Sensor Activated Home Hub Curtains

ECE 445 Project Proposal

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1. Introduction

1.1 Objective

Calls to help mitigate climate change is a well known issue, but many do not know how effective simply opening and closing curtains can do to help conserve energy. Simply “closing the curtains during the winter helps reduce up to 10 percent in heat loss from a warm room [1].” However, as effective as this simple solution is, the actual process of doing so is rarely undertaken. In addition, waking up through sunlight exposure is a very effective way to improve a person’s circadian rhythm and has been proven to help to help “increases in the level of the hormone serotonin, which is important to sleep [2]” as well as reducing the stress hormone cortisol.

Our device will aid the regulation of temperature and light in a room through automated curtains, thermostat and light control. The decision to open and close a set of curtains depending on the data input of several sensors. These sensors will monitor different factors such as temperature inside the home versus outside, surface temperature of the window, and environmental lighting. These readings can also be used to further integrate a smart home’s network of devices.

1.2 Background

Similar products that aim to control curtains in residential homes have been limited to products like the Aqara curtain controller system that focuses on helping users “open or close curtains via [their] smartphone, cube controller, or wireless switch anywhere [3].” These products do not contain any sensors that would analyze the different factors that would minimize the need for centralized heating. Furthermore, devices that do happen to use some form of sensor data, only leverage the data to perform simple tasks, and isolate that data within the device itself. Our aim is to not only allow the device to perform decisions with the data, but share the data as well to allow other smart home devices to make use of that data.

In addition, there have been a few products marketed for Industrial uses such as Curtains for Barns curtain system that does analyze the “temperature, humidity, wind direction and speed [4].” However, these are more focused on air quality for their animals and have not focused on more residential applications. Thus, while there are products that may be a bit similar in concept, our Smart Curtains device is the first of its kind to use automated curtain control to help the average person conserve energy.

1.3 Visual Aid

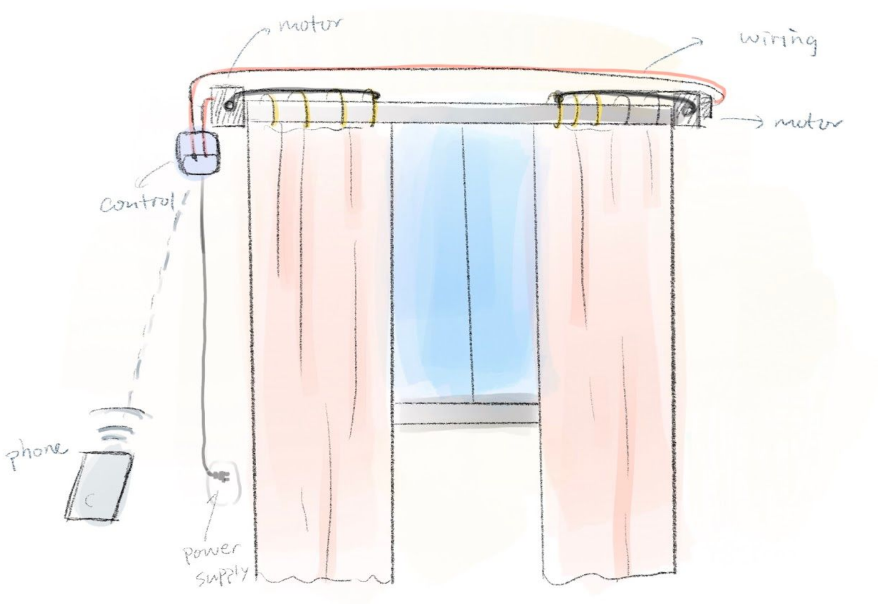

Figure 1: Physical Design -- Overall

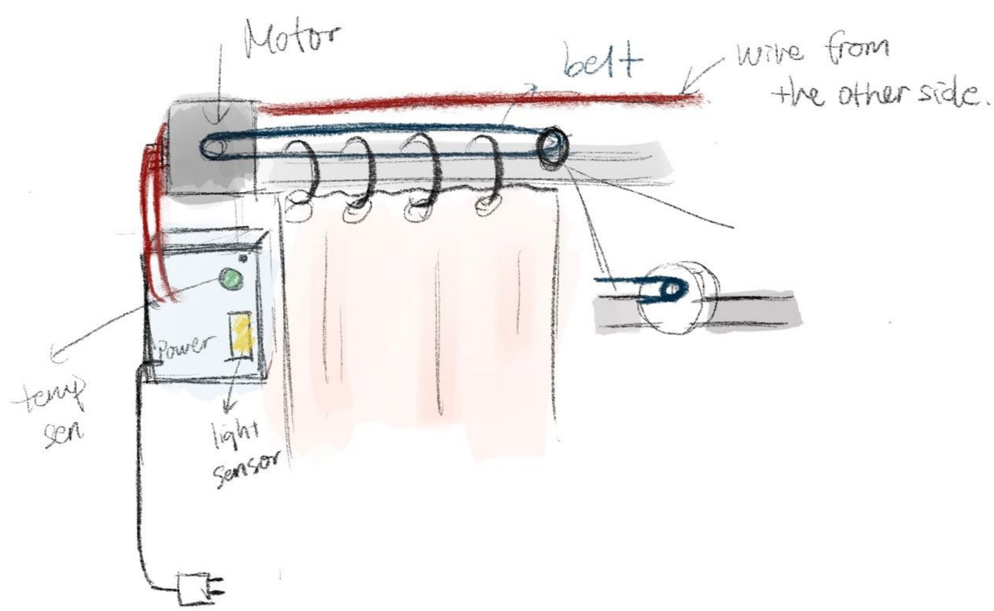

Figure 2: *Physical Design -- Close-Up*
Note: *the light sensor will face outside*

1.4 High Level Requirements List

- The device should exhibit 0.17 N-m torque for a curtain rod with diameter of ¾ inches through the use of each motor, showing that the device is capable of opening and closing curtains that are up to 4 lbs.

- ~~The device should be able to connect to a wifi server in 60 seconds and communicate information with less than 25% data loss.~~

- The device must have a reliable connection to the data server being hosted. In order to test such, the device must be able to maintain a connection uptime of at least 90% of the time during a transmission. During a constant stream of data bytes, less than 10% of the bytes can be dropped.

- ~~The device can use sensor data in order to make decisions to autonomously open or close with an accuracy bigger than 75%.~~

- Using sensor data, such as lighting levels and temperature readings, the device should autonomously decide what state to put the curtains in (open, closed, partially opened, etc). Given the same environmental information, the decision the device makes should align with the user's decision at least 75% of the time (i.e Given 4 scenarios, 3 of the device's choice is the same as the user's)

2. Design

2.1 Block Diagram

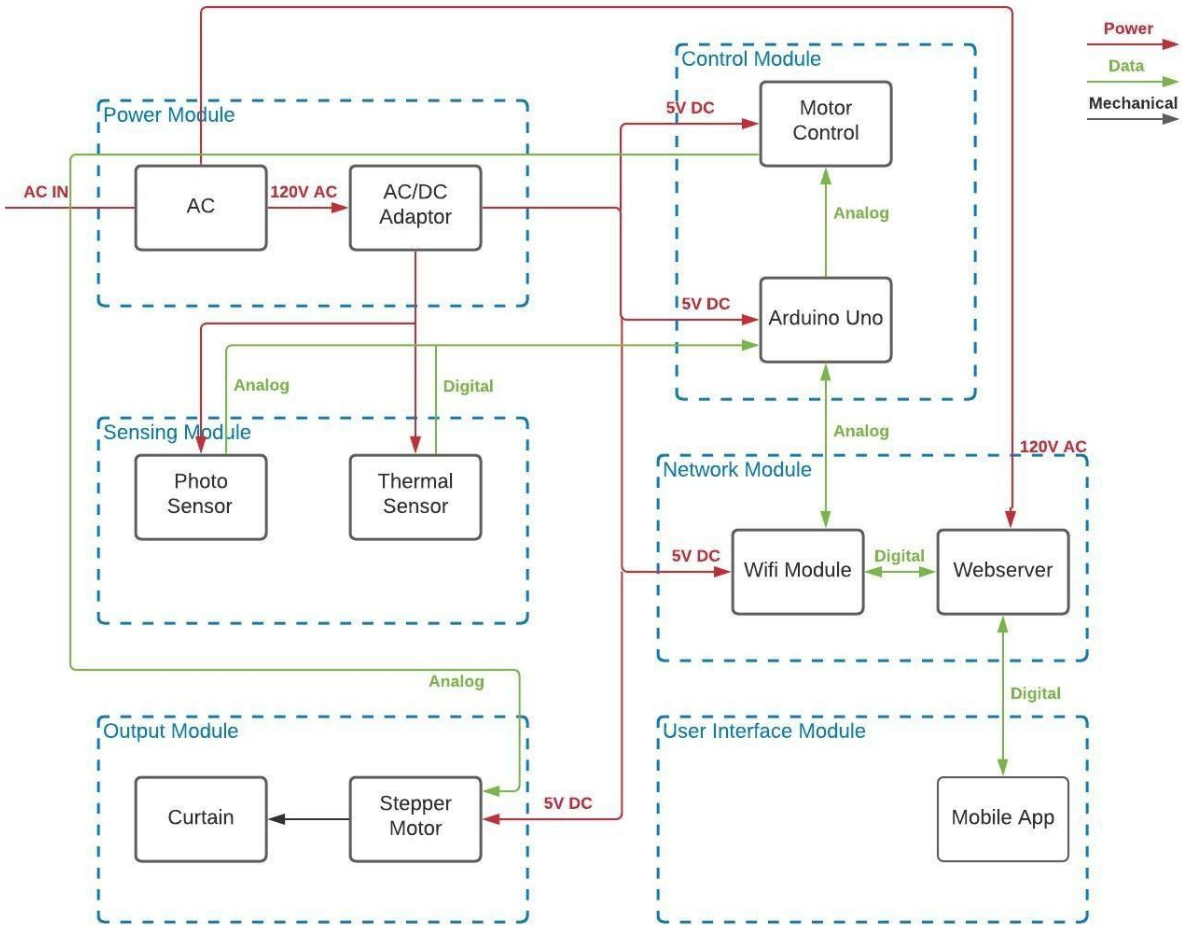

Figure 2: Block Diagram

2.2 Network Diagram

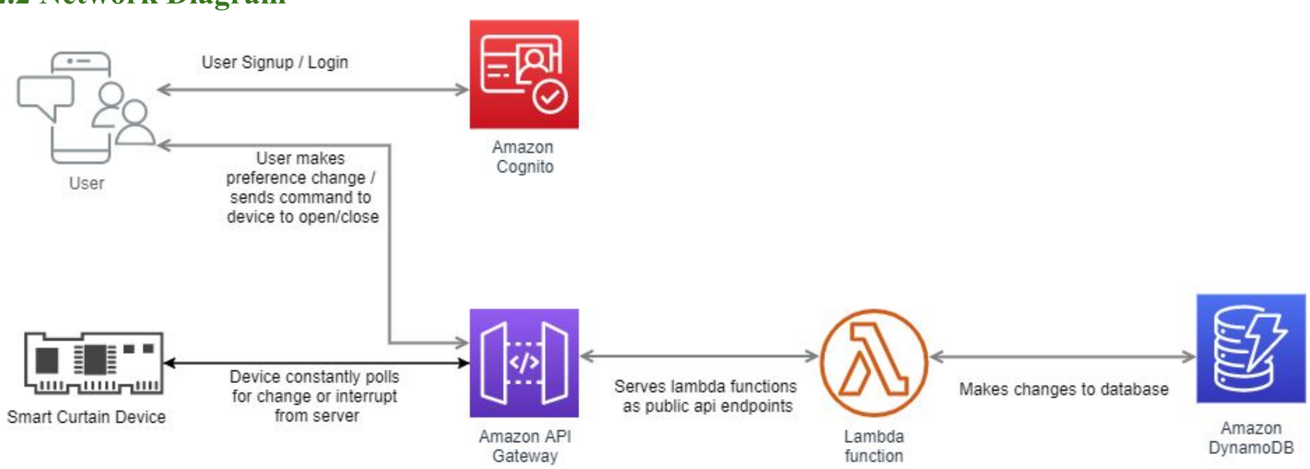

Figure 3: Network Diagram

2.2 Requirements & Verification

2.2.1 Power Module

We require a continuous and easily accessible power source to keep our network up running continuously. We chose to get AC power from a wall socket and convert this power into DC to give a more regulated voltage supply to our system.

Requirement	Verification
1. Power Supply: Power supply must be able to draw 120V of AC power from a wall outlet 2. AC/DC Adaptor: The Adapter is able to convert the incoming power into 5V or 12V DC, at a rate of 12V +- 5% at a rate of 2A.	1. Using a multimeter, we can measure the power being drawn by the supply to verify it is 120V 2. Using a multimeter, we can measure the power after the adapter, incrementally scaling the power until it reaches the max power of 120V and ensuring the adapter is outputting 12V at 2A.

2.2.2 Control Module

This control module communicates with the stepper motor, photo sensor and thermal sensor to decide whether or not to keep the curtains open or closed. This module contains our control logic.

Requirement	Verification
1. Arduino UNO: Arduino must be able to run provided instructions at any time given the provided power is supplied 2. Motor Control: Motor control can interpret the state given by the arduino and start sending power, continue sending power, or stop sending power to the stepper motor.	1. Arbitrary code, such as changing the states of the onboard LEDs on the arduino, can run upon power being supplied to the arduino (startup). 2. The arduino will send three different states to the motor control: begin, continue, and end. The motor can be observed to see if it follows these three states since the motor control should provide and stop providing power based on these states.

2.2.3 Sensor Module

Photo sensor and Thermal sensors will be used to communicate with Arduino and decide if the curtains should be open or closed.

Requirement	Verification
1. Photo Sensor: Photosensor is able to detect lux value within an accuracy of 20%, correctly identifying the light state of the environment	1. Check if the signal given by the arduino determines what the lighting of the room is correct in three different scenarios: pitch black, dimly lit, and fully lit. (Being able to read the state of a room falls roughly with the range of 20% in lux readings).
2. Thermal Sensor: Thermal sensor is able to detect the temperature of a surface with accuracy of 10%	2. Using three object with controlled temperature surfaces (ie. ice cube, boiling water, etc), check the temperature read by the sensor and compare it with temperature read with a thermometer.

2.2.4 Output Module

The output module will consiste of the physical motors and curtain. It will communicate with the motor control in order to change or retain the position of the curtains.

Requirement	Verification
1. Stepper Motor: Able to supply 20N +- 2.5N of torque given constant power supply	1. We can attach a scale and have the motor spin, pulling on the scale to measure the provided force to ensure it meets the given requirements.

2.2.5 Network Module

The network module will support the interface between the mobile app and the wifi. This module will also communicate with the Arduino UNO in order to communicate user preferences with the control unit.

Requirement	Verification
1. Wifi Module: Is able to receive data at rate of less	1. Have the device's wifi module connect a server, and send a constant

than 5% data loss, and send at a rate of less than 5% data loss	stream of bits for a minute then compare the data loss from expected to received by the server. Do the same the other way, sending a constant stream to the device and compare the expected data received versus what was sent.

2.2.6 User Interface Module

The user interface module is the main platform that the user will be able to dictate their preferences to the curtain control system. It will also be able show the user each component's status.

Requirement	Verification
1. Mobile App: Allow multiple users with different user ids to save their preferences. Be able to allow each user to override the energy conserving recommendations for curtains, and be able to allow each user to set a time for the curtains to open or close.	1. Have 2 users with different settings to see if the app works for the selected user. When the app gives energy conserving recommendations, choose the opposite and see if the curtain follows the user instead of sensors.

2.3 Schematics

2.3.1 Circuit Schematics

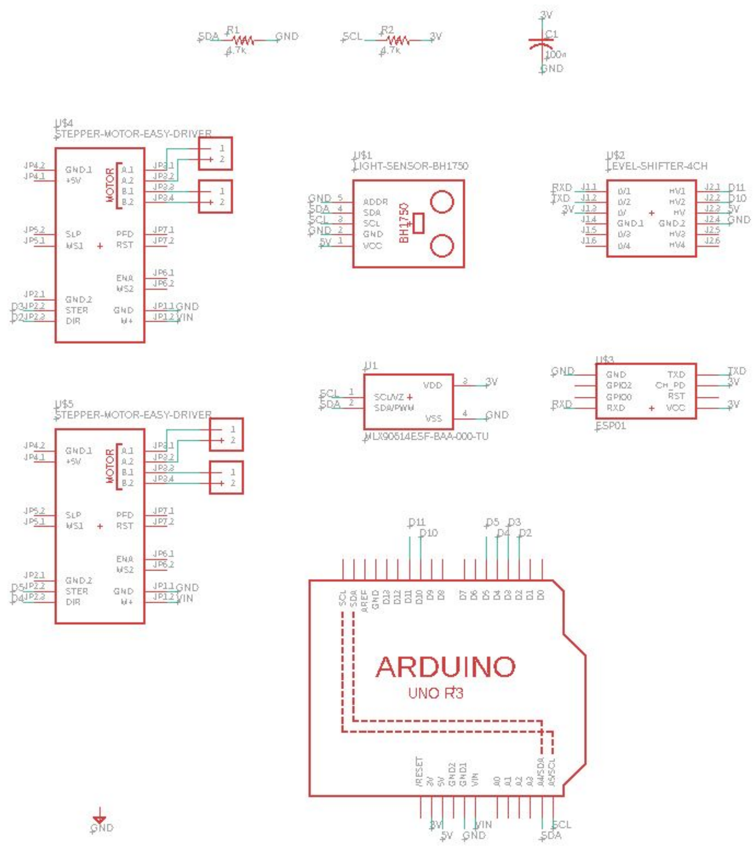

Figure 4: *Circuit Schematics*

2.3.2 PCB Layout

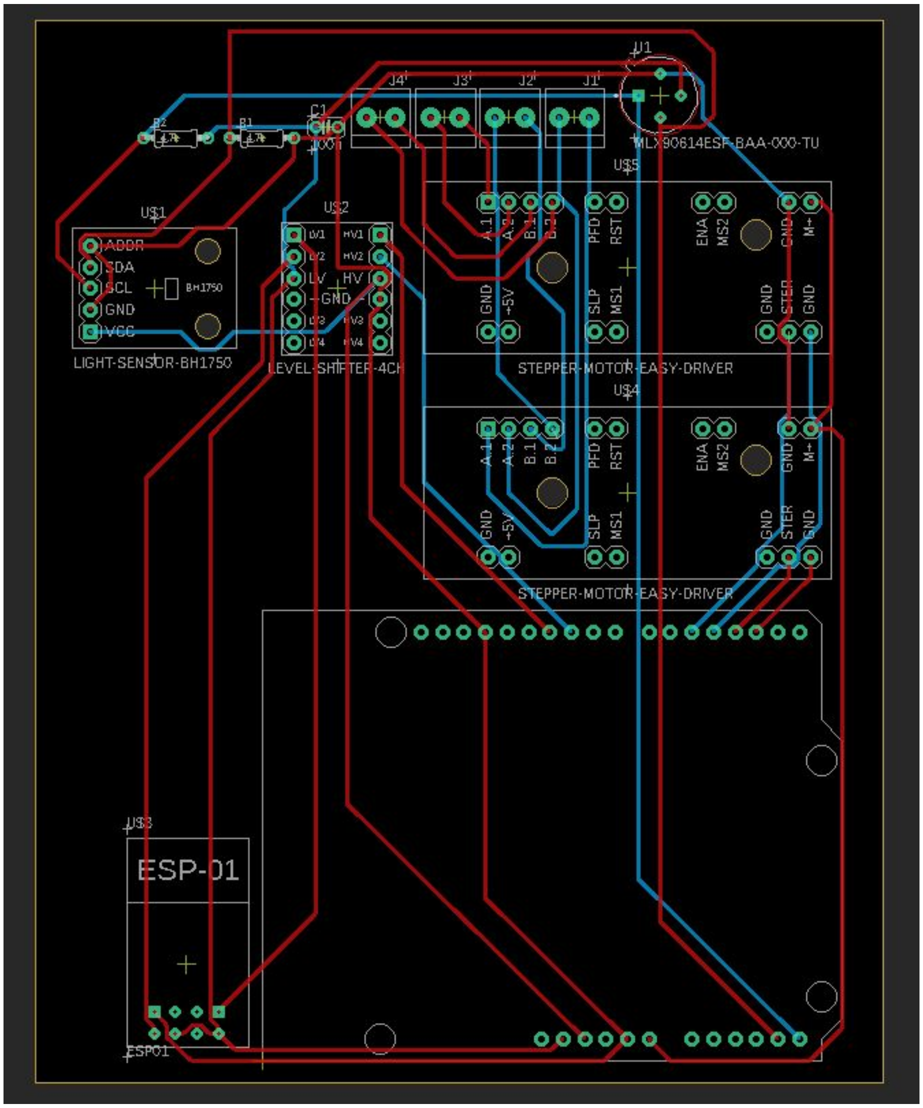

Figure 5: *PCB Layout (not final design)*

2.4 Tolerance Analysis

One important tolerance we must consider is the output of our step motors. At the given max output rating of the motors, the device will be able to operate the curtains as expected. However, we must also consider that the motor will not be running at max output. In these situations, we can consider the variable force given by the motor to control speed at which the device operates the curtains. However, there is a cutoff before the curtain cannot move. The friction coefficient of nylon on dry steel is around .40. The average heavy curtain to retain heat weighs in at around 2kg (4lb). Thus to calculate the minimum force to push the whole curtain is:

$$F = (m * g) * \mu$$

$$F = (2kg * g) * .4 = 7.848\ N$$

The actual mechanical calculations are of course more difficult, as the motor will not push or pull the entirety of the curtain all the time, but instead one section of the curtain. Thus the actual mass of the curtain being pulled ramps up as more or less of the curtain is being pulled. However, for simplicity sake we can make the assumption that if 8N is the least amount of force necessary to move the curtain. With a motor with a 1” (.0254m) circumference, then we can calculate the torque required by the motor to be:

$$\tau = F * m$$

$$\tau = 7.848N \; * \; 0.0254\text{m} = .1993 \text{ N*m}$$

As such, the motor must operate at a capacity of at least .2 N*m of torque in order to move our curtains (with the assumption we are moving the whole mass all the time).

Another tolerance we need to care about is the light sensor. Since the BH1750 sensor is light source independent, it’s important to differentiate between sunlight and room lighting. Typically, a very dark day can have as low as 107 lux and an average home has 150 lux. One way to solve that is turn on and off the sensor basing on sunrise and sunset time. Another solution is that the sensor can be adjusted to face directly towards or slightly angled from the window. To make sure more than 60% of the light that the sensor measures is from the window, the sensor can be angled up to 45 degrees away from the window.

2.5 Risk Analysis

The motor poses the most significant threat to the completion of our project because of the heavy force that it needs to exert on the curtains. While we have chosen to work with the stepper motor which is prone to stalling and slipping when forced to move a heavy thermal curtain. In order to mitigate this we may need to employ multiple motors.

However, this introduces the problem of reduced processing time of the controller. We may need to add an additional processor to allow the arduino to take on other tasks. The minimum weight that the motor will need to undertake is 4 lbs.

The network connectivity of the device is a major aspect of its features, as it’s secondary function aside from interacting with curtains is to provide information to other smart home devices. In order for this to be possible, the device must be able to accurately and consistently relay sensor data. A concern is connectivity reliability of the device. The device will have a wifi module that connects to the user’s home wifi, which then relays data to the server. Data transfer speeds aside, the concern is how reliably the wifi module can transmit data to and from the device. In different user environments, the wifi module may have to cross through multiple walls and floors in order to reach a wifi router. Even then, the reliability of the wifi module itself is put into question. However, despite all these concerns, using a wifi module is still the best option, as other forms of wireless data transmission, such as bluetooth, only exacerbate these concerns and add unneeded complexity. If the wifi module is noticeably unreliable, a possible idea is to implement two wifi modules on the device, such that the overlap of the simultaneously running modules can cover up for each other's data drop or downtime.

3. Cost and Schedule

3.1 Cost Analysis

3.1.1 Labor

Assume hourly salary for a newly employed electrical engineer is $50/hr and assume an average workload is 10 hrs/week. With a total of 16 weeks of work this semester, the total labor cost would be:
$50 × 2.5 × 10 hrs/week × 16 weeks = $20000.

3.1.2 Parts

Name of Part	Manufacturer	Quantity	Cost	Link
Arduino Uno Rev3	Arduino	1	$23	Arduino Uno Rev3
ROB-12779 Driver	Sparkfun	2	$14.95 * 2	Easy Driver
Nema 17 Motor	Usongshine	2	$9.97 * 2	Motors
Motor Mount	Chiloskit	2	$10.51	Motor Mount
AC/DC Adapter	VeeDoo	1	$8.99	AC/DC Adapter
Pulley and belt set	2GT Timing Belt & Pulley	2	$13.88 * 2	Pulley & belt
Infrared Thermometer	Melexis	1	$29.95	Infrared Therm
Wifi Module	Espressif	1	$7.93	Wifi Module
Photo sensor	DFRobot	1	$4.50	Photo sensor
Logic Level Converter	Sparkfun	1	$2.95	Logic Level Converter
4.7k Resistor	Yageo	2	$0.1 * 2	4.7K Resistor
100nF Capacitor	TDK Corporation	1	$1.25	100nF Capacitor
Terminal Block	NTE	4	$0.57 * 4	Terminal Block

	Electronics, Inc			
Curtains (2 panels)	BGment	1	$24.88	Curtains

Total price of parts:194.04 + tax.

3.1.3 Total

Total Cost = Labor + Parts = 6400 + 194.04 + tax = 20194.04 + tax.

3.2 Schedule

Week	Daniel	Rachel	Anusha
3/1	Setup web server api	Design circuit schematic	
3/8	Create database schema for data	Modify pcb	Research on ideal sensor values
3/15	Setup database	Setup motor control	Setup motor control
3/22	Setup functions to make changes to database	Setup Sensor control and improve circuit if needed	Setup sensor control
3/29	Setup endpoints database functions as api for application and device	Installation and finalize design (and wiring)	Finalize Arduino code
4/5	Create mobile app front end	Testing and troubleshooting	Create mobile app front end
4/12	Connect mobile app to send data between server and device	Final debugging with mobile app	Debugging with mobile app
4/19	Prepare for demonstration		
4/26	Prepare for presentation and start final paper		
5/3	Finish final paper		

4. Discussion of Safety and Ethics

The power supply that we have chosen poses a significant safety hazard as it is dealing with voltages and currents that are extremely high [5]. In addition to paying close attention not to any personal burns and shocks, we need to be careful not to overload our motor and arduino with too much power. In order to avoid this, we independently test our circuitry in the lab before connecting modules.

We also need to be careful with rain and water damage as much of this circuitry will be in close proximity to windows. The photo and thermal sensor will both need to be waterproof in case of any unintentional runoff. In order to protect the circuitry itself, we will need to have a protective case surrounding the sensor and control modules.

Another concern we need to consider is that of security. Since we are transmitting data and curtain control over the wifi network we need to ensure that only the user will be able to access the information that is being transmitted. This security will be provided through password locks. We would uphold IEEE Code of Ethics, #1: “to hold paramount the safety, health, and welfare of the public…[6].”

Furthermore, since this device interacts with the physical barrier that maintains privacy in a home’s windows. Although heating and lighting are the forethoughts of this project, we must keep in mind to not infringe upon a home by reducing the control of the user to use curtains as a means to not allow outsiders a view on their homes. In order to maintain this, the user must always feel in control of when the curtains are open or closed, and allow the user to disable any behavior that automatically opens or closes the blinds.

5. References

[1] NRDC. 2020. ‘How to Keep Warm and Save on Your Energy Bills This Winter’. [Online] Available at: https://www.nrdc.org/stories/how-keep-warm-and-save-your-energy-bills-winter [Accessed 16 Feb 2020].

[2] VeryWellHealth. 2020. ‘Get Morning Sunlight and You'll Sleep Better’. [Online] Available at: https://www.verywellhealth.com/morning-sunlight-exposure-3973908 [Accessed 16 Feb 2020].

[3] Aqara. 2020. ‘Curtain Controller’. [Online] Available at: https://www.aqara.com/en/smart_curtain_motor.html [Accessed 16 Feb 2020].

[4] Curtains For Barns. n.d. ‘Fully Automated Curtain Systems’[Online] Available at: https://curtainsforbarns.com/complete-systems/ag-curtain-automation/ [Accessed 16 Feb 2020].

[5] Health and Safety Authority. 2021. ‘Electricity in the workplace’. [Online] Available at: https://www.hsa.ie/eng/Topics/Electricity/Dangers_of_Electricity/Electricity_in_the_Workplace/#:~:text=The%20main%20hazards%20with%20electricity,in%20a%20spray%20paint%20booth. [Accessed 16 February 2021]

[6] Ieee.org. 2021. ‘IEEE Code of Ethics’. [Online] Available at: https://www.ieee.org/about/corporate/governance/p7-8.html [Accessed 15 February 2021]