

Design, Development, and Performance Evaluation of a Solar-Powered Infrared Thermometer for Sustainable Healthcare Applications

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Abstract— This paper presents the design and development of a solar-powered infrared thermometer, aimed at providing an accurate, portable, and sustainable solution for healthcare applications. The system integrates key components such as an infrared temperature sensor, microcontroller, OLED display, motion sensor, buzzer, solar panel, rechargeable lithium-ion battery, and charging module. The device operates on the principle of non-contact infrared thermometry, whereby emitted thermal radiation is converted into temperature readings. A solar panel was incorporated to ensure continuous power supply, eliminating dependence on disposable batteries and reducing environmental impact. The software, developed using the Arduino Integrated Development Environment (IDE) with C/C++ programming, performed tasks including sensor initialization, data acquisition, calibration, display management, power optimization, and error handling. Prototyping was first carried out on a breadboard and later transferred to a permanent Printed Circuit Board (PCB) layout, with the components housed in a compact, lightweight enclosure designed for durability and ease of use. Testing and evaluation were conducted in three phases: unit testing of individual components, system testing under varying environmental conditions, and performance evaluation against calibrated reference thermometers. Results showed that the thermometer produced stable, accurate, and reliable temperature readings, with a maximum deviation of $\pm 0.1^{\circ}\text{C}$ from a standard reference thermometer, while maintaining energy efficiency through low-power components and sleep modes. The project demonstrates that renewable energy can be effectively combined with modern sensing and embedded systems. The developed device offers a cost-effective, eco-friendly, and practical alternative to conventional thermometers, with strong potential for application in rural healthcare delivery, community health programmes, and other non-contact temperature-measurement needs.

Keywords— Solar energy; Infrared thermometer; Non-contact temperature measurement; Embedded systems; Sustainable healthcare; Renewable energy; Microcontroller.

I. INTRODUCTION

Temperature measurement is one of the most essential parameters in science, engineering, agriculture, medicine, and industrial operations. Accurate temperature readings are critical for ensuring product quality, process safety, and effective decision-making across diverse sectors. Traditionally, thermometers relied on contact-based techniques such as mercury-in-glass thermometers, thermistors, and thermocouples. While these devices have been widely used for decades, they present notable drawbacks, including slower response time, risk of contamination, mechanical fragility, and challenges in measuring moving or hazardous objects (Li et al.,

2021). With technological advancement and the demand for safer, faster, and more reliable measurements, infrared (IR) thermometry has gained increasing relevance. Infrared thermometers operate on the principle that all objects above absolute zero emit infrared radiation proportional to their temperature. By detecting and converting this emitted radiation into electrical signals, IR thermometers provide accurate surface-temperature readings without physical contact. This non-invasive feature has made IR thermometers indispensable in healthcare (fever detection), agriculture (soil and crop monitoring), food safety, environmental monitoring, and industrial quality control (Mousavi et al., 2021). In parallel, the growing global emphasis on sustainability and renewable energy has driven the integration of solar power into technological innovations. Solar energy is abundant, environmentally friendly, and increasingly affordable, making it an ideal energy source for portable, low-power devices. A solar-powered infrared thermometer represents an innovative convergence of renewable energy and digital sensing technologies. Such a design reduces dependency on disposable or rechargeable batteries, lowers operational costs, and enhances usability in rural or resource-constrained areas where electricity supply is unreliable (Adekunle & Olawale, 2022). The COVID-19 pandemic further amplified the critical role of infrared thermometers in public health. They were extensively deployed for non-contact mass screening in schools, workplaces, airports, and healthcare facilities to minimize physical contact and reduce the spread of infections. However, their widespread use exposed practical challenges, particularly the reliance on disposable batteries and the associated maintenance costs. In low-resource regions such as Nigeria, frequent battery replacement became both a financial and logistical burden (Okeke & Eze, 2023). Integrating solar energy into infrared thermometers therefore offers a sustainable, cost-effective, and eco-friendly solution that ensures continuous operation even in areas with weak health infrastructure or unreliable electricity access. Thus, the development of a solar-powered infrared thermometer addresses both technological and societal needs. On one hand, it improves energy efficiency and environmental sustainability by reducing e-waste from discarded batteries; on the other, it strengthens healthcare capacity in emerging economies by ensuring reliable, accessible, and affordable temperature measurement. Accurate and reliable temperature measurement is indispensable across

healthcare, industrial, agricultural, and scientific applications. The advent of infrared thermometers has addressed several limitations of conventional contact-based thermometers by enabling fast, hygienic, and non-contact temperature measurements. However, despite these advantages, conventional infrared thermometers remain constrained by their dependence on disposable or rechargeable batteries as their primary power source (Mousavi et al., 2021).

II. LITERATURE REVIEW

One of the most widely adopted solar-powered medical technologies is the vaccine refrigerator. These devices are essential for maintaining the cold chain, ensuring that vaccines remain potent even in remote areas; the World Health Organization and UNICEF have promoted solar direct-drive refrigerators in Africa and Asia, where unreliable electricity poses a major challenge to immunisation programmes, and such innovations have significantly improved vaccination coverage rates. Beyond refrigeration, solar energy has also been applied to sterilisation units, diagnostic kits, and water-purification systems used in healthcare settings. Solar-powered autoclaves provide sterilisation for surgical instruments in rural clinics, reducing infection risk, while portable diagnostic kits powered by solar panels allow healthcare workers to test for conditions such as malaria, HIV, and tuberculosis in field settings. In addition, solar-powered telemedicine devices increasingly support digital healthcare initiatives by integrating solar panels with communication technologies, enabling health workers in remote locations to connect with specialists in urban centres. Extending solar technology to infrared thermometers represents a logical next step in sustainable medical innovation: by embedding small solar panels into these devices, healthcare providers can ensure continuous operation while reducing battery waste, improving efficiency and aligning with global sustainable-healthcare goals. The environmental benefits of solar-powered medical devices are equally important. Unlike disposable batteries, which contain harmful chemicals such as lead and mercury, solar energy eliminates hazardous-waste generation, contributing to cleaner healthcare environments and a reduced ecological footprint. The design of an infrared thermometer (IRT) requires careful attention to the selection and integration of components to ensure accuracy, efficiency, and user-friendliness. At its core, the device relies on an infrared sensor that detects radiation naturally emitted from an object or human body and converts it into an electrical signal for processing. The sensitivity, response time, and calibration of this sensor directly determine the accuracy and reliability of the thermometer (Yilmaz et al., 2021). Adebayo and Yusuf (2021) developed a solar-powered blood pressure monitor that proved highly beneficial in rural healthcare centers lacking dependable grid supply, demonstrating that solar integration in diagnostic tools could improve patient monitoring and expand primary healthcare reach in off-grid communities. Ezech et al. (2022) developed and tested solar-powered sterilization units in Nigerian hospitals and clinics, reducing dependence on costly and environmentally harmful diesel-powered autoclaves while improving infection control. Similar efforts have extended to solar-powered vaccine refrigerators, widely adopted across

Africa and Asia to support immunisation programmes, and to solar-powered diagnostic kits and telemedicine tools for malaria and tuberculosis testing and remote specialist consultation. Despite these successes, there remains limited research specifically focused on solar-powered infrared thermometers. Most existing work has concentrated on larger or more complex devices, leaving a gap in the literature regarding small, portable diagnostic tools a gap this study seeks to address, given that continuous, reliable thermometer operation is essential for disease surveillance and community health programmes.

III. SYSTEM BLOCK DIAGRAM

The block diagram of the solar-powered infrared thermometer illustrates the interaction of the major functional units of the system, comprising the sensing subsystem, processing subsystem, display/feedback subsystem, and the solar power subsystem.

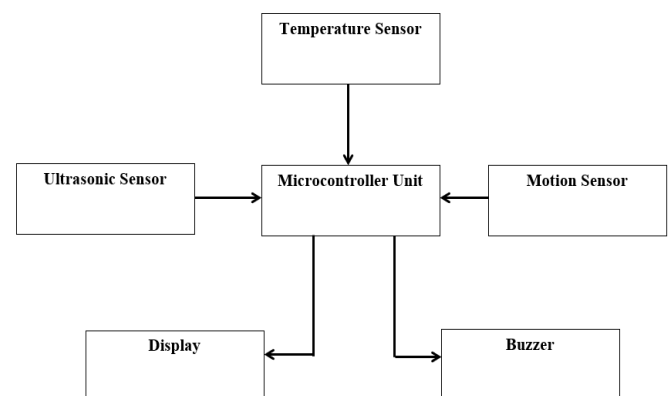


Figure 1: Block Diagram of the Solar-Powered Infrared Thermometer

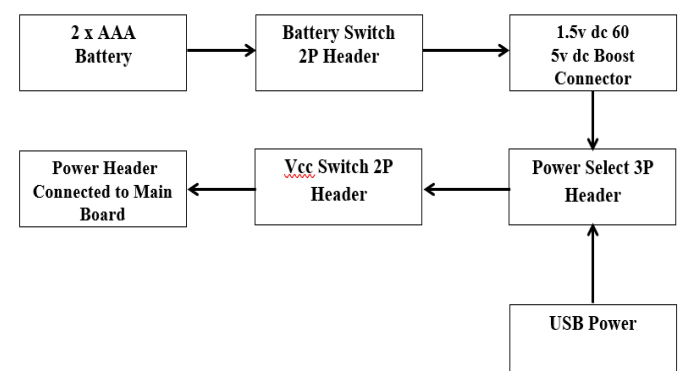


Figure 2: Block Diagram of a Conventional IR Thermometer (for comparison)

In summary, the fundamental sensing and processing units sensor, signal conditioning, processor, and display are identical in both device types. The distinguishing feature of the solar-powered variant is its power subsystem, which incorporates solar harvesting, voltage regulation, and energy storage, making it more autonomous, environmentally friendly, and cost-effective over the long term.

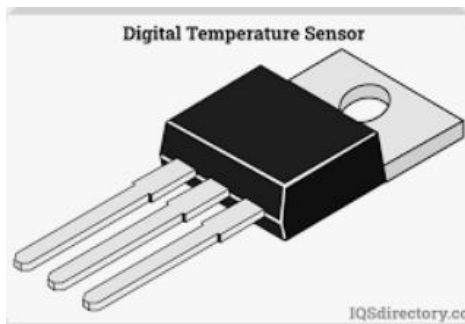
TABLE 1: Comparison of Standard IR Thermometer and Solar-Powered IR Thermometer

Feature	Standard IR Thermometer	Solar-Powered IR Thermometer
Power Source	Batteries or grid electricity	Solar panel + rechargeable storage
Energy Independence	Dependent on battery replacement	Self-sustaining in sunlight; reduces battery dependence
Block Complexity	Simple (sensor → processor → display → battery)	More complex (solar → charge controller → storage → sensor → processor → display)
Application	Anywhere with available batteries	Ideal for remote/rural areas with limited electricity
Sustainability	Generates battery waste	Eco-friendly; reduces e-waste

a. System Components

The major components used in the design of the solar-powered infrared thermometer are itemised below:

1. Temperature Sensor (MLX90614) a digital, non-contact infrared thermometer supplied in a TO-39 package, combining an IR-sensitive thermopile detector chip with a signal-conditioning ASIC. It measures ambient temperature from -40°C to $+125^{\circ}\text{C}$ and object temperature from -70°C to $+380^{\circ}\text{C}$, with an accuracy of $\pm 0.5^{\circ}\text{C}$ within the 0°C to $+50^{\circ}\text{C}$ range for both ambient and object temperature.



2. Ultrasonic Sensor (HC-SR04) used to measure the distance between the forehead and the sensor, with an effective range of 2 cm to 400 cm (approximately 0.066 ft to 13.12 ft).



3. Microcontroller (ATmega328P-PU) the central processing unit, responsible for controlling the character/graphic display and coordinating all peripheral operations.



4. Motion Sensor (AM312 PIR) a three-pin (VCC, OUT, GND) passive infrared sensor that detects motion so the MCU can exit low-power (sleep) mode; the OUT pin outputs a high signal upon detecting motion.



5. OLED Display (128 × 64 pixels) displays the distance between the forehead and the sensor, the ambient temperature, and the measured body temperature.



6. Buzzer: provides an audible signal indicating device readiness, active scanning, and completion of a measurement. It operates on a 5 V DC supply, drawing approximately 30 mA, and is driven by a 2N3904 NPN transistor.



b. Project Design Overview

The design was structured to meet the key objectives of accuracy, portability, and sustainability while addressing the challenges of healthcare delivery in environments with unreliable power supply. At the core of the design, a solar power system charges a rechargeable lithium-ion battery, providing continuous power both indoors and outdoors and eliminating dependence on disposable batteries. A power-management circuit regulates charging and discharging, protecting the battery from overcharging, deep discharge, and voltage fluctuations. The infrared sensor was selected for its high sensitivity, accuracy, and non-contact operation features especially suited to hygienic, rapid healthcare screening. It interfaces with the MCU, which processes infrared radiation data into digital temperature readings; embedded calibration routines automatically adjust readings for varying environmental conditions such as ambient temperature and humidity. Energy efficiency was supported through low-power components: the OLED display was chosen over conventional LCDs for reduced power draw and better visibility, while the motion sensor activates the thermometer only when a subject is detected, conserving energy during idle periods. An audible buzzer provides immediate feedback once a measurement is complete. The software layer complements the hardware with algorithms for data acquisition, signal filtering, and error correction, ensuring accuracy even in less-controlled environments.

c. Circuit Design

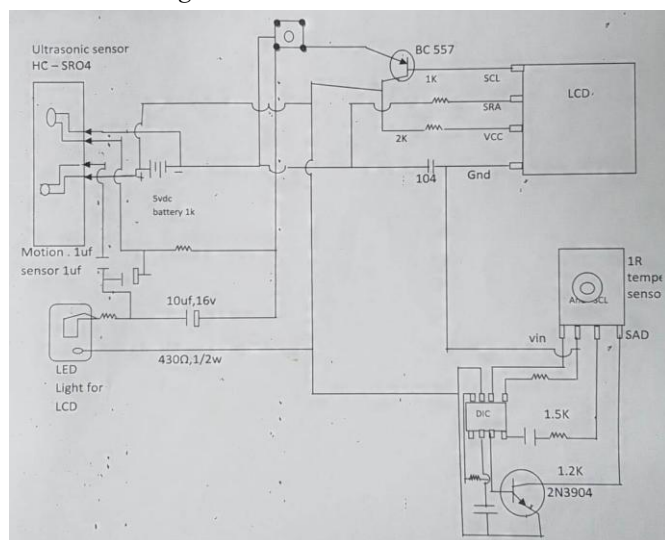


Figure 3: Circuit Diagram of the Solar Infrared Thermometer

The circuit integrates the solar charging module, energy-storage system, and temperature-sensing circuit. The infrared sensor (MLX90614) connects to the microcontroller via I²C communication pins (SDA, SCL), while the microcontroller drives the display through digital I/O pins, presenting temperature in Celsius or Fahrenheit. The power section consists of a solar panel connected to a charge controller that regulates current delivered to the rechargeable battery. A voltage regulator ensures a steady 5 V supply to the microcontroller and sensor, and bypass capacitors stabilize the

circuit against voltage fluctuations. The circuit was first simulated in Proteus software before physical implementation on a PCB/Veroboard.

d. Software Development

The software was developed using the Arduino IDE with C/C++, chosen for compatibility with the selected microcontroller and the availability of open-source libraries for rapid prototyping. The program was modularly structured to enhance readability, scalability, and debugging, and comprised the following core tasks:

- System Initialization configures the infrared sensor, display, buzzer, motion sensor, and voltage-monitoring unit at startup before measurements begin.
- Data Acquisition the infrared sensor transmits signals corresponding to detected thermal radiation, read by the MCU via ADC or digital protocols (I²C/SPI) as applicable.
- Data Processing and Calibration raw sensor data is converted to temperature using built-in formulas and calibration constants, with additional software-based calibration compensating for ambient variation; moving-average filtering reduces noise and improves stability.
- User Interface and Display: processed values are shown in real time on the OLED display, with the buzzer providing audible confirmation upon completion of a reading.
- Power Management: a battery-monitoring routine tracks voltage and issues a low-battery warning when levels fall below a safe threshold; sleep states minimize current draw when idle, with the motion sensor serving as a wake-up trigger.
- Error Handling and Reliability exception-handling routines detect communication errors between the MCU and peripherals and automatically reinitialize affected modules without requiring a manual reset.

e. System Flowchart

The flowchart below illustrates the sequence of operations executed when the solar infrared thermometer is in use.

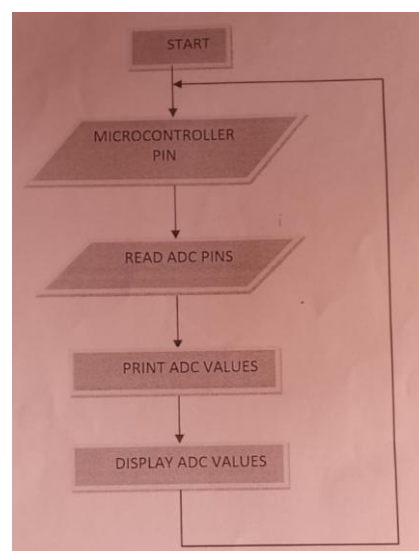


Figure 4: Flowchart of System Operation

IV. SYSTEM IMPLEMENTATION

The implementation stage translated the design into a functional prototype, integrating both hardware and software components for accurate, reliable, and sustainable real-world performance.

Hardware Subsystem: The hardware comprised the infrared temperature sensor, microcontroller, OLED display, motion sensor, buzzer, solar panel, charging module, and rechargeable lithium-ion battery. Each unit was selected for low power consumption, reliability, and compatibility, and arranged on a compact, portable framework suited to field use by healthcare personnel.

Power Subsystem: A solar panel was linked to a regulated charging module (TP4056), which manages the charging and discharging cycles of the lithium-ion battery, protecting against overcharging, over-discharging, and short circuits. The battery serves as the primary power source during periods of low solar intensity or indoor use.

Signal Integrity: During implementation, signal lines were shielded to reduce electromagnetic interference, and the power supply was regulated for voltage stability, reducing the risk of component malfunction and improving overall reliability.

a. Software Implementation

The software was structured into modular functions, each responsible for a specific task, to enhance maintainability, simplify integration, and allow future scalability (e.g., wireless data transmission or additional sensors) without restructuring the entire program. Major tasks mirrored the design stage: initialization routines; data acquisition and processing; display and feedback; power optimization via sleep states triggered by the motion sensor; and error handling with automatic module reinitialization. Development followed an iterative testing approach — unit testing of individual modules, followed by integration testing, and finally system-level testing against calibrated reference thermometers.

b. Construction

Circuit prototyping began on a breadboard to verify component compatibility, sensor readings, and wiring before transfer to a perfboard/PCB for durability and structural integrity, with components permanently secured by soldering.

The infrared and motion sensors were positioned at the front of the enclosure for unobstructed, non-contact measurement and subject detection. The lithium-ion battery and TP4056 charging module were mounted together within the casing to reduce wiring complexity and energy loss, while the solar panel was externally mounted to maximise sunlight absorption. The OLED display was mounted on the upper panel with the buzzer positioned adjacently for immediate audible feedback. The complete assembly was housed in a lightweight but sturdy, ergonomically designed enclosure with ventilation slots to prevent overheating and organised wire management to minimize clutter and short-circuit risk. A matte-finish plastic casing was selected for its combination of light weight, resilience, and affordability, suited to rural and semi-urban healthcare settings where devices are exposed to dust and heat.

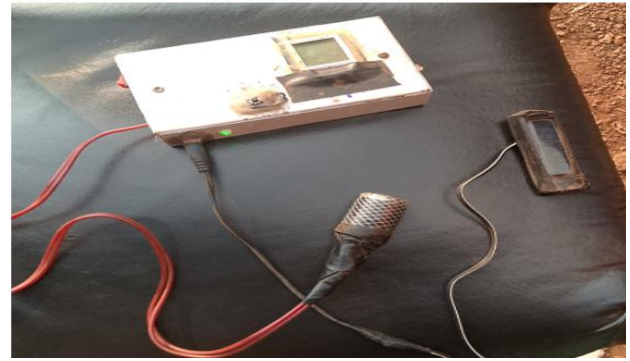


Figure 5: Photograph of the Constructed Solar Infrared Thermometer

c. Integration and Testing

Integration combined the hardware and software subsystems into a fully functional unit. After assembly, the system was powered on and communication between the microcontroller and peripherals verified, with the infrared sensor output validated against a standard medical thermometer. Testing was conducted in three phases:

- Unit Testing:** verification of individual modules such as sensor operation, display, buzzer, and power supply.
- System Testing:** running the integrated system under different environmental conditions (indoor, outdoor, varying light) to confirm stability.
- Performance Evaluation:** comparing temperature readings with a calibrated reference thermometer to determine accuracy and repeatability.

V. RESULTS AND DISCUSSION

TABLE 2: Comparison of Temperature Measurements

Test No.	Standard Thermometer (°C)	Solar IR Thermometer (°C)	Difference (°C)
1	36.5	36.4	0.1
2	36.7	36.8	0.1
3	37.0	36.9	0.1
4	37.2	37.1	0.1
5	36.8	36.9	0.1
6	38.0	38.1	0.1
7	37.5	37.4	0.1
8	36.9	37.0	0.1
9	37.8	37.7	0.1
10	36.6	36.5	0.1

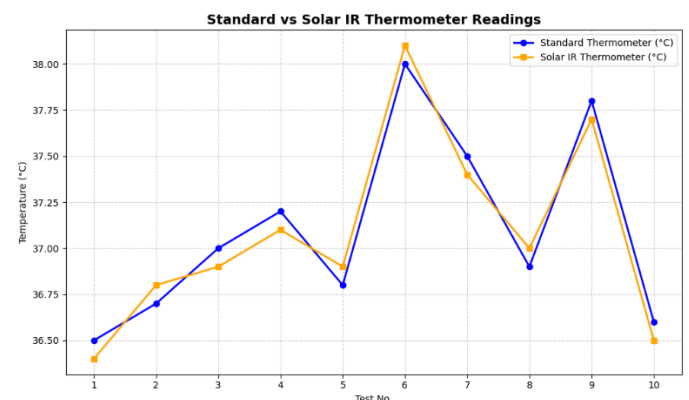


Figure 6: Comparison of Standard and Solar IR Thermometer Readings Across 10 Test Trials.

The line graph shows temperature readings ($^{\circ}\text{C}$) recorded by a standard thermometer (blue) and a solar-powered infrared thermometer (orange) for 10 test samples. Both thermometers exhibit closely matching trends across all trials, with a consistent average deviation of approximately 0.1°C , indicating that the solar IR thermometer provides comparably accurate temperature measurements to the standard reference device.

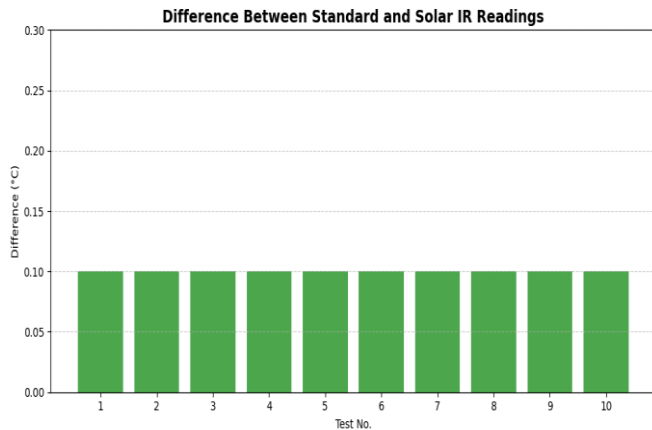


Figure 7: Average difference between the two thermometers: 0.10°C

The bar chart illustrates the deviation ($^{\circ}\text{C}$) between the standard thermometer and the solar IR thermometer for each of the 10 test samples. A uniform difference of 0.1°C is observed across all trials, demonstrating consistent measurement accuracy and reliability of the solar IR thermometer relative to the standard reference device.

TABLE 3: Testing Phases of the Solar Infrared Thermometer

Phase	Description	Purpose
Unit Testing	Verification of individual modules such as sensor operation, display, buzzer, and power supply.	To ensure each hardware and software component functions correctly.
System Testing	Running the integrated system under different environmental conditions (indoor, outdoor, varying light).	To confirm system stability and smooth interaction between subsystems.
Performance Evaluation	Comparing temperature readings with calibrated reference thermometers.	To validate accuracy, reliability, and repeatability of measurement results.

A. Discussion

The results in Table 3 show that the developed solar-powered infrared thermometer produced readings very close to those of the standard reference thermometer, with the difference remaining within $\pm 0.1^{\circ}\text{C}$ across all ten tests conducted indicating a high level of consistency and reliability. For example, in Test 1 the standard thermometer recorded 36.5°C while the solar-powered unit recorded 36.4°C , a difference of only 0.1°C ; similar small variations were observed throughout, confirming effective performance under normal operating conditions. The accuracy achieved can therefore be considered satisfactory for practical healthcare and environmental-monitoring applications. The minimal variation observed may be attributed to sensor sensitivity, ambient environmental

temperature, measurement distance, and slight calibration differences; nevertheless, the error margin remained within acceptable limits for infrared temperature-measurement devices. In terms of performance, the device demonstrated fast response time, stable operation, and reliable readings without dependence on external electrical power. The integration of solar energy ensured continuous operation while reducing dependence on disposable batteries, confirming that the system is both energy-efficient and environmentally sustainable. Table 4 further confirms that the thermometer delivered consistent, accurate, and rapid readings across all three testing phases, and that the solar-powered charging system proved reliable in sustaining continuous functionality without disposable batteries.

Overall, the results validate the effectiveness of the developed solar-powered infrared thermometer as a viable alternative to conventional infrared thermometers, combining measurement accuracy with the added advantage of renewable-energy utilisation, making it suitable for hospitals, rural healthcare centres, industries, and other environments requiring reliable and sustainable temperature monitoring.

B. Implementation Cost Analysis

A cost analysis was carried out to estimate the financial requirements for building the prototype, covering electronic components, construction materials, and assembly. The breakdown is presented in Table 4.

TABLE 4: Cost Analysis of the Solar Infrared Thermometer Implementation

Component/Material	Quantity	Unit Cost (₦)	Total Cost (₦)
Infrared Temperature Sensor	1	7,500	7,500
Microcontroller (Arduino Nano)	1	6,000	6,000
OLED Display	1	5,000	5,000
Motion Sensor (PIR)	1	3,000	3,000
Buzzer	1	500	500
Lithium-ion Battery	1	4,000	4,000
Solar Panel (10 W)	1	8,000	8,000
Charging Module (TP4056)	1	2,000	2,000
Enclosure/Case	1	5,500	5,500
Wires, PCB, and Miscellaneous	—	3,500	3,500
Total Estimated Cost	—	—	45,000

The estimated implementation cost of the solar infrared thermometer was approximately ₦45,000, making it a cost-effective solution compared with imported commercial alternatives.

VI. CONCLUSION

The design and construction of a solar-powered infrared thermometer have been successfully achieved. The project demonstrated how renewable energy sources can be integrated with modern sensing technology to produce an accurate, portable, and sustainable healthcare device. By combining an infrared temperature sensor, microcontroller, OLED display, motion sensor, buzzer, and solar charging system, the thermometer measures body temperature non-invasively while ensuring continuous operation in areas with unstable electricity supply. The incorporation of a solar-powered rechargeable

battery eliminated reliance on disposable batteries, reducing both operational cost and environmental waste. The software implementation further enhanced system reliability through modular programming, calibration routines, and power-optimisation strategies. Testing confirmed that the device delivered stable and accurate readings comparable to standard reference thermometers, with deviations of no more than ± 0.1 °C. Overall, the project achieved its objectives of accuracy, portability, sustainability, and usability, making the thermometer highly suitable for healthcare delivery in rural and resource-constrained environments.

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