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A Smart, Low Cost, Wearable Technology for Remote Patient Monitoring

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***Abstract*—Accurate measurement and timely communication of vital signs is critical to determine health status of patients in the hospital. Absence of reliable vital signs values or delay in their communication leads to medical errors which often result in life threatening situation. This is caused mainly by the manual nature of current monitoring practices and large patient to nurse ratio in under-resourced clinical settings. The neonatology department faces major issues in this regard as ill and/or premature new-born infants require constant monitoring to avoid any subsequent adverse event. To address this issue, an affordable and automated system to continuously measure three important vital signs; temperature, pulse rate, and pulse oxygen concentration using microelectronics and Internet of things is presented here. The system measures the vital signs using wearable sensors and communicates the data wirelessly with maximum error of 0.1 °C temperature, 0.6 % oxygen saturation, and 0.8 beats per minute(BPM) in pulse rate. It also automatically alarms to indicate life-threatening conditions based upon the values of these vital signs. The overall system costs only 7000 PKR (45 USD) and it can be reused across patients due to its wearable nature. It is a compact, smart and easy to handle system having approximate weight and dimensions of 50g and 190 × 85 × 20 mm respectively. The results presented here will enable widespread adoption of the system**

***Index Terms*—Neonatal department, vital signs, centralized system, temperature, pulse rate, oxygen concentration, wireless, micro controller, sensor, STM32F407, ESP8266.**

I. INTRODUCTION

On 20TH February 2018, United Nations International Children Emergency Fund (UNICEF) published a report indicating the countries having the highest infant mortality rate around the globe [1]. All these countries are either developing or underdeveloped including Pakistan, Central African Republic, Afghanistan, Somalia, Lesotho, Guinea-Bissau, South Sudan, Cte d'Ivoire, Mali and Chad. The names of countries are provided here in the order of their infant mortality rate, left to right, from highest to lowest i.e., Pakistan has the highest infant mortality rate throughout the whole world, Central African republic has second highest, Afghanistan has third highest and so on. This report also indicated the mortality rate in different countries. In Pakistan, 1 out of every 22 newborns dies, in Central African Republic 1 out of every 24 new born dies and so on. For neonates, the probability of dying in first month is highest and decreases progressively after that. It means that special attention should be paid to this age group. Neonatal department is thus the most crucial department to control the infant mortality rate. According to the reports, most of these deaths are preventable i.e., these infants can be saved with simple interventions. The main reasons of such deaths are poor mother-child care facilities, unclean water, polluted air, unavailability of proper instruments, and medical error. Out of these reasons, medical errors can be easily prevented. The main reason of these medical errors is the deficiency of manpower (doctors and nursing staff) in the hospitals and the lack of state-of-the art facilities and infrastructure like automatic patient monitoring systems. This leads to late start of registration of new patients in hospital, late admission of patients in respective wards, latency in diagnosis and prescription process, and hence delay in providing life-saving care. The ill/premature infants present in intensive care or critical care units require continuous monitoring and cannot

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This work involved human subjects or animals in its research. The authors confirm that all human/animal subject research procedures and protocols are exempt from review board approval.

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bear critical delay in life care. In 2016, the World health organization published a report on the topic of medical error. One of the main errors which was mentioned in the report was therapeutic errors [2]. Therapeutic error means the delay in initiating medication and inadequate monitoring of vital signs (heart rate, oxygen saturation and temperature). This report also stated that these errors are avoidable by taking proper corrective measures. Khurshid Khowaja and his group conducted research in a tertiary care hospital of Karachi, Pakistan regarding medication errors. They concluded that 5.5 percent of preventable deaths are because of medical errors [3]. They suggested the use of software programs to monitor the health of patients. The patients in the ICU are more likely to experience these issues compared to the step-down units. The reason is the complexity of their conditions and need for urgent interventions. In ICU, timely health update of every patient for any necessary intervention is essential for doctors and nursing staff. It is a problem due to resource limited settings in developing countries. As the number of patients increase the situation becomes more complicated. We personally surveyed multiple hospitals of Lahore, the provincial capital of Punjab. Punjab is most populous province of Pakistan [4], containing more than half of country's total population [5]. Lack of modern patient monitors was noted at all of the major hospitals. For example, there were only 8 Intensive care patient monitoring systems in the ICU of neonatology department of a major hospital which is supposed to cater to hundreds of patients on a daily basis. Although the medical staff works hard, this deficiency of patient monitoring often leads to life threatening situations. The monitoring of vital signs is essential to determine the health status of these patients. There are three basic vital signs which should be measured to get an insight of a patient's state in the hospital. These vital signs are temperature, heart rate, and oxygen saturation [6]. Sometimes blood pressure is also measured along with these vital signs. These vital signs provide the medical staff important insights about patient's health status and enable them to make therapeutic decisions. These are the key elements to monitor the patient's progress during their stay in hospital [7]. These are primary indicators of a patient's current medical status and must be monitored continuously and documented properly [8]. The more accurately and continuously the vital signs can be measured, the safer the subsequent medical care becomes [9]. Current hospital grade patient monitors are too expensive and are too bulky for bedside applications in many under-resourced settings. Therefore, the aim of this research paper is to present a solution to minimize medical errors by automating collection, processing and communication of vital signs. This can avoid a significant number of preventable deaths. There are some other wearable health monitoring devices which have been introduced in the market for smart health monitoring. Vital Tracer's smartwatch VTLAB is a wearable medical grade device [10]. It collects raw biological signals and converts them into reliable vital sign data such as blood pressure, blood oxygen content (SpO2), heart rate and respiratory rate. Cosinuss's health monitoring device for continuous vital signs monitoring cosinuss° Two is an in-ear wearable sensor. It can measure heart rate, respiratory rate and temperature [11]. Then these values can be monitored on a smart phone through Bluetooth connection. Vívosmart® 4 monitoring system measures basic vital signs heart rate, oxygen saturation along with some other parameters through wristwatch [12]. It then converts them into electric signal and displays these values on watch's LED display. Though these systems are good solutions for personalized monitoring, they do not have centralized monitoring capability required in hospital settings. Also, the existing systems are significantly expensive for developing world's applications. For a government hospital in a country like Pakistan which spends less than 0.75 % of GDP on healthcare, these systems are not affordable [13]. For oxygen saturation measurement, the pulse oximeter is generally attached to thinner body tissues. The higher blood flow rates in thinner body tissues such as fingertip and earlobe facilitate heat transfer and helps in accurate SpO2 measurement [14]. Therefore, fingertip measurement is typically used in most of the hospitals and clinical practices for SpO2 monitoring [15]. The existing wearable systems measure value through wrist bands and sometime through earlobes sensors [11]–[13]. The goal for our design was to use fingertip measurements of SpO2 using a device with a wearable form factor in hospital settings. This would also make it easier for doctors and nursing staff to use our system, to understand it and to compare its readings with traditional pulse oximeters. Our proposed solution is based upon a system which is designed to automate the monitoring of important vital signs of infants in Critical Care Unit (CCU) and Intensive Care Unit (ICU). This system is very economical and will be suitable for use in developing countries and can save thousands of lives each year. Moreover, the COVID-19 pandemic highlighted the value of remote and automated patient monitoring to decrease the burden and exposure of an already limited staff to dangerous diseases which can in fact decrease the available healthcare workers. Therefore, it is prudent to enable the development of such dedicated and suitable wireless remote patient monitoring solutions. The contents of TABLE I compare the cost, measuring location and most important features of already existing wearable devices, as mentioned on their websites with our proposed system.

TABLE I
COMPARISON OF WEARABLE HEALTH MONITORING DEVICES

System	Cost($)	Location	Features
VTLAB [11]	1000	Wrist	HR, SpO2, temp
Cosinuss° Two [12]	350	Earlobe	HR, SpO2, temp
Vívosmart® 4 [13]	129.99	Wrist	HR, SpO2
This work	45	Fingers	HR, SpO2, temp

II. PROBLEM DESCRIPTION

Under-resourced hospitals in developing and under-developed countries lack resources to monitor many of their patients in a timely manner. This leads to poor patient outcomes, especially for neonates and infants. Automation of patient monitoring can bridge this gap and enable the existing medical staff to perform their duties in a more efficient manner. Moreover, such automation can use modern data science and artificial intelligence to determine the most vulnerable patients to enable optimum resource allocation.

III. System Design

In this work, we present an affordable and scalable system for automated monitoring of three important vital signs (heart pulse rate, blood oxygen concentration and temperature) through a wearable design for patients in the ICU. Although such systems exist in the developed countries, the same systems can simply not be used for most cases in the developing world due to cost, complexity, and infrastructure requirements for these systems. Following needs are the focus of this work.

1) Cost: Current systems are expensive and hence are available in an extremely limited quantity in under-resourced settings.
2) Interface: Though they measure values continuously and accurately but do not report those automatically to a central location. Also, the alternative systems are expensive and don't necessarily provide clinical grade data and decision support.
3) Form Factor: The existing patient monitors require significant space and dedicated patient beds which are often hard to get in the hospitals in the developing world.

Therefore, it is the need of hour to use modern technology to design a system with the following attributes.

1) The system should measure basic vital signs accurately without requiring large unit at the bedside.
2) The systems should be able to function without a dedicated human operator.
3) It should be a centralized system that can utilize the existing infrastructure in the hospitals.
4) It should be of low cost and easy to manufacture for scalability.
5) There should be a simple alarm and notification system in case of any emergency.

The results from the patient monitoring system are communicated to the medical staff continuously through existing wireless communication system (hospital WiFi) where already available and through other data communication networks where this facility is unavailable. The results are then displayed on a centralized dashboard (monitor). The wearable design uses simple LEDs (Light emitting diodes) and optional audio alarm to indicate emergency conditions. This system provides a view of patient's measurements in real time through a compliant web interface. Through this interface, doctors will be able to view patient's current vital signs value from anywhere on their personal communication device (smartphone, tablet). This website uses security features to protect data privacy. Moreover, an automated and smart algorithm can process the vital signs to determine the emergency conditions to signal an alarm to the medical staff. For most applications, the algorithms can be fairly simple and can alarm for a risk condition by checking vital signs against their threshold values (e.g., Temperature > 38°C, SpO2 < 90%, Heart Rate > 150 BPM). Hence, the required computational complexity is not too high.

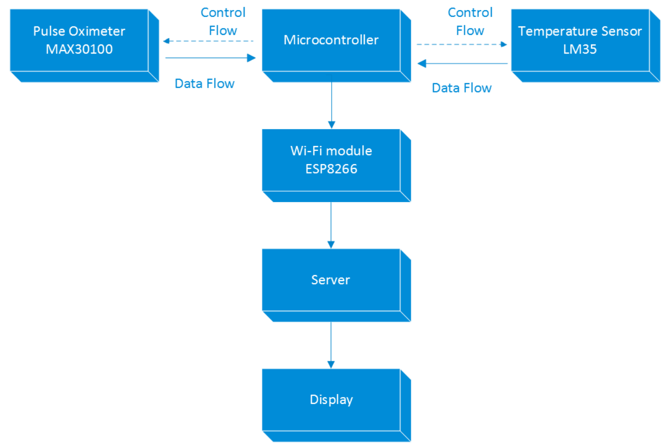

Fig. 1. Block diagram of components.

IV. Related Work

There have been other efforts in the domain of automated health monitoring systems for under-resourced settings [16], [17]. However, there are certain important improvements presented in this work to result in a more practical solution. Most of the earlier systems presented in the literature rely on Arduino as micro controller. Arduino operates at much lower frequency (16MHz) than STM32F407 (110MHz) which forms the basis of our system design [18]. That is why the processing speed of our system is better than the existing systems. This makes our system more suitable for ICU environment where critical decisions need to be made quickly. Moreover, most of the existing systems do not include the measurement of respiratory rate or use two separate sensors to measure heart rate and respiratory rate [19]. Our system can measure both vital signs using a single sensor, making wearable module compact, low cost and easy to handle. Moreover, the existing systems use smartphones as intermediate communication devices [20]. The smartphone can only communicate with a single wearable module at a time, requiring a separate smartphone for every module, hence increasing the cost and complexity of the overall system. The presented system utilizes WiFi for communication between the wearable device and the central monitoring station. The WiFi module is very economical compared to smartphones, leading to an affordable solution compared to the previous systems. Moreover, it increases the reliability of the system by providing a dedicated communication channel for the system. Finally, the proposed system uses fingertip for monitoring SpO2, making it comparable with currently approved products. In conclusion, the proposed system provides most important and complete information regarding vital signs of a patient at high speed, lower cost, and more reliably than the previously designed systems. This makes the presented system novel and of interest in many applications.

A. Block Diagram

The block diagram of all the component is shown in Figure 1.

The pulse oximeter and temperature sensor communicate the raw data values to STM32F407 micro controller

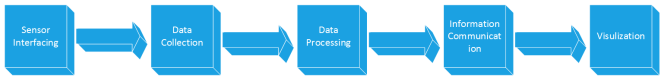

Fig. 2. Block diagram of process.

using I2C (Inter-Integrated Circuit) communication [21]. The STM32F407 processes data and communicates to WiFi module ESP8266 [22] that sends information to the server.

The block diagram of the data collection process is shown in Figure 2. The data is collected from sensors, then filtered and processed by the micro controller. The information is then sent through UART (Universal Asynchronous Receiver/Transmitter) to ESP8266 that sends the information to server.

B. Flow Chart

The flow chart of system describing how the data from the vital signs monitoring can be used to automate smart-decision making process is presented in figure 3. The temperature, pulse rate and oxygen saturation of patients are measured using clinical grade sensors and are communicated as raw values to a micro controller (STM32F407) [23]. The micro controller converts the raw values to clinical format. The information is then sent to a server that further displays the information to the medical staff. The parameters are checked. If they are out of limit an alarm is generated in the form of buzzer and LEDs to gain staff's attention immediately.

V. Implementation

There are several important trade-offs that need to be balanced for an optimal implementation of the proposed system architecture. This includes system size and weight, user interface, data communication and storage to name a few.

The presented system is designed as a wearable glove with two sensors (MAX30100 and LM35) embedded on its inner side, enabling good thermal contact with patient's body and minimizing environmental variations. Temperature sensor for body temperature is completely covered by the glove to minimize the effect of ambient temperature on clinical measurements. Similarly, there will be negligible effect of ambient light on pulse oximeter's readings due to the encapsulation provided by the wearable glove.

A. Component Selection

1) Micro Controller: For our system, we required a micro controller having efficient processor to continuously process the raw data values at high speed. We selected STM32F407 because of its 32 bit ARM Cortex-M4 with FPU core, powerful processor and 110 MHz frequency [23]. It is very suitable for our system because it has been specifically designed for medical, industrial and consumer applications. It has 1M byte flash memory and 192 Kbyte RAM. It has three ADC's(analog to digital converters) and two I2C interfaces which makes it very appropriate for our system. Its dimensions are only 5.6 × 3 × 0.8 inches which played important role in designing a concise system. STM32F405 can also be used as micro controller in our system for obtaining similar results [24].

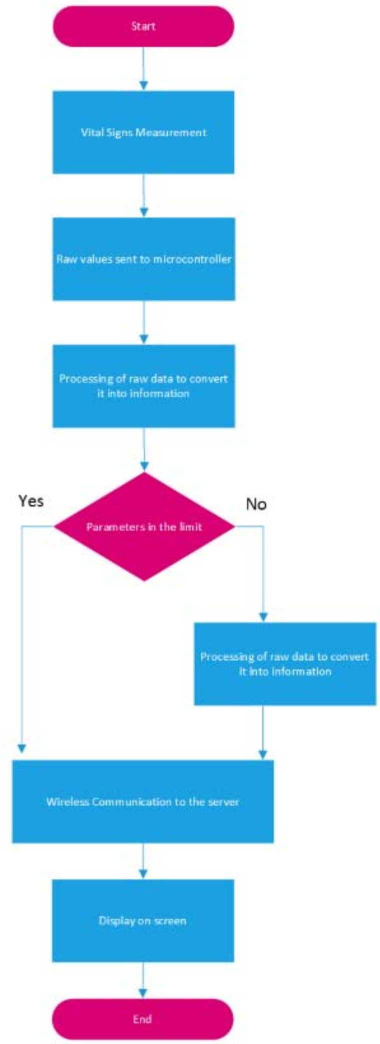

Fig. 3. Flow chart.

Fig. 4. Wearable glove with mounted sensors.

2) WiFi Module: ESP8266 is a low cost high frequency (2.4 GHz) WiFi module which is very appropriate for our system. It reduces communication stack overhead on the main processor. ESP8266 is designed with advanced power management technologies and intended for mobile devices, wearable electronics and the Internet of Things applications. ESP8266 WiFi integrates memory controller and memory units including SRAM and ROM. ESP8266 has one I2C and 2 UART Interfaces, UART1 and UART0, which makes it very suitable for our system. ESP32 can also be used as WiFi module in our system for obtaining similar results [25].

3) Temperature Sensor: We selected LM35 as temperature sensor to achieve clinical accuracy over the physiological range [26]. Moreover, it functions through a linear relationship between temperature and voltage which is simpler to apply and handle. It is extremely low cost due to wafer level trimming and easily available. It is suitable for remote applications. Further, it has exceptionally small self-heating content, 0.08 °C in still Air. Therefore, it does not overheat and provides accurate results. TMP235 can also be used in our system for same purpose with simple modification [27]. It is also incredibly low cost, has same sensor gain but different maximum and minimum supply voltage and supply current limits.

4) Pulse Oximeter: We used MAX30100 sensor for pulse oximeter due to its low cost and clinical grade accuracy [28]. It is a small (5.6 × 2.8 × 1.2 mm) multipurpose sensor. A single MAX30100 can be used both for heart rate and oxygen saturation measurement, thus enabling a compact system design. It has been designed specifically for wearables and medical monitoring devices. It has integrated ambient light cancellation capability which helps to get accurate readings. It is incredibly low cost and easily available in the markets and both these attributes played important roles to decrease the overall cost of the system. MAX30102 can also be used in our system for the same purpose to obtain similar results with slight modifications [29].

B. Sensor Interfacing

1) Pulse Oximeter: The sensor communicates the raw data values to STM32F407 via I2C communication. The sensor is configured by setting its mode to HR (Heart Rate) for pulse rate and/or SpO2 (oxygen saturation) mode is enabled by writing appropriate values to its registers. The LED is configured to operate at 50mA current for both Infrared(IR) and Red(R) devices. This ensures that current is sufficient for working of IR and R LEDs. The sensor was initially calibrated using a commercial pulse oximeter.

2) Temperature Sensor: Temperature sensor communicates the raw data values to STM32F407 micro controller. The analog values are converted to voltage that has linear relation with temperature. An ADC (analog to digital converter) is used to convert the values into a digital format. The sensor is self-calibrated and does not require any external calibration. We confirmed its calibration using a calibrated hot plate.

C. Data Collection

1) Pulse Oximeter: After configuring the MAX30100, the data is read by FIFO (First In First Out) read and write pointers and the difference of these pointers provides the number of available samples recorded by FIFO data register [30]. For all the samples, the data is read from FIFO data register and stored in a variable. Since each sample is of 4 bytes (32 bits) and FIFO data register only stores 1 byte (8 bits) of data at one time instance so it is read four times and stored in an array variable. The first byte is left shifted and combined with second byte through OR function to receive the Infrared (IR) data. The third byte is left shifted and joined with fourth byte through OR function to get the Red data. After reading one sample, the read pointer is incremented. When all the samples recordings are read and iterations are completed then read pointer is reset. The FIFO data, read, write, overflow registers are then reset to record and read the new samples.

2) Temperature Sensor: LM35 functions through interrupt handler which is invoked when there is an interrupt generation on LM35. An interrupt is enabled to access the data from direct memory and is stored in ADC buffer.

D. Data Processing

1) Pulse Rate: For processing the pulse oximeter data, the DC (Direct Current) signal is removed from IR data so that it oscillates about the x-axis. The noise due to any ambient light or motion is filtered by applying Butter worth filter with sampling frequency 100 Hz and cut-off frequency 10 Hz. For final processing, the pulse rate is obtained by counting pulses per minute. For this purpose, the zero crossings are monitored. If the signal falls below 0, then a counter, zero is updated. If the counter is multiple of 2, implying it has crossed zero crossing twice and a pulse has passed then another counter of pulse is updated and pulse rate is calculated by recording the time at that instance [31].

$$PulseRate = \frac{pulse \times 60}{TimeRecorded(sec)} \tag{1}$$

However, to ensure that the counter zero does not increase for all the time pulse remains below 0, a flag initialized to 0 is set to 1 when the pulse is above 0. And counter zero is only updated if flag is 1 to prevent recording for the time pulse is below 0. The flag generation is enabled through conditional statements. If pulse rate is out of limit, a red flag appears on the screen of relevant infant showing that, that specific infant is having abnormal value of any vital sign and require urgent intervention.

2) Oxygen Saturation: Oxygen saturation is measured from relative absorption of IR and R LEDs. The ratio of raw data of both LEDs gives information of a variable ratio RMS (Root mean squared value), which is normalized by eliminating ambient light effect to give Oxygen saturation using the formula [31].

$$Oxygen = 110 - (18 \times ratioRMS) \tag{2}$$

The flag generation is enabled through conditional statements similarly as done in case of pulse rate. In normal condition, the flag remains off.

3) Temperature: The dc value is removed by subtracting the offset and temperature is calculated by this linear relation that 1 centigrade temperature is equivalent to 10mV [32].

$$Temperature = \frac{adc\_buffer}{10} \tag{3}$$

The flag generation is enabled through conditional statements in the same way as happens in the case of heart beat and oxygen saturation. In normal condition, the flag remains off.

E. Alarm Generation System

This system incorporates following two different alarm systems and each one of them enables according to the need of time.

1) Emergency alarm system
2) Priority alarm system

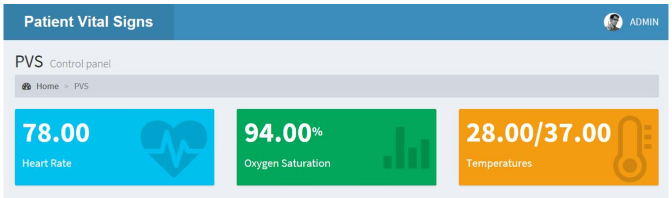

Fig. 5. Website for display of vital signs.

1) Emergency Alarm System: If the value of heart rate, oxygen saturation or temperature of a single infant falls beyond a safe limit, emergency alarm system is enabled while priority alarm system remains disabled. A red flag appears on the screen under the patient's name to show an abnormal situation. The alarm system has also been installed in hardware that consists of three different colored LEDs and a small buzzer. Whenever any vital sign value falls below a safe limit, the corresponding GPIO(General purpose input/output) pin is set to high to enable the buzzer to go on and LED of specific color to lit up to identify this specific parameter. In normal condition, the GPIO pins remain reset.

2) Priority Alarm System: If the values of heart rate, oxygen saturation or temperature of more than one infant fall beyond a safe limit, priority alarm system is also enabled in addition to emergency alarm system. A red flag still appears under the name of each relevant patient. But for this alarm generation, system uses a scoring-based algorithm taking into account all three vital signs of infant. Through this algorithm, system determines the sequence of required intervention for each infant, depending upon their health situation. It shows the name of the patients on the screen in the order of required sequence of intervention. This alarm system will help nursing staff to make decision regarding order of intervention, if more than one infant's vital sign's value deteriorates at one time.

F. Information Communication

The numerical Vital signs information is sent wirelessly via a UART to WiFi module ESP8266. ESP8266 sends the data to server through client- server architecture [33]. It connects the network connection for which the credentials are entered so ESP8266 can access the network through the username and password. For communication, system can use the existing WiFi servers of hospital wards. In the hospitals where such WiFi servers will not be available, system will use dedicated 4G internet devices for its operation, which will come with system package.

G. Visualization

A dedicated website for this purpose is developed using Java script and HTML (Hypertext markup language) programming languages for front end, C# for back end and for interfacing with the system hardware. These vital signs values can be displayed on a centralized dashboard or medical staff can also access the website using a web link on their communication devices.

The website has security feature too, to protect patient's data using specific credentials for login.

The website also contains graphs of all mentioned vital signs (heart rate, temperature and oxygen saturation). There are in total three graphs which can show trend of vital sign values of patients. The x-axis of each graph shows time in hour. The y-axis of graphs show the measuring unit of each vital sign, beats per minute (BPM) for heartbeat, percentage (%) for oxygen saturation and degree centigrade (°C) for temperature.

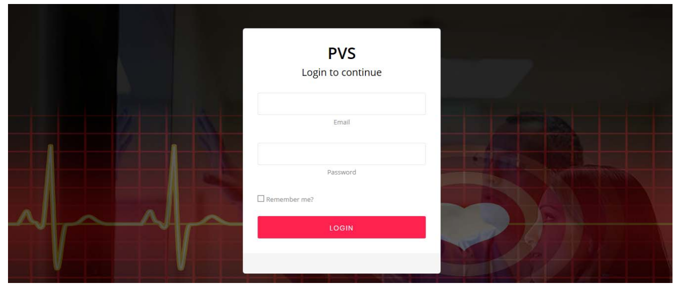

Fig. 6. Security feature of website.

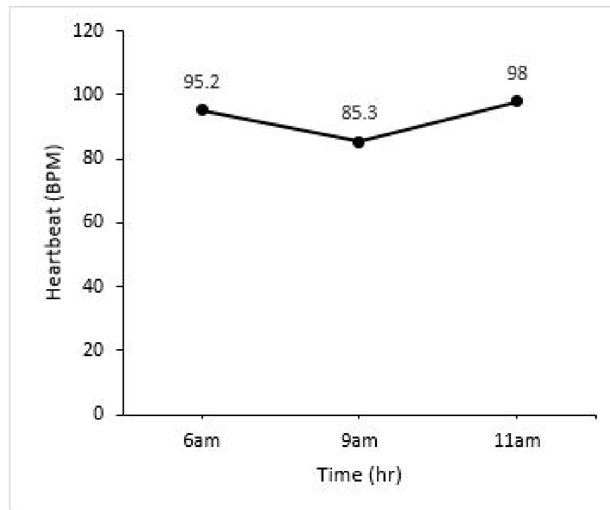

Fig. 7. Graph showing trend of heart rate of a healthy volunteer.

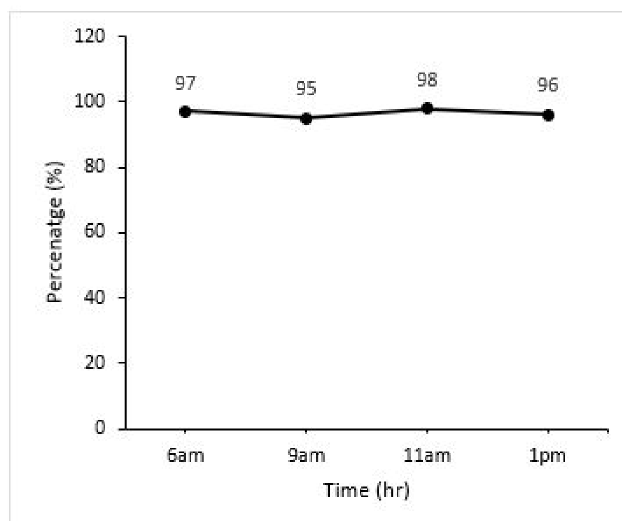

Fig. 8. Graph showing trend of oxygen saturation of a healthy volunteer.

The graph shown in figure 7 shows the trend of heart rate values of a healthy volunteer. This trend will help doctors and nursing staff to have better insight about current condition of the patient.

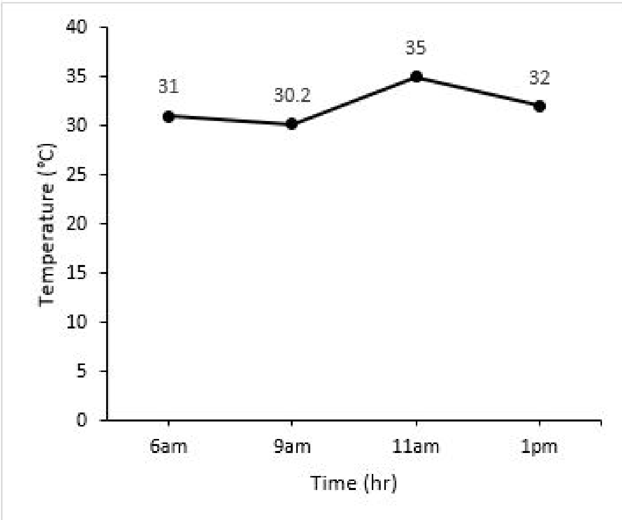

Fig. 9. Graph showing trend of temperature value of a healthy volunteer.

TABLE II
RESULTS FROM TEMPERATURE SENSOR

Variable	Temperature(°C)
Room temperature using presented system	28.5
Room temperature using digital thermometer	28.6
Body temperature using presented system	37.1
Body temperature using digital thermometer	37.2
Error	0.1
Error	0.1

The graph shown in figure 8 shows the trend of oxygen saturation values of a healthy volunteer.

The graph shown in figure 9 shows the trend of temperature values of a healthy volunteer. All these graphs will help doctors and nursing staff to better understand the health situation of infants. This will also help them to make decision about further steps regarding treatment of that infant.

VI. RESULTS AND DISCUSSION

A. Temperature

The results for room and body temperature, as measured using our system and digital thermometer are shown in Table II.

The graph shown in figure 10 shows the temperature variations of two volunteers ill with fever (Child and Adult) measured using our system.

B. Oxygen Saturation

We measured the oxygen saturation of two different healthy volunteer using our system. The RMS value of relative absorption ratio of IR and R LED corresponds to oxygen saturation. After measuring Oxygen saturation using our system, we measured the SpO2 of both volunteers using HR/SO2 sensor of smartphone. Then we compared the results of our system and the smart phone.

The maximum error value after 2 measurement is less than 1 percent (0.6 percent oxygen saturation).

C. Pulse Rate

We measured the pulse rate of two healthy volunteer using our system. The waveform of IR LED corresponds to pulses.

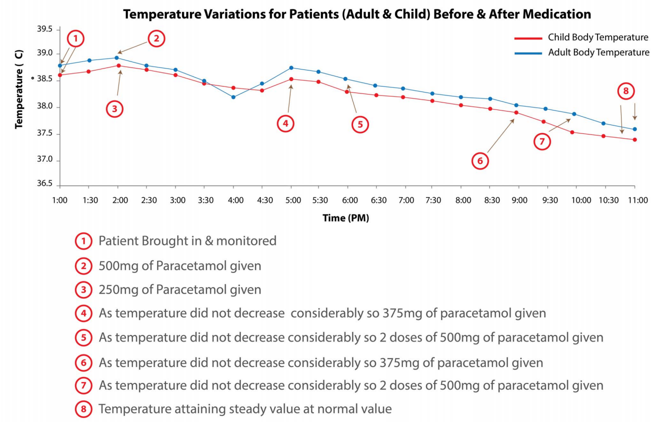

Fig. 10. Temperature variations of a child and adult volunteer measured through presented system.

TABLE III
RESULTS OF OXYGEN SATURATION READING

Variable	Oxygen Saturation (%)
Person A's value from presented system	96.9
From HR/SO2 sensor of smart phone	97
Person B's value from presented system	98.4
From HR/SO2 sensor of smart phone	99
Error	0.1
Error	0.6

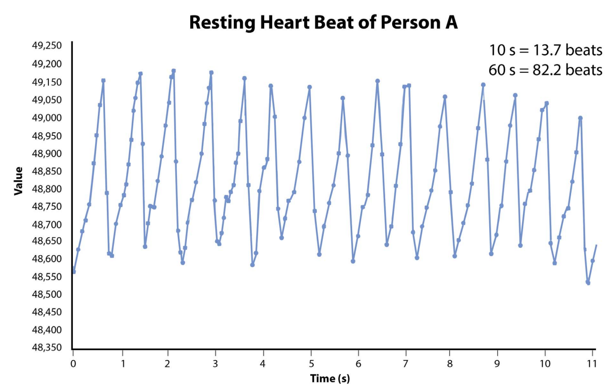

Fig. 11. Resting pulse rate of person A from system.

TABLE IV
RESULTS OF HEART RATE READING

Variable	Pulse Rate (Beats per min)
Person A's value from presented system	82.8
From HR/SO2 sensor of mobile phone	82
Person B's value from presented system	86.4
From HR/SO2 sensor of mobile phone	86
Person A's value Error	0.8
Person B's value Error	0.4

The x-axis shows time in milli seconds. Pulse rate is calculated by counting pulses (by zero crossings) in one minute.

After measuring pulse rate using our system, we measured the pulse rates of both volunteers using HR/SO2 sensor of smartphone. Then we compared the results of our system and the smart phone.

The maximum error value after 2 measurement is less than 1 BPM (0.8 BPM).

Pulse rate of volunteer A was also measured after 30 minutes of jogging using system presented here and using HR/SO2 sensor of smart phone. Then both values

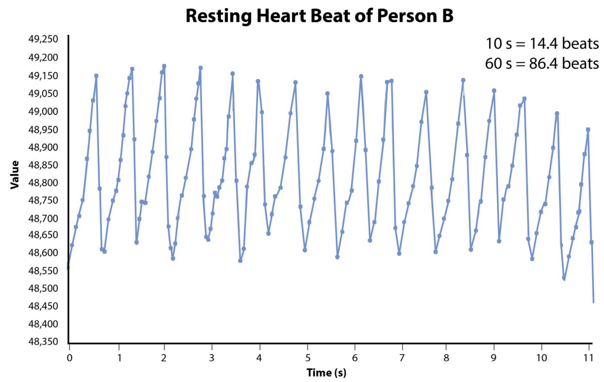

Fig. 12. Resting pulse rate of person B from system.

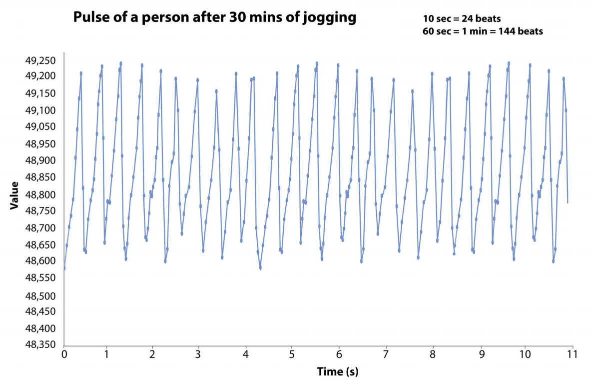

Fig. 13. Pulse rate of volunteer A after jogging.

TABLE V
RESULTS OF HEART RATE READING

Variable	Pulse Rate (Beats per min)
From presented system	144.2
From HR/SO2 sensor of smart phone	144
Error	0.2

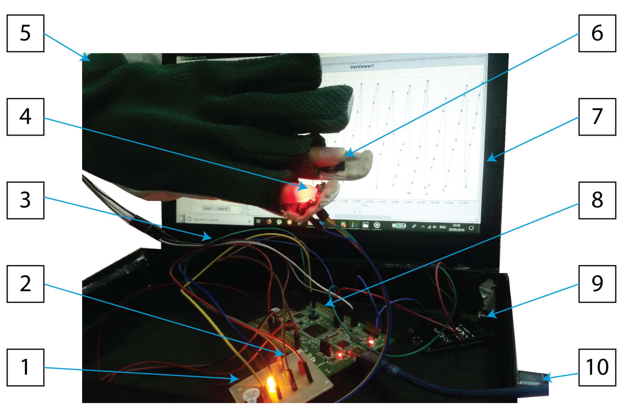

Fig. 14. Complete system.

are compared. The system accurately tracked the higher pulse rate as shown in the graph.

D. Complete System

The following picture shows the whole hardware of presented system including wearable module, micro-controller, WiFi module and alarm generation system.

1) Alarm generation system
2) Wires connecting alarm generation system and micro-controller
3) Wires connecting alarm generation system and micro-controller
4) MAX30100 pulse-oximeter
5) Wearable glove
6) LM35
7) Local display
8) Micro-controller STM32F407
9) Wifi module ESP8266
10) Data cable

VII. CONCLUSION

This paper presents a low cost and convenient patient vital sign monitoring solution for low-resource settings. Three important vital signs are accurately measured, converted to clinical values, displayed on a centralized screen and web server using wireless communication system through the existing WiFi networks or dedicated 4G devices. The server can also be accessed by doctors anywhere through their personal communication device (tablet, smart phone) via a secure login-based website. The values of the vital signs are updated in real time eliminating the need of frequent visits of medical staff. If the values of these vital signs fall beyond the set safe limit, an alarm is triggered. The related LED will also be lit (both on the wearable unit as well as on the centralized screen) to show which parameter is out of limit, indicating the need of intervention. The whole system costs maximum 7000 PKR (45 dollars) and it can be reused for new patients due to its wearable nature. For vital signs display, already existing nurse monitoring stations will be used and hence will not add any significant cost to the system. Therefore, the system can be implemented with exceptionally low overall cost. The novelty of the presented system is in the wearable glove design which improves system accuracy without any expensive electronics, as well as reduces system cost and complexity. Moreover, to the best of our knowledge, this is the first known example of an affordable vital signs monitoring system integrated with a centralized data collection and visualization system equipped with remote login available for the doctors. The system enables smart decision making by using simple scoring schemes. In the future, more advanced algorithms can be implemented using the information provided by the system.

VIII. FUTURE WORK

There are more features that can be added in our system to increase its functionality, to make it more reliable, accurate, secure and to decrease the dependence on human resources. Automatic blood pressure capability can be added in the system by pulse wave analysis of the waveform obtained from the existing on-board PPG (Photoplethysmography) sensor. Humidity sensor can be added in our system for ensuring mother womb like environment for premature infants inside the incubators. HDC 1080 is a low cost, low power digital sensor that can measure humidity with an accuracy of 2 percent [34]. Moreover, we can develop a simple single PCB to integrate all components on it to reduce systems size. A small coin cell battery can be added to autonomously operate the system for several days. Artificial intelligence and machine learning algorithms can be added to our system for predicting the future events by training the data set using patient history (through EHR integration). Patient data can be secured using encryption and access control. Biometric identification can be used along with these credentials to enhance this feature.

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