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Development of an IoT Embedded Wearable Device with Non-Contact Temperature Detector for Early Detection of Fever

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Abstract: One of the most common and early symptoms of any viral infections is fever which is the reaction to a disease-specific stimulus causing the increase of human body temperature. The current common method of monitoring the human body temperature uses the application of non-contact infrared thermometer (NCIT) and is only limited for stationary conditions within short distances and mostly suitable for indoor premises. The available technology to detect human body temperature for longer distances uses the thermal camera which is costly and large. Thus, it is challenging to detect anyone with high body temperature in non-stationary conditions, at longer distances, especially outdoor. The paper proposes an innovation to the current practice, for a wearable non-contact temperature detector device which is portable. The wearable non-contact temperature detector embeds a thermal sensor and a microcontroller to a normal hat. It is able to detect objects with higher temperature (37.5 °C) within 1 meter radius of 60° angle view in stationary and non-stationary conditions. The wearable device communicates via Bluetooth to a mobile device to display the detected temperature and notifies the user via alert message and alarm for high temperature detection. Display of the object's thermal image is also available with a resolution of 8 × 8 pixel. The wearable non-contact temperature detector is able to achieve 99% accuracy of temperature measurement for detection distance of up to 70 cm for indoor and within 20 cm for outdoor when tested with normal temperature subject and high temperature objects and compared with the actual temperature detected via a commercial NCIT device.

Keywords: Non-contact temperature detector, wearable devices, thermal sensor, thermal image, thermal camera, IoT embedded, COVID-19

1. Introduction

Viral infections occur when the immune system is unable to fight off the invasion of any viruses that enters the body. Viral infections cannot be treated with common antibiotics and in some cases may lead to complications due to the side-effect of antibiotics [1]. Among the common viral infections are dengue fever, common cold (usually caused by rhinovirus, coronavirus and adenovirus), the H1N1 influenza, Ebola, Severe Acute Respiratory Syndrome (SARS), and the most current that hits the world today is the Coronavirus Disease 2019 (COVID-19) [2], [3]. The effects of these virus attacks depend on the type of virus, the state of a person's health and how the virus can affect the person. Viral infections cause a huge impact on the world's population health especially on the increased cases of mortality.

Coronavirus Disease 2019, also known as COVID-19 is a disease that is caused by a new strain of coronavirus [4]. This virus is linked to the same family of viruses as the severe acute respiratory syndrome (SARS). The stages of

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COVID-19 symptoms range from less common, most common and serious symptoms. Most patients exhibit common symptoms such as fever, dry cough, and tiredness [4,5]. While some patients may have less common symptoms which include body aches and pains, sore throat, conjunctivitis, headache and loss of taste or smell, others may encounter serious symptoms such as difficulty in breathing, chest pain or pressure and loss of speech or movements [5]. COVID-19 can be spread through direct contact of respiratory droplets and from contaminated surfaces [4]. To reduce the spread of COVID-19, the public are required to follow the Standard Operating Procedure (SOP) which includes wearing a mask, seeking medical attention if symptoms are discovered, cleaning hands often, reducing physical communication, covering nose and mouth when coughing or sneezing and maintaining at least a meter distance from others [4].

Cases of COVID-19 are currently on the rise globally. Even though it has been over a year, the public should still be aware of their surroundings when being outdoor, as the spread of COVID-19 is unexpected. Introducing the SOP is one of the government's initiatives to reduce or slow down the spread of COVID-19 among the people. With proper SOP adherence by the public, it is hoped that the number of cases will reduce. However, it is not as simple as the prediction. As of October 2021, 195 countries have been affected by the COVID-19 pandemic with more than 240 million confirmed positive cases causing more than 4.8 million deaths [6]. In general, statistics have clearly shown that the cases continue to rise daily, which is a concern to all.

1.1 Human Body Temperature Measurement

Body temperature is one of the oldest known diagnostic methods, and it serves as a vital indicator of health which aids in the early diagnosis of illness. The human body's temperature is the first physiological parameter to change in the detection of any disease in a person. Asymmetrical temperature distribution in some areas of the human body denotes an abnormality because the temperature distribution of the human body is typically symmetrical [7]. Among the most common symptoms of COVID-19, fever is the easiest to detect because it can be monitored by taking one's body temperature [8.9]. It is the body's response to a disease-specific stimulus. Fever is a common indicator of many infectious diseases, making it an important component for rapid fever identification of individuals suspected of having a disease [10]. In general, there are two (2) methods for detecting fever: contact devices or non-contact devices. A contact device requires physical contact, for example, a digital thermometer for axillary and oral measurements. A non-contact device measures the temperature of an object by reading the levels of infrared emissions such as non-contact infrared thermometer (NCIT) and thermal camera.

There are several factors that can influence temperature measurement readings. One of them is sweating which can affect temperature measurements as it acts as a filter for infrared radiation [11]. According to a study, the target emissivity, reflect temperature, and air transmittance between air and the object must all be considered and corrected to obtain accurate temperature measurement of an indoor surface [12]. For outdoor and large area detection, the number of sensors improve the ability of a system to measure temperature. A study by Dongning Qu et al state that a single thermal sensor can only cover limited detection area in battlefield surveillance or smart housing which require detecting, locating and tracking of multiple humans’ movements. As a results, multiple pyroelectric sensors must be deployed to detect the movement of the human target in the large detection area [13]. Aside from that, it was discovered that physiological and environmental factors could affect measurement of body temperature as well. Ge Chen *et al* found that as the forehead temperature may be influenced by physiological and environmental factors, the wrist temperature reading can be considered when measuring the body temperature during the pandemic as the wrist area is covered with clothing, which may help to keep the temperature stable [8].

1.2 Infrared Thermal Imaging & Thermal Camera in Temperature Measurement

Infrared thermal imaging technology detects and converts human body infrared radiation from invisible surface temperature changes into visible infrared thermal images [14]. Infrared of varying intensities will be transmitted to the lens from various parts of the human body surface. Following that, infrared detectors and signal processing will take place, converting them to electrical signals. The infrared signals will then be sent to the thermal imaging screen. The primary performance indicators of an infrared thermal image include working band, detector type, spatial resolution, temperature resolution, field of view, frame frequency, and temperature measurement range.

Fig. 1 illustrates the working principle of a thermal camera [15]. The lens of the thermal camera allows the infrared frequencies to pass through and focuses them to a special sensor array which can detect and read them. The sensor is constructed as a grid of pixels that reacts to the infrared wavelengths. The sensor converts the infrared wavelengths into electronic signals that are sent to the processor and further converted into a colour map of different temperature values using an algorithm. The resulting matrix of colours is sent to the memory and displayed as the thermal image of the object.

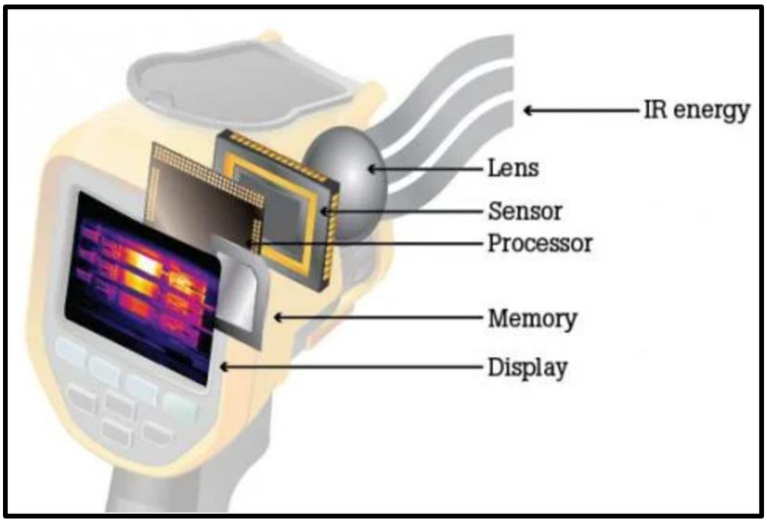

Fig. 1 - Working principle of a thermal camera [15]

According to a study by Shahrukh Khan et al, while there are invasive methods to measure core body temperature at various sites, such as the esophagus, urinary bladder, or nasopharynx, these methods are not suitable for use during pandemic situations such as COVID-19 due to their limitations of application. To address the issue, the non-invasive method using NCIT was deployed. Temporal Artery Thermometers (TATs) were used in their study as the reference reading, which was 36.90°C, and the mean body temperature measurement of NCIT was 36.64°C. The average temperature difference between NCITs and TATs measured was 0.26°C. According to the Bland-Altman analysis, the mean difference was significantly widened at temperature 37.5°C, whereas the temperature measured using NCITs and TATs were closely aligned for temperatures below 37.5°C [16]. Another non - contact portable infrared thermometer, Termoprint was designed for fever screening in clinical settings. The device is able to provide body temperature reading and list symptoms aassociated with pandemic flu. in a ticket - size summary which can be used for further examinations by the doctor. The Termoprint shows comparable performance to reference instrument in terms of accuracy and precision particularly in temperature range between 35°C to 38°C and measurement distance up to 3 cm [10].

Nishant Aggarwal et al did a review and meta-analysis on several researches and compared the diagnostic accuracy of NCIT and thermal scanners [17]. There were 19 studies in the quantitative synthesis using 21 non-invasive devices (10 NCIT and 11 thermal scanners). 13,874 readings were obtained from 12,759 patients using the 21 devices. Most of the studies which used NCIT devices used axillary, tympanic, or rectal thermometer readings as their reference. Meanwhile, tympanic and rectal thermometer readings had been used as the reference for the studies which used thermal scanners. There were 5562 total readings obtained from the 10 NCIT devices used in the studies. The obtained pool sensitivity and specificity of the temperature measurements were 0.781 (95% CI 0.628-0.882) and 0.926 (95% CI 0.799-0.975), respectively. Meanwhile, the pooled sensitivity and specificity obtained when the temperature measurements were taken at the forehead is 0.808 (95% CI 0.656-0.903) and 0.920 (95% CI 0.769-0.975), respectively. 8312 readings were obtained from the 11 thermal scanners with the pooled sensitivity and specificity of 0.818 (95% CI 0.758-0.866) and 0.923 (95% CI 0.823-0.969). From the study, it was observed that the use of NCIT and thermal scanners have their own reasonable sensitivities and specificities for the diagnostic of fever. From the study, it was also found that there are several factors that could affect the accuracy of the measurement for those using thermal scanners. One of them is environmental factors such as variation in the temperature, absolute temperature and relative humidity. NCITs devices were found not suitable to be used under direct sunlight or near radiant heat sources. In addition, there were also some factors which were related to screened subject that could lead to false negative readings such as application of make-up on the target area, the use of antipyretics or significant perspiration. Other than that, the rise in the hypothalamic set point which happened at the stage of fever initiation also can cause the cooling of the skin and lead to false negative reading for thermal scanners. Furthermore, these false negative readings also can be occurring for the subjects who are pregnant, menstruating or have recently hot or done strenuous physical activity.

While the technology of NCIT provides accurate temperature measurement with zero contact, the implementation may lead to long queues as the NCIT must be placed perpendicular (90°) to the surface of detection for accurate temperature measurement. In other words, the surface of detection must fill the field of view of the NCIT [18]. Addition to that, most NCIT are suitable for temperature measurement of stationary objects within short distances and the common distances is 15 cm [19], thus more appropriate to be used for indoor premises. The NCIT is not suitable to be used outdoor and not able to detect moving objects. As a result, the risk of COVID-19 transmission is much higher as the body temperature of those surrounding a person is unknown. The study by Nishant Aggarwal et al also indicates that although NCIT measurements were closely aligned for temperatures below 37.5°C, it may be an not be the most appropriate or safest device to use during a pandemic for mass fever screening [17]. Armote Somboonkaew et al also found that the forehead skin thermometer is not suitable for mass human screening in a large public area, despite the fact that it is convenient because it only takes a few seconds to complete the measurements and is limited to one person at a time [20].

Temperature monitoring for longer distances is available using thermal cameras. For example, the use of thermal cameras in airports to monitor the body temperature of incoming visitors. Although this may be an alternative for temperature monitoring of moving objects and in outdoor conditions, these thermal cameras are large, costly and unsuitable for use as a portable temperature scanner. A study by A. Bhargavi Haripriya et al implemented thermal cameras to identify regions in the feet with significant temperature difference, which is suitable to be used as a preliminary diagnostic tool for skin cancer detection, identifying diabetic foot ulcers, monitoring thyroid disorders and as fever screening. The low-cost, compact, portable and lightweight thermal camera can accurately measure the temperature distributions without any significant delays and does not require any model-specific software for analyzing and processing the image. The study shows that the cost of the current thermal camera increases with the resolution, due to the enhancements made in the computation power, computed-based algorithms and processing software [21]. Daniel Santoso et al also stated that most of the thermography systems are expensive and non-portable [10]. In their design an infrared thermometer, MLX90614 was incorporated to screen human body temperature. Additionally, to make the thermometer immune against ambient light and sunlight, an optical filter was added and an ultrasonic range sensor from Dt-Sense was employed to ensure that temperature was performed within proper distance.

Boris G.Vainer et al also used IR camera with a built-in InAd-based FPA detector as a basic measuring thermal imaging system. In addition, laser Doppler flowmetry (LDF) was used as the additional material for direct method of microcirculatory perfusion measurements and several means to monitor key cardiovascular activity indices [14]. Dongning Qu et al used a GridEye sensor which integrates 64 thermophiles sensor units in a form of 8 by 8 which can be used to detect moving and static targets [13]. Integration of internet of things (IoT) was also introduced in temperature monitoring systems where notifications were sent when high temperature was detected to the assigned mobile device via Global System for Mobile Communication (GSM) [19]. The system uses EmguCV cross platform for face detection process and provides the details of user’s history of visited places via Google Location History (GLH). Another design by Nenad Petrovic et al, used the python version of OpenCV which is an open-source computer vision for the implementation of mask detection and social distancing check algorithms as well as Message Queueing Telemetry Transport (MQTT) [9].

From the issues mentioned above, there is a need for an alternative innovation in the technology of temperature detection. Despite the benefits of similar works by others which are also wireless and portable, currently there are limited designs which are wearable. Thus, the paper proposes to innovate a wearable non-contact temperature detector which is portable and able to detect humans with high temperatures (>37.5°C) in both stationary and non-stationary conditions at longer detection distances and possibly outdoor. The scope of the project focuses on the non-contact temperature detection within one-meter detection distance. The proposed device will notify users via an alarm and alert message when high-temperature human is detected. The accuracy of the wearable non-contact temperature should be as closely possible to the actual temperature measurement when measured using a commercial NCIT device.

2. Methodology

The design of the non-contact wearable temperature detector consists of two parts: hardware and software. The main hardware in the design includes a thermal infrared sensor [22], a microcontroller, a Bluetooth module, and smartphone. The overall system uses Arduino IDE to execute the microcontroller for temperature scanning and MIT App Inventor to design the mobile application. Fig. 2 displays the hardware design of the wearable non-contact temperature detector. The system includes a thermal sensor that scans the human body temperature. The temperature reading from the sensor will be analyzed by the microcontroller, and the data will be transferred to the mobile apps via Bluetooth module, which serves as a wireless communication link between the microcontroller and the mobile apps. The mobile apps display the temperature reading as well as a thermal image with a resolution of 8 $\times$ 8 pixels.

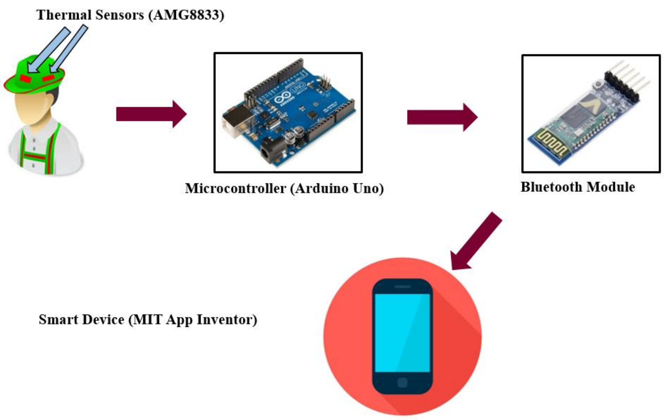

Fig. 2 - Architecture of the wearable non-contact temperature detector with thermal infrared sensor.

2.1 Design Process

The proposed design consists of a thermal infrared sensor which is placed on a hat at the front location and is connected to the Arduino Uno microcontroller. The AMG8833 is used is the design as it is found to be a commonly used and reliable sensor for a wearable non-contact temperature detection. The sensor scans the average temperature of the human body's skin surface. The thermal infrared sensor is an 8 × 8, 64 pixels infrared array sensor used to scan the temperature of the human body who is within one (1) meter from the user. It is able to detect objects between the temperature range of 0°C to 80°C with an accuracy of ± 2.5°C for up to 7 meters of object's distance (viewing angle of 60°). The temperature measurements will be processed and analyzed by the Arduino Uno microcontroller. The HC-06 Bluetooth module enables short-range wireless communication between the microcontroller and the mobile apps. The Bluetooth 2.0 communication protocol is used by the module as it is low in cost, allows flexible wireless transmission and able to transmit files at speeds of up to 2.1 Mb/s. The mobile apps will display the measured temperature readings and thermal image of the detected object, as well as generate an alert notification to notify the user when a high-temperature object is detected. The operating voltage range is between 3.3V to 6V and the operating temperature range is from -20°C to +55°C with an operating current of 40mA.

The Arduino IDE Software is used to execute and run the microcontroller. The software is used to run the entire process of analyzing temperature measurements as well as sending and receiving data to and from the mobile apps. Aside from that, the temperature measurements and calculated values can be viewed via the serial monitor for troubleshooting purposes, before connecting the microcontroller to the apps.

The MIT App Inventor platform is used to create the mobile apps. MIT App Inventor is a user-friendly, visual programming environment that enables the creation of a fully functional apps for smartphones and tablets. Its block-based tool enables the development of complex, high-impact apps in a short time compared to the traditional programming environments.

2.2 Operational Flow

Fig. 3 depicts the flowchart of the IoT embedded temperature detector system. Once the Temperature Scanner apps is launched, the Bluetooth module will connect the apps to the microcontroller. Upon connecting, the apps will send the value "1" to the microcontroller, which initiates the calculation for the average temperature of the detected object. The first step in determining the temperature of an object is to compute the average temperature of the GridEye sensor data array (64 data array) [13,22]. The GridEye Sensor works in tandem with the software to identify the number and position of object/subject based on their body temperature, resulting in an output in form of thermal data image and recognizes where appropriate distancing or density is or is not maintained [22]. The second step is to determine the ambient temperature (*AT*). Since the GridEye has a temperature accuracy of ±2.5 °C [22], temperatures which are out of the average temperature range by ±2.5 °C will be considered as targets, while the remaining temperatures are considered as background temperature. The average ambient temperature is determined by calculating the average values of all background temperature. The following step calculates the temperature difference ΔT as shown in equation 1 where T_0 is the temperature of measurement object and AT is the ambient temperature.

$$\Delta T = T_0 - AT \quad (1)$$

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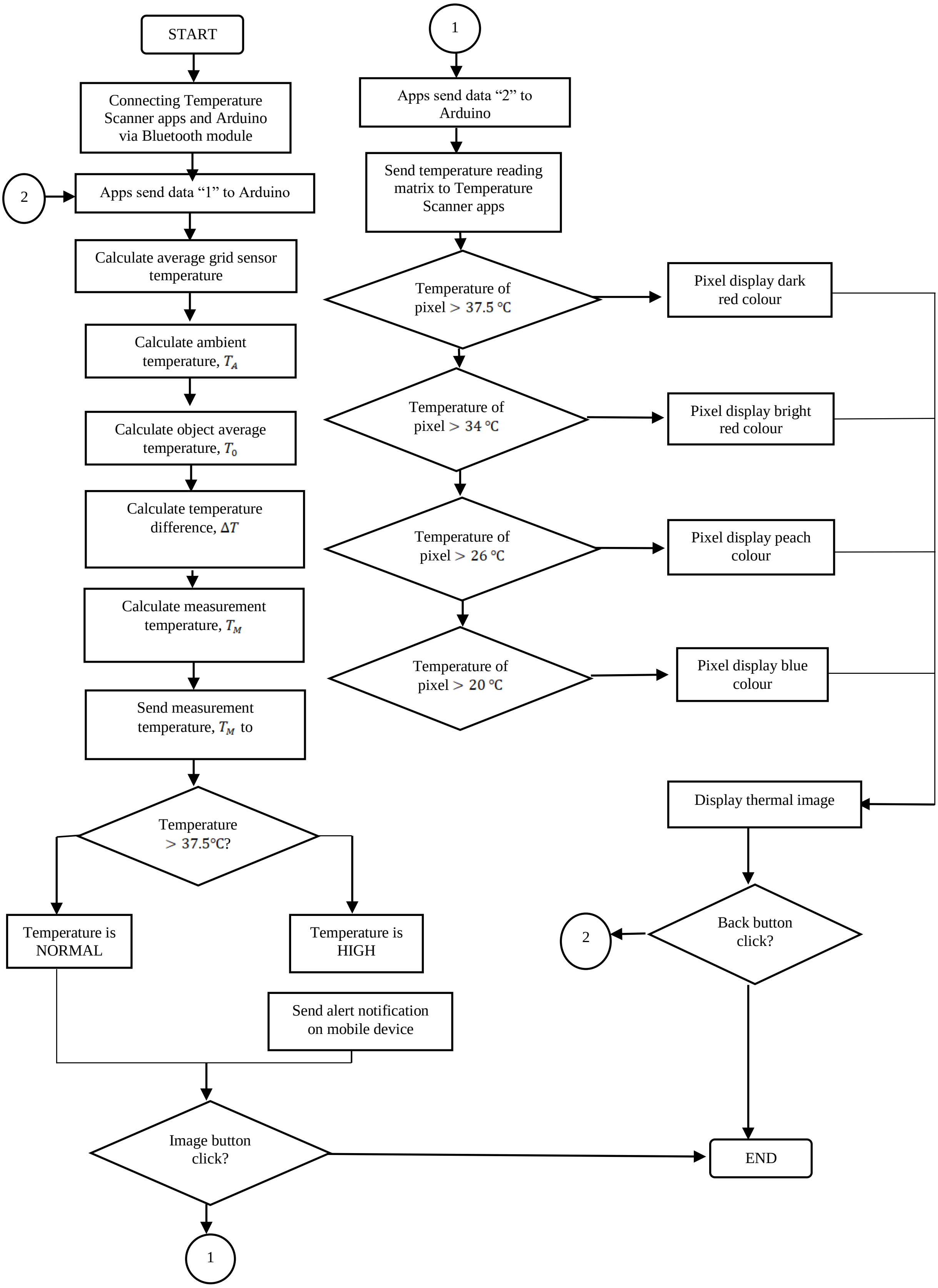


Fig. 3 - Operational flow of the IoT embedded temperature detection system.

The last step is to calculate the measurement temperature (*MT*) of the human target as shown in equation 2.

$$MT = AT + \Delta T * S_0/S_P \tag{2}$$

where S_0 is the size of infrared object and S_P is the size of GridEye sensor pixel.

The calculated temperature will be sent to the mobile apps and further compared with the set threshold to determine whether it is normal or high. The temperature threshold was set to 37.5 °C as it is the limit of human body temperature to declare as fever [21]. If the temperature is lower than the threshold, the apps will display "Temperature is NORMAL," otherwise it will display "Temperature is HIGH." The apps will generate an alert notification to notify the user that a human with high temperature has been detected. If the Image button is pressed, the apps will send the value "2" to the microcontroller, instructing it to send the temperature measurements matrix. The microcontroller will send the matrix to the apps once it has received the instruction represented by value “2” from the apps. Once the Temperature Scanner apps receives the temperature matrix, each temperature pixel will be analyzed. The thermal image has 64 temperature pixels as the AMG8833 sensor resolution is 8 × 8 resulting in a temperature matrix of 8 × 8 [22]. The image colours of each pixel will be displayed according to the range of temperature as shown in Table 1. If the pixels' temperature rises above 37.5 °C, the pixel on the thermal image will display dark red colour. If the temperature is less than 37.5°C but greater than 34°C, bright red colour will be displayed. The pixel temperature will turn to peach if the temperature is between 26°C and 34°C, else the pixel displays blue colour. The mobile application returns to the initial screen when the “Back” button is pressed; otherwise, the process is terminated.

Table 1 - Image pixel colour according to its temperature range

Temperature Range	Image Colour
> 37.5 °C	Dark Red
> 34.0 °C and < 37.5 °C	Bright Red
> 26.0 °C and < 34.0 °C	Peach
> 20.0 °C and <26.0 °C	Blue

2.3 Temperature Detection Accuracy - Experimental Setup

Several experiments were conducted to validate the temperature detection accuracy of the wearable non-contact temperature detector. Temperature measurements of the wearable device were compared to the temperature measurements obtained from a commercial NCIT device at different detection distances for both indoor and outdoor conditions (Table 2). The commercial NCIT is able to measure skin temperature from 32.0°C to 42.5°C with an accuracy of ± 0.3°C. Temperature measurement experiments were conducted on a human subject to test the ability of detecting normal human body temperature for ten (10) different distances (10 cm to 100 cm), in indoor and outdoor conditions. A similar experiment was conducted with a metal container holding hot water, to mimic high temperature of the human body. The ability of the system to detect high temperature objects for both indoor and outdoor conditions was tested, under the same 10 (ten) detection distances. Both types of experiments were repeated three (3) times for reliability purposes.

Table 2 - NCIT reference temperature reading for normal temperature & high temperature in indoor and outdoor conditions

NCIT Temperature	Indoor	Outdoor
Normal (normal human body temperature)	36.50 °C	36.70 °C
High (hot water in a metal container	41.50 °C	42.20 °C

The accuracy of temperature measurement was presented as percentage accuracy (%) by taking the ratio of the temperature measurement from the wearable device and the temperature measurement from the NCIT as shown in equation 3.

$$Accuracy = \frac{(NCIT\ Reading - Thermal\ Sensor\ Reading)}{NCIT\ Reading} \tag{3}$$

3. Results & Discussion

3.1 Device Operation

As shown in Fig. 4, a single thermal sensor was placed facing the front of the user. The microcontroller was installed at the bottom of the hat and wired to the thermal sensor.

(a) (b)

Fig. 4 - (a) Front view and; (b) bottom view of the wearable non-contact temperature detector

3.2 Mobile Application User Interface

The Temperature Scanner mobile application was designed to allow temperature monitoring via a mobile device, by displaying the temperature measurements and thermal image of detected objects. The followings are examples of the apps display at different process stages. Fig. 5 shows the Temperature Scanner icon on the mobile device home page. There are three (3) main screen displays; Screen 1 (in Fig. 6) is the app's loading page once it is launched, Screen 2 (in Fig. 7 (a) & 8 (a)) are the screen displays once temperature data is received from the microcontroller via Bluetooth module and Screen 3 (in Fig. 7 (b) & 8 (b)) display the thermal image of the detected object resulting from the received temperature measurement matrix.

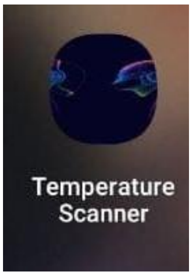
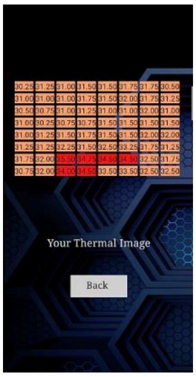


Fig. 5 - Temperature Scanner Apps icon

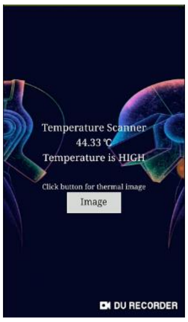
Fig. 6 - Temperature Scanner Apps loading page (Screen 1)

(a)

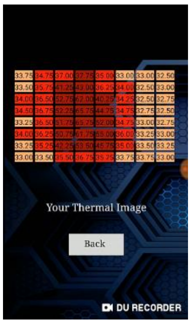


(b)

Fig. 7 - Example of normal temperature detection which displays (a) temperature measurement and 'Temperature is normal' in Screen 2 and the; (b) thermal image in Screen 3



(a)



(b)

Fig. 8 - Example high temperature detection which displays (a) temperature measurement and 'Temperature is high' in Screen 2 and the; (b) thermal image in Screen 3

Fig. 7 (a) and 8 (a) show the examples of the display on Screen 2 for normal temperature detection and high temperature detection, respectively. In both screens, the average temperature of the detected object and the notification text "Temperature is normal" or "Temperature is HIGH" are displayed. The thermal images for both normal and high temperature detection are shown in Fig. 7 (b) and 8 (b), respectively. The mobile apps generate an alert notification as well as a sound alarm for high temperature detection, as shown in Fig. 9.

Fig. 9 - Alert notification

3.3 Temperature Detection Accuracy - Experimental Results

Referring to Fig. 10, the wearable non-contact temperature detector was able to detect normal subjects with average accuracy ranging from 98.33 % to 99.94 % for indoor conditions with detection range between 10 cm to 100 cm. However, the accuracy of detection for normal subject was lower for outdoor conditions, ranging from 96.58% to 99.41 %. Table 3 presents the average temperature measurements acquired from ten (10) different detection distance for three (3) trials. The average percentage of accuracy for indoor and outdoor is 99.42 % and 97.68 %, respectively. The average temperature was calculated by adding all ten readings of difference distance and dividing by ten (10). The pattern of the temperature reading, as shown in Table 3, is in the 70 cm range; it continues to fluctuate in the same region of reading but abruptly decreases for distance more than 70 cm.

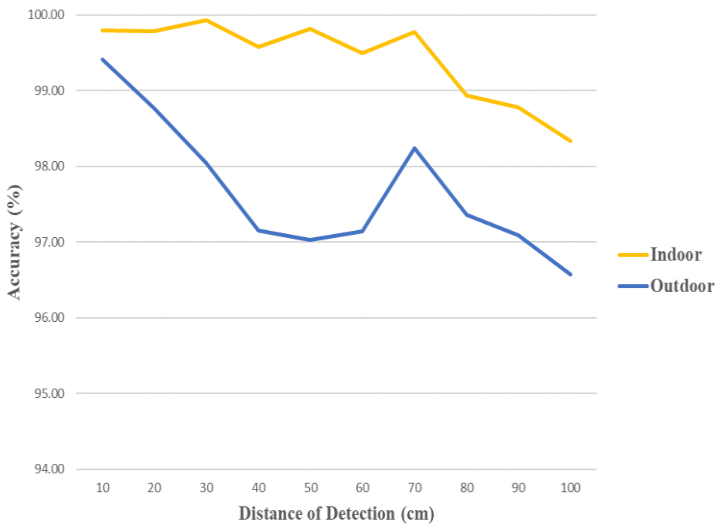


Fig. 10 - Accuracy of temperature measurement plots of normal human body temperature (average of three (3) trials))

Table 3 - Average normal human body temperature measurements & average measurement accuracy for indoor and outdoor conditions

Distance (cm)	Indoor		Outdoor	
	Temperature (℃)	Accuracy (%)	Outdoor (℃)	Accuracy (%)
10	36.51	99.80	36.92	99.41
20	36.54	99.78	37.15	98.78
30	36.50	99.94	37.42	98.05
40	36.65	99.58	37.74	97.16
50	36.50	99.82	37.79	97.03
60	36.66	99.50	37.75	97.14
70	36.50	99.77	36.06	98.25
80	36.11	98.94	35.73	97.36
90	36.06	98.78	35.63	97.09
100	35.89	98.33	35.44	96.58

Fig. 11 plots the average temperature measurements of three (3) high temperature trials that mimics high body temperature for human, for both indoor and outdoor conditions, for detection distance ranging from 10m to 100 cm. For indoor condition, the wearable device was able to detect high temperature objects with average accuracy ranging from 98.33 % to 99.87 %. The accuracy dropped between 96.52% to 99.69% when tested outdoor. The average percentage of accuracy for indoor and outdoor is 99.34 % and 98.10 %,

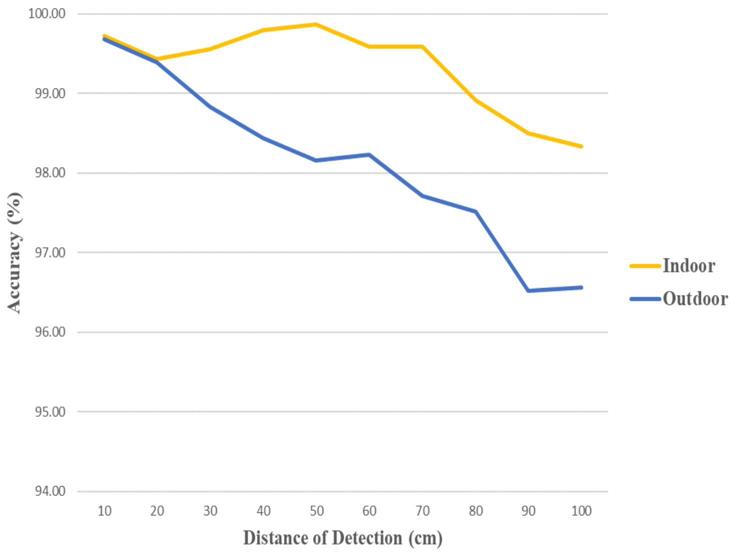


Fig. 11 - Accuracy of temperature measurement plots of high temperature (average of three (3) trials))

From the results, it is also found that the accuracy of the temperature measurement decreases in outdoor conditions for both normal and high temperature cases. This may be due to environmental factor that causes the difference in temperature measurements. When a person is outdoor, the body may absorb heat from the surroundings which results in increase of body temperature. Similarly, the body temperature decreases and gets cold when a person is in an air-conditioned room. Sweating can also have an effect which lead to the error of the temperature measurements due to its function that acts as a filter for the infrared radiation [11].

Table 4 - Average high temperature measurements & average measurement accuracy for indoor and outdoor conditions

Distance (cm)	Indoor		Outdoor	
	Temperature (℃)	Accuracy (%)	Temperature (℃)	Accuracy (%)
10	41.45	99.72	42.21	99.69
20	41.73	99.43	42.46	99.39
30	41.65	99.56	42.42	98.83
40	41.58	99.80	42.35	98.44
50	41.47	99.87	42.13	98.16
60	41.54	99.59	41.45	98.23
70	41.48	99.59	41.24	97.72
80	41.05	98.93	41.15	97.52
90	40.88	98.50	40.73	96.52
100	40.81	98.33	40.75	96.56

While indoor and outdoor conditions as well as detection distances may cause reduction in measurement accuracy, it is worth to note that there are other factors that rise the human body temperature and may cause false detection of a subject/an object actual temperature which is not actually fever. Age is one of the most fundamental factors influencing normal body temperature. The impact of age on body temperature is most noticeable in children and the elderly. Children have very high metabolic rates, which means their bodies convert food to energy at a much faster rate on average than adults. This also means that children have a higher baseline body temperature than adults [23]. Exercise or physical exertion may also contribute to the increase of human body temperature [23]. During strenuous physical activities, muscles generate a tremendous amount of heat, causing the body temperature to rise. The body attempts to dissipate excess heat in order to return to a normal state. However, there are times when the body is unable to cope with the increase in temperature and loses enough heat to keep the core temperature stable. The more work the muscles have to do; the more heat is produced. This may also cause false detection of the body temperature.

Stress also contributes to the increase of human body temperature [23]. When confronted with a stressful situation, the body's temperature rises. This rise in body temperature is mediated by stress hormones such as cortisol and adrenaline. This rise in temperature is the body's adaptive response to perceived threats. Adrenaline, which mediates the body's "fight or flight" response, increases heat production in the liver while also driving other adaptive changes. The liver, as one of the largest and most metabolically active organs in the body, has a significant impact on body temperature.

4. Conclusion

To address the need for an alternative innovation in the technology of temperature detection, a prototype of a wearable non-contact temperature detector was developed. The wearable device is portable and able to detect objects with high temperatures (>37.5°C) in both indoor and outdoor conditions with detection accuracy reaching up to 99.42% (indoor) and 98.10% (outdoor) from the actual measurement. It is able to provide real-time temperature data in every 1-2 seconds and integrated with a mobile application that allows easy temperature monitoring using a mobile device. The Temperature Scanner mobile application displays the temperature of the detected object and also the thermal image with resolution of 8 × 8 pixels. Alert notifications and alarm are generated to notify user when high-temperature objects are detected.

For further improvements, the accuracy of the system can be improved by using other types of thermal sensors with higher sensitivity (i.e: the MLX90640 thermal sensor which has higher resolution (32 × 24 pixels) compared to the AMG883 (8 × 8 pixels). There are also two options for the field of view: 55°x35° and 110°x75°. Another suggestion is to use four (4) thermal sensors to allow temperature detection from all direction (360° angle view).

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