Journal of Carcinogenesis
Covering Genesis to Therapeutics

Journal of Carcinogenesis, ISSN: 1477-3163
2025; Vol 24: Issue 3, https://carcinogenesis.com/

A wearable IoT-based health vital signs monitoring system to reduce mortality rate in developing countries

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ABSTRACT

Early detection and diagnosis of basic health condition will result in successful treatment of diseases and reduced fatality rate in developing countries. It is possible to extract human bio-signals and use it to better understand the bodily health status and reaction to external factors. This new Vital Smart System (VSS) design has in-built sensors which a user wears as a wrist band without interfering with his/her daily life activities to monitor his/her major vital signs (BT, BP, HR), of which current system has limitations to achieve. Using the Dynamic System Design Methodology (DSDM), a more technically robust, cost-effective and portable real time device was designed. This device contains an IoT interface (BLE) that connects to smart phones; a GSM interface (SIM900A) relying on AT command framework that accesses defined medical personnel on the network in cases of emergencies; optical health LEDs that alerts the user; thus, enabling consistent self-assessment of the individual's health condition. In this research therefore, we provided a generalized smart three-in-one vital sign system that ensures effective monitoring and early detection of the user's health status via an optimization of offline and online cross-interfaces of standalone sensors.

Keywords: *Real-time monitoring, Internet of Things (IoT), Temperature (BT), Vital signs, Wearable health device.*

How to Cite: Anthony Ifeanyi Otuonye1, Sunny Kalu Egereonu1, Emmanuel Chukwudi Amadi1, Mercy E. Benson-Emenike1, Ikechukwu Ignatius Ayogu1, Kelechi Allswell Douglas1, Tochi Chima Ewunonu1, Thaddeus Ogadimma Okonkwo1, Vivian Chinyere Mbamala1, Mathew Emeka Nwanga1, Kenneth Okechukwu Okeke1, Juliet Chinenye Duru2, (2025) A wearable IoT-based health vital signs monitoring system to reduce mortality rate in developing countries, *Journal of Carcinogenesis, Vol.24, No.3,* 592-598.

1. INTRODUCTION

By definition, Vital Signs are the different, most important physiological/medical signs that can be measured; to indicate the status of the body's vital functions. According to [1], It is possible to extract human bio-signals and use it to better understand the bodily health status and reaction to external factors. Early detection and diagnosis of basic health conditions could lead to successful treatment and reduced fatality rate in developing countries, as many illnesses and diseases can be diagnosed early and hence treated before it becomes fatal. For example, heart attack, which is believed to be instantaneous gives signs, symptoms, to the sufferer but because the signs are not identified and responded to, the illness gets to the stage where it simply knocks down the sufferer. Hence observing the human vital signs are necessary. There are five traditional vital signs that have a major importance to be measured: heart rate, blood pressure, respiratory rate, blood oxygen saturation and body temperature. These five signals are generally considered essential to evaluate human health and a continuous monitoring should be made, especially in patients [1].

A good number of wearable medical monitoring systems for vital sign have been identified, but most of the identified systems measured only one vital sign [2]. Thus, this research dwells on developing a device to monitor three of the major five vital signs (of which others are relative to). The basic three vital sign which manifests in various health issues include Blood Pressure, Heart Rate and Body Temperature.

According to [3], a wearable health device (WHD) is an emerging technology that enables continuous ambulatory monitoring of human vital signs during daily life (during work, at home, during sport activities, etc.) as well as within a clinical environment, with the advantage of minimizing discomfort and interference with normal human activities. WHD have in-built sensors which a user wears without interfering with his/her daily life activities. The wearable devices may be in the form of cloths, wrist bands, shin tights etc. Sensors or actuators have been successfully connected to many physical devices in the past to gather a huge amount of information. According to established facts, for instance, such technology has enabled the development of miniature wearable biomedical devices for certain ubiquitous patient monitoring. It is now straightforward to monitor a series of vital signs, which could enable self-assessment of an individual's health condition.
Based on the review of literature and the pilot analysis carried out in this work, the existing standalone single vital sign measurement apparatus, though 80% accurate, is 60% deficient, in the efficient and consistent real-time monitoring of users' vital signs, therefore showing a research gap to be bridged in this work [4]. This research therefore set out to hybridize and optimize the impact of this standalone apparatus for a design inexpensive, easy to read/use, and real-time hybrid (three-in-one) smart vital sign monitoring device.

Our primary objective in this research therefore is to develop a Smart Wearable Devices for easy Monitoring and early detection of Health Vital Signs. Specifically, the researchers reviewed and analyzed existing Vital Health Signs Monitoring systems, designed the logical and physical input-output modules for the new system using UML, as well as constructed the IoT-based network for vital signs transmission.

2. METHODOLOGY

The methodology adopted in this research include the Unified Modeling Language (UML) and the Object-Oriented-Analysis-and-Design Methodology (OOADM) [5]. These are popular approaches for the analysis and design of software intensive systems by the application of object-based programming [5]. The UML entails the use of standardized component diagrams to model the system and for effective communication with other stakeholders in the system development process. For the development of the Wearable Health Vital Signs Monitoring System in this study, the following steps were taken in line with the UML and the OOADM methodology:

a. Needs Assessment

The main objective here is to capture the needs of stakeholders, patients and doctors in particular.
The Functional Requirements include:

- Collection of vital signs from IoT sensors, which the user wears as a write band (heart rate, BP, temperature, etc)
- Transmission of data in real time
- Doctor to receive, and can view the patient's vital signs through a GSM interface
- User receives alerts via SMS if the vital signs reach maximum thresholds.

The non-functional requirements include:

- High reliability and accuracy (>95% sensor accuracy)
- Low latency (alerts received within 5 seconds).

Here, the UML's use case Diagram was adopted to identify the following:

- Patient/ user: wears sensors, receives alerts.
- Doctor: Monitors dashboard
- IoT sensor device: Automated actor

Measurements:

- Requirement completeness (up to 90% stakeholder agreement)
- Requirement traceability (all functional requirements successfully mapped to a use case)

b. System Analysis

Here, the objective is to study current challenges in patient monitoring. The following discoveries were made:

- manual vital checks in hospitals are ineffective.
- Late medical response due to delay in detecting abnormalities

Here, the UML's Activity Diagram was used to show the workflow, and illustrated thus:

Nurse checks patient vitals → Records on paper → Doctor reviews later.
Measurements:

- Average delay in response time: 2 – 6 hours.
- Error rate in manual recording: approximately 15%.

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c. Object Oriented Analysis

Here, all system classes/ objects and relationships were identified, including the following:

- Patient (attributes: ID, name, age, medical history).
- Doctor (attributes: ID, name, specialization).
- VitalSignRecord (attributes: timestamp, heartRate, bp, temperature).
- Alert (attributes: alertID, type, severity, status).

Here, the UML's Class Diagram was adopted to illustrate relationships thus:

- Patient ↔ VitalSignRecord (one-to-many).
- Doctor ↔ Patient (many-to-many).
- Alert → Patient (association).

d. System design

Here, the system architectural designs and interactions were caried out using a layered architecture showing:

- **Device Layer:** IoT sensors for collection of vital signs.
- **Network Layer:** MQTT/HTTP protocol for data transmission.
- **Application Layer:** Mobile App showing doctor and patient dashboards/ interfaces.

Measurement:

- System performance (expected < 2 seconds for data transmission).

e. System Validation/ Testing

To ensure correctness, the following testing were carried out on the new system:

- **Unit Testing** (sensor data handling, alert generation).
- **Integration Testing** (sensor → GSM → dashboard flow).
- **System Testing** (end-to-end).

A test case of abnormal heart rate to verify alert sent to doctor.

Measurements:

- Test pass rate (≥ 95%).
- Defect density (≤ 1 per 1,000).
- User satisfaction ≥ 85%.
- Average alert time ≤ 5 seconds.

This research work showed varying implementations of such parameters such as multiple vital sign measurement, computational accuracy, real-time monitoring, cost effectiveness, result interpretation for medical recommendations, data storage for historical use, ease of use/read, processing speed. For each of the parameter listed above, the devices are given a score card on a 0-100% basis. The table 1 and figure 1 below summarizes the existing reviewed-devices performance.

Table 1: Parametric Score of Existing System

S/no	Parameter	Score (%)
1	Multiple vital sign measurement	50
2	Computational Accuracy	90
3	Real-time Monitoring	40
4	Cost Effectiveness	40
5	Data storage for historical use	30
6	Ease of Use/Read	70
7	Processing Speed	60
8	Result Interpretation	30
9	Device Adaptability	60

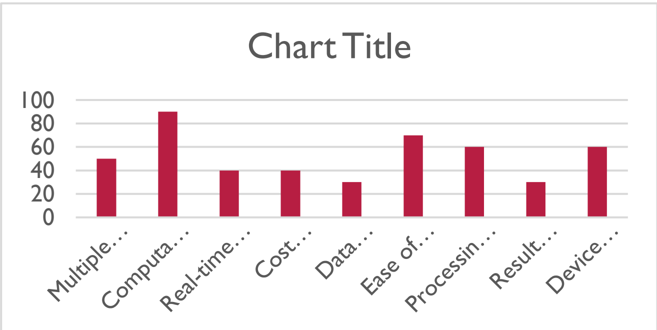

Figure 1: Performance Parameters of Existing Systems

The embedded wearable device for vital sign sensing comprises of the temperature sensor LM35, and the piezo-electric sensor HK-2000B, the ADS1015 12bit ADC, the AVR328 microcontroller, LCD, LEDs, GSM module, Bluetooth module, Li-ion battery for power supply etc. These are the major components used to design the hardware following the modular method.

3. RESULTS

Detailed results from each phase of system development are presented in table 2.

Table 2: Results from development phases

Phase	UML Diagram	Measurement
Needs Assessment	Use case, Activity diagram	Requirement coverage ≥ 90%
Problem Analysis	Activity diagram	Error rate in manual recording (15%)
System Design	Component diagram	Response time ≤ 2s
System Development/ Implementation/ coding	Class diagram	System performance (< 2 seconds for data transmission).
Validation/ Testing	Test scenarios	Test pass rate ≥ 95%

The individual hardware functionality to be designed is represented as a module. Electronic components are then used to satisfy the requirements of the module. The modules of this hardware are temperature sensing module – used to measure the body temperature; pressure sensing module – used to measure the blood pressure; ADC module – used to provide increased resolution for the voltage being measured; processing module – used to process the voltage gotten from the measurement and convert the voltage to the physical parameter value (data), package the data for display and interconnectivity; display module – used to display information; optical indicator module – used to give optical indication of the health status of the patient; GSM module – used to connect to the GSM network in other to send SMS etc; Bluetooth module – used to connect the wearable device to a smart phone; and buttons module – used to provide user input to the wearable device.

All the components making up the embedded wearable device are put together to achieve different functionalities of the modules required for the system to become effective. These components are depicted in the system block diagram in the figure 2.

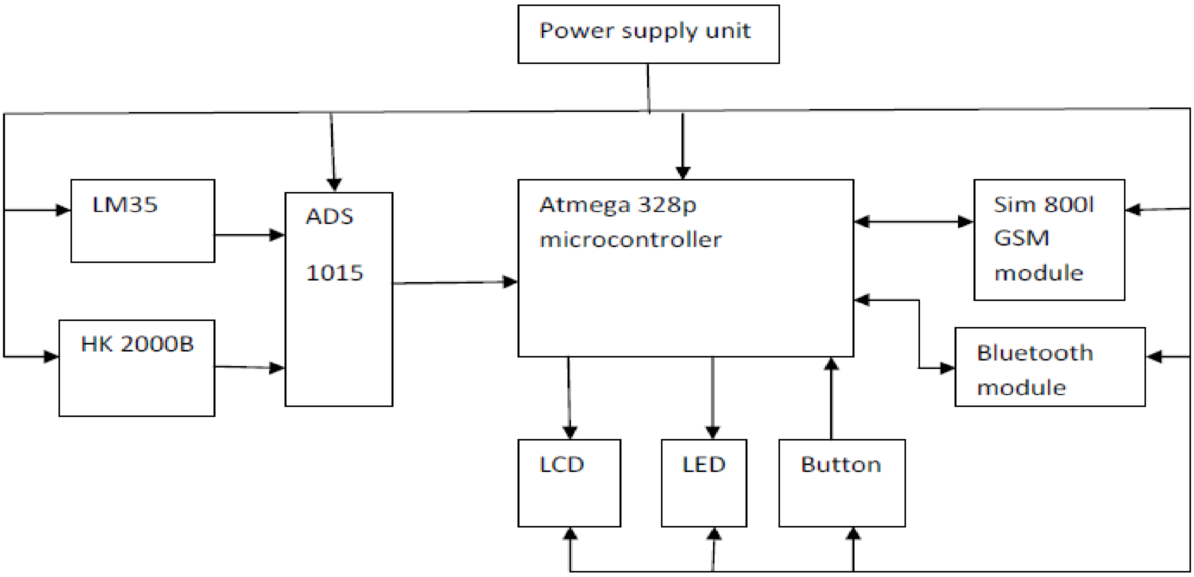

Figure 2 The High-Level System Block Diagram

Algorithm Statement for the Wearable Device

1) *Setup the ADC module*
2) *Setup the serial port for Bluetooth transmission*
3) *Setup the GSM module for SMS messaging*

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4) *Take measurements using temperature sensor and pressure sensor*
5) *Update LCD with measured data*
6) *Update LEDs with status information*
7) *Transmit the vital sign data*
8) *Send SMS to medical personnel*

The above algorithm statements were followed to design the proposed hardware system flowchart, dataflows, use-case and activity models encapsulating the system logics, behavior and structure of the proposed system hardware modules.
The behavioral use case diagram for the new system is presented in figure 3.

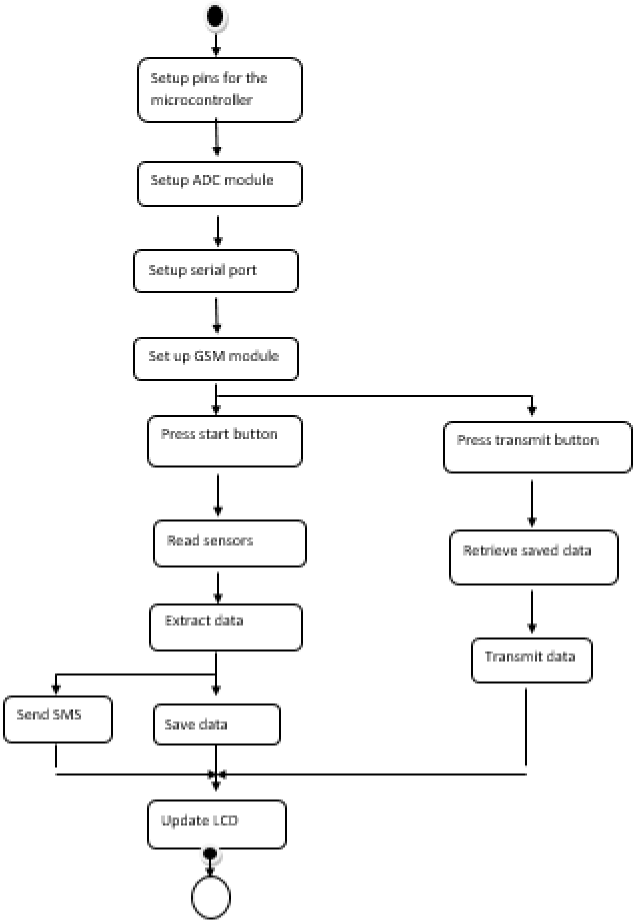

Figure 4: Activity Diagram for the Wearable Device

System Firmware

The telemedicine wearable device has the Atmel328P as its core processing chip. This chip has a firmware written using C++ programming language in the Arduino IDE. The operation of the telemedicine wearable device was represented as functionalities; the program written was meant to implement the functionalities as required for the telemedicine wearable device to operate in other to achieve some of the project objectives. The written code follows an algorithm which implements the functionalities that include –

i. To setup the Atmel328P pins for relevant IO operation
ii. To setup the ADS1015 ADC module
iii. To setup the Bluetooth module for RF communication
iv. To setup the GSM module
v. To take sensor(s) reading using the ADS1015 ADC module
vi. To extract and compute relevant data from the readings
vii. To transfer data to LCD for update
viii. To transmit data serially using the serial port
ix. To respond to user requests using the buttons

The VIS Architecture

First a wearable device is developed which can measure the biometric parameters such as blood pressure, heart rate and

body temperature. These sensors and measurements are managed by a microcontroller. The microcontroller ensures power management of the device and optimizations during measurement. It equally packages the measured data in a secure format and interfaces with a Bluetooth Low Energy, BLE, based IoT interface. For BLE based IoT interface, data security can be enhanced to equally consumes very little power [2]. For this project, wearable device will be worn on the wrist.
The Wearable Wrist Device will measure the Vital signs and send SMS to the Patient's Doctor, if vital sign reading indicates the patient's health is beginning to deteriorate. It equally gives optical alerts using colored light on the health status of the patient. Figure 5 below shows the Wearable Device (VIS) Architecture.

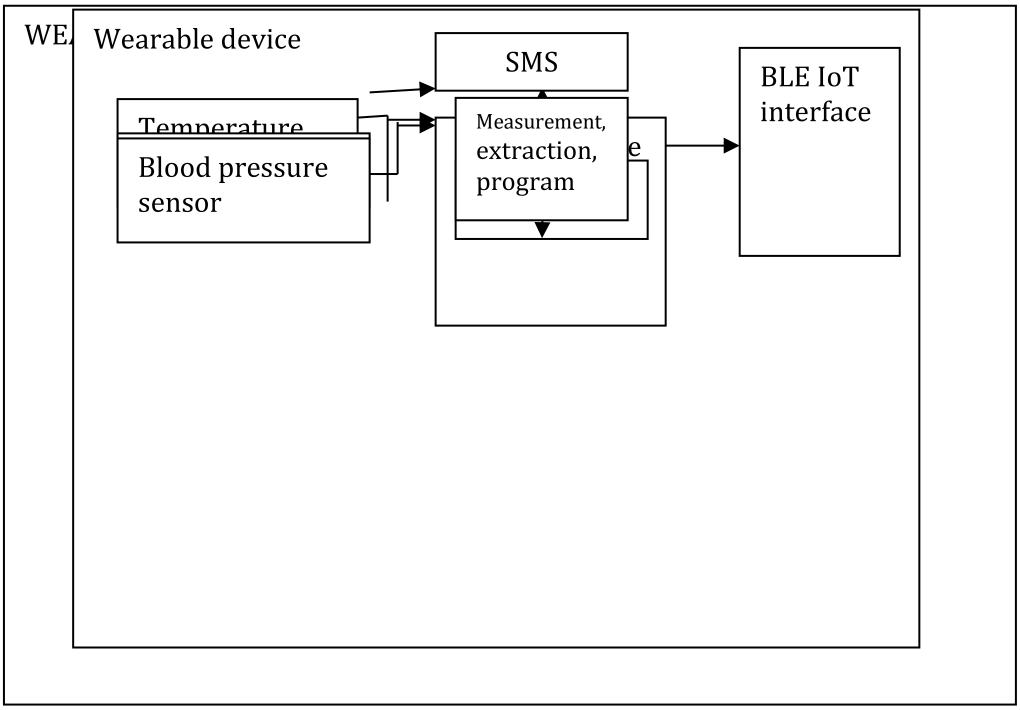

Figure 5: The Smart VIS Wearable Device

4. CONCLUSION

The objective of this study was to design and model an IoT-based Health Vital Signs Monitoring System using UML and Object-Oriented Analysis and Design methodologies, aimed at improving real-time patient monitoring, early detection of abnormalities, and reducing delays in medical response. The analysis revealed that traditional manual monitoring methods are prone to errors, inefficiencies, and critical delays, while the proposed system ensures timely data collection, secure transmission, automated alert generation, and accessible dashboards for doctors and patients. Findings demonstrate that the system architecture enhances accuracy, responsiveness, and usability, with measurable improvements in error reduction, alert delivery time, and user satisfaction. It is recommended that healthcare institutions adopt this IoT-enabled approach, begin with pilot deployments to refine usability, ensure compliance with data security standards, and integrate the system with existing hospital information systems for scalability and long-term sustainability.

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