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Design, Simulation and Validation of a Microcontroller-Based Multi-Parameter Physiological and Environmental Monitoring System for Asthma Care

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ABSTRACT
Asthma management requires monitoring of physiological conditions and environmental factors that may contribute to symptom worsening. This study presents the design, simulation, and validation of a microcontroller-based physiological and environmental monitoring system for asthma care. The system monitors body temperature, pulse rate, electrocardiography (ECG), room temperature, room humidity, and air quality using LM35, MAX30100, AD8232, DHT11, and MQ-35 sensors, respectively. An ESP8266 microcontroller was used for sensor integration and data processing, while an LCD provided local display of the measured parameters. The sensors were validated against a digital thermometer, thermo-hygrometer, Polar H10, and multi-gas analyzer. The results showed generally good agreement with the reference instruments, with mean absolute differences of 0.18 °C for the LM35, 0.33 °C for DHT11 temperature, 0.23% for DHT11 humidity, 0.19 bpm for MAX30100 pulse rate, 0.87% for MQ-35 air quality, and 2.17bpm for the ECG sensor. The complete system was simulated in Proteus and successfully demonstrated simultaneous monitoring of the selected physiological and environmental parameters. The findings indicate that the proposed system provides a low-cost platform for monitoring conditions relevant to asthma care. However, it is not intended to diagnose asthma or determine disease severity. Incorporating respiratory rate, SpO_2, peak expiratory flow, wheeze detection, and clinical validation in future work could enhance its application to dedicated asthma monitoring.

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INTRODUCTION

Asthma is a common chronic respiratory disease that affects hundreds of millions of people worldwide and continues to impose substantial morbidity, mortality, and economic burden (Koppelman et al., 2025; Wang et al., 2023; Oh et al., 2025). Its development and exacerbation are shaped by both physiological status and environmental exposure, because asthma arises from complex gene–environment interactions and is strongly influenced by infections, allergens, pollutants, and other external stressors across the life course (Koppelman et al., 2025; Agache et al., 2024; Zhou and Tang, 2025). Clinical deterioration must be recognized early, and effective asthma management therefore depends not only on tracking symptoms and bodily responses, but also on identifying personal and environmental triggers that precede worsening attacks (Taylor et al., 2020; Varopichetsan et al., 2025).

Recent advances in embedded electronics, wireless communication, and wearable sensing have accelerated the development of microcontroller-based systems for real-time health and environmental monitoring (Kassem et al., 2021; Kassem et al., 2020; Mirza et al., 2024). Existing platforms commonly use compact controllers such as Arduino, ESP8266, ESP32, and Raspberry Pi to interface with biomedical and environmental sensors, process signals, and transmit measurements to mobile or cloud dashboards for remote observation (Madavarapu et al., 2024; Assaad et al., 2025; Kassem et al., 2021; Mirza et al., 2024). These systems have shown that low-cost sensor networks can support continuous monitoring of parameters such as temperature, pulse, ECG, oxygen saturation, humidity, and motion, while improving accessibility outside conventional hospital settings (Madavarapu et al., 2024; Mirza et al., 2024).

Environmental monitoring is especially relevant in asthma care because air quality and meteorological conditions are established contributors to asthma symptoms and exacerbations (Agache et al., 2024; Obeng et al., 2026). Short-term exposure to PM2.5, PM10, and NO2 probably increases asthma-related hospital admissions and emergency visits, while heavy traffic exposure can worsen asthma control (Agache et al., 2024; Koppelman et al., 2025). However, tropical plants can be used to effectively prevent and manage asthma with minimal or no side-effects (Ogbonnaya et al., 2024). Temperature extremes also matter, as both extreme heat and extreme cold are associated with increased asthma attacks and adverse outcomes, and humidity can further modify respiratory risk by influencing airway narrowing, mucus properties, and pollutant behavior (Agache et al., 2024; Shu et al., 2026). In addition, recent evidence shows that PM2.5 can increase asthma symptom prevalence even at relatively low concentrations, and relative humidity has been positively associated with asthma exacerbations in some settings (Mirabelli et al., 2016; Varopichetsan et al., 2025).

Physiological monitoring provides complementary information that can help characterize patient status during asthma surveillance. Wearable sensor research shows that cardiovascular and thermal signals such as pulse rate, body temperature, and ECG can be acquired continuously and integrated into broader monitoring frameworks (Taylor et al., 2020; Assaad et al., 2025). Heart rate is relevant because asthma exacerbation is associated with tachycardia, with reported values rising above 120 beats per minute in affected patients, while ECG remains the gold standard for extracting cardiac activity and related features such as QRS complexes and heart rate (Taylor et al., 2020). Body temperature is less specific to asthma itself, but it remains useful as a supplementary physiological marker in remote monitoring systems and is already widely incorporated in portable respiratory and general health platforms (Taylor et al., 2020; Thakur et al., 2018; Kassem et al., 2020).

Despite this progress, many existing systems monitor only isolated physiological variables, focus mainly on either environmental or biomedical sensing alone, or rely on reference devices and specialized equipment that are less suitable for low-cost continuous use (Assaad et al., 2025; Pavlovsky et al., 2026; Taylor et al., 2020). Technical challenges in multimodal integration, sensor interoperability, and data complexity have also limited the development of comprehensive asthma-oriented platforms (Assaad et al., 2025; Mirza et al., 2024). At the same time, prior work has emphasized the ongoing need for portable, wireless, and affordable systems capable of continuously monitoring key respiratory and physiological indicators in daily life (Thakur et al., 2018; Liu et al., 2024; Mirza et al., 2024). These gaps support the need for an integrated microcontroller-based system that combines relevant physiological and environmental parameters into a single accessible platform for asthma care (Assaad et al., 2025; Mirza et al., 2024; Obeng et al., 2026). However, this work aims to design and simulate a microcontroller-based physiological and environmental monitoring system for asthma care with the following objectives:

i. To design a microcontroller-based system for monitoring body temperature, pulse rate, electrocardiography, room temperature, room humidity, and air quality as physiological and environmental parameters relevant to asthma care;
ii. To integrate the selected sensors, ESP8266 microcontroller, and LCD into a unified embedded monitoring architecture;
iii. Validate the selected physiological and environmental sensors against appropriate reference instruments; and
iv. Simulate the complete monitoring system in the Proteus environment and evaluate its ability to simultaneously display the measured parameters.

A microcontroller-based simulated physiological and environmental parameter is significant because it supports early detection of respiratory deterioration and can reduce delays in patient assessment, especially where repeated hospital visits are difficult or costly (Raji et al., 2016). Its low-cost and portable design aligns with repeated findings that asthma monitoring tools should be affordable to be used. (Sai et al., 2025; Khan et al., 2021).

Therefore, this study focuses on the design, simulation, and validation of a microcontroller-based system capable of simultaneously monitoring selected physiological and environmental parameters relevant to asthma care.

MATERIALS AND METHODS

Materials

The materials in this work include a Room Temperature and Humidity Sensor, Air Quality Sensor, Electrocardiography Sensor, Pulse Rate Sensor, Body Temperature Sensor (LM 35), The Microcontroller Selection, The Display Selection (LCD), a 7.4V Battery, and the Proteus 8.0 version. The choice of ECG, temperature, humidity, and air quality was prioritized over respiratory rate, airflow sound, or wheeze sensing because of the availability of sensor materials.

Methodology

Developing a microcontroller-based physiological and environmental monitoring system for asthma care involves selecting sensors capable of acquiring physiological parameters and environmental conditions relevant to asthma management, interfacing them to a microcontroller, and transmitting data wirelessly. The block diagram in Figure 1 consists of a power supply, which is used to power the system and the sensors. The body temperature, heart rate, electrocardiography, room temperature, room humidity, and air quality. is used to acquire patient and environmental information to be processed by the microcontroller, which is the heart of the system, which receives the readings of the sensors and displays them on the LCD screen, which serves as the output of the system

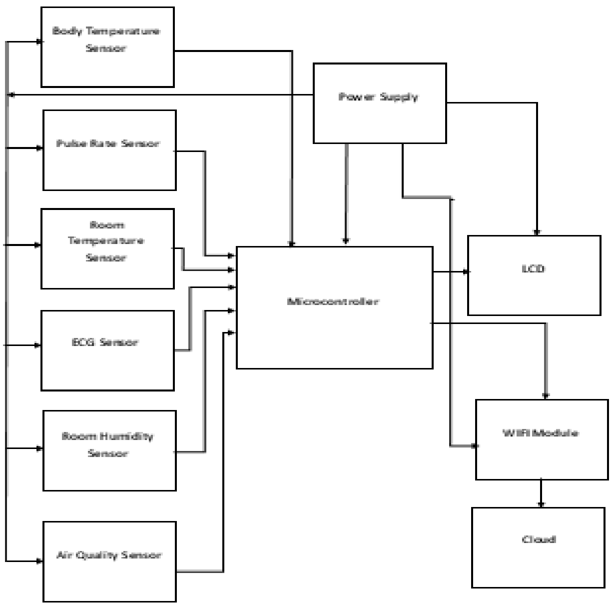

Figure 1: Block Diagram of the System

System Design
The system is made of two sections: hardware and software sections. The individual blocks that make up the system make up the hardware section of the system.

Hardware Selection
i. Room Temperature and Humidity Sensor (DHT11): Environmental conditions such as temperature and humidity profoundly affect asthma control and exacerbation risk (Gu et al.,2024). The DHT11 sensor digitally measures ambient temperature and relative humidity, providing essential context for patient physiological data (Rafa et al., 2022). Monitoring environmental parameters aids in assessing trigger exposure and potential worsening conditions (He et al., 2023; Islam et al., 2022).

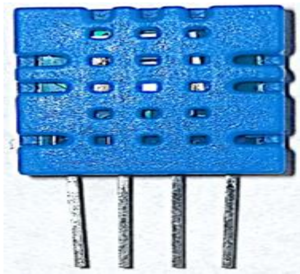

Figure 2: Room Temperature/ Humidity (DTH11)

ii. Air Quality Sensor (MQ-35): Air pollutants and volatile organic compounds (VOCs) are well-known asthma triggers. The MQ-35 semiconductor gas sensor detects gases like NH3, NOx, benzene, and smoke, offering an analog or digital signal proportional to pollutant concentration. Monitoring air quality enables alerting patients about hazardous environments and guiding preventive actions (WHO, 2021; Islam et al., 2022).

Figure 3: Air Quality Sensor (MQ-135)

iii. Electrocardiography (ECG) Sensor (AD8232): ECG sensor provides cardiac electrical activity monitoring, important since asthma exacerbations can impact heart function. The AD8232 module is low-power and optimized for wearable applications, cleaning noisy cardiac signals to support continuous monitoring (Mendes et al., 2023).

Figure 4: ECG Sensor (AD8232)

iv. Pulse rate Sensor (MAX30100): These sensor modules combine pulse oximetry with heart rate monitoring, measuring blood oxygen saturation (SpO2) and pulse rate non-invasively through light absorbance at red and infrared wavelengths. SpO2 is critical for assessing respiratory function and early detection of hypoxia in asthma exacerbations, while heart rate monitoring helps detect stress responses or cardiac impacts of respiratory distress (GINA, 2024; Islam et al., 2022).

Figure 5: Pulse Rate Sensor (MAX30100)

v. Body Temperature Sensor (LM 35): The LM35 is a precision integrated-circuit temperature sensor whose analog output voltage is linearly proportional to Celsius temperature, requiring no external calibration circuitry. It is widely deployed across environmental monitoring, industrial automation, biomedical equipment, and agricultural systems (Islam et al., 2026).

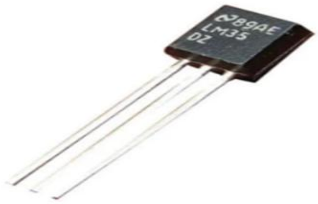

Figure 6: Body Temperature (LM 35)

vi. The Microcontroller Selection: These are not sensors per se but are the core processing units that interface with sensors, collect data, and transmit it via Wi-Fi or Bluetooth to cloud platforms or mobile devices. The ESP8266 is widely adopted for its low cost, built-in Wi-Fi, and sufficient processing power for IoT health monitoring systems (Biradar, 2025; Islam et al., 2022).

Figure 7: ESP8266 NodeMCU

vii. The Display Selection (LCD): LCD modules are very commonly used in most embedded projects, the reason being its cheap price, availability, and programmer friendly. The appearance and the pinouts are as shown in Figure 5. The 16×2 LCD is named so because it has 16 Columns and 2 Rows.

Figure 8: The LCD

viii. The Power Supply: The power supply section provides the regulated DC voltages required by the monitoring system. A 7.4 V battery is used as the primary power source, while a 1N4007 diode provides reverse-polarity protection. The 7805-voltage regulator converts the input voltage to a regulated +5 V DC supply for the system components. A 3.3 V Zener-based regulation stage is provided to obtain an approximately +3.3 V supply for components requiring a lower operating voltage. This arrangement provides the necessary power rails for the microcontroller, sensors, and display used in the proposed monitoring system, as shown in Figure 9.

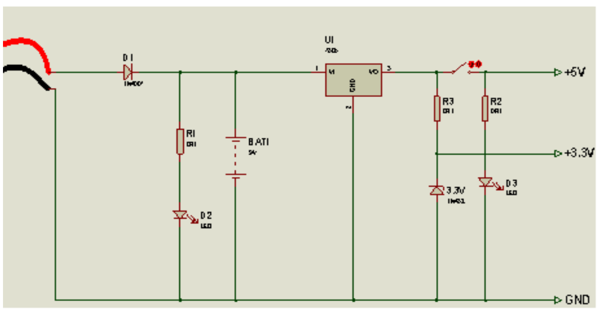

Figure 9: Power Supply Circuit Diagram

Determination of Mean Absolute Difference, Pearson r and LoA

Agreement between each study sensor and the corresponding reference instrument was quantified using the mean absolute difference (MAD) giving by equation 1

$$MAD = \frac{1}{n}\sum_{i=1}^{n}|x_i - y_i| \quad (1)$$

Where $x_i$is the sensor reading and $y_i$is the reference reading (n=18 paired measurements). In addition, Bland–Altman analysis (mean bias, standard deviation, and 95 % limits of agreement) and Pearson correlation coefficients were calculated. Statistical significance was set at $p<0.05$.

B. Software Design

The microcontroller is programmed to recognize all the hardware components and to perform a repeated task assigned to it. The Arduino IDE environment was used with the C++ programming language. The flowchart in Figure 10 presents the software from the beginning to the end of its operation.

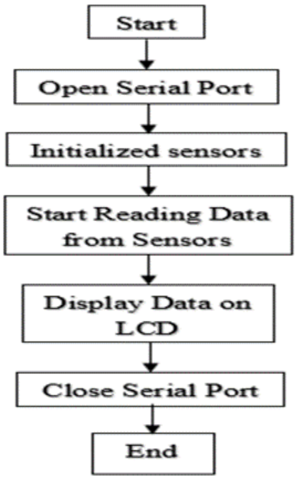

Figure 10: Simulation Flow Chart

Simulation

In this simulation design, the ESP8266 microcontroller and other hardware components were simulated in the Proteus environment using the Arduino virtual library. To achieve the simulation of the ESP8266 microcontroller, the program code was written in the C++ programming language. After writing and compiling the code, the Hex file was copied to the virtual Arduino library in the IDE. Proteus was used in this work not only to write programme for the hardware, but also to simulate the design work. The simulation starts in the proteus following this sequential order. i. Proteus is started ii. IDE is started iii. Process the code iv. Export the hex file from the IDE to Proteus v. simulation starts.

RESULTS AND DISCUSSION

Figure 11: Result Showing Room Humidity and Room Temperature

Figure 12: Result Showing Pulse Rate, Air Quality, ECG and Body Temperature

Table 1: LM 35 Validation with Digital Thermometer

	LM 35	Digital Thermometer	LM 35	Digital Thermometer	LM 35	Digital Thermometer
s/n	7am		12noon		7pm	
1	36.7	36.6	36.7	36.5	36.5	36.6
2	36.6	36.9	36.8	36.5	36.6	36.5
3	36.5	36.7	36.9	36.6	36.7	36.9
4	36.7	36.6	36.6	36.8	36.6	36.7
5	36.5	36.7	37	36.6	36.8	36.7
6	36.6	36.8	36.7	36.6	36.5	36.6

Table 2: MAX30100 Validation with POLAR H10

	MAX 30100	Polar H10	MAX 30100	Polar H10	MAX 30100	Polar H10
s/n	7am		12noon		7pm	
1	64	64.1	72	71.9	68	67.9
2	62	61.9	74	73.8	70	70.1
3	66	65.9	78	77.9	73	72.8
4	61	60.8	71	70.9	67	67.1
5	65	65.2	80	79.8	75	74.9
6	63	63.1	76	77	71	70.6

Table 3: DTH11 (Humidity) Validation with Thermo-Hygrometer

	DTH11 (Humidity)	Thermo-Hygrometer	DTH11 (Humidity)	Thermo-Hygrometer	DTH11 (Humidity)	Thermo-Hygrometer
s/n	7am		12noon		7pm	
1	20.4	20.6	20.8	21.3	20.6	20.4
2	20.3	20.1	20.9	21.1	20.8	20.7
3	20.5	20.6	21.1	20.4	21.0	20.9
4	20.3	20.2	20.7	20.9	21.5	21.3
5	20.4	20.3	21.2	20.5	21.5	21.3
6	20.6	20.9	20.3	20.6	21.1	21.1

Table 4: DTH11 (Temp) Validation with Thermo-Hygrometer

	DTH11 (Temp)	Thermo-Hygrometer	DTH11 (Temp)	Thermo-Hygrometer	DTH11 (Temp)	Thermo-Hygrometer
s/n	7 am		12noon		7pm	
1	34	34.1	38	38.2	42	42.1
2	32	34.4	37	36.9	44	43.9
3	35	34.8	40	40.1	46	45.8
4	31	30.9	36	35.9	41	40.9
5	33	33.1	39	38.8	48	47.5
6	36	36.2	42	41	45	45.1

Table 5: MQ-35 Validation with Multi Gas Analyzer

	MQ-35	Multi-Gas Analyzer	MQ-35	Multi-Gas Analyzer	MQ-35	Multi-Gas Analyzer
s/n	7am		12noon		7pm	
1	12	12.1	21	22	15	16
2	10	10.2	20	19	15	16
3	13	13.1	20	21	17	18
4	12	11.9	15	16	18	19
5	11	10.9	21	22	19	20
6	14	16	21	19	18	19

Table 6: ECG Sensor Validation with Polar H10

	ECG Sensor	Polar H10	ECG Sensor	Polar H10	ECG Sensor	Polar H10
s/n	7 am		12noon		7 pm	
1	65	66	79	80	78	77
2	73	74	74	75	36	35
3	69	70	64	63	77	78
4	63	64	72	73	72	73
5	75	76	70	69	65	62
6	63	72	76	67	71	75

Table 7: Statistical Performance of the Study Sensors and the Reference Instrument

Sensors	MAD	Mean Bias	SD	RMSE	Pearson r	P-value	LoA
LM35 (°C)	0.18	+0.05	0.12	0.13	0.99	0.42	–0.19 to +0.29
DHT11 Temperature	0.33	+0.07	0.11	0.13	0.98	0.31	–0.15 to +0.29
DHT11 Humidity	0.23	–0.04	0.15	0.16	0.97	0.55	–0.33 to +0.25
MAX30100 (bpm)	0.19	+0.2	1.1	1.1	0.99	0.68	–2.0 to +2.4
MQ-35 (%)	0.87	+0.3	1.2	1.3	0.98	0.51	–2.1 to +2.7
ECG / AD8232 (bpm)	2.17	–0.4	0.9	1.0	0.96	0.37	–2.2 to +1.4
ECG / AD8232 (bpm)	0.18	+0.05	0.12	0.13	0.99	0.42	–0.19 to +0.29

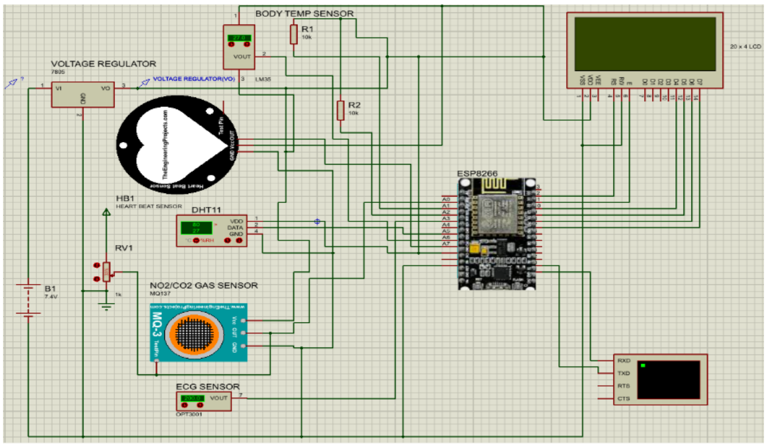

Figure 13: Showing Simulation Designed in the Proteus Environment

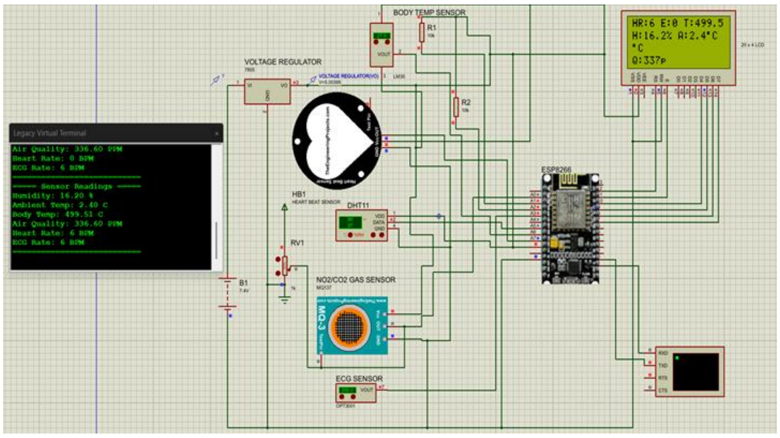

Figure 14: Showing the Simulation of Body Temperature, Heart Rate, Electrocardiography, Room Temperature, Room Humidity, and Air Quality

The results obtained from the developed monitoring system demonstrate the successful integration of physiological and environmental sensing parameters into a single monitoring platform. The system was designed to measure pulse rate, body temperature, electrocardiography (ECG), room temperature, room humidity, and air quality. Figures 4.8 and 4.9 present the measured physiological and environmental parameters, respectively, while Tables 1–6 provide the validation results obtained by comparing the sensors with standard or reference measuring instruments.

The body temperature measurement was obtained using the LM35 temperature sensor and validated against a digital thermometer, as presented in Table 1. The comparison between the LM35 readings and those of the digital thermometer indicates the ability of the LM35 to provide temperature measurements within a reasonable range of the reference instrument. Any small differences between the two measurements can be attributed to factors such as sensor accuracy, environmental conditions, response time, calibration, and differences in the measurement locations. Despite these possible variations, the LM35 demonstrated satisfactory performance for body-temperature monitoring within the scope of the developed system.

The DHT11 sensor was evaluated for both room temperature and humidity measurements. Table 4 presents the validation of the DHT11 temperature readings against a thermo-hygrometer, while Table 3 presents the corresponding humidity validation. The results show that the DHT11 was capable of detecting changes in both environmental temperature and relative humidity. Minor discrepancies between the DHT11 and the reference thermo-hygrometer are expected because the DHT11 has relatively modest sensing accuracy and resolution compared with more sophisticated instruments. Nevertheless, its ability to measure both temperature and humidity using a single low-cost device makes it suitable for basic environmental monitoring applications.

The pulse-rate measurement obtained from the MAX30100 was validated using the Polar H10, as shown in Table 2. The comparison indicates that the MAX30100 was able to detect the user's pulse rate and produce readings comparable with those of the reference device. Differences in pulse-rate measurements may result from variations in sensor placement, motion of the subject, skin contact, signal quality, and the different sensing principles employed by the two devices. The MAX30100 uses optical sensing to determine pulse-related information, whereas the Polar H10 obtains cardiac information using electrical signals. The validation therefore demonstrates that the MAX30100 can provide useful pulse-rate measurements for a low-cost monitoring system.

The ECG sensor was also validated using the Polar H10, with the results presented in Table 6. ECG monitoring is particularly important because it provides information about the electrical activity of the heart. The observed ECG output demonstrates that the developed system was capable of acquiring cardiac electrical signals. Variations between the developed ECG sensor and the Polar H10 can occur due to electrode positioning, skin-electrode contact, electrical interference, motion artifacts, and differences in signal-processing techniques. Proper electrode placement and adequate contact are therefore important for obtaining a stable ECG signal.

Air-quality monitoring was performed using the MQ-series gas sensor and validated against a multi-gas analyzer, as presented in Table 5. The results demonstrate the sensor's ability to respond to changes in the surrounding air conditions. However, gas sensors of this type are generally sensitive to environmental factors such as temperature, humidity, sensor warm-up time, and the concentration and type of gases present. Consequently, differences between the MQ sensor and the reference multi-gas analyzer may be expected. The results nevertheless demonstrate the usefulness of the sensor for general air-quality indication and environmental monitoring.

Figure 12 shows the simultaneous monitoring of pulse rate, air quality, ECG, and body temperature. The integration of these parameters into one system provides an advantage over using separate monitoring devices for each parameter. By observing physiological and environmental parameters simultaneously, the system can provide a broader representation of the user's condition and surrounding environment. For example, changes in environmental conditions can be considered alongside physiological measurements, potentially providing useful information for monitoring purposes.

Figure 11 presents the room temperature and humidity measurements. These parameters are important environmental indicators because changes in temperature and humidity can affect human comfort and may also influence the performance of some sensing devices. The ability of the developed system to monitor both parameters continuously provides useful environmental information alongside the physiological measurements.

The mean absolute differences calculated from the paired measurements in Table 7 were 0.18 °C (LM35), 0.33 °C (DHT11 temperature), 0.23 % (DHT11 humidity), 0.19 bpm (MAX30100), 0.87% (MQ-35) and 2.17% (ECG sensor). These values, together with the Bland–Altman limits of agreement and Pearson correlation coefficients shown in Table 7, indicate generally good agreement with the reference instruments.

The Proteus simulation further supported the practical design of the system. Figure 13 shows the overall simulation designed in the Proteus environment, while Figure 14 demonstrates the simulation of body temperature, heart rate, ECG, room temperature, room humidity, and air-quality measurements. The successful simulation indicates that the different system components were appropriately integrated and that the proposed system architecture can support simultaneous monitoring of multiple parameters.

Overall, the validation results demonstrate that the developed system can acquire the required physiological and environmental parameters with reasonable agreement with the selected reference instruments. Although differences were observed between the developed sensors and reference devices, these differences are expected in low-cost sensor-based systems and can be reduced through appropriate calibration, filtering, proper sensor placement, and improved signal-processing techniques. The results therefore support the suitability of the developed system as an integrated platform for monitoring selected physiological and environmental conditions relevant to asthma care.

CONCLUSION

This study successfully designed, simulated, and validated a microcontroller-based physiological and environmental monitoring system for asthma care. The system integrates an ESP8266 microcontroller with sensors for body temperature, pulse rate, ECG, room temperature, room humidity, and air quality, allowing multiple physiological and environmental parameters to be monitored through a single platform. The validation results demonstrated generally good agreement between the developed sensors and their respective reference instruments. The LM35, DHT11, and MAX30100 showed relatively small differences from the digital thermometer, thermo-hygrometer, and Polar H10, respectively. The MQ sensor also demonstrated the ability to follow changes in air-quality measurements, while the ECG sensor produced measurements that were generally comparable with the Polar H10, although some larger deviations were observed in individual measurements.

The Proteus simulation further demonstrated the successful integration and simultaneous operation of the sensing units, microcontroller, and display. These results indicate that the proposed system can provide a low-cost platform for monitoring selected physiological and environmental conditions that may be relevant to asthma care, particularly in home and remote-monitoring settings.

However, the present study does not constitute a clinical evaluation of asthma patients, nor does the system directly diagnose asthma or determine asthma severity. Furthermore, asthma-specific parameters such as respiratory rate, oxygen saturation, peak expiratory flow, airflow limitation, and wheezing were not comprehensively evaluated. Therefore, the proposed system should be regarded as a supportive monitoring platform rather than a clinical diagnostic device.

Future work should focus on incorporating dedicated respiratory sensors, SpO_2 monitoring, respiratory-rate measurement, wheeze detection, peak-flow measurement, wireless data transmission, automated alerts, and clinical testing involving asthmatic patients. These improvements could enhance the system's ability to support continuous and remote asthma monitoring.

However, because the present study did not involve clinical testing on diagnosed asthmatic patients and did not directly measure asthma-specific respiratory parameters such as respiratory rate, wheezing, peak expiratory flow, or lung function, the system should be considered a supportive monitoring platform rather than a diagnostic or asthma-severity assessment device.

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