Thermal Display

ECE 445 Design Document

Joey Espino
Santiago Puértolas
Amitesh Srivastava
Team 36
TA: Hershel Dave Rege

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1 Introduction

1.1 Objective

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' [2] 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 that would use cut-outs of thermochromic paper as individual pixels. This would be a 3ftX1ft reconfigurable display monitor to display texts with high quality. We will use a grid of heating coils controlled from a microcontroller to heat individual pixels to make them change color based on the text we wish to display.

1.2 Background

The University of Illinois at Urbana-Champaign is making a $15 million investment in the emerging area of quantum computing. This investment will see the formation of the Illinois Quantum Information Science and Technology Center (also known as IQUIST). The IQUIST Center is looking for a sign that they can display in their new building that is unique and visually appealing. The request for this display was originally made by Professor Paul Kwiat. The idea is to incorporate engineering and physics concepts to a sign that will create a display that one cannot easily purchase online (such signs are not exciting or unique). The sign we will be designing will be the first of its kind and have a unique and colorful representation that will hopefully intrigue viewers into learning more about what IQUIST is all about. Our display must look as attractive and intriguing as possible.

There are many different materials/fabrics that could have been used as a unique approach to use as a display. One such material that we looked into was a magnetically-activated sheet. The issue with this material is that it was not visibly appealing: the paper is a very dark tint and the difference between a unactivated region and a stimulated region was not as great as the thermochromic paper's differential.

Additionally, we plan to seek help from Professor Paul Kwiat for understanding the theory and practical applications with thermochromic papers.

1.3 High-Level Requirements

- The display must be able to reconfigure the text within 10 seconds.
- The display must be able to display letters with clarity using the "Seven-segment" font character representations.
- 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. This would be part of a "stretch goal"

2 Design

The design is made up of three main modules: Power Supply, Display Unit and Control Unit, as shown in the block diagram in Fig. 1. The Power Supply ensures that each component receives adequate power. It comprises of two Voltage regulators, one for the control unit and one for the display unit. The Control Unit is made of a microcontroller, temperature sensors and proximity sensors. The microcontroller takes in the data from the sensors and then controls the heating circuits of the display to show the desired output. Finally, the display will be made up of two main components, a heating circuit grid, accompanied by a cooling system and a thermochromic paper grid. As the thermochromic material is temperature sensitive, it is important to monitor its temperature carefully for it to display the desired output. The heating circuit and the cut outs of the thermochromic paper aligned as pixels will ensure the clarity of text on the display. Because the heating circuit is accompanied by the cooling system (a thin metal sheet), the temperature would drop fast, and the display would be able to reconfigure the text within 10 seconds. The proximity sensors used would be ultrasonic sensors which will detect when a person is walking past the display and the microcontroller will then produce a feedback on the display accordingly.

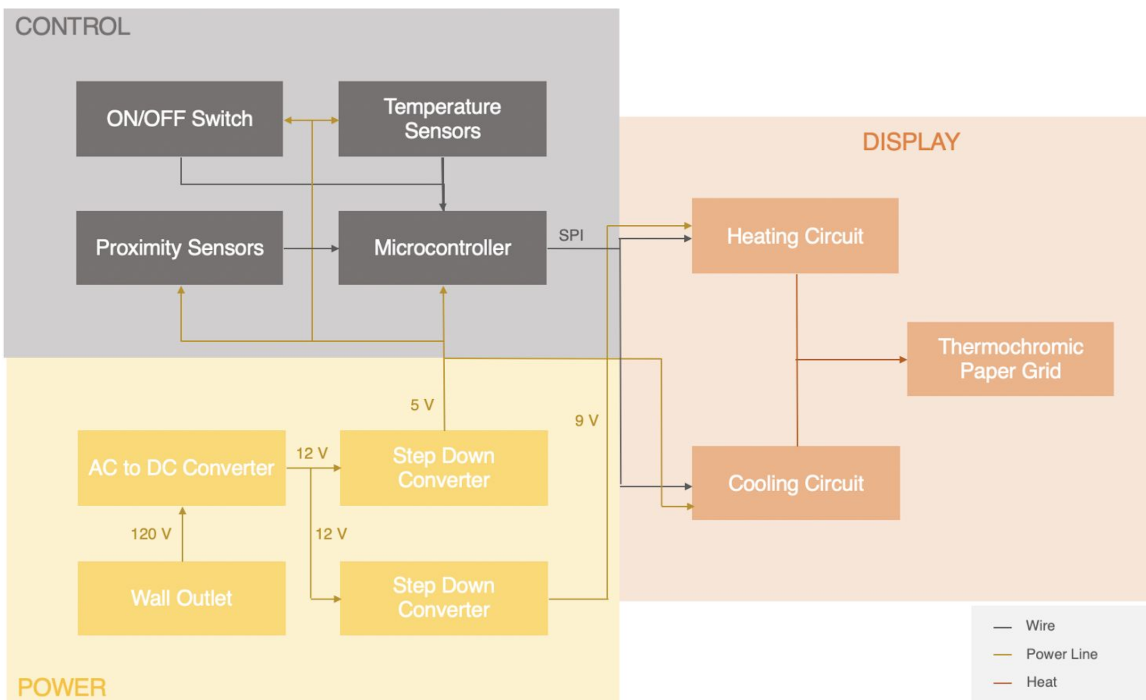


Fig. 1. Block Diagram

The physical design, shown in Fig. 2, will comprise of 4 parallel layers, and will be about 6 inches thick, 3 ft wide and 1 ft tall. The display will sit in a mechanical plastic frame with 9-10 holes around the heating and metal conducting layer to provide an outlet for the heat. It will also include a base to place an array of ultrasonic sensors at the bottom.

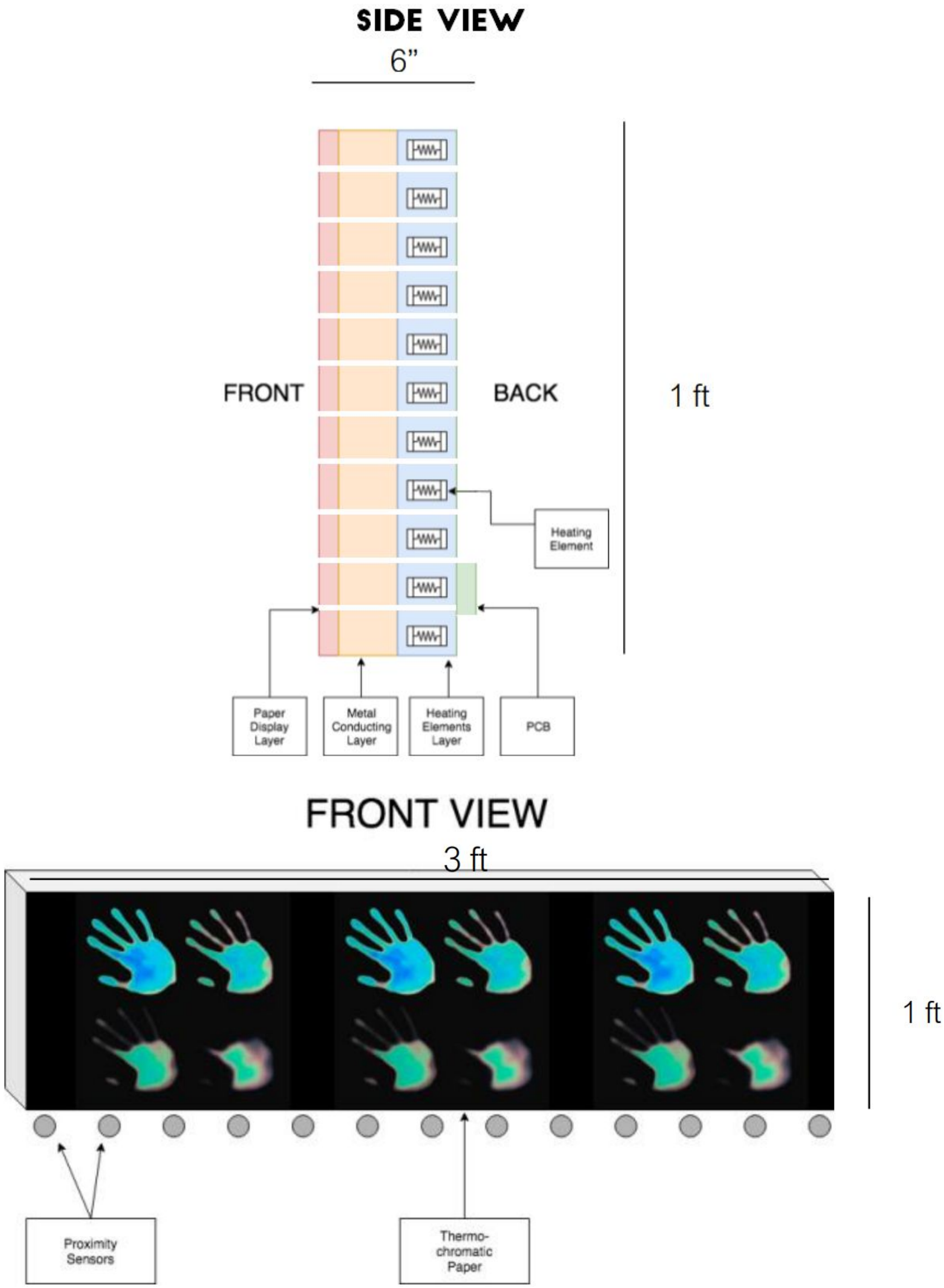


Fig. 2. Physical Diagram

2.1 Power Supply

A power supply is required to power the microcontroller, the sensors and the heating circuit. This will be taken from a wall outlet (120 V) and then will be converted to DC supply and passed through Step Down and Step up Converters based on the equipment it will be powering in the system. The power supply block is responsible for supplying the appropriate current and voltage to the different components of the system. The microcontroller, sensors, and heating/cooling circuits operate at different combinations of voltage and current, and therefore must be routed their appropriate resources.

Note: In the event that there are a lot of people standing in front of the display, and all the pixels are activated, the power drained was calculated to be ~ 140 W. However, this worst case scenario won't occur since the system will be designed to only acknowledge 1 person at a time by considering the closest person, in which case the power consumption comes to about 30W.

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 90-degree Fahrenheit and for the microcontroller and sensors to run indefinitely.

2.1.2 AC to DC Converter

The Microcontroller and other sensors work on DC current; not AC. Therefore, the AC to DC converter will convert the AC current coming from the wall outlet to DC current which can be used by the different devices in the system. This converter used will be the "EPBOWPT 12V 2A Power Supply AC to DC Adapter". The 12V adapter will be used because of its cheap cost and because the microcontroller and the heating grid use input voltages that can be achieved by using step down converters.

Requirement	Verification
Using an input of 120V of AC current, it outputs a DC current with a potential of 12V.	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.

2.1.3 Voltage Regulator 1

This Voltage regulator will be there for the Control Unit. A 5V linear regulator (TI part number UA78M05CDCYR) will be used to change the voltage of the incoming current from 12V to 5V. It will also always maintain the voltage at around 5 V. This chip, must be able to handle both the peak input (12.3V) and minimum input (11.8V) at the peak current draw (mA).

Requirement	Verification
1. Regulator provides 5 V +/- 3% from a 11.8-12.3V source. 2. Maintains thermal stability below 125ºC.	1. A. Use the function generator in the Senior design lab to generate a 12V input. B. Connect the output of the regulator to a multimeter and check if the voltage is 5V or not. 2. During verifications A and B, use a thermocouple to ensure the IC stays below 125ºC

2.1.4 Voltage Regulator 2

This voltage regulator will be there for the Display Unit. It may be accompanied by a Voltage Step-Down converter, depending on the choice of the heating element. The heating elements may require about 9V power supply. This sub-module will also be responsible for supplying power to each heating element in the heating grid, individually. The microcontroller will be connected to it in order to decide which elements in the grid to provide current to, so that the "Seven-Segment" font characters are clear and recognizable.

Requirement	Verification
1. Regulator provides 9 V +/- 3% from a 11.8V - 12.3V source. 2. Maintains thermal stability below 125^{o}C. 3. The regulator must be able to provide an output voltage as required for the specific heating elements within the heating circuit grid, as requested by the microcontroller.	1. A. Use the function generator in the Senior design lab to generate a 12V input. B. Connect the output of the regulator to a multimeter and check if the voltage is 5V or not. 2. During verifications A and B, use a thermocouple to ensure the IC stays below 125^{o}C. 3. Program the microcontroller to heat up a set of given pixels and note the output.

2.2 Control Unit

The microcontroller will hold the logic for how the heating elements will operate to display the precise words we want to convey on the screen. The output of the microcontroller dictates which heating elements are supplied current, which is how each pixel of the sign is activated. The microcontroller takes input data from the ultrasonic sensors in an open-loop design and alters the display in a manner that traces the path of an obstruction in front of the sign. For example, if a person steps in front of the right-most quarter of the screen, the proximity sensors on that side of the screen will pick up on this and send an analog signal to the microcontroller. The microcontroller responds to this signal by changing the color of that portion of the screen. This is the interactive function of the display design. The temperature sensors also feed into the microcontroller to regulate the temperature of the sign, ensuring that is does not overheat. For example, if the temperature sensors sense that the sign is heating up to a temperature that can potentially harm the system or cause safety issues, the microcontroller will cut the power supply to the heating grid. The microcontroller itself is activated with an ON/OFF push button.

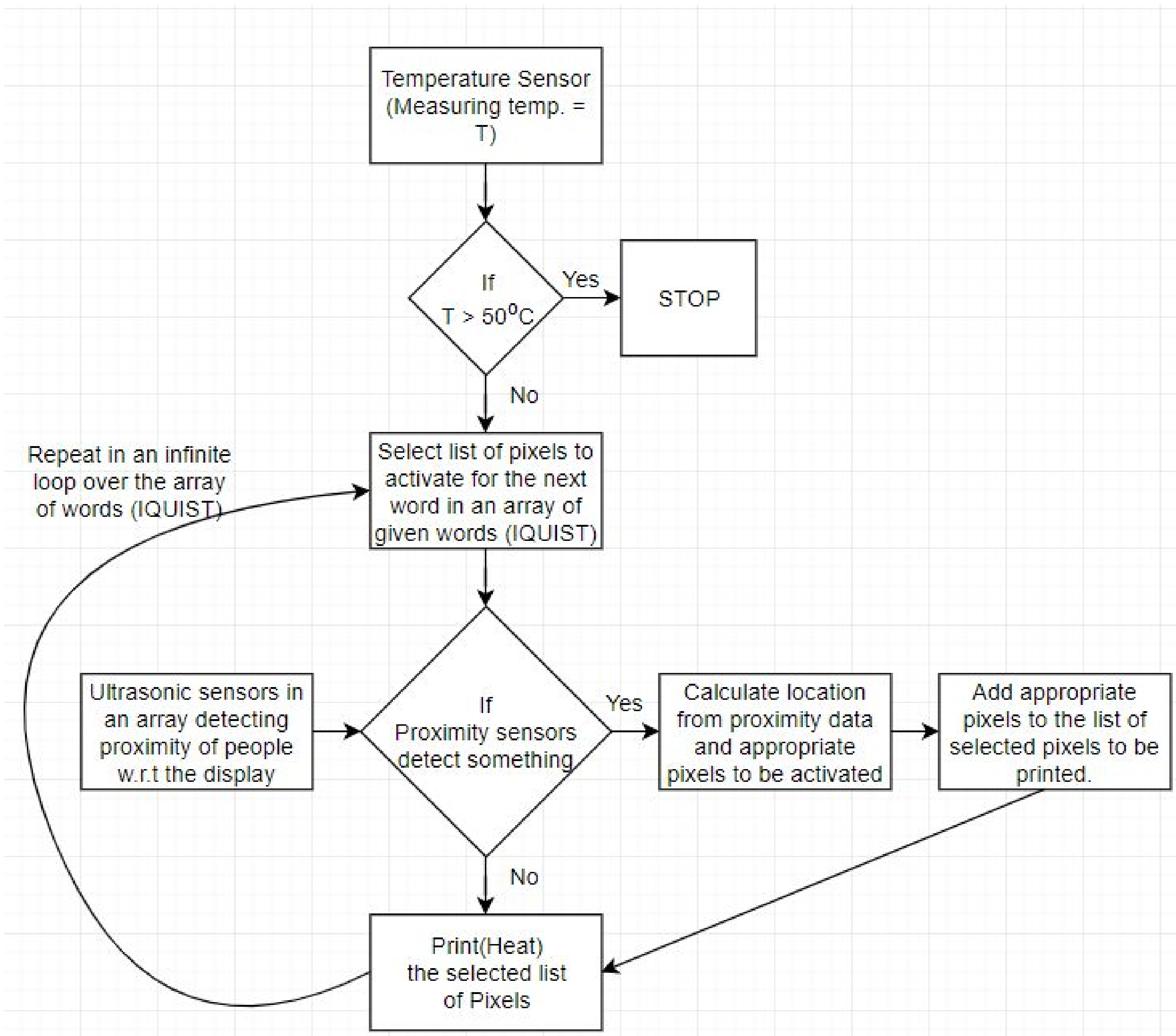


Fig. 4. Control Unit Flowchart

2.2.1 Microcontroller

The chosen microcontroller chip is the ATmega328p chip as it is one of the standard Arduino Uno Microcontroller chips with more than enough processing power and i/o ports. Furthermore, it communicates with the ultrasonic sensor using the SPI data protocol and has a clock speed of 10MHz. Such speeds are necessary in order for the controller to process temperature and proximity sensor data quick enough to provide a seamless user feedback when the user walks in front of it. Also, the number of i/o ports are necessary in order to implement a heating grid, and control each pixel independently.

Requirement	**Verification**
1. Can both receive and transmit over SPI at speeds greater than 4.5Mbps 2. Has enough i/o ports (at least 4) in order to implement a heating grid.	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 verification required.

2.2.2 Proximity Sensors

An array of five Ultrasonic sensors will be used in order to know where the user is standing and be able to show a feedback to his movements in the display.

Requirement	Verification
1. Must be able to detect a user standing in-front of the sensors up to about 1 m away from them. **2.** Must be able to report the proximity of the user within 0.5 seconds, so as to be able to see the required output while the user walks in-front of it.	1. A. A user will stand about 1 m away from a single ultrasonic sensor. B. The readings of the sensor that are read into the PCB chip will be observed on a computer screen and proximity will be noted. 2. A. A user will walk at a distance of 1 m, in front of the array of ultrasonic sensors. B. The readings of every sensor will be noted down on the computer screen. The array of sensors should report the proximity reading in the same order

2.2.3 Temperature Sensors

Four temperature sensors will be placed on the four sides of the display to be able to compute the average temperature of the thermochromic paper. The chosen sensors are Resistance Temperature Detectors as they allow for the highest accuracy, of between 0.1 and 1ºC. This will make sure that the temperature of the display doesn't go beyond safe limits for the display to work coherently (close to 50 C).

Requirement	Verification
1. The temperature sensors must be able to accurately measure the average temperature of the backplane of the thermochromic paper with an accuracy between 0.5º and 1ºC	1. A. The temperature sensors will be used to measure the temperature of a previously known 'hot body' such as an aluminum plate. B. The measurement will be double-checked by using a secondary independent temperature sensor (a thermometer or a thermocouple can be used).

2.2.4 On/Off Switch

A button to allow the user to switch off the display without having to unplug it from the supply, or in case there is an emergency such as overheating due to a short-circuit.

Requirement	Verification
1. Must be able to communicate with the microcontroller easily and be easily-pressable.	1. Press the button without any strain and ensure the Microcontroller switches on.

2.3 Display Unit

The display block comprises of the heating elements, the cooling system and the thermochromic paper. Cut outs of the thermochromic paper are used as pixels for the display. Each cut-out will be placed on a thin metal plate (Copper or Aluminum). Since metals have high thermal conductivity, they heat up and cool down quickly. The heating elements will be arranged in the form of a grid. Each pixel will have its own heating element which would be in contact with the surface of the thin metal plate. When a specific pixel is to be lit up, the microcontroller will ensure that only the heating circuit for that pixel is receiving power through the ‘voltage regulator 2’ and this would heat up the metal plate. Within seconds, the metal plate would then transfer this heat energy to the thermochromic paper and the pixel would change color accordingly. When the pixel is to be shut off, the heating circuit would lose power and the metal plate would cool down, acting as a heat sink and cooling down the thermochromic paper. When the temperature reduces, the paper would deactivate.

2.3.1 Heating Circuit Grid

The heating circuit will be made of a matrix of pixels. Each pixel will be made of 10 cm of a heating element, Nichrome wire and its control circuit. According to the calculations below, in order to heat up the wire to generate enough heat to change the color within 10 sec and **reconfigure the text fast enough**, we need to apply about 9 V to each pixel. Different materials will be tested to see which one allows for the lowest power consumption.
The grid would be placed on a thin sheet of a metal with high thermal conductivity (Copper or Aluminum). This would serve as the cooling system of the display unit.

There are two possible alternatives for the design of the display when it comes to controlling the pixels and making sure they are activated in such a way that allow the display to show the desired output:

Designing a Control Unit

By designing a Control Unit, the pixels would be entirely controlled through it. It would receive one character to display (in ASCII code), the place within the display to display it (Register Select signal), a five volts power signal, ground, a Read/Write and an Enable signal. Then, the control unit would use flip-flop memories to translate and enable the specific pixels it requires to display the character received.

Figure 5 shows a schematic view of this design.

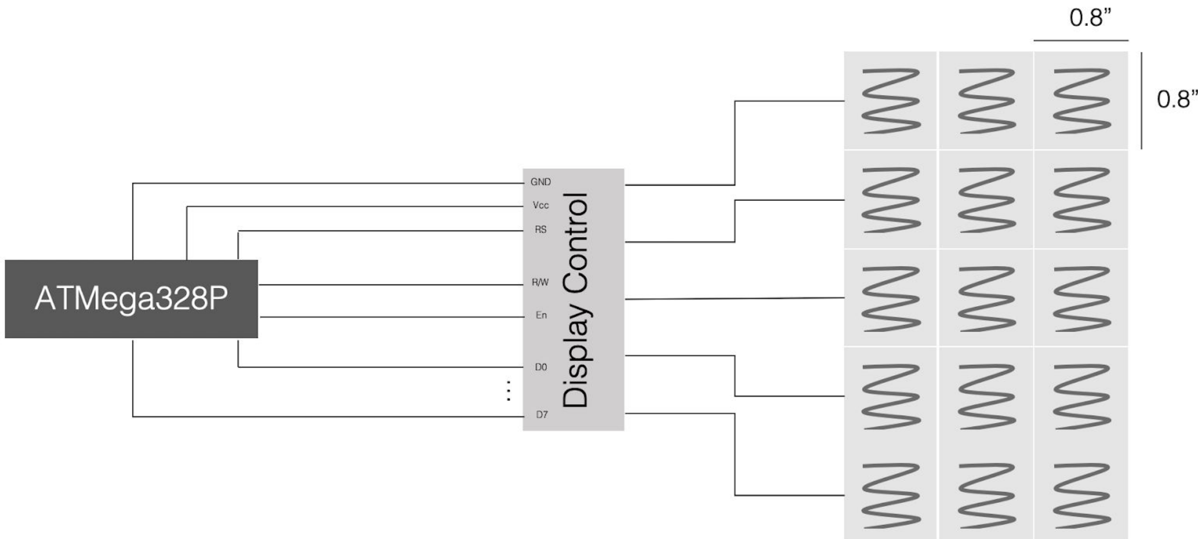


Fig. 5. Schematic view of Display Control unit

This alternative would be very complicated to design hardware-wise as it would involve using multiple flip-flops to design the memory to store the characters while they are being displayed. Further on, a supporting circuit would need to be designed so that the average voltage delivered to the pixels is constant at nine volts until that character is updated, and for that a very large capacitor would be necessary. This is not ideal as a large capacitor in each pixel would increase the power consumption, and increase the size of the pixels.

Using a LED Matrix Driver

There are solutions in the market geared towards the control of individual LEDs in order to make a display, one of these are LED Matrix Drivers such as the MAX7219CNG. These drivers act as the previously mentioned control unit but are only able to display one character in one eight by eight LED grid. A good way to adapt this to our design is to look at the pixels as if they were LEDs, each pixel is one LED, by doing this, we are able to use an array of 18 drivers to control the 540 pixels that our display has. The drivers would control matrixes of 5 pixels wide and 5 pixels tall. A schematic view of how this design alternative would work is shown in Figure 6.

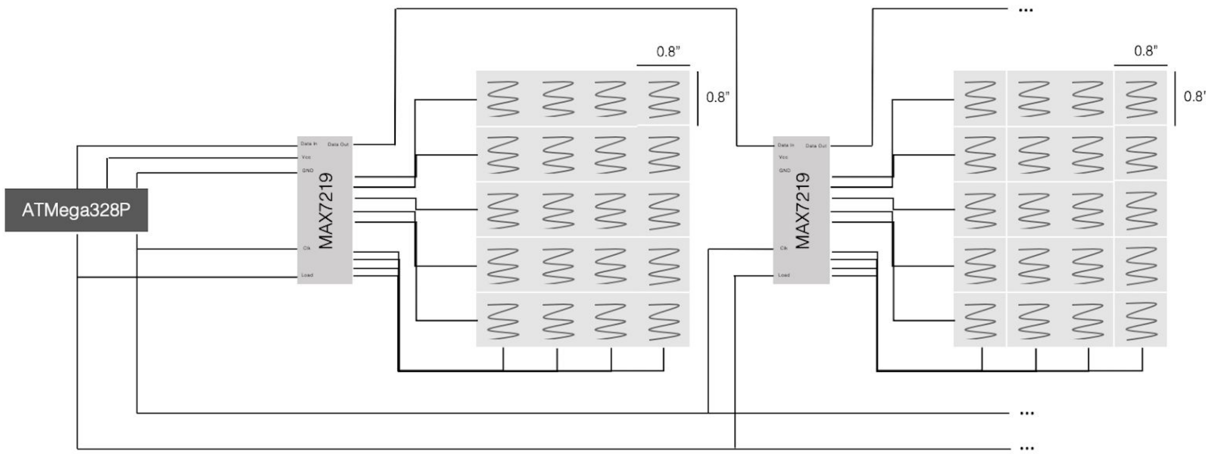


Fig. 6. Schematic view of Drivers

This solution is efficient hardware wise as these drivers are relatively inexpensive and have a very low power consumption. Furthermore, this solution would only use 5 input/output pins from the Microchip. The only downfall of this solution is that it requires more software development, and a support circuit would still be needed in each pixel to ensure that they are powered at 9 volts while the Microchip is communicating with the other drivers.

The most suitable option for our design is the second one as it's an already developed solution that can be easily adapted to our display while maintaining the advantages of low power consumption and low cost.

Pixel Support Circuit

As it was mentioned before, every pixel will need an additional circuit to deliver a constant 9 volt voltage to the Nichrome wire. In order to achieve this, a transistor is needed as the drivers provide 5 volts instead of the necessary 9 volts, a capacitor be necessary as it allows to supply a constant voltage to the heating element. Figure 7 shows a schematic of the support circuit.

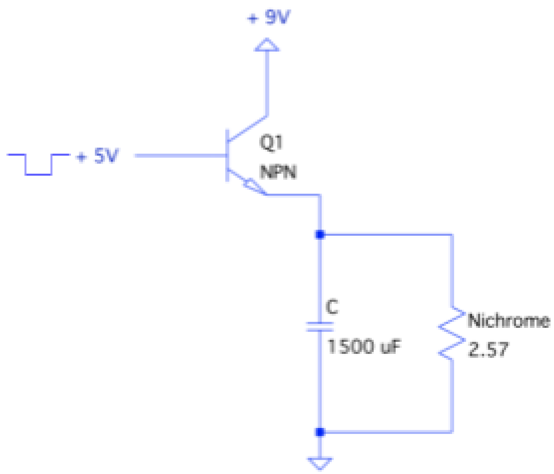
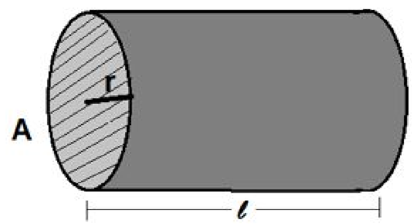


Fig. 7. Schematic view of Support Circuit

Requirement	**Verification**
1. 10cm of the heating element manages to increase temperature by (**Ramp up Rate**) 10 degree Celsius within 4-5 seconds going up to 30 ℃ in from room temperature at a voltage of 5-9 V. 2. The Aluminum plate transfers heat evenly on to the surface of the thermochromic paper.	1. A. Using a thermocouple, the temperature of the Nichrome wires will be monitored as 9 V is applied to it. B. The time and temperature change will be noted when the required temperature is reached. 2. A. The Nichrome wire will be placed on the aluminum plate, with the thermochromic paper over it. B. On heating the wire for about 3-5 seconds, the paper should change colour evenly.

Calculations



$$R = \rho \frac{l}{A}$$

For Nichrome wire,

ρ = 1.3 x 10^-6

For each pixel, we will use 10 cm of Nichrome wire, considering that the pixel size is 1 by 0.8 inches.

l = 10 cm (0.1 m)

For a 'Nichrome 80' wire of gauge 30, the diameter is 0.254 mm.

Therefore, cross-sectional area $A = \pi r^2$ and r = 0.127 mm (1.27×10^{-4} m)

$$\mathbf{A = 5.064506 \times 10^{-8}\ m^2}$$

Total resistance for the heating element per pixel R = 0.2567 x 10^1 = 2.567 ohm

Assuming a current of 'I' going through the wires,

Power = I^2 * R

Q = tI^2 * R

Assuming we want the temperature change in 3 sec, t = 3

Q = 7.2 I^2

Q = mC(Tf - Ti)

m = A*l*density

= 5.064506 x 10^-8 x 0.1 x 8400

= 42541.8504 x 10^-9 Kg

= 4.2541 x 10^-5 Kg

I ~ 0.05A

Note: More voltage needs to be applied, in order to compensate for the time it would take for the Aluminum plate to transfer heat to the paper. It totals up to approximately 0.2 A after experimenting with *different values with the aluminum slab. However, Thermal Paste between the Nichrome Wires and the Aluminum Slab should allow us to reduce the amount of current required per pixel.*

2.3.2 Cooling System

The thermochromic paper requires a cooling system in order to dissipate the heat when the current is switched off. When the heat is dissipated, the paper gets 'deactivated' and changes color back to its original color. For this, an Aluminum plate is used as a heat sink. Aluminum is cheap and has a high thermal conductivity, which helps in dissipating heat. This is important if we wish to reconfigure the text within 10 seconds.

Requirement	Verification
1. Aluminum plate of 1 by 0.8 inches, should be able to dissipate enough heat to change the color back within 5-7 seconds.	1. A. Heat a thermochromic paper to a point where it just changes color. B. Leave the paper over the Aluminum plate and measure the time it takes for the color to change back.

2.3.3 Thermochromic Paper Grid

This is the outermost layer of the display. It will be made of thermochromic paper settled on the thin sheet of metal. The grid will be created by treating cut-outs of the paper as an individual pixel and placing each pixel corresponding to each heating element on the heating circuit grid. Thermochromic papers have different activation points and the one chosen was the one with activation point at 30ºC.

Requirement	Verification
1. The thermochromic paper must begin to change color at 30ºC and have completely changed color at 35ºC. 2. The thermochromic paper must not change color at room temperature.	1. A. The thermochromic paper will be heated with nichrome wire on Aluminum plate. B. The paper will constantly be monitored using a thermocouple and it will be ensured that the color only begins to change at 30ºC.

3 Tolerance Analysis

One of the most critical features of the project is the heating grid. We plan to build the grid with nichrome 80 wires as the heating elements. If the wires don't heat up fast enough or if the adjoining Aluminum plate doesn't transfer heat fast enough, the resulting output on the display would look extremely shabby and may not be readable.

The time taken for the Nichrome wire to change temperature by ΔT at a fixed applied voltage V is

$$t = \frac{mC\Delta T\, R}{V^2}$$

Where R is the resistance of the 10 cm long heating element for each pixel. While calculating the Resistance of the 10 cm wire, the electrical resistivity of the Nichrome 80 alloy is used. Ideally, the resistivity is 1.3×10^{-6} Ωm with a tolerance of ±15%. The resistivity can vary from 1.1×10^{-6} to 1.5×10^{-6} Ωm.

$$\rho \propto R$$

Once, the Nichrome wire reaches the optimum temperature, the Aluminum slab would begin to transfer the heat on to the Thermochromic paper evenly. The thickness of the slab would have to be taken into consideration accordingly. However, the time it takes for the aluminum to conduct heat to increase the temperature of the paper by ΔT would be

$$t = k(\Delta T)A/Power$$

Where A is the cross-sectional area of the sheet and k is thermal conductivity of aluminum. The fluctuation in thermal conductivity of Aluminum is extremely low, about 5% i.e.

$$k = 205 \pm 10.5 \text{ W/mK}$$

Since the area A of the sheet is extremely small, the fluctuation in k doesn't affect the time much. Therefore, the time in which our display would change colors would need a tolerance of about 15%. Since we aim to have the color switch within about 3 seconds, a difference of about 0.45 seconds won't cause much of a problem for us.

Another major component is the microchip. ATMega328P. This chip ideally runs at 3.3 V and 1.5 µA but can run at up to 5.5 V and 80 µA when active. However, this maximum value is not recommended.

Therefore, we need to make sure that our voltage regulators have a very low margin of error. We are currently considering the Texas Instruments TPS76333DBVRG4 regulator which claims to have a 3% margin of error. That would mean, the voltage would remain within 5 ± 0.1 V which is desirable.

4 Cost

Our fixed hourly costs for labor is estimated to be $40 per hour [7], 15 hours per week per person for 3 people, for 16 weeks (1 semester).

$$2.5 * \frac{\$40}{hour} * \frac{15\ hours}{week} * 16\ weeks\ * 3\ people\ =\ \$72,000$$

Part	Description	Manufacturer	Part #	Quantity	Cost

25-30º Thermochromic Paper	4”X4” Used for Research/Prototyping 1 pixel	Education Innovations Inc.	-	1	7.95$
30-35º Thermochromic Paper	4”X4” Used for Research/Prototyping 1 pixel	Education Innovations Inc.	-	1	7.95$
35-40º Thermochromic Paper	12”X12” Used for Research/Prototyping 1 pixel	Edmund Optics.	-	1	25$
30-35º Thermochromic Paper	4”X4” Used for main display pixels	Education Innovations Inc.	-	27	7.95$
Nichrome Wire	Resistive wire used for prototyping heating elements	Master Wire Supply	-	1	17.99$
AC-DC Converter	Input: 100-240V AC 50/60Hz Output: 12V 2A	eBoot	-	1	6.99$
Voltage Regulator	TPS76333DBVRG4	Texas Instruments	595	2	$1.1
Microcontroller Chip	ATMEGA328P-PU	Microchip Technology	556	1	$2.50
Ultrasonic Sensor	U500.DA0.2-IAMJ.72F 1000mm	Baumer	112006 25	5	$4
Temperature Sensor	RTD Probe	Walfront	-	4	$6
Aluminum Plate	0.25" ALUMINUM PLATE 6061-T651 12”x36”	OnlineMetals	1248	1	$60

Step Down Converters	Mini MP1584EN DC-DC Buck Converter Adjustable Power Step-Down Module pack	eBoot	-	2	$7.85
PCB	Printed Circuit Board to hold all electrical components	PCBway	-	1	$75
MAX7219CNG	LED Driver	Maxim	-	18	$9.98

Total Cost of Parts = $240.26

Total Cost = Cost of Parts + Cost of Labor = $ 72,240.26

5 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 and	Finalize display circuit, start unit testing ultrasonic sensors
3/11/19	First Round PCBway orders	Finish PCB design	Continue microcontroller programming	Complete display circuit arrangements
3/18/19	Spring break	Vacation	Vacation	Vacation
3/25/19	Final round	Start work on framing project in	Complete microcontroller	Start conversation with machine

	PCBway orders	shop	programming	shop concerning creating physical frame for sign
4/1/19	Nothing due this week	Continue to work on physical frame in the machine shop	Continue to work on physical frame in the machine shop	Continue to work on physical frame in the machine shop
4/8/19	Nothing due this week	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

6 Safety and Ethics

This project poses a potential fire hazard if the temperatures rise to a dangerous level. We safeguard any potential harm to humans in 2 layers of protection. The first layer of protection is provided by temperature sensors that measure the overall temperature of the sign. If this fails, the next layer of protection would be to implement overcurrent protection on the power supply. If the wrong combination of voltage/current is supplied to a component, it could potentially fry that component. We do not want anything to release any smoke or catch fire, so we will be safeguarding against this by regulating the temperature of display and by placing overcurrent protection on the power supply. We will also place a **fuse** at the hem of the

Heating circuit grid, to make sure that the circuit is disabled if the temperatures ever rise beyond critical limit.

Electrical Safety can be a concern since the power is being supplied directly from the wall outlet, which provides a voltage of 120V. The safety will be maintained by using voltage regulators and a **fuse** at different points in each unit of the system. This would not only ensure that the voltage remains constant, but also that the temperature doesn't rise high enough to damage the equipment.

Mechanical Safety won't be much of a concern since the project does not use moving parts. However, users may touch the heating coils by mistake while trying to view the project. Therefore, we will provide a casing for the entire display to hide the heating coils from sight and avoid human contact.

Ethically speaking, the project does not cause any violations. Since we do not ask for any personal data or intrude into anyone's privacy, the project would not have any ethical concerns. As the IEEE Code of Ethics state [6], we hold paramount the safety, health, and welfare of the public.

References

[1] Chitambar, Eric. “Announcing the Illinois Quantum Information Science and Technology Center (IQUIST).” *Chitambar Quantum Information Group*, quantum-entangled.ece.illinois.edu/2018/10/30/announcing-the-illinois-quantum-information-science-and-technology-center-iquist/.

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