Thermochromic Paper Display

Inspired by Spring 2019 Project 36, “Thermal Display”

By

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Table of Contents

1. Introduction

1.1 Objective

Society has become dependent on the growth of technology and its applications in our everyday lives. However, we tend to be complacent when problems have been solved and we don't strive for innovation anymore. In terms of the current state of modern displays, we predominantly use LCDs for all our displays from computers to televisions. After speaking to a number of art college students, a need from some of our peers was to have a method of electronic expression outside of the norm. Curiously, we began to think what other ways outside of the LCD can we display images on a platform that is similar yet fundamentally different from the former method.

We decided to create a new form of display based on a previous team's project "Thermal Display". Our project would involve using thermal paper but rather than have a coil heat it to form an image, we would be using a high-powered laser to heat the paper. Essentially, we will be dividing the paper into pixels and warming it to the desired color by scanning a laser across the paper and changing the intensity of the laser. This method hence will give way to a new means of display and projecting desired images. Figure 1 demonstrates the image of a handprint formed on thermal paper. The laser based system here will not have as high a resolution, however grayscale images will appear similarly to the hand shown (in Figure 1).

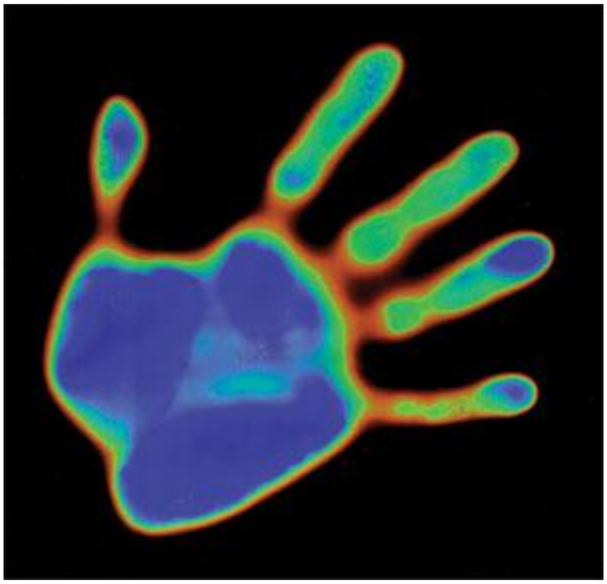

Figure 1: Handprint formed on Thermochromic Paper

1.2 Background

The University of Illinois previously made a multi-million dollar investment in quantum computing [1]. The investment led to the creation of the Illinois Quantum Information Science and Technology Center (IQUIST). Professor Paul Kwiat made a request for a sign that could be shown in the new center and was original yet unique in its own way. It had the intention to be visually appealing while using the general concepts of physics. With this in mind, we set off to learn more about the previous group's ideologies and decided to use these as standards when creating and researching a new type of display to build, thus essentially mirroring the influence and necessity behind finding an adequate solution.

We decided to set apart our project from the previous group's project through the use of lasers instead of heating coils. We predict that we will be able to have a more accurate form of heating the thermal paper to produce the entire image. Also in regards to the background setup, the circuitry of the project will also differ. We will be implementing motors and motor controllers in combination with the lasers to assist in the project.

1.3 High-level Requirements

- The ability to display monochromatic, 25 pixel by 25 pixel images or letters on a roughly 6 in by 6 in square screen within 1 minute.
- The laser must have a maximum beam width of 2 mm to account for pixel sizing.
- Power consumption should be similar to that of a modern monitor (approximately 100 kWh/year).

2. Design

2.1 Physical Design

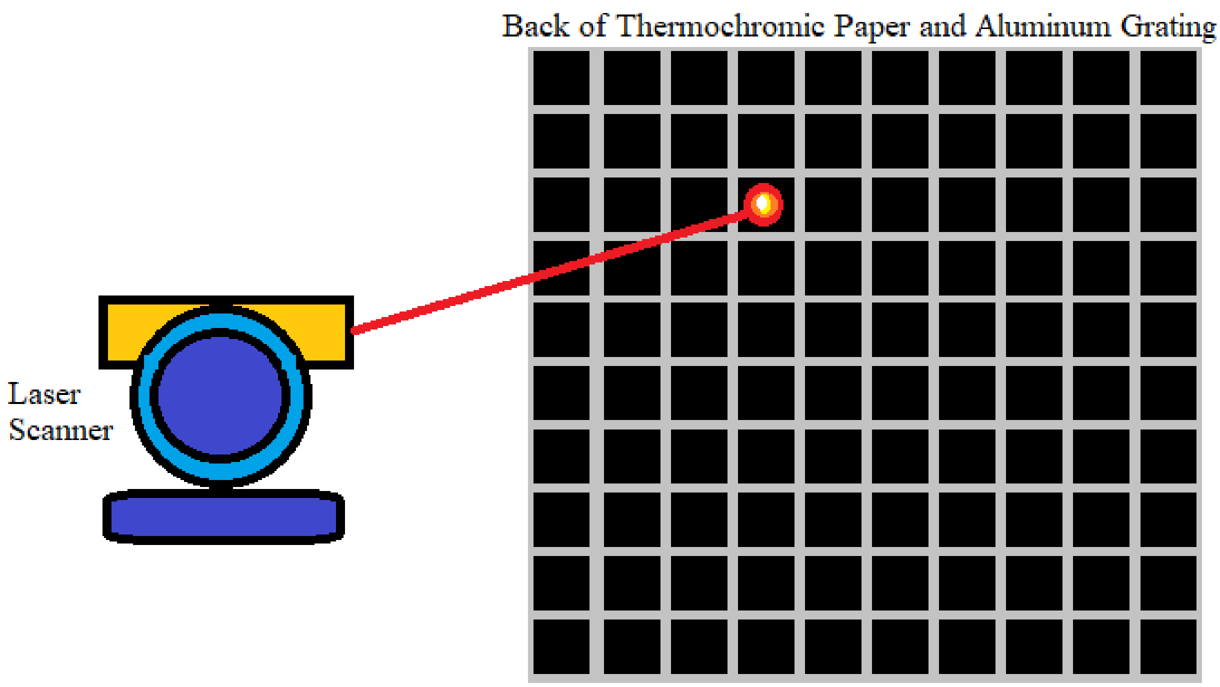

Figure 2: Expanded View of Display Components

Pictured above in Figure 2 is a simple render featuring the physical aspects of our design. The structure will include a layer of thermochromic paper mounted against an aluminum-mesh heat sink and a laser mount housed a short distance away. The laser mount includes the high-powered laser for heating, two motors and a gear system to aim the laser at the appropriate pixel.

2.2 Block Diagram

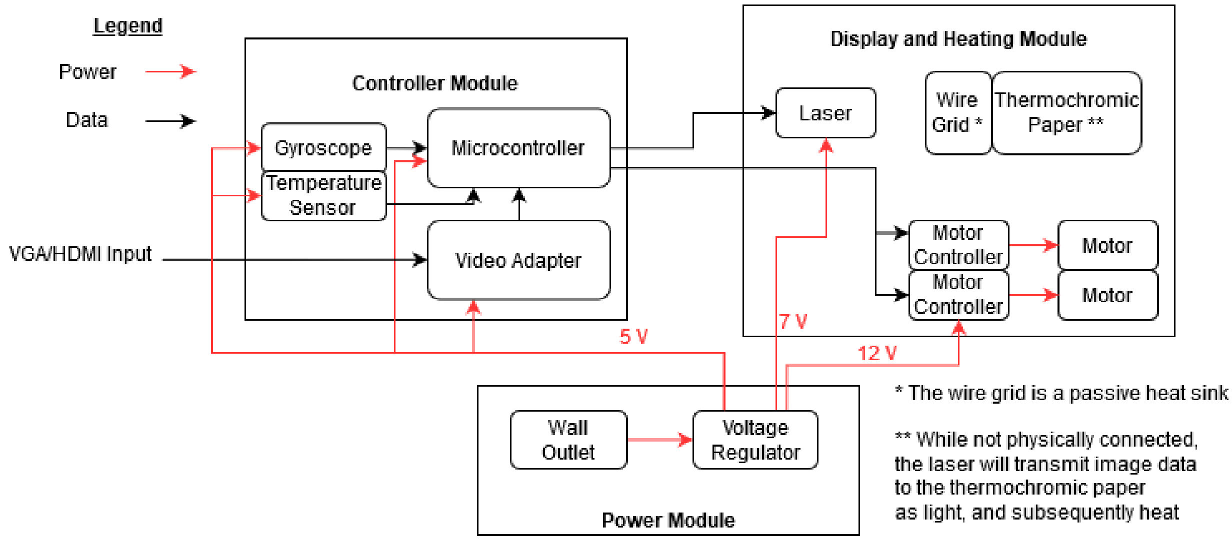

Figure 3: A High-Level Function Block Diagram

As shown in Figure 3, our project requires three modules for successful operation: a power module, a controller module, and a display and heating module. The power supply ensures that the system can be powered continuously with stable 5 V, 7 V and 12 V sources for the respective module voltage requirements. The controller module consists of a microcontroller (ATMega or other), and gyroscope for precise control of the laser. The microcontroller takes in data from the sensors and controls the motors and heating of the laser in creating the final image. The display and heating module is made up of two motors and their controllers, the laser directed at specific areas on the paper and the wire mesh that will form the pixel grid by constraining the heat to a certain area per pixel, it would also act as a heat sink to prevent burning the paper. Each motor in this module controls a single axis to angle the laser appropriately.

2.3 Functional Overview and Block Requirements

Display and Heating Module

The display and heating module is responsible for generating and rendering the final image. It consists of a laser, its motor-controlled mount, a sheet of thermochromic paper and a passive aluminum grid which acts as a heat sink. By using the laser to heat up the back of the thermochromic paper an image will be formed on the front.

Thermochromic Paper

This is the physical material that will be heated by the laser and will change color as heat is generated by laser absorption to create the final image. We are still exploring the specific paper or material we will use to create the thermochromic display. Generally, the system functions by converting light from the laser into heat which in turn changes the color of the paper for a temperature range of 30 ℃ to 35 ℃. By modulating the intensity of the laser, the amount of heat transferred to the paper can be controlled. When the laser stops heating the paper it will cool down via the aluminum wire grid. If using liquid crystal technology, the paper will remain black if outside the operating range.

While not physically attached to the laser, the laser will print an image onto the thermochromic paper via heat. This heat will be managed by the wire mesh which will focus the heat on the specific pixel and absorb excess heat.

Requirements:

- The paper must change color between a certain temperature range (ideally 30-35 degrees Celsius) and remain at that temperature outside of that range (room temperature of roughly 25 ℃).

Wire Grid

The aluminum wire grid is a passive feature of the design which is mounted directly against the back of the thermochromic paper by glue or other bonding agent. This unit consists of a square grid made of aluminum which acts as a heat sink and enforces pixel borders. Since the 6 in by 6 in square will be split into a 25 pixel by 25 pixel array, each pixel is roughly 6 mm by 6 mm. To promote quick heat dissipation the aluminum will take up all but a 2 mm by 2 mm square centered at each pixel, i.e. the grid is made of 4 mm thick wire which forms 6 mm by 6 mm squares.

Requirements:

- The wire grid must be able to absorb the excess heat and direct heat of the laser operating between the desired temperature and within a tolerance range in cases where temperature range is exceeded.

Motor and Motor Controllers

The laser mount and guidance consists of the motors, motor controllers and gyroscope depicted in Figure 2. This unit is controlled by signals from the microprocessor and in turn aims the laser at the desired pixel. The motion of the laser will vary based on how much energy or time of heating is required to get the desired effect or color before proceeding to the next pixel. The speed of the laser is only limited by the speed of the motors but this wont be a problem as most standard motors move very fast and we can turn on or off the laser in states where the required motion speed can be met to allow the motion before turning the laser back on to continue. The laser will be placed on one motor which is attached to the other. The base motor would be setup up to turn the upper system parallel to the base (horizontally) and the second motor would then be stacked on it and have the laser connected perpendicularly to its rotational axis which controls the vertical direction of the laser. With this setup the laser would be able to point at any point on the

2d plane of the thermochromic paper as long as it is setup vertically straight as shown in Figure 4 below [5].

Requirements:

- Mount and guidance must be able to direct the laser precisely within the 6 in by 6 in wire grid. Each motor will provide control in either the horizontal or vertical axis.

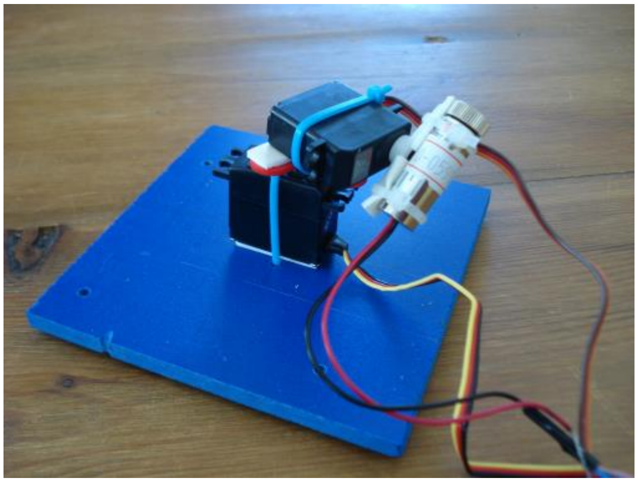

Figure 4: Dual Servo Motor Laser guidance setup

Laser

This unit consists of a single high-powered laser capable of heating a 2 mm by 2 mm square on the thermochromic paper to a range of 30 ℃ to 35 ℃. As outlined in the wire gird section, only a small portion of pixel space on the thermochromic paper is exposed to the laser, hence the 2 mm by 2 mm heating requirement. The effective intensity of the laser can be modulated either via controlling the current to the laser diode or via pulse-width modulation with a static current load. Likely pulse-width modulation will be used to simplify the laser circuit. The heating of the paper would be based on how much power the material absorbs from the laser, this will largely depend on the wavelength of the beam and the material of the paper. But to ensure the appropriate power is delivered to the material we will need to test/simulate how much energy is needed to just change the color of the material without reflecting harmful energy or burning through the material which we can do through various laser intensity-absorption equations [6]. We will need to run testing/simulations to find the right energy required for specific colors on the specific thermochromic material. But essentially the lower the energy required the less likely it is to burn and the more precisely the wavelength range is configured the less likely it will burn through as we will be staying within the range that does not go anywhere near the threshold of burning or melting as the metal wire mesh will help us absorb some of the heat and diffuse it quickly.

Requirements:

- Laser must be configured to release a beam radius with enough energy to heat up each pixel to 30 ℃ to 35 ℃ by providing the necessary power/energy range to trigger color change.
- Laser must have constant beam focal length to simplify the complexity of the laser control equations/calculations. material.

Controller Module

The controller module takes standard video or image data as well as the signal input from the gyroscope and converts it into control signals. These signals control laser intensity and angle laser mount system to create a final render on the thermochromic paper.

Microcontroller

The microcontroller ties each component of the controller module together. It will run code which factors in gyroscope and image data and outputs laser and motor controller signals to aim the laser appropriately. Based on ambient temperature recorded by the temperature sensor the microcontroller will modulate the absolute intensity of the laser to precisely heat the thermochromic paper between its operating range (of 30 ℃ to 35 ℃).

Requirements:

- Can receive data input from the gyroscope for two axes to calculate which pixel the laser is aimed at.
- Has at least ten I/O ports to take input from the gyroscope and the temperature sensor and send output to the motors to control the laser.

Gyroscope

This will be used to calculate where the laser should be directed to heat up the appropriate pixel on the paper.

Requirements:

- Gyroscope should be able to send data bits from the two degrees axes that it captures to the microcontroller.

Temperature Sensor

This sensor is used to measure ambient temperature during operation for calibration purposes.

Requirements:

- Should be able to determine ambient temperature in a range of at least 10 ℃ to 40 ℃ within ∓1 ℃ .

Video Adapter

The HDMI/VGA Adapter takes in standard video input and converts it into a format usable by the chosen microprocessor.

Power Module

This unit routes appropriate power to each submodule. Since the device is designed for non-portable, static use, a wall supply is used.

Wall Outlet

A standard wall outlet operating at 120 V 60 Hz AC will be used as the main input to our system. Paired with a DC adapter, voltage will be stepped down to that usable by the voltage regulators of our choice. The laser and motor are the largest power users of the system however power will likely be less than 10 W.

Requirements:

- Should provide steady power of roughly 10 W throughout the duration of device use.
- Should provide surge protection to prevent explosions.

Voltage Regulator(s)

This integrated circuitry steps down high voltage from the supply to the required 5 V, 7 V, and 12 V. These power lines are then routed to their respective submodules.

Requirements:

- Must convert DC output from wall adapter to steady 5 V and 12 V (+/- 5 %) supplies.

2.4 Risk Analysis

The block which poses the highest risk towards the successful completion of this project is the laser mount and guidance system. While the system seems simple at first glance, it is particularly complex, especially after factoring in accuracy and safety. To ensure appropriate resolution and image clarity, precise control of the laser is required in two ways: first by its direction guidance which is controlled by the motors and secondly by the focus and intensity of the beam itself. Tolerances must be extremely tight. The addition of the gyroscope will help mitigate tolerancing issues as it will provide a feedback system that can check against the perceived state of the system.

As a result of the safety requirements and concerns, as explored further in the Ethics and Safety section, the laser control consisting of the motor controller, gyroscope and laser modules must have substantial redundancies. Should the guidance fail, the laser could be aimed at the same location, burn a hole through the thermochromic paper and thus be exposed to the user. For example, the range of the laser should be constrained to the thermochromic paper mechanically or programmatically (via gyroscope readings). Further should the laser position be stationary for longer than five seconds, it will be turned off.

3. Ethics and Safety

We regard the safety of the public in high esteem, therefore we have taken measures to prevent any possible harm to viewers and users. In the aspect of electronic safety we are drawing power from a wall outlet which is at 120 V. We plan on maintaining safety by using a voltage regulator which would power our projects at safe rates of 5 V to the respective components. We would have also covered all wires properly and tucked away from exposure in order to prevent direct contact with any person.

There are some concerns involved with the laser, especially if it is contact with the skin due to radiation. This could bring about thermal injuries and/or more casualties [2]. Therefore, we have decided to use a protective casing over the laser and the thermal paper so they do not come in contact with human skin. More precautions such as gloves, goggles and a distance measure are being taken into consideration as a form of an extra layer of protection.

We recognise that maintenance will play a part in our project so we have taken precautions to keep this working at its best optimum ability. With the layer of mechanism that is involved with both the motors and the lasers, we know that a potential safety hazard could occur if rusted or unkept equipment is in exposure or used by others [4]. We have decided to oil and disinfect equipment at regular intervals so that it’ll be in top shape for the lasers and motors to be used.

The use of a laser, where it sounds exciting to most, is actually very technical to use. Properly trained personnel must be the ones that use laser and proper training must be given to those planning to work on it. On the other side of the spectrum we have decided that under no circumstances will those younger than the age of 12 and those unqualified to work with equipment will be allowed to work with the project. Consequently, this is a form of protection so those that may be unaware of the dangers do not misuse the project thus endangering themselves and those around them.

Overall from an ethical approach, we made sure to uphold the standards of the IEEE Code of Ethics [3]. We have the personal and physical safety of our viewers as our top priority, we do not tamper nor abuse the information given to us by users. We have the purpose of this project to be of the betterment of society and an avenue for the creativity of others' expressions. Our precautions align particularly with the Article 5 of the IEEE Code of Ethics, to improve the understanding of the people in society through our project. We aim to use this project to encourage others to think outside the box and provide alternatives to our modern day processes. We do not encourage the use of this to harm or threaten others but to invite variety in our lives.

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