Automated Closet

ECE 445 Design Document
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1. Introduction

1.1 Problem and Solution Overview

Choosing what to wear is an unavoidable part of everyone's routine and as of today, there is no real "automation" to this process. Moreover, many people spend a lot of time in the mornings deciding on what clothes to wear. In Illinois especially, the weather varies drastically every day and many people always have to consult weather apps to judge what they should wear for the day. This is a hassle and takes away precious minutes of sleep in the morning. According to a study done in 2016, women spend as much as 17 minutes choosing their outfit every morning, while men can take up to 13 minutes [1].

We propose an automated closet system that can select an outfit for the user based on the type of clothes, weather, color, and other metrics. The user will have to insert data about the clothes when the first time the closet system is set up. For every article of clothing, a database would store details about each clothing piece such as color, size, type of clothing, sleeve length, fit, etc...

Although motorized closet systems exist, they don't have the decision making capabilities needed to optimize their functionality. Most solutions are similar to the Closet Carousel, which simply has a foot pedal to control movement [2]. This solves the problem of increasing usable closet space, but there is clear room for innovation in lightening the decision making load on the user. Additionally, these solutions can require significant effort to install, reaching weights upwards of 135 lbs with an exorbitant price tag of $3000 or more to match [3]. Our solution will provide this additional functionality in an easy-to-use package.

1.2 Visual Aid

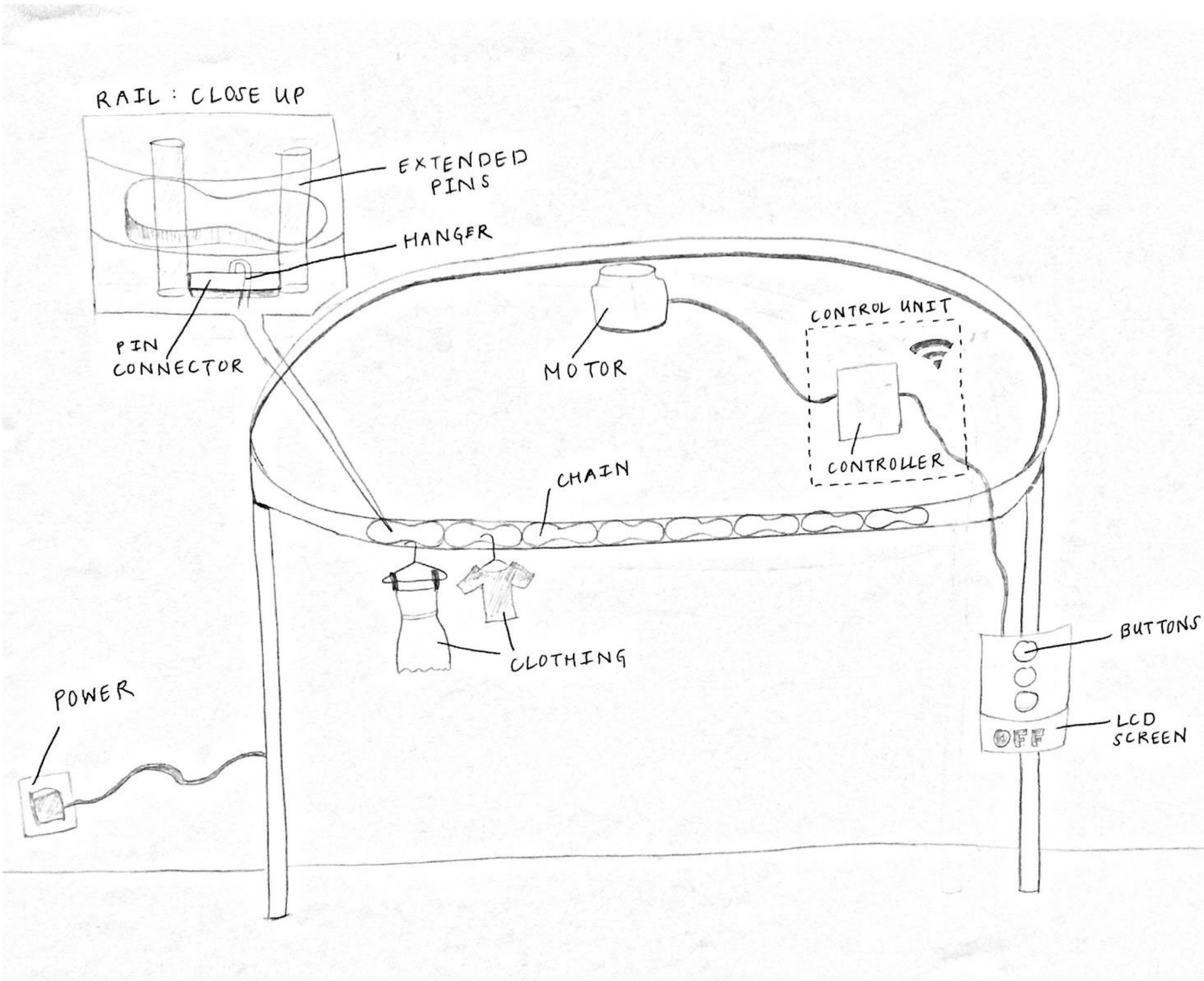

Figure 1: Illustration of System

1.3 High-Level Requirements

- The closet suggests an outfit to the user
- The closet connects to an online database and can pull information on current weather and about clothing in the closet
- The closet spins with all the clothes in the system and is able to track the position of clothes that are input into the system by the user

2. Design

2.1.1 Block Diagram

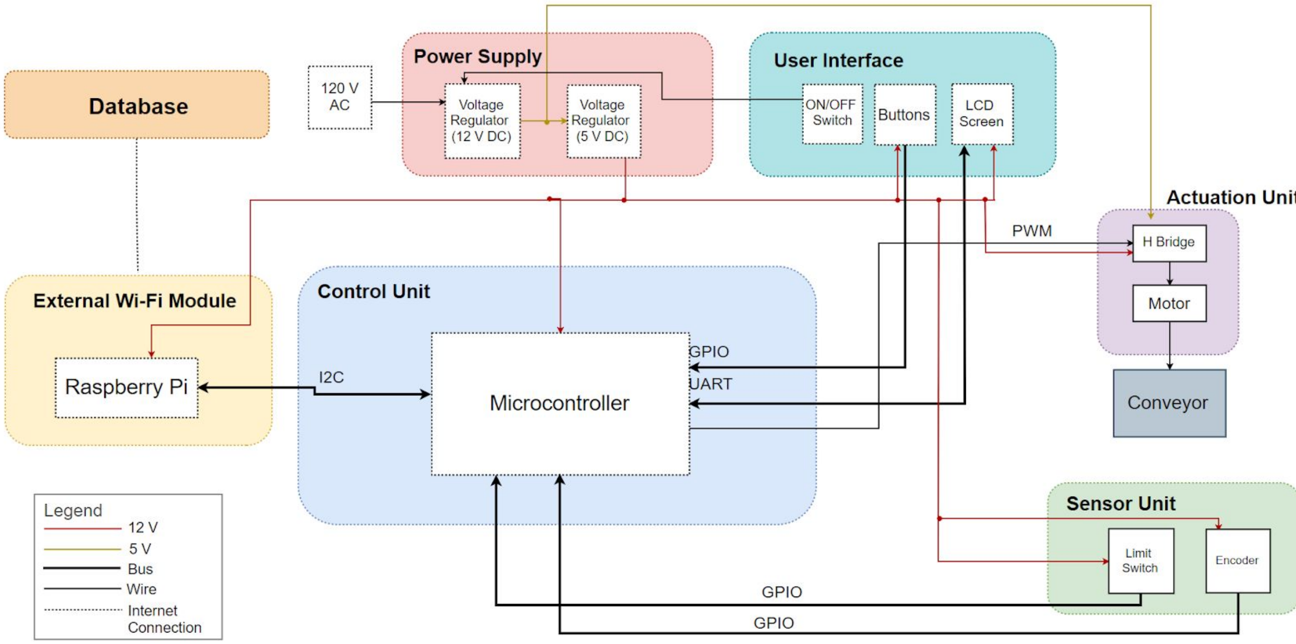

Figure 2: Block Diagram

2.1.2 Physical Design

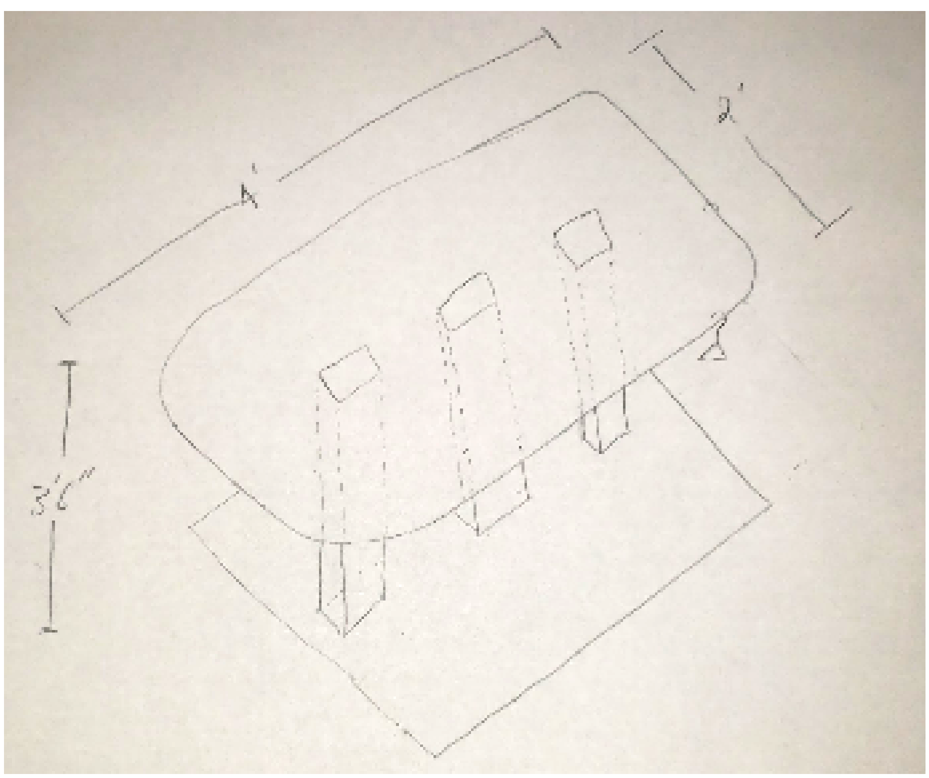

Figure 3: System Dimensions

2.2 Block Requirements

2.2.1 Power Supply

The power supply will provide the power necessary to operate our motor as well as our microcontroller and connected devices. The power for both of these tasks will be provided by a wall outlet.

Risk Analysis: Since this module supplies power to our entire project, a failure here could lead to no functionality in our entire project. A potential issue we may run into is heat from the power supply. If we run into any overheating, we will add a heat sink to the power supply.

Requirements	Verification
Requirement 1: The first regulator must be able to provide up to 10A of continuous current. *Requirement 2*: The second regulator must be able to handle current draws of 4A.	A. Attach a resistor at the output of each regulator and use a multimeter to measure current through the circuit when skipping over downstream components. The first regulator should be able to handle a current of 10A. The second should be able to handle a current of 4A.

2.2.1.1 120VAC to 12VDC Voltage Regulator

Our motor requires 12V to perform as expected, so this regulator will provide a steady 12V to be used by the motor. The 12V will also be used as an input to a second regulator which will power the microcontroller. As this regulator will supply current to both the motor and second regulator, it must be able to handle enough current for both. We expect this load to be between 5A and 10A, depending on motor load.

2.2.1.2 120VAC to 12VDC Voltage Regulator

This second regulator will step down the 12V used for motor power to 5V used for microcontroller logic and power for components that connect to the microcontroller. This must be able to supply a peak current similar to that required by an Arduino Mega as well as a Raspberry Pi, around 4A together.

2.2.2 Control Unit

The control unit will process user input from the UI module, track the position of the conveyor using sensor input, control the motor speed and direction through PWM, and send API requests to online databases to query weather and closet data.

Risk Analysis: The Control unit is possibly the single most complex subsystem in our project. Its goal is to interface with almost every other module, so its functionality is crucial to the functionality of this project. Since the majority of the control unit's errors will come from the software aspect of this project, we plan to mitigate any issues we may face by writing modular code and unit testing each module.

Requirements	Verification
Requirement 1: Must be able to read input to and send output from a Raspberry Pi *Requirement 2:* Must be able to send a PWM signal to move closet at an appropriate speed *Requirement 3:* Can make closet stop at a specific index	A. Connect Raspberry Pi to Control Unit and send a serial message from the Raspberry Pi and see if we can read the serial message on the control unit B. Command a known PWM signal frequency and duty cycle, and measure the output with an oscilloscope to ensure the output meets expectations. C. Spin encoder a measured distance, use response from callback functions to ensure no counts were missed.

2.2.2.1 Microcontroller

Our microcontroller will be doing all of our decision making, both for clothes selection and motor speed. In order to accomplish this, it must be capable of handling communication with multiple devices at the same time, and have enough available channels for single device communication protocols such as UART.

2.2.3 Actuation Unit

The actuation unit uses PWM input from the microcontroller to control the bidirectional DC motor used on the conveyor system.

Risk Analysis: The Actuation Unit can pose a very significant risk to the completion of our project. This module is what allows our closet system to rotate, so it is crucial that this component works. To ensure that the motor we chose can support the weight of all the clothes, we ran an analysis as shown below in Figure 2.

Linear Mechanism

	Free Speed (RPM)	Stall Torque (N*m)	Stall Current (Amp)	Free Current (Amp)
775pro	18730	0.71	134	0.7

# Motors per Gearbox	Gearbox Efficiency	Travel Distance (in)	Applied Load (lbs)	Pulley Diameter (in)
1	60%	96	60	3

Driving Gear	Driven Gear		Elevator Linear Speed	Arm Time to move Travel Distance
1	10	No Load:	5.9 in/s	16.31 sec
1	10	Loaded:	5.6 in/s	17.14 sec
1	5			
1	1			
500.00 : 1	<-- Overall Ratio		Current Draw per Motor (loaded)	Stall Load
			4.52 amps	1256.75 lbs

Figure 4: Motor Design Calculations

Using the specs for our motor with a 500:1 gearbox, we can theoretically hold over 1200 lbs of clothes without stalling the motor.

Requirements	Verification
Requirement 1: Produce a voltage anywhere from -12V - 12V *Requirement 2:* Supply at least 6A *Requirement 3:* Move a load of 20 lbs at at least 4 in/sec	A. Attach a multimeter to the output of the H-Bridge module and gradually change the commanded output from -12V to 12V. Ensure that output meets these levels and that behavior is linear. B. Attach a resistor at the output of the H-Bridge and use a multimeter to measure current through the circuit without the motor attached. The H-Bridge should be able to handle a current of 6A. C. Attach a 20lb weight to the output shaft of the motor and wind it upwards, attaching a winch drum that accounts for any reductions added after the gearboxes. We will use a timer to measure the time it takes to

	move the weight a predetermined distance to check for speed

2.2.3.1 H-Bridge

The H-Bridge is responsible for using the PWM signal from the microcontroller to control the magnitude of the output voltage. To supply enough current to safely run the motor, we may need multiple devices in parallel depending on the models available.

2.2.3.2 Motor

The motor is responsible for moving all of the weight loaded on the conveyor. For safety reasons, we will be limiting its speed so that clothes move at 6 inches per second.

2.2.4 Sensor Unit

The sensor unit produces signals for the microcontroller to handle, indicating rotational speed and position of the conveyor.

Risk Analysis: The Sensor module can pose a risk to the completion of our project. Since this module is the only way we know the position of our automated closet system, a failure here could lead to the wrong clothes being presented. To mitigate any issues we may face, we will be using debounced limit switches along with a quadrature encoder to ensure that we don't have any failures in our positional accuracy.

Requirements	Verification
Requirement 1: Hangar index must increment every time a hanger passes by the limit-switch. *Requirement 2:* Control unit must be able to determine the magnitude and direction of the closet system.	A. Mount limit switch on a 2x4 post, and push tabs along the side of the post in one direction. Ensure the switch triggers only once every time a tab passes and the tabs continue moving unimpeded. B. Attach encoder output pins to oscilloscope and turn in both directions. Ensure that both pins produce a visible output and reverse their phase when the encoder is turned the opposite direction.

2.2.4.1 Limit Switch

The limit switch will send a digital signal to the microcontroller whenever it is pressed, helping to count hanger sections as they pass by.

2.2.4.2 Encoder

The quadrature encoder will track the more detailed movement of the conveyor between hangers, helping the microcontroller to adjust motor speed as it approaches the target position. It will operate at the microcontroller logic level and send at least 16 counts per revolution over its two digital pins.

2.2.5 UI Module

The UI module interacts with the user to display outfit information and process the user's decision. To do this, we will use an LCD screen and push buttons.

Risk Analysis: The UI module can pose a risk to the completion of our project. Since this module is the only way the user can interact with the product, a failure here could render our entire automated system useless. Fortunately, since our UI system is fairly simple, we expect little trouble with this module.

Requirements	Verification
Requirement 1: Display must show message for type of clothing when closet stops at a piece of clothing *Requirement 2:* Emergency stop stops the closet immediately. *Requirement 3:* Closet must be able to spin to positions on rack where clothes need to be reset when hitting the RESET button *Requirement 4:* Closet must be able to reset clothes in rack using the RESET button	A. At any index, print the index number on the screen B. Make the closet spin by powering the H-bridge, the emergency stop button should cut power at the H-bridge. C. Attach the button in series with a resistor and battery, and connect a multimeter to check the voltage drop across the button. If the voltage difference is 0 when the button should be on and non-zero when off, then the button properly disconnects power.

2.2.5.1 LCD screen

The LCD screen will display prompts and messages to the user. To do this, the screen will need to have enough pixels to make distinguishable words on the screen, as well as be able to communicate via UART with the microcontroller.

2.2.5.2 Button Interface

The user will have a set of 2 buttons that will answer prompts and indicate decisions. These buttons must have stable output to the microcontroller to ensure behavior at all times.

2.2.5.3 On/Off Button

An on/off button will allow the user to begin a controlled shutdown of the closet system, cutting power to motors and minimizing microcontroller activity.

2.2.6 External Wi-Fi Module

The external Wi-Fi module connects the microcontroller to the internet so it can make API requests, which we will use to get information about the weather.

Risk Analysis: The external Wi-Fi module poses a significant risk to the successful completion of this project. Not only does this module have to talk to the microcontroller, but it also must be able to make API calls to weather websites as a part of our clothing-decision process. If we can't access the internet, our clothing-decision process will not work. We also plan on storing information about each piece of clothing on an external database and making API calls to that database. Similarly, we will not be able to get information about the types of clothing in the closet if we cannot access the internet.

Our decision to use Wi-Fi comes with many potential issues. Not being able to see a network and dropped network connections are among many of the problems we may face. To circumvent this issue, we plan on having an access point nearby to address any intermittent signal issues. For a worst-case scenario, we can use an ethernet cable instead.

Requirements	Verification
Requirement 1: Must be able to talk to control unit. *Requirement 2:* Must be able to fetch information from weather API *Requirement 3:* Must be able to connect to a system that stores information about the clothing	A. See Verification A for Control unit B. Ping openweathermap.org and check for a valid response C. See "Database" for verification process

2.2.6.1 Raspberry Pi

The Raspberry Pi will be responsible for making requests to online APIs and communicating the results for the microcontroller to act on.

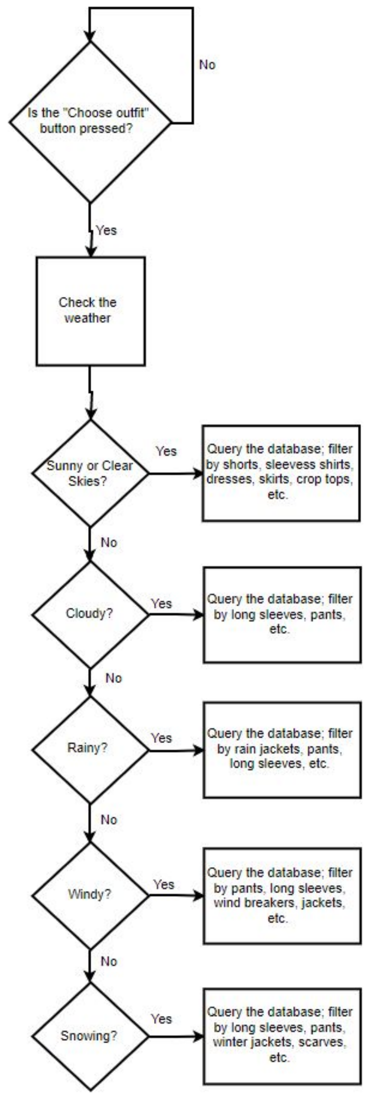

Figure 5: Weather-decision algorithm

2.2.6 Database

The database is connected to the microcontroller via the external Wi-Fi module. We can make requests to the online database to gather information about the clothing. We decided to use an online database to make our workload easier. Since there are already databases that have premade APIs, we figured it would be easier for us to use one of those rather than set up our own database.

Risk Analysis: The database is connected to the internet. This poses the problem of our closet always needing to be connected to the internet. In today's day and age, all parts of the home (including the closet) have Wi-Fi, so we do not see any large issues with using an online database for storing clothing information.

Requirements	Verification
Requirement 1: Must be able to store information and send it to the External Wi-Fi module when queried.	A. Set up a fake database and see if we can query it from the External Wi-Fi module using the Firebase API (or a textfile as mentioned by David Null).

2.2.7.1 Firebase Database

The Firebase Database will be an online database using Google's Firebase that will hold information about each individual piece of clothing such as the type of clothing, weather information, etc...

2.3 Tolerance Analysis

An important tolerance we must make sure is met is the output of the 12V-5V step-down voltage regulator. This output is being used to supply power to both the Raspberry Pi and ATMega, which handle all of the local decision making and controls. Any lapse of power to these units can cause the entire system to fail. Therefore, we must ensure that the regulator is able to supply our worst-case current consumption demands. In our case, we must plan on the ATMega consuming 1.4A at max consumption [6] as well as the Raspberry Pi needing a recommended 2.5A [7]. With our LCD screen consuming a maximum of 300 uA [8], the 5A voltage regulator we have selected will nominally handle the current requirements of devices using 5V. Per the manufacturer's tolerances, this device has a voltage accuracy of +/- 1.5% [9]. Therefore, in the worst case our regulator will be supplying 4.925V, which is still safely above our 3.9003V current draw.

2.4 Schematic

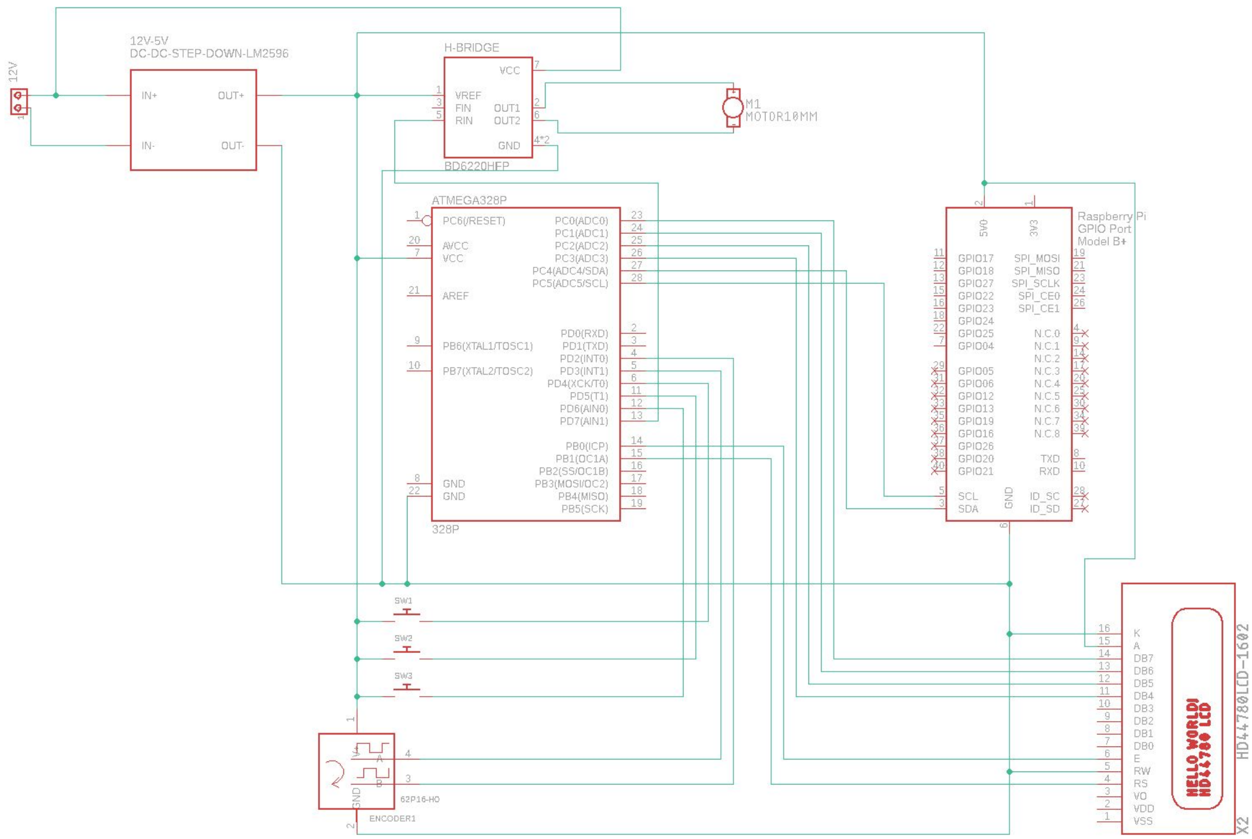

Figure 6: Design Schematic

3. Cost & Schedule

3.1 Cost

Labor = 10 hrs/week * 10 weeks/worker * 3 workers * $30/hr = $9000 in Labor

Subsystem	**Product Name**	**Quantity**	**Price**	**Total**
Actuation	H-Bridge	1	$6.03	$6.03
Actuation	775 Pro	1	$19.99	$19.99
Actuation	Gearbox	1	$62.96	$62.96
Controller	ATMega	1	$12.20	$12.20
Controller	microSD Card	1	$9.29	$9.29
External Wi-Fi Module	Raspberry Pi 3 B+	1	$35.00	$35.00
Power Supply	12V-5V Regulator	1	$9.59	$9.59

Power Supply	120V AC- 5V DC Regulator	1	$39.99	$39.99
Sensor	Encoder	1	$25.00	$25.00
Sensor	Limit switch	1	$1.50	$1.50
UI	LCD Screen	1	$10.95	$10.95
UI	On/Off Rocker Switch 16A 125V	1	$0.73	$0.73
UI	Pushbutton Switches	1	$5.85	$5.85
Sum				$239.08

We were not told the full Bill of Materials for the physical design. When discussing the design with the machine shop, they gave us an estimate of about $300 for the physical materials to make the closet.

Total Cost = Labor + Electronics Cost + Physical parts = $9000 + $239.08 + $300 = **$9539.08**

3.2 Schedule

Week	Billy	Shania	Nikhil
9/29 - 10/5	Design review; Talk to machine shop about physical design	Design review; Talk to machine shop about physical design	Design review; Talk to machine shop about physical design
10/6 - 10/12	Order parts; Design PCB for early order	Come up with code framework; Start writing Python code for determining outfit selection	Come up with code framework; Set-up database; Determine necessary parameter fields for outfit selection
10/13 - 10/19	Continue PCB design; Figure out interface between microcontroller and external Wi-Fi module	Continue coding; Python script to query database	Continue coding; Figure out interface between microcontroller and external Wi-Fi module
10/20 - 10/26	Work on individual reports; Machine shop tentatively done with physical design	Work on individual reports; Machine shop tentatively done with physical design	Work on individual reports; Machine shop tentatively done with physical design
10/27 - 11/2	Interface UI module with controller module	Interface Sensor unit with controller module	Build and test the power supply module
11/3 - 11/9	Continue working on	Continue working on	Continue working on

	controller module	controller module	controller module
11/10 - 11/16	Work on whatever modules that need to be finished	Work on whatever modules that need to be finished	Work on whatever modules that need to be finished
11/17 - 11/23	Start working on final presentation	Start working on final presentation	Start working on final presentation
11/24 - 11/30	Prepare for mock/final demo and organize final presentation	Prepare for mock/final demo and organize final presentation	Prepare for mock/final demo and organize final presentation
12/1 - 12/7	Prepare for mock/final demo and organize final presentation	Prepare for mock/final demo and organize final presentation	Prepare for mock/final demo and organize final presentation

4. Discussion of Ethics & Safety

There are a few potential safety concerns with our project. Since the automated closet will have moving parts that are driven by a motor and the user will be interacting directly with them, the moving parts pose a safety hazard. We will extensively test all the moving parts. Every moving part of the system will be individually tested to make sure its behavior is safe and predictable. Preventative safety measures will be taken to ensure there are no risks for the user with regard to the moving parts. For instance, we chose that the motor will move the rail at 6 inches per second since that is still fast enough for the user to look at the clothes, yet slow enough that if there is something that happens, the user is able to have time to react. The average human reaction time is between 150 ms - 200 ms [5] which means our system will give the user a lot of time to act in case there is an issue (i.e. something gets caught, clothing item slips off hanger, etc.)

In addition, another potential hazard is exposed mechanical parts. Since the technology we develop will be integrated directly into the closet, it will be exposed to users of the automated closet. We will ensure that we encase all parts of the closet in some material so the user doesn't accidentally touch something they shouldn't, such as moving parts. For example, the motor will be placed in the back middle of the entire system close to the chain, so it will be far from the user. The motor will also be encased in a box so it is properly covered. The moving chain which makes up the rail for the system will be covered completely as well so the user doesn't accidentally touch it. We will make sure that all edges are smooth and polished to mitigate the risk of injury. Another reason to have buttons for the user interface is that the user does not actually have to interact with the components of the system, which also increases safety. The

ON/OFF switch is also located in an easily accessible place so if the system needs to be powered off, the user can do so easily.

The input to our power supply module is 120V AC from the wall. Voltages in this range can cause serious bodily harm if handled improperly. We will take precautions when working with the voltage regulator. Namely, we will not touch the power supply module when it is powered. For the end users, we will cover the power supply module so people do not accidentally touch live wires and risk electrical shock.
We are designing the automated closet because we wish to alleviate people's lives by automating the task of choosing clothes. According to number 5 on IEEE's code of ethics, it is our responsibility to brief others on the capabilities of new technology [4]. We hope our product will be helpful for people and we plan on educating others about our product. Number 1 on IEEE's code of ethics states that the safety of the public is most important and that any potential concerns are addressed and appropriately handled [4]. We acknowledge all the possible safety issues and will make sure to take preventative measures to ensure our product is safe for the public.

4. References

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