THERMAL DISPLAY

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Abstract

'Thermal Display' is a thermally activated display that uses Thermochromic paper, otherwise known as 'Liquid Crystal Sheets', as its viewing screen. The liquid crystals respond to changes in temperature by changing color. With increase in temperature, their color changes to red, orange, green, and then to blue. The display is composed of 45 'pixels', each of which is a tightly wound Nichrome wire, pressed against the thermochromic paper and connected to a microcontroller via 8-bit shift registers. The pixels have a ramp rate of 9 seconds to go from black to blue when initially turned on and an average ramp rate of 5 seconds for the same. The content displayed on the screen is 3-or-fewer-letter words and is readable within 2-3 seconds of activation as the liquid crystal sheet turns red. An ultrasonic sensor allows the user to wave their hand over the product 10 cm away, to change the content being displayed on the screen, which by default switches between the words 'HEY' and 'BYE', within 15 seconds. Additionally, a Bluetooth app is connected to the 'Thermal Display' that allows the user to enter any 3-or-fewer-letter word and view it on the display screen.

Contents

1. Introduction

1.1 Purpose

Display technologies have come to a point where innovation has somewhat been stunted. Since the first LCD displays came out, most displays after that (LED, OLED, etc.) looked essentially the same, but with improvements towards making images more realistic. For a center of innovation, the display technologies need to stand out more and therefore, professor Paul Kwiat asked us to build a thermal activated display for the IQUIST (Illinois Quantum Information Science and Technology Center) [1] office. Thermally activated display technologies do not exist in a feasible form yet. The ones that do exist, like the Thermochromic Display by 'Che-wei Wang' [9] don't look very appealing. Wang's 'Thermochromic Display' simply consists of standard light bulbs arranged in a grid, with a layer of thermochromic paint on them. When each light bulb is turned on, it heats up and the increase in temperature causes the change in the Thermochromic paint, thus giving it a new color. Furthermore, it only produces linear patterns and doesn't produce any kind of readable letters or an image using the light-bulbs. Other companies such as LCR Hallcrest [3], H&H Graphics [4], etc. focus on building thermochromic paper with printed designs or text underneath them. They have been marketing their product for advertising. On touching the paper long enough, the body heat increases the temperature of the surface of the paper. This causes the thermochromic paper to become transparent and the text underneath is then revealed.

Our solution is to build a thermochromic display, composed of a grid of 45 'pixels', each of which is a tightly wound Nichrome wire, pressed against the thermochromic paper and connected to a microcontroller via 8-bit shift registers. This would be a 0.5ftX2ft reconfigurable display monitor to display texts with high quality. The Nichrome wires for the different pixels will be heated individually, which would change the color on the thermochromic paper with rising temperature, based on the text we wish to view on the screen.

1.2 Function

'Thermal Display' is a thermally activated display that uses Thermochromic paper, otherwise known as 'Liquid Crystal Sheets', as its viewing screen. The liquid crystals respond to changes in temperature by changing color [6]. With increase in temperature, their color changes to red, orange, green, and then to blue. There is a heating grid composed of tightly wound Nichrome wires, pressed against the thermochromic paper, that allow heating up specific areas of the display. These Nichrome wires are connected to a microcontroller via 8-bit shift registers that allow them to be controlled individually. A Bluetooth app and an ultrasonic sensor allow for user interaction with the display. The high-level requirements for the product as originally described are:

1) The display must be able to reconfigure text within 10 seconds.
2) The display must show legible letters using the "Seven-segment" font character representations.
3) The display must have a feedback mechanism such that the column pixels corresponding to the user's position activate when a user walks by in-front of it at a distance of 1m from the display.

The product meets the first 2 requirements perfectly. However, the feedback mechanism was changed later due to certain limitations. To make the above described mechanism look good, at least 4 more columns and 2 more rows of pixels would have to be built. However, that would then require us to use an industrialized 3-D printer to build the outer case since the ones available on campus did not support such a large print. Additionally, that would have increased the maximum current draw to 8.91A and it is extremely difficult to find components that support a current rating that high. Instead, the feedback mechanism used is as follows:

Upon placing the user's hand at about 10cm away from the ultrasonic sensor, the display on the screen should switch to 'BYE' from its original configuration and if it was already displaying 'BYE', then it would switch to the default text or the user-defined one.

Additionally, we created a Bluetooth app to increase user input. The app allows the user to enter any 3-letter-word and use it to change the original configuration of the display, as required.

1.3 Subsystem Overview

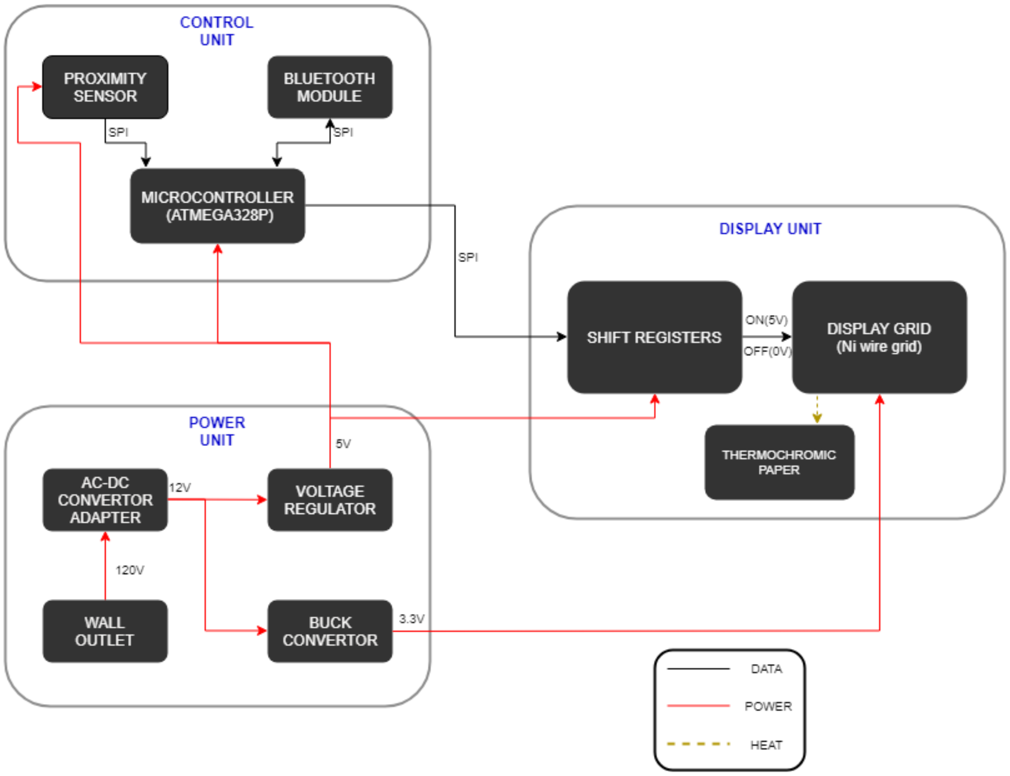

Figure 1.1: Block Diagram

Figure 1.1 shows the Block Diagram of the Thermal Display. It is made up of 3 primary components: Control Unit, Power Unit and the Display Unit. The Power Unit takes input from the wall outlet and sends 5V via the Voltage Regulator to the Proximity Sensor, Microcontroller and the Shift Registers. The Buck Convertor in the Power Unit sends 3.3V to the Display Grid (made up of Nichrome wires and n-Channel MOSFETs). The Control Unit has a Microcontroller which stores the program for controlling individual pixels in the display grid, to display letters. It takes input from a Bluetooth app that tells it which 3-letter-word to display. The proximity sensor sends the proximity data to the Microcontroller. When the distance of the user is less than 10cm, the displayed letters on the screen change to 'BYE'. The Display Unit takes input from the Microcontroller, which sends 2 sets of 8-bit data to the shift registers. The shift registers use this data to switch on or off the required individual pixels in the Display Grid. The Display grid uses n-Channel MOSFETs to drive 3.3V through a coil of Nichrome wire when the 'on' signal is given by the shift registers for that pixel. The text displayed on the screen is reconfigurable within about 10s. The ramp-up rates of the viewing screen to go from black to blue is about 5s. The ramp-up rates depend mainly on the current passing through each pixel. A current of about 0.09A ensures desirable rates and allows the text to be reconfigurable in required time. Originally, the display unit used a 'Matrix Driver' instead of shift registers, and a 'Cooling Unit' as a layer of Aluminum, with fans to ensure fast cool-down rates for the pixels. However, the Matrix Driver required additional hardware (high current rating diodes) for each pixel and was unreliable. Additionally, the layer of Aluminum caused an increase in the required amount of current per pixel to about 0.25A. The changes in design were made to reduce the hardware used, as well as to reduce the total required current.

2 Design

2.1 Power Unit

The power unit is comprised of a wall outlet, an AC/DC convertor adapter, a voltage regulator, and a buck convertor. Figure 2.1 shows a more detailed block diagram of the power unit. The Wall Outlet provides an input of 120V of AC current to the AC/DC convertor. This adapter converts 120V AC to 12V DC current. This 12V DC current is fed as input to a buck convertor and a voltage regulator. The buck convertor converts it and provides an output of 3.3V to the Display Grid and the voltage regulator provides 5V to all the components in the thermal display.

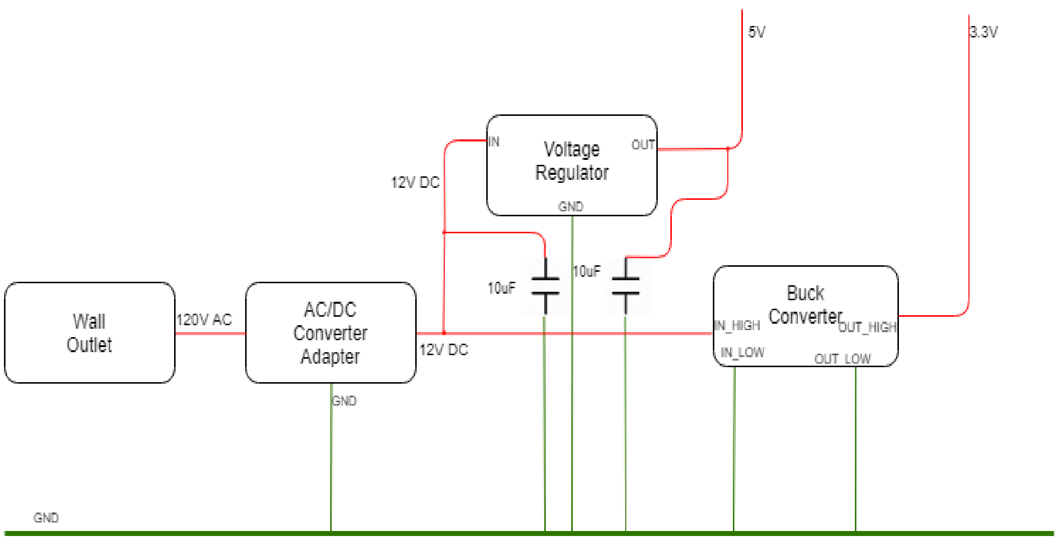

Figure 2.1: Power Unit Block Diagram

The total power consumption and maximum current draw are calculated as follows:

$$Power = i^2 R \times n \quad (1)$$

Where 'i' is the current flowing through each pixel, 'R' is the resistance of the Nichrome wire in each pixel and 'n' is the total number of pixels.

$$i = 0.09A$$
$$R = 35\Omega$$
$$n = 45$$
$$Power = 0.09^2 \times 35 \times 45$$
$$= 12.76W$$

The total power consumption by the display grid when all the pixels are activated is 12.76W.

$$Total\ Current = i \times n \quad (2)$$
$$= 0.09 \times 45$$
$$= 4.05A$$

The maximum current draw when all the pixels are activated is 4.05A.

2.1.1 Wall Outlet

The entire system will be powered from a wall outlet. This will provide enough power to heat up the heating coils to a temperature of about 35℃ and for the microcontroller and sensors to run indefinitely.

2.1.2 AC/DC Converter and Adapter

The converter converts 120V AC current to 12V DC current and is rated for 5A current and a maximum power output of 60W. This is important as it may have to provide up to 4.05A at a time. The converter used requires a 2.5 mm DC power jack to provide output to the circuit.

2.1.3 Voltage Regulator

The Voltage regulator used is the MCIGICM 7805 linear voltage regulator [8]. This voltage regulator can step down input voltage from 7-35V to 5V and maintain the potential difference with 2% regulation. This chip takes an input from the AC/DC converter at 12V and outputs a 5V current to the different microchips used in the project.

2.1.4 Buck Converter

Buck converters are known for their high current rating while converting voltages down to huge amounts. A DC-DC adjustable step-down Buck converter is used to step down voltage from 12V to 3.3V. The converter used is the 'LM2596 buck converter' and can handle a total output power of 75W. It is rated for 5A of current and therefore will be safe to use for the project which has a maximum current draw of about 4.05A.

2.2 Control Unit

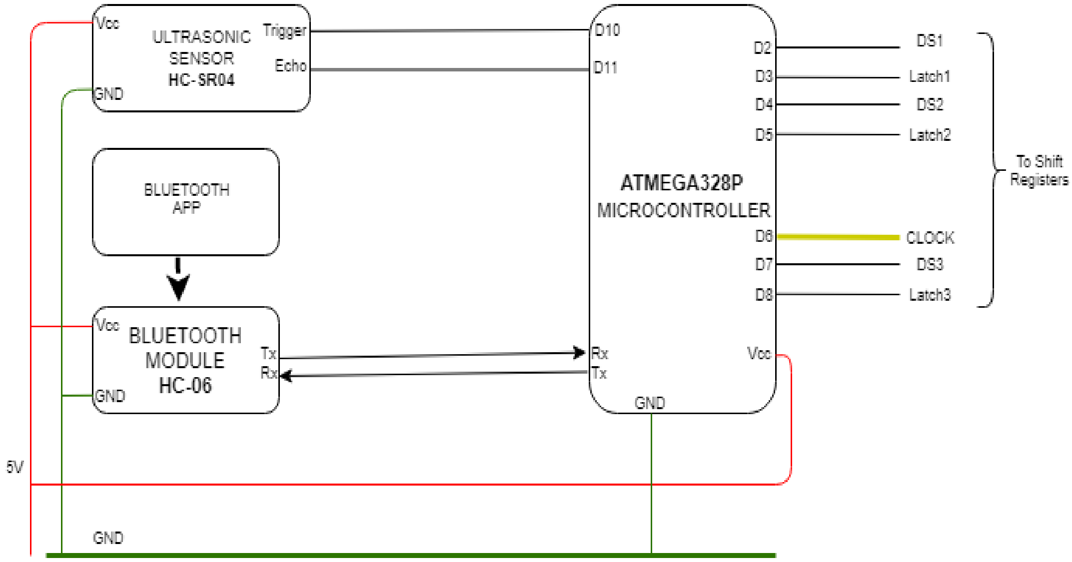

Figure 2.2: Control Unit Block Diagram

As seen in Figure 2.2, the control unit comprises of 3 main components: The microcontroller, the ultrasonic sensor and the Bluetooth module. The microcontroller houses the code for controlling the shift registers in the display unit, to heat individual pixels as required. The ultrasonic sensor communicates with the microcontroller via SPI protocol and provides the distance of the user from the screen. The Bluetooth module receives data from an android app that sends it the text data to be displayed on the screen. Using the input from the ultrasonic sensor and the Bluetooth module, the microcontroller decides which pixels to activate to display the required text. It then sends out this data to the shift registers via the respective 'latchPins' and 'dataPins'.

2.2.1 Ultrasonic Sensor

The sensor used is the HC-SR04. It has a working frequency of 40Hz, with a max range of 4m and a min range of 2cm [2]. The sensor requires a supply of a short 10uS pulse to the trigger input to start the ranging, and then the module sends out an 8-cycle burst of ultrasound at 40kHz and raises its echo. The distance can be calculated using the time interval between sending the trigger signal and receiving the echo signal.

$$distance\ (in\ cm) = \frac{time\ (in\ microseconds)}{58} \tag{3}$$

When this distance is less than 10cm, the microcontroller sends data to the shift register to display the letter 'BYE' on the display if it was displaying anything else at the moment. If it was already displaying 'BYE', the microcontroller then sends it data to display 'HEY' by default, unless otherwise specified.

2.2.2 Bluetooth Module

The Bluetooth module used is the HC-06 module. It receives data from an Arduino app via Bluetooth and then sends it to the microcontroller over an SPI protocol [7]. The module receives instructions from the Microcontroller through the RXD pin on the module and sends data to the microcontroller via the TXD pin. It works at power levels between 3.6V-6V and has a Bluetooth range of up to 9m. An android app on the phone allows the user to send a 3-letter-word text to the Bluetooth module which is then sent to the microcontroller and is used to display the required word on the display.

2.2.3 Microcontroller

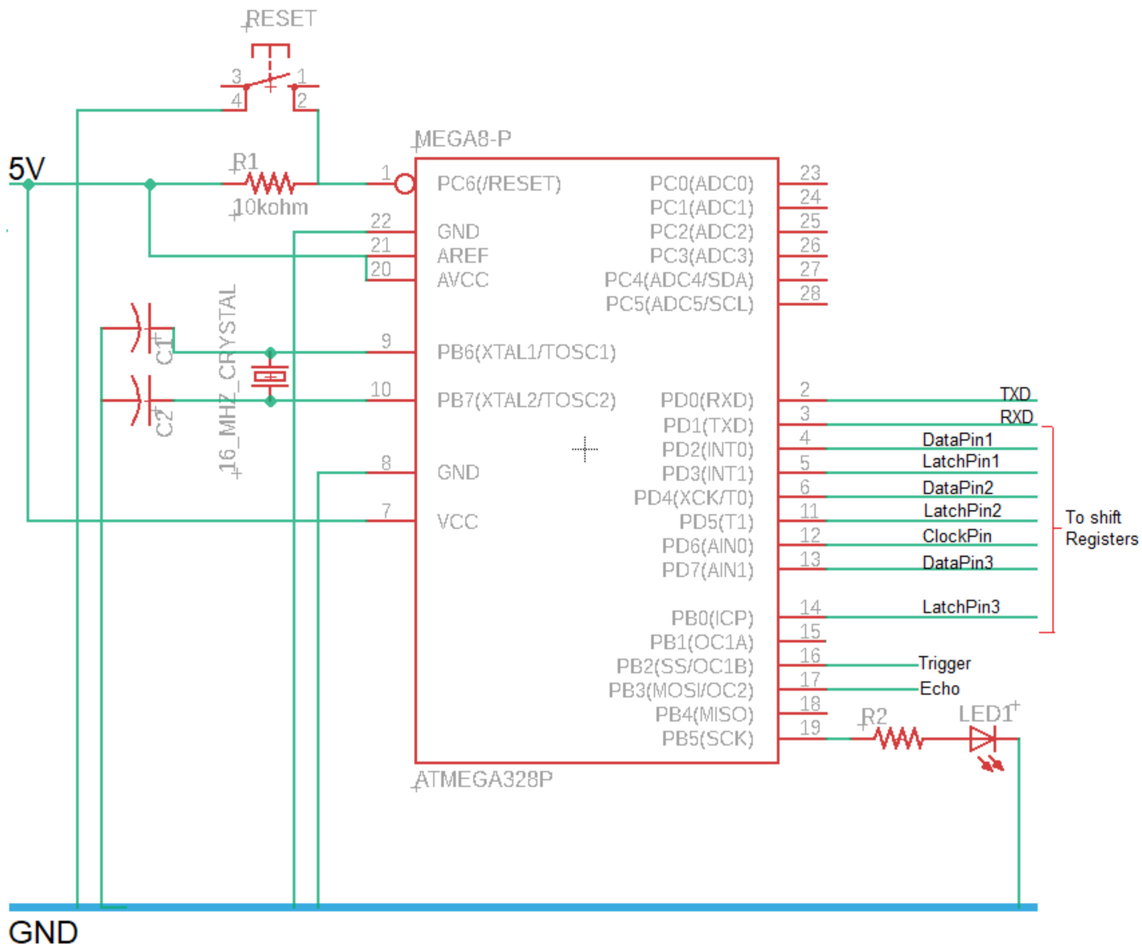

Figure 2.3: ATMEGA328P Detailed Schematic

The microcontroller used is the ATMEGA328P as it is one of the standard Arduino Uno Microcontroller chips with more than enough processing power and i/o ports. Figure 2.3 shows the schematic of the microcontroller in detail. Furthermore, it communicates with the ultrasonic sensor using the SPI data protocol and has a clock speed of 10MHz. Such speeds are necessary for the controller to process proximity sensor data quick enough to provide a seamless user feedback when the user waves his hand in front of it. Also, the number of i/o ports are necessary to implement the display grid using the shift registers and control each pixel independently.

2.3 Display Unit

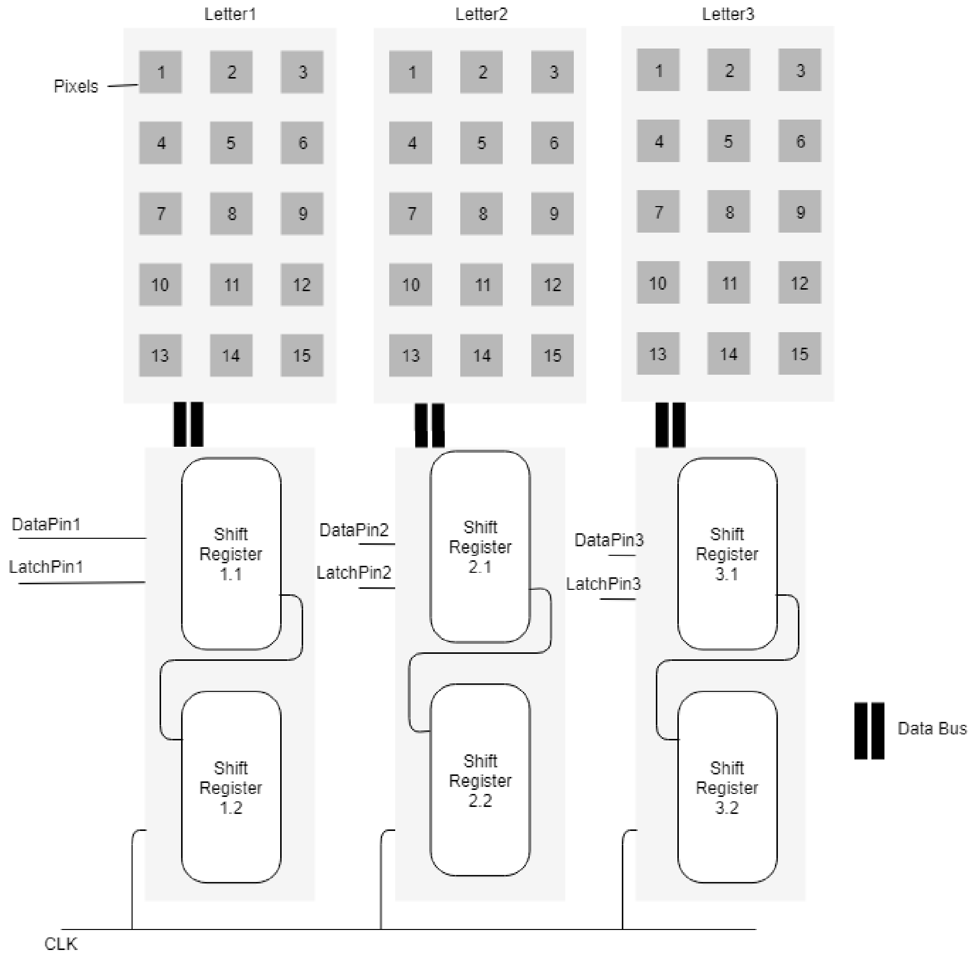

Figure 2.4: Display Unit Arrangement

The Display unit consists of shift registers, a grid of Nichrome wires connected to them via n-Channel MOSFETs and a thermochromic paper screen. Figure 2.4 shows how the 3 letters are controlled in parallel by 2 cascaded shift registers each. Each letter is displayed using a matrix of 5x3 Nichrome wires in a row first order. 2 cascaded shift registers control the output through each shift register via n-Channel MOSFETs which, when activated (5V signal), run a current of 0.09A at 3.3V through each Nichrome wire pixel. The Nichrome wires are pressed against the thermochromic paper, which when heated, changes color in the heated regions.

2.3.1 Shift Registers

The shift registers used are the SN74HC595N 8-bit shift registers. Figure 2.5 shows a detailed view of how the Nichrome wires for each letter are connected to the 2 cascaded shift registers. The cascaded shift registers share the same Latch Pin and Data Pin on the microcontroller. All the shift registers share the same clock pin.

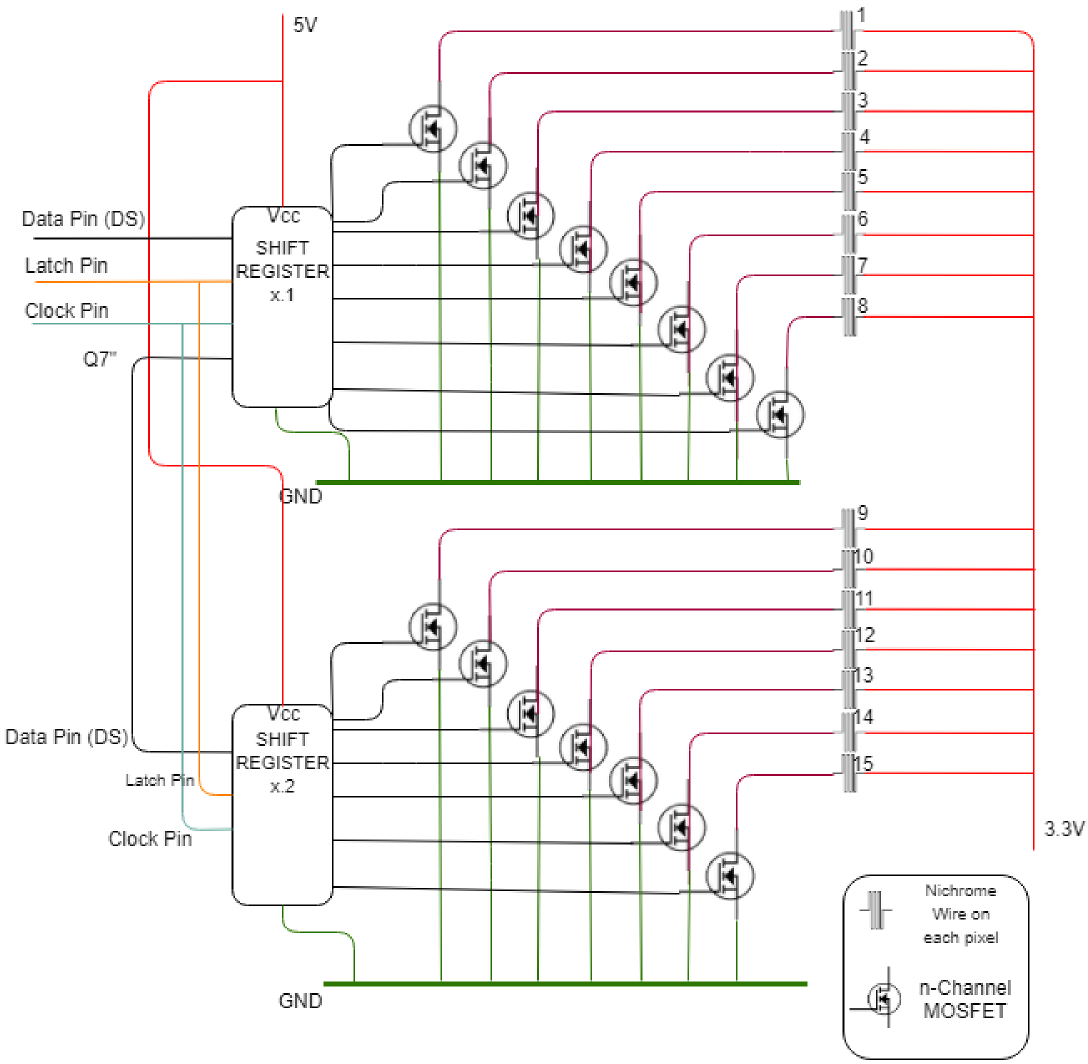

Figure 2.5: Display Unit Schematics

2.3.2 Display Grid

The display grid consists of a grid of tightly wound Nichrome wires. The heating element chosen was 'Nichrome 80 Alloy' because of its malleability and high resistance. There were several different gauges of Nichrome wires to choose from, ranging from 22 to 36. The choice was made based on the resistance of the different gauge wires and the ramp-up rates they provided on the thermochromic paper to turn to blue.

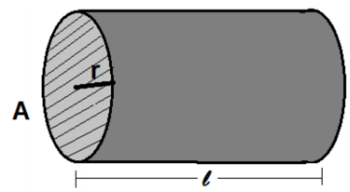

Figure 2.6: Cross-sectional area of a Nichrome 80 Alloy wire

Figure 2.6 shows the cross-section of a Nichrome 80 alloy wire, where A is the cross-sectional area, and r is the radius of the wire.

$$Resistance(R) = \rho \frac{l}{A} \quad (4)$$

$$\rho = 1.3 \times 10^{-6}$$

Based on the different gauges, the cross-sectional area was calculated, and the following results were noted in Figure 2.7.

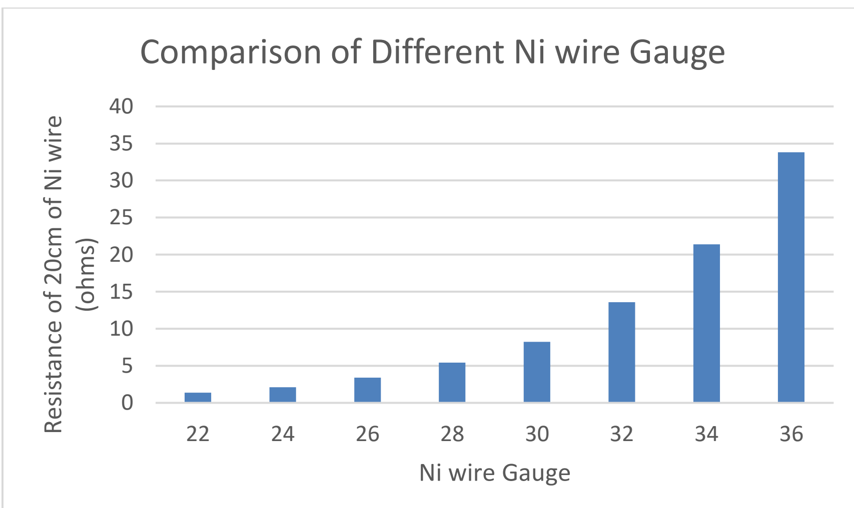

Figure 2.7: Resistance comparison of different gauge Nichrome wires

Additionally, for different Ni wire gauges, the ramp-up rates were recorded (to Blue) and the results were graphed as follows in Figure 2.8.

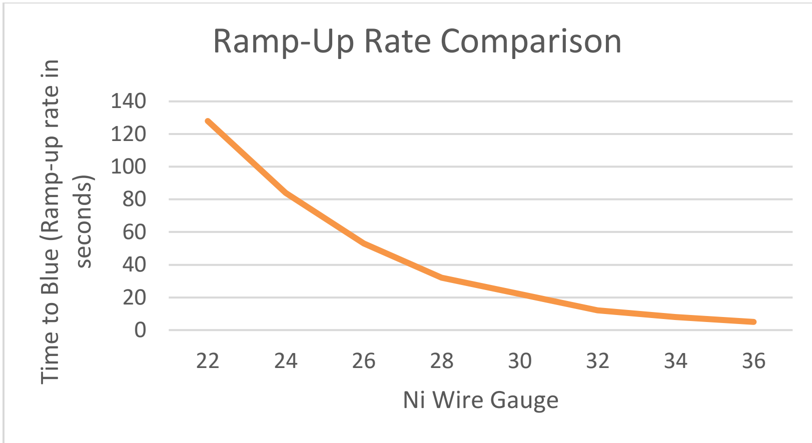

Figure 2.8: Ramp-up rate comparison of different gauge Ni wires

As a result, after careful consideration, despite the 36-gauge wire being as thin as thread, thus making it difficult to build pixels from, it was chosen due to the best ramp-up rate (5sec) and the highest resistance for 20cm of wire (33Ω).

2.3.3 Thermochromic Paper

The thermochromic paper used is the one with the activation energy between 30℃-35℃. This was chosen because the activation range is higher than room temperature so the pixels won't turn blue by default and yet it is low enough for the ramp-up rates to be under 5-6 seconds.

2.4 Software

The software can be classified into 2 major parts: Code to print character on screen and the code to decide what character to print on the screen.

```
void printCharacter(char dispChar){
  switch (dispChar)
  {
    case 'A':
        sr1 = 247; // 11110111
        sr2 = 218; // 11011010
        break;
    case 'B':
        sr1 = 247; // 11110111
        sr2 = 222; // 11011110
        break;
    case 'C':
        sr1 = 242; // 11110010
        sr2 = 78; // 01001110
```

Figure 2.9: Character Print Library

The code to print a character on screen required us to build a library that would map each character to two 8-bit numbers that would be used as input for the shift registers. Figure 2.9 shows an example of the library for the letters 'A', 'B' and 'C'.

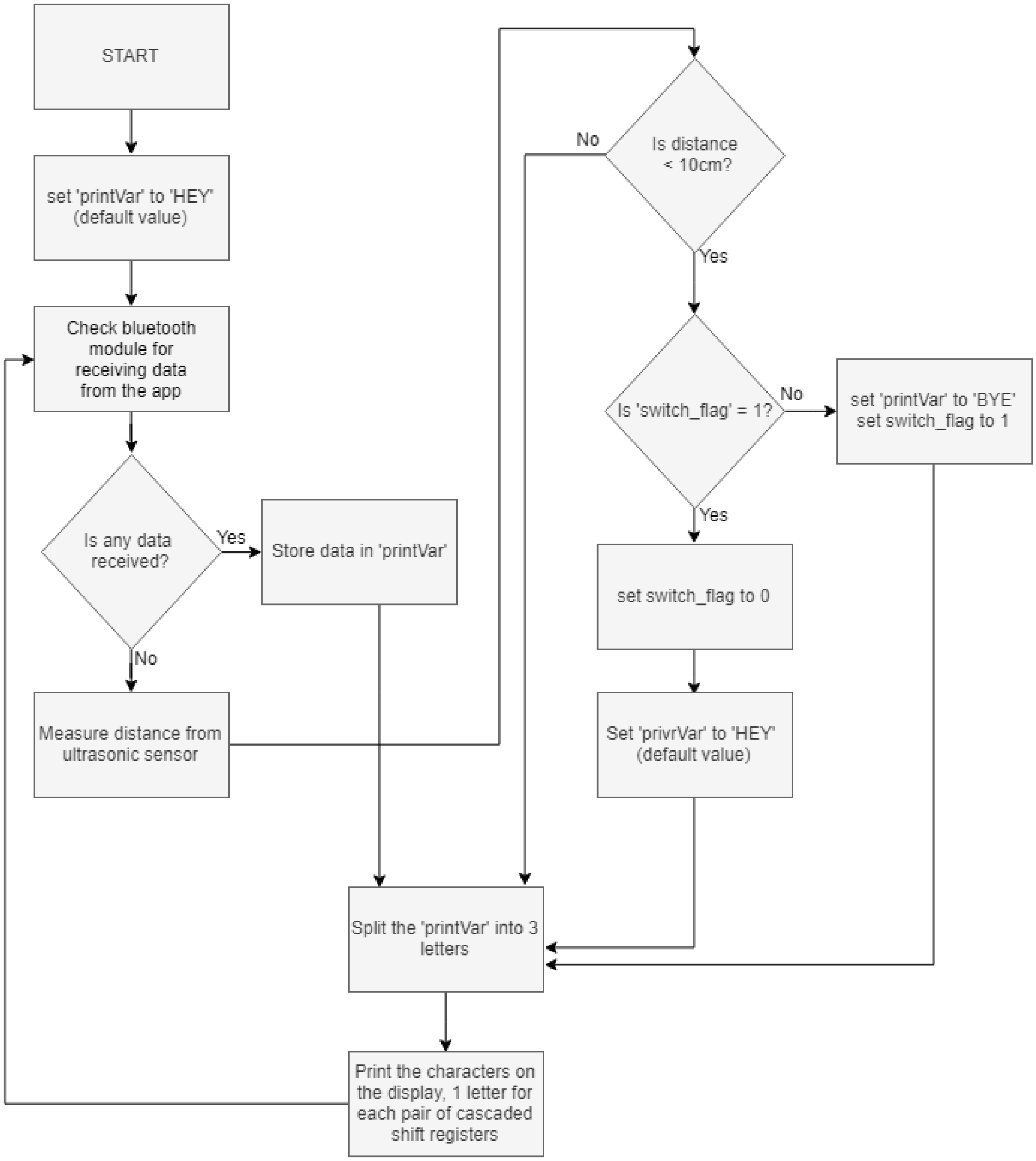

Figure 2.10: Software Flowchart

The code to decide what character to print on the screen takes an input from the Bluetooth module and the ultrasonic sensor to decide the character. Figure 2.10 shows the flowchart for the software used. The 'switch_flag' determines whether to display 'BYE' on the screen and 'printVar' is the variable that is printed on the screen in the end.

3. Design Verification

3.1 Pixel Ramp-Up Rates

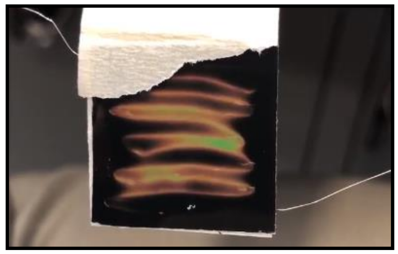

Figure 3.1: Pixel testing

Before beginning to work on the project, the first thing to do was to pick out the correct materials and their amount for each pixel to achieve the required ramp-up rates. The amount of material was determined by the size of each pixel that we wanted to build, which was about 2.54cmx2.54cm. To achieve a uniform heat spread, the material had to be tightly wound, and thus we decided to use about 20cm of the heating element. This heating element was tightly wound on a piece of sticky foam sheet of 2.54cmx2.54cm and then pressed against a cut-out of the 30-35℃ thermochromic paper of the same size. Figure 3.1 shows the prototype pixel made for testing the pixel's ramp-up rates. The heating element was then connected to the breadboard by soldering wires to its 2 ends and then a variable power supply was connected to the breadboard in series with the pixel. Then, the power supply was increased until the measured current draw was about 0.1A. The voltage was noted and once the heating element cooled down, it was provided with 0.1A of current and the time for the thermochromic paper to turn to blue was measured. This measurement was performed 4 times and the average was noted. The different elements used were PTC heating element and Nichrome 80 Alloy wires of gauge 22 to 36. The ramp-up rate of 36-gauge Ni 80 alloy wire came out to be 5 seconds, which was within the desirable ramp-up rate.

3.2 Shift Register Individual Pixel Control

Shift registers are used to control each pixel individually i.e. to be able to activate an individual pixel independent of the other ones. Since we are using 45 pixels, and the project is to be scaled further to hundreds of pixels, we decided to use shift registers. To test if shift registers could control the pixels properly, we performed 4 tests. First, a single shift register was connected to an Arduino on a breadboard and had an LED connected to each of its output pins. A program to turn on one LED at a time till all of them turn on was stored in the Arduino Uno and the output was noted. The LEDs turned on in the required pattern and the test was successful. Next, two shift registers were cascaded together and had a total of 16 LEDs connected to their output pins. A similar program was run on the Arduino Uno and the pattern was noted. The expected pattern was observed, and the test was successful. Next, two shift registers were connected to the Arduino in parallel. The registers shared both clock pins and latch pins but had their separate data Pins. A program to run the same pattern was run on the Arduino but it failed. Only one set of LEDs were showing the expected pattern. The test had failed and thus, the latch Pins were then separated as well. The test was repeated, and the observed pattern matched the expected one. The test was successful.

3.3 MOSFET switching

n-Channel MOSFETs are used for switching on current to each pixel because each pixel requires about 0.09A of current but the shift registers cannot provide that high amount of current. Additionally, the shift registers provide an 'on' signal with an output of 5V. To test the n-Channel MOSFETs, 2 tests were done. Firstly, a single n-Channel MOSFET was connected to the prototyped pixel and an input of 3.3V. Then, the current passing through the pixel was measured using a multimeter and the ramp-up rate checked. The current passing came up to approximately 0.09A with the expected ramp-up rate.

Next, the MOSFETs were introduced in between the shift registers on the breadboard and the LEDs connected to them. The same test for shift registers was then conducted and the expected pattern was recorded. The test was successful.

3.4 Bluetooth Connectivity

An android app was made using 'MIT App Inventor2' which allowed the user to enter data and send it to the Bluetooth module via Bluetooth. The Bluetooth module was hooked up to the Arduino and the data received was printed on the Serial Monitor. To connect the Bluetooth module to the app, the Bluetooth name was "HC-06" and the password used was "1234". The first test was to send a single number at 9600 baud. The numbers '1' and '0' were sent and the same was printed on the Serial Monitor. The test was successful.

The next test was to send a single character. The Serial Monitor then printed out the ASCII value of the character and the test was successful.

The next test was to send a word of 3 characters. The Serial Monitor however, printed them as 3 different character entries. The test was unsuccessful as the expected outcome was the same word with 3 characters. The code had to be changed to expect 3 characters and then concatenate them into one word thereafter. The same test was repeated and was successful.

3.5 Proximity Sensor Measurement

The proximity sensor used is the Ultrasonic Sensor "HC-SR04". The sensor was hooked up to an Arduino on a breadboard and the Output of the sensor was used to calculate distance and then was printed on the Serial Monitor. A ruler was used to measure 10cm from the furthest point of the sensor. An object was placed in front of the sensor at that distance and the output was recorded on the Serial Monitor. The distance displayed would be 10cm±0.2cm. The error range was 2% and was acceptable for the project. The test was successful, and the proximity sensor was verified.

4. Costs

4.1 Parts

Table 1: Parts Costs

Part	Manufacturer	Retail Cost ($)	Bulk Purchase Cost ($)	Actual Cost ($)
30-35ºC Thermochromic Paper	Education Innovations Inc.	7.95	7.95	7
Nichrome 80 - 250' - 36 Gauge Resistance Wire	Master Wire Supply	6.49	4	6.49
5A DC-DC Adjustable Buck Converter	D-PLANET	3	3	3
Atmega328P-PU IC	Fii	1.46	1.14	1.20
CONN PWR JACK 2.5X5.5MM SOLDER	CUI Inc.	1.70	1.44	1.44
SWITCH SLIDE SPDT 5A 120V	E-Switch	3.05	2.89	2.89
SWITCH TACTILE SPST-NO 0.05A 24V	Omron Electronics Inc-EMC Div	0.49	0.27	0.27
Liquid Crystal Sheets	NGS Correlations	25.95	25.95	25.95
L7805 Voltage Regulator	MCIGICM	1.16	0.89	1.16
12V 5A 60W AC DC Power Supply Adapter	CHANZON	15.84	15.84	15.84
IRF510x45	Vishay Siliconix	43.80	43.80	43.80
8-bit Shift Register SN74HC595N	Texas Instruments	4.54	4.54	4.54
PCBx2	PCBWay	7.43	7.43	75.56
Ultrasonic Sensor HC-SR04	Baumer	4	3.78	4
3-D print case	UIUC	$30	$25	$30
Total				**223.14**

4.2 Labor

Our fixed hourly costs for labor is estimated to be $40 per hour, 15 hours per week per person for 3 people, for 16 weeks (1 semester). Equation 5 shows how we reach at our total cost of labor.

$$2.5 \times \frac{\$40}{hour} \times \frac{15\ hrs}{week} \times 16\ weeks \times 3\ people = \$72{,}000 \tag{5}$$

4.3 Schedule

Table 2: Schedule

Week	Deadline	Amitesh	Joey	Santiago
2/18/19	Design Document	Begin experimenting with heating element	Begin experimenting with heat sink material	Begin experimenting with display material
2/25/19	Design Review	Finalize heating element, consult on power circuit prototyping.	Finalize heat sink material, consult microcontroller prototyping	Finalize display material, consult display circuit prototyping
3/4/19	Soldering Assignment	Continue to work on power circuit	Continue to work on microcontroller	Finalize display circuit, start unit testing ultrasonic sensors
3/11/19	First round PCBway orders	Finish PCB design and 15 pixel prototype	Continue microcontroller programming	Complete display circuit arrangements
3/18/19	Spring break	Vacation	Vacation	Vacation
3/25/19	Final round PCBway orders	Start work on framing project in shop	Complete microcontroller programming	Start conversation with machine shop concerning creating physical frame for sign.
4/1/19	Nothing due	Continue to work on physical frame in machine shop	Continue to work on physical frame in machine shop	Continue to work on physical frame in machine shop
4/8/19	Nothing due	Make connections from PCB to heating elements	Make connections from PCB to heating elements	Make connections from PCB to heating elements
4/15/19	Mock Demo	Prepare for mock demo, debug	Create basic program for mock demo	Prepare for mock demo, debug
4/22/19	Mock Presentations	Continue to debug/ make changes according to feedback from mock demo	Continue to debug/ make changes according to feedback from mock demo	Continue to debug/ make changes according to feedback from mock demo
4/29/19	Presentations	Prepare for final presentation/start final report	Prepare for final presentation/start final report	Prepare for final presentation/start final report
5/1/19	Final Report	Work on final report	Work on final report	Work on final report

5. Conclusion

5.1 Accomplishments

The project satisfies both the necessary requirements perfectly, but the reach goal is accomplished in a different way. The display can show 3-letter-words on the screen and the text can be reconfigured within 10 seconds as required due to the high ramp-up rates achieved where it takes only 5 seconds for the Liquid Crystal Sheet to turn blue from black when heated.

The reach goal was to provide a user-feedback mechanism by activating different columns of pixels as the user walked by in-front of the screen. However, since the display size (about 24cm in length) is much smaller than original design (3ft in length), a new way to have user-feedback was implemented. An ultrasonic sensor acts as a button that switches the display to 'BYE" from its current configuration when the user hovers his hand over it at less than or equal to 10cm in distance. Additionally, an android app communicates with the Microcontroller via a Bluetooth module and allows the user to enter any 3-letter-word text that is then displayed on the project's screen.

5.2 Uncertainties

The project mainly deals with uncertainties in power and current draw. Currently, each Nichrome wire draws about 0.09A of current to generate a ramp-up rate of 5 seconds to blue. However, if a pixel is left turned on for too long, the resistance of the wire could change and this would change the current draw accordingly. Other uncertainties arise for future work on the project. On scaling the project to 432 pixels from the current 45 pixels, the current draw would be close to 43.2A. It may become difficult to provide such a high amount of current at a low potential difference of 3.3V as electrical components rated for such high current are difficult to come by.

Additionally, we may use multiple ultrasonic sensors in an array if the project is scaled up. This may cause issues if the different sensors interfere with each other. We are not sure if the pulse that one sensor sends out could potentially interfere with the pulse that other sensors send out, so further testing would need to be done.

5.3 Ethical considerations

The project does not infringe upon the privacy or require any form of user information and therefore does not have any ethical issues. As the IEEE Code of Ethics state [5], we hold paramount the safety, health, and welfare of the public.

5.4 Future work

The first improvement we would make is to scale up the design to a 432-pixel-display. This would improve the resolution of the display.

Currently, the pixels are connected to wires which are then plugged into the PCB board to allow for the user to replace any pixels if they burn out. However, this causes the product to have a very messy wiring arrangement. To fix this, a PCB board could be used which would be the size of the display screen, with through-holes in places for the pixels to simply 'plug' in. This would reduce the number of wires to be used by an exponential amount.

Another improvement that would be to optimize the pixel making process. Currently, all pixels are made by hand and take a large amount of time to make. One way to speed this process up is to design a 3D printed mould of a pixel's windings to make the pixels consistent.

References

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Appendix A Requirement and Verification Table

AC to DC Converter and 12V Adapter

This is an off the shelf adapter that has a maximum current rating of 5A and outputs a DC voltage of 12V.

Table 3: AC to DC Converter and Adapter Requirements and Verifications

Requirement	Verification	Verification status (Y or N)
1. Using an input of 120V of AC current, it outputs a DC current with a voltage of 12V.	1. a. Connect the converter to the wall outlet. b. Use a multimeter with one end on the inside of the output terminal of the converter and the other end touching the outer walls of the terminal. c. Measure the voltage and the current passing through under the DC current settings.	Y

Voltage Regulator

This is the 7805 5V voltage regulator with a maximum current rating of 1.5A

Table 4: Voltage regulator Requirements and Verifications

Requirement	Verification	Verification status (Y or N)
1. Regulator provides 5V +/- 3% from a 11.8-12.3V source.	1. Use the function generator in the Senior design lab to generate a 12V input and connect the output of the regulator to a multimeter and check if the voltage is 5V or not.	Y

Buck Converter

This is a 180kHz fixed frequency PWM buck DC/DC module, capable of driving a 5A load with high efficiency. It can convert input voltages from 4-38V to 1.25V to 36V. And thus, we are using it to output 3.3V DC.

Table 5: Buck Converter Requirements and Verifications

Requirement	Verification	Verification status (Y or N)
1. Regulator provides 3.3V +/- 3% from a 11.8V-12.3V source. 2. Regulator must be able to provide current up to 4.05A.	1. Use function generator to generate 12V input. Connect the output of the regulator to a multimeter and check if the voltage is 3.3V or not. 2. Program the microcontroller to heat up a set of given pixels and note the current draw using a multimeter. The current draw should be the number of pixels multiplied by 0.09A.	Y

ATMEGA328P Microcontroller chip

This is the default microcontroller chip often used with Arduino Uno. It is easy to use and has plenty of tutorials online.

Table 6: ATMEGA328P Requirements and Verifications

Requirement	Verification	Verification status (Y or N)
1. Can both receive and transmit over SPI at speeds greater than 4.5Mbps. 2. Has enough i/o ports in order to implement a heating grid. (at least 7)	1. a. Connect microcontroller to USB SPI bridge, such as FT4222, and to a terminal such as Putty b. (Start timer) send a 0.45Mbit block of random data from the USB bridge into the Kinetis. c. Echo data back, this time transmitting over SPI from the Kinetis. d. (Stop timer) ensure that data received matches data sent, and that time elapsed does not exceed 100ms 2. No technical verifications required.	Y