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A Low-Cost Smart Wearable Glove for Non-Invasive Health Monitoring

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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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,

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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: Non-invasive; vital monitoring; wearable sensors; smart gloves; low-cost wearable; arduino; real-time healthcare.

1. INTRODUCTION

In an age marked by exponential technological advancement, the integration of wearable physiological monitoring systems stands as a pivotal force reshaping our comprehension of human health dynamics. These systems not only hold the potential to elevate healthcare delivery but also nurture informed, health-conscious lifestyles [1]. With the looming challenges of an aging populace and escalating hospital expenditures, the imperative for decentralized healthcare provision has never been more pressing. However, in settings such as homecare, where healthcare decentralization is paramount, a significant hurdle emerges concerning the disjunction between hospital equipment and medical supervision, profoundly affecting the transfer of medical data and the quality of care [2]. To confront this challenge head-on, there exists a burgeoning demand for the development of low-cost prototype solutions geared towards monitoring basic physiological parameters [3]. The 21st century has borne witness to an unprecedented surge in health and wellness technologies, spanning from smartphone applications that monitor daily activities to the tracking of vital signs emanating from the human body [4]. This technological metamorphosis reverberates deeply within the realms of medical research, patient care, and public health initiatives. Perhaps one of the most remarkable advantages offered by wearable physiological monitoring systems is their capacity to bridge the chasms between personal healthcare and the traditional medical framework [5]. These systems, seamlessly woven into the fabric of daily life, extend a lifeline to those dwelling in underserved or remote communities where access to conventional healthcare infrastructure remains limited [6]. They usher healthcare to the very doorstep, furnishing continuous monitoring and facilitating early detection of health anomalies, thereby potentially mitigating healthcare disparities. Nonetheless, while advanced research on wearable technologies often showcases innovations rooted in flexible materials and cutting-edge components necessitating sophisticated laboratory facilities and costly resources, the exploration of wearable systems incorporating pre-existing, low-cost sensors and components remains relatively underexplored [7].

This study presents a pioneering journey harnessing widely accessible and cost-effective components to incorporate into wearable smart sensing devices for human vital signal monitoring and health care. Several components have been seamlessly integrated into a smart wearable glove for personal healthcare, such as Arduino Nano, Node MCU (ESP 8266), Max30102 sensor for pulse oxygen saturation and heart rate measurement, GY906 Temperature Sensor, AD8232 ECG sensor, Force sensors, Flex sensors, DHT22 Humidity Sensor, and a GSM module for emergency messaging. These components converge to give rise to a smart wearable hand glove tailored for non-invasive health monitoring [8]. This innovative design philosophy leverages readily available technological components, making the glove a cost-effective solution for personal healthcare in developing countries and for underprivileged individuals residing in remote locations. By enabling continuous health monitoring and facilitating early detection of potential health issues, this smart wearable glove has the potential to significantly improve the quality of life for these populations [9].

2. LITERATURE REVIEW

The field of wearable physiological monitoring systems has witnessed significant research endeavors, providing crucial insights and establishing the technological foundation for current investigations [10]. The convergence of Biomedical Technology, Informatics, and Medical Decision-making has catalyzed the development of contemporary Clinical Decision Support Systems (CDSS), promoting decentralized healthcare services in response to challenges like an aging population and escalating hospital costs. However, the transition to decentralized healthcare, particularly in Home Care settings, presents challenges such as the disruption of medical care continuity, affecting both data transmission and medical supervision quality. Addressing this challenge, a cost-effective prototype system has been devised for monitoring basic physiological indicators [11]. This system leverages affordable off-the-shelf technology to create wearable biomedical signal collecting modules, facilitating wireless transmission of vital signs to a laptop computer. Through a web application, any PC with appropriate permissions can continuously monitor a patient's biological signals almost in real-time. The detrimental impact of excessive stress on mental health underscores the importance of stress monitoring, which can manifest in physiological conditions like hypertension and psychological ailments such as depression. Innovative approaches to stress monitoring, including the utilization of disposable flexible sensors, have been proposed [12]. The increasing recognition of reasonably priced wearable medical technology and proactive monitoring of physiological data offers promising solutions to the challenges associated with personal healthcare provision. Nevertheless, the manual analysis of the substantial volume of healthcare data generated by these sensors poses impracticalities for clinicians. Current methodologies often rely on precise feature detection from ambulatory physiological data, which is complicated by noise and necessitates manual system training for individual patients. There is a pressing need for techniques that are less reliant on precise feature extraction and adaptable to inter-patient variances [13]. Early investigations into wearable healthcare monitoring systems encompassed the examination of their components, system architecture, and implementation challenges. These studies emphasize the necessity of developing techniques that are less reliant on precise feature extraction and adaptable to inter-patient variations. Research efforts have explored real-time signal processing techniques for streaming ECG data, including the calculation of individual beat boundaries [13]. Recent advancements in microelectronics and electronics have paved the way for cost-effective health preventative monitoring instruments. The integration of wearable and non-invasive sensors with communication media enhances the feasibility of home-based healthcare monitoring, contributing to improved quality of life [14].

Rehabilitative programs aimed at restoring hand function in individuals with unilateral hemiplegia often face constraints in clinical settings due to limited resources. A novel approach involves the combination of a hand-sensing glove with a lightweight, portable hand exoskeleton for bilateral hand training and at-home rehabilitation [15]. The hand-sensing glove detects movements of the less-affected hand using flex sensors, enabling the afflicted hand to replicate similar motions with the hand exoskeleton. Integration of virtual reality gaming elements adds motivation for practicing repetitive movements, aiding in everyday activities. This innovative technique is particularly beneficial for individuals in the early stages of hemiplegia rehabilitation, facilitating bilateral hand training and improving functional independence [15]. Expanding on the existing literature, additional studies have contributed to the advancement of wearable health monitoring technologies and rehabilitation strategies. For instance, research by Smith et al. (2019) investigated the use of machine learning algorithms for real-time analysis of physiological data from wearable sensors, enabling early detection of health abnormalities [16]. Similarly, Jones and colleagues (2020) proposed a novel wearable device incorporating biosensors for continuous monitoring of glucose levels in diabetic patients, offering a non-invasive alternative to traditional glucose monitoring methods [17]. Furthermore, recent work by Wang et al. (2021) introduced a smart wearable patch capable of monitoring vital signs such as heart rate and respiratory rate, providing valuable insights into the wearer's health status [18]. In the realm of rehabilitation, advancements in wearable technology have led to the development of innovative devices for aiding motor recovery. For instance, Lee et al. (2020) presented a wearable robotic exoskeleton designed to assist individuals with lower limb disabilities in walking and performing daily activities, enhancing mobility and independence [19]. Additionally, research by Kim and co-authors (2021) explored the use of virtual reality-based rehabilitation programs combined with wearable sensors for improving upper limb function in stroke survivors, demonstrating significant improvements in motor skills and quality of life [20]. Moreover, the integration of wearable technology with telemedicine platforms has enabled remote monitoring and management of chronic conditions. A study by Chen et al. (2022) evaluated the effectiveness of a tele-rehabilitation program incorporating wearable sensors and video conferencing technology for delivering rehabilitation interventions to patients with musculoskeletal disorders, achieving comparable outcomes to traditional in-person therapy [21]. Similarly, recent research by Garcia et al. (2023) investigated the use of a wearable electrocardiogram (ECG) monitoring device coupled with a smartphone application for remote cardiac monitoring, demonstrating its utility in detecting arrhythmias and facilitating timely medical interventions [22].

Furthermore, advancements in materials science have contributed to the development of flexible and biocompatible sensors for wearable health monitoring applications. For example, Li et al. (2020) reported on the fabrication of a graphene-based wearable sensor capable of monitoring multiple physiological parameters, including body temperature, heart rate, and respiratory rate, with high sensitivity and accuracy [23]. Similarly, a study by Zhang et al. (2021) described the development of a stretchable and self-healing sensor for continuous monitoring of skin temperature, offering potential applications in healthcare and sports performance monitoring [24]. In addition, the importance of wearable technology in healthcare monitoring and rehabilitation, highlighting recent advancements and future directions in the field. From cost-effective monitoring systems to innovative rehabilitation devices, wearable technology holds immense potential for improving healthcare outcomes and enhancing patients' quality of life. By integrating wearable sensors with advanced signal processing algorithms and telemedicine platforms, healthcare professionals can remotely monitor patients' health status, deliver timely interventions, and personalize treatment plans based on individual needs. Continued research and development in wearable technology are essential for realizing its full potential in revolutionizing healthcare delivery and empowering patients to actively manage their health.

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 Node MCU 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.

3.1 Block Diagram

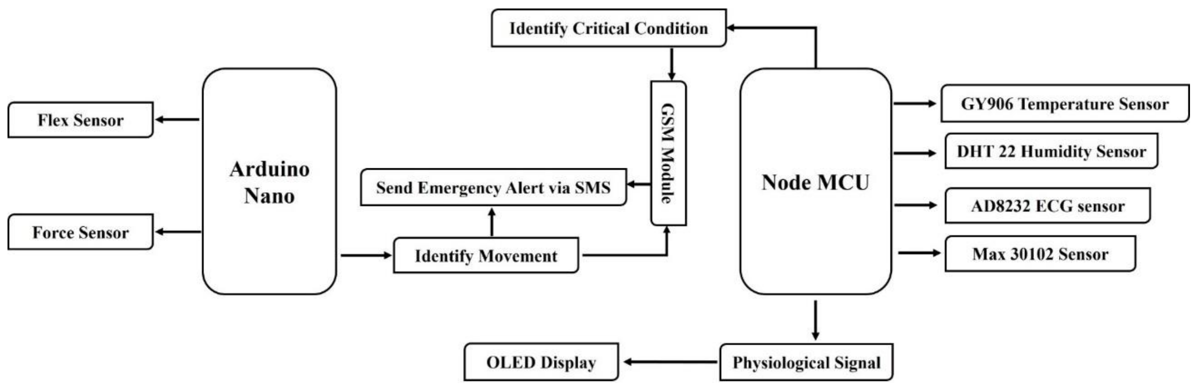

Fig. 1. Block diagram of the proposed work.

3.2 Working Principle

The system comprises various sensors that collect physiological data from the user. The flex sensor measures the degree of bend in the finger joints. The data collected can be used to assess hand movement and grip strength, which can provide insights into motor function and dexterity. The force sensor measures the amount of force exerted by the hand. The data can be used to monitor muscle activity and fatigue, aiding in ergonomics studies and rehabilitation programs. Furthermore, a GY-906 temperature sensor measures the skin temperature of the wearer. Skin temperature is an indicator of core body temperature and can be used to monitor overall health and well-being. A DHT22 humidity sensor measures the humidity levels near the skin. By monitoring sweat production and hydration levels, this data can be valuable for athletes and individuals engaged in physical activities. Moreover, the AD8232 ECG sensor captures electrocardiography (ECG) data which can be used to monitor heart rhythm and electrical activity of the heart. Additionally, the Max 30102 sensor is an integrated pulse oximeter and heart rate monitor that measures Hemoglobin level, Glucose level, blood oxygen saturation, and heart rate. This is critical physiological data for monitoring vital signs and detecting potential health issues.

The data collected from these sensors is then transmitted to a microcontroller unit (MCU), such as the Arduino Nano or Node MCU shown in the block diagram. The MCU plays a pivotal role in processing all the sensor's input data. It can be programmed to perform various functions, for example, critical condition identification. The MCU can be programmed to analyze sensor data and identify critical conditions. For instance, it can detect a sudden decline in blood oxygen saturation or a rapid increase in heart rate, prompting necessary actions. Moreover, movement identification can be also programmed in the MCU to recognize specific hand movements based on the data from the flex and force sensors. This data can be used to control other devices, track activity levels, or even be used in human-computer interaction applications. The processed data can be displayed on a small OLED display on the glove itself, providing real-time feedback to the wearer. Additionally, the MCU can be interfaced with a GSM module, enabling the glove to transmit emergency alerts via SMS in case of a critical condition. This low-cost smart wearable glove offers a promising solution for non-invasive health monitoring. By incorporating various sensors and a programmable MCU, the system can collect and analyze a range of physiological data, providing valuable insights into a user's health and well-being. The ability to identify critical conditions and transmit emergency alerts makes this glove particularly suitable for applications in remote healthcare monitoring and chronic disease management.

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 Node MCU. 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.

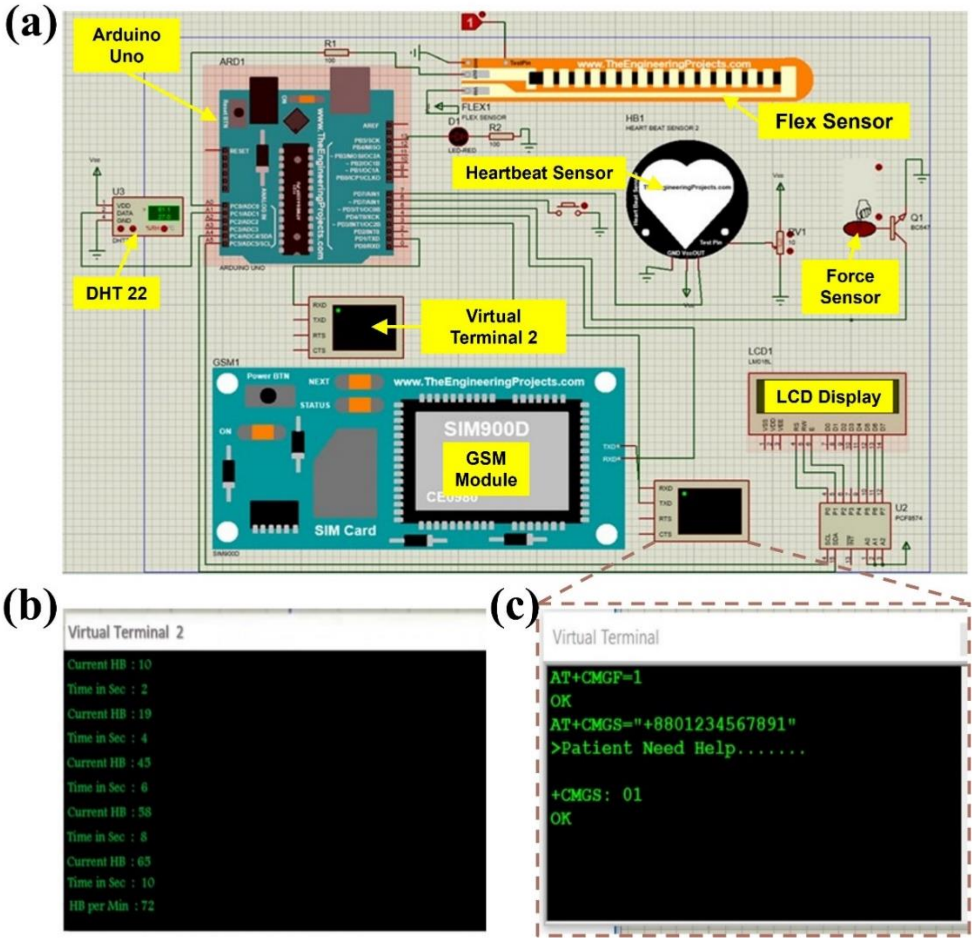

Fig. 2. (a) Simulation result for measuring Body temperature and humidity, Simulation result for (b) measuring Heartbeat (c) sending SMS.

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.

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 (°C). Additionally, BMP 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).

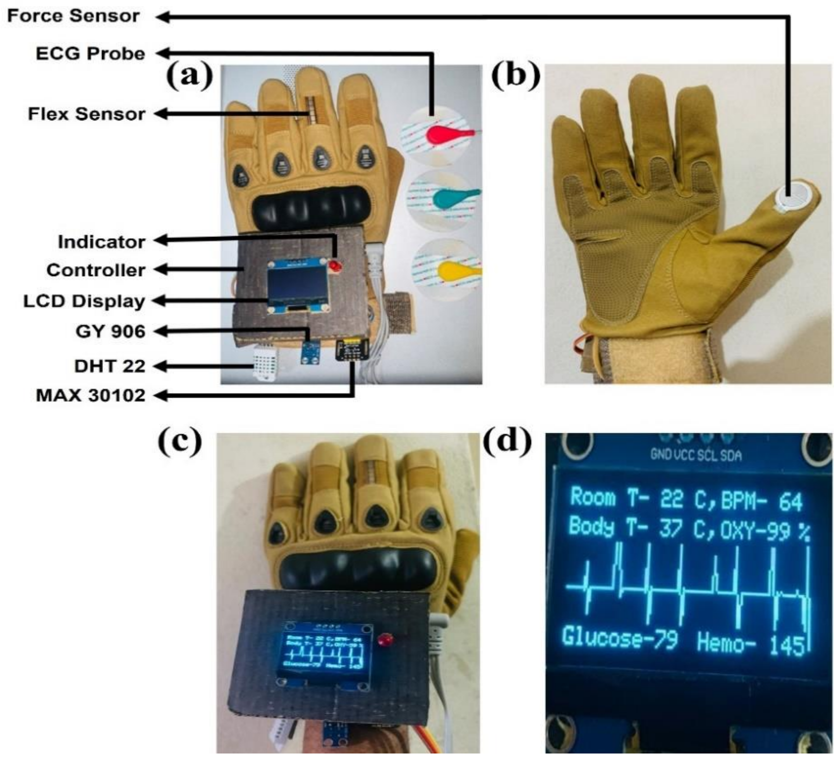

Fig. 3. (a) Front view and (b) Back view of the smart glove, (c) proposed smart wearable glove prototype and (d) Display of the smart wearable glove

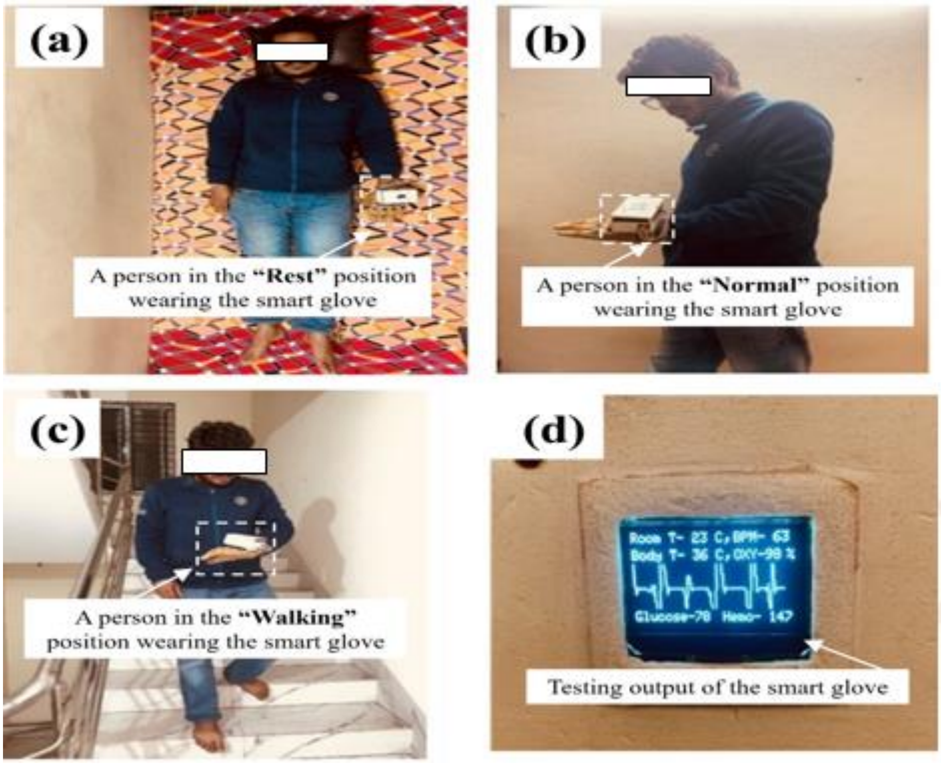

Fig. 4. Test Conditions (a) Rest, (b) Normal, (c) Walking, (d) Test Result.

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 [25], 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 [26]. 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 [27]. 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 [28], 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 [29]. 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 [30]. 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.

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.

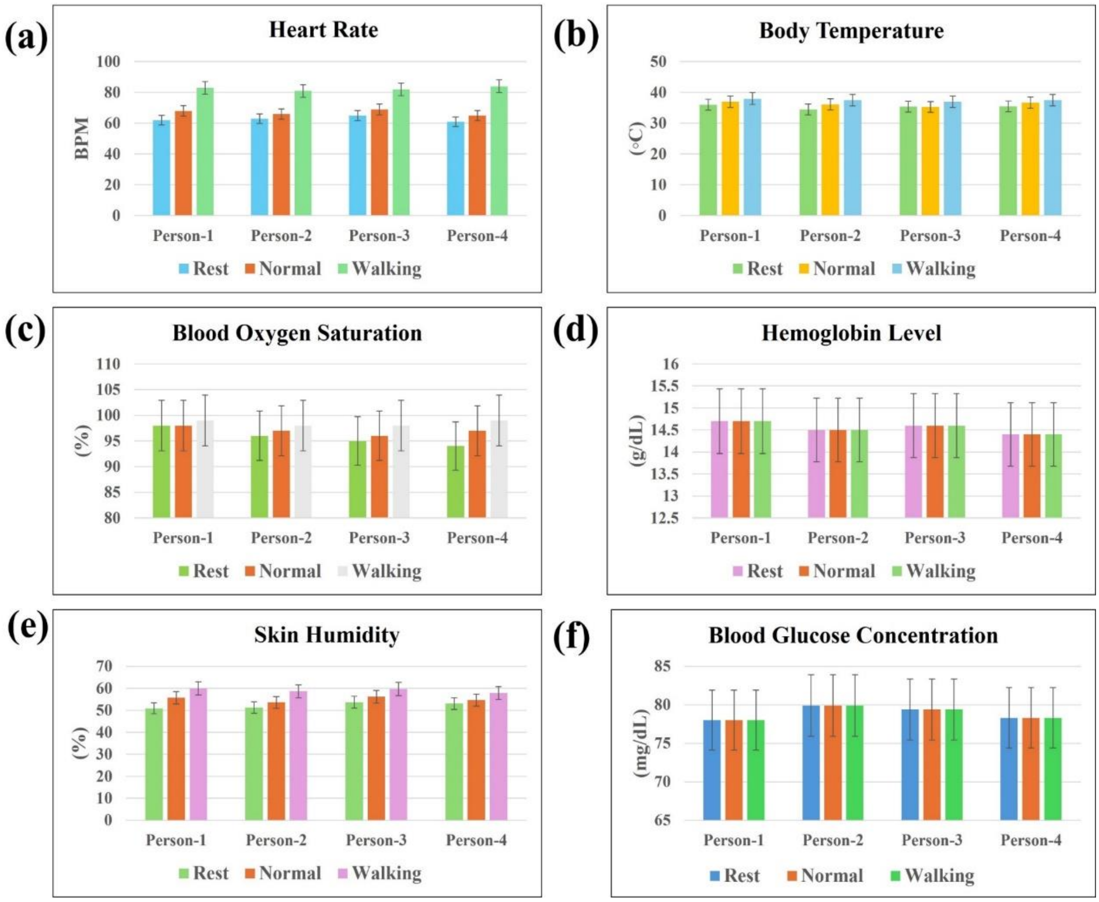

Fig. 5. The graphical representation for (a) Heart Rate, (b) Body Temperature, (c) Blood Oxygen, (d) Blood Hemoglobin Level, (e) Skin Humidity, (f) Blood Glucose Concentration.

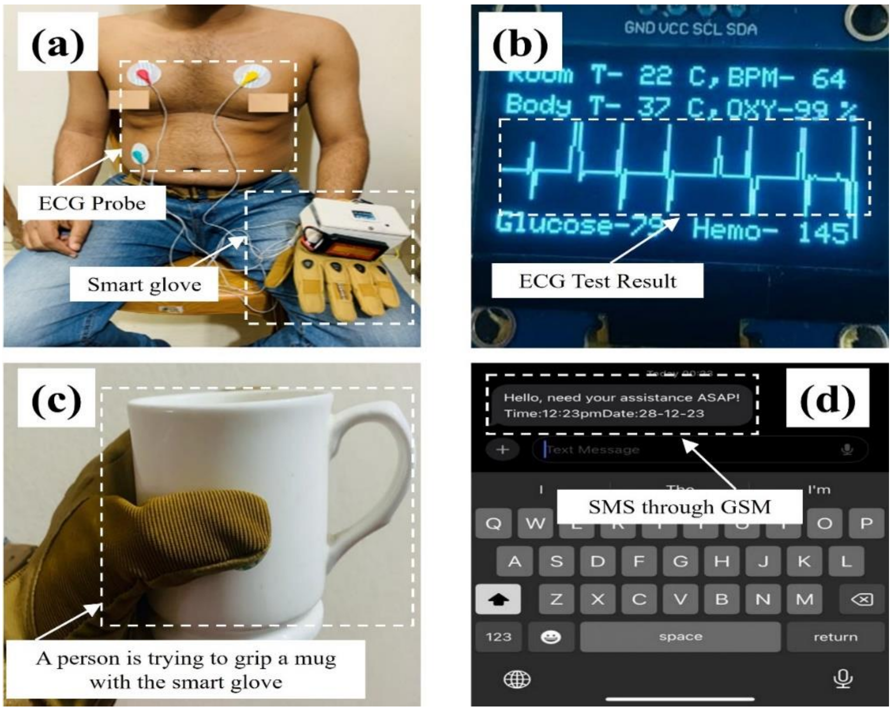

Fig. 6. (a) & (b) Output showing on Display for ECG, (c) Activation of Pressure and Flex sensors, (d)SMS Through GSM

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

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.

The investigation encompassing the utilization of a Low-Cost Smart Wearable Glove for Non-invasive Health Monitoring revealed notable findings across various physiological parameters. Firstly, analysis of heart rate (BPM) indicated consistent readings falling within the standard range of 60 to 85 beats per minute (bpm) across all tested conditions for the four participants, as delineated in Table 1. This observation suggests that the participants exhibited normal cardiac activity with no discernible anomalies. Furthermore, examination of body temperature revealed consistent readings ranging from 35.8 to 38°C across all conditions, aligning with typical body temperature ranges within the referenced table. This uniformity indicates normal thermoregulatory function among the participants, with no indication of fever or hypothermia. Similarly, blood glucose levels were found to be within the range of 78 to 80 mg/dL across all testing conditions, a range indicative of normal glycemic control as outlined in Table 1. This consistency suggests stable glucose metabolism among the participants, with no concerning fluctuations. Additionally, analysis of skin humidity levels yielded readings ranging from 54 to 60%, consistent with typical levels as documented in Table 1. These findings indicate adequate skin hydration and physiological homeostasis among the participants under the tested conditions.

Table 1. Table showing range of parameter

Sensor	Range of parameter
BPM [25].	49 to 100 (Men) 55 to 108 (Woman).
Body Temperature [26].	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 [30].	Between 70 mg/dL (3.9 mmol/L) and 100 mg/dL (5.6 mmol/L).
Skin Humidity [29]	Between 30% and 60%
Blood Hemoglobin [28]	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 [27]	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.

Table 2. The final 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 Jumper Cable (Male to Male/ Male to Female/Female to Female)
Li po Battery	1	1700	1700 (Li po Battery)
Total (in BDT)		9948	20681

Moreover, examination of blood hemoglobin levels revealed a consistent range of 14.4 to 14.8 g/dL across all conditions, aligning with the normal range of hemoglobin concentration as referenced in Table 1. This suggests that the participants maintained healthy blood oxygen-carrying capacity, indicative of good overall health. Furthermore, blood oxygen saturation levels were found to be within the range of 94 to 99%, consistent with the normal range as provided in Table 1. This indicates efficient oxygenation of tissues and organs among the participants, reflective of normal respiratory function. Finally, the comprehensive assessment of the participants' physiological parameters utilizing the Low-Cost Smart Wearable Glove indicates consistent readings within normal ranges across all tested conditions. These findings collectively suggest that the participants' health statuses are within normal limits, without any indication of critical health concerns.

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.

7. CONCLUSION

A low-cost and feasible wearable smart glove has been presented that can non-invasively detect human vital signals such as heart rate, blood oxygen saturation, body temperature, skin humidity, blood glucose level, and hemoglobin level. 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 four persons for real-time validation of health conditions, followed by a thorough analysis of their final impacts. The results showed excellent repetition confirming its reliability and potential in the application of personal healthcare in developing countries. Integrated GSM module and predesigned algorithm ensured safety features such as automated notification of critical conditions via smartphone app or text message. 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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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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