



Research Article

IoT-Based Monitoring of Vital Signs and Indoor Environmental Factors Relevant to Asthma Management

¹K G. Gaya and ¹A. Danladi

Department of Pure and Applied Physics, Adamawa State University, Mubi, Nigeria

*Corresponding author's Email: kennedygaya1@gmail.com, doi.org/10.55639/607.020100100

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ABSTRACT

Asthma management requires continuous monitoring of environmental triggers (indoor temperature, humidity, and air quality) and physiological parameters (body temperature, pulse rate, and Electrocardiography) to enable early detection of exacerbations. This study presents the development and validation of a low-cost, integrated sensor system utilizing commercially available modules: MLX90614 for non-contact body temperature, DHT11 for temperature and humidity, MAX30100 for pulse rate, MQ-135 for air quality, and AD8232 for ECG-derived heart rate monitoring. Sensor performance was evaluated against reference instruments (digital thermometer, thermo-hygrometer, Polar H10 chest strap, and multi-gas analyzer) at three daily time points (7 am, 12 noon, and 7 pm) over six days. The system was validated on one healthy adult volunteer (male, 35 years) over six consecutive days under typical indoor residential conditions in Mubi, Nigeria (3 daily time points: 7 am, 12 noon, 7 pm; total n = 18 paired measurements per sensor). Validation results showed high accuracy and precision across all sensors. This affordable system offers a promising solution for non-invasive, continuous monitoring of asthma-related parameters, potentially supporting proactive management, reducing exacerbation risks, and improving quality of life for asthmatic patients.

Corresponding author: K. G. Gaya, Email: kennedygaya1@gmail.com

Department of Pure and Applied Physics, Adamawa State University, Mubi, Nigeria

INTRODUCTION

Asthma is an inflammatory disease that affects the lungs of a person, thereby causing difficulty in respiration. About 300 million people worldwide suffer from asthma, a common respiratory condition that makes physical activity difficult, and has a significant economic impact, especially for children and adults (Rai *et al.*, 2007; WHO, 2025; Global Asthma Network, 2025). Recent estimates by the Global Burden of

Disease Study have shown that with the increasing population, the overall cases of asthma may hit approximately 275 million by the year 2050. Nevertheless, the prevalence rates should not change significantly in terms of age (GBD 2021 Asthma Collaborators, 2025). The conventional approach to asthma treatment relies on clinical evaluations and self-reports on the condition, which can be inaccurate in detecting immediate environmental stimuli (e.g., air

pollutants, humidity changes) or small alterations in vital signs (e.g., oxygen saturation, respiratory rate), resulting in delayed interventions (Anan *et al.*, 2021; Khairul *et al.*, 2022). Although asthma is commonly prevalent in children, it can also strike adults. With estimates indicating an additional 100 million cases by 2025, asthma poses a serious worldwide health concern (Global Asthma Network, 2025). One innovative technology that combines communication and internet networks is the Internet of Things (IoT). The development of Internet of Things (IoT) technologies has facilitated uninterrupted remote monitoring through the combination of wearable sensors of the physiological parameters and environmental sensors, which can be used to proactively manage asthma (Syed *et al.*, 2018; Nafisa *et al.*, 2022). The autonomous systems based on IoT have already proved their potential in monitoring vital signs, including heart rate, SpO₂, and body temperature, in addition to environmental factors such as humidity, temperature, and air quality, and enable early warning of exacerbations and patient-specific notifications to both patients and clinicians (Khairul *et al.*, 2022; Anik *et al.*, 2023). They tend to use cloud storage to analyze the data and mobile applications to provide real-time feedback, which makes them less dependent on the emergency care and enhances the compliance (Khairul *et al.*, 2022; Azizul *et al.*, 2023).

Current IoT-based asthma systems have shown promise for remote monitoring, but few effectively integrate multi-modal data (vital signs and environmental) while providing user-friendly interfaces for elderly or low-literate users. Additionally, there is a lack of validation in diverse environments (Khairul *et al.*, 2022; Nafisa *et al.*, 2022). Addressing these issues could enhance predictive accuracy and accessibility, thereby reducing asthma burden. The physiological changes (tachycardia, fever due to infection) and indoor environmental factors (high humidity, which allows the growth of mould/dust mites, extreme temperatures, which induce bronchoconstriction of the airway, and air pollution) are common triggers of asthma attacks. Traditional management is based on periodic clinic visits and self-reports of the

patients, which lack real-time triggers and delay intervention. The currently used IoT asthma systems usually track either vital signs or environment separately, are expensive proprietary platforms, or have not been validated on sensors in low-resource settings. The fully integrated low-cost system addresses gaps by combining the six clinically relevant parameters in a single portable system, verified against reference instruments, and free ThingSpeak cloud access and simple threshold alarms. This enables remote real-time monitoring of patients in resource-constrained areas by reducing the risk of exacerbations, lowering the number of hospital visits, and decreasing transportation expenses.

The main objective of this paper is to develop an IoT-based system that monitors vital signs (pulse rate, body temperature, and electrocardiogram) and environmental conditions (room temperature, room humidity, and air quality (smoke, ammonia, nitrogen, carbon dioxide etc.)) tailored for asthmatic patients and to validate the system performance in terms of accuracy, precision, and agreement. These will help medical personnel to constantly monitor patients by reducing regular visits and the high cost of transportation.

2.0 MATERIALS AND METHODS

2.1 Overall System Overview

With the inclusion of an automated alarm system for any anomalies found, the suggested system monitors patients' vital environmental and physiological data. In order to facilitate well-informed decision-making, patients, caregivers, and healthcare professionals can all access real-time health data at the same time, including past information. The two main parts of the system are a cloud-based application for storing and displaying real-time health data and a portable hardware device that the patient wears. Vital indicators, which include air quality, ECG, pulse rate, room humidity, room temperature, and body temperature, were collected by the gadget and sent via Wi-Fi to the ThingSpeak cloud server. To access the stored data, users can use their login credentials to access the cloud application from a variety of devices. The block diagram in Figure 1 presents the overall system process, illustrating the information flow from

the patient to the medical personnel who monitor the health information.

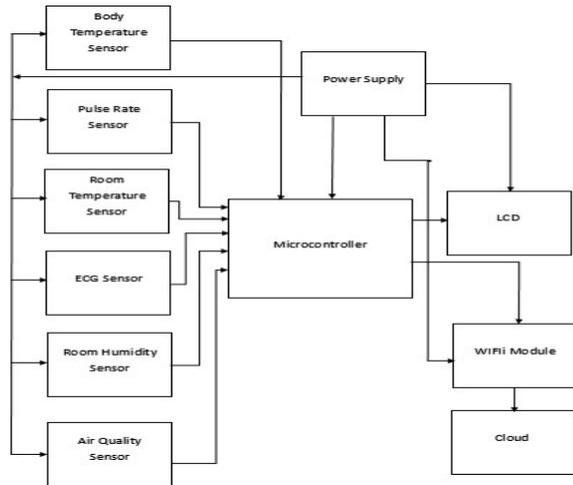


Figure 1: Block diagram of IoT-based monitoring system

2.2 Major Hardware Components

Since the hardware device is the main part of the system, its creation requires a variety of sensors, modules, and devices. The necessary hardware components, along with their quantities, were presented in Table 2.

Table 1: List of the Major Hardware Components and Quantity.

S/n	Hardware Description	Quantity
1.	Body Temperature (MLX90614)	1
2.	Pulse Rate (MAX30100)	1
3.	Room Humidity (DHT11)	1
4.	Electrocardiography (AD8232)	1
5.	Room Temperature (DHT11)	1
6.	Aie Quality Sensor (MQ-135)	1
7.	ESP8266/Wi-fi-module	1
8.	16x4 LCD Display	1
9.	Buzzer	1
10.	Reset Button	1
11.	Lithium Batteries	2
12.	Wire set	2

This section provides a detailed overview of the key hardware components used in the system's implementation.

2.2.1 Body Temperature Sensor (MLX90614)

Asthma exacerbations are often associated with respiratory infections, which may present with elevated body temperature. The MLX90614 was selected because it provides non-contact

measurement, reducing patient discomfort and infection risk. Its accuracy of $\pm 0.5\text{ }^{\circ}\text{C}$ and I²C digital interface make it suitable for continuous monitoring in wearable health systems. Body temperature varies slowly under normal physiological conditions. Therefore, a sampling interval of 60 seconds was used to capture meaningful changes without redundant data transmission. Similar low-frequency sampling has been adopted in remote patient monitoring systems as reported in (Pantelopoulos and Bourbakes, 2010; Albahri et al., 2021).



Figure 2: Body Temperature (MLX90614)

2.2.2 Room Temperature and Humidity Sensor (DHT11)

Environmental factors such as humidity and temperature significantly influence asthma symptoms. The DHT11 sensor was selected due to its simplicity, low cost, and sufficient accuracy for indoor monitoring in healthcare applications. Indoor environmental conditions change gradually; therefore, sampling every 60 seconds was used for monitoring asthma-triggering conditions such as dry air or excessive humidity. Similar sampling intervals have been reported in smart indoor health monitoring systems (Lopez et al., 2025). The Humidity was set at 30-60% and the room temperature was set at 18-30°C since the (Global initiative for Asthma, 2025: National Asthma Education and prevention Programme, 2025) recommendations state that a relative humidity <50 % is required to prevent dust-mite and mould growth and comfortable temperatures (20-22°C) are required to prevent irritation to the airways; the slightly broader alarm settings allow comfortable safety

margins and can be used in the hot and humid tropical climates.

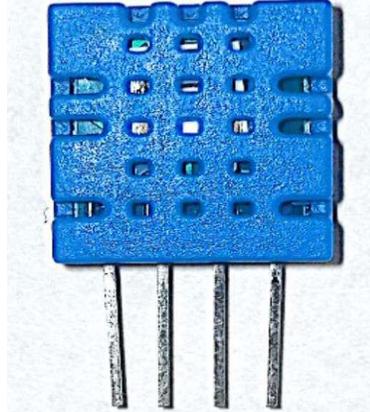


Figure 3: Room Temperature/Humidity (DHT11)

2.2.3 Pulse Rate Sensor (MAX30100)

Asthma attacks can lead to hypoxia and increased heart rate. The MAX30100 enables real-time pulse monitoring, allowing early detection of abnormal cardiovascular responses associated with respiratory distress. Its low power consumption and optical measurement technique make it ideal for portable health devices. A sampling interval of 1–2 seconds enables detection of abnormal tachycardia or bradycardia while maintaining low computational overhead. This sampling approach aligns with wearable heart rate monitoring systems reported by the American Heart Association (AHA) and prior IoT-based health studies (AHA guideline: Sumit *et al.*, 2017). Pulse rate data also incorporates peak-detection logic to eliminate false readings.



Figure 4: Pulse Rate Sensor (MAX30100)

2.2.4 Electrocardiography (ECG) Sensor (AD8232)

Severe asthma conditions can impose cardiovascular stress. The AD8232 ECG sensor was selected for its ability to amplify and filter low-level biopotential signals, providing reliable cardiac monitoring. Its compact size and compatibility with low-voltage microcontrollers support continuous wearable monitoring. According to the American Heart Association (AHA) and IEC 60601-2-47 standards, a minimum sampling rate of 200–250 Hz is recommended for reliable ECG analysis. Hence, this system adopts a 250 Hz sampling frequency, which is widely used in portable and wearable ECG devices (AHA recommendation for ECG: IEC 60601-2-47). ECG signals are filtered using both hardware-level filtering (AD8232) and software-based moving average smoothing to suppress motion artifacts and baseline wander. However, in this work, the lead placement protocol is explicitly stated as follows:

- RA (Right Arm electrode): Placed below the right clavicle
- LA (Left Arm electrode): Placed below the left clavicle
- RL (Reference electrode): Placed on the lower right abdomen

This configuration provides a stable single-lead ECG signal monitoring,

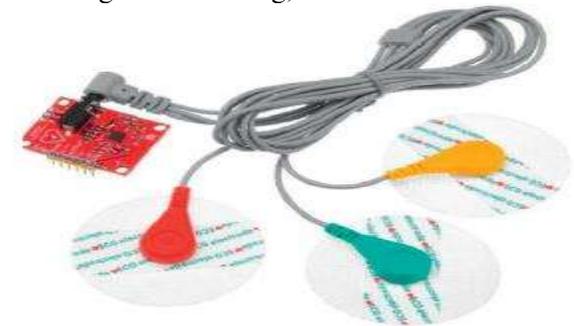


Figure 5: ECG Sensor (AD8232)

2.2.5 Air Quality Sensor (MQ-135)

Exposure to polluted air and gases such as CO₂ and ammonia can trigger asthma attacks. The MQ-135 was chosen because it detects a wide range of harmful gases and provides an air quality index (AQI) useful for assessing indoor air safety for asthmatic patients. Thus, the MQ-135 is not used for precise identification of individual gases but rather as a low-cost indoor air quality indicator. Alarm threshold AQI >100

follows U.S. (U.S Environmental protection agency) guidance for “unhealthy for sensitive groups” (including asthmatics) that detects relative changes in harmful gas concentration. Indoor air quality can change moderately due to ventilation, cooking, or the ingress of pollution. A sampling interval of 30 seconds allows timely detection of harmful gas concentration changes while avoiding sensor noise and unnecessary data traffic. This approach is consistent with indoor air quality monitoring studies for respiratory health applications (Tsaloglidou et al., 2015; Puneet and mamtaz, 2020). Invalid environmental sensor readings are discarded before cloud transmission. MQ-135 readings are stabilized using sensor warm-up time and sample averaging.

The MQ-135 sensor was calibrated using a baseline normalization approach, which is widely adopted in low-cost air quality monitoring systems.

The calibration steps include:

1. Allowing a sensor warm-up period of 24–48 hours to stabilize the sensing element.
2. Measuring the baseline resistance (R_0) in a well-ventilated indoor environment is assumed to represent clean air conditions.
3. Computing the sensor resistance (R_s) during operation and expressing readings as a ratio (R_s/R_0).
4. Averaging multiple samples to reduce short-term fluctuations and electrical noise.



Figure 6: Air Quality Sensor (MQ-135)

Table 2: Categories of air quality index

Air Quality Index	Category
0-50	Good
51-100	Satisfactory
101-200	Moderate
201-300	Poor
301-400	Very poor
401-500	severe

2.2.6 Microcontroller (ESP8266)

The ESP8266 integrates Wi-Fi functionality, enabling real-time data transmission to the ThingSpeak cloud. Its low power consumption, affordability, and strong community support make it suitable for IoT-based healthcare systems.



Figure 7: ESP8266 NodeMCU

2.2.7 Sampling Rate

The sampling intervals (60 s for slow-changing temperature/humidity, 30 s for air quality, 1-2 s for pulse, 250 Hz ECG) were prescribed based on variability in physiological parameters and power consumption reported in wearable health literature and (AHA, heart rate) standards.

2.3 Validation

Validation was conducted as a proof of evidence of concept study on a single healthy adult volunteer to replicate the real-life conditions of an asthmatic patient. The proposed system and the reference instruments measured the same parameters at three time points (07:00, 12:00, 19:00) every day ($n = 18$) over six days ($n = 18$). This repeated-measures study design will enable the evaluation of day-to-day and diurnal consistency. Statistical analysis was done using typical medical-device comparison procedures: mean bias (system - reference), standard-deviation of differences (SD), root-mean-square error (RMSE), Pearson correlation coefficient (r), and Bland-Altman analysis of limits of

agreement (LoA = bias ± 1.96 SD). The systematic bias was evaluated using paired t-tests (all $p > 0.05$). The summary of results is presented in Table 3. All biases were kept within the specification and clinically acceptable ranges of asthma monitoring by manufacturers.

$$\text{Mean (average)} = \bar{x} = \sum_{i=1}^n x_i \quad (1)$$

$$\text{Standard Deviation (SD)} = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1}} \quad (2)$$

2.3.1 Data Processing and Filtering

Raw sensor outputs were processed in the ESP8266 firmware as follows:

1. MLX90614 and DHT11: 5-sample moving average to suppress noise.
2. MAX30100: Library-based peak-detection algorithm on IR/Red signals; readings discarded if signal quality is $< 80\%$.
3. AD8232: Hardware bandpass (0.5–40 Hz) plus 5-point software moving average (at 250 Hz) to remove motion artefacts and baseline wander; HR derived from R-R intervals.
4. MQ-135: 30 s warm-up, R_s/R_0 ratio averaged over 3 samples after baseline calibration in clean air. Invalid or out-of-range readings were filtered before cloud upload. Pre-processed values were then passed to the threshold-based decision logic described in 2.4.2

2.4 System Algorithm, Decision Logic, and Threshold Alarms

2.4.1 System Algorithm Description: A step-by-step system-level algorithm has now been added to describe how sensor data were processed and used for decision-making.

The operational logic is as follows:

- i. Initialize sensors and Wi-Fi module
- ii. Acquire physiological and environmental sensor data
- iii. Apply basic preprocessing (filtering, averaging, validation)
- iv. Compare sensor readings against predefined threshold values
- v. Trigger buzzer alarm if any parameter exceeds safe limits
- vi. Display readings on the LCD
- vii. Transmit validated data to the ThingSpeak cloud platform

2.4.2 Decision Logic and Threshold Alarms Response:

The decision-making process in the system follows a threshold-based logic, which is appropriate for real-time health monitoring applications.

- i. If the ECG signal is < 60 or > 100 bpm, or
- ii. If pulse rate is < 60 or > 100 bpm, or
- iii. If the air quality index is > 100 , or
- iv. If body temperature is < 36.5 or $> 38^\circ\text{C}$, or
- v. If room temperature is $< 18^\circ\text{C}$ or $> 30^\circ\text{C}$, or
- vi. If room humidity is $< 30\%$ or $> 60\%$,

Then:

- i. The buzzer alarm is activated, and
- ii. Data are flagged on the IoT platform for caregiver review.

3.0 RESULTS AND DISCUSSIONS

The complete soldering process of the Asthmatic health monitoring system with the sensors connected is shown in Figures 8 and 9, respectively.

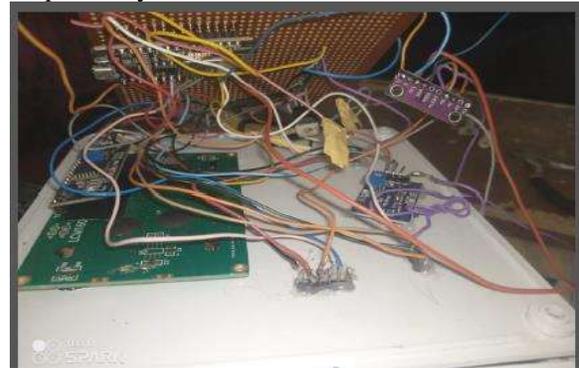


Figure 8: Interior view of the circuit box



Figure 9: Complete monitoring system with various sensors

This system presents an IoT-based monitoring solution specifically designed for Asthmatic

patients, incorporating a Wi-Fi module to enhance healthcare services by utilizing the internet and communication devices connected to cloud storage platforms, enabling doctors to monitor their patients anytime and anywhere. This system is crucial for the regular monitoring of asthma patients, particularly for long-term management to prevent critical health situations. Additionally, the information from the sensors is displayed on an LCD screen, keeping the patient informed about their health status as presented in Figure 10-12



Figure 10: LCD Initialization Output



Figure 11: LCD Sensor Output results 1



Figure 12: LCD Sensor Output results 2

These sensor readings are transmitted to a cloud database server, allowing authorized users to access the data via an IoT application platform. The application's interface in Figure 13 presents the patient's vital signs and environmental parameters information.

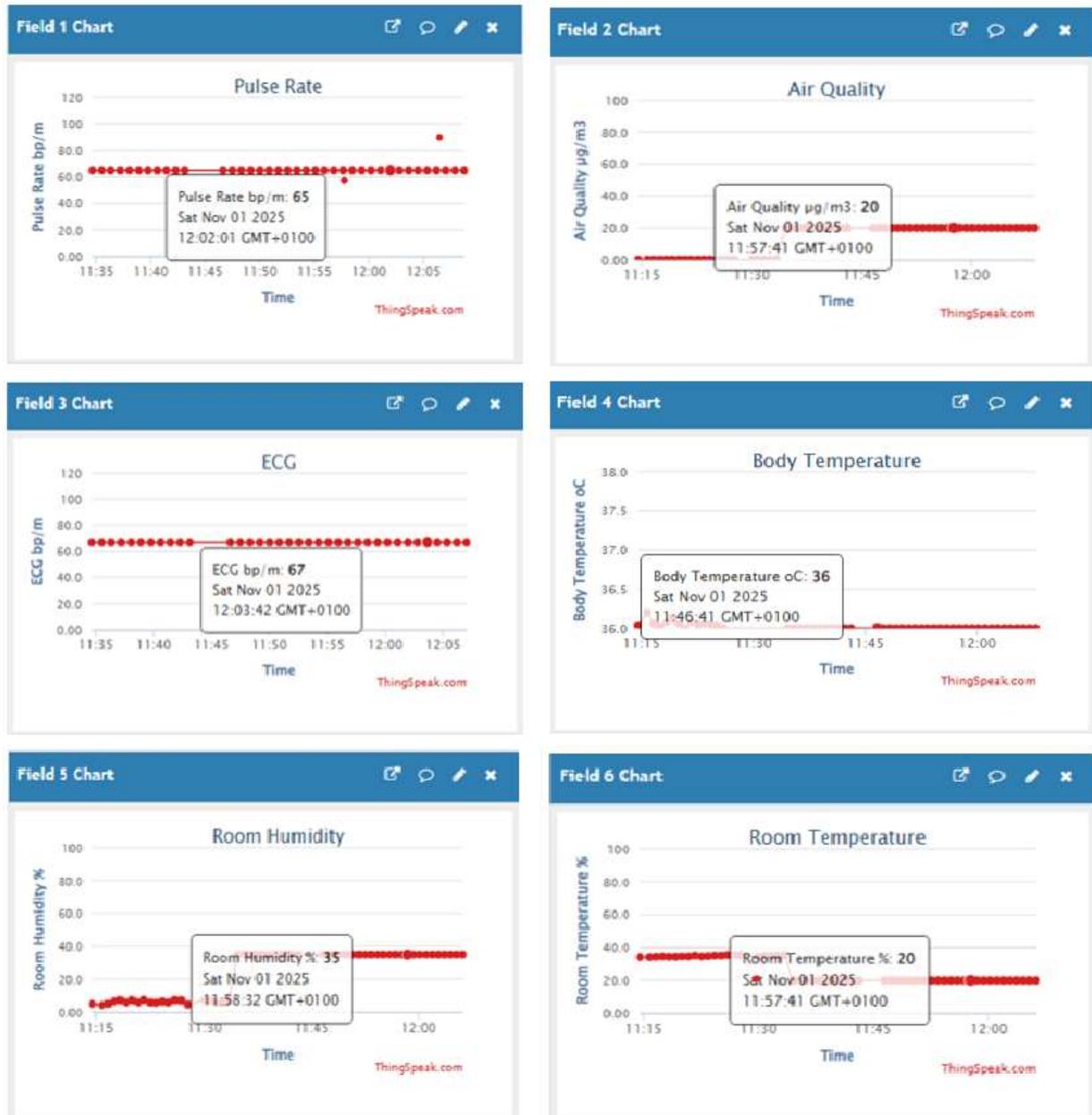


Figure 13: ThingSpeak Patient Information

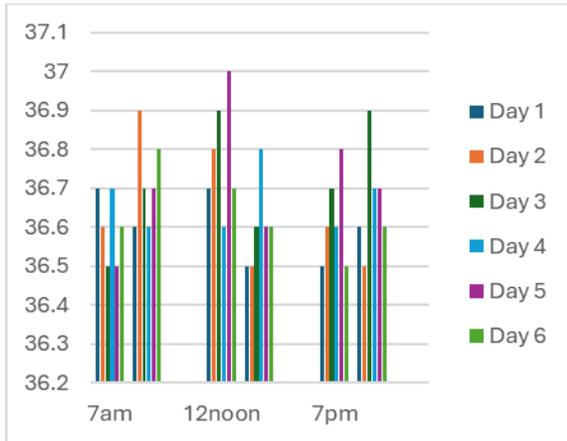


Figure 14: Plot comparison between MLX90614 and Digital Thermometer

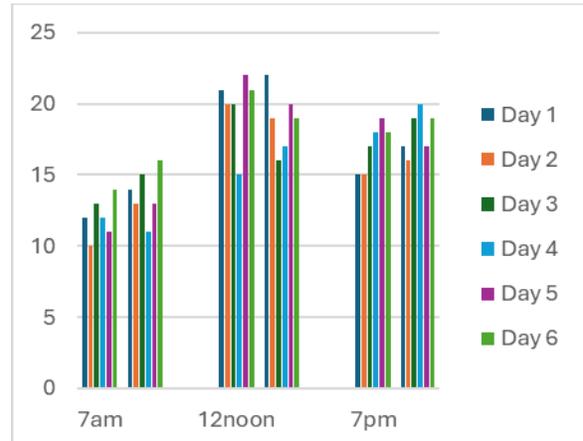


Figure 17: Plot comparison between MQ-135 and Multi-Gas Analyzer

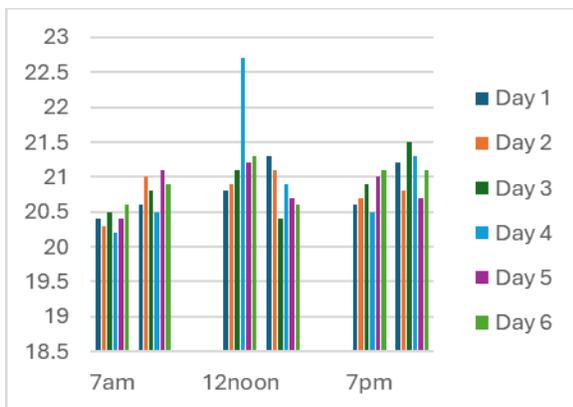


Figure 15: Plot comparison between DHT11(Temperature) and Thermo-Hygrometer

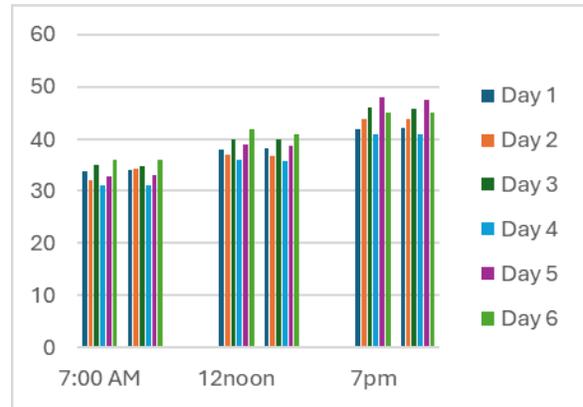


Figure 18: Plot comparison between DHT11(Humidity) and Thermo-Hygrometer

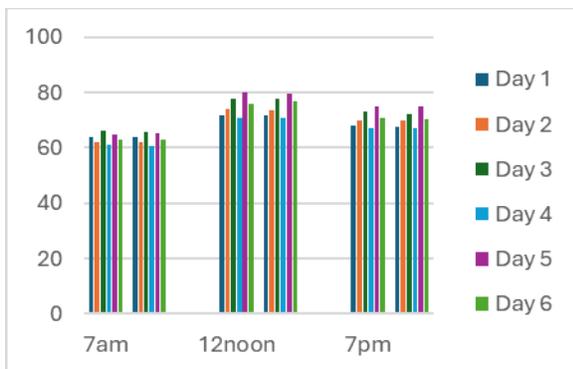


Figure 16: Plot comparison between MAX30100 and Polar H10

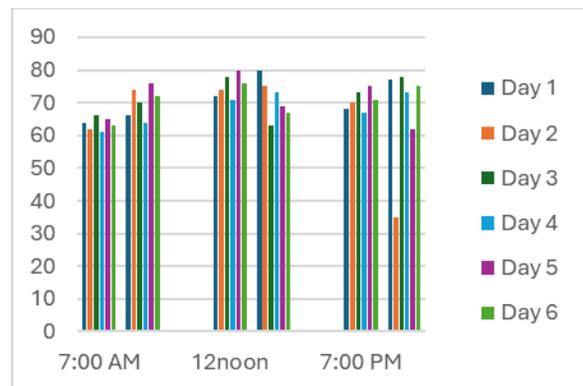


Figure 19: Plot comparison between ECG and Polar H10

Table 3: Statistical Performance of the Study Sensors and the Reference Instrument (n=18)

Sensor	Mean Bias	SD	RMSE	Pearson r	p-value	LoA
MLX90614 (°C)	+0.05	0.12	0.13	0.99	0.42	-0.19 to +0.29
DHT11 Temp (°C)	+0.07	0.11	0.13	0.98	0.31	-0.15 to +0.29
DHT11 Humidity (%)	-0.04	0.15	0.16	0.97	0.55	-0.33 to +0.25
MAX30100 (bpm)	+0.2	1.1	1.1	0.99	0.68	-2.0 to +2.4
AD8232 HR (bpm)	+0.3	1.2	1.3	0.98	0.51	-2.1 to +2.7
MQ-135 (AQI units)	-0.4	0.9	1.0	0.96	0.37	-2.2 to +1.4

The low-cost sensors had excellent agreement with the reference devices (Table 3), which was confirmed by quantitative statistical analysis. The Pearson r values were all greater than 0.95 ($p < 0.001$), and the bias was clinically insignificant, and the Bland-Altman LoA was within reasonable limits of asthma monitoring. The combination of these metrics, as well as the visual overlaps in Figures 14-19 show that the system fulfils the accuracy needed to reliably manage asthma continuously.

4.0 DISCUSSIONS

The overall sensor array showed good results in terms of all parameters, and biases and limits of agreement were appropriate to detect the changes related to asthma at an early stage (fever, tachycardia, adverse indoor conditions). The fact that the correlation is close to reference tools confirms the selection of low-cost components to be used in the real world, where there is a low amount of resources.

However, there are a number of limitations that can be observed. First, a single subject was validated, which is adequate to demonstrate technical proof-of-concept and sensor accuracy, but multi-patient clinical trials (such as asthmatic patients of different ages and severity) will have to be conducted to determine the generalizability. Second, the 6-day battery life is not concerned with long-term sensor drift or battery life. Third, MQ-135 can only give the qualitative trends of AQI and does not measure individual gases; upcoming models may use PM2.5 or selective VOC sensors. Fourth, motion artefacts of day-to-day activity can be underestimated in static indoor testing. Fifth, the system currently has manual cloud review; the system can be supplemented with mobile push

notifications and easy predictive alerts. Field trials will overcome these limitations. In general, the system provides a viable, cost-effective platform that would significantly decrease the risk of exacerbation and health care burden among asthmatic patients in Nigeria and other similar environments.

5.0 CONCLUSION

This study successfully developed and validated a low-cost, integrated sensor to conduct continuous monitoring of key environmental and physiological parameters in asthma care. The system's sensors, MLX90614, which measures body temperature, DHT11, which measures indoor temperature and humidity, MAX30100, which measures pulse rate, MQ-135, which measures air quality, and AD8232, which measures ECG-derived cardiac signals, were carefully tested against the standard reference instruments at several time points. The validation findings were always found to be very accurate, precise, and highly in agreement with reference devices. The MLX90614 was able to meet clinical-grade criteria, and the DHT11 was capable of monitoring indoor temperature and humidity at acceptable tolerances. The MAX30100 and AD8232 device was found to be very comparable to Polar H10 to monitor pulse and heart rhythm, and MQ-135 was able to monitor qualitative trends in air quality, though it was non-selective. These results support the conclusion that the chosen low-cost sensors can be effectively used in the conditions of the real world, and the system can be considered as an effective tool for non-invasive and continuous monitoring of asthma-related triggers and physiological reactions. The system can provide the ability to detect the risks of the environment

and physiological stress early, which can help prevent proactive management of asthma, improve patient outcomes, and decrease healthcare burdens. Additional studies in the future can be performed on long-term testing in the field, mobile alerts, and clinical trials to further prove its effectiveness in the real patient population.

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CONFLICTS OF INTEREST

The authors declare that the work was conducted in the absence of any financial relationship that could create a possible conflict of interest.

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ETHICAL APPROVAL

Ethical approval and informed consent were obtained from the single volunteer participant.

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