

Research Article

Development of a Remote Upper Arm Temperature Monitoring Device in Adults

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Abstract

Introduction: Patient health condition diagnosis and monitoring using conventional healthcare services delivery is typically time-consuming tiring, expensive and limited in accuracy. Wearable Technology (WT) based on flexible electronics has gained tremendous attention in recent years for Remote Patient Monitoring (RPM) due to its satisfactory features. This technology provides opportunity for disease pre-diagnosis and immediate therapy in order to avoid health crisis. Temperature, as one of the pivotal body vitals for timely detection of abnormality in the human body needs to be continuously measured and monitored. With advent of WT, increase in population, increase in epidemics globally, need for more patient's participation, increased demand on Physician time and service delivery call for RPM. Attention. Global epidemiology and burden of fever necessitated the Development of Remote Upper Arm Temperature Monitoring (RUATM) Device in adults. **Methodology:** The device employed DS18D20 temperature sensor, an ESP32 microcontroller, 16*2 Liquid Crystal Display and RUATM server of the developed RUATM mobile application (RUATMiOS). Graphic User Interface (GUI) of RUATMiOS is fed from the system server through its socket. Remotely located physician can access temperature readings of the client on android phones and personal computers for remote monitoring of the patient's health condition. The RUATM system was tested on 24 individuals from University College Hospital (UCH), Ibadan under supervision of a medical doctor. Its workability, sensitivity, specificity and accuracy was determined. Moreover, its performances compliance with OMCare digital clinical thermometer, an existing was conducted to validate employability of the device in medical service delivery. **Results and Discussion:** Results of clinical trial of the RUATM system produced Mean readings of 35.41 ± 0.74 and 35.99 ± 0.51 for RUATM and clinical thermometer, respectively. Pearson correlation of performance of RUATM system on the digital clinical thermometer was 0.67. This correlation coefficient depicts strong relationships with readings from clinical thermometer. This implies that the developed RUATM device can be effectively used for temperature measurement, and remote temperature monitoring in patients. **Recommendations:** The developed RUATM system can be enhanced through miniaturization of its size and weight, increased precision, for improved affordability and market competitiveness. GSM communication can also be incorporated because of areas without internet connectivity.

Keywords

Remote Patient Monitoring, Vitals, Temperature, Healthcare Service Delivery

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1. Introduction

Remote Patient Monitoring (RPM) technology's demonstration of potential ability to help in reduction of providers' burdens, improve value-based performance metrics, and responsive ad release of patients control over their care and massive volume of data generated offers great volume of information to Physician [1-3]. RPM gained acceptance since 2020 during the COVID-19 movement restriction [4]. Meanwhile, there are six classes of parameters for success of RPM interventions which include: target population, accurate detection of decline in health, provision of responsive and timely care, personalized care; enhanced self-management and collaborative and coordinated care of patients [5]. Benefits of wearable Technology (WT) include real-time delivery, quick access to patient data, lower medical costs, reliable data transmission in harsh environments, storage at room temperature, non-invasive implementation, mass scalability, and convenience of use [6, 7].

Centrality of measurement of vital signs to good health and an improved health service delivery cannot be overemphasized [8, 9]. Generally, change in body temperature that falls outside the normal temperature range in a specific time of the day, is one of the major symptoms of ill-health in all humans, geographical location and regions of the world notwithstanding [10]. Many illnesses, such as fever, chicken pox, rabies, infections, etc., reflect their initial presence through increase in the body temperature [11]. There are several points in the body where body vitals, especially temperature can be obtained easily and conveniently, these include the rectal, axillary region, oral cavity and the forehead [12].

Proper monitoring of temperature is for personal health status monitoring, early ill-health detection and downtime prevention, hence the Development of Upper Arm Remote Temperature Monitor (UARTM) Device in Adults. The research designed and simulated the UARTM device's framework, developed and deploy compatible mobile application for the developed device, and also evaluated and validated the developed UARTM system using, sensitivity and specificity and correlation coefficient between UARTM-measured and digital clinical thermometer-measured temperature.

2. Literature Review

Table 1. WHO Statistics on Malaria, African Region [13].

S/N	Country	Cases (%)	Death (%)
1.	Angola	3.4	2.4
2.	Benin	2.0	1.7
3.	Burundi	1.5	0.9

S/N	Country	Cases (%)	Death (%)
4.	Burkina Faso	3.3	3.4
5.	Central African Republic	0.7	0.8
6.	Cameroon	2.7	2.3
7.	Chad	1.4	2.0
8.	Cote d'ivoire	3.0	2.4
9.	Democratic Republic of Congo	12.3	12.6
10.	Ethiopia	1.7	1.5
11.	Guinea	1.8	1.6
12.	Ghana	2.2	2.0
13.	India	1.7	1.2
14.	Kenya	1.3	1.9
15.	Liberia	0.8	0.6
16.	Madagascar	1.6	1.6
17.	Malawi	1.7	1.2
18.	Mali	3.1	3.3
19.	Mozambique	4.1	3.8
20.	Niger	3.2	3.9
21.	Nigeria	26.6	31.3
22.	Rwanda	1.2	1.2
23.	South Sudan	1.2	1.2
24.	Sudan	1.3	1.2
25.	Senegal		0.7
26.	Sierra Leone	1.1	1.4
27.	Togo	0.8	0.6
28.	Uganda	5.1	3.2
29.	United Republic of Tanzania	3.1	4.1
30.	Zambia	1.4	1.4
31.	Others	4.4	3.7

Source: [13].

Global Technical Strategy (GTS) for malaria 2016-2030 calls for a reduction in malaria case incidence and mortality rates of at least 40% by 2020, 75% by 2025 and 90% by 2030, from a 2015 baseline. Globally in 2021, there were an estimated 247 million malaria cases in 84 malaria-endemic countries - an increase of 2 million cases compared with 2020. This is a lower increase compared to the jump from 232 mil-

lion cases in 2019 to 245 million in 2020, which revealed the massive impact of the first year of the COVID-19 pandemic on global malaria control efforts. Global malaria deaths also rose from 568 000 in 2019 to 625 000 in 2020 but fell to 619 000 in 2021. The WHO African Region continued to bear the

highest burden, accounting for some 95% of global cases and 96% of global deaths in 2021 [13]. Malaria burden for African region is reflected in (Table 1) reflected highest percentage of cases and death due to malaria [14].

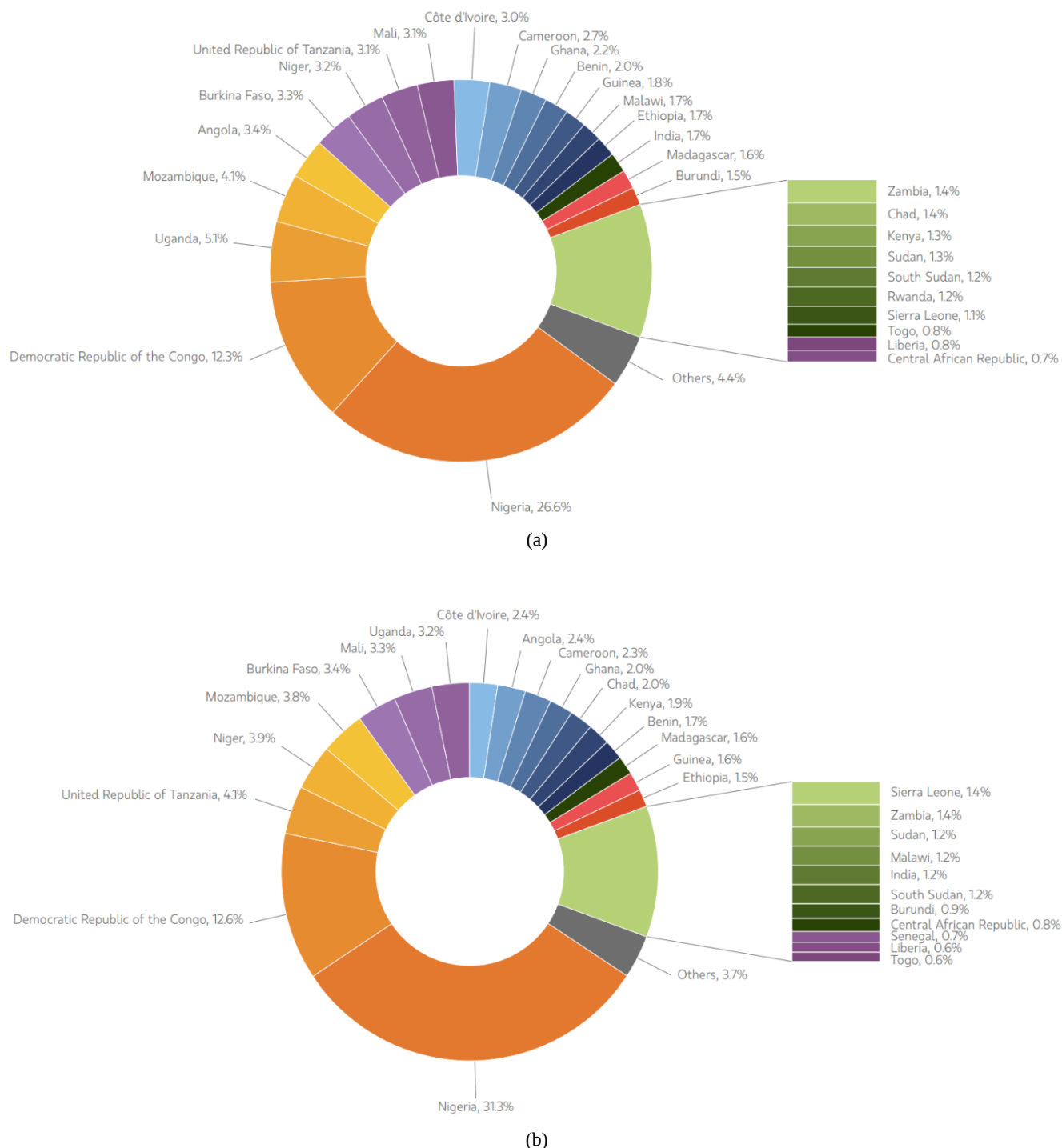


Figure 1. a. African Cases of Malaria in every 1,000. b. African cases of death in every 1000.

African region with death cases higher than reported cases. This is an eye opener that a lot of life is been lost to Malaria fever globally, and Africa not excluded.

Before the pandemic 2020, emphasis on Remote Patient Monitoring Systems (RPMS) concentrated on architecture, applications, methodologies and their performance. Post

pandemic concentration centered on applications architectures and performance [15]. Measured Core Body Temperature (CBT) from wrist-worn sensors with temperature sensing pill introduced into body of respondents. A post-colorectal surgery remote patient monitoring, coupled with telephone calls on 21 patients monitored five (5) times per day. It was discovered that remote patient monitoring is a welcome and promising idea to patients and physicians, alike [16].

In 2022, Qiao developed an end-to-end framework to measure people's vital signs based on the Remote Photoplethysmography (rPPG) methodology from video of a user's face captured with a smartphone was proposed. Vital measured were Heart Rate (HR), Heart Rate Variability (HRV), Oxygen Saturation (SpO₂) and Blood Pressure (BP) [17]. The work proposed a low-cost, accurate wireless temperature monitoring system. The system used a temperature sensor, an Analog Digital Converter (ADC), a data transmission module, and a receiver. The temperature sensor was calibrated to produce an output voltage that is proportional to the temperature. The ADC converts the analog output voltage from the temperature sensor to a digital signal. Data transmission module transmits the digital signal to the receiver. Receiver decodes the digital signal and displays the temperature on a computer or LCD. The system was tested in various conditions and at various distances. Results showed that the system can work accurately in all applicable conditions. Maximum distance for transmitting captured data is 50 meters when using 5 volts of input power. The next step is to reduce the size and operating voltage of the device to make it suitable for use in a low-power environment [18].

Etiel developed a wearable device worn on the wrist of the bearer. It measures temperature continuously, using a predictive algorithm. It was tested on datasets of 33 individuals and shows a correlation coefficient of ($r=0.72$), the average bias of 0.11 °C compared with tympanic membrane thermometers, Bland-Atman provided a statistics average bias of 0.11 °C with a limit agreement of -0.67 to + 0.93 °C [12]. CBT employed CALERA sensor technology which consists of a miniaturized heat flux sensor combined with skin temperature and heart rate sensors to continuously monitor CBT. It employed a combination of physiological sensing, classical statistical modeling, and embedded machine learning algorithm to provide its estimation. CBT is estimated on-device, and transmitted to a receiver by Bluetooth and Network Address Translation (NAT) communication protocols. It has a low power consumption. Performance metrics used were: Bias, Mean Absolute Error (MAE), and the Pearson correlation coefficient. Assuming an elevated CBT event sample base limit (reference point) of 38 °C, detection performance was measured using False Positive Rate (FPR) and False Negative Rate (FNR) given as where False Positive (FP), False Negative (FN), True Negative (TN) True Positive (TP) and False Negative (FN).

Gassemi, Hozeinzadeh and Ekhlesi designed and implemented a Wireless Body Temperature Monitor with warning

system via Short Message Service (SMS) [19]. The system was designed for online body vital monitoring and an SMS alert system. The device employed two circuits which communicate with each other by radio receiver and transmitter module. MAX30205 temperature sensor which measures the temperature, controlled by Arduino UNO and send it to the receiver circuit. At the receiver circuit, the captured data is displayed. The circuit can also warn through SMS if the set threshold is exceeded. The device was able to communicate over a distance of 1 km while its operating voltage range was 2.6 to 3.4 volts.

Alam designed and developed a Heartbeat and Temperature measuring system for remote patient monitoring which employs Wireless Body Area Network, controlled by PIC16F73 microcontroller. LM35 and Infrared (IR) sensors were used to capture temperature and heartbeat data from fingertip of users, respectively [20]. A multi vital monitoring system was proposed which monitors temperature and heart beat rate with help of LM35 and LM358 sensor. The extracted data is transmitted with the help of nRF24L01 module. Transmitted readings are received at the other end with help of RX and displayed on the LCD of the remote receiver [21]. Apart from being a proposition, the TX and RX will require more hardware for the implementation.

3. Methodology

The Upper Arm Remote Temperature Monitoring (UARTM) device was designed as follows. The RUATM can operate in such a way that a user that wears the device can be anywhere. The temperature of its bearer is being continuously read by one meter probe transmitted to either a clinician, care giver/relative, as may be necessary Figure 2 depict the block diagram of the developed UARTM system. Temperature sensor acquires data from the skin of a patient, displays the readings on the 16 by 2 Liquid Crystal Display (LCD), this continuously measured temperature of a user is sent through the wireless connectivity to the cloud which can be accessed by the clinician and caregiver. sends the same to socket of the application software. Any abnormality in the temperature of the user can be reported at both end, user (buzzer) and caregiver (iOS).

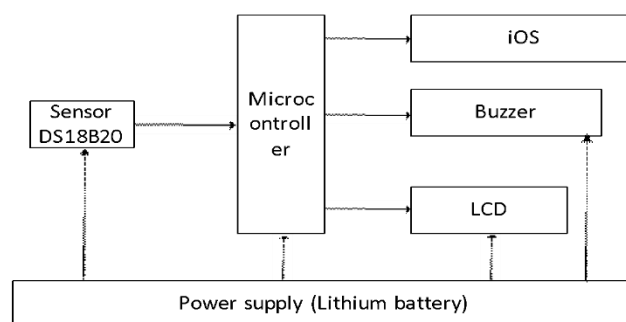


Figure 2. Block diagram of UARTM.

3.1. Product Requirements

The developed product ensured the following high-quality specifications. Temperature Measurement Accuracy of $\pm 0.35^\circ\text{C}$, 60-second interval for readings, alarm, compact design, light weighted, patient-centered, premium material, versatile operation and operating environment, ease of decontaminant and low maintenance design.

The UARTEM system is a combination of hardware implementation and software development. The hardware implementation entails the Computer-Aided Design (CAD) and Manufacturing aspect and the electronic circuitry. The RU-ATM is designed to transmit the temperature data to a web application where the clinicians, patients or any other end-user can get access to the data to make informed and data-driven decisions as is required. The web application development falls under the software development category.

3.2. UARTEM Hardware Development

Hardware development for RUATM involved meticulous design and manufacturing to ensure that the electronic circuitry was securely and efficiently encased.

CAD Model Design: The initial step in the hardware development was to create a detailed CAD (Computer-Aided Design) model using Autodesk Fusion 360. Autodesk Fusion 360 was selected because of its robust design capabilities, ease of use, and integration with various manufacturing processes.

Design Considerations: The CAD model was designed to accommodate all the electronic components of the RUATM device, including the ESP32 microcontroller, DS18B20 temperature sensor, ELEGOO power module, and the Liquid Crystal I2C LCD. Specific attention was given to the layout and spacing of these components to ensure optimal performance and ease of assembly (Figure 3). The design included precise measurements and mounting points for each component to ensure a secure fit and to avoid any interference between the components. Ventilation openings were also created to facilitate adequate airflow and prevent overheating of the electronic components.

Additive Manufacturing (3D Printing): Once the CAD model was finalized, it was ready for manufacturing. 3D printing was selected for its ability to produce complex geometries with high precision and relatively low cost.

Preparation for Printing: The final CAD model was exported from Autodesk Fusion 360 in STL (Stereolithography) format, which is a standard file format used for 3D printing. The STL file was then imported into the Flash Forge slicing software, where the model was sliced into thin horizontal layers. This slicing process generated the G-code, which is the set of instructions used by the 3D printer to create the physical object layer by layer.

3D Printing Process: The model was printed using a Fused Deposition Modeling 3D printer (Flash forge Creator Pro 2). PLA (Polylactic Acid) filament, a biodegradable and

eco-friendly material, was chosen for printing the frame due to its strength and ease of use.

Post-Processing: Once the printing was complete, the frame was carefully removed from the printer's build platform. There was no need to remove any support structures as none was used during printing because the design of the frame made it to be a stable model.

3.3. Software Development

The website development in the software implementation for the remote monitoring and temperature display on the website was executed with Next.js (client) and Node.js (server). The programming language utilized was JavaScript. The frontend of the website is hosted on the Vercel platform while the backend of the site is hosted on the Render platform where the PostgreSQL database is being used as the database for this website.

The website development for the remote monitoring and temperature display was implemented using a modern web technology stack. The client side of the application was built with Next.js, a powerful React framework that enables server-side rendering and static site generation. The server side was developed using Node.js, a versatile JavaScript runtime that allows for efficient and scalable backend services.

Technologies and platforms, programming language: java script, frontend framework: Next.js

Backend Runtime: Node.js Frontend Hosting: Vercel Backend Hosting: Render Database: PostgreSQL.

Frontend: The frontend of the website is hosted on the Vercel platform, which is optimized for Next.js applications. This provides seamless deployment, high performance, and global CDN distribution, ensuring that the website loads quickly and efficiently for users around the world.

Backend: The backend of the website is hosted on the Render platform. Render is known for its simplicity and reliability in deploying full-stack applications. It handles the server-side operations, including data handling and API management. A PostgreSQL database is used to store temperature data, providing robust and scalable data storage.

3.4. Electronics Circuitry

Completed Circuit Description

The electronic circuit consist of ESP32 microcontroller, ELEGOO power module, DS18B20 temperature sensor, 9V battery, jumper wires, 4.7k Ω resistor, and a Liquid Crystal I2C LCD.

Power Supply: The 9V battery was connected to the ELEGOO power module. This produce 5V output, which was used to power the ESP32; D318B20, and the led display.

ESP32 Connections: The 5V and GND pins of ESP32 were connected to the power and ground rails on the vero board, respectively.

DS18B20 Temperature Sensor: Vcc pin of the DS18B20

was connected to the 5V power source while its GND pin was connected to the ground. Its Data pin was connected to GPIO 18 on the ESP32. A 4.7k Ω resistor was placed between data pin and the Vcc pin of DS18B20 to serve as a pull-up resistor.

Liquid Crystal I2C LCD: SDA pins of the LCD was connected to GPIO 21 on the ESP32, respectively. The VCC and GND pin of the LCD were connected to the 5V power supply and ground.

Detailed Pin Connections:

ESP32: The 5V pin was connected to the power rail. The GND pin was connected to the ground rail. GPIO 18 was connected to the data pin of the DS18B20. GPIO 21 was connected to the SDA of the LCD. GPIO 22 was connected to the SCL of the LCD. **DS18B20 Temperature Sensor:** The VCC pin was connected to the power rail. The GND pin was connected to the ground rail. The data pin was connected to GPIO 18 on the ESP32 with a 4.7k Ω resistor to VCC.

Liquid Crystal I2C LCD: The SDA pin was connected to GPIO 21. The SCL pin was connected to GPIO 22. The VCC pin was connected to the power rail. The GND pin was con-

nected to the ground rail.

Assembly Steps:

ESP32 Mounting: The ESP32 was placed on the vero board, and the power and ground rails were connected to its 5V and GND pins.

DS18B20 Connection: The DS18B20 was placed on the vero board. Its VCC and GND pins were connected to the power and ground rails, respectively. Its data pin was connected to GPIO 18 on the ESP32, with a 4.7k Ω resistor soldered between the data pin and the VCC pin.

LCD Installation: The LCD was placed on the vero board, with its SDA and SCL pins connected to GPIO 21 and GPIO 22 on the ESP32, respectively. The VCC and GND pins of the LCD were connected to the power and ground rails.

Powering the Circuit: The ELEGOO power module was connected to the 9V battery, and the circuit was powered up by turning on the power module. This setup allowed the ESP32 to read temperature data from the DS18B20 sensor and display the temperature on the LCD.

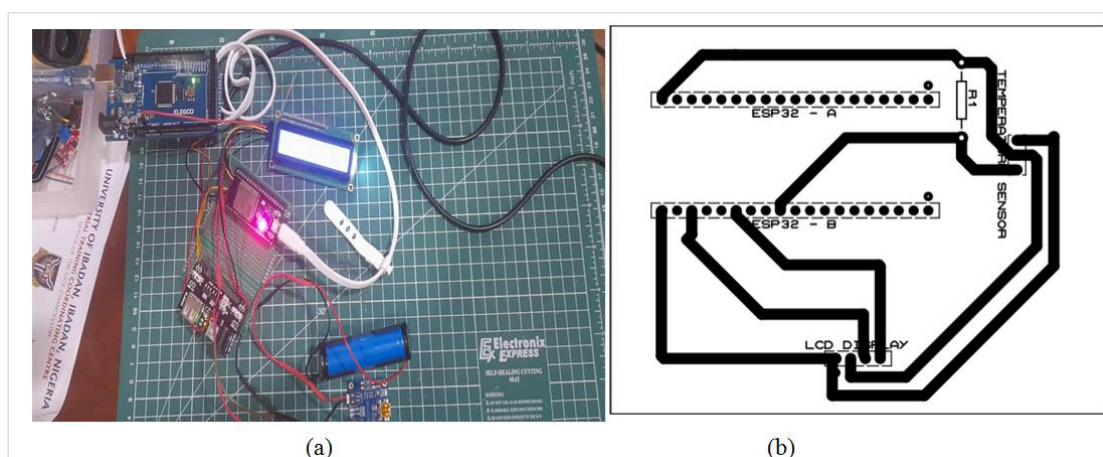


Figure 3. Circuitry of the UARTM system.

4. Results and Discussion

4.1. Results Presentation

The result shall be presented in Table 2 which reflects temperature readings from UARTM and Omcare digital clinical thermometer.

The developed device was clinically tested on 24 individ-

uals, and the readings vis-à-vis readings from digital clinical thermometers (Table 2). The readings from the developed UARTM system reflected TP of 24, FP=0, TN=0 and FN=0. Applying 3.2, 3.3, 3.4 and 3.5, the system produced 0.00, 0.00, 1.00 and 0.00 for FPR, FNR, Specificity and Specificity, respectively. The Specificity of 1.0 revealed that the UARTM device does not fail to measure the temperature of the patient at any time, once the power supply to the device is adequate to drive the device.

Table 2. Result for Device Validation.

S/N	RUATM	Clinical Thermometer (OMCare)	S/N	RUATM	Clinical Thermometer (OMCare)
1.	36.19	36.20	13.	35.38	36.20

S/N	RUATM	Clinical Thermometer (OMCare)	S/N	RUATM	Clinical Thermometer (OMCare)
2.	35.50	35.10	14.	36.06	36.20
3.	36.08	36.80	15.	36.50	36.60
4.	35.56	35.80	16.	36.19	36.50
5.	34.90	34.80	17.	36.31	36.50
6.	35.31	35.90	18.	35.69	35.80
7.	36.31	36.10	19.	36.50	36.40
8.	35.25	35.40	20.	35.38	35.80
9.	35.44	35.50	21.	36.38	36.70
10.	35.13	36.70	22.	35.44	35.40
11.	35.25	35.90	23.	36.19	36.10
12.	38.81	35.80	24.	35.38	35.60

4.2. Discussion of Results

Results of clinical tests of the UARTM System and readings from the “Omcare” Clinical thermometer are shown on Table 2. Meanwhile, the developed device required more duration before its readings stabilized, longer than it took the clinical thermometer. Validation of the device through Data analysis with Python revealed a significant correlation among readings from the two devices. Results of paired sample t-test when the readings of the developed UARTM device produced

were compared with the clinical thermometer generated the results (t -statistic= 1.171, p -value=0.113) at 0.05 level of significance. Since 0.113 is much greater than the critical level (0.05), the second null hypothesis is therefore rejected.

Also, the scatter plot of correlation between the developed device and clinical thermometer is shown in Figure 4 while group means for the two classes is shown in Figure 5. The Pearson correlation value is 0.670. This relationship indicates the existence of strong correlation between readings by the two devices, and therefore the developed UARTM device can be used in place of the existing clinical thermometer.

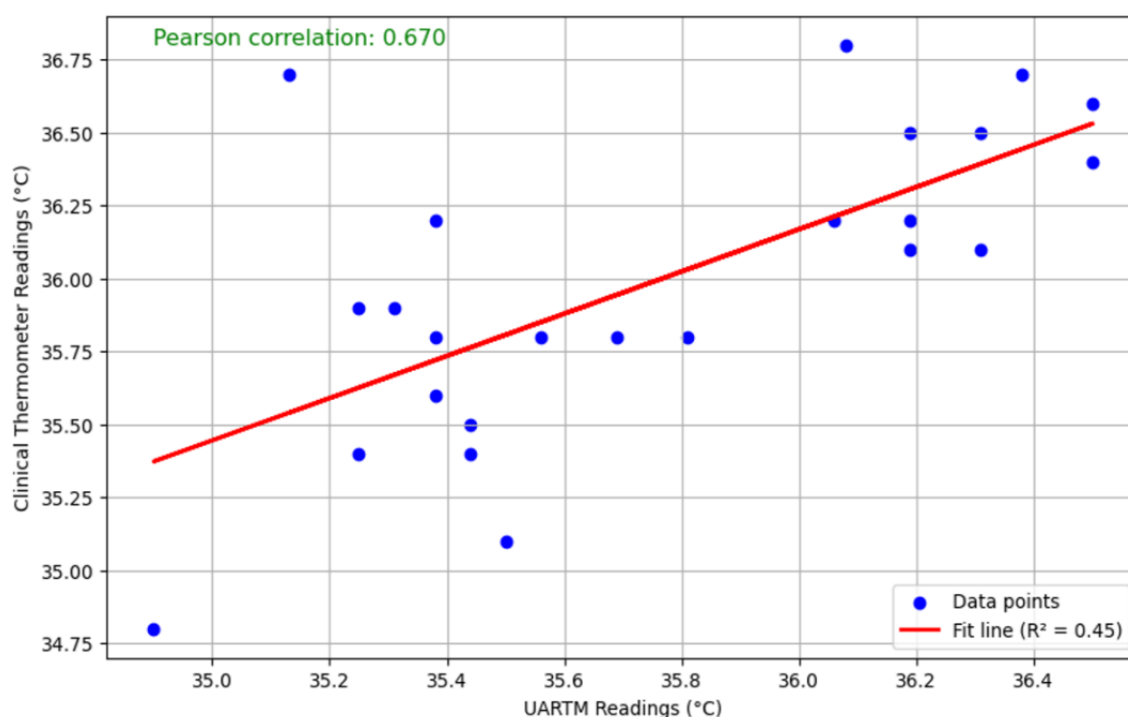


Figure 4. Scatter Plots of Data of the Readings of UARTM and digital clinical thermometer.

Moreover, with the possibility of remote use of the developed UARTM device, it can be used to support Remote Patient Monitoring (RPM) healthcare service delivery in the health sector.

4.3. Comparison with Existing Products

Features of the developed device were compared with some existing products based on the following characteristics,

namely: remote monitoring capability, logging facility, extensibility of the probe, precision of readings, contact nature, LCD display of results compatibility with other devices. The developed device was able to satisfy the intended earlier enumerated features, though it has a bigger value in terms of size and weight compared to existing devices. It can remotely monitor temperature, logging capability, extensible temperature probe, higher precision (2d.p), contact technology, LCD display and can be driven using DC source.

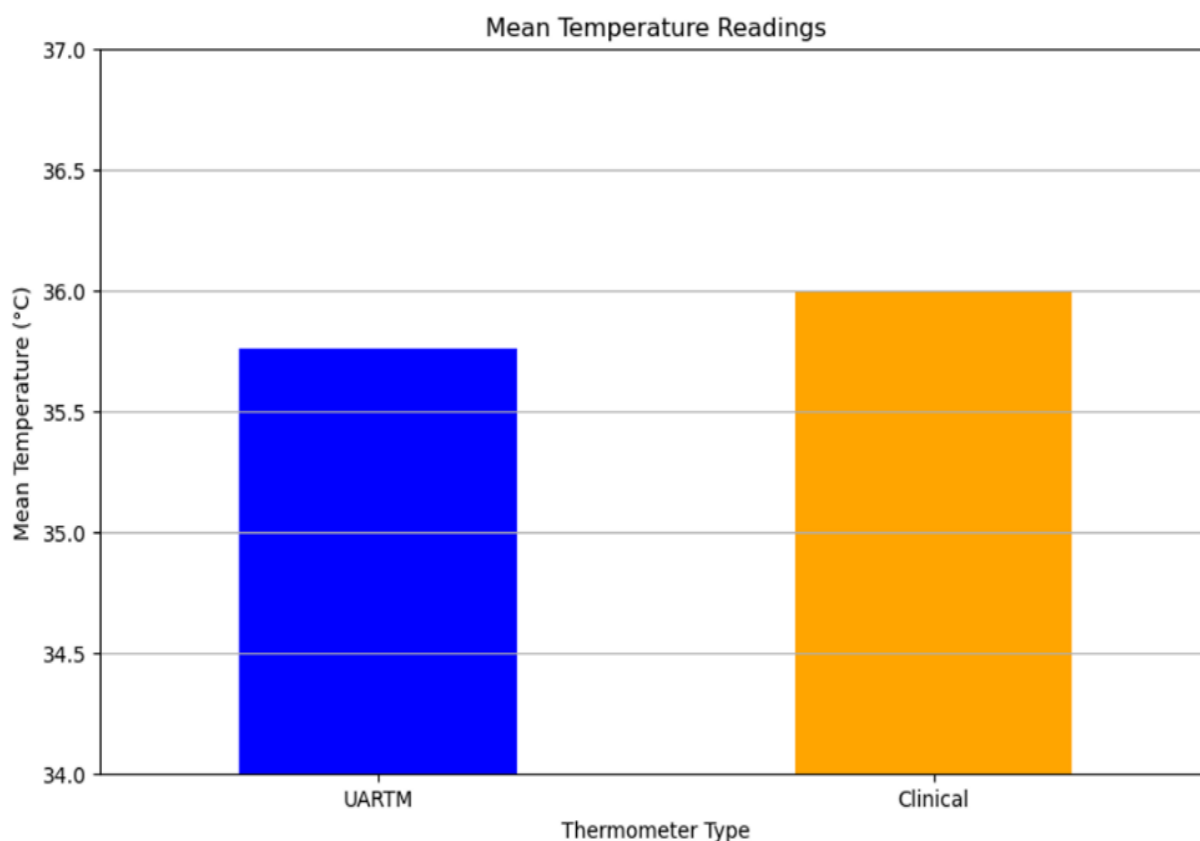


Figure 5. Bar chart of UARTM and digital clinical thermometer.

5. Conclusion and Recommendations

The research had successfully conducted a need assessment for development of an Upper Arm Remote Temperature Monitoring device, applicable in Remote Patient Monitoring (RPM) in medical services delivery. An effective framework for an Upper Arm Remote Temperature Monitoring had been designed, simulated, implemented and clinically validated among intending users. The device reflected a correlation value of 0.67 with the existing clinical thermometer (contact). Meanwhile, a real-time generated temperature reading from temperature sensor (probe) of the device requires more time than it is required by the clinical thermometer. Data captured are made available real time to the relative, caregiver, and

medical personnel attached to the patient.

Responses from end users of the developed device revealed the following realities (recommendations) about the UARTM System revealed that the developed device can: be miniaturized both in size and weight while functionality of the device is maintained, inclusion of rechargeability of the device for consistent functioning and reading accuracy, be calibrated for quicker temperature data capturing, in order to cater for people living in places where there is no internet facility, GSM module should be incorporated in the device, and platform can be developed in the department of Biomedical Engineering, in conjunction with UCH (UI_UCH) where the device can be integrated for physicians can attend to patients more proactively and remotely.

Abbreviations

BMI	Body Mass Index
RPM	Remote Patient Monitoring
CAD	Computer Aided Design
TP	True Positive
FP	False Positive
TN	True Negative
FN	False Negative
LCD	Liquid Crystal Display
RUATM	Remote Upper Arm Temperature Monitoring

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Conflicts of Interest

The authors declare no conflicts of interest.

Appendix

Table 3. Summary of Related Works.

S/N	Authors and Year	Characteristics/Features	Location of Measurements	Sensor(s) employed	Communication	Accuracy	Limitation	Recommendation
1.	Etienne [12].	Ingestible temperature-sensing pill, Bland-Altman	Wrist-worn			0.11°C and Regression $r = 0.78$		
2.	Ghassemi [19].	Temperature measurement	NA	MAX30205, Arduino UNO	GSM (SMS)	0.1 °C	1 Km distance and 2.4 Distance limitation to 3.6 volts	
3.	Ko Ko [22]	Temperature, Heart rate, Blood pressure, SPO2, Blood sugar	Hand held					
4.	Alam [20].	Heart beat (Photo diode) and temperature (LM35 IC)	Fingertip		Wireless Body Area Network (GSM 850MHz)		5 volts	
5.	Fajrin [23].	Temperature (DS18B20)	Any part of the body.	Atmega328	GSM (SMS) and Blue-tooth	0.829%		
6.	Parihar, Tonge and Ganorkar [21].	Temperature (LM35) and heartbeat (LM358)		Atmega328	LCD and nRF module	NA	It was a proposed framework	Recommended for implementation
7.	Alam, Sultan and Alam [20]	Temperature and heartbeat (optical technology)	Fingertip	LM35 IC and IR sensors. PIC16F73 microcontroller, Wireless Area Network	GSM (SMS) to remote physician	NA	It was compared to ascertain its reliability	

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