

Original Research Article A Low-Cost Smart Wearable Glove for Non-invasive Health Monitoring

ABSTRACT

Wearable physiological signal monitoring systems hold notable potential in the future of personal healthcare by seamlessly integrating into daily life, providing continuous monitoring, and aiding in the early detection of health issues. This research presents a wearable health monitoring glove, with a focus on cost-effectiveness while maintaining efficiency for developing countries. The wearable glove can track vital physiological indicators like Blood Pressure, Body Temperature, Glucose level, Blood Oxygen Saturation, Hemoglobin level, ECG, Room Temperature, Humidity, and Motion Tracking. A user-friendly interface facilitates easy interaction, while efforts in energy-efficient design and power management aim to prolong battery life. Also, real-time data monitoring ensures precision in signal analysis and the extraction of vital health data of individuals. The proposed wearable hand glove utilizes a collection of sensors and integrates them towards the diverse detection of skin humidity, temperature, blood oxygen, hemoglobin, etc. non-invasively. Apart from its technical features, the research explores potential applications in healthcare, fitness tracking, and research fields, presenting a versatile solution. Beyond its technical attributes, the research explores potential applications in medical and personal healthcare, fitness tracking, sports, etc. Collaborative efforts with regulatory bodies assess the feasibility of obtaining necessary approvals or certifications, while scalability considerations pave the way for potential mass production and market deployment.

Keywords: Physiological signals, Real-time monitoring, Affordable, Hemoglobin level, Glucose level, Blood Pressure, Blood Oxygen Saturation, ECG, Temperature.

1. INTRODUCTION

In an age characterized by swift technological advancements, inconspicuously integrated wearable physiological monitoring systems are fundamentally reshaping our comprehension of human health. These gadgets not only hold the potential to improve healthcare delivery but also promote informed and health-conscious lifestyles. The 21st century has experienced a marked uptick in health and wellness technologies, ranging from smartphone applications that track daily activities to sophisticated wearables that monitor vital signs. This technological progression profoundly influences medical research, patient care, and public health endeavors. Wearable physiological monitoring systems serve as crucial links in healthcare, seamlessly blending into daily routines, offering continuous monitoring, and assisting in the early detection of health issues, particularly benefiting marginalized communities. Beyond their technological sophistication, these systems incorporate advanced components such as Arduino Nano, NodeMCU (ESP 8266), Max30102 sensor for pulse oximetry and heart-rate monitoring, GY906 Temperature Sensor, AD8232 ECG sensor, Force and Flex sensors, DHT22 Humidity Sensor, and a GSM module for emergency messages, rendering them formidable allies in the pursuit of well-being. This research presents a cost-effective wearable physiological signal monitoring system, transcending conventional boundaries in healthcare and wellness management.

2. LITERATURE REVIEW

In the realm of wearable physiological monitoring systems, a considerable body of research exists, offering invaluable insights and laying the technological groundwork that has facilitated current research [1]. The integration of Biomedical Technology, Informatics, and Medical Decision-making in contemporary Clinical Decision Support Systems (CDSS) has led to the acceptance of decentralized healthcare services, motivated by issues like an ageing population and rising hospital costs. However, in decentralized healthcare settings like Home Care, a notable issue arises regarding the discontinuity of medical care, impacting both the transmission of medical data and the quality of medical oversight. In order to tackle this difficulty, a prototype system that is both cost-effective and has been documented for monitoring basic physiological indicators has been developed[2]. This system's design incorporates affordable "off-the-shelf" technology to create wearable biomedical signal collecting modules. These modules allow a laptop computer to receive vital signs wirelessly. Any PC with a web browser and the necessary permission codes may monitor a patient's biological signals continuously and almost in real time using a web application. Excessive stress is a significant contributor to mental illness, affecting both physiological well-being (e.g., hypertension) and psychological conditions (e.g., depression). A prior study suggests an innovative approach to stress monitoring using disposable flexible sensors [3]. The widespread use of reasonably priced wearable medical technology and the proactive monitoring of crucial physiological data are becoming more and more recognized as answers to the high risks and expenses of providing personal healthcare. However, manual analysis of the vast volume of healthcare data generated by these sensors is impractical for clinicians. Current methods often rely on accurate feature detection from ambulatory physiological data, which can be challenging due to noise. Moreover, because users' physiological signal morphologies differ, these methods usually require manual system training for every patient. The first reports cover the components of wearable healthcare monitoring systems, their system architecture, and the challenges of putting these techniques into practice. They stress the need of creating techniques that are less dependent on precise feature extraction and flexible enough to accommodate variances among several patients. Early papers describe findings from testing on a public database from PhysioNet (QTDB) and explore real-time signal processing techniques for calculating the border boundaries of individual beats in streaming ECG data[4]. Advances in microelectronics and electronics in recent times have created opportunities for the development of inexpensive health preventative monitoring instruments. People are adopting these devices more frequently; they use sensors to translate different vital indications from the human body into electrical data. The creation of effective healthcare monitoring systems has been made easier by the integration of wearable and non-invasive sensors with communication media, which enhances the comfort of living at home[5]. Rehabilitative programs designed to help people with unilateral hemiplegia regain hand function so they can carry out everyday tasks on their own are based on successful bilateral hand training. Nevertheless, the quantity of training required for the best possible neuronal reorganization is frequently restricted by the resources available in clinical settings. A novel approach to these problems is presented in a recent study that combines a hand-sensing glove with a lightweight, portable hand exoskeleton for bilateral hand training and at-home rehabilitation. The less-affected hand's movement is detected by the hand-sensing glove using a flex sensor, which allows the afflicted hand to mimic similar motions using the hand exoskeleton. The system includes a virtual reality game to provide motivation for practicing repeated movements, which will ultimately help with everyday living activities. This innovative technique is especially helpful for individuals with hemiplegia who are still in the early stages of rehabilitation since it not only makes bilateral hand training easier, but it also helps with everyday duties[6].

3. METHODOLOGY

A wearable health monitoring system that is cost-effective employs two simultaneous processes, utilizing health sensors to gather raw data. This data then undergoes processing through NodeMCU and Arduino Nano, allowing for real-time display on an OLED screen. In instances of critical health conditions, the system activates the GSM module to send alerts, notifying designated individuals. The inclusion of flex and force sensors enables the detection of finger movements, which triggers alerts for assistance. This comprehensive system seamlessly integrates data processing, real-time visualization, IoT connectivity, and proactive alert mechanisms, ensuring immediate caregiver notification for prompt support. Further clarification of the system's operational processes is provided in accompanying block diagrams, as seen in Fig. 1.

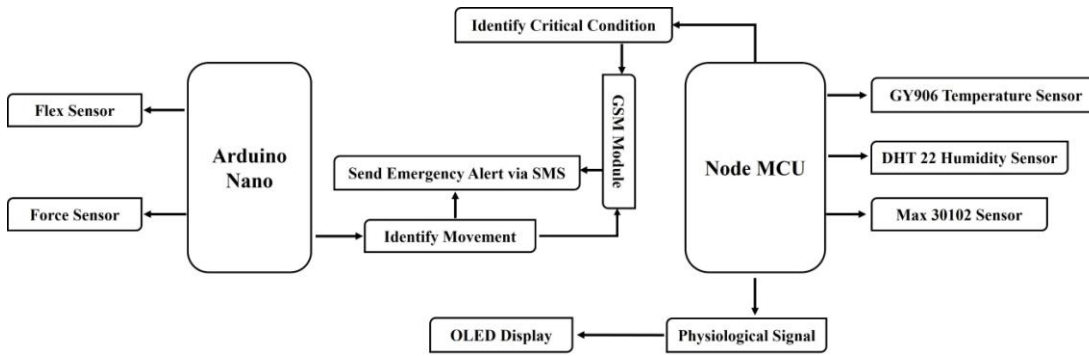


Fig. 1.Block diagram of the proposed work.

4. IMPLEMENTATION

In evaluating the efficacy of the affordable wearable physiological monitoring system integrated with IoT, a comprehensive strategy was adopted, covering both simulation and hardware validation techniques. By utilizing PROTEUS and ARDUINO, the simulation intricately replicated interconnected components such as the ECG sensor, blood sensor, temperature sensor, GSM module, and NodeMCU. This simulation framework proved to be a robust tool for meticulously assessing the system's functionality and reliability, facilitating the identification and resolution of potential challenges prior to physical implementation. The integration of the DHT22 sensor in the simulation allowed for the recording of both body temperature and humidity, with results displayed visually on the LCD screen. This simulation phase, as illustrated in the accompanying figure, played a pivotal role in offering valuable insights into the system's performance, guiding subsequent improvements throughout the research endeavor.

The heart rate sensor, activated by a push switch, provided real-time data on the individual's cardiovascular health. Its adjustability with a potentiometer offered personalized control over monitoring parameters. Pressure and flex sensors, sensitive to specific movements or pressure variations, triggered a blinking LED and activated the GSM module, initiating the transmission of an SMS to designated recipients to alert them of potential health issues. Virtual terminals were utilized to provide an up-to-date overview of the individual's physiological status and promptly address emergent situations.

This comprehensive approach, integrating simulation and hardware validation, not only bolsters the credibility of the research findings but also underscores the practical applicability and potential impact of the system in real-world health monitoring contexts.

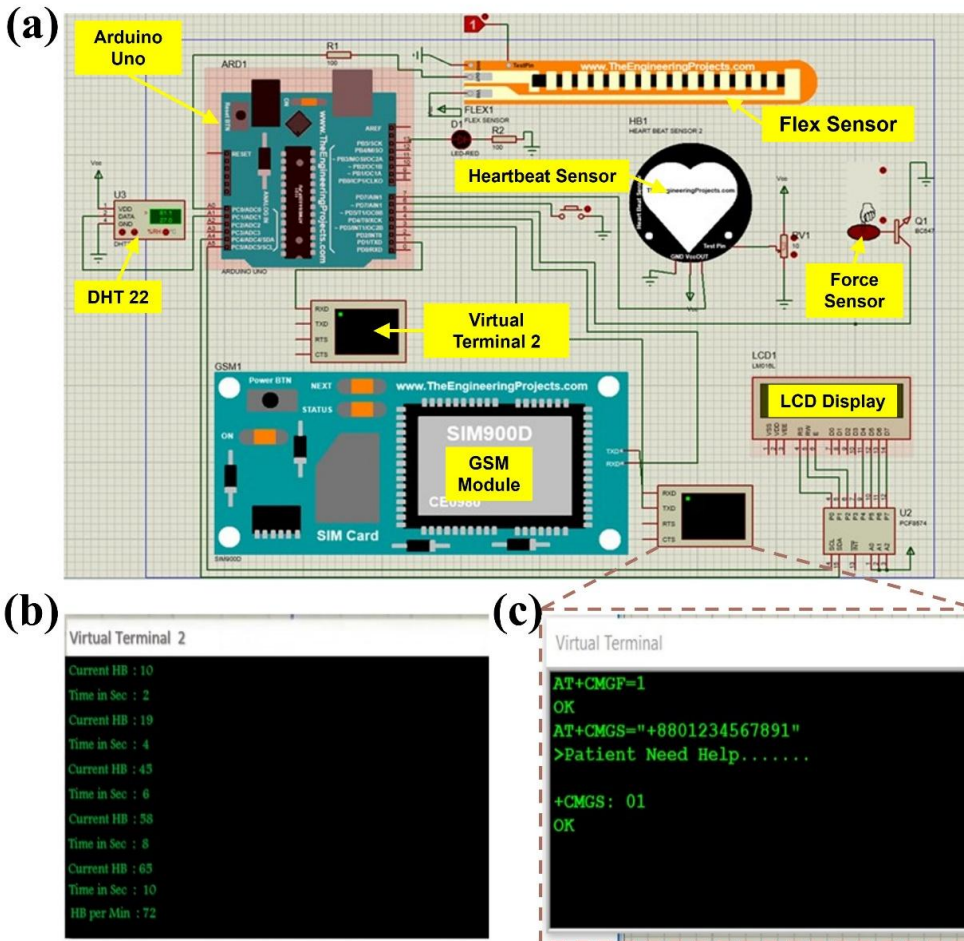


Fig.2. (a) Simulation result for measuring Body temperature and humidity, Simulation result for (b) measuring Heartbeat (c) sending SMS.

The successful implementation and robust performance of the hardware in this study were thoroughly confirmed through rigorous testing. The combination of integrated sensors, controllers, and communication modules exhibited remarkable reliability and accuracy in capturing and transmitting physiological data. The ECG sensor diligently monitored heart rate, the blood sensor provided precise blood-related parameters, and the temperature sensor ensured accurate readings. The GSM module played a crucial role in facilitating seamless communication, allowing timely alerts in critical health situations. Additionally, the integration of flex and force sensors enhanced the system's ability to cater to specific user requirements. The results from hardware testing affirm the feasibility and effectiveness of the wearable physiological monitoring system, emphasizing its potential applications in healthcare. The monitoring display offers real-time data from various sensors, providing a comprehensive overview of essential physiological metrics. Under normal health conditions, the system consistently monitors vital parameters, contributing to its proactive role in health monitoring solutions.

In Fig.3(a) and 3(b), the model of the smart glove is described. The glove is equipped with strategically positioned sensors, including flex and force sensors, to accurately capture data related to finger movements and applied force. These sensors are seamlessly integrated into the glove's fabric, ensuring user comfort and inconspicuousness. This meticulous design consideration further enhances the practicality and user experience of the wearable physiological monitoring system.

In this Fig.3(c) and 3(d) serves as an illustrative visual representation, meticulously detailing the physical structure of the proposed smart wearable glove prototype. Within this figure, labeled indications delineate the various sensors seamlessly incorporated into its design. This visual depiction offers a comprehensive overview of the glove's construction, adeptly highlighting specific sensor locations by name. The clarity and precision presented in this figure contribute to a deeper understanding of the intricate design and sensor placement within the smart wearable glove, providing support for the research findings and technological innovations presented in the study.

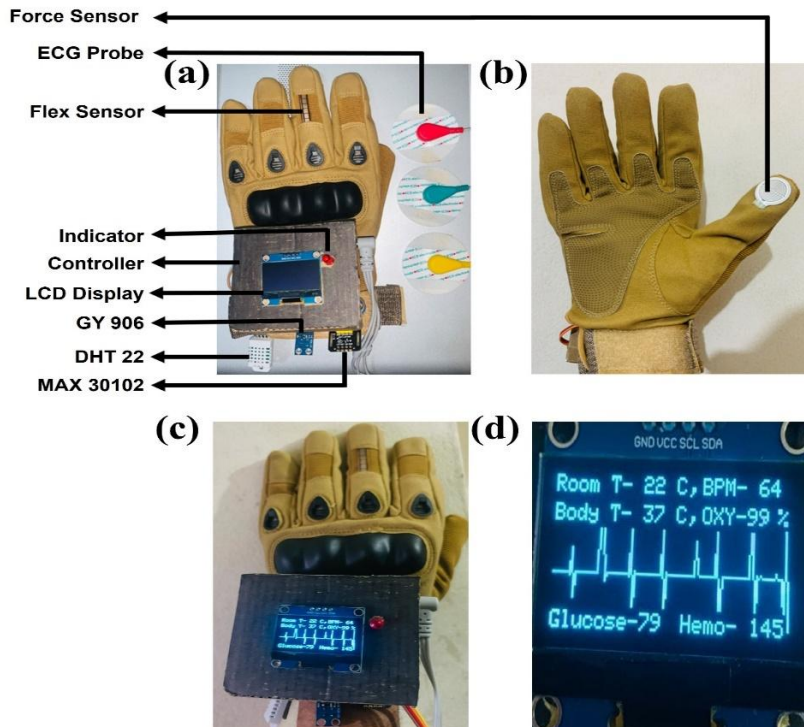


Fig.3.(a) Front view and (b) Back view of the smart glove, (c) proposed smart wearable glove prototype and (d) Display of the smart wearable glove.

5. RESULTS AND DISCUSSION

A thorough set of tests was conducted, and the outcomes have been carefully recorded. Here we recorded data from four-person, person-1: male and age: 25, person-2: female and age: 24, person-3: female and age: 25, person-4: male and age: 26. In Fig. 4(a), 4(b), and 4(c) offer visual summaries of the testing phase for the proposed system under three different conditions: rest, normal activity, and walking. These figures depict the setup of the experiments, the methodologies used for data collection, and the key parameters measured during each condition. The graphical representations within these figures are crucial in demonstrating how the proposed system functions across various scenarios, allowing for a visual understanding of any observed differences or trends during rest, normal activity, and walking. This aids in a detailed assessment of the system's performance across different physiological states.

In Fig. 4(d) illustrates the experimental setup, data collection methods, and key parameters measured during each condition. It presents real-time data from various sensors after wearing the gloves, excluding humidity due to space limitations. The parameters include Body Temperature (Body T) and Room Temperature (Room T), measured in degrees Celsius ($^{\circ}\text{C}$). Additionally, BPM represents heart rate or blood pressure per minute, OXY signifies blood-saturated oxygen in percentage (%), Glucose denotes blood-saturated glucose in milligrams per deciliter (mg/dL), and Hemo indicates blood hemoglobin count in grams per deciliter (g/dL).

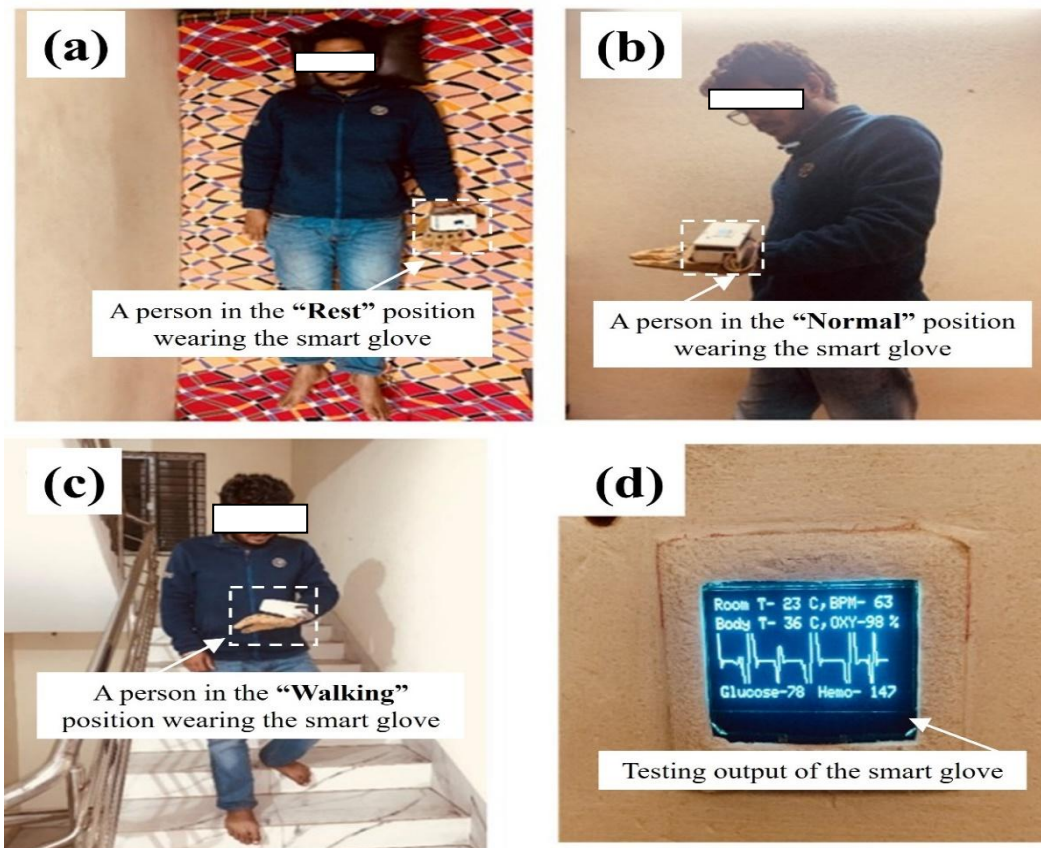


Fig.4. Test Conditions (a) Rest, (b) Normal, (c) Walking, (d) Test Result.

In Fig.5(a), the graphical representation of our test results provides insights into the variation in heart rate (BPM) under different conditions. Comparing BPM at rest and during walking shows a noticeable increase during physical activity. Despite the higher BPM during walking, the values consistently fall within the normal range [7], indicating the individual's good cardiovascular health. The slight rise in BPM during walking is a typical physiological response as the heart pumps blood faster to meet the demands of increased activity. Therefore, based on the results, it can be inferred that the person is in good physical condition.

Moving to Fig.5(b), body temperature readings of 36°C at rest, 37°C under normal conditions, and 38°C while walking are within the generally accepted range for body temperature [8]. In this case, the observed temperatures do not suggest a significant deviation from the norm.

In Fig.5(c), the values for the three scenarios—resting, normal, and walking—remain within the normal range, as indicated by [9]. The slight increase in oxygen saturation during walking is a typical physiological response associated with the natural enhancement of blood circulation during physical activity. This indicates good cardiovascular function.

In Fig.5(d), the consistent hemoglobin levels across the three scenarios—resting, normal, and walking—suggest that movement, in this context, does not notably impact hemoglobin levels. The oxygen-carrying protein in red blood cells called hemoglobin is more impacted by medical disorders, diet, and general health than by recent physical exercise. As the levels consistently fall within the normal range [10], it can be concluded that the individual is in good health regarding this aspect.

Proceeding to Fig. 5(e), the graphical representation of skin humidity during walking conditions shows an increase exceeding the normal acceptable range, as indicated by [11]. This is attributed to sweating during physical activity. Sweat, mainly composed of water and electrolytes, is released through the skin pores to regulate body temperature, resulting in increased skin humidity.

Finally, in Fig.5(f), it is observed that the values for glucose levels remain consistent across all three conditions—resting, normal, and walking. This indicates that neither walking nor resting directly affects glucose levels in this context. Notably, the observed glucose values fall within the normal range [12]. Glucose regulation is primarily influenced by factors such as

insulin production, dietary habits, and metabolic processes, rather than immediate physical activity or rest. Maintaining glucose within the normal range is a positive indicator of metabolic health.

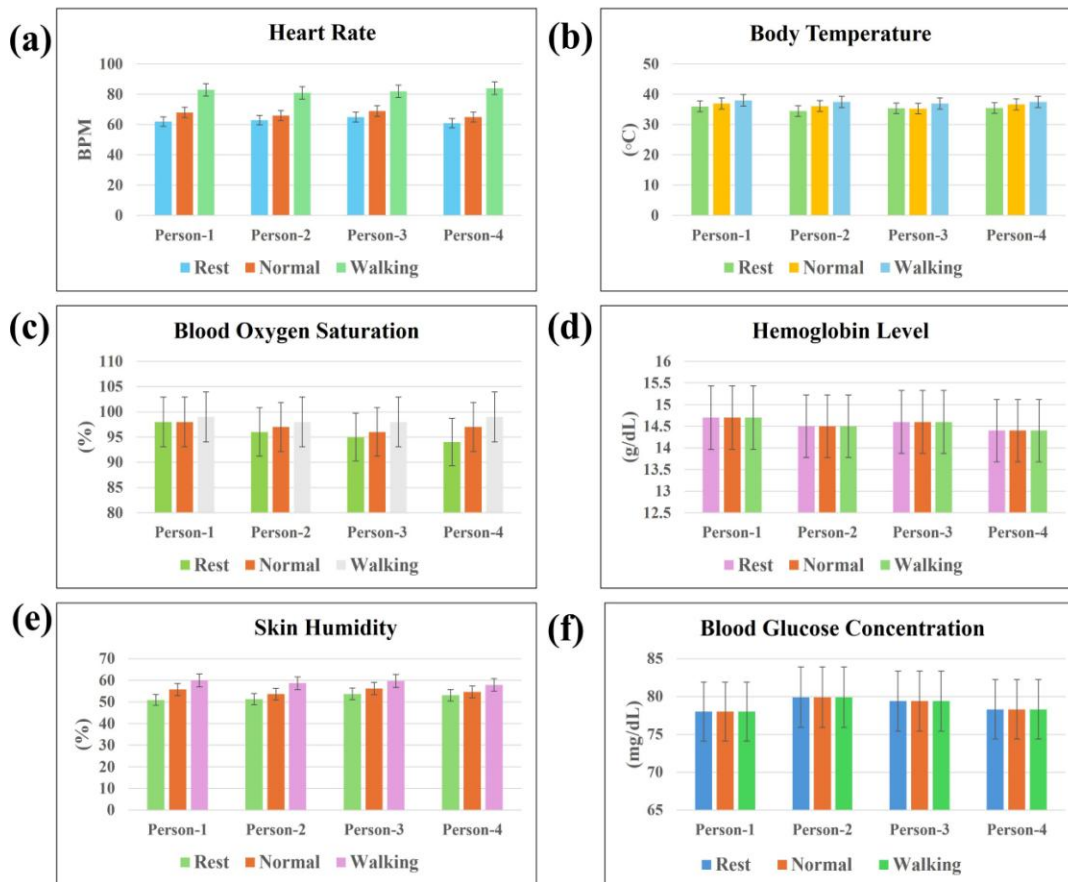


Fig.5. The graphical representation for (a) Heart Rate, (b) Body Temperature, (c) Blood Oxygen, (d) Blood Hemoglobin Level, (e) Skin Humidity, (f) Blood Glucose Concentration.

In Fig. 6(b), the monitoring display exhibits real-time data from various sensors, with humidity omitted due to space constraints. Parameters include Room T (Room Temperature) and Body T (Body Temperature), both measured in degrees Celsius (°C). Additionally, BMP indicates heart rate or blood pressure per minute, OXY represents blood-saturated oxygen in percentage (%), Glucose denotes blood-saturated glucose in milligrams per deciliter (mg/dL), and Hemo signifies blood hemoglobin count in grams per liter (g/L). This comprehensive display offers a snapshot of vital physiological metrics for effective health monitoring. Data collection occurs under normal health conditions, with the wearable physiological monitoring system continuously monitoring various vital parameters. If any deviation from predefined sensor values occurs, a robust alert system is activated, notifying the concerned person via phone through the GSM module. This alert serves as an early warning mechanism, facilitating timely intervention and assistance. In critical situations, the system initiates an emergency protocol. If the wearable device detects a severe health concern, an automatic emergency call is placed to the nearest medical center or ambulance service. This immediate response ensures prompt and potentially life-saving assistance is dispatched to the patient, mitigating risks associated with critical health conditions. Through this proactive and automated approach, the wearable physiological monitoring system not only monitors the user's health but also acts as a crucial link in facilitating rapid emergency response when needed.

In Fig. 6(d), an intriguing scenario is presented where the wearable physiological monitoring system shows responsiveness to the user's specific needs.

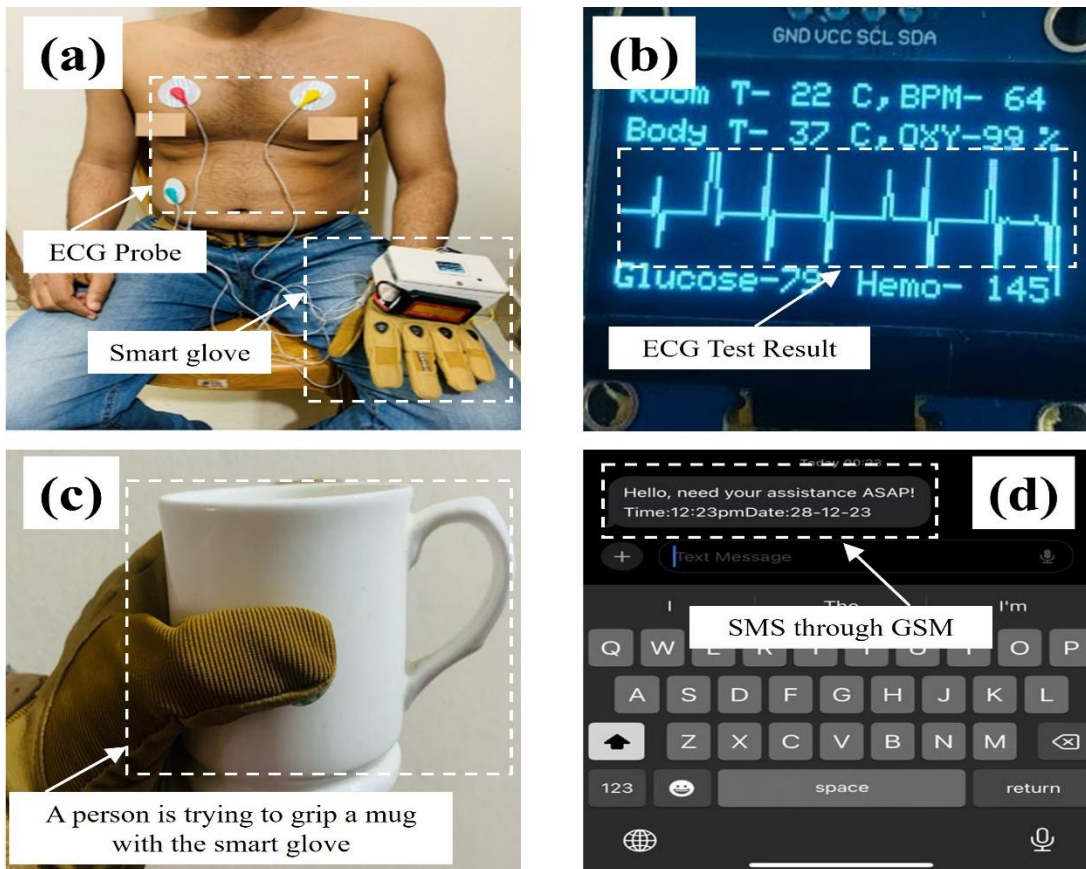


Fig.6. (a)&(b) Output showing on Display for ECG, (c) Activation of Pressure and Flex sensors, (d)SMS Through GSM.

In this situation, when the patient indicates a wish to hold or grasp an object, the intelligent design of the system becomes operational. Flex and pressure sensors, strategically incorporated, capture subtle finger movements and applied pressure, triggering an SMS alert sent via the GSM module to the designated individual, informing them of the patient's need for assistance. Upon detecting these movements or pressure alterations, an advanced mechanism is activated, resulting in an immediate and automated response through a text message alert. The aim of this alert is to promptly update the designated individual about the patient's unique condition. This proactive approach ensures that necessary help or support can be promptly provided in response to the specific requirements voiced by the patient.

Table 1. Table showing range of parameter

Sensor	Range of parameter
BPM [7].	49 to 100 (Men) 55 to 108 (Woman).
Body Temperature [8].	0–12 months: 95.8–99.3°F (36.7–37.3°C), Children: 97.6–99.3°F (36.4–37.4°C), Adults: 96–98°F (35.6–36.7°C) , Adults over age 65: 93–98.6°F (33.9–37°C).
Blood Glucose [12].	Between 70 mg/dL (3.9 mmol/L) and 100 mg/dL (5.6 mmol/L).
Skin Humidity [11]	Between 30% and 60%
Blood Hemoglobin [10]	For adult males: 13.8 to 17.2 grams per deciliter (g/dL). For adult females: 12.1 to 15.1 g/dL.
Blood Oxygen Saturation [9]	Between 95% and 100%

ECG [20].

RR interval: 0.6-1.2 seconds.
 P wave: 80 milliseconds.
 PR interval: 120-200 milliseconds.
 PR segment: 50-120 milliseconds.
 QRS complex: 80-100 milliseconds.
 ST segment: 80-120 milliseconds.
 T wave: 160 milliseconds.

6. PROJECT FINANCE

The summarized table provides a comprehensive overview of the essential components needed for the integrated waste management system, along with their estimated costs. The project's main objective was to develop this thorough system, and the cost analysis focuses on acquiring the necessary equipment for its successful implementation. Estimating project costs required extensive research, involving a thorough examination of components listed on various producers' and sellers' websites in Bangladesh and India. This thorough approach also involved a detailed comparison of costs between used sensors and similar ones available in the Indian market, offering a comprehensive understanding of the financial aspects related to acquiring resources for the project.

Table 2. Thefinal cost for the project and analysis

Name of component	Quantity Used	Our System with integrated sensors (in BDT)	Equivalent Sensors (India) (in BDT)
Node MCU	1	575	1795 (ESP 32)
GY906Temperature Sensor	1	1440	1500 (Temperature Sensor Max 30205)
DHT 22 Humidity Sensor	1	190	1707 (Grove - Temperature & Humidity Sensor Pro)
Ad8232 ECG Sensor	1	790	4645 (Proto Central MAX30003 Single-lead ECG Breakout Board - v2(ECG))
Max30102 Sensor	1	390	5307 (Pulse Express Pulse-Ox & Heart Rate Sensor with MAX32664)
Flex Sensor	1	1350	1474 (Flex Sensor)
Force Sensitive Resistor 0.5	1	890	799 (Force Sensitive Resistor 0.5)
Arduino Nano	1	540	1321 (Arduino Nano Every)
GSM Module (Sim 800L)	1	400	425 (GSM Module (Sim 800L))
Resistor - 10k	10	18	18(Resistor - 10k)
Red LED	5	5	5(Red LED)
Hand Gloves	1	600	600 (Hand Gloves)
0.96 OLED Display	1	420	500 (0.96 OLED Display)
Breadboard	1	140	180 (Breadboard)
Jumper Cable (Male to Male/Male to Female/Female to Female)	5	500	500
Li po Battery	1	1700	1700 (Li po Battery)
Total (in BDT)		9948	20681

7. CONCLUSION

The proposed wearable glove for non-invasive physiological health monitoring system research has accomplished all outlined objectives, surmounting inherent limitations through dedicated and meticulous efforts. A rigorous examination of the integrated system was conducted on the human body for real-time validation of health conditions, followed by a thorough analysis of their final impacts. This assessment included the identification of future scopes and the provision of recommendations for further developments. A comprehensive financial analysis was undertaken to assess the project's economic viability and sustainability. In summation, this research not only showcases financial feasibility but also holds the promise of long-term sustainability in developing countries towards personal health care.

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