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Development of a Low-cost Thermal Camera for Electrical Condition Monitoring

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Abstract Abnormal rises in temperature of electrical equipment could be a sign of electric fault. By measuring the temperature of the equipment, it is possible to detect the early sign of electrical failure. Therefore, preventive maintenance based on thermal inspection is important to ensure the safety operation of the electrical system. Thermal inspection is normally done by using a handheld thermal camera. However, professional thermal camera is expensive and not suitable to be installed at a fixed location for continuous temperature monitoring. In this paper, a low-cost embedded system is proposed for measuring the temperature of electrical equipment based on thermal imaging. The system can be permanently installed to continuously monitor the thermal condition of an electrical installation. The proposed system consists of a Raspberry Pi 3 controller board connected to a MLX90640 32×24 pixels thermal sensor and a Pi NoIR camera. The temperatures measured by the thermal array sensor are converted into a heat map to form a thermal image. The thermal image is then overlaid on the visual image and displayed on the LCD screen. The system can be programmed to generate warning signal when the measured temperature is above a certain threshold value. Experiments carried out on the developed system showed that it is able to locate the hotspot regions of an electrical installation.

Keywords Thermal Imaging, Electrical Condition Monitoring, Electrical Fault Detection, Temperature Measurement, Embedded System

1. Introduction

Poor electrical contact due to loose connection, corrosion or rust, and short circuit due to deterioration in the insulation material are some of the major causes of electrical faults. These faults will usually cause rise in temperature of the electrical components. It may result in overheating and could even lead to fire or explosion. Hence, it is important to conduct temperature measurement on the electrical equipment during preventive maintenance to detect signs of abnormal temperature rise [1].

Equipment temperature is usually measured by using a thermometer. Thermometer can be broadly classified into two major categories, which are contact and non-contact types. A contact thermometer measures the temperature of an object using the heat transfer phenomenon known as conduction, which requires physical contact with the object. However, since physical contact is needed for the measurement, it may not be suitable for certain hazardous environments such as measuring equipment with high voltage. On the other hand, non-contact infrared sensor measures the temperature of an object by reading the level of infrared radiation emitted by the object. This can be performed at a distance without any physical contact with the equipment.

Non-contact temperature measurement using handheld thermal camera has been widely used in the industries for preventive maintenance [2][3]. However, handheld infrared camera is usually not used for continuous or real-time monitoring of equipment temperature. It is only used for temperature measurement when carrying out routine inspection or maintenance. Thus, it could not capture the changes in temperature profile and the thermal behaviour of the equipment [4]. It is also difficult to modify a handheld infrared camera to provide real-time warning when there is a fault occurred. Furthermore, they are normally very expansive and may not be suitable to be installed permanently at a fixed location for real-time monitoring. Thus, in this paper, a low-cost embedded system for electrical condition monitoring based on thermal imaging is proposed.

2. Related Work

Zhang developed a non-contact infrared thermometer to measure the body temperature which can be used to replace the traditional mercury thermometer [5]. Their design consists of a single chip MICYOCO (SCM) IC which acts as the main controller, a MLX90614 thermal sensor, an LCD display and an alarm system. The working principle of MLX90614 is to transform the infrared radiation signal emitted by an object into electrical signals and read by the microcontroller through its ADC port. The digitized signal is then processed by the SCM controller to calculate the temperature value and display it on the LCD. Zhang compared the temperature values obtained from his system and a standard mercury thermometer. He showed that there is only a small difference in temperature measurement. His system has the advantage over traditional mercury thermometer since it uses non-contact temperature measurement which is more convenient to measure temperature from ear, forehead and other parts of the body [5]. In another work, Long [6] extended the functionality of a non-contact thermometer with voice reporting of body temperature and time. However, there are some limitations in their system. The measuring distance between the sensor and object has to be within 2 – 4 cm. Besides, it only measures temperature value at a single point. Hence, this sensor is not suitable to be used for non-contact electrical inspection.

An embedded hardware for non-contact temperature measurement is proposed by Gaofeng et al. in [7]. The system is based on a Samsung S3C2410 controller connected to a TSEVOIC temperature sensor through I^2C interface. They showed that the system can perform fast measurement with high precision and good stability. However, the sensor can only measure temperature at a single point at one time.

Sruthi et al. proposed a low cost thermal imaging system for medical application [8]. They used the MLX90620 which is a 16×4 pixels IR array sensor for temperature measurement. The advantages of their system based on infrared thermal sensor are on the safety with no radiation for medical diagnosis purpose. However, the limitation of using the MLX90620 thermal sensor is that the resolution of the generated thermal image is very low, and it is difficult to visualize the thermal pattern of an object.

This paper proposed an embedded system for electrical condition monitoring based on thermal imaging. The system is composed of a Raspberry Pi 3 Model B+ controller, a MLX90640 thermal array sensor, a visual camera and a 7-inch touch screen display. The system can perform continuous monitoring of the equipment temperature using non-contact measurement. It can also be programmed to send out warning signal when the measured temperature exceeds certain threshold value.

3. Methodology

3.1. The Hardware Design

Figure 1 shows the block diagram of the proposed system. The core of the system is a Raspberry Pi 3 (RPi3) board which acts as the main controller for the system. A MELEXIS MLX90640 far infrared thermal sensor is used for temperature measurement. MLX90640 is a small size 32×24 pixels IR array sensor that can measure object temperature between -40 to 300°C. The sensor is connected to the RPi3 through I^2C interface to get the thermal measurement data. Two ceramic capacitors (100nF and 1μF) are connected in parallel with the power pins of the sensor to reduce noise in the measurement.

Besides the thermal sensor, a visual camera (Pi NoIR Camera Module v2) is included in the design to capture visual images. The camera is connected to RPi3 through the Camera Serial Interface (CSI) connector. It captures 8 Megapixels visual image which is used to preview the measurement area. The thermal images from thermal sensor will be overlaid on the visual images to provide better visualization for the temperature measurement of an object. A 7-inch LCD module is attached to the RPi3 through the Display Serial Interface (DSI) connector. It is used to provide user interface and display the measurement results. Figure 2 shows the front and back views of the developed system.

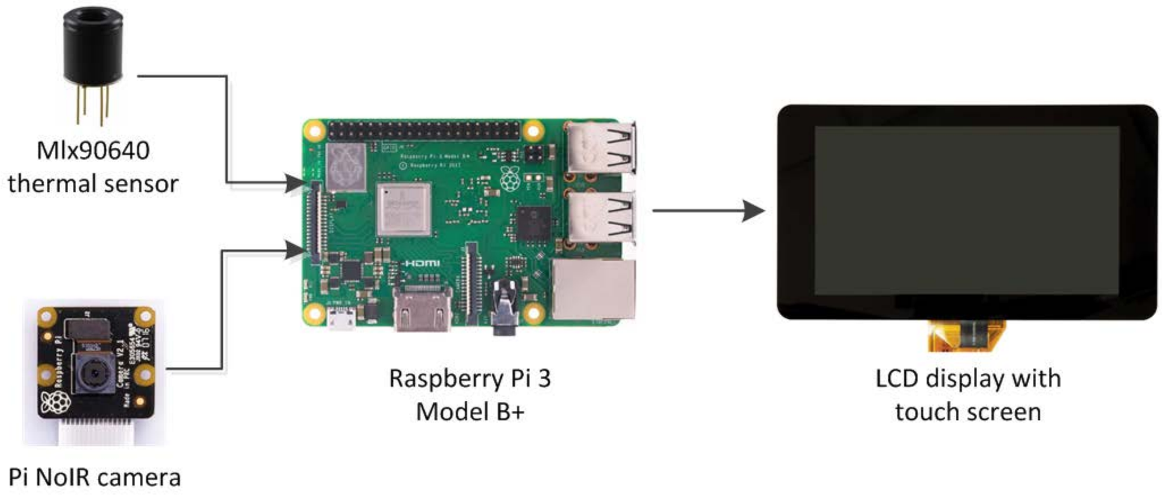


Figure 1. Block diagram of the proposed system

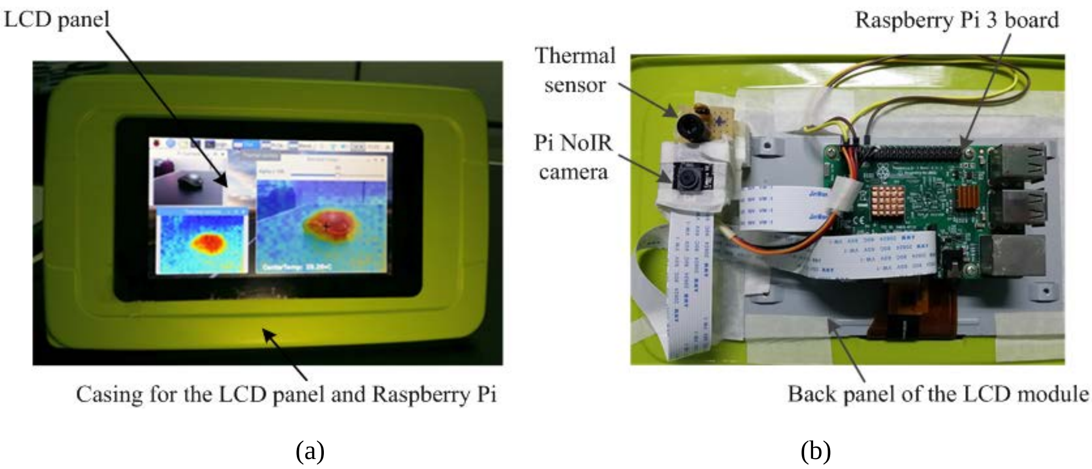


Figure 2. Assembly of the developed system. (a) Front view. (b) Back view

3.2 The Software Implementation

Figure 3 shows the software flow chart of the developed thermal imaging system. When the system is powered up, it boots up the RPi3 and runs the thermal imaging software. First, the software initializes the thermal sensor and the camera module. It then reads 768 temperature data from the thermal sensor and calculates the temperature values. The temperature values are arranged into 32×24 pixels configuration to generate a heat map or thermal image using the "JET" color map. The software then reads a frame of visual image from the NoIR camera. Both thermal and visual images are then resized and aligned to form an overlaid image. The percentage of overlay can be adjusted through the keyboard by pressing '+' or '-' button. The thermal, visual and overlaid images are then displayed on the LCD screen. The software was written in C language and compiled using the GNU C compiler. MLX90640_API library is used for reading the thermal sensor and Open CV image processing library [9] is used in the implementation. Figure 4 shows a screenshot of the LCD display for measuring the temperature of a cup of hot water.

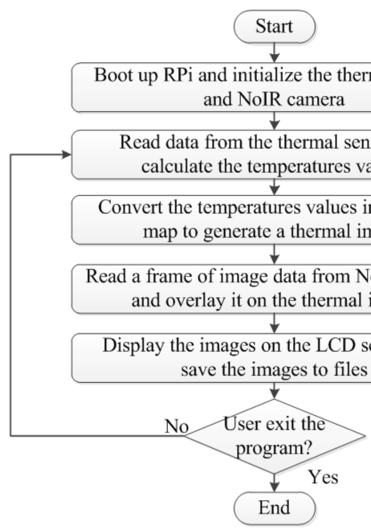


Figure 3. Flow chart of the developed thermal imaging software

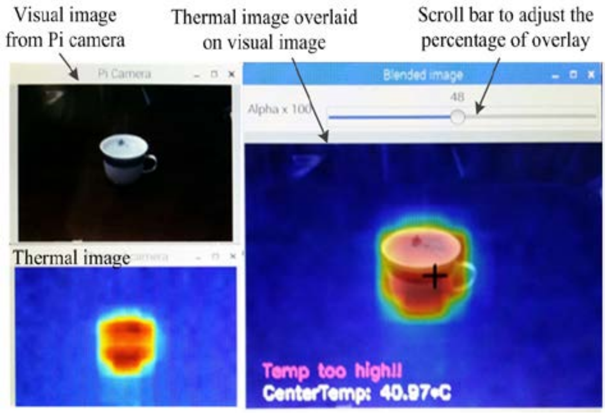


Figure 4. Screen shot of the LCD display showing the captured visual, thermal and overlaid images

4. Results and Discussion

The accuracy of temperature measurement for the developed system was evaluated by the comparing it to a commercial handheld thermal camera (Testo 875-1i). An experiment was conducted by using a cup of hot water. Temperature measurement was recorded every 30 seconds for a period of 5 minutes while the water was slowly cooling down. Figure 5 shows the graph of temperature values measured by the developed system and the handheld thermal camera.

It can be seen that there are small differences in the measured temperature values. The temperature measured by the developed system is consistently lower compared to the handheld camera with an average difference of 1.2°C. There are some parameters used in the calculation of temperature for the MLX90640 thermal sensor such as emissivity and reflectivity of the measured object. In the experiment, these parameters have not been properly adjusted and therefore causing the differences in temperature reading. These parameters need to be properly calibrated to obtain more accurate results.

Next, experiments were carried out to test the capability of the developed system to measure the temperature of electrical components and detect possible electrical fault. Two tests were conducted, one on a multi socket power extension plug and the other on an electrical distribution panel.

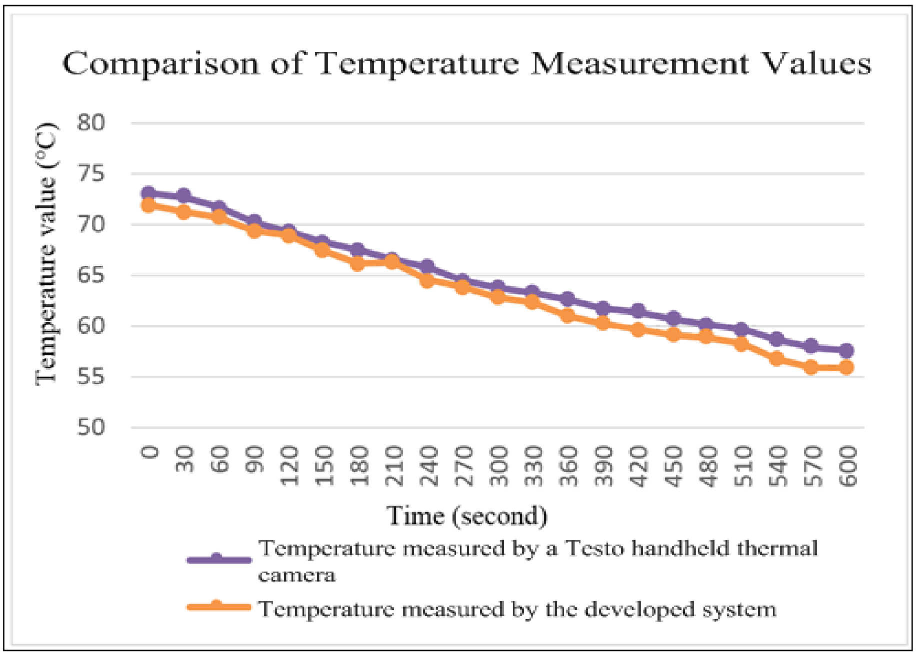
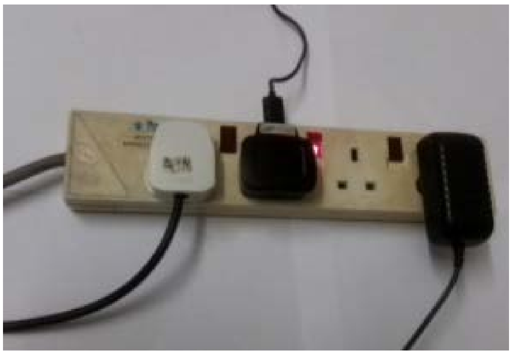


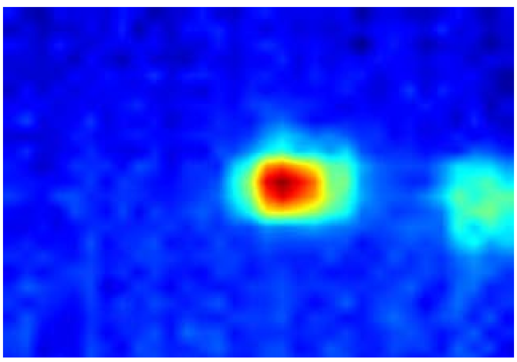
Figure 5. Temperature measurement from a Testo handheld thermal camera and the developed system

Figure 6 shows the measurement results on a multi socket power extension plug. The thermal camera is able to detect the high temperature region as shown in Figure 6 (b) and (c). The high temperature regions showed up as reddish color while the cool temperature parts are in blue color. From the overlaid image, it is observed that the plug on the second socket showed abnormally higher temperature, which could be a sign of electrical fault.

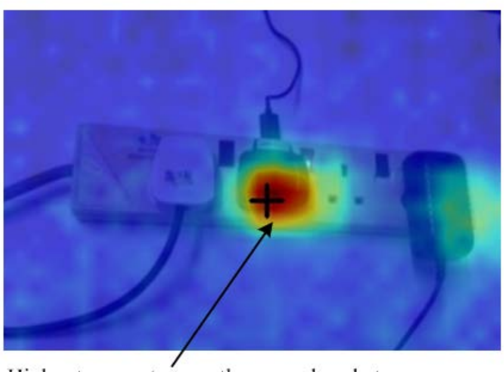
The second test was conducted to monitor the temperature of a power distribution panel. For the purpose of this test, one of the wires on the panel was deliberately loosened to simulate a loose connection fault. Due to the poor electrical contact, the temperature around the wire has increased.



(a)



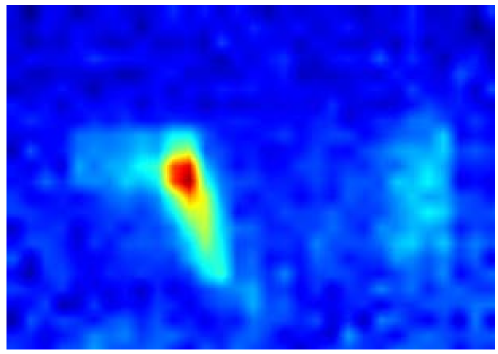
(b)



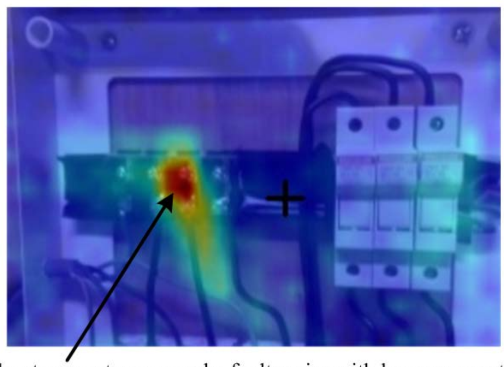
(c)

Figure 6. Measurement on a multi socket power extension plug. (a) Visual image. (b) Thermalimage. (c) Overlaid image. Higher temperature was detected on the second socket

(a)



(b)



(c)

Figure 7. Measurement on a switchboard panel. (a) Visual image. (b) Thermal image. (c) Overlaid image. Higher temperature was observed around a wire with loose connection.

The measurement result is shown in Figure 7. It can be observed from the thermal and overlaid images that there is a hotspot region near the location of the loose wire. This showed that the system is able to capture and locate the fault region in the electrical installation.

5. Conclusions

This paper described the development of a low-cost thermal camera that can be used for electrical condition monitoring. Compared to a commercial handheld camera, the components' cost of the proposed system is much lower. The system can be installed at a fixed location to continuously monitor the thermal condition of electrical equipment without any physical contact. It can be programmed to provide real-time warning signal when the equipment temperature reaches an alarming level. The proposed system is composed of a Raspberry Pi 3 controller, a MLX90640 thermal array sensor, a visual camera and an LCD display. The measurement results are shown on the LCD in the form of thermal, visual and overlaid images. Experiment on the developed system showed that it is able to locate the areas with high temperature which are the possible fault regions of an electrical installation.

Acknowledgements

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