Development of an Infrared Thermometer with SMS Feedback

[1]Nwaneri, Solomon Chiekezi, [1]Edozie, Chibogwu Adaeze and [1]Uregbulam, Ugochi Chinomso,
[1]Department of Biomedical Engineering, Faculty of Engineering, /university of Lagos, Akoka, Lagos. E-mail: snwaneri@unilag.edu.ng; +(234) 8035431589

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Abstract:
The non-contact infrared thermometer is an essential medical device in hospitals for measuring a patient's surface temperature while preventing the transmission of infection from one person to another. While taking such measurements, it is crucial for physicians to have the values sent to their mobile phones for reference purposes. The aim of this study was to develop an infrared thermometer with Short Message Service (SMS) feedback. The thermometer was built using an infrared sensor for contactless temperature measurement, a microcontroller for data processing, a liquid crystal display for user interface, and a GSM module to enable the transmission of SMS text alerts. The performance of the prototype was tested by comparing temperature readings against a commercially available certified infrared thermometer across 20 adult subjects in a controlled setting. The results showed strong correlation (R=0.976) between the readings from the developed thermometer and reference device, demonstrating comparable clinical accuracy in detecting temperature fluctuations. However, a small fixed bias of 0.2- 0.4°C was observed in the prototype readings due to calibration differences. Overall, this study successfully demonstrated a proof-of-concept infrared thermometer integrating contactless sensing and wireless transmission of temperature data via SMS. The prototype achieved accuracy comparable to commercial thermometers, indicating feasibility of creating a low-cost, mobile-connected infrared thermometer using this approach.

Keywords: Infrared sensor, Infrared thermometer, Surface temperature measurement

1. INTRODUCTION

BODY temperature is an important vital sign that is often measured to determine the state of health of a patient [1]. Precise temperature monitoring is a critical requirement across a wide range of applications, ensuring accuracy, safety, and operational efficiency. However, conventional temperature measurement methods often fall short when it comes to providing real-time feedback. This limitation becomes especially apparent in situations requiring continuous monitoring. The need for more precise and responsive temperature monitoring forms the bedrock for the design and development of an innovative infrared thermometer with SMS feedback capabilities. An infrared thermometer is an advanced non-contact temperature measurement device that uses infrared technology. The infrared thermometer can measure temperature by detecting the infrared radiation emitted by an object, converting it into a temperature reading. Infrared thermometers detect infrared radiation from a surface and convert the radiation to temperature based on the emissivity of the object [2].

Infrared thermometers have become increasingly popular in recent years among consumers and healthcare providers due to their utility and ease of use [3]. Applications range from fever monitoring, evaluating industrial equipment, monitoring food temperature, to advanced scientific uses. With advanced optics and electronics, modern infrared thermometers can accurately measure temperature from a close distance [2]. The provision of Short Message Service (SMS) feedback adds a new dimension to the utility of this advanced thermometer. This feature allows users to receive immediate alerts via SMS, ensuring that they are promptly informed of any temperature variations.

One promising application of the smart infrared thermometer, which has the potential to revolutionize healthcare by providing non-contact temperature measurements and real-time data transmission through SMS. This opens new potential applications in areas such as patient health tracking, public health surveillance for diseases, and workplace environmental monitoring for safety. This study draws attention to the limitations of traditional temperature measurement methods and highlights the potentials of SMS. By designing and developing an innovative smart infrared thermometer with SMS alert capabilities, the project aims to enhance temperature monitoring accuracy, responsiveness, and automation across various domains, contributing to improved outcomes, safety, and operational efficiency. This feature ensures that healthcare providers are promptly informed of any changes from the desired temperature range, allowing them to take swift actions. The traditional methods of temperature measurement, involving the use of oral, axillary, or rectal thermometers, necessitate direct contact with the body. This gives rise to issues of inconvenience, discomfort, and the potential infection risk. Additionally, these methods lack the capability for data monitoring and analysis, thereby limiting the capacity to promptly detect and respond to abnormal temperature variations. Moreover, the manual recording and tracking of temperature data is prone to errors and delays, hindering effective temperature management in healthcare, public safety, and industrial settings. This is especially critical in situations where prompt action is required to prevent the spread of infectious diseases, ensure workplace safety, or provide timely medical interventions.

Also, the lack of connectivity and remote monitoring capabilities restrict the ability to collect and analyze temperature data. Thus, there is a pressing need for an innovative solution that overcomes the limitations of traditional temperature measurement methods. This solution should provide accurate and non-invasive temperature measurement, enable data monitoring, and offer remote access and connectivity for seamless integration with existing systems. By addressing these challenges, a smart infrared thermometer with SMS feedback can significantly enhance temperature monitoring practices and contribute to improved public health, safety, and overall well-being. Furthermore, despite advancements in healthcare technology, conventional thermometers remain prevalent, and the full potential of a smart infrared thermometers is yet to be explored. The lack of affordable, accessible, and user-friendly smart infrared thermometers utilizing SMS for communication presents a significant gap in healthcare applications. Addressing this issue can not only improve temperature monitoring but also contribute to better disease control and public health.

The aim of this study is to develop a smart infrared thermometer capable of sending temperature readings through SMS for remote monitoring. The specific objectives of this study are to:

1. Design the CAD and schematic diagrams for the infrared thermometer
2. Fabricate the smart infrared thermometer.
3. Integrate SMS-based communication.
4. Evaluate the performance and reliability of the device.

Traditional temperature measurement techniques are known to have some limitations including the inability of the temperature readings taken at home or other locations to be remotely transmitted to the consulting physician. Traditional thermometers, such as mercury or digital thermometers, require direct contact with the body to obtain temperature readings. While these methods have been widely used, they have certain limitations, including inconvenience, discomfort, and potential infection risks [4]. However, advancements in technology have led to the development of smart infrared thermometers, which offer non-invasive temperature measurement. These thermometers utilize infrared technology for their operations. This innovative approach has revolutionized temperature measurement practices, providing accurate and hassle-free solutions for various applications, including healthcare, public safety, and industrial settings.

Due to the widespread use and prevalence of text messaging, or SMS, this technology has become a major focus for healthcare researchers and providers [5, 6, 7, 8]. Key advantages of SMS include its adaptability, cost-effectiveness, automated delivery, and overall acceptability. Major healthcare organizations like the American Medical Association and World Health Organization recommend utilizing SMS for health interventions [9]. Integrating SMS capabilities into an infrared thermometer provides a cutting-edge approach for enhancing temperature monitoring and healthcare management. This innovative integration empowers both patients and providers by enabling real-time temperature data transmission and alerts via ubiquitous text messaging.

II. LITERATURE REVIEW

A number of studies have designed a non-contact infrared thermometer. For instance, Guangli [10] designed a non-contact infrared thermometer designed specifically for infants and young children. The limitation of the device is its inability to remotely transmit the results. Usamentiaga et al. [2] provided a comprehensive review of infrared thermography for non-contact temperature measurement and defect detection. It covers underlying principles, factors influencing accuracy, applications in medicine and industry, and the evolution of infrared cameras and analytical methods. The rapid advances have expanded infrared thermography's versatility as a temperature and testing tool across domains. Also, Ghassemi et al. [11] developed a thermometer prototype enabling wireless temperature monitoring and SMS alerts. It combines precise non-contact thermal sensing with Arduino processing, radio communication, and cellular messaging. Testing showed excellent agreement with a reference thermometer. This demonstrates an effective approach to create a smart, connected thermometer for remote healthcare applications. Likewise, Yamanoor et al., [12] designed a low-cost open-source non-contact thermometer as an innovative device during the COVID-19 pandemic as alternative to the traditional thermometer to prevent the transmission of COVID-19 from one person to the other. They utilized the AMG8833 thermal imaging sensor that detects the infrared radiation and processed the detected signals using Raspberry Pi.

Bhattacharjee et al. [13] developed an Arduino-based contactless thermometer prototype optimized for accuracy and cost. It uses an infrared sensor for non-contact temperature measurement and an ultrasonic sensor for distance sensing. A distance compensation algorithm was implemented to improve accuracy. Testing showed the prototype achieved high accuracy comparable to clinical thermometers when measuring human forehead temperature at calibrated distances. Tanjung et al. [14] designed a non-contact thermometer using an Arduino, infrared sensor, display, and GSM module for SMS alerts. Testing on participants showed high accuracy comparable to a thermogun. It effectively measured body temperature from a distance and sent SMS notifications when predefined thresholds were exceeded, showcasing utility for remote fever monitoring.

Most of the non-contact infrared thermometers were developed using MLX9014 sensor [15 – 22]. Some of the developed non-contact infrared thermometers were IoT based [15, 17] while others were not [16]. While there were slight differences in the temperature range measured by the thermometers in the various studies, -70°C to 380°C was generally reported [16, 17, 18]. Some of the thermometers included alarms to alert users if the temperature being measured exceeds a predefined temperature [15]. A variety of microcontrollers were used to implement the non-contact thermometers in previous studies including Arduino Nano [19, 22] and Arduino Uno [16]. Benjamin et al. [17] developed a digital thermometer with a clock using an ATmega328P. Precise temperature monitoring is important for patients' well-being. The inability to identify and address sudden spikes or drops in body temperature can lead to critical situations. Therefore, by leveraging advancements in infrared technology, the aim is to create a device that offers accurate temperature measurements while being easily transportable, thereby making it more accessible across several healthcare settings. The integration of SMS feedback into the smart infrared thermometer can revolutionize the aspect of temperature monitoring. Through this, the system can provide temperature readings in real-time without requiring continuous human supervision. This characteristic has its advantages, especially in situations where consistent and prompt data collection is crucial for informed decision-making and timely response. Furthermore, the inclusion of SMS alerts enhances the system's functionality by facilitating immediate notifications to healthcare providers in cases of temperature irregularities. This study focused on creating a functional smart infrared thermometer suitable for healthcare applications in various environments. Specifically, this paper describes the design and development of a compact and portable smart infrared thermometer, the integration of SMS-based communication and the evaluation of the performance and reliability of the device. Ethical approval for the study was obtained from the Health Research and Ethics Committee (HREC) of the College of Medicine, of the University of Lagos with ethical approval number CMUL/HREC/10/23/1301.
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III. METHDOLOGY

This study adopted a user centered research methodology by ensuring that the design is suitable for users of the device.

A. Materials

The device was designed and implemented with several electronic components including a medical grade infra-red thermopile sensor (MLX90614ABB), quad-band GSM/GPRS module (SIM800L), ATmega328P, a low dropout linear voltage regulator (MIC29159-3), ON/OFF power switch, a button switch, 5V laser diode, and light emitting diodes (LEDs). Various values of capacitors, resistors and transistors, 1N4007 diode, 5V voltage regulator, and PCB copper plate.

The MLX90614ABB is an infrared thermopile sensor that contains an array of infrared-sensitive thermocouple junctions that can detect the infrared energy passively emitted from an object without any physical contact. By precisely quantifying the infrared energy wavelength and intensity, the MLX90614ABB can determine the object's temperature. A key advantage of the MLX90614ABB is its wide temperature measurement range from -40 to 125 ˚C for the ambient temperature and -70 to 382.2 ˚C for the object temperature. The sensor has a fast refresh rate of 0.5 Hz to quickly capture temperature fluctuations. Its low power consumption allows integration into compact battery-powered devices [15].

The well-known 8-bit ATmega328P microcontroller, a low-power CMOS microcontroller was programmed to enable it interpret the signals received from the temperature sensor. The MIC29159-3 is a low dropout linear voltage regulator capable of providing a stable, accurate 3.3V DC output from a wide input voltage range down to 3.6V.

The SIM800L, a quad-band GSM/GPRS module provides seamless connection of the infrared thermometer to cellular networks. Power consumption of SIM800L is quite low and it supports frequencies in the range of 850/900/1800/1900MHz.

A 5V laser diode is a laser module that emits a laser beam when supplied with 5 volts of electrical power. These diodes are used in applications such as laser pointers, laser engravers, and distance measurement devices.

B. Device Modeling and Simulation

There is a relationship between an object's temperature and the amount of energy it emits. The Stefan-Boltzmann law describes this mathematical relationship showing the power emitted by a black body as shown in equation 1:

$$P = \sigma \times \varepsilon \times A \times T^4 \quad (1)$$

Where, P = Power emitted in Watts
σ = Stefan Boltzmann constant($5.67 \times 10^{-8} \mathrm{Wm^{-2}K^{-4}}$)
ε = Emissivity of the project
A = Surface area emitting radiation
T = Absolute temperature in Kelvin

For an infrared thermometer, based on the Stefan-Boltzmann law, the amount of infrared radiation emitted by an object is related to its temperature which is detected by the infrared thermometer. The behaviour of an infrared thermometer can be described based on the Stefan-Boltzmann law, by making T the subject of the equation as shown in equation 2.

$$T = \left(\frac{P}{\sigma A}\right)^{1/4} \quad (2)$$

This study primarily involves medical device design and was conducted in three stages including prototype development, software development and device testing.

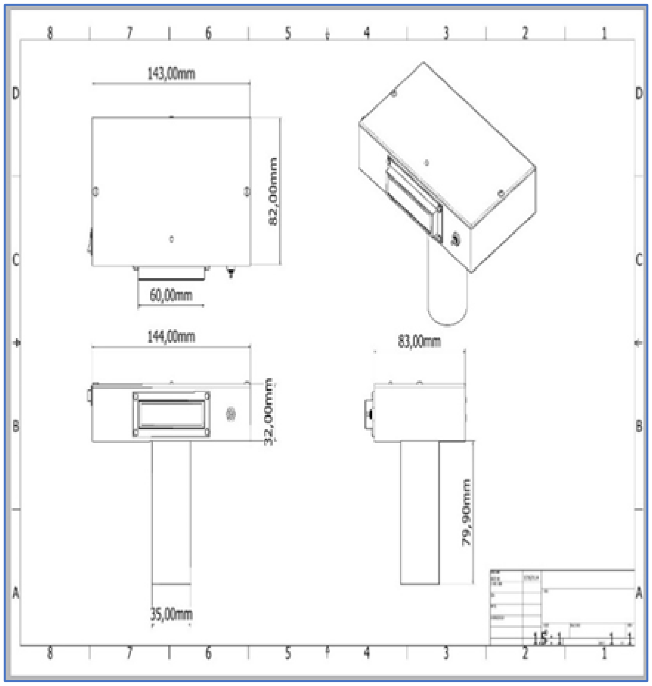


Fig. 1: CAD design of the device

C. Device Design and Implementation

Computer Aided Design of the device was done using inventor software. The device was designed to have two sections: The body and the holder. The body houses the circuit board and all the components. While the holder is attached to the body. The holder is where the user holds to measure his temperature or that of someone else. The body of the infrared thermometer has a dimension of 144 mm × 83 mm × 32 mm as shown in Figure 1. The design also makes provision for an LCD screen placed at the centre of the body with a dimension of 60 mm × 16 mm. The front view of the device is shown in Fig. 2. While Figure 3 shows the top view of the device. The holder has a height of 79 mm and a diameter of 35 mm.

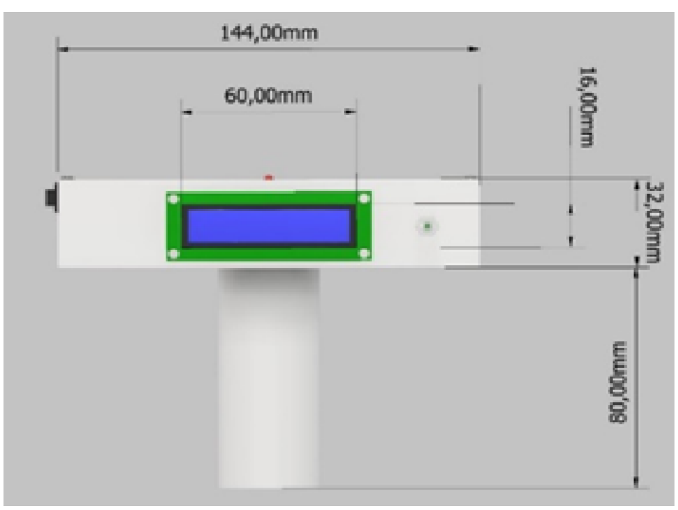


Fig. 2: Front view of 3D CAD design of the infrared thermometer

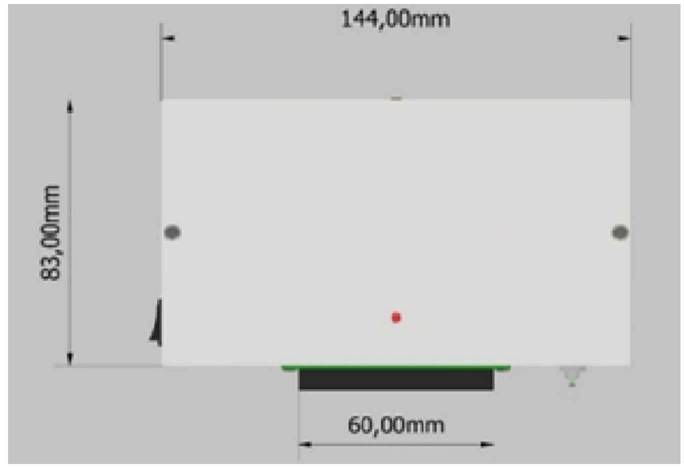


Fig. 3: Top View of the 3D Design

The various electronic components were assembled in the housing of the device based on the circuit design. Figure 4 shows the functional block diagram of the infrared thermometer. The thermometer consists of an infrared temperature sensor that reads temperature measurements in seconds by pointing at a body part. The thermometer has a sleek, compact rectangular design that makes it easy to hold and transport. The thermometer's small box shape fits neatly in the palm of the hand or a pocket or purse. The exterior is made of smooth plastic providing both durability and a smooth appearance. On one side it spots the switch and the push button for easy operation while at the other end the infrared sensor is equipped with a laser for accurate temperature measurement. Inside the thermometer's plastic housing are the electronic components including a microprocessor. This microprocessor serves as the brain of the thermometer, swiftly calculating the temperature and then sending this vital information via SMS, ensuring that user's healthcare provider can promptly access and analyze your health status from anywhere.

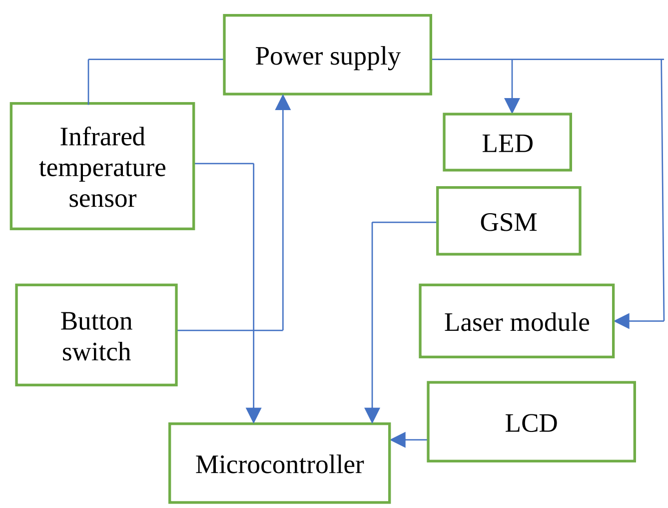


FIG. 3: BLOCK DIAGRAM OF THE INFRARED THERMOMETER

At the core of this thermometer's functionality is the principle of infrared temperature measurement. All objects emit a certain amount of infrared radiation based on their temperature. The user interface of this thermometer typically includes a simple button or switch to initiate temperature measurement. When the user presses this button, the thermometer follows a sequence that encompasses capturing infrared radiation, processing the data, and finally, sending an SMS if the alarm threshold is exceeded.

The infrared thermometer employs an infrared sensor, MLX90614, a critical component of this thermometer which specializes in capturing and converting this radiation into electrical signals. It is designed to detect infrared radiation emitted by objects or a person's body. This sensor contains a low-noise amplifier, a 17-bit analog-to-digital converter (ADC), and a powerful digital signal processing (DSP) unit. Its wide temperature measurement range of -40°C to +125°C and high resolution of 0.01°C ensure precise and reliable readings. After capturing the incoming infrared radiation, the MLX90614 sensor processes this data and converts it into a digital signal. This digital signal contains information about the object's temperature, which is then sent to the microcontroller for further processing.

The Atmega328pu microcontroller, which functions as the brain of the thermometer receives the digital temperature data from the sensor and carries out several vital functions. First, the microcontroller collects and manages the temperature data from the sensor. Also, the microcontroller is programmed to transmit temperature data via SMS to a designated recipient. To accomplish this, the microcontroller is connected to a mobile communication module. When a user initiates a temperature measurement, the microcontroller processes the data, composes an SMS message containing the temperature reading, and provides recipient information. The wireless communication module is a fundamental component enabling SMS feedback. It facilitates hardware and software interfaces for sending SMS messages over a cellular network. The microcontroller interacts with this module to compose SMS messages and directs it to send the messages to the patient and healthcare providers. When temperature reading is taken, the microcontroller processes the temperature data, formats it, and creates an SMS message. This SMS message contains the temperature reading, as well as supplementary details such as the date and time of measurement. The mobile communication module then utilizes the SIM card and the cellular network to transmit this SMS message to the recipient's specified phone number.

When powered on, the thermometer initiates a boot up sequence under the control of the microcontroller unit (MCU). This involves initializing the MLX90614 infrared thermopile sensor, SIM800L GSM module, OLED display, and other components. After boot up completes, the main application firmware on the MCU begins operating in an infinite loop. It first acquires temperature readings from the MLX90614 sensor over the I2C bus when the push button is pressed. The MCU applies calibration algorithms to the raw sensor data to derive accurate temperature values. The compensated temperature readings are shown on the LCD display for user viewing. The MCU composes an SMS alert message containing the current temperature reading. This SMS is sent to a predefined mobile number using the GSM module. This sequence allows the thermometer to autonomously measure temperature, display readings, send alerts when thresholds are exceeded, respond to SMS data requests, and notify users about low battery condition while running on battery power. The integration of the infrared sensor, MCU, display, and cellular module enables continuous remote temperature monitoring with real-time SMS feedback.

After the SMS feedback was integrated in the smart infrared thermometer, it was able to measure temperature without making contact with the body of the person being measured while still able to temperature reading as SMS to a registered mobile phone . Figure 4 shows the developed infrared thermometer being tested.

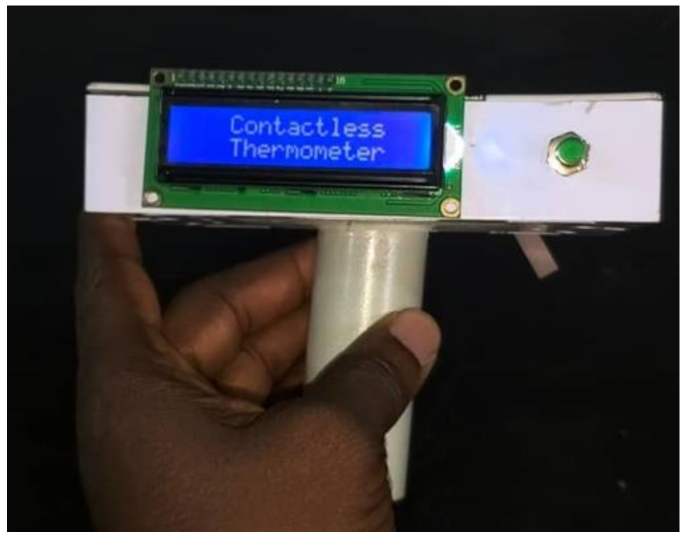


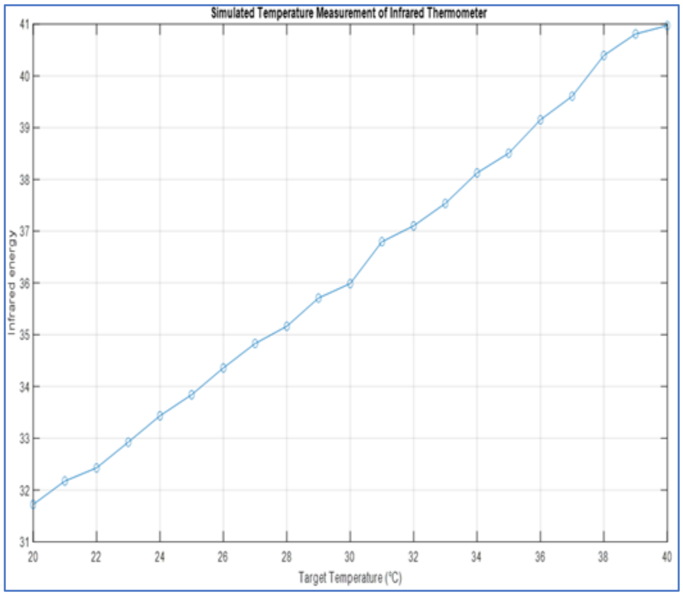
Fig. 4: The infrared thermometer during development

The device was tested to determine its functionality by taking measurements on 5 persons. The maximum field of view of the thermometer is 90º.

IV. RESULTS AND DISCUSSION

The modelling and simulation result that reveals the relationship between the target temperature and the infrared energy is shown in Figure 3. An increase in the target temperature is followed by a corresponding increase in the infrared energy. At a temperature of 20ºC, the infrared energy was about 30J. While at 30ºC, the infrared energy increased to 36J. The implication of this result is that at higher temperatures, higher infrared energies are emitted. The phenomenon of black body radiation clearly explains the relationship between energy and temperature. With increased temperature, a body emits a higher degree of radiation.

Furthermore, experiments were conducted to evaluate the accuracy of the thermometer by comparing its temperature measurements against a commercially available certified standardised infrared thermometer (ST) with a specified accuracy of ±0.2°C. An initial test was done by placing the thermometer at 5 cm, 10 cm, 15 cm, 20 cm, 25 cm, 30 cm and 30 cm from the forehead of the user.



The device was tested by measuring the temperature of both thermometers at various distances as shown in Table 1.

Table 1: Readings of proposed device versus Kinlee infrared thermometer

Distance (cm)	Temperature (ºC) (Proposed device)	Temperature (ºC) (Kinlee Infrared Thermometer)
5	38.67	36.7
10	37.35	36.5
15	36.93	36.4
20	36.39	36.4
25	36.63	36.3
30	36.77	36.3
35	36.31	36.2
40	36.19	36.1
45	36.59	36.1
50	36.39	36.0

Pearson correlation coefficient of 0.8385 was obtained which indicates a strong association between measurements of both thermometers.

The forehead was chosen as the measurement site because of its regular use in clinical practice for non-invasive body temperature assessment. Testing was performed indoors to control the environment. The results showed strong agreement between the DTP and ST thermometer readings, indicating comparable performance. Across the various measurements, the difference between the DTP and ST measurements ranged from 0.1°C to 0.4°C. Importantly, the DTP exhibited a small but consistent positive bias relative to the ST, with the DTP reading slightly higher than the ST for every subject.

The calculated correlation coefficient (R) between the DTP and ST temperatures was 0.976. This high R value close to 1 indicates a very strong positive linear relationship between the DTP and ST temperatures. The coefficient of determination (R2) was 0.953, meaning approximately 95.3% of the variation seen in DTP temperatures can be attributed to changes in the ST temperatures. This implies no significant different in the performance of both devices. The consistently higher DTP temperatures signify the presence of a fixed bias, likely originating from calibration differences between the thermometers. The tight correlation suggests this bias stem from a systematic offset rather than random errors. Further refinement of the calibration algorithm and parameters during the DTP's development could help eliminate this small positive bias.

In addition to correlation analysis, a paired t-test was conducted to statistically evaluate whether the mean difference between the DTP and ST readings was significant. The calculated t-statistic came out to 2.9656. With 20 paired observations, the critical t-value from reference tables was 1.686. Since the calculated t-statistic exceeded the critical value, we can conclude that the temperature measurements from the DTP and ST were statistically significantly different. Goh et al. [19] tested their prototype against oral thermometer measurements and found temperature differences within ±0.29°C when used properly, indicating clinical accuracy. The current study similarly found strong agreement with a reference thermometer, with 0.2 - 0.4°C differences.

Like the present study, Bhattacharjee et al., [10] reported a strong linear relationship (R2 = 0.998) between their device and standard device at calibrated distances, affirming accuracy. Tanjung et *al.* [14] also successfully demonstrated non-contact fever measurement capability within 0.1°C of reference devices. The small consistent positive bias of 0.2-0.4°C observed here has also been noted in other infrared thermometer studies. Zhang [17] found a similar bias attributed to calibration differences. Benjamin et al. [18] demonstrated a strong correlation despite a minor fixed offset between their device and commercial infrared thermometers.

Overall, the testing methodology, statistical analysis, performance metrics, and findings closely align with multiple prior studies evaluating prototype infrared thermometers. The results obtained here reinforce the conclusions of earlier works regarding the feasibility of developing highly accurate yet affordable infrared thermometers using this design approach. Ongoing refinements to calibration and testing will further improve consistencies with established clinical thermometers.

This study offers several benefits, including enhanced temperature monitoring, remote accessibility and efficient data management. The device is non-invasive and very safe. Risk is minimal. The device is powered by a 9 V battery which is very safe. This study is one of few studies that developed a smart infrared thermometer capable of sending temperature readings through SMS for remote monitoring. The utility of the thermometer is enhanced by its instant messaging functionality necessary not only in hospitals but also in other important places such as banks, airports and event centres. At airports, for instance, the use of our newly developed device in checking immigrants at entry points will help in preventing the spread of infectious diseases from one country to the other. This is particularly needed during periods of epidemic and pandemic outbreak like the COVID-19 pandemic. Also, the smart infrared thermometer will be of immense benefit to physicians and nurses in monitoring the surface temperature of patients in intensive care unit of hospitals. The smart infrared thermometer has a good potential for use in telehealth care with possible reduction in cost and inconvenience. With this device, the consulting physician can remotely monitor a patients' health condition and directly get the actual temperature reading without asking patients for the values.

Future studies may consider integrating artificial intelligence (AI) into the thermometer for predictive and trend analysis of measured temperature. The integration of AI in medical devices can significantly enhance their performance. With the integration of AI into an IoT enabled infrared thermometer, remote monitoring of the thermometer to determine abnormal patterns and trends could be established.

II. Conclusion

The advancement from traditional thermometers to smart infrared thermometers with SMS feedback has revolutionized temperature measurement practices. These smart thermometers offer non-invasive and accurate temperature measurement, enabled by infrared SMS technology. The newly developed infrared thermometer integrated with SMS feedback performed to clinical accuracy. Ongoing calibration refinements can eliminate a small fixed bias. This device demonstrates the feasibility of creating an accurate, mobile-connected infrared thermometer using lower cost design and development approaches. Based on the good performance of the developed infrared thermometer, indicating strong correlation with standard device, it is pertinent to note that while a strong correlation is good, the highest level of accuracy in healthcare ought to be maintained. Future studies will consider the use of additive manufacturing in improving the aesthetics of the prototype. The infrared thermometer will also be investigated in situations involving various age groups, medical conditions, or industrial processes to evaluate its adaptability and accuracy.

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