Design and Fabrication of Low-Cost Thermal Imaging Device Prototype to Detect Heat Energy Loss in Electrical Equipment

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Abstract. Ability to detect heat energy loss from electrical equipment can be proven crucial to avoid overheating and unexpected fire incident. The thermal remote camera was invented to prevent power outages or electrical machinery failures. Thermal imaging cameras are device which converts thermal energy (heat) into infrared spectrum to inspect a specific object or scene. Imagery that reflects the spatial variability of temperature differences in a scene observed by a thermal camera are called thermal images. Due to the complexity of the device, it can be cost and not a solution sought for. This research presents the designing and fabrication of low-cost thermal imaging cameras that plays major role in detecting heat energy losses in various applications. This prototype of thermal imaging cameras is tested to monitor and diagnose the heat health, especially in electrical installations and components in non-contact mode. Based on the test result presented, the prototype able to detect heat energy spectrum up to 80°C. The 8x8 thermal array able to calculate average temperature of the tested items.

1. Introduction

Electricity is a necessary component of modern life. As electricity became more widely used as a primary source of power in houses, electrical appliances became an increasingly important aspect of daily life too. It is used to illuminate rooms, operate fans, and operate household appliances such as electric stoves, air conditioners, and so on. Electrical fires caused by the failure or malfunction of electrical appliances have resulted in a substantial number of casualties and losses in some cases. The current leaking from the installation's live sections to the ground is referred to as leakage current. When electrical equipment or power lines fail, current leakage occurs. If the leakage is not identified on time, the leakage point will generate a lot of heat and potentially cause a fire event in the case of the leakage current increases [1][6][7].

The term "thermal remote sensing" was used to describe a method of preventing power outages or the failure of electrical machinery. It can be used to conduct routine thermal assessments as part of the maintenance of electrical equipment [1][6]. Thermal imaging cameras are responsible for the conversion of heat energy (temperature) into infrared spectrum to evaluate a specific object or scene. Images that reflect the spatial distribution of temperature differences in a scene scanned by a thermal camera are called thermal images. It can be only observed a small portion of the electromagnetic spectrum. In the electromagnetic spectrum, visible light occupies a minor portion, but infrared radiation (IR) occupies the majority. The visible and microwave sections of the electromagnetic
spectrum are separated by infrared radiation. Heat, also known as thermal radiation, is the principal source of infrared radiation. Infrared radiation is emitted by any element with a temperature greater than absolute zero (273.15°C or 0 Kelvin).

The image created by an infrared detector is called a thermogram, and it is processed using a technique called thermography [1][7]. Thermal imaging cameras are advanced equipment that process and display the acquired image on a screen. In the radiometric image, each pixel represents a temperature measurement. Complex algorithms are included into the thermal imaging camera to do this. As an outcome, the thermal imaging camera is ideal to be used in electrical applications for various heat energy dissipation detection purposes.

This paper is starting with introduction and literature studies, and discusses about the methodology used in this research, discussing results and discussion, before concluding at the end of the paper.

2. Literature Review
Various researches are conducted related to detecting heat energy loss in various applications. Weiyu et al (2019) in his paper [1], mentioned about why thermal remote sensing is required to be produced. The author continuously stresses the danger of failing to discover an electrical leakage problem in a timely manner, and if the condition worsens, it may result in a fire or explosion.

The concept presented by Saha A.K. et al (2018) is almost like the prototype presented in this paper [2]. They employ satellite imagery for applications such as desertification monitoring and detecting sparse shrublands and grasslands. As a result, they employ an Adafruit AMG8833 IR thermal camera to apply those concepts, and the approach remains the same here: the AMG8833 will monitor the heat signatures associated with the sand. Based on this article, more information about AMG 8833 has been explained, such as how this sensor network works, which microcontroller is suited for sensor (as long as the microcontroller has I2C protocol, AMG8833 may be driven by it), and how far it can detect the target (up to 7 meters).

Haripriya A. B. et al (2020) in their paper [3] mentioned in a teaching laboratory, the ability to visualize chemical processes might be useful. The recent arrival of thermal imaging cameras to the science lab has allowed students to better understand thermodynamic concepts. In reality, most learners will gain from this method, emphasizing the usefulness of it in college laboratory settings. As a result, they describe a simple fully accessible Arduino thermal imager that can be manufactured for less than $100 USD, bridging the budget gap for instructors enthusiastic in incorporating imaging technology into their lectures [4].

All these papers are generally mentioning about the importance of having low-cost thermal imaging devices that can be used for commercial and domestic use to detect the heat discharge. The next section discusses about the methodology used in this research.

3. Methodology
The research methodology starts with identifying the required components for the fabrication. The components as shown in Table 1 are ordered from local and oversea suppliers. As it can be seen in Table 1, the hardware cost is approximately $100.00 to manufacture a single unit of low-cost thermal imaging device, in line with the suggestion from Haripriya A.B. et al (2020) [3]. But, it need to be understood that this is a cost when a single unit in fabricated. If the components are obtained in bulk for production, it is estimated that the price to be reduced to a price range of $50.00 to $60.00 per unit, depending on the order size. Table 2 shows the comparison of the proposed thermal device with the existing devices in the market.

In the next subsections, some of the important methods used in this research are explained in detail.

3.1. Final Temperature Estimation using Adafruit AMG8833 8x8 Thermal Camera Sensor
The Adafruit AMG8833 IR Thermal Camera Breakout (Figure 1) is the perfect choice for this design because it has an 8x8 array of thermal sensors in-built in a single board. It is compatible with the Arduino Mega 2560 microcontroller. With a precision of ±2.5°C (4.5°F), it can measure temperatures
ranging from 0°C to 80°C (32°F to 176°F). It can sense a human from up to 7 meters (23.3 feet) away. Its highest frame rate is 10Hz, hence it can be utilized to make a 10-frame-per-second tiny thermal camera.

Table 1. Components used in Thermal Imaging Device Prototype.

| Components                           | Approx. Price in USD |
|--------------------------------------|----------------------|
| 1 Adafruit AMG8833 8x8 Thermal Camera Sensor | $30.00               |
| 2 Arduino Mega 2560 Microcontroller   | $42.00               |
| 3 3.5” Touch Screen TFT LCD          | $15.00               |
| 4 18650 Li-Ion Battery               | $7.00                |
| 5 TPS 2 Pin ON/Off Switch            | $0.35                |
| 6 Connectors & Other Electronics     | $2.30                |
| 7 3D Printed Casing                  | $4.00                |

Table 2. Comparison with Existing Devices

| Device                                    | Price   | Accuracy | Quality |
|-------------------------------------------|---------|----------|---------|
| 1 Thermal Tester HT-02D                   | $192.00 | 98%      | Good    |
| 2 Banggood Noyafa NF-521 Thermal Imaging Camera | $180.00 | 99%      | Good    |
| 3 Smart Sensor Infrared Thermal Imager    | $528.00 | 100%     | Good    |
| 4 HIKMICRO E1L Thermal Imaging Camera     | $350.00 | 98%      | Good    |
| 5 Proposed Low-Cost Thermal Imaging Device | $100.00 | 99%      | Good    |

The AMG8833 monitors heat radiation from an infrared-emitting grey body in a passive manner. The Stefan-Boltzmann law is used to compute the temperature (equation (1)):

$$\Pi = \varepsilon A \sigma T^4$$  \hspace{1cm} (1)
where, $\varepsilon$ is the emissivity (a number between 0 and 1), $A$ is the surface area, $\sigma$ is the Stefan-Boltzmann constant, $T$ is the body's temperature, and $P$ is the radiant power. Since typical infrared thermometers (thermopiles of thermocouples) measure radiative power rather than temperature, a conversion is required [5]. The following is a simple equation (equation (2)) for approximating the temperature of a grey-body:

$$V = k(T_{\text{obj}}^4 - T_s^4)$$

where, the voltage measured by the raw sensor is represented by the $V$. The variable $k$ is an empirical constant that takes into account any $A$, $\varepsilon$, $\sigma$ and electronic noise. The remaining $T_{\text{obj}}$ is the temperature of the object being measured, whereas $T_s$ represents the temperature of the sensor. The temperature of the sensor is removed to verify that the temperature of the object is not influenced by the sensor's temperature. These sensors are frequently calibrated using the target material at various temperatures to guarantee the value of $k$ remains precise in order to be able to find an accurate temperature prediction [5]. Once it is completed, the empirical equation as shown in equation (3) can be used to calculate the temperature of an object:

$$T_{\text{obj}} = \left(\frac{V}{k} + T_s^4\right)^{1/4}$$

Equation (3) is the formula to estimate the final temperature of a grey-body using an infrared detector.

3.2. Prototype Casing Design using SolidWorks 2018

SolidWorks software version 2018 was used to design this prototype. When developing the prototype, various design considerations must be considered. It should be smaller in size so that users could bring it with them wherever they go. It should be simple to use and store as well. The casing should be designed to be ergonomic, light, and durable. In the compact prototype, the electronics must also be kept safe, allowing for easy installation of electronics such as an LCD and a thermal imaging sensor. The user must be able to see the images transferred to the LCD via the sensor better. Thus, the LCD positioning is important. Figure 2 shows the prototype casing design using SolidWorks 2018. The SolidWorks design is passed to the 3D printer for 3D printing. The final assembled prototype is shown in Figure 3. The items numbered in the figure are explained in Table 3.

![Figure 2. Prototype Casing Design using SolidWorks 2018.](image-url)
Figure 3. Final Assemble Prototype of The Thermal Imaging Camera.

Table 3. Explanation of Numbering in Figure 3.

| Function/ Description                                                                 |
|---------------------------------------------------------------------------------------|
| 1 +ve Li-ion battery connected with red wire                                           |
| 2 -ve Li-ion battery connected with black wire                                        |
| 3 TPS 2 Pin ON/Off Switch connect with Li-ion battery and battery connector to DC    |
| 4 Battery connector to DC Jack Arduino is connect with DC jack port on Arduino Mega   |
| 5 Used magnet to cover remote                                                         |
| 6 Aluminium plate used to make a force that pull on the magnet                        |

4. Result & Discussion

The final prototype is tested in various thermal conditions such as hot water, lamp, smartphone and electrical fan. Each experiment is conducted for a time of 300 seconds with reading taken for every 30 seconds intervals each to observe the thermal changes detected by the prototype. 300 seconds are selected as the measurement time interval for the heat to reach baseline saturation.

The hot water is left to be cooled to the room temperature. For lamp and smartphone, they were turned off after been on for 5 minutes. For electrical fan, in contrast, the reading was taken from turned off condition to turned on for 5 minutes. Figure 4 to Figure 7 show the temperature – time graph of all the thermal conditions tested detected by the prototype thermal imaging device, compared with conventional thermal tester HT-02D. Based on the graphs shown, over a period of 300 seconds, the graphs show graduation reduction in the temperature, detected by the proposed system. At times, there are slight increase in the temperature measurement before the trend continues to reduce further. It may be due to the temperature disturbance or air turbulence in measurement area. Taking the
measurements over longer period of time such as 300 seconds can help in reducing outliers in the measurement.

Figure 4. Result for Hot Water Thermal Condition Detected by The Prototype.

Figure 5. Result for Lamp Thermal Condition Detected by The Prototype.
Figure 6. Result for Smartphone Thermal Condition Detected by The Prototype.

Figure 7. Result for Electrical Thermal Condition Detected by The Prototype.

Figure 8 shows the physical experiment of measuring the temperature for event 1 hot water. It can be seen that at the initial stage, the screen shows mostly red spectrum on the LCD screen, indicating the temperature is hot. After 5 minutes, the red spectrum started to turn to yellow and green colours, indicating the temperature are reducing. The temperature values also shown for each element of the 8x8 thermal sensor pixels. Table 4 shows the experiment details and the comparison results with conventional thermal tester.
Figure 8. Physical Experiment of Measuring Temperature for Event 1 Hot Water (for 5 minutes).

Table 4. Experiment Details and Comparison Results with HT-02D Conventional Thermal Tester.

| Experimental Conditions | Initial Temperature | Final Temperature | Comparison Result with HT-02D |
|-------------------------|---------------------|-------------------|-----------------------------|
| Hot Water               | 69.69°C             | 31.16°C           | Within ±2.5°C               |
| Lamp                    | 30.27°C             | 28.87°C           | Within ±2.0°C               |
| Smartphone              | 34.29°C             | 31.00°C           | Within ±1.5°C               |
| Electrical Fan          | 26.13°C             | 27.93°C           | Within ±1.5°C               |

Based on the result shown in the figures above and Table 4, it can be seen that the low-cost thermal imaging device developed is comparable to the conventional unit of thermal tester in market. The accuracy of the device is within ±1.5°C to ±2.5°C with the available unit, yet the price of the developed unit is multiple time cheaper than the conventional thermal imaging camera.

5. Conclusion
The research intended to design and fabricate a low-cost thermal imaging device prototype capable of detecting heat energy dissipation from electrical devices. The device casing is designed using SolidWorks 2018 and the design is printed using 3D printing materials. The electronics components such as Adafruit AMG8833 8x8 Thermal Camera Sensor, Arduino Mega 2560 Microcontroller and 3.5" Touch Screen TFT LCD are used in achieving the heat energy loss detection effectively. The prototype is powered using arrangement of 18650 Li-Ion Batteries. Based on the testing conducted at various temperature conditions for daily used products and electrical appliances, the results show a
successful detection of temperature and heat losses in comparison to conventional HT-02D unit. Thus, the objective of the research to create an effective low-cost thermal imaging device prototype is achieved.

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