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# Thermal-Based Color Detection: An Assistive Technology for Blind or Visually Impaired Users

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*Abstract*— **Assistive technologies have significantly improved the quality of life for blind or visually impaired (BVI) individuals, yet most solutions rely heavily on tactile or auditory feedback. Thermal feedback, though promising, remains underexplored, particularly in the context of color recognition. We propose a novel assistive system that utilizes haptic thermal-based feedback to assist BVI users in distinguishing colors, offering an alternative sensory substitution method via temperature perception. The system integrates a TCS34725 color sensor and a TEC1-12706 Peltier module interfaced with an Arduino microcontroller. Once the color sensor determines color values, the corresponding temperature signal is generated by dynamically controlling the Peltier element through a MOSFET circuit. This approach allows users to interpret color solely through variations in thermal sensation, removing the need for visual or numerical interpretation. A working prototype has been developed and tested with 8 distinct colors, each mapped to a unique, perceptible temperature range. The system demonstrates consistent color-to-temperature translation for most colors, providing preliminary validation of the concept.**

## I. Introduction

Color plays a significant role in many aspects of our everyday lives, such as distinguishing objects, navigation, guiding decision-making, and shaping interactions with the environment. However, opportunities to experience such perceptions are limited for individuals who are blind or visually impaired (BVI). As technology continues to evolve, assistive technologies have emerged to bridge this sensory gap, offering innovative means of interpreting visual data through alternative modalities.

Assistive technologies are designed to enhance the quality of life for individuals with disabilities by providing functional tools that compensate for lost or limited abilities [1]. For BVI users, such systems often rely on sensory substitution, a method by which information typically perceived through vision is conveyed via other senses, such as touch, hearing, smell, or temperature. Prior solutions like Color Glove, ColorOdor, and EyeMusic exemplify the diverse approaches to color recognition through tactile, olfactory, and auditory cues [2]. While each offers unique advantages, tactile feedback has shown the greatest adaptability due to its direct and intuitive nature. However, the reliance on single sensory channels in most existing systems [3], [4] limits the richness of feedback and user flexibility.

To address this limitation, we propose an assistive system that utilizes haptic thermal-based feedback to expand the perceptual bandwidth available to BVI users. Our design utilizes a TCS34725 color sensor and a TEC1-12706 Peltier thermal module, both controlled by an Arduino microcontroller. When the sensor detects a specific color, the Peltier element is modulated via a MOSFET circuit to produce a corresponding temperature response. For instance, a strong red input (e.g., R:255, G:0, B:0) can be mapped to the highest temperature in the predefined range. This system allows BVI users to identify colors based on distinct thermal sensations rather than visual or numeric interpretation.

The current prototype supports 8 distinguishable color-temperature mappings, each producing a consistent and perceptible thermal response. While the prototype demonstrates proof of concept, ongoing development aims to expand the color spectrum, refine thermal granularity and multimodal capabilities. The overall goal is to convert the system into a compact, wearable device for seamless integration into daily life. By combining tactile and thermal feedback, This research contributes to the advancement of sensory assistive technologies, offering BVI users an intuitive, non-visual pathway to experience and interact with color, potentially enhancing accessibility in both personal and educational environments.

## II. Methodology

### A. Color Sensing Module

The development of the system involved constructing a color detection system using the TCS34725 color sensor interfaced with an Arduino microcontroller. Once the system was assembled and the code successfully compiled, the sensor was programmed to capture and output RGB values to the serial terminal at 10-second intervals. To improve the reliability of the color readings, a custom mapping function was developed and refined through iterative testing and calibration. This calibration process involved comparing sensor outputs against known printed color samples under varied lighting conditions to achieve more accurate and realistic color representations.

### B. Thermal Sensing Module

In parallel, the thermal feedback component was evaluated using a TEC1-12706 Peltier module. Initial functionality was verified by directly connecting the module to a 5V power source, confirming that the unit reached its maximum heating capacity within approximately 5–7 seconds. Subsequently, a temperature control circuit was developed using an Arduino-compatible MOSFET setup. This circuit enabled controlled heating, stabilization, and passive cooling cycles, ensuring safer and more manageable thermal responses suitable for tactile feedback.

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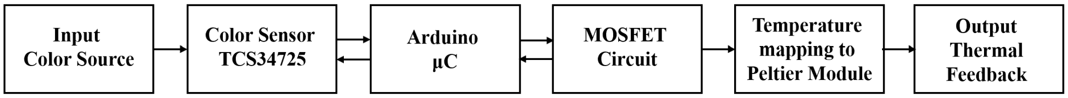


Fig. 1. Proposed haptic thermal-based feedback assistive system.

### C. System Integration

After validating the independent operation of both the color sensing and thermal feedback modules, the systems were integrated (Figure 1). The Arduino was programmed to interpret RGB inputs from the color sensor and trigger corresponding thermal responses from the Peltier module based on predefined thresholds.

Initial testing used black and white as control colors; white triggered heating, while black resulted in no thermal output. This confirmed successful communication between the sensor and the heating module. Following this, further tests were conducted using a subset of warm colors: red, orange, yellow, and white. Due to the absence of a heat sink, only heating responses were explored at this stage, with cool colors reserved for future development.

Each warm color was mapped to a distinct temperature level, with red producing the highest thermal response and white the lowest. The system consistently generated accurate temperature outputs in response to these colors, validating the mapping logic and the effectiveness of the integrated system.

## III. Results

### A. Color Detection Accuracy

The color detection system successfully identified and output RGB values for a range of test colors under controlled lighting conditions. Figure 2 shows the comparison of the tested color and the outputted RGB colors. Most warm colors, such as red, orange, and yellow, were consistently distinguishable within their defined RGB thresholds. However, limitations were observed when detecting cooler tones like blue and purple, which tended to yield inconsistent or inaccurate readings. These discrepancies are likely due to the color sensor's spectral sensitivity and the influence of ambient lighting. Additionally, the use of printed CMYK-based test samples introduced further inconsistencies, as these do not translate perfectly into RGB space.

| Tested Color (R,G,B) | Outputted Color |
|---|---|
| **Red** (255, 0, 0) | **Vivid Red** (228, 0, 0) |
| **Orange** (225, 128, 0) | **Vivid Orange** (255, 115, 0) |
| **Yellow** (255, 255, 0) | **Light Yellow** (255, 255, 136) |
| **Green** (0, 255, 0) | **Light Green** (131, 209, 108) |
| **Blue** (0, 0, 255) | **Navy Blue** (0, 26, 136) |
| **Purple** (127, 0, 255) | **Midnight Blue** (0, 0, 91) |
| **Black** (0,0,0) | **Black** (0, 0, 0) |
| **White** (255, 255, 255) | **White** (255, 255, 255) |

Fig. 2. Comparison of tested and outputted RGB colors.

Despite these challenges, the implemented mapping function allowed for a flexible interpretation of color data. For instance, the device was able to categorize red as long as the red channel exceeded a set threshold while green and blue remained low. This design choice improved the reliability of the system and provided a functional base for thermal output generation.

### B. Thermal Feedback Response

Initial heating tests showed that the Peltier module could safely reach a distinguishable range of temperatures within seconds, making it suitable for real-time feedback. When integrated with the Arduino, the system successfully varied the heating intensity based on detected color values. During testing with red, orange, yellow, and white, the Peltier module generated progressively lower heat levels, matching the color's placement along the warm spectrum. This thermal gradation was repeatable and consistent, validating the effectiveness of the color-to-temperature mapping.

Notably, without a heat sink, the system was limited to heat-based feedback only. Cool colors such as blue and green were not tested for cooling feedback due to hardware constraints. However, the system design accommodates future integration of a heat sink and improved temperature regulation circuits.

## IV. Conclusions and Future Work

This research presents a novel approach to assistive technology utilizing the haptic thermal-based feedback to enable BVI users to perceive and distinguish colors. By integrating a color sensor with a Peltier module, the system translates visual color information into discernible temperature variations, offering a unique form of sensory feedback. The current prototype demonstrates the feasibility of this method for identifying a limited range of warm colors. Future work will focus on refining the resolution of thermal feedback, expanding to a broader color spectrum, exploring multimodal feedback, and converting the system into a wearable device.

## References

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