Self-Cleaning Table

ECE 445 Design Document

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Team 60

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2/27/20

1 Introduction

1.1 Objective

When people go out to eat at a restaurant, there are high expectations for the safety of the preparation of their food. In the US, we have the FDA to set and enforce standards related to food preparation. However, the FDA does not currently have any standards regarding the hygiene of dining areas, as can be seen from reading through the 2017 FDA Food Code [1]. States can add additional rules to this, but many states, including Illinois, also fall short in this regard [2]. In such a wealthy and developed society, nobody should be negatively affected by a person who used the same table before them.

Our goal is to design a device which will automatically clean a table between uses. We will mount a moving arm to the table, which contains all of our cleaning utensils. In order to ensure that the cleaning process occurs after every use, we will have a method for reliably detecting when patrons are present. We will also include extra safeguards which prevent cleaning at the wrong times, such as when a patron goes to the bathroom and leaves their food on the table.

1.2 Background

While most or all restaurants are willing to clear tables, many fast-food establishments rely on their customers to clean up after themselves. By providing a tray with every order of food, restaurants help avoid direct contact between food and the table. This helps to contain messes and germs, but it does not fully protect the table. If a customer makes a mess and simply chooses to not clean up after themself, then the cleanliness of the restaurant suffers. Studies show that restaurant cleanliness is among the most important factors for repeat patronage [3], as well as for restaurant quality evaluations [4]. Thus, it should always be in a restaurant's best interest to keep their dining areas as visually clean as possible. If no employee comes around to disinfect the table between uses, which is very likely during peak hours, then this also leaves potential for the spread of disease between patrons. In a study of tabletop objects in bar and grill restaurants, E. Coli was found on the surface of 4% of ketchup bottles and 8% of menus[5]. Sick customers are not going to be returning customers, so it is in everybody's best interest for tables to be disinfected between uses.

Our device will be able to clean up any reasonably sized spills and messes. If piles of garbage or large ketchup spills are detected, then our system will indicate visually and audibly that it requires an employee to help clean up. Otherwise, the regular cleaning cycle will be able to wipe down the table, leaving it both visually clean and disinfected.

1.3 High-Level Requirements

- The microcontroller must be able to use the sensors to reliably determine when people use and then leave the table.
- All components must have little or no impediment to customer use of the table, relative to the usable surface of the table and the available legroom.
- After cleaning, the surface of the table should be clear of all crumbs and small spills.

2 Design

The main device will be a moving arm which spans the shorter width of the table. The arm will move across the length of the table via a pair of guide rails and a screw drive on the underside of the table. When not in use, the arm will retract into a housing unit on the end of the table, such that it does not impede the patrons' dining space. We will know when to begin cleaning by using a motion sensor on the underside of the table to detect patrons, as well as a sensor on the arm to detect items left on the table. If no people or items are present, then the arm will spray the table with a disinfectant solution, and then squeegee the table, and then dry the table. All of these cleaning utensils are mounted to the moving arm, so the entire process requires only one pass.

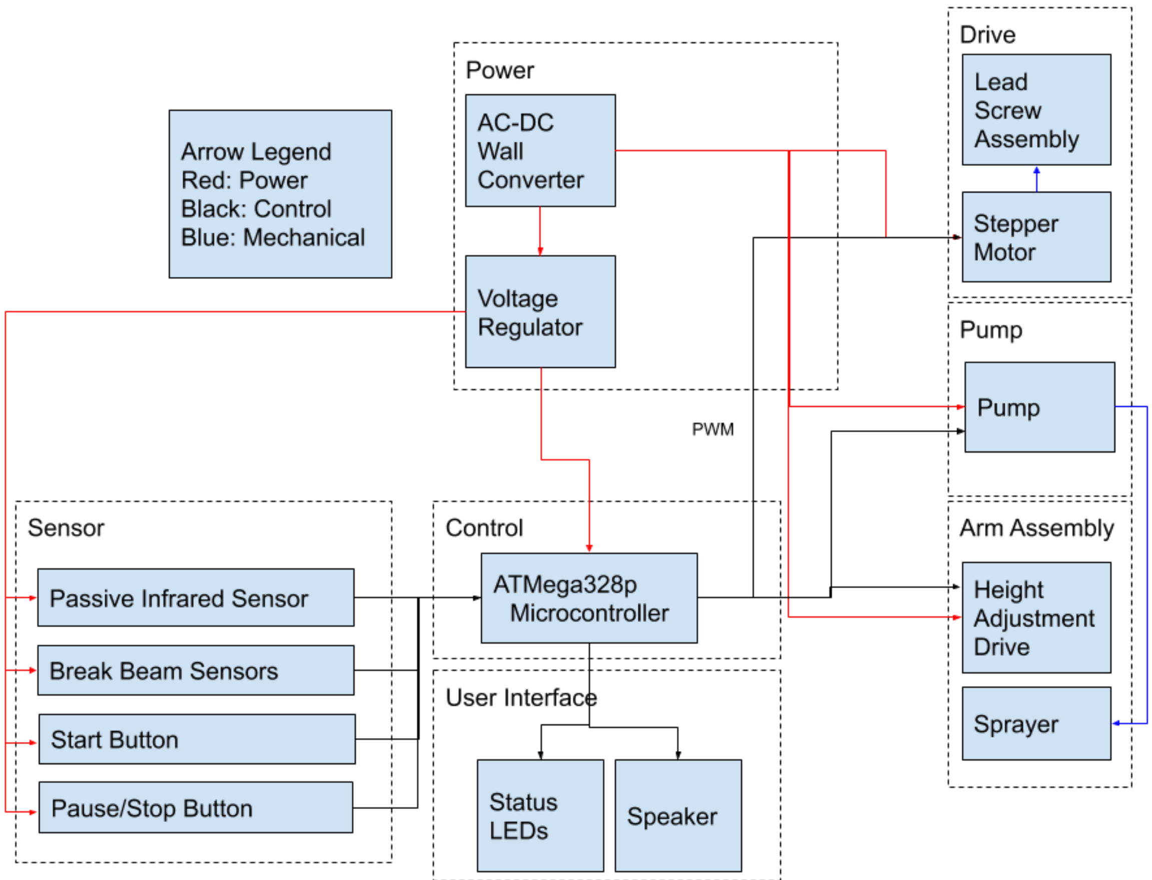

Fig 1. Block Diagram

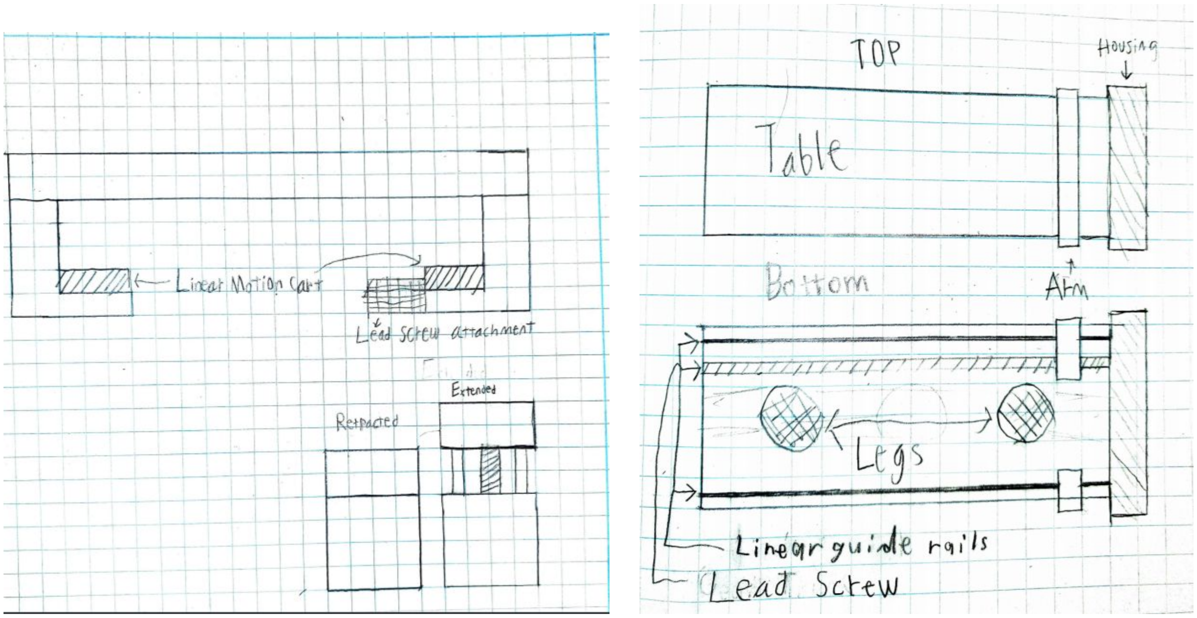

Fig. 2. Physical design sketches; Arm Assembly (left) and Arm Mounted to Table (right)

2.1 Power Supply

A Power supply is necessary to operate all subsystems. The motors, sensors and microcontrollers all need power. Power will come from a wall connection and will be regulated to power that each subsystem can use.

2.1.1 AC/DC wall converter

Will take in wall power and convert the AC signal to a usable DC voltage which will be further converted to usable voltages by the other power components. We need to step down the voltage to a reasonable level for our linear voltage regulator, but also provide enough current for powering our motor.

Requirement	**Verification**
1. Provides rated voltage to motor driver within the tolerances required by the motor 2. Provides enough power for voltage regulator and motors.	1, 2. a. Connect to power supply set to 12v to input b. Connect to wall outlet c. Connect electronic load to output d. Connect oscilloscope to output pin e. Monitor voltage across a range of currents up to 4A current draw to ensure voltage stabilities

2.1.2 Voltage Regulator

A 5v linear voltage regulator which will provide power to the microcontroller and sensors. We will be buying the regulator, and connecting it as shown in Fig. 4.

Requirement	Verification
1. Provides 5v +/- 5% to all low voltage* components. 2. Can provide rated power to each low voltage* component while all components are operating **low voltage = less than 5V*	1,2. a. Connect to power supply set to 12v to input b. Connect electronic load to output c. Connect oscilloscope to output pin d. Monitor voltage across a range of currents up to maximum current draw to ensure criteria are met. e. Will also need to be tested while connected to AC/DC converter to ensure the entire power system is accurate. f. The same procedure will occur

2.2 Control Unit

The control unit will take in sensor data and determine whether cleaning of the table can occur. This is also in charge of controlling the motion of the arms and cleaning operators, as well as providing status information for the user.

2.2.1 ATMega328p microcontroller

This controller takes in input from each sensor and determines if cleaning is safe to perform. This controller was chosen because it is one of the most popular microcontrollers for projects like this, and it is the same microcontroller as in the Arduino Uno. Because we plan to connect and monitor several devices at the same time, this seems like a great option for us.

Requirement	Verification
1. Must be able to power each LED with 10mA. 2. Must be able to provide adequate PWM to safely control the motor. 3. Must be able to power and communicate with all devices concurrently.	1. a. Wire the microcontroller on a breadboard in the same way as this tutorial: https://www.arduino.cc/en/Main/Standalone b. Flash the 'Blink LED' example onto the microcontroller, verify that the LED flashes. 2. a. Connect the drive pins of the

	motor to PWM pins on the Arduino b. Flash a basic PWM example onto the microcontroller, verify that motor turns in both directions. 3. a. Connect the PIR sensor, break beam sensor, speaker, LED's, and motor. b. Flash a program which activates all devices at the same time. c. Verify that all LED's light up, the motor spins, the speaker sounds, and the sensors are triggered correctly.

2.2.2 Status LEDs

LEDs that display the status of the table between: ready for use, waiting for clearing, and currently cleaning. We will use a green light to indicate that the cleaning operation is currently running, a yellow LED to indicate that the system has been paused, and we will blink the yellow LED if a problem has occured.

Requirement	Verification
Must be clearly visible from at least 3 meters away with drive current of 10mA.	A. Set the power supply to output 10 mA B. Connect the LED ito the power supply C. Measure 3 meters distance from LED circuit D. Ensure that LED is clearly visible when pointed in the viewer's direction

2.2.3 Speaker

Will provide an audio response to items being on the table while attempting to clean in order to notify staff to bus the table. This is only a secondary method of alerting the users, so we are choosing to use a speaker that we already owned.

Requirement	Verification
1. Must be able to be loud enough to hear from 3 meters away for notification	1, 2. A. Connect the speaker to the ATMega328, with a simple speaker program flashed to the microcontroller. B. Measure 3 meters distance from speaker

	circuit C. Ensure that speaker is clearly audible when pointed in the observer's direction

2.3 Sensors Unit

2.3.1 Passive Infrared Sensor

PIR sensors are effective motion sensors. This sensor will be placed on the bottom of the table and determine whether or not people are sitting at the table by detecting movement of their legs and feet.

Requirement	Verification
Must be able to reliably tell when people are seated at the table.	A. Connect the sensor to an Arduino B. Mount the PIR sensor, aimed towards the floor C. Load the Arduino with a program that blinks an LED when the sensor is triggered. D. Verify that the LED blinks when a person sits next to the sensor. E. Verify that the LED is off when nothing

2.3.2 Break-Beam Sensor

This sensor will be attached to the cleaning arm in order to determine if cutlery, plates, or large messes are on the table that would obstruct the cleaning process.

Requirement	Verification
Must be able to detect objects protruding from the surface of a table, with a beam gap of 9.5"	A. Connect the sensor to an Arduino B. Mount the transmitter and receiver 9.5" apart. C. Load the Arduino with a program that blinks an LED when the sensor is triggered. D. Verify that the LED blinks when a hand is placed between the transmitter and receiver. E. Verify that the LED is off when nothing is between the transmitter and receiver.

2.4 Drive Unit

The drive unit is the module responsible for movement of the cleaning arm along the table, it must be able to support the weight of the arm, and provide sufficient torque to move the arm back and forth.

2.4.1 Stepper Motor

Stepper motors are high precision motors, suited for precise amounts of rotation. This will drive the lead screw, generating all linear motion of the arm.

Requirement	Verification
Must be able to move the arm to within 1 inch of the desired position.	A.

2.4.2 Lead Screw Assembly

Has a lead screw shaft that drives the cleaning arm up and down the table. Consists of one lead screw and two linear guide rails that the arm is attached to. The linear guide rails with attached carts will guide the arm. The linear guides will be plastic sleeve bearing guides in order to limit cost and provide movement even in potentially dirt filled environments.

Requirement	Verification
1. Must be able to move the arm to within an inch of the desired position. 2. Must be able to move the arm all the way to the end of the table.	1. A. After attaching an arm we will run the arm control circuitry and measure with a ruler the distance the arm travels. B. Different lengths will be tested that will represent scale models of common table lengths

2.5 Arm Assembly

2.5.1 Height adjustment arm

Two pneumatic actuators will raise and lower the arm, in order to get the cleaning utensils off of the table surface. If we did not do this, then we would end up pushing everything onto the floor, instead of into our housing.

Requirement	Verification
Lift arm 1” to get the cleaning utensils off of the table surface.	A.

2.5.2 Sprayer

The sprayer will administer the cleaning solution from the cleaning arm onto the table.

Requirement	Verification
1. Full coverage of table with liquid. 2. No spraying off the sides of the table.	1, 2. A.

2.6 Water Pump

The water pump will take the water and cleaning product solution and pump it up to the sprayer apparatus.

Requirement	Verification
Pumps harsher chemicals than just water, specifically a bleach solution	A.

2.7 Schematics

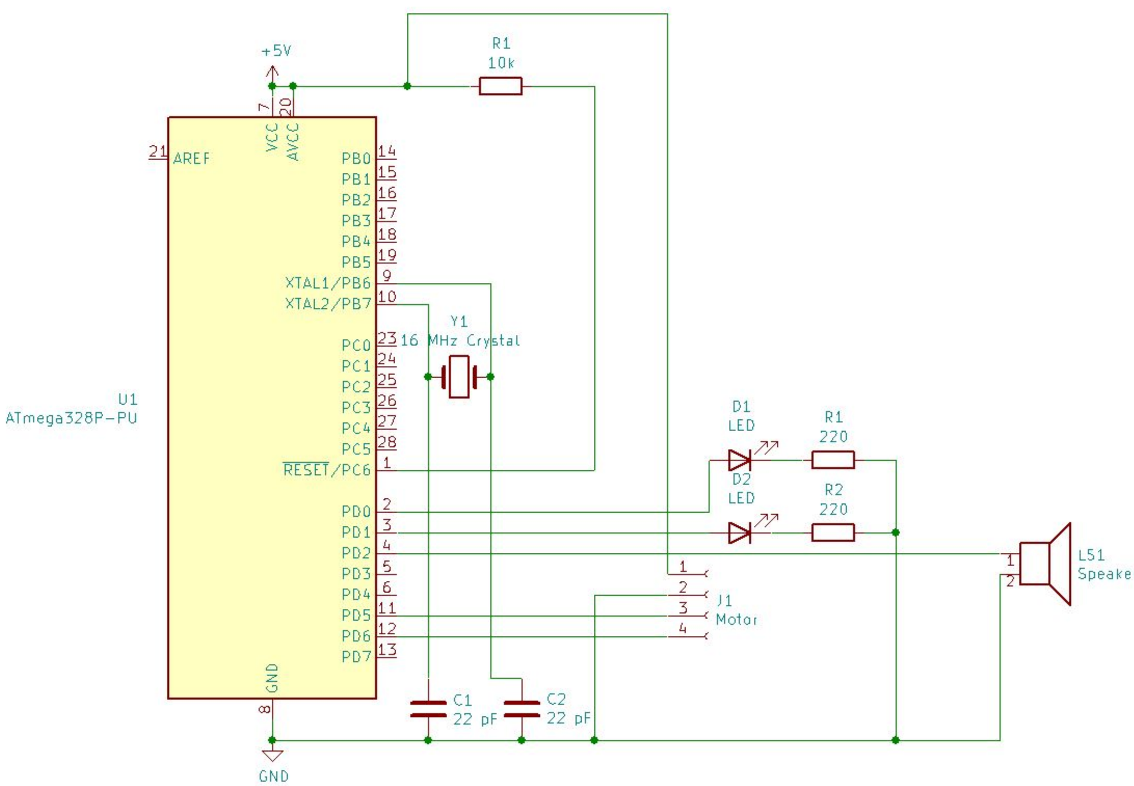

Fig. 3. ATMega328 Schematic

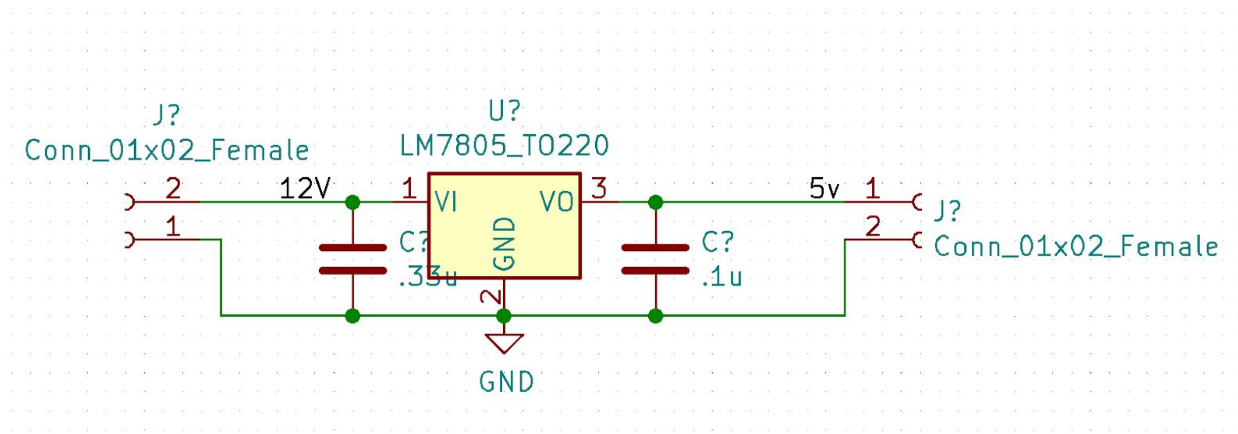

Fig. 4. Power Schematic

2.8 Board Layout

2.9 Software

The software written for the system will all need to run on the ATMega 328p microcontroller specified above. There are a few distinct and fairly simple submodules that the microcontroller will need to manage. We will use an Arduino Uno or equivalent to help debug the software and test out components, before we actually move to using the ATMega 328p.

2.9.1 State Diagram

The most fundamental thing that the software must do is keep track of the current state of our system. The expected control flow is shown in fig. 3. below, with a sub-control flow shown in fig. 4. For the cleaning cycle. A brief description of each control listed below, along with any corresponding status LED’s.

Idle: Nobody has approached the table.
Waiting: People are present at the table. Waiting for them to leave.
Cleaning: All people have left the table. The arm moves and cleans the table. Green LED on.
Pause: Pause state is for customers who are leaving the table but do not want the arm to trigger. Yellow LED on.
Error: If the cleaning cycle is interrupted (break beam sensor triggered, the motor stalls, etc.). Yellow LED blinking and speaker chirping. Waiting for reset signal.

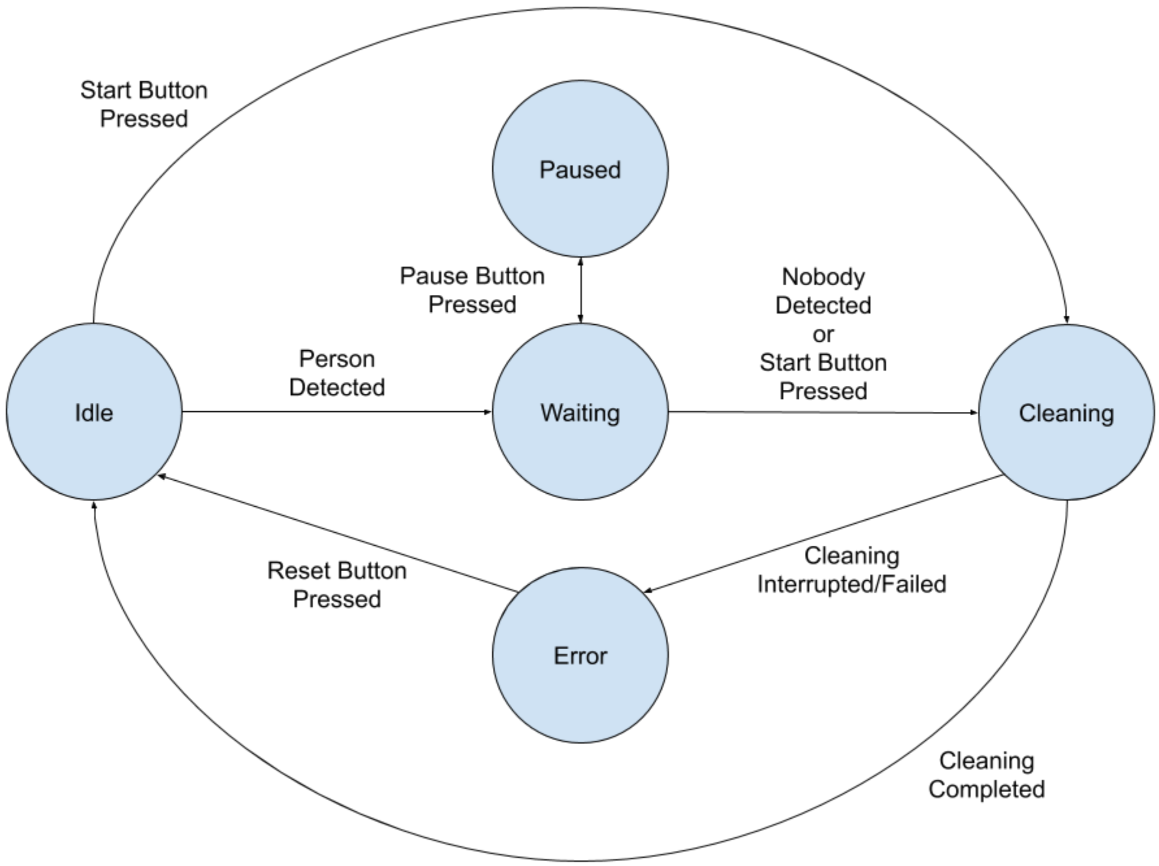

Fig. 5. Control Flow Diagram

2.9.2 Motor

The motor provides position data using built in Hall Effect sensors, which connect to the microcontroller through a pair of digital input pins. This section of code will be responsible for decoding the position data, and then keeping track of the total number of rotations that the motor has turned. It will be important to be able to differentiate between clockwise and counterclockwise motion, so that we can be careful to turn the motor only as far as necessary, and can correct for any extra turns of the motor. This section of code will also be responsible for controlling the speed and direction of the motor.

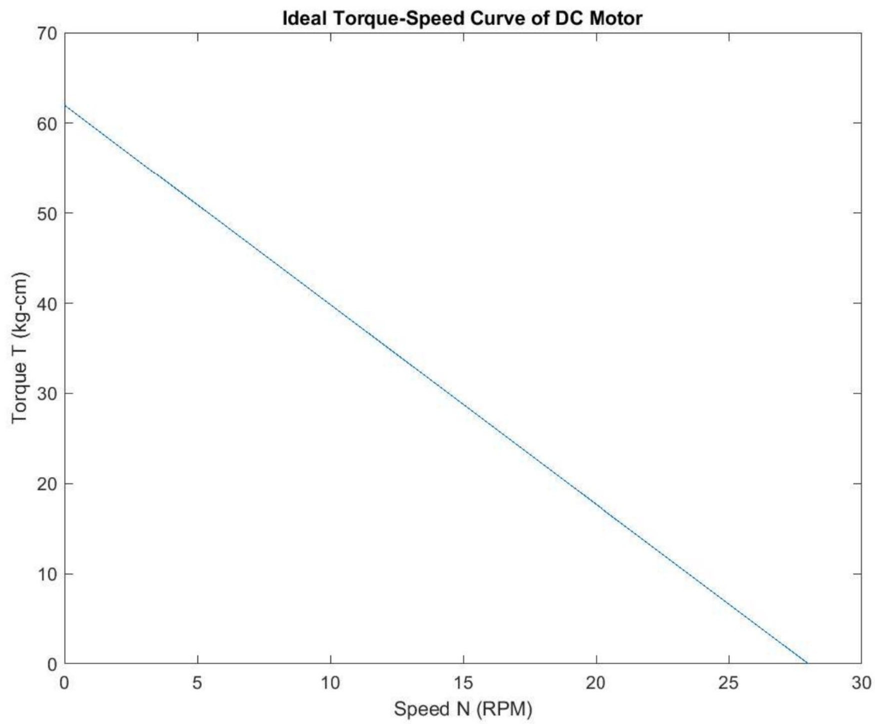

Fig. 6. Ideal Torque-Speed Curve Of Our DC Motor

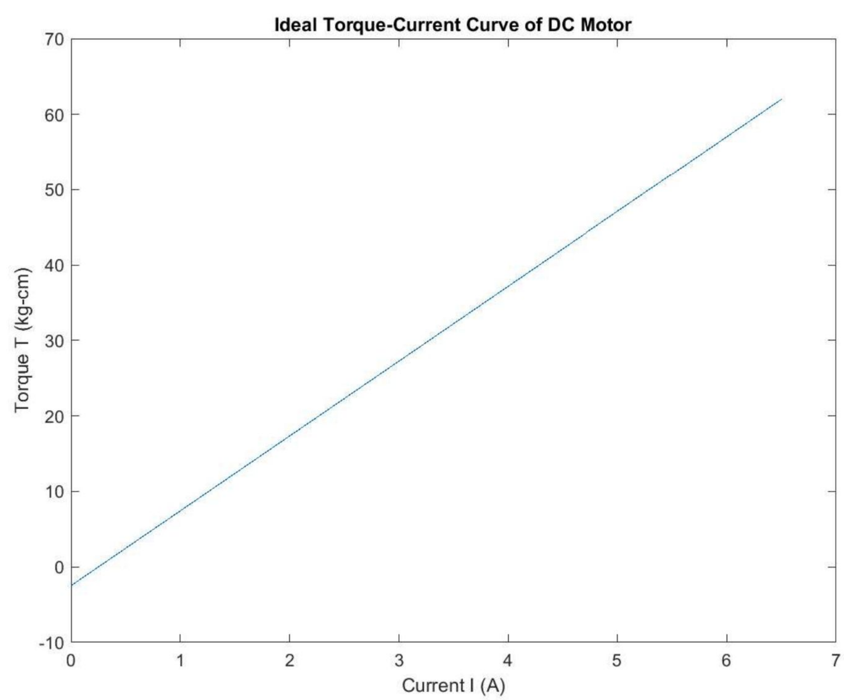

Fig. 7. Ideal Torque-Current Curve Of Our DC Motor

2.10 Tolerance Analysis

The lead screw assembly is the largest risk of operation to this project. Being able to safely and consistently drive the arm across the table is essential to the operation. Since none of our group has experience with this type of system this is the largest opportunity for failure. Friction and weight will be the largest problems to deal with. To design for those forces the lead screw will need to be carefully selected along with the motor in order to ensure enough torque is present. Along with that adequate coupling from the screw to the cleaning arm is needed in order to transfer that force effectively. Linear guide rails should minimize friction and will support the weight of the cleaning arm. The guide rails have their own set of problems such as lubrication and weight capacities. These issues are also made more difficult because we need to minimize size and cost. The motor needs to be as small as possible while still providing torque, and the linear guides need to be small as to not impede leg room, but large enough to support the weight of the system. We will be working closely with the machine shop in order to maximize success with this design, and changes can be made to the guide design based on machine shop feedback without compromising the electronic design. We will also be conducting extensive research in order to fill the gaps in our knowledge.

$$T_f = \frac{F_f}{2\pi p \eta} \quad \omega = 2\pi p v \;\; F_f = \mu_s W$$

We first solve for the shaft speed, N, and angular velocity, ω.

Table 1. Input Constants to Torque Estimation

Input Variable	Value
v Linear Velocity of Load	$2\frac{in}{s}$
p Pitch of Lead Screw	$0.125\frac{in}{rev}$

$$\omega = 2\pi p v = 2\pi(.125)(2) = 1.5706\frac{rad}{s} \quad (1)$$

$$N = \frac{\omega(60)}{2\pi} = \frac{(1.5706)(60)}{2\pi} = 15\ RPM \quad (2)$$

Table 2. Calculated Values of Torque Estimation

Calculated Variable	Value
ω Shaft Angular Velocity	$1.5706\frac{rad}{s}$
N Shaft Speed	$15\ RPM$

$$T_f = \frac{F_f}{2\pi p \eta} \quad \omega = 2\pi p v \;\; F_f = \mu_s W$$

3 Costs

Part	Cost (prototype)	Cost (bulk)
Lead Screw	16.58	
Fastening	1.85	
Elbow brackets	15.24	
Coupling	11.93	
Sleeve bearing	19.66	
Framing- T slot aluminum	11.77	
AC/DC converter	14.00	
5V regulator	0.50	
Total		

4 Schedule

Week	Anders	Armando	Kevin
2/24/20	Research and pick out linear motion parts	Research and pick out motor and pneumatics	Research and pick out sensors and microcontrollers
3/2/20	First draft of PCB design	Talk to professors about water in labs	Begin collecting code for testing components
3/9/20		Investigate casing options	Write code for control flow
3/16/20			Write code for cleaning subsystem control flow
3/23/20	Verification of screw drive and power system	Verification of motors and pneumatics	Verification of sensors and control systems
3/30/20			Full system test on breadboard
4/6/20			
4/13/20			
4/20/20			Begin collating data for Final Report
4/27/20	Verification that high level requirements were all met	Generate plots for final report and presentation	Ensure that verification for all components was completed
5/4/20	Prepare final presentation	Prepare final presentation	Prepare final presentation

5 Ethics and Safety

5.1 Safety

Our project has multiple potential safety hazards. This project is only a prototype of a product that would be used in Food service establishments and would operate near the general public. We will only address safety hazards having to do with the prototype, although more would be present in the actual product.

This product would be in close contact with water during cleaning and the general use of the table. This can lead to short circuits and electrical fires if water leaks onto electrical connections. The lab we would be working in is an electrical lab where water is not permitted. We will thus not use water to test any part of our equipment when in the lab since we are only proving a concept with our prototype. We will only construct the hose assembly and set up a control scheme. If we end up ahead of schedule and want to begin testing with water, we will consult the TA's and lab safety coordinator before proceeding. We will waterproof connections as we build and test with adequate circuit protections when water testing.

This project uses a connection to a wall outlet for power. This brings up multiple hazards that are made more serious by the possible power from a wall connection. We can have potential shock hazards from a variety of sources including accidental shorts to the housing of our project and accidental human contact with live electrical equipment. We will avoid this by following the safety recommendations listed in the electrical safety portion of the University of Illinois Division of Research Safety[6]. We will ensure that all exposed metal parts are properly grounded to the ground pin on our outlet connection. We will also ensure that we are always wearing non-conductive, long sleeve clothing to reduce accidental human contact with electrical components. The main safeguard we will have is a shutoff button near the machine in case of an emergency.

As a project with spinning drives and moving parts, there are several mechanical hazards to consider. People near the operating project could get hair or loose clothing caught in the spinning drives or moving rails of the machine. We will ensure that we are 1 foot away from the device when testing moving parts. We will also avoid loose clothing and jewelry. The shutoff button also helps with this issue as well. We are also designing the project to move at slow speed and sense if anything is in the way of a moving part. A final safeguard is wearing safety glasses when testing the actual machine.

5.2 Ethics

This project also has ethical considerations. It is heavily mechanical, and requires a broad scope of electrical engineering knowledge. This can lead to violations of 2 different IEEE codes of ethics, #6: "to maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations;" [7], and #7: "to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others;" [7]. To address #6, we will first review the relevant course material in power, control systems, circuits, and other fields of study in order to ensure the highest technical competence. We will also consult the machine shop to assist us with the manufacturing of components. Finally, we have a diverse group that has expertise in various areas, making us qualified to undertake this task. To address #7, we will seek guidance from the TA's and other course staff on mechanical issues, and accept any criticism to improve on our project.

As a machine built for automating a job done by humans, this may displace certain employees who currently work as table bussers in the restaurant industry. This displacement may cause issues between labor unions and employers, as well as eliminate jobs for the public. This may violate #2 of the IEEE code of ethics: "to avoid real or perceived conflicts of interest whenever possible" [7]. Although our device automates a job, it doesn't fully eliminate the need for bussers. This job takes little time to perform, and cannot automate the clearing of dining ware and trash. We also see that our project is suited for fast food restaurants and establishments where there aren't dedicated bussers. These facts lead to a low amount of overall job displacement. Some small displacement is inevitable, but we feel overall cleanliness and public health are of higher priority.

References

[1] *Food Code, 2017 Recommendations of the United States Public Health Service Food and Drug Administration*, 9th ed. College Park, MD: National Technical Publication Service, 2017.

[2] *Illinois Register, Department of Public Health, Notice of Adopted Rules,* Title 77: Public Health, Chapter I: Department of Public Health, Subchapter m: Food, Drugs, and Cosmetics, Part 750: Food Code, 2019

[3] N. Barber, R. J. Goodman, and B. K. Goh, “Restaurant consumers repeat patronage: A service quality concern,” *International Journal of Hospitality Management*, vol. 30, no. 2, pp. 329–336, Jun. 2011.

[4] Seung Ah Yoo, “Customer Perceptions of Restaurant Cleanliness: A Cross Cultural Study”, M.S. thesis, Department of Hospitality and Tourism Management, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, July 2012

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[7] “IEEE Code of Ethics,” *IEEE*, 25-Nov-2019. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 13-Feb-2020].