Interactive Donor Wall Illumination

Design Review

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1 Introduction

1.1 Objective

The donor wall is located on the southwest side on the first floor in ECEB. It celebrates and appreciates everyone who helped and donated for the building and the department. The problem with the hallway with the donor wall is two-fold. Because of poor lighting, the donor names are not noticed as much as they should, especially after the sunset. Also, because of the lack of chairs and tables for people to study on or socialize, the hallway is just a “highway” for people to walk through. To bring more attention to the donor names and to liven up that hallway, we are going to design and implement an interactive, highly responsive, and maintenance-free illumination system for the donor wall. Firstly, LEDs will be placed behind the names to always softly illuminate each name. Secondly, LEDs will fill in the translucent gaps (non-copper areas) in the “circuit board” with interactive illumination. Thirdly, Sensors will be embedded throughout the design to implement interactive and highly responsive system. According to various signals received by the sensors, a microcontroller will be used to control LEDs to control interactive patterns. As a result, our design will allow the donor wall to bring more attention to the donors and to liven up the hallway.

1.2 Background

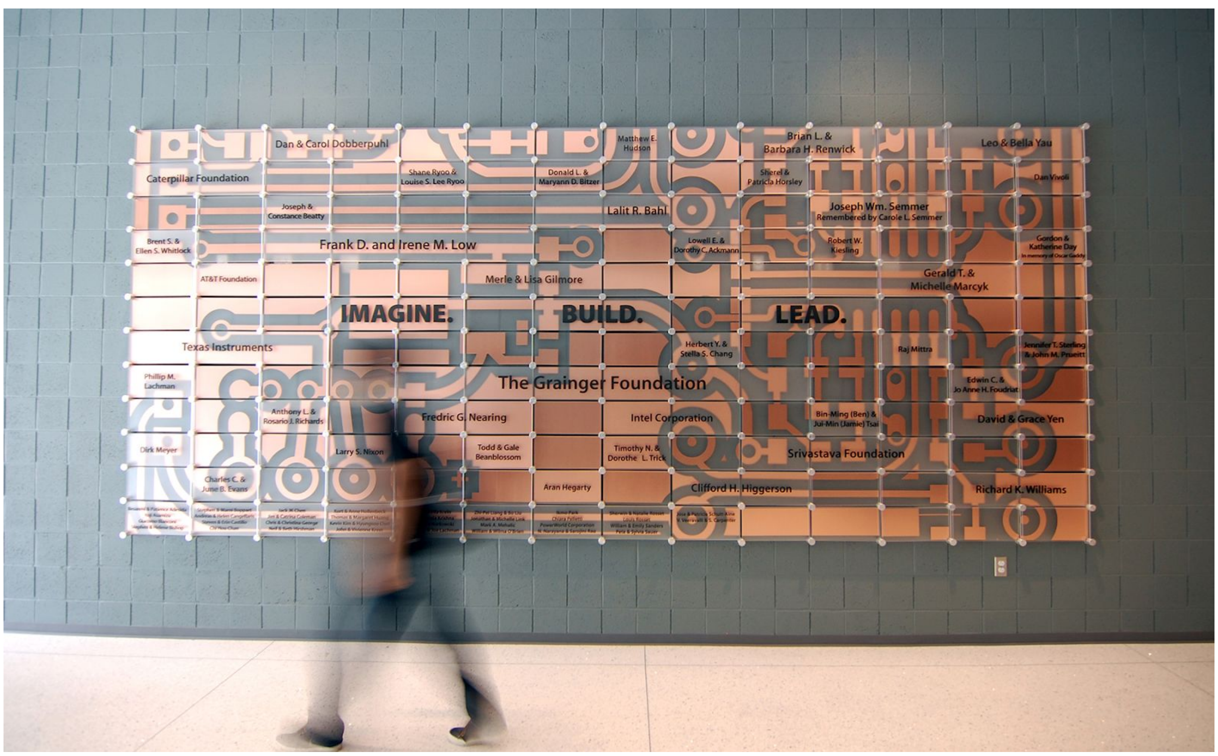

Figure 1: Image of Donor Wall (touched up by Kurt Bielema)[1]

Our team have been in touch with Skot Wiedmann, Todd Sweet, Catherine Somers and Timothy Newman to discuss any potential limitations of our project, the purpose and the background of the donor wall, and any concerns that they may have about the project. The most important takeaways from the meetings is that the original purpose of the donor wall is to celebrate and highlight the donor names. In case this project were to be actually installed on the donor wall, they would require the illumination system bring more attention to the donor names and not disrupt or destroy the original purpose of the donor wall. Also, Skott Wiedmann is our mentor for the project. He designed the copper layout on the donor wall and have experience with interactive art projects similar to ours.

1.3 High-level Requirements

- The illumination system must be highly sensitive to interaction and be visually pleasing as much as possible.
- The illumination system must bring more attention to the donor names on the donor wall.
- The donor wall illumination system must be stable or functional for a prolonged period of time (no required maintenance for at least a month).

2 Design

2.1 Functional Overview

There are three main modes to our donor wall illumination project. They are listed below in the order of how much a person is engaged in the interaction with the donor wall. Note that for all three modes, the name blocks on the donor wall are always softly illuminated from the back center of the acrylic glass. Also, note that for all three modes, the varying parameters between each modes are the number of pulses, consistent or inconsistent time interval, and short and long time intervals.

- **Default Mode (No engagement)**:
  When there is no obstacle near and in front of the donor wall, the name blocks are always softly illuminated from the back center of the acrylic glass. Also, seemingly random quick pulses of “currents” flows throughout the board at a relatively slow inconsistent interval (~2 pulses every 1-2 second). In this mode, the initial pulses starts from the outer edges of the donor wall. Whenever a pulse ends up at or goes through a name block(s), the already soft illuminated name block(s) is slowly and smoothly illuminated with a stronger intensity. After 1 or 2 seconds of strong intensity, the name block is slowly and smoothly returned back to the soft glow. The aesthetics should be calming and smooth. In other words, there are a few quick pulses starting at the edges of the donor wall at inconsistent time intervals to have a relatively infrequent “highlights” of the name blocks.

- **“Human is Present or Moving” Mode (Some or potentially no engagement):**
  When an obstacle such as human(s) passes by or is present in front of the donor wall within about 3 or 4 meters, multiple motion sensors (Passive Infrared Sensor, PIR) will be used to detect human(s). Once detected, the LEDs will animate about 4 or 5 smooth but quick pulses of “currents” flowing through the circuit at a regular interval (about every 1 second). At every interval, the starting points of each pulse are the (un)varying position of the detected person. If possible, it’s desired to have each pulse to be in the same direction as the direction of a walking person. If not, some pulses may diverge out from the detected position of a person. Then, as each pulse arrives to the name blocks, the already soft illuminated name block(s) is slowly and smoothly illuminated with a stronger intensity. After 1 or 2 seconds of strong intensity, the name block is slowly and smoothly returned back to the soft glow. In other words, there are quick and multiple pulses starting at consistent time intervals at the detected locations of a person to have relatively more “highlights” of the name blocks than that of the default mode. This mode will require quite complex sensor and control units.
- **All-Mode-Override Mode (Complete engagement):**
  - When a person’s hand is present in front of a name block within about 10 *cm* (this distance may change depending on the sensor’s parameters), the LEDs will display about 20 or 30 exploding, diverging, and quick pulses starting from that particular name block. Each pulse will travel out from the particular name block to every other name block. Then, as each pulse arrives to the name blocks, the already soft illuminated name block(s) is slowly and smoothly illuminated with a stronger intensity. After 1 or 2 seconds of strong intensity, the name block is slowly and smoothly returned back to the soft glow. Once every name block has been “highlighted,” the illumination system goes back to the default mode. This mode overrides any previous modes. Proximity sensor will be used and will allow the users to interact with the donor wall without physically touching.
  - Another option is to have the pulses “explodes” but fades out gradually. This effect is easily described by a water drop dropping into water. The “waves” starts where the drop fell and it dies out as it travels outward. We will physically experiment which effect (either gradual decrease of pulse intensity or constant pulse intensity to illuminate all the rest of name blocks) is the best to choose.

2.2 Block Diagram

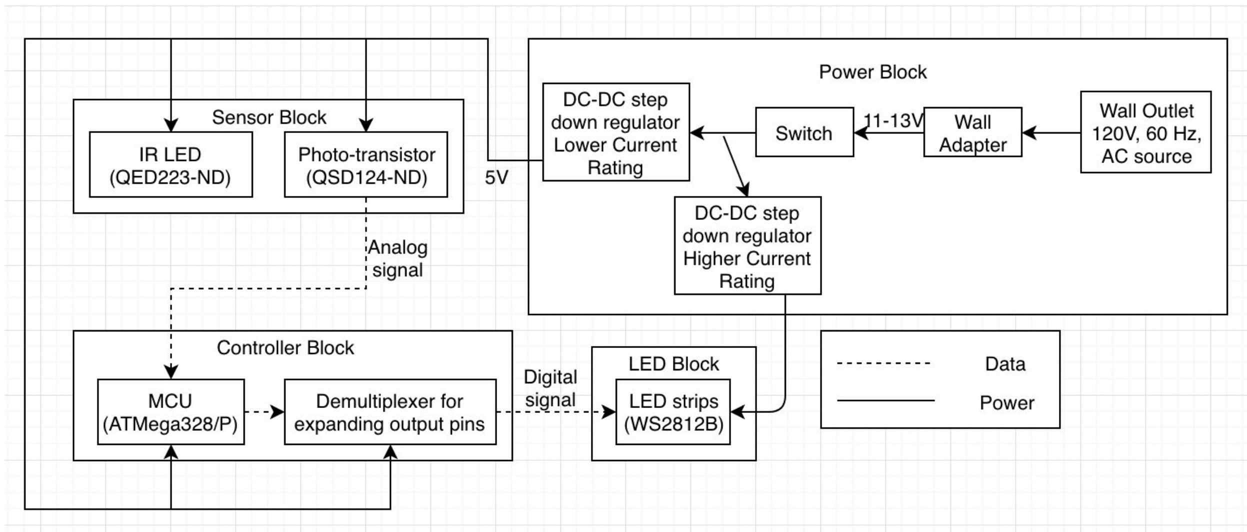

Figure 2: Donor Wall Illumination Block Diagram

Figure 2 shows the block diagram for our project. We will use the wall outlet, 120V 60Hz AC as our power source and use an adapter that will convert from AC from the wall output to 5V DC. This power will be supplied to all the other blocks. For sensors, we use IR LED and phototransistor to measure and detect any obstacle in front of each acrylic panels. The analog data from sensors will be sent to microcontroller and converted to digital data by integrated ADC(analog to digital converter). The microcontroller will check if the data values are in some threshold (detailed value needs to be tested) to determine which mode is triggered. Lastly, the digital signal will be sent to LED strips through demultiplexer to achieve different animation.

2.3 Physical Design

We are going to build a model of the real donor wall, which will be a combination of small portions of the actual art display to ensure that all possible challenges from the copper background design would be included in our model. Our model will be three panels in length and two panels in height compared to the actual model which is fourteen panels in length and twelve panels in height as seen in *Figure 1*. Each regular-sized panel, except the extra long panels with the donor's name on it, are 15.5in in length, 7.5in in height and 0.25in in thickness. Each of the panels are separated by a distance of 0.25in on each sides and held up by knobs on each corners of the panel. The knobs on the actual donor board are measured to be 1.5in in diameter and they are screwed into the wall in the ECE Building as seen in *Figure 3*. The machine shop will provide us with the needed knobs screwed into the backdrop made of MDF, which will be our fake wall.

Figure 3: Close-up Image of Donor Wall from the side

One of our major roadblock is the cost of our model as the acrylic glass proved to be very expensive. The actual model has three layers of acrylic glass with copper sheet between the last layer and the second layer as seen in *Figure 3*. To reduce the cost of our model, we are implementing our model on two layers of acrylic glass for the board with donor's name on it and one layer of acrylic glass for the boards without the donor's name as shown in *Figure 4*. The copper sheet will be implemented in our model by using masking tape and by spray painting on the backside of the second layer. The name blocks of the donors on the front side of the first layer of acrylic will be implemented by using black tape cut out in the shape of various letters and taped to the front side of our first layer. The knobs that hold the panels will be custom made by the machine shop using aluminum to reduce the material cost. All the acrylic glass of the actual model are frosted but the bare material comes as clear acrylic glass. Thus, we sanded one side of each of the clear acrylic glass with sandpaper to achieve the frosty material property.

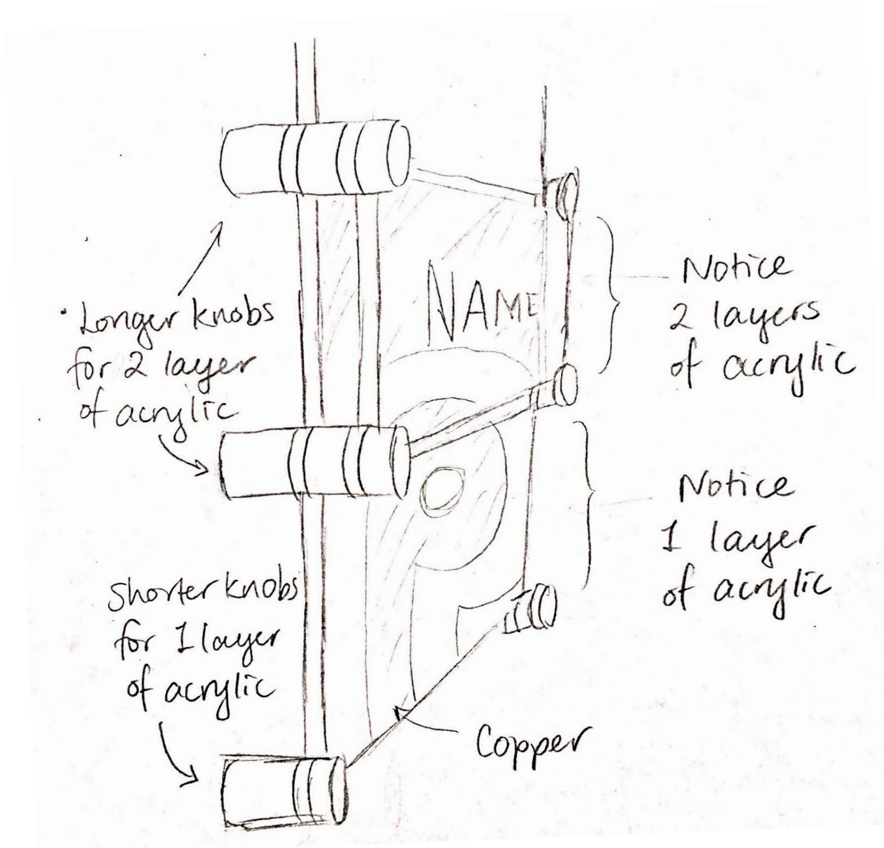

Figure 4: Cheaper Implementation of Our Model

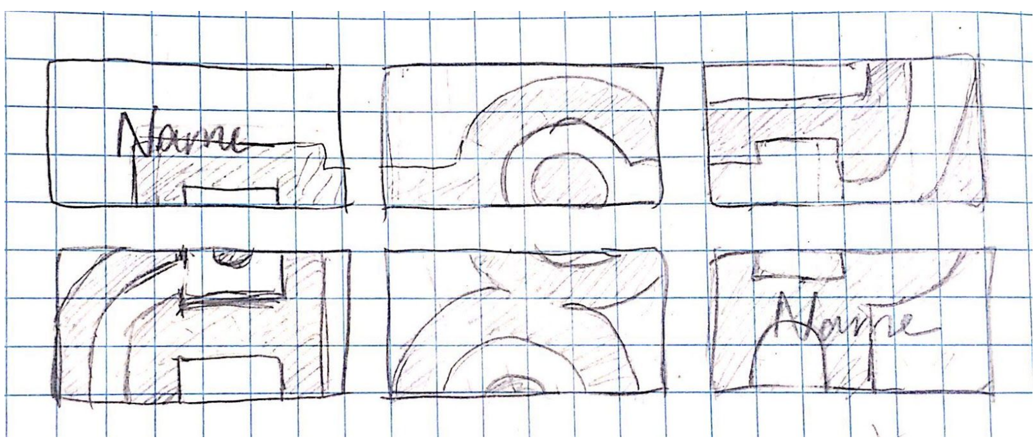

Figure 5: Example of Our Model (front view)

Figure 5 shows an example of what our acrylic glass model will look like and their relative position. This is our first design that we put together for our model of the Donor Board, and it is subject to change if there are other variations of copper circuit background design that needs to be included in the model.

2.4 Block Design

2.4.1) Sensor Block

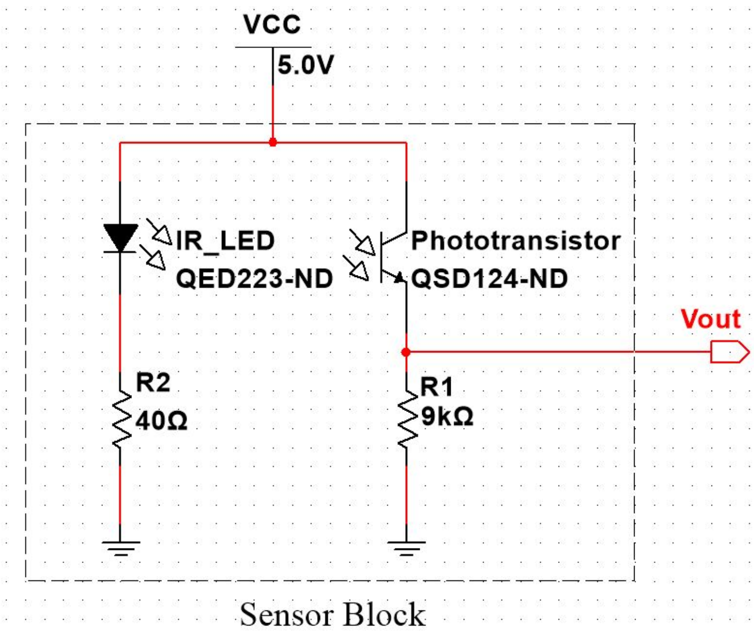

Figure 6: Circuit Schematic of Sensor Block

The functionality of the circuit is as follows. The IR LED is connected to 5V and it emits Infrared light mostly at a wavelength of 880 nm. IR LED also emits Infrared light in other wavelengths but it simply produces the the most of Infrared light at 880 nm. The $40\ \Omega$ resistor is used as a current-limiting resistor. The calculation of this resistor value is discussed in detail in the Tolerance Analysis section. The NPN phototransistor is connected to $5V$ and this phototransistor is the most sensitive to Infrared light at 880 nm. When there is nothing in front of the wall, the phototransistor is "off" and the voltage at V_{out} would be ambient Infrared light dependent. As a person or an obstacle comes in front of the sensor, the Infrared light from the IR LED gets reflected back into the phototransistor. As the person gets closer to the sensor, the voltage at V_{out} increases. As shown in more depth in the Tolerance Analysis, the voltage gradually increases as the distance of a person to the sensor decreases only when the transistor is off. When the transistor turns on, the voltage at V_{out} increases dramatically. Based on the resistance value chosen for $R1$, the voltage range at V_{out} differs greatly.

In terms of the sensor block's interface with the rest of the blocks, the power V_{cc} of 5V is supplied from the power block. The IR LED is on all the time. For varying amounts of infrared light from the IR LED reflected back into the phototransistor, the output voltage V_{out} would vary accordingly. As the $9\ k\Omega$ resistor connects the emitter of the phototransistor to the ground, the phototransistor would turn on as infrared light from IR

LED gets reflected into the phototransistor. Accordingly, the phototransistor would turn off when there's not enough infrared light coming into the sensor. The output V_{out} from the sensor block is then fed into the controller block. The controller block then processes the V_{out} to determine which mode to activate.

This circuit has been tested extensively and has been prototyped on perf board. Looking at a scale from 0V to 5V, the voltage output is stable. However, looking at the voltage output at a range from 0V to 500mV, the waveform is not stable. Since the sensor block deals with changing the mode at a range of 0V to 500mV, the fluctuations in the voltage output must be taken care of. So far, many random capacitors has been tested at the output node. Adding a $10\mu F$ capacitor has been proven to provide a constant voltage output enough for in the range of 2 digital units. This capacitor's value will be determined more extensively upon testing with oscilloscope and plotting the data to see which capacitor produces voltage output with the least fluctuations without visually apparent delay in response time. If adding the capacitor to filter out the fluctuations is not enough, the rest of the fluctuations can be taken care of through software implementations. At this point, it would not make sense to implement another complicated filtering circuit when it could be just an addition of one line of code in the software side.

Requirement	Verification	Points
1. When supplied with 5V from a bench power supply, IR LED turns on and the voltage drop across the LED does not go under 1.62V for 1 hours in room temperature 2. When supplied with 5V from a bench power supply, the phototransistor works with IR LED, Arduino Development board and three LEDs (development board used only for testing and the three LEDs to visually indicate each mode) to detect the three different modes. The transitions between each modes should be when the distance of the person is 100 cm and from the phototransistor consistently for 1 hour in room temperature. NOTE: The voltage measured cannot be specified because the range of the measured voltage varies largely depending on the amount of Infrared light present in the environment. NOTE: The development board is used for requirement because of limited ADC resolution of the microcontroller. 3. The same as #2 except the working distance is at 20 cm.	1. a) Supply the IR LED supplied with 5V from a power supply. b) Set up a multimeter to read the voltage across the IR LED. c) At an interval of 15 minutes, measure the voltage across the IR LED. 2. a) Given that the requirement #1 is fulfilled, setup the IR LED circuit. b) Check whether the IR LED is on using a phone camera capable of seeing Infrared light. c) Setup the phototransistor circuit. d) Connect the sensor circuit to microcontroller and load the program. e) At a regular interval of 15 minutes, walk in front of the sensor to check whether the modes change at 100 cm. 3. a) The same as #2 except the working distance is at 20 cm.	1. 4 2. 8 3. 8

Table 1: Requirement and Verification Table for Sensor Block

2.4.2) Control Block

This block contains two main parts. The microcontroller part and the demultiplexer part for expanding output pins. We are going to use ATmega328/P chip as our microcontroller. The reason we choose this chip is that this microcontroller is used on the Arduino Uno Dev Board, so it is easier for us to test our algorithm using the Arduino board in development phase, but for the final project, we will build up our own PCB for the microcontroller and the decoder parts. We need to design our PCB properly to fulfill the necessary functions of the Arduino Uno. The circuit schematic design of our PCB is in supporting material section.

Because we need to test the effect of LED strips and the final number of strips needs to be determined after we build up the final model and really see the effect visually, we may or may not need to use the demultiplexer to expand output pins. If we need to use demultiplexer, we are going to use two 16-channel parallel demultiplexer. Each output from demultiplexer will be AND with data line to send signals to LED strips. We have 26 led strips to be controlled, but there is not enough output pins on the microcontroller, so using demultiplexer is a good choice to handle many outputs.

2.4.2.1 Microcontroller

The microcontroller continuously reads data from sensor block. Depending on the data from the sensors, microcontroller checks if the data is above or below some threshold, which means user is detected or not. And microcontroller decides which mode the whole system is in currently and sends signals to LED strips to control them animate different effects. When nothing is near the board, the input values are lower than a threshold, LEDs are controlled to flow through the board with no other restriction. When someone is moving before the board, the starting point of the current flow will be the board with higher input value. When someone is putting his or her hand before a block, the starting point of the current flow will be the board with highest input value and this value is higher than a threshold (specific value needs to be tested). So the input values are separated into 3 different ranges to control different modes.

Requirement	Verification	Points
Correctly compare the input data and switch to correct mode	a) Start from handling the case that has only 3 boards, putting them in a row, initially. Each board has a sensor circuit on it. So we have 3 inputs now and these 3 inputs are sent to microcontroller. b) Then we put three LEDs on the breadboard to represent three mode. LEDs are connected to three output pins of microcontroller. c) Then we walk through the boards, or put hand in front of one board or leave the board empty. This is the simulation of 3 different situations.	5

	d) Then in the software, we compare these 3 inputs by threshold conditions. Then determine which mode is triggered. Then the LED representing that mode should be turned on. e) In the end, we apply this algorithm and expand these conditions for 6-input case.	

Table 2: Requirement and Verification Table for Microcontroller

2.4.2.2 Multiplexer and Demultiplexer

Because we do not have enough output pins on the microcontroller chip, we may need to use demultiplexer to increase the number of output pins. We are going to use two 1-to-16-channel demultiplexer. So we can have up to 32 outputs in total. Each demultiplexer needs 4 select bits and 1 data in bit. And there are 4 unused output pins on the chip. So if we need to add more LED strips, there is still free space to expand more.
For now, the 6 analog input pins on the chip are enough to read in the sensor data. And if we change our design to have more sensor inputs, we will use multiplexer to expand input pins.

Requirement	Verification	Points
Send data through the demultiplexer to the LED strips.	a) We set a output channel to be high by setting up the select bits accordingly. b) Then this output channel and the data output pin is AND together. c) If the data is sent correctly, then the LED strip on the other side of the AND gate should perform correct effect, which is programmed in the software and sent out through that output data pin on chip.	10 (If not using demux, then put these points on software)

Table 3: Requirement and Verification Table for Multiplexer and Demultiplexer

2.4.2.3 Supporting Material

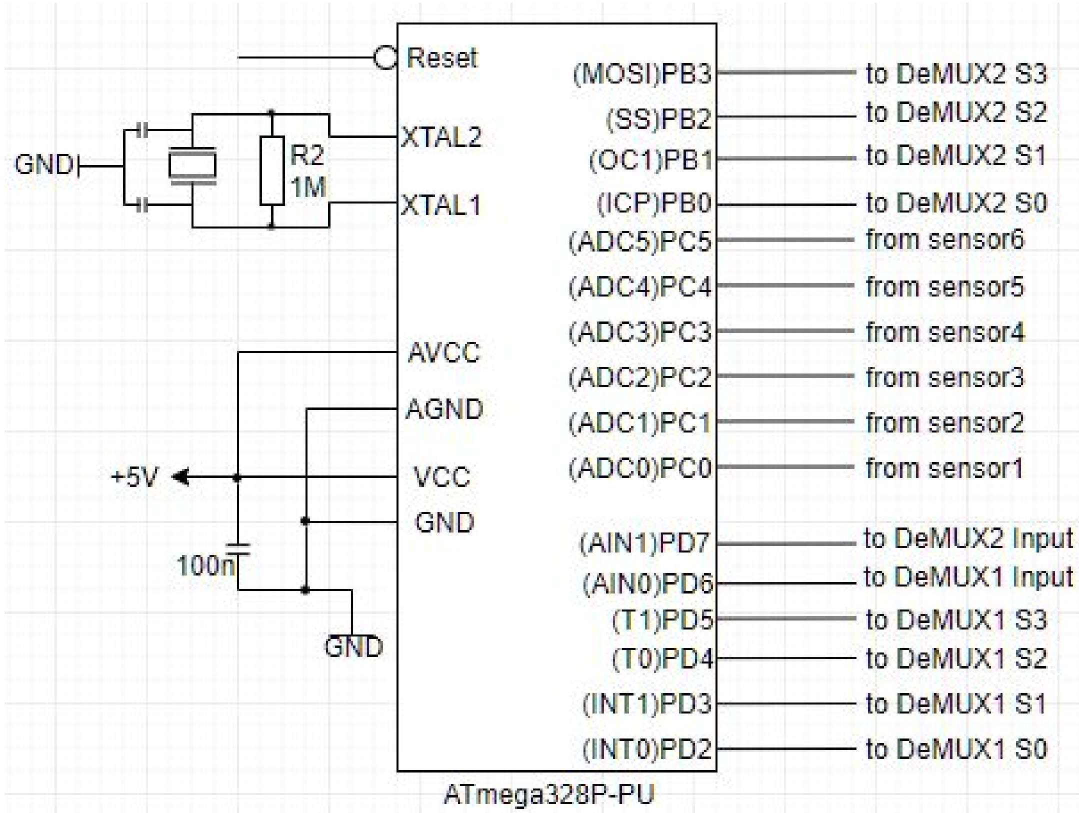

Figure 7: Micro Controller Circuit Schematic

This is the circuit schematic of micro processor. We draw this diagram based on the circuit schematic of the Arduino Uno board[4] given on the Arduino Website and the datasheet of the chip ATmega328P[5].

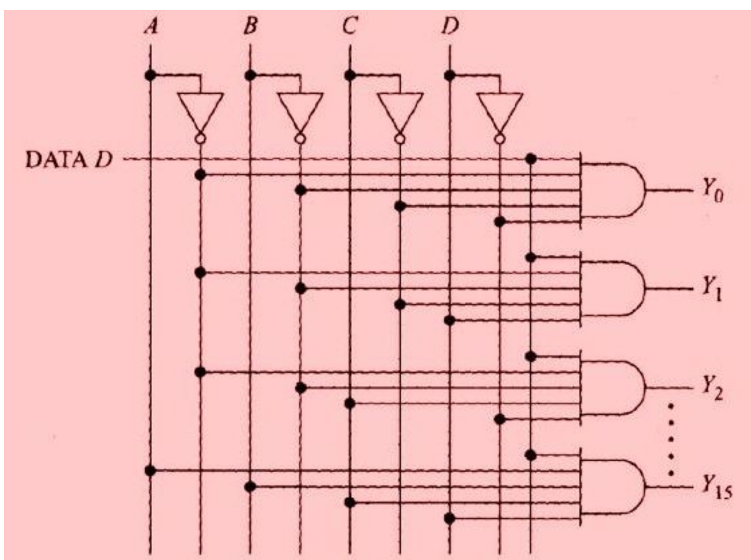

Figure 8: Basic idea of how demultiplexer works with data[6]

This is the idea of how we will use demultiplexer to select correct led strip and send the data D to that led strip. 4 inputs A,B,C,D, each on will be set to 1 or 0 to select one output channel to be high and every output is AND with the DATA D, so the DATA D will be sent out through the chosen channel. In the *Figure 8,* data is going out through one of Y0 to Y15.

We are using the 74HC154 chip as demultiplexer. *Figure 9* is the function table of the chip. One important thing to notice is that the selected output is low for this chip, so we need to use inverter to invert each output from the chip and then AND with the DATA D.

Table 3. Function table[1]

Input						Output															
$\overline{E0}$	$\overline{E1}$	A0	A1	A2	A3	$\overline{Y0}$	$\overline{Y1}$	$\overline{Y2}$	$\overline{Y3}$	$\overline{Y4}$	$\overline{Y5}$	$\overline{Y6}$	$\overline{Y7}$	$\overline{Y8}$	$\overline{Y9}$	$\overline{Y10}$	$\overline{Y11}$	$\overline{Y12}$	$\overline{Y13}$	$\overline{Y14}$	$\overline{Y15}$
H	H	X	X	X	X	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
H	L	X	X	X	X	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
L	H	X	X	X	X	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
L	L	L	L	L	L	L	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
		H	L	L	L	H	L	H	H	H	H	H	H	H	H	H	H	H	H	H	H
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		H	H	L	H	H	H	H	H	H	H	H	H	H	H	H	L	H	H	H	H
		L	L	H	H	H	H	H	H	H	H	H	H	H	H	H	H	L	H	H	H
		H	L	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	L	H	H
		L	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	L	H
		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	L

[1] H = HIGH voltage level
L = LOW voltage level
X = don't care.

Figure 9: Function Table of Chip 74HC154[7]

2.4.3) Power Block

The whole system will be powered from the wall outlet with AC source of 120V and 60Hz. We will use a wall adaptor that we have from home to convert the AC source of 120V to a DC source with outputs of 12V and 5A. The three main part of our design that needs to be powered up is the control block, sensor block and the LED strips.

The control block and the sensor block needs 5V to function and the current we measured from our first prototype with the sensor block and Arduino is about 550-600mA.

$$(90\ mA\ \times 6\ panels)\ +\ 20\ mA\ =\ 560\ mA\ (for\ all\ 6\ panels) \qquad (Eq.\ 1)$$

The 90mA is measured from our first sensor circuit. There will be a sensor block for each panel, thus I multiplied by 6. The 20mA is the expected current drawn for the controller block.

We have first prototype for only the sensor, thus we are unable to give solid numbers for current outputs of the LED block. This is because the LED block current will depend directly on the physical model design and the lighting animation, such as how many LED will be on at once and the intensity of the LEDs at various modes. The lighting animation overall will change when we light our physical model as it is dependent on the aesthetics. We have one panel currently to work with, but it will look differently when we have six of the panels together and see the current flow for longer distances. Thus, the number of LEDs to be used, how many LEDs will be on at once and at what intensities the LEDs will be lit all dependent on the physical model and is subject to change depending on the overall appearance. If we lit all of the LEDs at once at highest intensities, we will need total current ranging from 5A to 10A depending on the number of LEDs. However, since we won't be lighting all the LEDs at the same time, the current can be anywhere between 1A to 5A which is a huge range. Thus, the power calculations has been done only for the sensor and the control block and not including the LED block.

The power needed just for the sensor and the control block is estimated to be around 2.75 -3W.

$$5V\ \times 560mA\ =\ 2.8\ W \qquad (Eq.\ 2)$$

The 5V is the voltage regulated from the voltage regulator powering the sensor and the control block. The 560mA is the calculated current from *Eq.1*.

Each LEDs in the strip needs 50mA to be lit up, thus depending on the length of our LED strip needed to go around the edge of the copper designs, our current from the source will vary. For our initial prototypes, we will use a wall adaptor mentioned above, but if our system needs more than 5A to power the LED strips in our final design we will buy a different wall adaptor that will have higher current output.

After the wall adaptor converts the AC source to a DC source, an in-line switch will be added to allow a user to turn the whole system on and off. This in-line switch will be determined after we confirm the wall adaptor used for our final design with the needed current output. The switch will also vary depending on the current output needed for the system and the type of wall adaptor we will be using. Thus, switch will be one of the last component that we will buy and to implement in our design.

After the switch, a voltage step down regulator is required to drop the DC source voltage of 12V to 5V needed to power the control block, the sensor block and the LED block. Most likely we will use two different voltage regulators, one for the sensor and the control block and the other one for the LED block. This is because the current rating for the LED block will probably be much higher than the current rating for the sensor and control block. The voltage regulator for the sensor and control block that we will most likely use is TS30011-M033QFNR, which can be ordered from Digi-Key. This will ensure a reliable 5V is supplied to the control block and the sensor block. The second voltage regulator for the LED block can only be determined as we do not know the current rating. The second voltage regulator will most likely also output 5V, but it can change depending on the current rating as we may have limited product options with higher current ratings. The input voltage requirement for the LED block is 3.5-5.3V, which is a larger range than the input voltage requirement for the sensor and control block. Thus, the voltage regulator we pick may not drop the voltage to exactly 5V but it may be 3 or 4V instead as it depends on the product options. The current rating between 1-5A is a very big range and there are multiple different voltage regulators for different current rating. We will determine and purchase the second voltage regulator only after determining the current rating for the LED block with our complete physical model.

Component	Requirements	Validation	Points
Step-Down Voltage Regulator for Sensor and Control Block	1. Steps down the 7-15V DC source to reliable 5V output with 10% error. 2. Functions normally with current range of 0-600mA. 3. The regulator stays at operating temperature of -65 ~ 150 degrees Celsius.	1. Connect voltage regulator to lab power source and probe the output with DMM. 2. Turn the power source up and down within the accepted input voltage and current range and read the output with the DMM. 3. Connect the voltage regulator to the wall adaptor and probe with DMM to make sure it works with wall adaptor too. Also measure the temperature of the voltage regulator with a thermometer while the system is running non-stop for one hour. 4. Connect the voltage regulator with switch included and turn the switch on and off and check for transients response. 5. Ensure all the outputs are within the accepted range.	1. 3 2. 3 3. 1.5
Step-Down Voltage Regulator for LED Block	1. Steps down the 7-15V DC source to reliable required voltage output, which will be determined once we have our physical model, with 10% error. 2. Functions normally with current range, which will be determined once we have our physical model. 3. The regulator stays at operating temperature of -65 ~ 150 degrees Celsius.	1. Connect voltage regulator to lab power source and probe the output with DMM. 2. Turn the power source up and down within the accepted input voltage and current range and read the output with the DMM. 3. Connect the voltage regulator to the wall adaptor and probe with DMM to make sure it works with wall adaptor too. Also measure the temperature of the voltage regulator with a thermometer while the system is running non-stop for one hour. 4. Connect the voltage regulator with switch included and turn the switch on and off and check for transients response. 5. Ensure all the outputs are within the accepted range.	1. 3 2. 3 3. 1.5

Table 4: Requirement and Verification for Power Block

2.4.4) LED Block

This is the block to display the result and LEDs are controlled by the control block. We are using WS2812B. This type of LEDs can be controlled individually through Arduino IDE and the density is 60 LEDs per meter. This density is high enough for us to animate the current flow. We are going to use 26 strips to animate what we want and 16 strips will be connected to one demultiplexer and other 10 strips will be connected to another demultiplexer. And we are using FastLED library to program LED strips. For now, we have tested how to control 2 strips on two different output pins to animate the current flow. Here is the code:

```
#include "FastLED.h"

#define NUM_LEDS_1 10
#define NUM_LEDS_2 10

#define DATA_PIN_1 5
#define DATA_PIN_2 6

CRGB leds_1[NUM_LEDS_1];
CRGB leds_2[NUM_LEDS_2];

void setup() {
  // put your setup code here, to run once:
  FastLED.addLeds<WS2812B, DATA_PIN_1, RGB>(leds_1, NUM_LEDS_1);
  FastLED.addLeds<WS2812B, DATA_PIN_2, RGB>(leds_2, NUM_LEDS_2);
}

void loop() {
  // put your main code here, to run repeatedly:
  for(int i = 0; i < NUM_LEDS_1; i++){
    leds_1[i] = CRGB(255,0,0);
    FastLED.show();
    delay(50);
    leds_1[i] = CRGB(0,0,0);
    FastLED.show();
  }

   for(int i = 0; i < NUM_LEDS_2; i++){
    leds_2[i] = CRGB(0,255,0);
    FastLED.show();
    delay(50);
    leds_2[i] = CRGB(0,0,0);
    FastLED.show();
  }

}
```

Figure 10: Screenshot of the Code

In this code, two 10-LED strips are connected to pin 5 and pin 6, respectively. And the strip on pin5 animate red color flowing through it, after this, the strip on the pin6 animate green color flowing through it. So with this simple algorithm, we can control the animation of current flow. Then we can use the demultiplexer to send signals to more strips.

The requirement and verification is not available for this part, because this is totally controlled by microprocessor and the power is supplied by power block.

2.5 Tolerance Analysis

Extensive tolerance analysis has been performed for the sensor block. The current-limiting resistor of 40Ω has been carefully chosen based on varying IR LED's performance at each temperature. Table 1 shows the IR LED's working voltage and current from the datasheet from the manufacturer. Note that the temperatures were arbitrarily chosen to be the approximate temperatures inside ECEB with the facilities' heating and air circulation system. Also, note that the calculation of the current-limiting resistor is valuable since it is desirable to have the IR LED illumination intensity to be as high as possible for maximum sensitivity and maximum V_{out} range. The last temperature of 60 °C is also chosen arbitrarily to be the maximum working temperature of the IR LED due to heating from prolonged hours of operation.

T_A (Ambient Temperature, °C)	15 (Minimum Weather)	22.5 (Average Weather)	30 (Maximum Weather)	60 (Maximum Heat Temp.)
I_e (Normalized radiant intensity, unitless)	1.3	1.1	0.99	0.9
I_f (Forward Current, mA)	103	101	95	90
V_f (Forward Voltage, V)	1.82	1.78	1.75	1.62

Table 5: IR LED Performance With Varying Temperature

With the knowledge of V_f, the voltage across the current-limiting resistor can be calculated by simply doing $V_R = V_{cc} - V_f$ where V_{cc} is $5V$ and V_f is shown in Table 1 for various temperatures. With the knowledge of I_f, the current through the current-limiting resistor I_R must be the same. The table below shows the relevant resistor value and minimum power rating calculations.

T_A (Ambient Temperature, °C)	15 (Minimum Weather)	22.5 (Average Weather)	30 (Maximum Weather)	60 (Maximum Heat Temp.)
Resistance (Ω) $R = \frac{V_R}{I_R}$	30.8738	31.88	34.2105	37.6
Power (mW) $P_R = V_R I_R$	327.54	325.22	308.75	304.2

Table 6: IR LED's Current-Limiting Resistor Calculation

From Table 4 and Table 5, the current limiting-resistor value is calculated and chosen to be 40 Ω with minimum power rating of $327.54\, mW$. The resistance value was chosen to be higher than $37.6\,\Omega$ because the maximum working temperature of the IR LED might be higher than 60 °C and also because the $40\,\Omega$ resistor is able to handle all relevant lower temperatures. As for the minimum power rating, the highest minimum power rating was chosen such that the resistor effectively dissipates as much heat as possible away from the sensors.

As for the other resistor value in parallel with V_{out}, it was experimentally chosen to be $9\,k\Omega$ with the IR LED powered up with $40\,\Omega$. The reason for the resistance value is explained below.

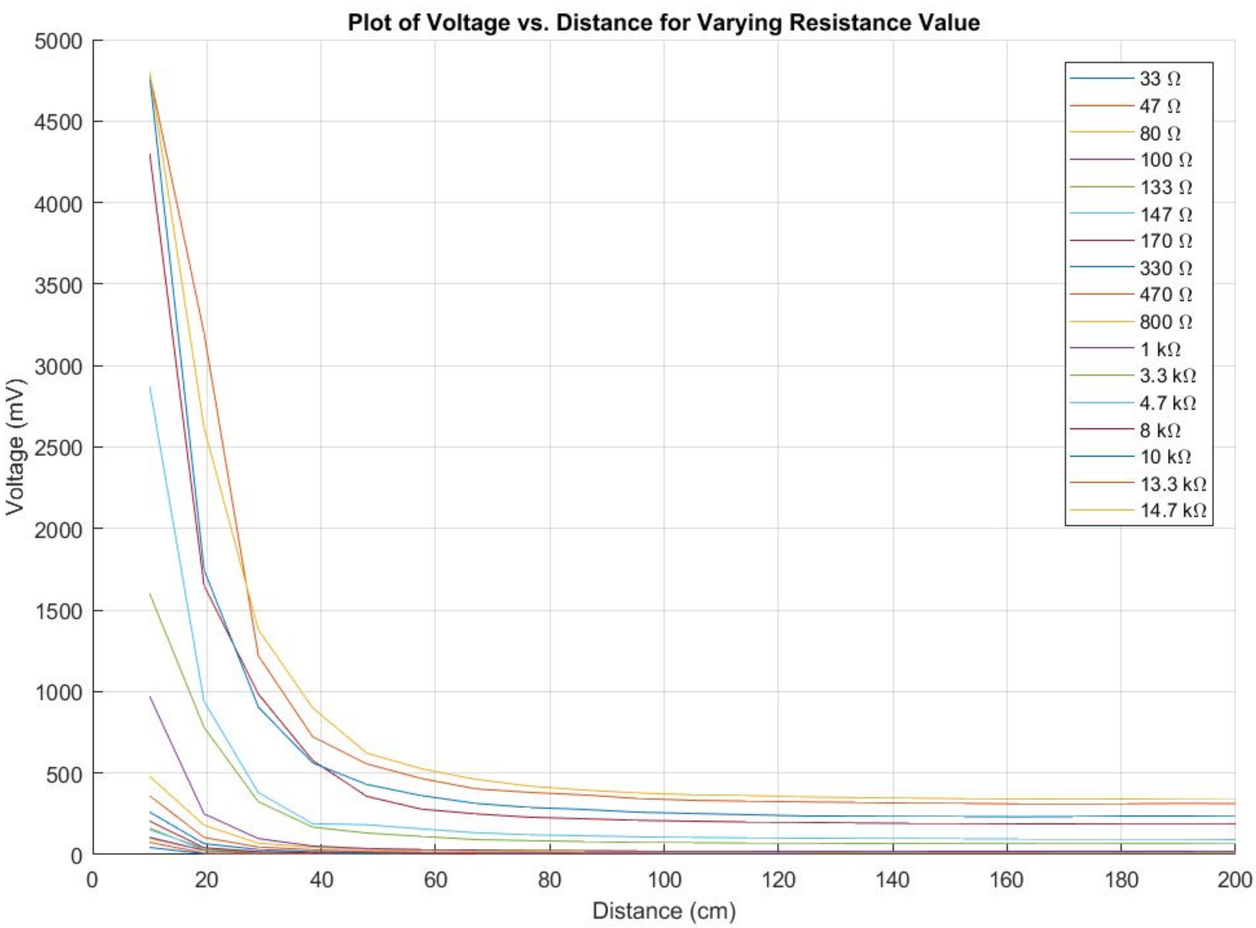

Figure 11: Plot of Voltage Across Resistor vs. Distance with Varying Resistance value

Figure 11 shows the plot of V_{out} versus distance of a person from the IR LED and phototransistor. As the resistance value increases, it's observed that the overall voltage and the range of voltage increases. For the purpose of the project, it's desirable to have the "all-mode-override" mode to be within the range of 0 to 30cm from the sensors. As can be seen from Figure 11, the curves that can be significantly distinguished from the voltages at distances from 40cm to 200cm to voltages at distances from 10 to 30cm are the curves for 8 $k\Omega$ and 10 $k\Omega$. So, at this point, it's known that the resistor value should be somewhere near 8 $k\Omega$ and 10 $k\Omega$.

The reason why 9 $k\Omega$ is chosen instead of any other resistor value near 8 $k\Omega$ and 10 $k\Omega$ is because of the "saturation" of maximum voltage. Looking at the curves for 10 $k\Omega$, 13.3 $k\Omega$, and 14.7 $k\Omega$, it's observed that the voltage curves "converges" at 10 cm. This means that the higher resistor value we use than 14.7 $k\Omega$, the maximum voltage range is decreased with constant maximum voltage at 10cm. Thus, there is no need to further experiment with higher resistor values. Also, comparing the voltage curves between 8 $k\Omega$ and 10 $k\Omega$, the 10 $k\Omega$ converged to the maximum voltage at 10cm while 8 $k\Omega$ does not. As a result, choosing a resistance value of 9 $k\Omega$ would allow for maximum voltage range and thus, maximum sensitivity.

Now that the circuit and the chosen resistance values has been explained in-depth, the table below shows the range at which the microcontroller block would have to set the "thresholds" for the three modes. Note that these voltages are experimentally determined.

Voltage Range (mV)	Distance Range (cm)	Mode Type
$V_{out} \leq 0.230V$	$d \geq 200cm$	Default Mode
$0.231V \leq V_{out} \leq 0.400V$	$30cm < d \leq 200cm$	"Human is Present or Moving" Mode
$V_{out} \geq 0.900V$	$0 < d \leq 30cm$	"All-Mode-Override" Mode

Table 7: Voltage Range Correspondence to Each Modes

One potential issue with this voltage range is that it requires the microcontroller to be able to process the voltage with many significant digits. For example, the microcontroller would need to reliably tell the difference between $0.230V$ and $0.231V$. To remedy such issue, another transistor can be used after the phototransistor but before the resistor. Such transistor would amplify the signal which would allow for larger voltage range and thus, lower significant digits.

Another potential issue that may become apparent for implementation of our project to the actual donor wall is how much the sensors would be affected by the sunlight through the windows.

Because sunlight also contains Infrared (IR) light, the phototransistors may easily pick up the IR light in the sunlight. This issue can be addressed in two ways. The first way to fix the issue of sensors being affected by the sunlight would be to change the environment around the donor wall to remove any significant source of sunlight through the windows. For example, the windows around the donor wall can be covered up so that it removes significant portion of sunlight. However, since this solution does not fix the problem entirely, it may not be the best solution. The second way to solve the issue is to use microcontroller to "calibrate" the voltage. For example, assume the voltage measured (V_{out}) without any obstacle nearby is 200mV. Then, say the voltage changes to 500mV with sunlight. The microcontroller can be programmed to interpret the 500mV as a 200mV. Then, if the rate of change of voltage is assumed to be constant, the microcontroller would successfully read in and interpret the data.

To determine whether the rate of change of voltages when the phototransistor is off, the derivative of the curves from Figure 12 has been plotted. As can be seen from the plot, the rate at which the voltage change per some distance does not relatively change with respect to the resistance values.

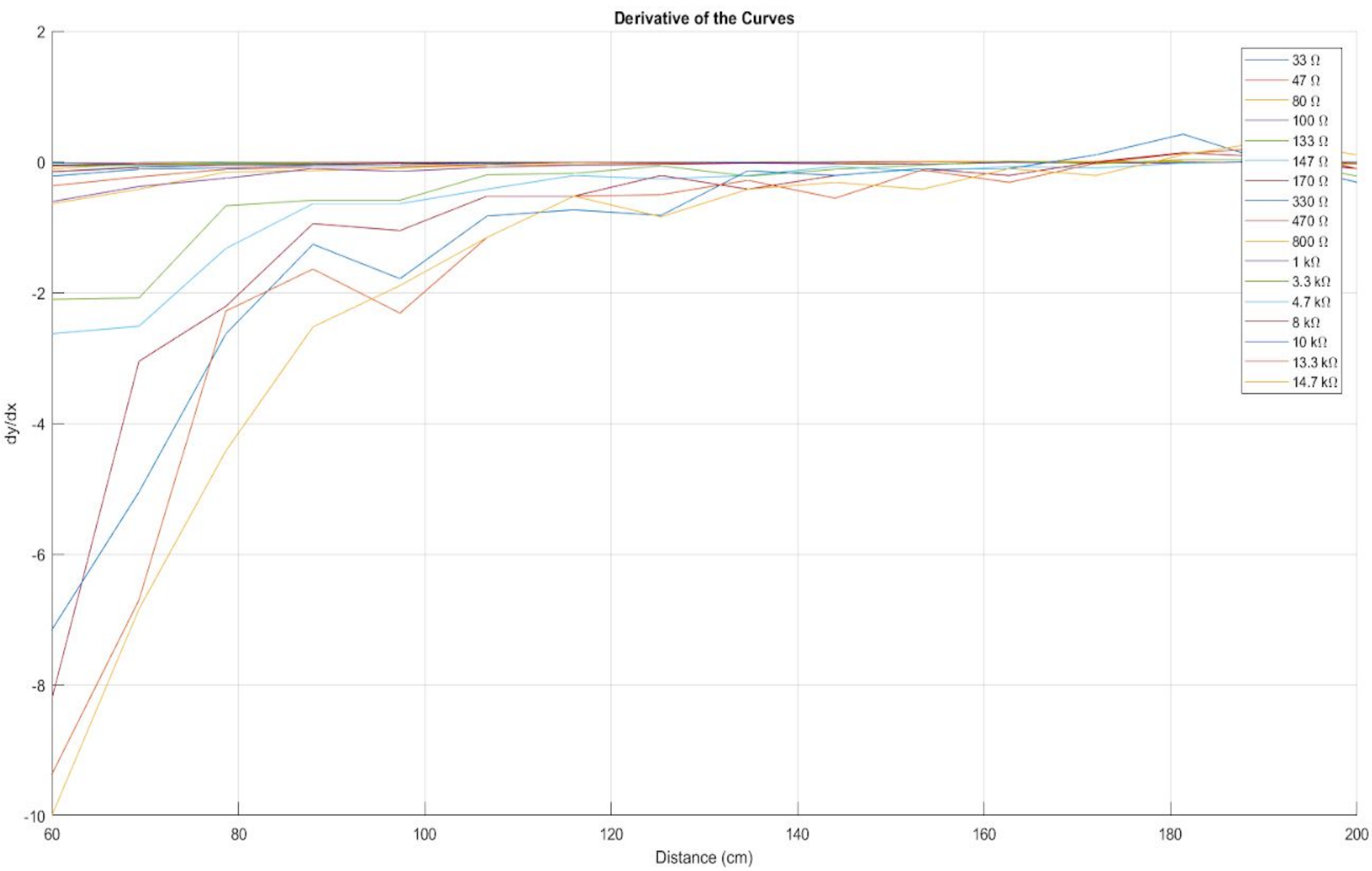

Figure 12: Plot of the Derivative of voltage vs. Distance

3 Software/ Programming

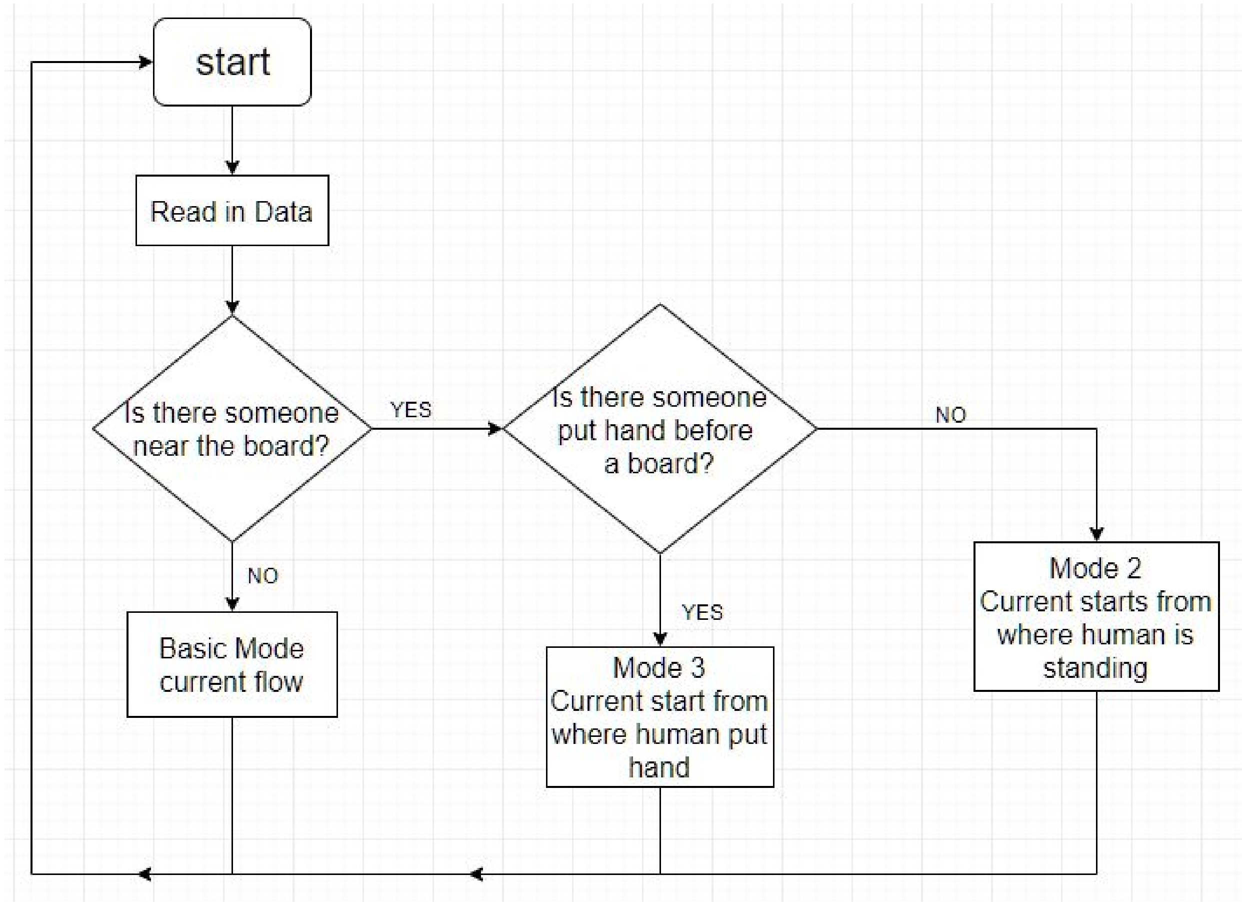

Figure 13: Flow Chart for the Software

This is the flow chart for the software. Program continuously reads in data from the sensors and check if the data meet conditions to enter another mode. The specific threshold need to be tested and tuned in the real experiment, but the idea of the flowchart will not be changed due to threshold. In each mode, we need to change select bits of the demultiplexer in a designed sequence to control different LED strips to work in correct time order. In each mode, the LEDs are controlled to do some animation, the current flowing through the board from side to side. After finishing this whole animation, software checks the inputs and then determines the mode should be triggered currently, then do the animation. Then checking the inputs again and animate again in a loop. So, after entering a mode, the animation should take 3 to 4 seconds to finish an animation action. Then it exits this mode and checks what is the next mode.

4 Cost

4.1 Labor Cost

We estimate our labor cost to be $35/hour and working about fifteen hours a week for each person. Our project is expected to be completed by the end of the semester of sixteen weeks. Thus, our cost come out to be $63,000.

$$\$35/hour \times 15\ hours/week \times 16\ weeks \times 3\ people \times 2.5 = \$63,000.00 \qquad (Eq.\ 3)$$

To make our model of the Donor Wall, we required the help of the Machine Shop in the Electrical Engineering Building. According to the Machine Shop, it will take a full day to saw the acrylic panels into its correct sizes and to make the custom knobs, which will be made from bare material aluminum. The labor cost is $400/day according to the representative from the Machine Shop.

4.2 Material Cost

Component	**Prototype (amount, cost)**		**Final Design (amount, cost)**	
Acrylic glass (15.5in x 7.5in x .22in)	2 scrap panels	$0	8 panels	$115
Copper	1 spray	$7.37	2 spray	$14.74
Knobs (aluminum)	0 knobs	$0	12 knobs	$50
Backdrop (Medium-Density-Fiberwood)	0 MDF	$0	1 MDF	$20
Wall Adapter	0 adaptor	$0	1 adaptor	$20-25
In-line Switch	0 switch	$0	1 switch	$8-15
DC-DC Voltage Regulator (12V to 5V) TS30013-M050QFNR from Semtech Corporation	1 chip	$1.37	1 chip	$1.37
IR LED (QED223-ND) from DigiKey [2]	6	$0	6	$0
Phototransistor (QSD124-ND) from DigiKey [3]	6	$0	6	$0
ATmega328P chip on Arduino Uno	1 unit	$22	Only chip	$4.67
WS2812B LED strip from Alitove	5 meter	$33	5 meter	$33

74HC154 demultiplexer from Texas Instrument	2 chips	$1.5	2 chips	$1.5
Crystal Oscillator HC-49S	0	0	1	$0.34
Total			**$709.99**	

Table 8 : Bill of Materials

Thus the grand total cost including the labor cost and the material cost is estimated to be **$64109.99.**

5 Schedule

	Anita	Sungmin	Zheng
Week of 10/01 **Design Document Due on Thursday by 11:59PM**	1. Determine how many LEDs are being used and how they illuminate the panel 2. Should have at least one frosted acrylic glass that allows us to test LEDs	1. Have a decent reliable sensor block to output voltage into the MCU	1. Have a detailed MCU circuit diagram that will interface with sensors and LEDs 2. Fix/adjust the block diagram to include all details
Week of 10/08 **Design Review Week (10/08/2018, 3:30PM, Room 2032), Peer review sign-up**	By the end of this week, all details to get the actual model of Donor Wall is all requested, processed, and well under way to finished construction from Machine Shop or an necessary physical tasks to be done on the acrylic glass	If any, troubleshoot the sensors with acrylic glass. If time allows, look into LED strips and LED illumination of donor name blocks. By the end of this week, sensor should be able to correctly interface with microcontroller.	Work with microcontroller to figure out how to control LED strips.

Week of 10/15 **Teamwork Evaluation Due Monday 11:59 PM, Soldering Assignment Due Friday 4:45PM**	1. Order sensors, adapters or other chips needed for the project. 2. Prepare the PCB file. 3. Finish up design the power block circuit.	1. Order sensors, adapters or other chips needed for the project. 2. Prepare the PCB file. 3. Finish up design the sensor block circuit.	1. Order sensors, adapters or other chips needed for the project. 2. Prepare the PCB file. 3. Finish up design the control block circuit. 4. Use the Arduino Board to control LED to mimic current flow in default mode.
Week of 10/22 The physical model should have been build up.	1. Submit the PCB file. 2. Place the LED strips in designed shape.	1. Submit the PCB file. 2. Place the sensors and the circuit in required places.	1. Submit the PCB file. 2. Use Arduino board to communicate between sensors and microcontroller. Control LED to mimic current flow in Third Mode.
Week of 10/29	1. Build up the PCB, finish up the soldering work to test if there is something wrong in the PCB. 2. Implement the Second Mode with Arduino Board.	1. Build up the PCB, finish up the soldering work to test if there is something wrong in the PCB. 2. Implement the Second Mode with Arduino Board.	1. Build up the PCB, finish up the soldering work to test if there is something wrong in the PCB. 2. Implement the Second Mode with Arduino Board.
Week of 11/5 **Final Round PCBway Orders. Last day for revision to the machine shop.**	1. If the PCB is not working correctly, make sure it can be fix by Thursday and submit final design circuit. 2. If the physical model needs to be	1. If the PCB is not working correctly, make sure it can be fix by Thursday and submit final design circuit. 2. If the physical model needs to be	1. If the PCB is not working correctly, make sure it can be fix by Thursday and submit final design circuit. 2. If the physical model needs to be

	changed, make sure it can be done by Friday.	changed, make sure it can be done by Friday.	changed, make sure it can be done by Friday. 3. Use the PCB as microcontroller and test the algorithm.
Week 11/12 Ideally, everything can work correctly as expected by the end of this week.	Debug the program. Or if there are add-on features, program as required.	Debug the program. Or if there are add-on features, program as required.	Debug the program. Or if there are add-on features, program as required.
Week of 11/19 **Fall break**	1. prepares for the Mock Presentation and starts working on the final paper and organize the notebook to get important part clear.	1. prepares for the Mock Presentation and starts working on the final paper and organize the notebook to get important part clear.	1. prepares for the Mock Presentation and starts working on the final paper and organize the notebook to get important part clear.
Week of 11/26	Everyone double checks the detailed requirement for the presentation. Work on the final paper	Everyone double checks the detailed requirement for the presentation. Work on the final paper	Everyone double checks the detailed requirement for the presentation. Work on the final paper
Week of 12/3	Prepare for the presentation and finish the final report by the end of the week.	Prepare for the presentation and finish the final report by the end of the week.	Prepare for the presentation and finish the final report by the end of the week.
Week of 12/10	Presentation, and fix some minor details in the final report, then submit.	Presentation, and fix some minor details in the final report, then submit.	Presentation, and fix some minor details in the final report, then submit.

Table 9 : Weekly Schedule

6 Ethics and Safety

6.1 Safety

With only a couple sensors and LEDs, it may not draw current to the dangerous amount. However, when the same circuitry is repeated over and over with multiple sensors and LEDs, the circuit may draw high current enough to kill someone. As a result, the sensors and LEDs just be made sure to have no exposed wire. Also, for stability of the circuit, it must be ensured that there are no significant changes in voltage or surges being fed into the sensors and LEDs. This can be done by designing a filter to protect the sensors.

6.2 Ethics

1. **to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, and to disclose promptly factors that might endanger the public or the environment;**

   According to the IEEE Code of Ethics[11], the first code explicitly asks us to warn the user that do not touch the circuit and only interacting with the model in appropriate ways. And because our project relates to handle a large number of IOs, we need to carefully and seriously test the input data. We also need to assess our project based on these accurately measured data because of the third statement in the Code of Ethics.

2. **to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others;**
   On the other hand, we will consider and evaluate the valuable and honest suggestions and advice from our TAs, professors and our sponsor. We need to correct ourselves actively when we encounter some unexpected errors in the progress, as specified in the seventh statement of Code of Ethics.

3. **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;**
   In the end, our project is aimed to let users enjoy art with no discrimination with our interactive design. We hope that our project can bring more fun to everyone.

7 Citations

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