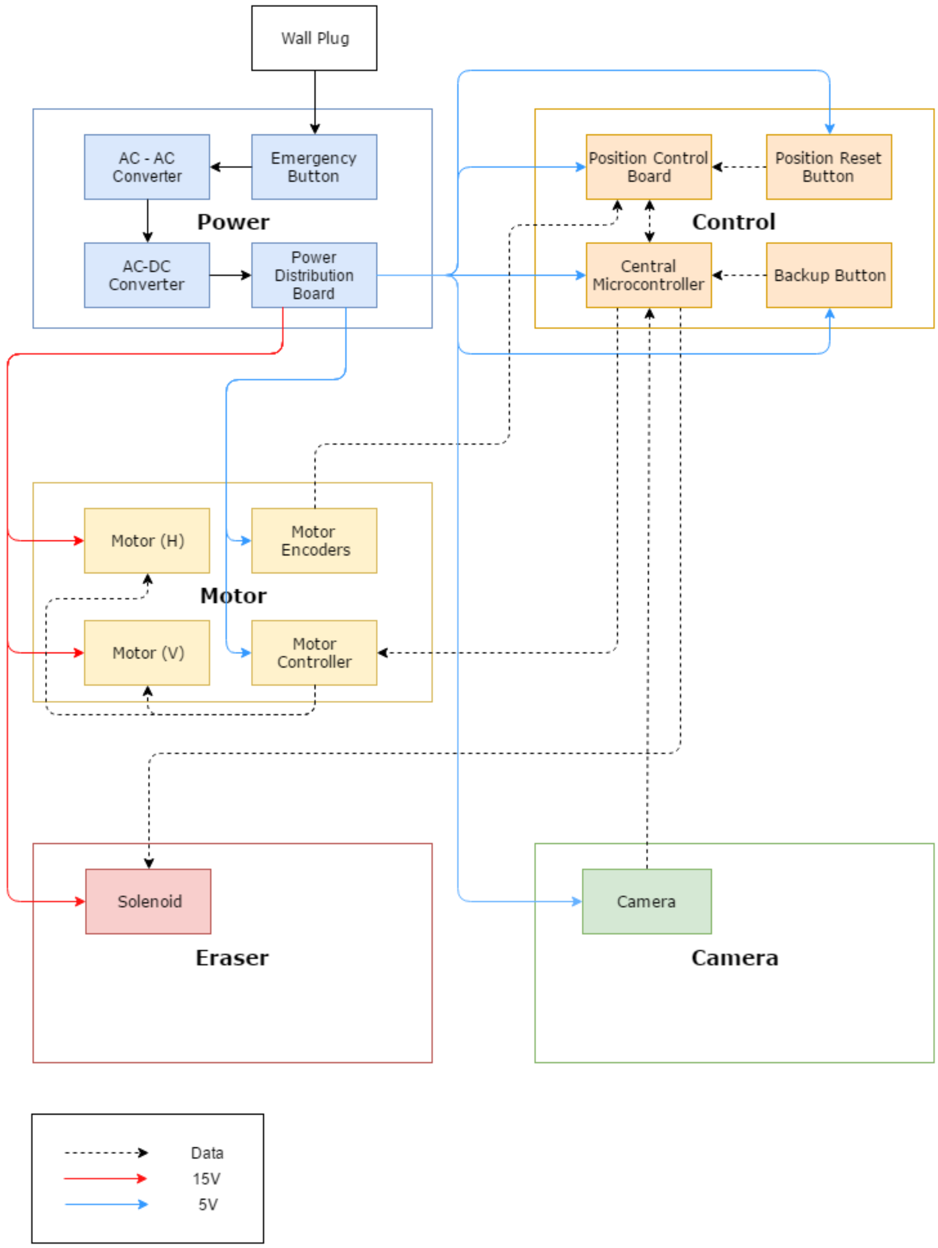

Figure 1 System Block Diagram

As presented in Figure 1, this project consists of 5 modules: power, control, motor, camera, and eraser. Power module converts 120V AC from wall outlet to 15V DC to support motor and eraser module and 5V DC to support control module. Control module collect position information from motor module and camera module to decide how the motor should move. Motor module takes PWM signals and drives motors accordingly. Camera module takes a picture of the board every two seconds and send the image to control module for command and position recognition. Eraser module presses or holds the eraser according to command signal from control module.

2.2 Design Details

2.2.1 Mechanical Design

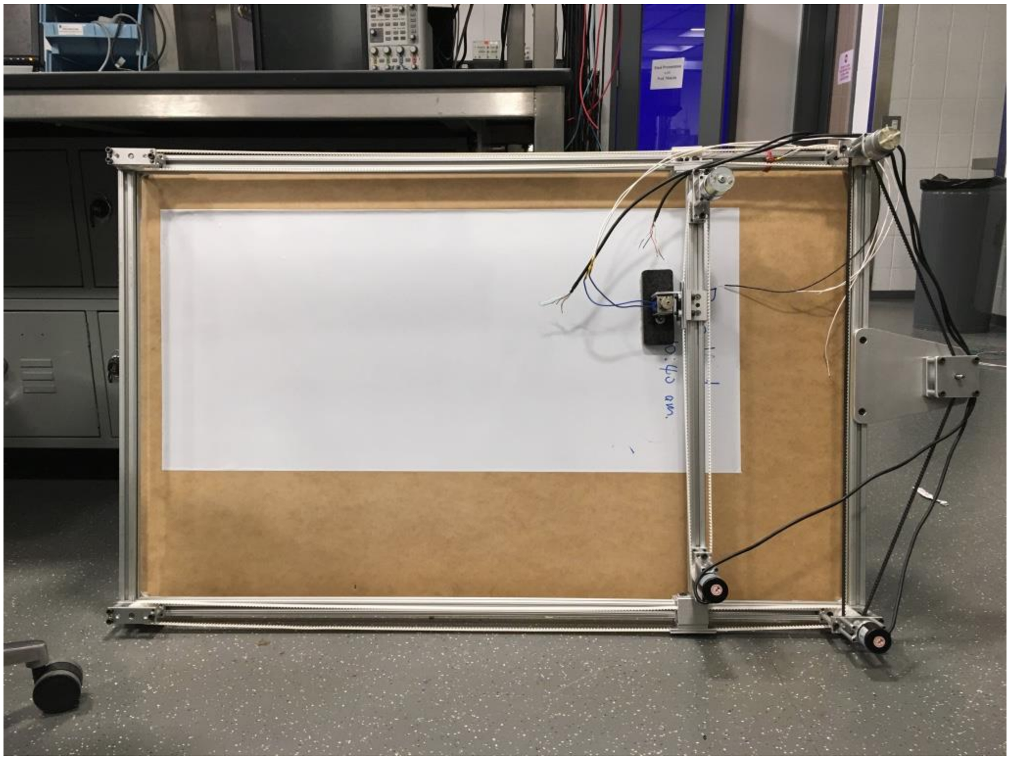

Figure 2 Mechanical Design of the system

The board is mounted against a metal frame that holds together the entire system. The top and bottom side of the frame serves as the rail for the vertical eraser holder. The eraser holder itself serves as the rail for the eraser to travel on the vertically. The first motor is on the left side of the top track. It moves the belt to move the eraser holder attached to it. The second motor is on the top side of the eraser holder. It moves the belt to move the eraser attached to the eraser holder.

2.2.2 Power Module

The power module takes 120V AC power input from wall. First, An AC to AC converter drops the voltage from 120V AC to 12 $\surd$3 AC. Then a AC to DC converter converts AC power to DC. Finally, a power distribution board would regulate the DC power to 15V to support motor module and 5V to support control board.

As we are working with 120V power supply, safety is a major concern. A mechanical switch is installed between the wall power supply and the rest of the system. This switch cuts of the entire system from power instantaneously.

Common US household power outlet provides 120-volt AC with 60 hertz power. The first step is to step 120-volt AC down for later DC rectifying. To simulate the circuit in SPICE, we use two inductors to simulate the functionality of a transformer. Since we need around 12~16 V for later voltage regulating, we are stepping the wall power down by 10. As shown in Fig.2. Using Equation. 1:

V1/V2 = N1/N2 = 120/12 = 10:1. (Equation. 1)

We selected a 120 AC to 12 √ 3 AC transformer, with a max 3.3A current, accordingly.

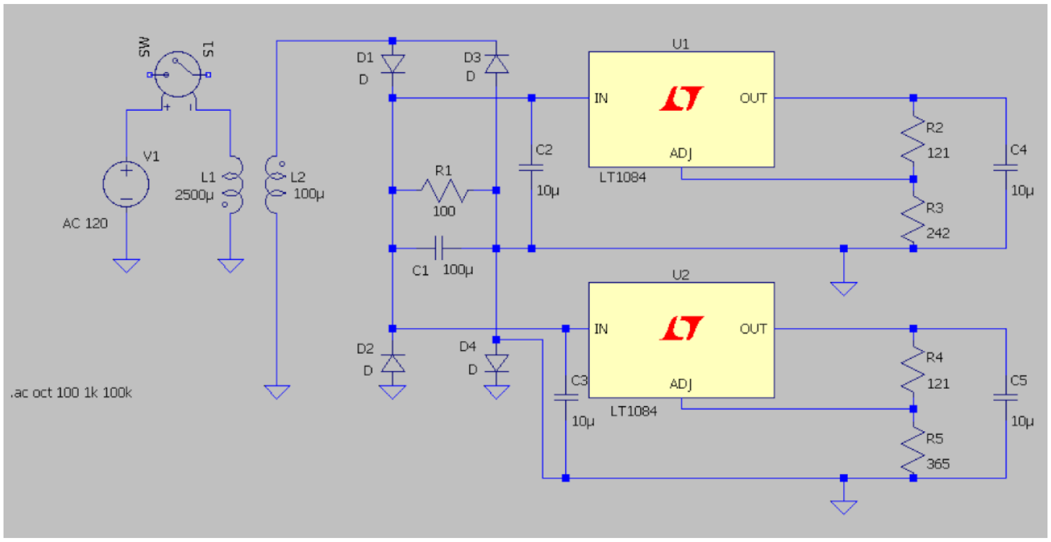

Figure 3 Power Conversion and Distribution Board Circuit in LTSpice

Moving on to the second step, we need to convert the AC power to DC power. In this step, we use 4 regular diodes(1N4004) to redirect the AC current flow to convert it into DC power (Full-wave bridge rectifier.) We are also using a 10uF capacitor in parallel with the output load resistor to smooth out the voltage ripple, which is about 24 V DC.

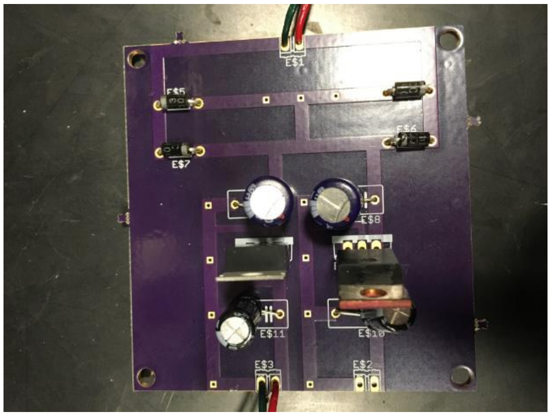

Figure 4 Image of power distribution board

After researching several qualified motors from the motor torque calculations from 2.2.3, we decided to use a 12-24V motor with the stall current of 1.8 A. We also acquired a solenoid for pressing the eraser that runs on the same voltage range. The solenoid draws 400 mA when pressed against the board. For the control board, the microcontroller voltage intake is 5 V and current only ~150mA. Based on above specs, we choose the distribution board's final output voltages to be 15 V and 5 volts.

In the power distribution step, we used two voltage regulators (LM7815 and LM7805) to regulate the 24 VDC to 12 VDC and 5 VDC to supply other modules. A 100uF capacitor is added in parallel to the output load to smooth out the voltage outputs ripple.

2.2.3 Control Module

The control module contains two major parts: a control board and a Raspberry Pi 3[1]. The control board keeps track of the eraser position on the board. It compares the position of the eraser with the destination provided by Raspberry Pi. The Raspberry Pi takes input from the camera module. It recognizes commands and erasing area information from the picture.

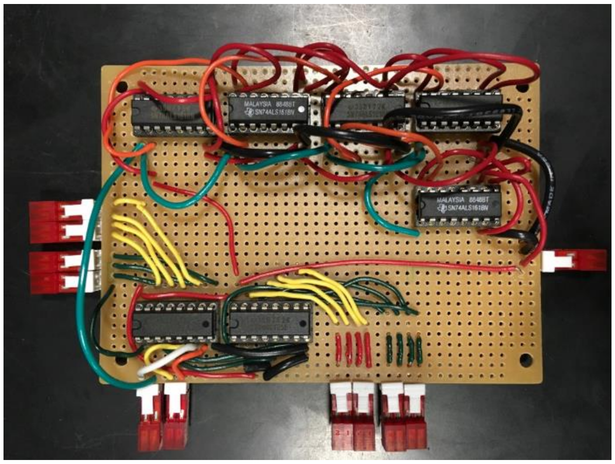

Figure 5 Image of control board

Our control strategy is straightforward. Run motor in the direction of the destination until eraser position equals destination. We chose to use incremental encoders to keep track of eraser position on the board. We also considered using computer vision method to keep track. However, as we capture the image every two seconds, computer vision is not a reliable way to do a precise control of the motors.

2.2.4 Motor Module

The motor module takes care of transforming PWM signal to power that drives the motors. The motor driver is powered by 16V power from the power distribution board. It is controlled via two BJTs connected to the PWM pins from Raspberry Pi. Turn on one BJT drives the motor forward. Turn on the other drives the motor backward. Both off to stop the motor. These two BJTs can't be turn on at the same time.

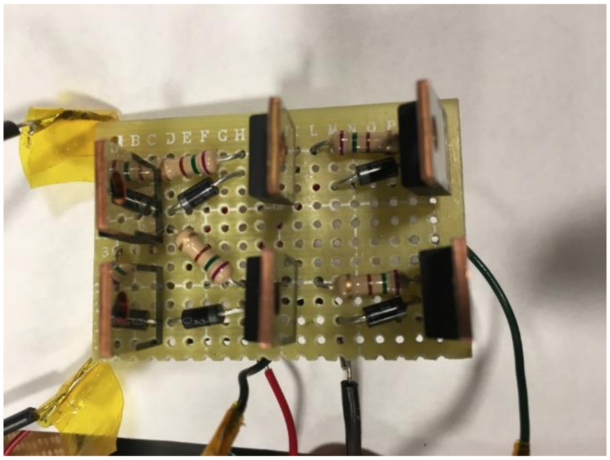

Figure 6 Image of H-bridge

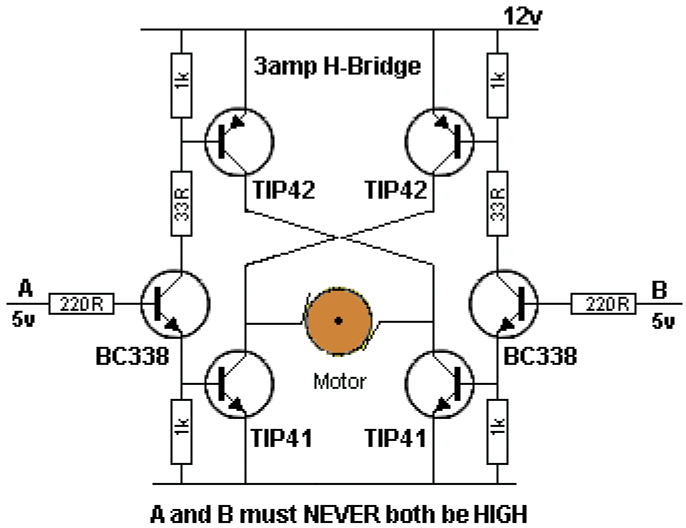

Figure 7 H-bridge circuit design [2]

We want our smart cleaning system to be able to clean the board at least as fast as human. If we consider a 90cm * 50cm (diagonal 40 inches) board, average human speed is 20 seconds (after testing using a 5cm * 12.5cm eraser). For our system to cover the same area. The eraser need to go over the horizontal length 50/12.5 = 4 times. Thus, the speed of the eraser need to be at least 360 / 20 = 18 cm/s.

Later we calculate motor torque based on the mechanical design's friction. To find out an appropriate motor for moving the eraser, we need to find out how much torque is required by finding out (1) the friction between the eraser and the blackboard and (2) the friction between the rail and wheels.

(1) After testing, we find out when we apply around 11.5N on a 10cm * 12.5cm eraser, it is sufficient to clean the board. The friction we measured is 4.5 N.

Eraser contact surface area: 10cm * 12.5cm = 125cm^2 = 0.0125m^2

Pressure: F / A = 11.5 N /0.0125m^2 = 920Pa

Friction coefficient: F_f / F_n = 4.5N / 11.5N = 0.39

We plan to use a 5cm * 12.5cm eraser

Eraser contact surface area: 5cm * 12.5cm = 62.5cm^2 = 0.00625m^2

Normal force to achieve same pressure: 0.00625m^2 * 920Pa = 5.75 N

Friction between eraser and board: 5.75N * 0.39 = 2.25N

(2) Since we don't have the rails and wheels ready yet, the best we can do is make an educated guess here. The entire structure on the rail should be less than 1 kg. Thus, the normal force on the rail should be less than 10 N. We plan to use steel rail and plastic wheels. Thus, the friction coefficient is 0.1~0.3. [3]

Friction between wheel and rail is less than: 0.1~0.3 * 10N = 1 ~ 3 N

Thus, we have the maximum friction: 2.25N + 3N = 5.25N. Assume we are winding the wire around a 2cm radius pipe. We need a min torque of 5.25N*2cm = 10.5 N*cm

2.2.5 Camera Module

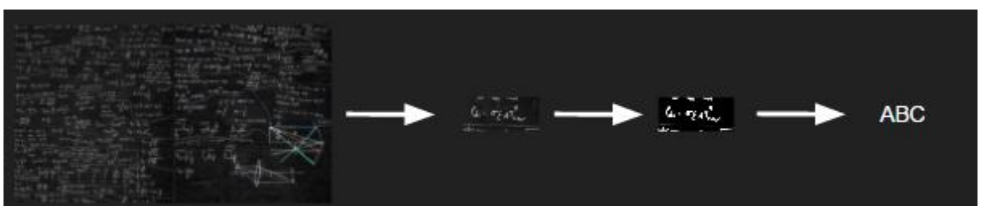

Figure 8 Illustration of KNN

The camera module takes picture of the board every two seconds and send to raspberry pi to determine which command to execute and what area of the board to erase. We used KNN, K-nearest neighbors, algorithm in OpenCV to match captured letters to training data to determine the handwriting. First, we separate words from the picture. Then we would do a set of transforms such as increasing the contrast to let the word stand out. After that, we would separate word into individual letters and find the most likely letter according to feature points.

2.3 Design Modification

2.3.1 Mechanical

We used sliders and rubber belt instead of wheels and steel cable in our final design. Rubber belt is less expensive than a custom-made steel cable winder.

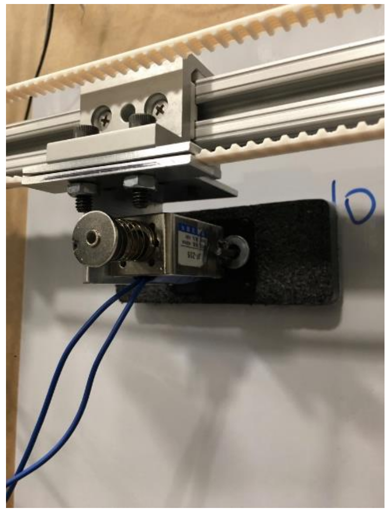

Figure 8 Image of rubber belt

However, it introduces larger friction for the motor to overcome. In consequence, it puts a heavier load on the power system. This trade off should be considered in future application of this project.

2.3.2 Motor

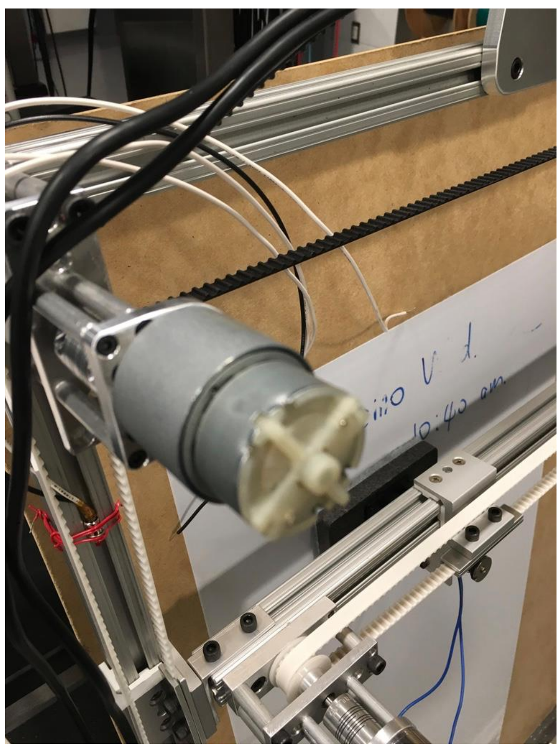

Figure 9 Image of motor

However, we latter discovered that the friction between slider and rail is the major friction the motor needs to overcome. And moreover, the friction turns out to be larger than our original estimation: the friction reaches as much as 80N. Thus, the minimum torque we need is 80N * 2cm = 160 N*cm. To achieve our original speed, we would need to take the entire system to another power level and cost level. So, we trade in the speed requirement for less power and less expensive component.

2.3.2 Voltage Converter

As we used sliders and rubber belt instead of wheels and steel cable in our final design, we raised the output voltage of the power distribution board from 12V to 15V aiming to boost up the speed of motors.

3. Design Verification

3.1 Project overall Verification

The primary goal of our project is the ability to clean the designated content on the board. We achieved this goal in the final demonstration. Our eraser system could move to indicated position, press down the eraser, and erase indicated area. After finishes, the eraser would move back to its home position and reset the position counter to clear any displacement error it accumulated during function execution.

Our handwriting recognition function, however, did not work as expected. We were unable to separate phrases from the entire picture for future recognition. We did manage to use K-nearest neighbor algorithm to recognize already separated phrases.

3.2 Verification Details

3.2.1 Power Module Verification

We started by verifying whether the output of the AC converter is the same as its datasheet. We measured a stable output of 12 √ 3 V ± 670 mV as indicated by the datasheet. Then we measured the outputs of the power distribution board. We get 15V ± 470 mV and 5V ± 270 mV. Both outputs are within range of other modules' working voltage.

3.2.2 Control Module Verification

Control module tracks eraser displacement as we expected. We measured an average displacement error of 0.47 cm. The error is well within range of the 2cm requirement. We also tested the PWM output from Raspberry Pi. It does increases the duty cycle gradually for the motor to have a soft start.

3.2.3 Motor Module Verification

The motor and solenoid actuators selection is working perfectly. The motor can run at a stable speed with a current of 400mA, and the solenoid supplies enough force to press down the eraser. The motor driver, H-bridge circuit is verified by successfully driving the motor to run forwards and backwards, whereas the solenoid actuator driver circuit, a BJT transistor could command the solenoid to press down when it is turned on.

3.2.4 Camera Module Verification

The camera module takes picture of the board every two seconds and send to raspberry pi. However, we failed to separate phrases from captured pictures.

4. Costs

4.1 Parts

	Part Name	Module	Price ($)
1	Wall Plug	Power	2
2	AC-AC Transformer Parts (transformer, diodes, inductors, resistors, capacitors)	Power	20
3	AC-DC Converter Board Parts (diodes, inductors, resistors, and capacitors)	Power	3
4	Power Distribution Board Parts (diodes, voltage regulators, inductors, resistors, and capacitors)	Power	4
			Module Subtotal: $29
5	H-Bridge Circuit	Control	3
6	Emergency push Button Switch	Control	0.5
7	Control Comparator Circuit	Control	5
			Module Subtotal: $8.5
8	Small camera	Camera	8
9	Microcontroller for image processing (Raspberry Pi)	Camera	40
			Module Subtotal: $48
10	Motor for rail	Motor	
11	Motor for eraser axis	Motor	
12	Encoder on rail	Motor	
13	Encoder on eraser axis	Motor	

14	Motor controller	Motor	
15	Solenoid	Motor	
Module Subtotal: $			
16	Eraser	Eraser	4
17	Track Structure	Eraser	20
18	Pivot	Eraser	0.5
19	Travelling wire/belt	Eraser	1
20	Small wheels	Eraser	0.5
Module Subtotal: $26			
Total: $114.75			

4.2 Labor

Name	Hourly Rate	Total Hour	Total Cost (Hourly Rate x 2.5 x Total Hour)
Yichen Gu	$30	250	$18,750
Lan Li	$30	250	$18,750
Total	$30	500	$37,500

4.3 Total

Parts	Labor	Total
$114.75	$37,500	$37,614.75

5. Conclusion

5.1 Accomplishments

Throughout these semester, we constructed and debugged a series of circuits, programmed our control system, and integrated hardware, software, and mechanical design together. We gained a much stronger understanding of each one of the module content, and integration skills of different types of modules, which will be vital to the future electrical and computer engineering careers.

5.2 Uncertainties

We befriended ourselves with the room for possible errors caused by lab equipment. Despite that bench equipment are the best debugging tools, real world circuit configurations and lab equipment errors can deviate us from our originally simulations of our design.

5.3 Ethical considerations

Ethical considerations from IEEE Code of Ethics [4]:

to accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment;

to be honest and realistic in stating claims or estimates based on available data;

to improve the understanding of technology; its appropriate application, and potential consequences;

to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others;

to avoid injuring others, their property, reputation, or employment by false or malicious action;

5.4 Future work

To continue our project in the future, we could consider using additional separation method to separate phrases from the entire frame. One method is adding boxes around commanding phrases to separate it away from irrelevant contents on the board. Since recognizing shapes is much easier than recognizing phrases, this could lover the difficulty of separating command phrases. Another method is using separate colors to do all the commanding on the board. This could also lower the difficult of recognition. Yet we should keep in mind the inconvenience each method brought to user and find a balance between recognition complexity and user convenience.

References

[1] @Raspberry_Pi. "Raspberry Pi 3 Model B - Raspberry Pi." Raspberry Pi. N.p., n.d. Web. 04 Oct. 2016.

[2] "H-bridge" Talking Electronics. N.p., n.d. Web. 14 Nov. 2016.

[3] "Coefficient of Friction, Rolling Resistance, Air Resistance, Aerodynamics."

[4] “IEEE IEEE Code of Ethics.” IEEE. N.p., n.d. Web. 04 Oct. 2016.

Appendix A Requirement and Verification Table

Requirements		Verification	Status
Power Module	AC-AC Converter Input 120V ± 5% Output 24V AC	1. Connect converter to a high voltage power supply 2. Set input to 120V + 5% AC 3. Measure if output is within range 4. Set input to 120V - 5% AC 5. Measure if output is within range	Y
	AC-DC Converter Input 24V Output 18~24V DC	1. Connect converter to a power supply 2. Set input to 24 AC 3. Measure if output is within range 4. Set input to 24 AC 5. Measure if output is within range	Y
	Power Distribution Board Input 18~24V DC Output 5V to Control 12V to Motor Current limit 6.5 A	1. Connect PCB to a power supply 2. Set input to 18V 3. Measure if both outputs are within range 4. Add motor module and sensors as loads to PDB 5. Run motor with no load and measure motor voltage 6. Hold motor at stop and measure motor voltage 7. Set input to 24V 8. Measure if both outputs are within range 9. Add motor module and sensors as loads to PDB 10. Run motor with no load and measure motor voltage 11. Hold motor at stop and measure motor voltage	Y
	Emergency Button Power cut off immediately after button is pushed	1. Connect multimeter to AC-AC converter input 2. Push button multimeter immediately go to zero	Y
Control Module	Motion Sensor Motion Sensor detects motion within 1.5m & 120 degree wide	1. Connect motion sensor to power, and output to LED 2. Stand in front of motion sensor to see if LED lights up	Y

	Motor Microcontroller Prepare	1. Connect switch to simulate motion sensor 2. Connect 9 switches to simulate H position 3. Connect 8 switches to simulate V position 4. Connect 2 switches to simulate function selection 5. Connect backup button 6. Connect motor output to four LEDs (H&V motor) 7. Connect pressure relay output to LED	Y
	Motor Microcontroller (Idle) Motor Microcontroller does not respond to any input in this state	Idle 1. Set function selection to 00 2. Set motion sensor to 0 3. Output should be 0000-STOP both motors before and after 5min 4. Pressure relay output should always be 0	Y
	Motor Microcontroller (All Erase) Motor Microcontroller controls eraser to traverse the entire board	1. Eraser start from top left corner 2. Set function selection to 01 3. Output should be 0001-HFORWARD for a while until H encoder counts matches MAX H position, shifts to 0100-VFORWARD for a step length equals eraser length, shifts to 0010-HBACKWARD for a while, repeat until V encoder reaches MAX V position 4. Pressure relay output should always be one	Y
	Motor Microcontroller (Erase) Motor Microcontroller controls eraser to traverse portion of board specified by H position input and V position input	1. Eraser start from top left corner 2. Set function selection to 01 3. Output should be 0001-HFORWARD for a while until H encoder counts matches switch simulated H position, shifts to 0100-VFORWARD until V encoder reaches switch simulated V position 4. Pressure relay output should always be zero until now 5. Set function selection to 10 6. Set switch simulated HV position to somewhere lower-right of original HV position 7. Output should be 0001-HFORWARD for a while until H encoder counts matches switch simulated H position, shifts to 0100-	Y

		VFORWARD for a step length equals eraser length, shifts to 0010-HBACKWARD for a while, repeat until V encoder reaches 6MAX V position 8. Pressure relay output should always be one until now	
Motor Module (10 points)	Motor Motors have enough torque to reach an average speed of 18 cm/s	1. Connect motor to winding pipe 2. Connect motor to power supply 3. Tie an object weigh slightly more than 5.25N on the wire to simulate friction 4. Supply 12V to the motor 5. Measure the time it takes for the eraser to traverse the entire board and calculate the average speed	Y
	Motor Controller Input 00 output stop Input 01 output run forward Input 10 output run backward	1. Connect motor controller to motor 2. Connect two switches to input to simulate two bit control signal. 3. Set input to 00 see if the motor stops. 4. Set input to 01 see if the motor run forwards. 5. Set input to 10 see if the motor run forwards.	Y
	Motor Encoder Encoder output count has less than 1% error	1. Connect motor to power supply 2. Connect motor to winding pipe 3. Connect motor encoder output to a counter 4. Run motor to wind up a wire 1 meter long 5. Calculate how many rotations the motor should run 6. See if the output counts matches rotations * resolution of the encoder	Y
Camera Module (10 points)	Camera Controller(Camera) Camera takes a picture every two seconds	1. Connect camera module to power supply 2. Connect LED to camera controller output to indicate when the camera takes a picture 3. Connect 9 LEDs to indicate H position 4. Connect 8 LEDs to indicate V position 5. Connect 2 LEDs to indicate function selection 6. Start recognition program 7. Measure if the LED indicate camera takes a picture flashes every two seconds	Y
	Camera Controller (<u>All Erase</u>)	1. Write “ALL ERASE” on the board	N

	Camera controller recognize "ALL EREASE"	2. Measure if function selection LED shows 01 within two seconds after the picture is taken.	
	Camera Controller(Erase) Camera controller recognize "ERASE" and erase area borders	1. Write "ERASE" on the board with a box (top left corner at the center of the board) surrounding it 2. Measure if function selection LED shows 01 within two seconds after the picture is taken. 3. H position LED shows 1 0000 0000, V position LED shows 1000 0000.	N