ECE 445 Design Document: Thermal Display

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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. 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 thermo-chromatic paper with printed designs or text underneath them. They have been marketing their product for advertising. On touching the paper long enough, the thermo-chromatic paper, becomes transparent and the text underneath them is revealed.

Our solution is to build a thermochromic display that would use cut-outs of thermochromic paper as individual pixels. This would be a 3ft x 1ft reconfigurable display monitor to display texts with high quality. We will use a grid of heating coils controlled from a micro-controller 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 The request for this display was originally made by Professor Paul Kwiat.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.

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 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.
- The display must be able to display letters with clarity using the "Seven-segment" display character representations.

2 Design

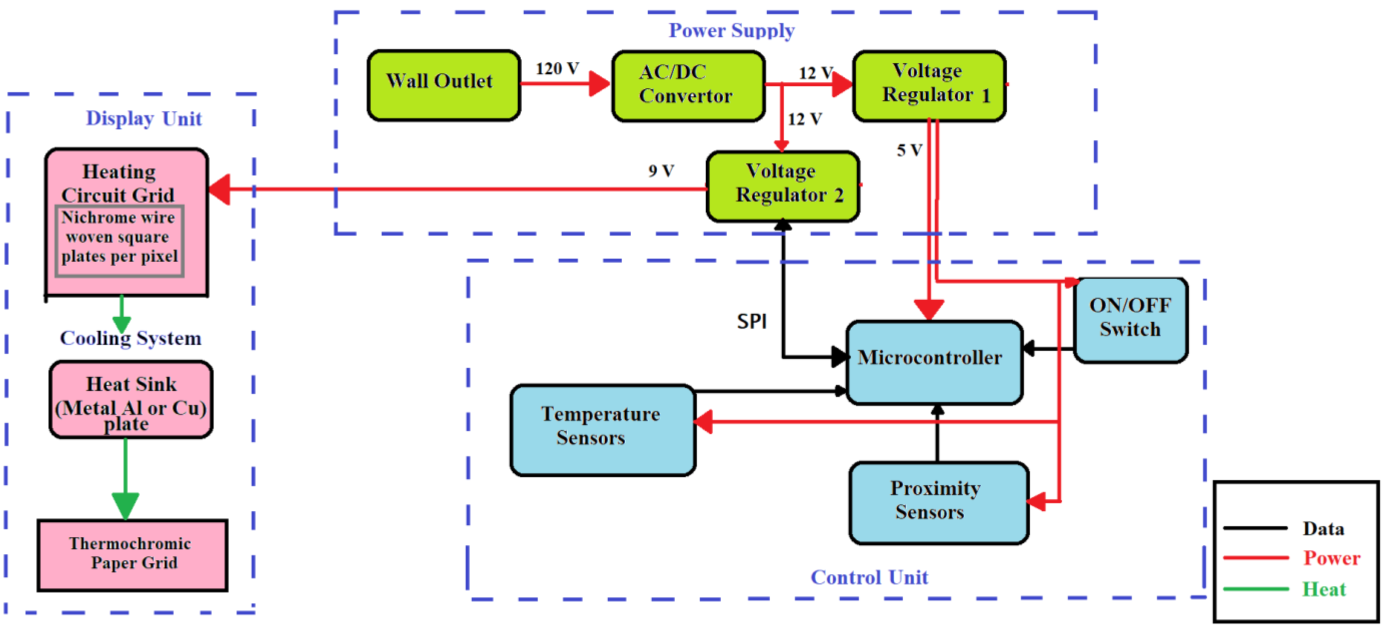


Fig. 1. Block Diagram

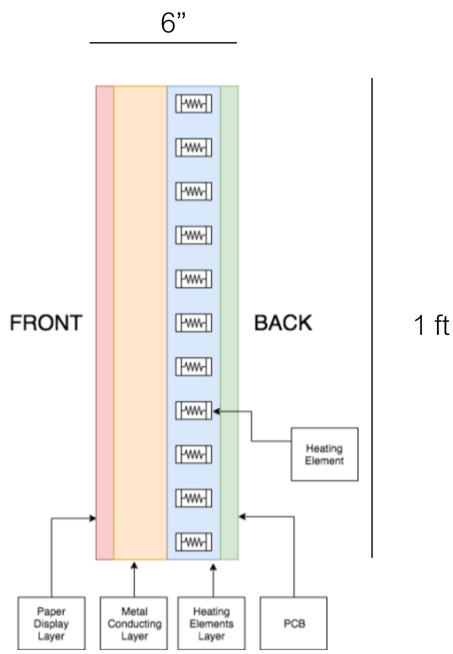


Fig. 2 Side View

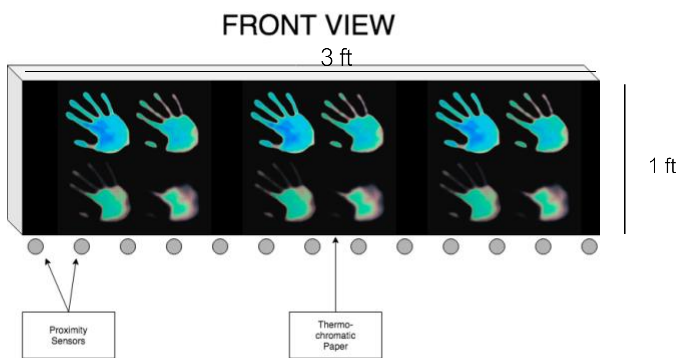


Fig. 3 Front View

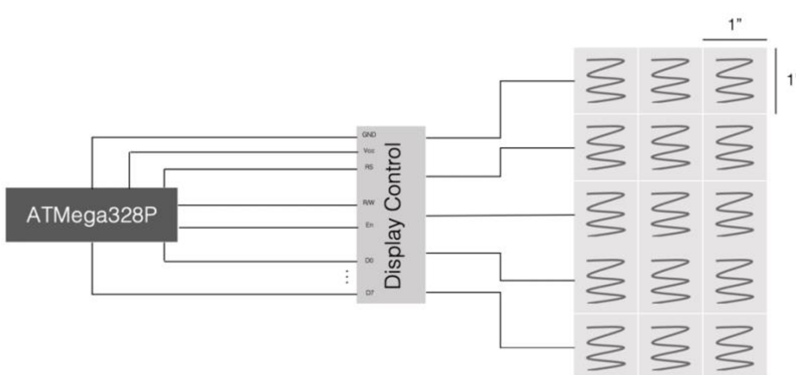


Fig. 4 Schematic View

2.1.1 AC/DC Convertor

Requirement	Verification
Using an input of 120V of AC current, it outputs a DC current of 12 V	A. Connect the convertor to the wall outlet. B. Use a multi-meter with one end on the inside of the output terminal of the convertor 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.

2.1.2 Proximity Sensors (Array of Ultrasonic Sensors)

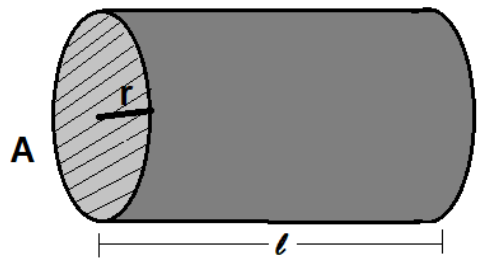
Requirement	Verification
1. Must be able to detect a user standing in-front of the sensors up to about 1 m away from them. **2.** Must be able to report the proximity of the user within 0.5 seconds, so as to be able to see the required output while the user walks in-front of it.	1. A. A user will stand about 1 m away from a single ultra-sonic 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

2.1.3 Heating Circuit Grid

Requirement	Verification
1. 10cm of the heating element manages to increase temperature by 10 degree Celsius within 1-5 seconds going up to 30 ℃ in from room temperature at a voltage of 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,

$$\rho = 1.3 \text{ x } 10^{-6}$$

For each pixel, we will use 10 cm of Nichrome wire, considering that the pixel size is 1 inch^2.

$$I = 10\ cm$$

For a 'Nichrome 80' wire of gauge 30, the diameter is 0.254 mm.
Therefore, cross-sectional area A = πr^2 and r = 0.127 mm (1.27 x 10^{-4} m)

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

Total resistance for the heating element per pixel R = 0.2567 x 10^1 = 2.567 ohm
Assuming a voltage of 'v' going through the wires,

$$Power = \frac{v^2}{R}$$

$$Q = t * \frac{v^2}{R}$$

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

$$Q = 1.168\ v^2$$

$$Q = mC(T_f - T_i)$$

The mass of the wire is:

$$m = A1 * density$$

$$m = 5.064506 * 10^{-8} * 0.1 * 8400$$

$$4.2542 * 10^{-2}\ g$$

v ~ 5 V

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.

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

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

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.

Ethics and Safety

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 [5], 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/.

[2] "Thermochromic Display." *Vimeo*, 7 Feb. 2019, vimeo.com/2616647.

[3] "Functional Printing." *Liquid Crystal Thermometers (LCs)*, www.hallcrest.com/our-products/special-effect-pigments/printed-thermochromic-display-circuits.

[4] H&H Graphics, LLC. "Thermochromic Printing Reveal Example." *YouTube*, YouTube, 15 Feb. 2017, www.youtube.com/watch?v=Dt6Rb1brnZ0.

[5] "IEEE Code of Ethics." *IEEE - Advancing Technology for Humanity*, www.ieee.org/about/corporate/governance/p7-8.html.