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Vital Sign Monitoring System for Healthcare Through IoT Based Personal Service Application

Manju Lata Sahu[1] · Mithilesh Atulkar[1] · Mitul Kumar Ahirwal[2] · Afsar Ahamad[3]

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Abstract
The most burning issues worldwide at present are the availability, accessibility, and affordability of the equitable healthcare services for all. It is getting more severe for developing countries due to increasing population and chronic diseases. The emerging technological interventions in the field of Internet of Things (IoT)-based healthcare systems are a promising solution to meet the general public's healthcare needs. Therefore, an IoT-enabled vital sign monitoring system has been presented in this paper. The presented system can monitor various vital signs in real-time and store the recorded trends locally. The system can also send the data into cloud for further analysis. Abnormality detection with alert notification and automatic calculation of early warning score has been implemented. An Android application is developed to store the vital signs records on a personal server to avoid the burden and maintenance cost of the central medical server. The presented system is straightforward, compact, portable and easy to operate through personal service application. Also, the presented system is compared with the most recent work available in the field.

Keywords Internet of thing · Healthcare · Vital sign monitoring · Personal service application · Mobile communication · Real-time monitoring · Abnormality detection · Alert notification

1 Introduction

Equitable global healthcare means access to good healthcare services to all the people worldwide is one of the major challenges specially for developing countries [1]. The existing healthcare system is overburden due to increasing population and chronic diseases and lack of healthcare services in terms of medical amenities, necessary infrastructures, qualified medical practitioners and diagnostic equipment [2, 3]. The healthcare service provider

✉ Mitul Kumar Ahirwal
ahirwalmitul@gmail.com

1 Department of Computer Application, National Institute of Technology, Raipur, Raipur, Chhattisgarh, India

2 Department of Computer Science and Engineering, Maulana Azad National Institute of Technology Bhopal, Bhopal, Madhya Pradesh, India

3 Oracle Corporation, Bangalore, India

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and researchers are tirelessly working to manage and mitigate the effect of rapidly increasing chronic and potentially fatal diseases like heart diseases, hypertension, asthma, and the emergence of new diseases which are growing rapidly in every county. The IoT based health monitoring system is emerging as an alternative solutions to the existing healthcare system to bridge the gap of equitable healthcare services to all [4]. It is playing the vital role in reforming and restructuring the way healthcare services are being [5]. Apparently, there is a need for an integrated healthcare solution which can monitor the different physiological parameters in real-time and provideimmediate detection and diagnostic tools for chronic diseases and various health related issues [6].

IoT enabled VSMS is seen as one of the promising solutions to deliver the equitable healthcare services to people at large globally [7]. This system consists of medical sensors, a processor, communication device, power supply and a smartphone for vital sign monitoring of the patient under different environment [8]. The vital signs are the key indicators for the estimation of the severity of health condition and level of the medical intervention [9]. However, these parameters are rarely recorded digitally other than paper chart despite being a valuable source of medical information. The continuous monitoring and recording of the vital signs in real-time over a period of time can be an effective instrument in diagnostic tool and emergency management [10]. This recorded data and noted trends can be used for alert notification driven by automatic decision support system [11]. IoT enabled VSMS offers a facility where a medical expert can quickly and easily monitor different vital signs of the person and provide necessary intervention as and when required [12]. It minimizes the use of hospital resources, infrastructure and medical practitioners. The possible applications of VSMS and physiological statistics are monitoring of health status, prognosis, diagnostic and personalized healthcare plan, abnormality and severity detection and disease prediction [4, 7, 10–12].

IoT enabled VSMS is initiating a paradigm shift in the health management approach from reactive diagnosis to proactive prognosis. The emerging trends in information and communication technology have accelerated the growth of the IoT based health monitoring systems; consequently, plenty of work has been reported in the last decade. The major contribution of the decades in IoT based healthcare applications with recent trends and future advancement are summarized in [13–32]. A cloud-based framework for mobile application has been proposed in [13] for symptom-based healthcare solution. The combination of wearable devices and mobile application has been proposed in [14] for ubiquitous health monitoring and generates alert during emergencies. The proposed system consists of a belt equipped with several sensors for vital sign monitoring and a Bluetooth device for data transmission. The work proposed in [14]was extended by [15]with chest strap with ECG, respiration, temperature and motion sensor. In this work, the abnormalities of the vital signs shown by Green, Yellow and Red colour followed by an emergency call. A cloud-based portable telemedicine system has been proposed in [16] which uses diagnostic devices for ECG, respiration and blood pressure measurement through a wired connection. The doctor's prescription and diagnosis procedure are communicated back through the same cloud network [17]. A telehealth care system has been proposed in [18]for physiological parameter monitoring and sending the data to an centralized electronic patient record with the help of web based application. In [19], patient-specific and adaptable inference model for multiple vital sign monitoring system has been proposed with. A mobile application with artificial intelligence was used in this system to accurately predict the patient's health condition and its deterioration over time. A concept for the health monitoring of the patient at home recently discharged from the hospital is proposed in [20]. The proposed system is capable of monitoring the different vital signs of the patient and triggers an alarm in case of an emergency. A similar system has been proposed in [21] for self-health monitoring. The proposed system is capable of continuous health monitoring in real-time and keeps the record of monitored data. A cloud-based framework for vital sign monitoring for rural healthcare in a developing country has been introduced in [2]. In this system, data is uploaded in the medical server, and the privacy and confidentiality of the patient are secured by identity-based encryptions and data. IoT based smart edge system has been proposed in [1] for vital sign monitoring with critical measuring index-based alert notification. The system measures different vital sings transmits it to the central medical server for further analysis and storage.

Despite the successive growth in last decades, there are certain issues in the existing system such as incompetency to meet the medical standard, measuring accuracy, incomplete health analysis due to limited parameters, unable to handle multiple abnormalities, cost and complexity along with the security and privacy issues for managing patient information. Furthermore, there are some technical and societal challenges in terms of systematic development, deployment, and adaptability of the existing system. Therefore, an attempt has been made to relook the early development of sensing technologies and telemedicine systems in the light of new requirement and applications. Consequently, a system has been developed with the help of the existing state of the art solutions for performing integrated and intelligent VSMS. In the proposed system, it is the user's responsibility to collect and process the data, recognize the patterns, detect the abnormalities with alert notification. It helps in eliminating the centralized medical server and hence reduces the burden and maintenance cost of the centralized medical server. Experimental study of the proposed system with digital data recording and analysis in real-time through personal service application (PSA) installed on Android device has been carried out. The main objective of the presented work is to bring improvement in the standard of results and measurement accuracy. Therefore, current state-of-the-art vital sign monitoring technology has been considered, with a focus on data acquisition, processing, and management. The different characteristics of the presented system are summarized below,

- The proposed system is capable of monitoring different vital signs like Body Temperature (BT), Percentage of Oxygen Saturation (SpO2), pulse rate (PR), Electrocardiograph (ECG), Heart Rate (HR), Respiration Rate (RR), Blood Pressure (BP) with high accuracy in real-time.
- The obtained vital signs are used for abnormality detection and alert generation.
- The system is capable in storing the data locally and also in cloud.
- The system is easy to operate, straightforward and portable.
- User-friendly Graphical User Interface (GUI) for an Android device.
- Increases availability, accessibility and affordability of the healthcare service to people at large.

The paper is organized as follows, Sect. 2 deals with the general description of IoT enabled VSMS followed by its architecture. In Sect. 3 briefly discusses the importance of vital signs for assessment of well-being. Different methods for measurement of the different vital sign are presented in Sect. 4. The presented architecture of the system is elaborated in Sect. 5. In Sect. 6, presents the outcome followed by the conclusion in Sect. 7.

2 IoT Enabled Health Monitoring System Architecture

The existing healthcare system is insufficient to provide timely healthcare services due to the ever-increasing population and growing chronic diseases [5]. Despite the advancement in healthcare technologies and infrastructure, the healthcare services are neither affordable nor approachable to the people at large. Thus, the main goal of the IoT enabled health monitoring is to empower the people for self-health management and keeping the records of their health status [5]. It helps to avoid an emergency and early death by timely prediction of abnormalities and severity of illness [9]. In addition, IoT enabled health monitoring offers a facility where a medical expert can quickly and easily monitor different vital signs of the person and provide necessary intervention as and when required. Furthermore, it will provide real-time data of the patient's physiological parameters, which will aid in predicting health status and supports in decision making for in time diagnosis. It minimizes the use of hospital resources, infrastructure and medical practitioners.

There is plenty of literature dealing with the architecture and framework for IoT enabled health monitoring system [21–25]. The most popular generalized architecture for IoT enabled health monitoring system is shown in Fig. 1. It has three stages namely body sensor network (BSN), communication gateway and cloud computing for storage and analysis [23, 24]. The task of the BSN is measuring the different vital sign such as PR, BT, SpO2, BP etc. with the help of sophisticated sensors and processing the measured data. In second stage, the processed data is communicated through different short-range (Bluetooth, ZigBee, RFID) and long-range (Wi-Fi, SigFox, LoRa) communication technologies. The Android devices are used as the gateway for data acquisition, visualization and storage either locally or globally. An application programming interface is used for data analytics and storage along with increased accessibility of internet [24]. This is the most important stage of the IoT enabled VSMS and can be treated as the reaching end to the user. In the third stage, the health data is sent to the cloud for analysis, visualization and storage. In this stage, decision support system and remote patient monitoring can also be implemented. This architecture offers simple operation with high degree of reliability, flexibility and portability. It is a highly adopted platform for IoT enabled health monitoring of the patients admitted in hospitals or residing at home and used in different application to provide healthcare services to stakeholders [25].

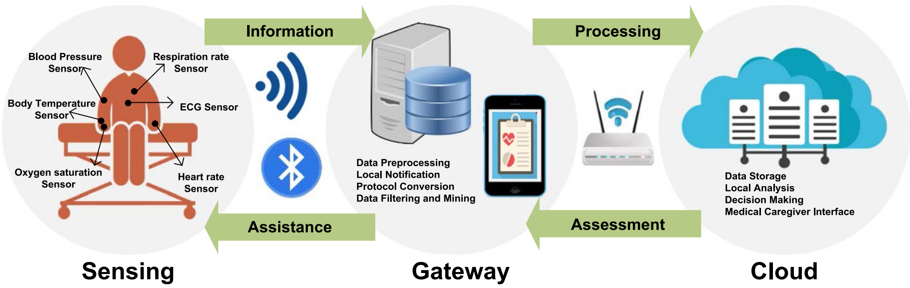

Fig. 1 Generalized Architecture of the IoT Enabled Health monitoring System [25]

3 Vital Signs: the Indicator's

The measurement of the vital signs, commonly known as philological parameters are the key indicator's for the estimation of the abnormality and severity of the patients health [7, 11]. The accurate measurement of vital signs provides important information about the diagnosis methodology and degree of the medical intervention [9]. According to the physiological examination, the standard vital signs for most of the health monitoring applications are BT, SpO2, PR, ECG, HR, RR, and BP.

The monitoring and recording of these vital signs on a regular or continuous basis is medically important. The accuracy of vital sign monitoring and its recording is highly dependent on the person's age, sex, height, weight and medical history. Due to the fact that all the patient bears different characteristics, therefore the accepted range of vital sign are considered as valid approximation which helps in further analysis by setting up of the orientation point. The measured vital signs values are compared with the medically approved range such as Modified Early Warning Scores (MEWS) [24]for evaluation and analysis leading towards predication of deterioration of health condition. The medically accepted vital signs for adults summarized in the MEWS used in hospitals for periodic monitoring of the patients are shown in Table 1.

4 Vital Signs Measurement Methods

The physiological sensors are small electronic devices attached to the different locations of the body, which measures the various physiological parameters and activities associated with the human body [12]. The different vital signs are measured in terms of equivalent electrical signals obtained from physiological sensors. The measured vital signs are communicated to the controller through wireless or wired medium which forms a Body Sensor Network (BSN). For the implementation of the VSMS, the commonly used physiological sensors are the BT sensor, ECG sensor, SpO2 sensor and non-Invasive cuff-based blood pressure (NIBP) sensor, etc.

4.1 Body Temperature

The measurement of the body temperature is important to understand the ability of the body to generate and release the heat. It is a critical vital sign that is primarily used to detect hypothermia, hyperthermia, hyperpyrexia, and fever, among other things. [5]. The value of the body temperature depends upon the location of the body, time of measurement

Table 1 Modified early warning score for vital signs in hospital settings [24]

Parameter	Range of score						
	3	2	1	0	1	2	3
BP (mmHg)	< 70	71–80	81–100	101–199	–	≥ 200	–
HR (bpm)	–	< 40	41–50	51–100	101–110	111–129	≥ 130
RR (bpm)	–	< 9	–	9–14	15–20	21–29	≥ 30
BT (°C)	–	< 35	–	35–38.4	–	≥ 38.5	–

and environmental conditions such as sweating decreases whereas shivering increase the body temperature. The body temperature varies with the location of the body and hence the selection of measurement location is important for accuracy. For instance, under room temperature the oral measurement comes to be approximately 37 °C degrees Celsius, whereas a rectal measurement typically falls approximately 37.6 °C [26, 27]. The classification of the body temperature of the healthy adult person is given in Table 2.

Optical temperature sensors and resistor-based thermistors are mature and widely used techniques for measuring body temperature, and they will continue to be used in the near future for non-invasive wearable temperature measurement [27]. The body temperature sensor is most commonly and widely used for body temperature measurement in all forms of VSMS. This sensor's operating temperature range is quite broad, ranging from − 40 to + 110 degrees Celsius. The accuracy of body temperature measurement is primarily determined by the location and manner in which the sensor is attached to the body. There are intensive research reported in the literature dealing with the body temperature measurement by printed the temperature sensors on polymers or by embedding it on cloths [28].

4.2 ECG

A type of diagnostic tool that measures the electrical activity of the heart is an electrocardiogram (ECG). Electrodes placed at various locations throughout the body are used to detect the electrical activity of the heart caused by depolarization and repolarization of the cardiac cell. The ECG monitoring system comes with 3-lead, 5-lead, 9-lead and 12 lead electrodes. In this work 5-lead, ECG sensor is used with the electrode placement as shown in Fig. 2 and summarized in Table 3. In addition to this, there are wearable ECG capable of accurately measuring the ECG signals for the assessment of the heart health [9, 30] and cardiovascular activities [31].

The ECG waveform is composed of a time series with various waves and line order repetitive in nature where Y-axis represents amplitude in millivolt and x-axis denotes time in a millisecond, as shown in Fig. 3. The various ECG components are commonly referred to as the P wave, P-R interval, QRS complex, ST segment, Q-T intervals, and T wave [33]. Table 4 summarizes the time duration of various waves, intervals, and segments. The number of heartbeats is calculated by counting the number of QRS complexes, which represent the number of ventricular depolarizations in a minute [13]. Heart rate is the number of heartbeats per minute, which is a function of time and measured in beats per minute (BPM). The heart rate can be calculated using a variety of methods based on an ECG signal. The six-second count is the most common, easiest, and reasonably accurate method of determining heart rate. In this method, the number of QRS complex over 6-s is multiplied by a factor of 10 to obtain the heart rate for one minute ($HR = N_{QRS/6s} x10$). This method

Table 2 Classification of the body temperature range for an Adult

Disease	Core body temperature
Hypothermia	< 35 °C (95.0 °F)
Normal	36.5–37.5 °C (98–100 °F)
Fever	37.5–38.3 °C (100–101 °F)
Hyperthermia	38.4–41.4 °C (101–107 °F)
Hyperpyrexia	> 41.5 °C (107 °F)

Fig. 2 Five Lead ECG electrode placement location [https://litfl.com/ecg-lead-positioning/, Date of access 18/03/2020]

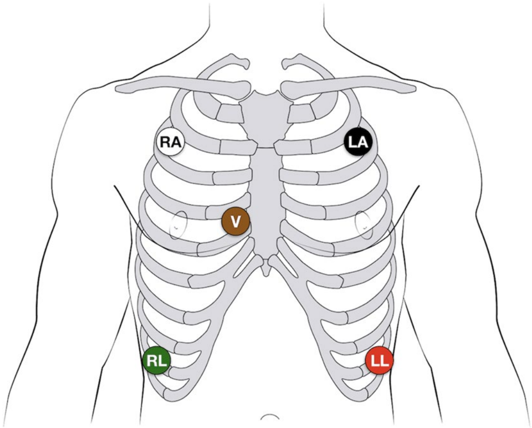

Table 3 Five lead electrode placement locations [31]

Inscription	Colour	Location
RA	White	Right Arm below the right clavicle
LA	Black	Left Arm below the right clavicle
RL	Green	Lover right rib margin over bone just below the right pectoral muscle
LL	Red	Lover left rib margin over bone just below the left pectoral muscle
V1	Broun	Fourth intercostal space at the right border of the sternum

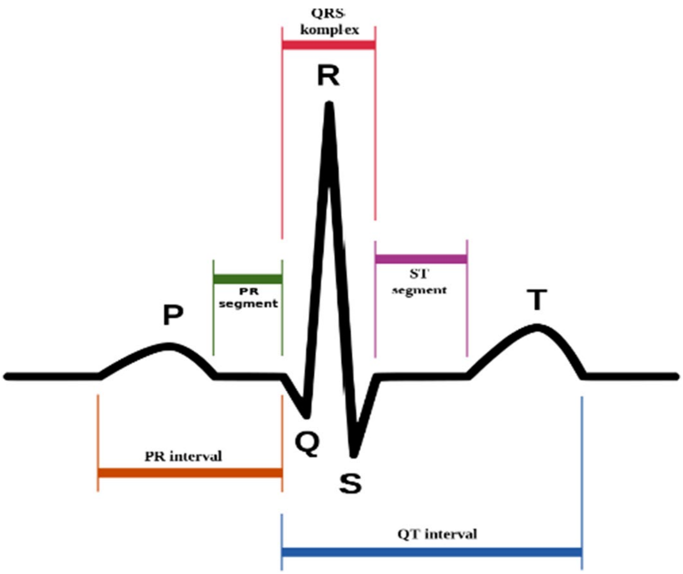

Fig. 3 Components of ECG graph [32]

Table 4 Summary of ECG waves, intervals and segments [31]

ECG Component	Represents	Normal Duration (sec)
P wave	Atrial depolarization	0.08–0.10
QRS Complex	Ventricular depolarization	0.06–0.10
T wave	Ventricular repolarization	n/m*
P-R interval	Atrial depolarization and AV nodal delay	0.12–0.20
ST-segment	Isoelectric period of depolarized ventricles	n/m*
Q-T interval	Length of depolarization pulse repolarization (Corresponds to action potential duration)	0.20–0.40

*Not measured

has been widely accepted for heart rate measurement of regular, irregular and languid rhythms. For cardiovascular assessment, resting heart rate (heart rate measured at rest) is used as the reference point. An adult's resting heart rate typically ranges between 60 to100 BPM. A resting heart rate of less than 60 BPM is considered bradycardia, whereas a resting heart rate of more than 100 BPM is considered tachycardia. The abnormalities in heart health are detected by the analysis of different components of ECG. However, in most of the vital sign monitoring system, the main focus is on resting heart rate, and its deviation from normal values are used to determine abnormalities.

4.3 Blood pressure

Blood pressure, measured in millimetres of mercury (mmHg), is the amount of force exerted by blood on the walls of blood arteries. Diastolic blood pressure (DBP) is the lowest aortic pulse pressure, while systolic blood pressure (SBP) is the highest [20]. The average value of these DBP and SBP is referred to as mean blood pressure. The magnitude of these pulse pressure depends on the location of measurement. The measurement location nearest to the heart reduces SBP and increases DBP and vice-versa. Mean arterial pressure (MAP), which is the average arterial pressurein a single cardiac cycle of the circulatory system, is measured to access systematic vascular function. The MAP is an important index for monitoring blood pressure and can be calculated using Eq. (1),

$$MAP = DBP + 1/3(BP - DBP), \tag{1}$$

There are two ways, oscillometric method and pulse transit time method for automatic blood pressure measurement non-invasively [20]. Oscillometric measurement is a cuff based non-wearable method, whereas pulse transit time (PTT) measurement is a cuff less wearable method. In the presented system cuff based oscillometric system is used for BP measurement. In this system, blood pressure is measured by placing a cuff on the patient's arm above the elbow while lying or sitting. The cuff is automatically inflated above the level at which the palpable pulse disappears, and the blood pressure is measured while the arm cuff is being deflated. For continuous monitoring of the BP, cuff based oscillometry method is not suitable, and hence researchers are paying attention to the cuffless method deals with PTT, which is significantly getting popularity for wearable applications [34]. According to the world health organization (WHO) optimal value for SBP is 120 mmHg, and DBP is 80 mmHg which is subject to the patient's age, posture, physical activity and food habits. There are two major abnormalities associated with the value of BP,

Table 5 Classification of blood pressure range for adults

BP Category	SBP mmHg		DBP mmHg
Normal	less than 120	and	less than 80
Prehypertension	120–139	or	80–89
High BP (Hypertension) Stage1	140–159	or	90–99
High BP (Hypertension) Stage2	≥ 160	or	≥ 100
Hypertensive Crisis (Emergency care needed)	> 180	or	> 110

Table 6 Classification of range of respiration rates for different age group [18]

Group	Age	Breaths/Min
Newborn	Birth-6 weeks	30–60
Infant	6 weeks–6 months	25–40
Toddler	1–3 years	20–30
Young Children	3–6 years	20–25
Older Children	10–14 years	15–20
Adults	Adults	12 – 20

hypotension (low BP) and hypertension (High BP) [26]. The classification of BP for the different condition is summarized in Table 5.

4.4 Respiratory Monitoring

Respiration is a vital and natural mechanism for all living species that maintains energy production by giving oxygen (O2) to the body and maintaining acid–base balance by eliminating carbon dioxide (CO2). The number of breaths inhaled per minutes is referred to as respiration rate. In normalrespiration, lungs exchange certain volumes of the air known as tidal volumes of the air inspired and expired. This exchange of the tidal volume of the air causes expansion and contraction of the chest cage, which is the main determinants of the respiration rate. This expansion and contraction produce a rhythmic respiratory rate and pattern. Normal respiration rate remains constant in general and depends on age, physical fitness, and mental health [19]. The range for the respiration of the different age groups is summarized in Table 6. For an adult, under the normal physiological condition, the optimal respiration rate and patterns remain at a constant average level of 12 breath/minute and vary between 12 to 20 breath/minutes. The respiration rate below 12 breath/minute is called bradypnea, whereas respiration rate above 20 breath/minute is referred to as tachypnea, both the conditions are treated as abnormal respiration rate.

Measurement of respiration rate aids in the detection of many health conditions such as apnea episodes, asthmatic attacks, panic attacks-induced hyperventilation, obstructions of the airway, and so on [4, 35, 36]. There are different methods of respiration monitoring classified as contact or noncontact methods. In contact methods, the sensing device is attached to the patient's body, whereas in noncontact methods measuring devices do not make any contact with patient's body. In general respiration rate monitoring system commonly rely on contact methods such as measurement of respiratory airflow, respiratory sounds or CO_2 emission, respiratory related abdominal or chest movements etc. [20].

In this work, chest impedance method is used for respiration rate measurement. In this method, the impedance between RA and LA or RA and LL or LA and LL is measured through ECG electrodes. In addition to this, ECG and Spo2 derived respiration are also getting popularity in recent time.

4.5 Pulse Oximetry measurement

The pulse oximetry or SpO_2 monitor is defined as the percentage oxygen saturation in the blood, which is used to determine the oxygenation or supply of oxygen to the body tissues. It is particularly significant for determining the amount of oxygen delivered to different tissues. It is an important indicator for respiratory functions and hence an integral part all VSMS [4]. It works on principle of photoplethysmography and determine the oxygen saturation of arterial blood as shown in Fig. 4. It usually employs two LEDs (light-emitting diodes) that produce red and infrared light through a translucent component of the body, such as tissue, bone, venous veins, and pigmentation which absorb a steady amount of light over particular period of time [37]. Deoxyhemoglob in absorbs more light in the red spectrum (600 to 750 nm) than oxyhemoglob in in the infrared Spectrum (850 to 1000 nm) [37]. The arteriolar bed pulsates and absorbs a varying amount of light as blood volume increases and decreases during systole and diastole [38]. The oxygen saturation is calculated using the ratio of light absorbed during systole and diastole [39]. This approach is very popular and widely used for precise blood oxygen saturation and pulse rate monitoring. A microcontroller is used for processing and integration of these data through an elaborate calibration algorithm. The oxygen saturation can be estimated as Eq. (2);

$$SpO2 = oxyhaemoglobin/oxyhaemoglobin + deoxyhaemoglobin \tag{2}$$

The normal SpO_2 value is above 95% under room air breathing is regarded as normal physiological conditions. The SpO_2 between 91 to 95% is referred to as symptoms of moderate hypoxemia, and less than 90%comes under severe hypoxemia, as summarized in Table 7.

4.6 Pulse Rate Measurement

Pulse rate is the most extensively used vital indicator. The pulse rate can be used to diagnose a variety of symptoms and emergencies, such as pulmonary embolisms, cardiac arrest, and vasovagal syncope [4]. Pulse rate sensors are mostly utilised and investigated

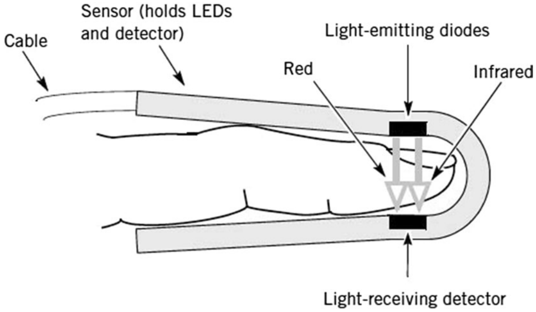

Fig. 4 Working principle of the Pulse oximeter (SpO_2) [35]

Table 7 Normal and abnormal value of oxygen saturation level [36]

SpO_2%	Status
95–100	Normal
91–94	Moderate Hypoxemia
86–90	Severe Hypoxemia

for activity tracking and medical applications. The sensor can be placed on the wrist, chest, Earlobe, or the fingertip of the body to monitor pulse rate. The pulse sensor can, however, be placed on the fingertip or earlobe to obtain a highly accurate pulse rate. There are numerous commercially available wrist and chest bands with a pulse rate sensor [5]. Pulse rate sensors include photoplethysmography (PPG), radio frequency (RF), and ultrasonic sensors, are commonly used in health monitoring systems. The use of a photoplethysmography sensor in combination with SpO2 measurement is recommended in the existing literature. Photoplethysmography is a well-known and successful pulse rate monitoring technology that employs tried-and-tested techniques and algorithms to produce high-quality signal output while reducing noise and external interference significantly [38].

Different vital signs and its measurement technology are summarized in Table 8. The vital sign measurement is the primary reference point for analysing the patient's physiological functions and abnormality indicators. However, despite being a valuable source of information, these data are currently recorded manually or in a paper chart in the intensive care unit (ICU) and rarely stored digitally. The systematic storage of vital signs data record will provide valuable information about the current health condition of the patient. It will also provide an insight into the patient's vital signs history, which will help to identify the occurrence of the abnormalities and severity prediction along with diagnostic methodology. Therefore, in this work, a ubiquitous vital signs measurement and data processing system has been presented. The vital sign monitoring and data acquisition, along with integrated processing, will allow us to follow the patients' health status and diagnosis procedure under various circumstances. The presented work focuses on vital signs data acquisition, data sampling, data management, and processing via smartphone technologies, taking into account current state-of-the-art vital sign monitoring technology, with the strong goal of making the system portable and user-friendly.

5 VSMS Framework

The record of vital signs measurement is used to deliver better healthcare services and clinical treatment. The prime objective for digital recording of the vital signs is to understand and analyse the patients' health status and trend along with existing health issues and past medical history. The digital record of vital signs will be used for a variety of assessment, treatment plan, monitoring system, severity detection, and as a primary diagnostic tool. The technological advancement in the field of information and communication technologies has accelerated the growth and deployment of VSMS. In this work, the possibility of having reliable and efficient VSMS with data recording has been explored to manage the complexity of the existing monitoring system. The presented VSMS is compact, lightweight, portable and affordable with easy to operate and quickly configurable. Also, an attempt has been made to meet out the specific requirement pertaining to user experience, hardware, software and operational domain. Hence the VSMS should be able to,

Table 8 Summary of measurement technologies for different vital signs [26]

Vital Sign	Range	Unit	Methodology	Transduced signal	References
HR	0.5–4 (ECG)	mV	Skin electrode; optical; Magneto-impedance sensor	Voltage/Current	[29, 30]
BP	10–400	mmHg	Piezoelectric capacitors; capacitive strain sensors	Drain current	[12, 20, 33]
RR	2–50	b/min ^{1}	Strain gauge/Impedance	Resistance	[20, 34, 35]
BT	32–45	^{o}C	Thermistors; thermoelectric effects; optical means	Resistance	[27, 28]
SpO_2	80–100	%	Optical means	Photodiode current	[35, 36]

- Measure the user's vital signs accurately from different non-invasive sensors.
- measure vital signs continuously in real time and periodically.
- display monitored data in real-time and store the data locally or in cloud.
- provide alert notification during the abnormalities and life-threatening event.
- provide health status and report of the different physiological parameters.
- calculate early warning score automatically and provide feedback on health status.
- User-friendly graphical user interface (GUI) for better interpretation.
- provide an easy interface with compatible device fulfils the application need in terms of storage, communication protocol, and processor speed.
- provide secure and password-protected access to the data on personal server in cloud.
- Supports Wi-Fi and Bluetooth connectivity

Variety of VSMS for measurement and monitoring of the physiological signal of the patients have been introduced as an outcome of the research and commercial projects in the last decades [11–18]. These developments are simple and deterministic to convey the information about patients' health. The presented architecture is inspired by the generalized three-layer architecture, which comprises body sensor network (BSN), personal area network (PAN) and wide area network (WAN) [40]. The first layer is responsible for physiological parameters sensing, and the last layer deals with the interconnected medical services. Middle layer plays a significant role in integration between first and last layers through personal service application deployed in the smartphone, which acts as a gateway. The middle layer provides very important services such as sensor network management, data aggregation and communication and hence the proposed work revolves around development and implementation of this layer.

In the presented system, the existing state of the art Berry Med vital sign monitor PM 6750 [41] with the temperature sensor, ECG sensor, SpO2 sensor and NIBP sensor has been used. The detailed descriptions and specifications of the physiological sensor used for vital sign measurement are summarized in Table 9. In the presented system, an attempt has been made to shift the data processing and management from a centralized medical server to decentralized personal server. Consequently, the result quality of the patient assessment and measuring accuracy of the system will improve with the reduction in the burden onthe medical server and its maintenance cost. In the presented system, it is the responsibility of the personal server for system management, data acquisition and processing along with abnormalities detection and alert notification. The architectural configuration of the VSMS framework is shown in Fig. 5. It consists of Sensing and Acquisition layer, Processing and Communication layer Analysis and Storage layer.

In sensing and acquisition layer, distributed sensor devices are placed on different parts of the body. The primary function of this layer is to sense different physiological parameters through a wired sensor network and transfer the data to the base station which is microcontroller unit (MCU) for further processing. The sensor network includes a thermistor-based temperature sensor, five lead ECG sensor, PPG based SpO2 sensor and NIBP cuff sensor. This sensor network is capable of measuring seven vital signs BT, SpO2, PR, ECG, HR, RR, and BP which are standard in most medical practices. Besides the primary function of sensing different physiological parameters, physiological data sampling, amplification, filtering and pre-processing are also performed in the sensing and acquisition layer. In pre-processing, sampled data are converted into more meaningful information with some initial calculation and calibration within the prescribed scales. This pre-processed data are then sent to MCU for further processing.

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Table 9 Sensor description and working procedure [37]

Sensor Name	Sensor image	Description	Procedure	Precaution
ECG		The ECG is the graphical recordof electrical signals produced by heart muscle in every cardiac cycle. These electric signals are collected by the electrode attached on the surface of the body. The electrical signals so obtained are very contaminated and weak. A dedicated MCU is used to processing (filtration and amplification) the electrical signals to make it observable. The ECG signals are used for calculation of the heart rate. The ECG electrodes are also used for the measurement of the respiration rate by chest impedance methods. The description of the five lead ECG is given in Table 3 and its placement on the body surface is shown in Fig. 2	The quality of EG waveform depends on, the quality of electrical signal obtained from electrode. The following measures should be taken while taking the ECG The electrodes are placed on the flat and non-muscular surface of the body The body surface has to be clean, dry and free from hairs and dead Connect the ECG lead wire to the electrodes first before attaching the electrodes to the body surface The ECG lead then be connected to the monitoring device for measurement	For good quality ECG signal, medical-grade ECG cable should be used All the electrodes should be properly and tightly attached to the body surface. It should not be connected to the conducting part or ground Interference of the not grounded electronic equipment's may cause inaccurate ECG waveform Patient, bed and monitoring equipment should not be touched during measurement All the electrodes should be recycled properly
Pulse Oximeter		The pulse oximeter is a non-invasive device that measures light absorption at specific wavelengths to determine the amount of oxygenated haemoglobin and pulse rate. The light produced by the probe passes through the tissue and is converted into electrical signals by the probe's photo detector. The electrical signal is processed by the microcontroller, which calculates the percentage of oxygen saturation in the blood and the pulse rate. The wavelengths measured by the sensor are 666 nm for the red LED and 905 nm for the infrared LED	The selection of the sensor depends on the patient's type and age. Finger SpO_2 is preferred for an adult, whereas wrist SpO_2 is preferred for infants Attach the SpO_2 sensor on the preferred location of the body Connect the plug of the SpO_2 on the controller for measurement Make sure that all the connections are neat, clean and proper	Suitable SpO2 sensor should be mount at a preferred place The SpO2 should be kept far from the electrosurgical apparatus and high-frequency equipment's SpO2 sensor cable should be properly tangled up The patient should not move excessively For prolong and continuous operation, the body surface of sensor placement should be checked frequently The SpO2 monitoring and BP monitoring should not be performed on the same arms simultaneously

Table 9 (continued)

Sensor Name	Sensor image	Description	Procedure	Precaution
NIBP		The oscillometric approach is used by the Non-invasive BP module to measure blood pressure.It measures the highest pressure of the aortic pulse, which is known as systolic blood pressure (SBP), whereas lowest pressure is known as diastolic blood pressure (DBP) (DBP). Mean arterial pressure (MAP) is the average arterial pressure of the circulatory system throughout a single cardiac cycle, which is measured by the BP module	The BP cuff selection is very important, which depends on the circumference of the patient’s arm Attach, the completely deflated BP cuff on the left upper arm preferably and ARTERIA mark on cuff should match with artery location BP Cuff neither wrapped very tightly nor loosely BP cuff should be placed in parallel to the heart Join the Air hose connector with BP cuff connector. Plug the other side of the air hose connector with the controller Inflate the BP cuff by turning on the automated pump during measurement and deflate gradually for the measurement SBP, DBP and MBP	The measurement should be taken when HR is above 50 BPM and below 230 bpm During measurement, the patient should be sitting or lying quietly as the patient movement, shivering and convulsion may lead to inaccurate result Severe shock, hypothermia and obesity may lead to inaccurate measurement The inflatable part of the cuff should be long enough to circle 50–80% of the arm Applying the cuff to a limb with an intravenous infusion or catheter in place is not recommended Air hose tube should not be blocked, twisted, or tangled
Body Temperature		This monitor uses the thermally sensitive resistance to measure body temperature. The temperature probe of the thermistor resistance changes along with the human body temperature. Then the monitor will measure the value of the resistance and calculate the temperature of the body	For the measurement of the body temperature of the patient, connect the temperature sensor leadto the controller Attach the temperature sensor on the appropriate place of the patient’s body Turn the controller on and wait until the temperature value gets stable	The temperature sensor cable should be shaped in the loose round to avoid mechanical damage and to get over bent In case of inaccurate measurement, monitor the patient’s body temperature with alternative methods and calibrate the temperature sensor accordingly

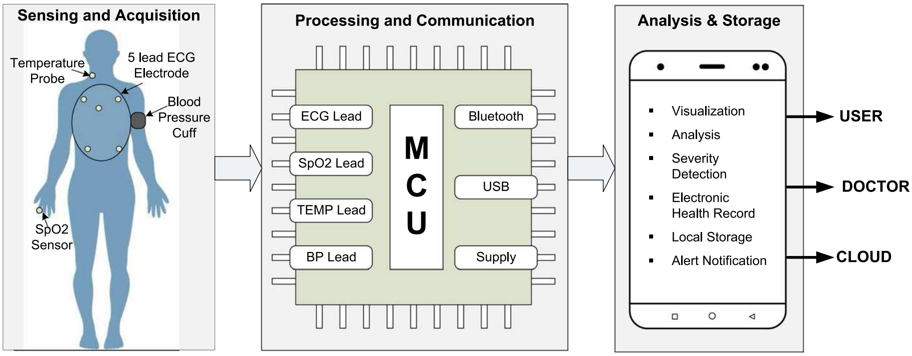

Fig. 5 Architectural configuration and data flow diagram of the proposed system

In processing and communication layer, two low power, STM32F103xC High-density performance line ARM-based 32-bit MCU [42] and CY8C58LP, 32-bit Arm Cortex-M3 core plus DMA controller [43] along with digital filter processor up to 80 MHz programmable embedded system on a chip have been used with integrated configurable analog and digital peripherals, memory, timers, CAN and USB communication with UART interface. Apart from this, the system also supports Bluetooth low energy (BLE) 4.0and can be connected with other smart systems such as smartphones and personal computer etc. For this purpose, BMSPPS3MC2 full regulatory certified BLE 4.0 module [44] embedded with 2.4 GHz transceiver, onboard Bluetooth stack with the integrated antenna has been used for delivering local connectivity for IoT application. The data is transferred over Bluetooth link through transparent UART interface, which enables easy integration with MCU and bridges the gap between VSMS and smart devices for convenient data transfer and control. These features are integrated into a compact and portable case.

In the analysis and storage layer, the processed data are sent to the personal service application that runs on the smartphone through Bluetooth. The primary function of this layer is data aggregation for better visualization and analysis, followed by data recording and storage locally. The PSA is the main component of the system which act as a bridge between the sensing system and user or medical professionals. Also, it acts as the gateway for sending the data in the cloud for further analysis and storage. The data aggregation on personal service application includes sensing network configuration (initialization, sensor calibration, communication protocol and operating modes) and management (communication channel sharing, time synchronization, data encryption and transmission) and coordination among them. The PSA is also capable of establishing a secure connection with the third party for sending the data for the integration of the medical record of the patient. The data aggregation, along with sensing network, plays a key role for measurement of vital sign and its real-time processing. Thus, it enables in the optimization of the existing solutions to fit into a small portable system with limited resources which was previously reserved for the PC with high computational power and infrastructure.

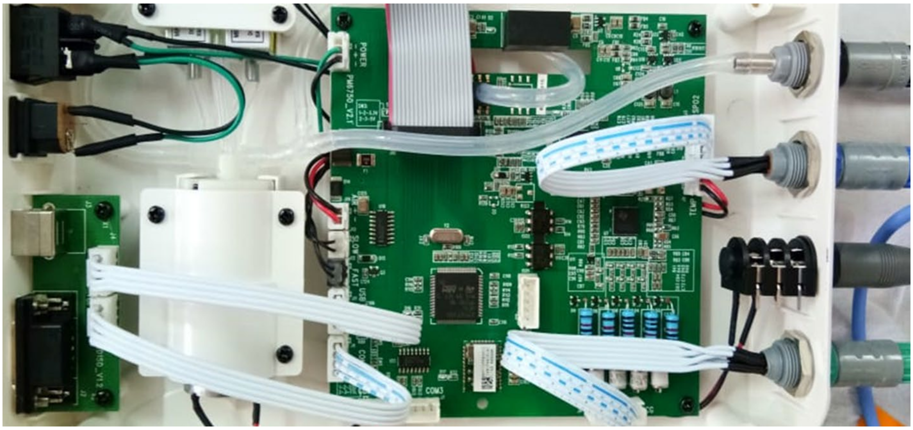

Fig. 6 Experimental setup of the vital signs measurement system

Table 10 Sensor Specification [37]

Sensor Name	Vital Sign	Measurement range	Accuracy	Unit
ECG	Heart Rate	25 ~ 250	±2	Bpm
	Respiration Rate	5 ~ 100	±2	Bpm
Pulse Oximeter	SpO2	35 ~ 100	±3	%
	Pulse Rate	25 ~ 250	±2	Bpm
NIBP	Systolic Blood Pressure	60 ~ 250	±3	mmHg
	Diastolic Blood Pressure	30 ~ 180	±3	mmHg
Body Temperature	Temperature	25 ~ 45	±0.2	°C

6 Experimental Results

The experimental setup of the IoT Enabled VSMS has been shown in Fig. 6. The focus of the presented work is on vital signs data acquisition, management and processing through Android devices considering the current state of the art vital sign monitoring system as it is with the strong objective of making the system portable and user friendly. In this regard, BerryMedPM6750 with body temperature, Spo2, ECG and BP sensor has been used. The detailed specification of the presented system with measuring accuracy range has been summarized in Table 10.

For better monitoring and visualization of vital signs data, a PSA for Android device has been developed. The developed application is capable of storing the data locally and in cloud. The developed application offers patient monitoring with three different modes,

1. Continuous vital sign monitoring with local storage
2. Continuous vital sign monitoringwith cloud storage
3. Periodic vital sign monitoring with local storage
4. Periodic vital sign monitoring with cloud storage

The snapshot of the developed PSA is shown in Fig. 7. As discussed earlier that the different vital sign has a huge dependency on the patient's age, sex, weight and medical history, therefore before starting monitoring and measurement of vital sign, patient information should be provided on the PSA for the effective preparation of the digital health record. Figure 7 shows the snapshot of different vitals sign measured and recorded. Also, the recorded data has been stored and plotted for better clarity, as shown in Fig. 8.

To validate the functionality of the proposed IoT enabled VSMS framework, vital signs of forty subjects with different age group has been measured and recorded. The statistical data obtained from different subject are summarized in Tables 11 and 12. Minimum and maximum value of the vital signs for an adult under healthy condition has been used for implementation of abnormality detection and alarming situations. The different vital signs used for abnormality detections are Body Temperature, SpO_2, Pulse Rate, Respiration rate and Blood. The variation of the different vital sign with a different health condition for the different subject is shown in Fig. 9. The proposed framework generates alert notification

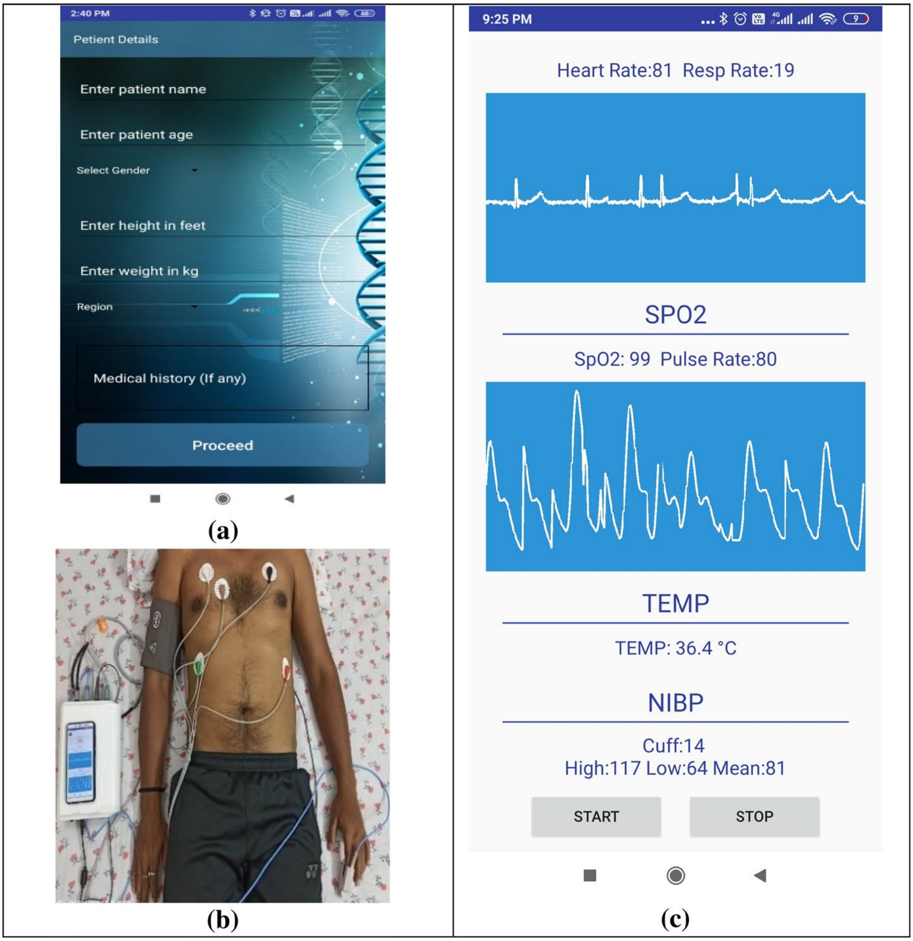

Fig. 7 Snapshot of the **a** Patient information for health record, **b** Experimental setup of for vital signs measurement and, **c** recording of the different vital sign on a smartphone

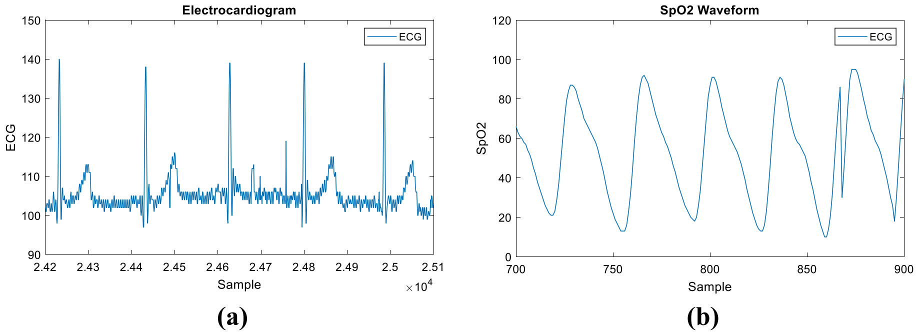

Fig. 8 Plot of Recorded data **a** ECG and **b** SpO2 (Little bit increase the font size for axis)

Table 11 Statistical Information of sample data taken from 40 subjects

Parameter	Age	SpO2	Heart Rate	Temp	SBP	DBP	Resp. Rate
Max	69	100	117	37.3	155	98	23
Min	23	96	54	36.6	106	62	11
SD	13.2	1.02	12.59	0.18	13.34	9.85	2.52
Median	40	98	88	36.9	131	80.7	17.4
Mean	43.53	98	84.22	36.94	131.3	79.5	16.84

Table 12 Statistical information of sample data male vs female

Parameters	Sex	Mean	Max	Min	Range	SD	Median
Age	M	45.15	69	26	43	12.96	41
	F	40.50	61	23	38	13.61	38.5
SpO_2	M	97.96	100	96	4	0.96	98
	F	98.50	99	96	3	0.85	99
Heart rate	M	82.08	117	54	63	14.24	80
	F	88.21	102	74	28	7.71	88
Temp	M	36.96	37.3	36.6	0.7	0.19	36.95
	F	36.92	37.2	36.7	0.5	0.16	36.9
SBP	M	134.76	155	114	41	13.77	134
	F	123.38	145	106	39	11.07	126
DBP	M	81.2	97	63	34	10.40	80
	F	80.30	98	62	36	9.79	81
Respiration	M	16.43	23.4	10.8	12.6	2.84	16
	F	17.64	20.4	14.8	5.6	1.54	17.6

whenever any of these vital sign touches either minimum or maximum value. The snapshot of the implementation of the alert notification is given in Fig. 10. There is a minimum threshold value Min and a maximum threshold value Max for each parameter. The values between Min and Max indicate a healthy state, whereas the values above and below the thresholds indicate worries or abnormal conditions based on their deviation from the

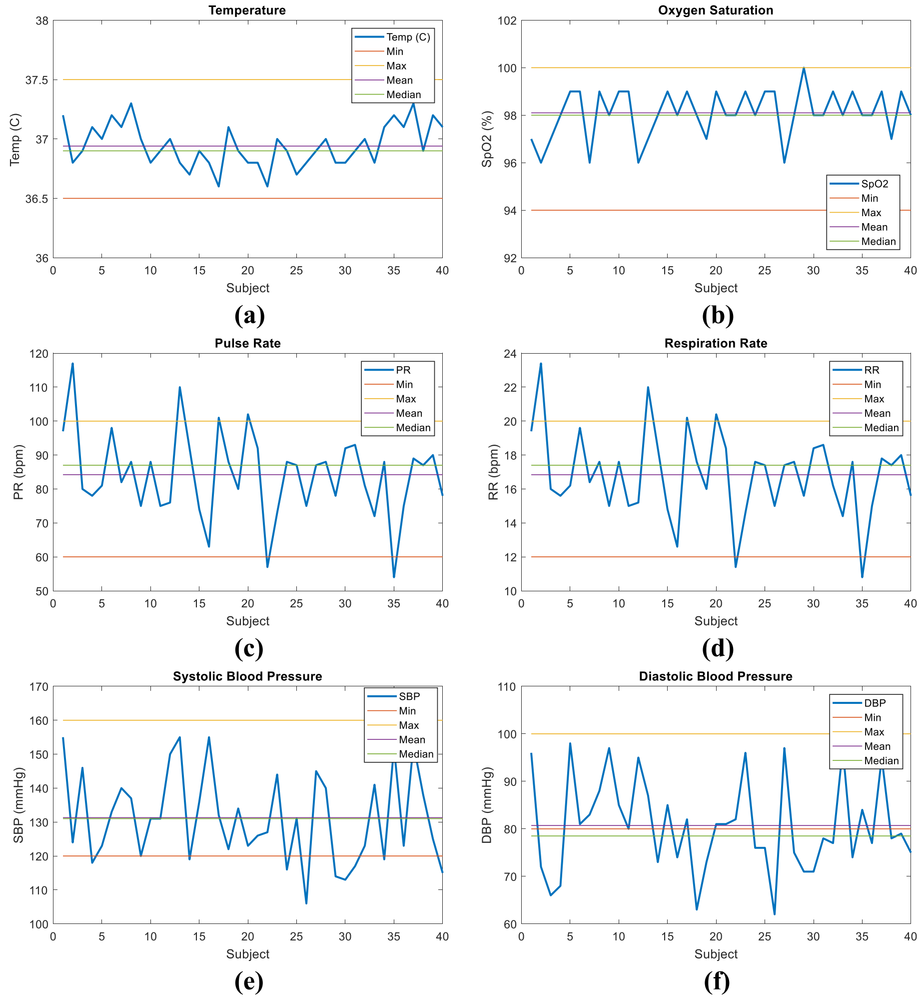

Fig. 9 Minimum, maximum, mean, and median values for various vital sign parameters. The X axis represents the number of patients, while the Y-axis represents the values of vital signs. **a** BT, **b** SpO2, **c** PR, **d** RR, **e** BP (Systolic), **f** BP (Diastolic)

normal or healthy value ranges. The mean and median value of all the vital signs for forty subjects has also been calculated for further analysis.

Early warning system is a scoring tool used in hospitals to access the patient health status by recording of patient's vital signs periodically. Benefit of Early warning system is to reduce the medical expenses, mortality rate and reduce the irregular records which help to better diagnosis and prediction of patient health condition. Hospitals are moving toward automatic digital solutions as a result of the need to establish an automatic early warning system In EWS, each vital sign assigned a sub-score based on degree of the deviation from the value as compared to a healthy person, these vital indicators reflect the patient health condition [23]. Then the total score is estimated through summation of all sub-scores. To calculate the score the physician or nurse should measure the vital sign of the patient and mark the vital sign with score based on its range in observation chart traditionally. The

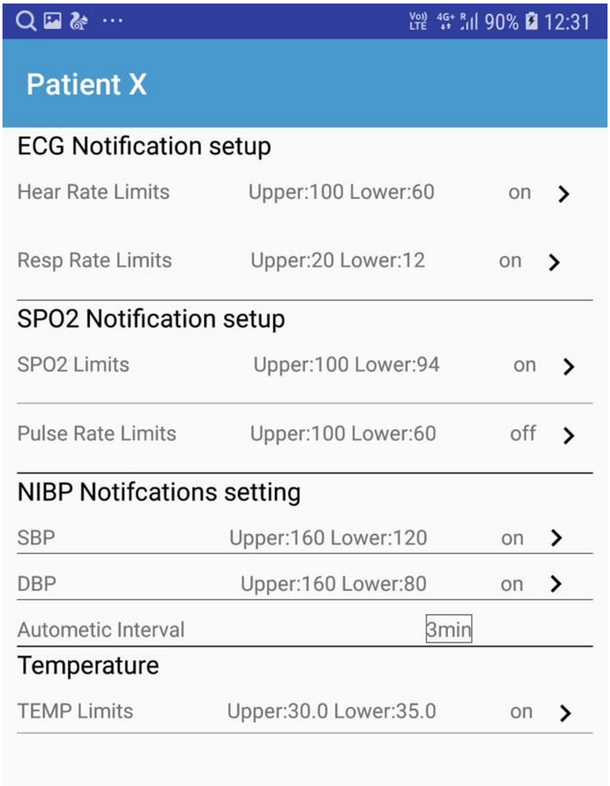

Fig. 10 Snapshot of the abnormality detection and alert mechanism

higher score indicates the level of abnormality in particular vital sign and total score tells the overall health status of the patient. Final score helps the medical staff to modify the treatment procedure and diagnostic. In the presented system an attempt has been made to calculate EWS automatically from different vital signs being monitored. The calculated EWS for 40 subjects as per MEWS given in Table 1 is shown in Fig. 11. The EWS can be communicated to the user or caretaker for appropriate medical intervention.

The presented IoT enabled VSMS has been compared with the existing work available in the literature and summarized in Table 13. It has been observed that the presented work offers monitoring of seven vital signs by using four sensor which are highest among all the reported work. The proposed work uses all the medical-grade sensors with safety norms. Also, it offers good accuracy relatively in comparison with the medical-grade equipment's used for the monitoring of the same parameters.

7 Conclusion

The deployment of IoT enabled healthcare services is in the very initial stage in the developing country, it has been anticipated that such a disruptive technology will have an everlasting impact in the delivery of equitable healthcare services to the people at large with affordable cost in the near future. In light of this, a reliable and user-friendly IoT enabled VSMS has been presented in this paper. The proposed system is capable of

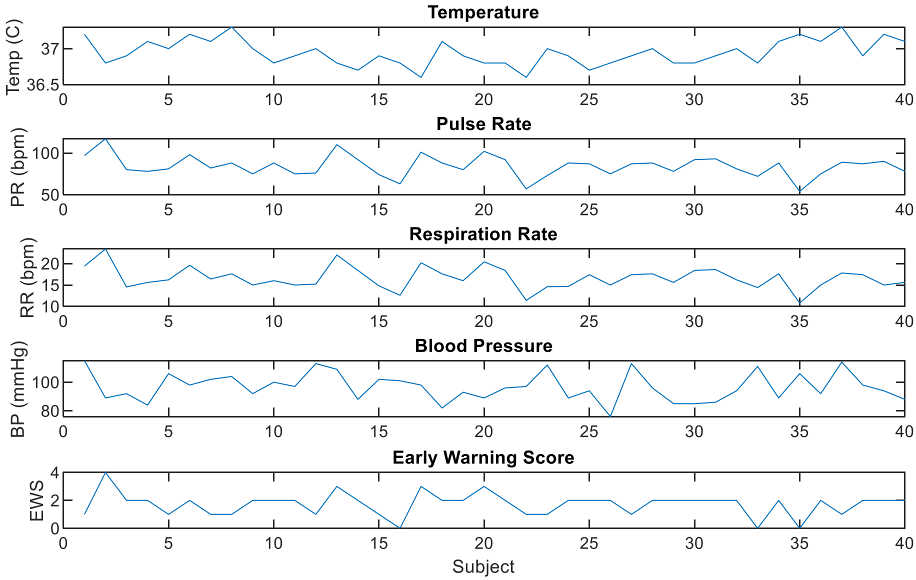

Fig. 11 Early Warning Score calculation from different Vital signs

monitoring and recording different vital sign in real-time. A personal service application has been developed for Android devices for the seamless integration of the system. The developed PSA is accurately satisfactorily measuring the different vital signs and performing the task of abnormalities detection with alert notification generation. EWS has also been calculated from the different vital signs successfully. The successful deployment of this system will increase the accessibility, availability, and affordability of the medical services. Despite these advances, the components of an IoT-based healthcare system confront a number of technological and nontechnical obstacles, necessitating the implementation of targeted strategies and regulations.

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Data Availability Statement Data collected in this study will be available on request for academic and research purpose only.

Declaration

Conflict of interest We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome. We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

Ethical Approval It is hereby confirmed that any aspect of the work covered in this manuscript that has involved either experimental work or research involving human participants and/or animals has been conducted with the ethical approval of all relevant bodies of National Institute of Technology, Raipur, India.

Table 13 Smart phone-based vital sign monitoring system

Ref	Year	Target Services	Application	Module/Gateway	Measured Parameters	Number of Sensor	Communication Technology	Place/Type
Proposed	–	Healthcare	Vital Sign Monitoring	Smart Phone	BT, SpO_2, PR, ECG, HR, RR, BP	4	BLE 4.0	Clinic/Home
Rohmetra et al. [45]	2021	Remote Healthcare	Vital sign Monitoring	Smart phone	SpO_2, HR, BT, BP	4	-	Home/ Clinical
Abdihalikov [46]	2020	Wearable Healthcare	Vital Sign Monitoring	Smart Phone / web app	SBP, HR, BT, RR, SpO_2	5	BLE 4.0	Clinical trail
Chen et al. [47]	2020	Neonatal Healthcare	Vital Sign Monitoring	-	ECG, RR, HR	3	BLE 4.0	Clinical
Fan et al. [11]	2019	Wearable Healthcare	Vital Sign Monitoring	-	BT, SpO_2, PR, BP	4	Bluetooth	Clinical
Pathinarupothi et al. [1]	2019	Remote Healthcare	Vital sign	Smart Phone / web app	BP, SpO2, PR, ECG	4	Wi-Fi/ Bluetooth	Home/ Clinical
Rahmani et al. [23]	2018	Remote Healthcare	Vital sign monitoring	Smart phone	BT, SpO_2, ECG, HR, RR, BP	6	Wi-Fi/ Bluetooth	Hospital/ Home/ office
Gondalia et al.[48]	2018	Patient Healthcare	Health Monitoring	Web app	BT, ECG, HR, Humidity, Accelerometer	5	Zigbee/ GPS module	Battle field
Sun et al. [49]	2018	Patient Healthcare	Vital sign monitoring	Tablet/ PC	PR, RR, BT	3	Wi-Fi	Hospital
Yu, Chan, and Zhao [50]	2018	Personalized Healthcare	Vital sign monitoring	Smart phone	HR, Motion, sleep	3	-	Home
Chen et al. [51]	2017	Wearable Healthcare	Vital sign Monitoring (Elderly)	Smart Phone	ECG, SpO_2, HR, BT	4	Wi-Fi, Bluetooth	Outside/ Home
Sailunaz et al. [2]	2016	Rural Healthcare	Vital Sign	Smart phone/ Tablet	BP, SpO2, PR, ECG, RR, BT, BG	7	Wi-Fi/ Bluetooth	Hospital/ Home
Varma et al. [20]	2015	Personalized Healthcare	Vital sign monitoring	Smart phone	HR, SpO2, BT	3	Bluetooth	Home

Table 13 (continued)

Ref	Year	Target Services	Application	Module/Gateway	Measured Parameters	Number of Sensor	Communication Technology	Place/Type
Fanucci et al. [8]	2013	Remote Healthcare	Vital sign (chronic heart failure (CHF))	Web app	BP, ECG, SpO2, Weight	4	Wi-Fi	Hospital

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Manju Lata Sahu has completed her Master in Computer Application (MCA) from Chhattisgarh Swami Vivekananda Technical University (CSVTU), Bhilai (C.G). Currently, she is pursuing Ph.D. in Department of Computer Application, National Institute of Technology, Raipur. Her research area includes Internet of Things (IoT), Smart Healthcare System and Wireless Sensor Network.

Mithilesh Atulkar is Associate Professor in the department of computer application at National Institute of Technology Raipur, India. He has more than twenty four years of teaching and research experience. He has several national and International publications in his credit. He has participated in various national and International seminars, workshops and conferences.

Mitul Kumar Ahirwal is Assistant Professor in the department of computer science and engineering at Maulana Azad National Institute of Technology Bhopal, India. He has more than four years of teaching and research experience. He has several national and International publications in his credit. He has participated in various national and International seminars, workshops and conferences. His research area is EEG signal processing, Brain Computer Interface, healthcare system. He has been involved as a reviewer with various reputed journals.

Afsar Ahamad has completed his Master in Computer Application (MCA) from National Institute of Technology Raipur, India. He is currently working as Software Development engineer in Oracle Corporation Bangalore, India. He has more than a year of work experience in research and development in association with department of computational and data science at Indian Institute of Science Bangalore. His research area include on Deep learning, Computer vision, Augmented Reality and Smart Healthcare.