Smart Black/Whiteboard Cleaning System

ECE 445 Senior Design

Design Review

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1 Introduction

1.1 Statement of Purpose

Although powerpoint is widely used in presentation nowadays, black/whiteboards are still not replaceable in some situations. After a long presentation or lecture, it is very possible for the presenter to forget cleaning the board. It is OK if the board is filled with lecture notes. But if the it is confidential information, there will be a problem. Also it is a hassle for professors to clean up the black board every time it is all written, so we would like to design a low cost smart black/whiteboard cleaning system.

1.2 Objectives

1.2.1 Goals:

- Less time and effort spent on cleaning boards.
- Prevent unintended access to notes after presenters left.
- Interact with the cleaning system through handwriting.

1.2.2 Functions and Features:

- Allows users to clean the board through writing commands on the board.
- Allows users to decide which portion of the board to clean.
- Cleans the board automatically when room is empty.
- LED indicates which function is on.

- Writing commands choose which function to turn on.

2 Design

2.1 Block Diagram:

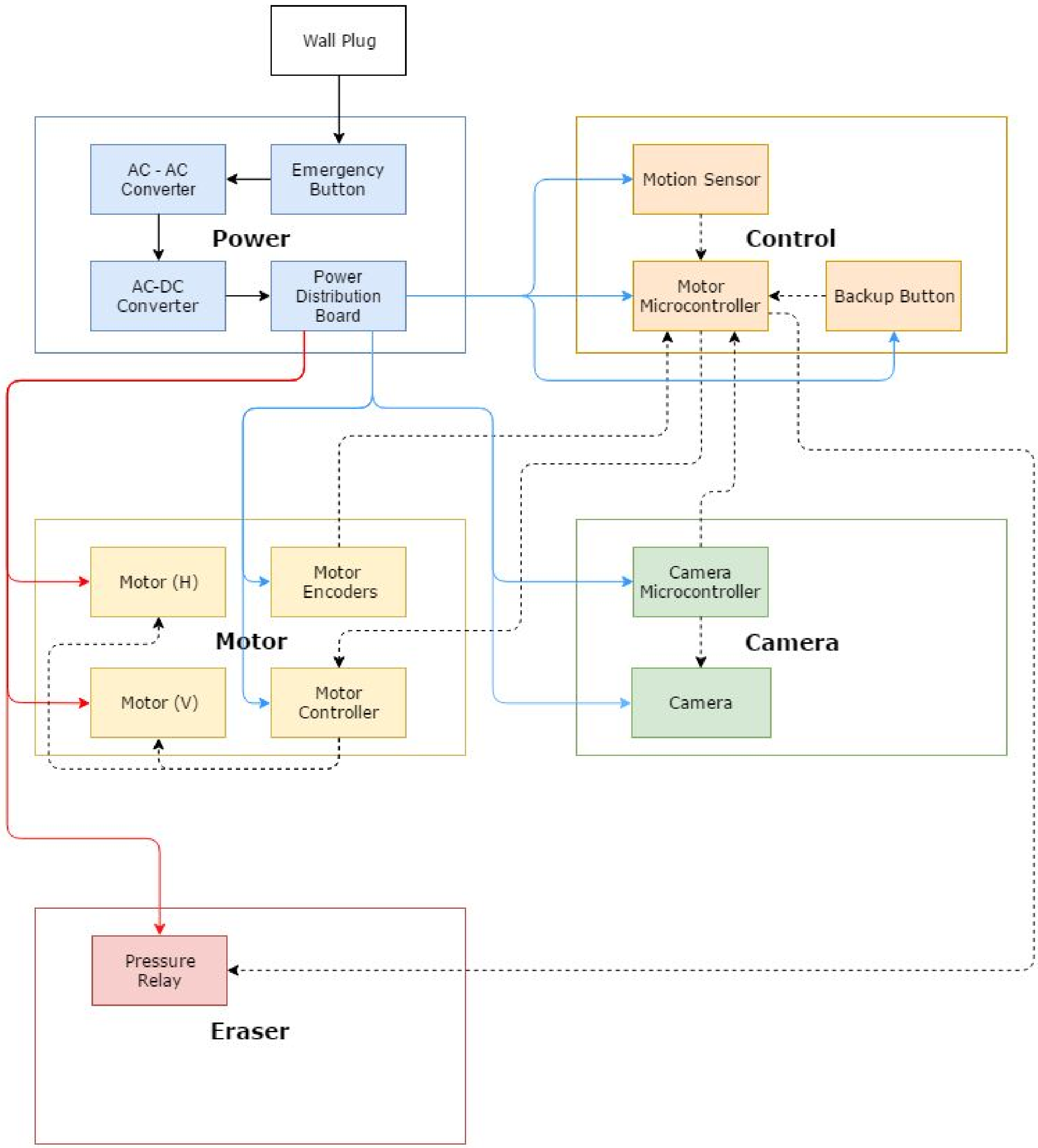


Fig.1: System Block Diagram

Red line: ~12 V power; Blue line: ~5 V power

Dashed lines: Data transmission direction

2.2 Block Description:

2.2.1 Power Module:

Input:

Power input: Wall outlet, 120V AC power.

Signal input: Emergency button, in between the power supply and the entire circuit.

Output:

Power output: 11V-13V to motor module, 4.5V - 5.5V to control board.

Internal:

Consists of an AC-AC converter to step down the voltage from wall outlet, a AC-DC converter to convert the AC power to DC power, and a power distribution board consist of two linear regulator to distribute two different voltages to other modules.

Parts:

- Wall Plug
- AC-AC Converter: Transformer[1] to draw AC voltage down. Primary Voltage: 150 - 230 V, Secondary voltage: 14V, Max Current: 6.25A.

- AC-DC Converter: Full-wave bridge rectifier with diodes[2], resistors, and capacitors.
- Power Distribution: Using two linear voltage regulators[3] to regulate the incoming DC voltage to ~12V for the motor module, and the other one to ~5V for the control module.
- Emergency Button: A physical switch between the wall current source and the entire circuit. Shuts off the system by opening the power

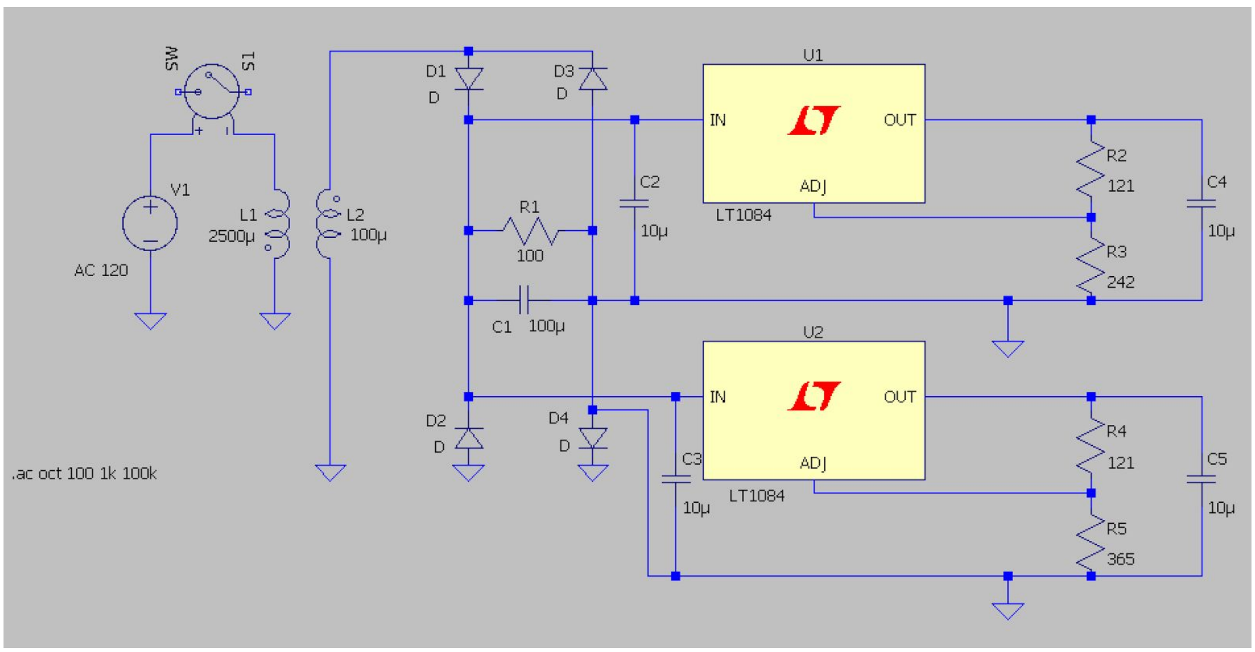


Fig.2: Power Board Circuit in LTSpice

2.2.2 Control Module:

Input:

Power input: 5V from power distribution board.

Signal input: Image processing module, motion sensor, backup button, and encoders on motors.

Output:

Signal output: Signal to motor controller module.

Internal:

The control board receives signals from image processing module, motion sensor, backup button, and encoders. It uses its own microcontroller keep track of brush position and determine when the brush should move or stop.

“ALL ERASE”: If a presenter wants to erase the entire blackboard, just write “ALL ERASE” anywhere on the board

“ERASE”: Presenter can write “ERASE” within a surrounded region on the board. Eraser will clean that portion of the board.

“CONFIDENTIAL/ANNOUNCEMENT”: When the content of the board is “confidential”, control will clean the board when motion sensor detects no motion for 5 mins. A board is default to be “confidential”, one can stop auto clean by writing “ANNOUNCEMENT” on the board.

Backup Whole-Clean Button: Located at the left side of the track, if for some reasons, the image-processing module is not responding to the cleaning command, you can still manually push the Whole-clean button to clean the blackboard.

Parts:

- Microcontroller:
- Motion Sensor: Ultrasonic Receiver (up to 3m range) on the control board, Transmitted mounted on desired locations
- Backup Button: Small push button Switch[4].

2.2.3 Motor Module:

Input:

Power input: 12V ± 5% from power distribution board.

Signal input: Signal from control module to tell the motor when to start and when to stop

Output:

Signal output: Output encoder data to control module to determine brush position.

Internal:

Run or stop the motor according to signals from control module. Motor has attached encoder to send brush position pulse information back to control module.

Parts:

- Motor Controller/H-bridge Circuit with relays. [5]
- 12V DC Motor 251rpm w/Encoder (SKU: FIT0186). [6][7]

2.2.4 Camera Module:

Input:

Camera facing the blackboard, taking one picture per second and

Output:

Transmit image-processed data to the control board for later usage.

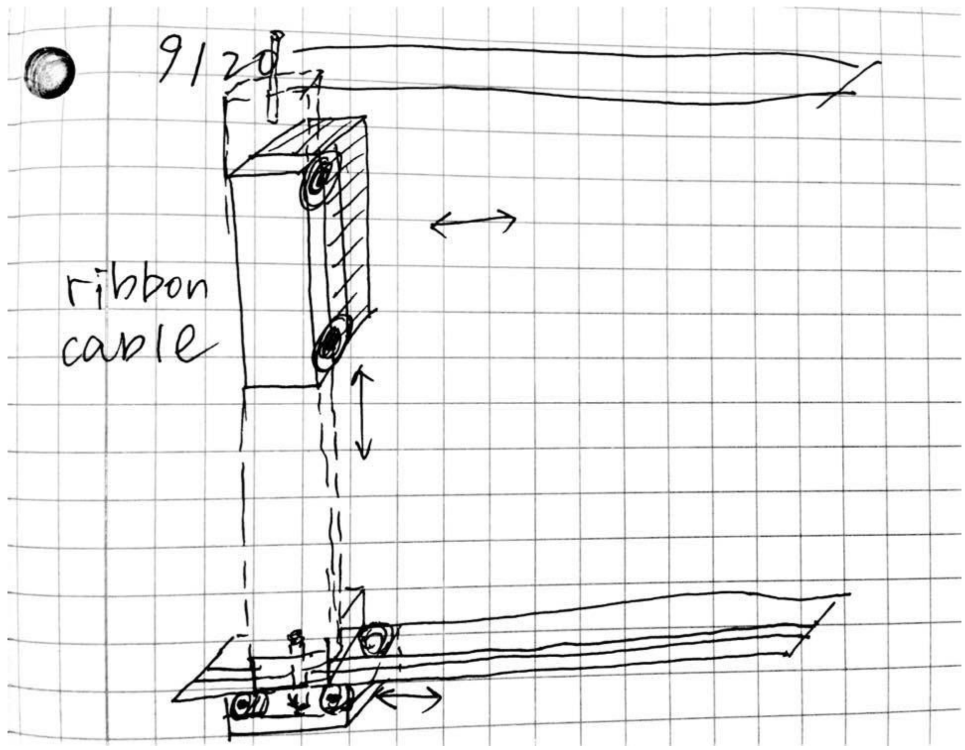
Internal:

A camera taking pictures and a microcontroller image process these picture dates to recognize if there is a cleaning command on the blackboard. When motion sensor does not detect motion, it sends a signal to the microcontroller to shut the camera off.

Parts:

- Camera: Raspberry Pi Camera Module V2[8]
- Microcontroller: Raspberry Pi 3 B[9]

2.2.5 Mechanical Design



Two tracks on the top and the bottom of the customized sized blackboard, and a vertical brush holder is attached to the tracks on both top and bottom side.

Solenoid Actuator will be used to press the brush holder down by stop supplying current to it, and the actuator will be released when constantly being supplied current.

The brush holder can travel in horizontal direction and the brush can travel in vertical direction on the brush holder.

The first motor will be on the left side of the top track, and a pulley on the right side. They move the belt to move the brush holder attached to it.

The second motor will be on the top side of the brush holder, and a pulley on the bottom side. They move the belt to move the brush attached to the brush holder.

3 Calculation

3.1 Power Board Calculation

To use the power directly from the wall, we are essentially processing 120V AC Voltage with the frequency of 60Hz. The first step is to step this high AC voltage down to a reasonable range for later DC rectifying.

To simulate the transformer part in the circuit, We need 2 inductors to mimic the functionality of a transformer. Since we need around 20~25 V for later voltage regulating, we are stepping the wall power down by 5 times.

$V1/V2 = N1/N2 = 120/24 = 5:1$.

Therefore, the inductors we used to simulate the circuit is to the ratio of 25:1.

$N1/N2 = (L1/L2)^2 = 25:1$

Moving on to the second step, we need to convert the the AC power to DC power. In this step, we are using 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 output, which is about 24 V DC.

In the power distribution step, we are using 2 voltage regulators(LT1084) to regulate the 24 VDC to 12 V and 5 V to supply other modules. (See 3.2) The resistance are calculated in the datasheet. We are also using a 10uF capacitor in parallel to the output load to smooth out the voltage outputs.

3.2 Motor Power Calculation

After researching several qualified motor from the motor torque calculations from 3.4, we decided to use a 12V motor with the maximum current intake of 6.5 A. For the control board, the microcontroller voltage intake is 5 V and current only ~150mA. Based on this data, we can now set up the 2 distribution board final output voltages to be 12 V and 5 volts.

Power module's maximum power consumption will appear when the motor is running at constant speed. (Only one motor will be running during the same time, which means horizontal axis motor can only run when the vertical axis motor stops, and vice versa.)

P_power module max = V * I = 12 * 6.5 = 78 W

3.3 Brush Speed Calculation

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).

In order for our system to cover the same area. The eraser need to go over the horizontal length 50/12.5 = 4 times. Total length covered is 90 * 4 = 360 cm. Thus the speed of the eraser need to be at least 360 / 20 = 18 cm/s.

3.4 Motor Torque Calculation

In order 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 brush 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 = 11.5N/0.0125m^2 = 920Pa

Friction coefficient: Ff/Fn = 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.[10]

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

4 Requirements and Verification

Requirements		Verification	Points
Power Module (10 points)	AC-AC Converter Input 120V ± 5% [11] 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	0
	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	5

	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	5
	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	0
Control Module (20 points)	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	0
	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	0
	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	5
	Motor Microcontroller (All	1. Eraser start from top left corner	5

	Erase) Motor Microcontroller controls eraser to traverse the entire board	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	
	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-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	10
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	0
	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.	10

		5. Set input to 10 see if the motor run forwards.	
	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	0
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	3
	Camera Controller(All Erase) Camera controller recognize “ALL EREASE”	1. Write “ALL ERASE” on the board 2. Measure if function selection LED shows 01 within two seconds after the picture is taken.	3
	Camera Controller(Erase) Camera controller recognize “EREASE” 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.	4
Total			50

5 Ethics and Safety

5.1 Power Safety.

AC power from wall can be very dangerous, so we have an emergency button to shuts off the circuit in the case of malfunctioning. A physical switch between the wall current source and the entire circuit. Shuts off the system by opening the power. Other than the most direct way, we also have several safety protection diodes in the circuit to avoid current from flowing backwards.

5.2 Content Protection

All pictures are taken real-time and can only be strictly used for the purpose of this cleaning system. All pictures will be erased after each image analyzing process for the cleaning system. Therefore, no information can be leaked from this systems.

5.3 Ethics

We found these especially important from IEEE Code of Ethics[12]:

1. 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;
2. to be honest and realistic in stating claims or estimates based on available data;
3. to improve the understanding of technology; its appropriate application, and potential consequences;
4. to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others;
5. to treat fairly all persons and to not engage in acts of discrimination based on race, religion, gender, disability, age, national origin, sexual orientation, gender identity, or gender expression;
6. to avoid injuring others, their property, reputation, or employment by false or malicious action;
7. to assist colleagues and co-workers in their professional development and to support them in following this code of ethics.

6 Cost and Schedule

6.1 Cost Analysis

6.1.1 Parts

	Part Name	Module	Price ($)
1	Wall Plug	Power	3
2	AC-AC Transformer Parts (transformer, diodes, inductors, resistors, capacitors)	Power	4
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	3
			Module Subtotal: $13
5	Microcontroller	Control	8
6	Ultrasonic Motion Sensors	Control	4
7	Backup Push Button Switch	Control	0.35
8	Emergency push Button Switch	Control	2.4
			Module Subtotal: $14.75
9	Small camera	Camera	8

10	Microcontroller for image processing (Rasberry Pi)	Camera	40
			Module Subtotal: $48
11	Motor for track	Motor	8
12	Motor for brush rotation	Motor	5
13	Encoder on rail	Motor	7
14	Motor controller	Motor	8
			Module Subtotal: $28
15	Brush	Brush	4
16	Track Structure	Brush	5
17	Pivot	Brush	0.5
18	Travelling wire/belt	Brush	1
18	Small wheels	Brush	0.5
			Module Subtotal: $11
			Total: $114.75

6.1.2 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

6.1.3 Grand Total

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

6.2 Schedule

Week	Task	Person in Charge
09/12	Talk to machine shop	Lan Li
09/19	Mock design review	Yichen Gu
	Determine details of design	Yichen Gu
09/26	Voltage converter (breadboarding + PCB design)	Lan Li
	Handwriting recognition	Yichen Gu
10/03	Design review	Lan Li
	Order parts	Yichen Gu
10/10	Power distribution board (breadboarding + PCB design)	Lan Li
	Control module (breadboarding + PCB design)	Yichen Gu
10/17	Get PCB and solder	Lan Li
	Motor controller board (breadboarding + PCB design)	Yichen Gu
10/24	Get PCB and solder	Yichen Gu
	Revising PCB design	Lan Li
10/31	Integration test and debugging	Yichen Gu
11/07	Integration test and debugging	Lan Li

11/14	Mock demo	Yichen Gu
11/21	Thanksgiving	None
11/28	Demonstration	Lan Li
12/05	Final presentation and paper	Yichen Gu

Reference

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[10] "Coefficient of Friction, Rolling Resistance, Air Resistance, Aerodynamics." Coefficient of Friction, Rolling Resistance, Air Resistance, Aerodynamics. N.p., n.d.Web. 04 Oct. 2016.

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