Wireless Sensor Node for Simultaneous Monitoring of Health Parameters

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***Abstract*— Many diseases, such as cardiovascular and dengue fever, require constant monitoring of certain health parameters of patients which sometimes, is disturbing to patients who requires plenty of rest. In this paper, we present a non-invasive technique based on wireless sensor networks to monitor the temperature, blood pressure and the pulse rate automatically without having to disturb a resting patient. The wireless sensor node captures these vital health parameters and then sends them to a smart phone via Bluetooth. The smart phone handles all the processing tasks and produces systolic and diastolic heart rates and gives alerts whenever an abnormal condition occurs. The prototype device managed to perform at 99.76 %, 88.40% and 92.70% accuracy levels on monitoring the temperature, blood pressure and pulse rate, respectively. The system, designed using low-cost peripherals with minimal electronic devices, can be used to monitor patients even from a remote location via wireless technology.**

***Keywords*— Wireless sensors, health monitoring, e-health**

I. Introduction

Blood pressure, heart rate and body temperature are commonly referred to as vital health parameters because most of diseases affecting humans can be identified by monitoring them periodically. For instance, hypertension (high blood pressure) or hypotension (low blood pressure) results in diseases such as kidney failures, nerve problems, heart attacks, paralysis, etc. In addition, a person suffering from dengue fever needs periodic monitoring of these vital health parameters. Sometimes, the process of constant manual monitoring of these parameters itself is a stressful occasion to the patient who needs rest. Such constant monitoring of vital parameters is essential for accurate clinical diagnosis.

The dengue fever, in particular, is a mosquito borne viral infection. Presently, approximately two-thirds of the world's population lives in areas infested with dengue vectors [2]. It is endemic in all continents except Europe and epidemic dengue haemorrhagic fever (DHF) occurs in Asia, America and some Pacific islands [3]. There are three stages in DHF, namely, febrile, critical (leakage phase) and convalescent phase. When a patient is admitted, it is important to identify as to which phase he/she belongs to. A platelet count of less than $100{,}000/mm^3$ usually suggests the end of the febrile phase, and may indicate the entry to the critical phase [1]. At this stage, to detect shock early, vital parameters like blood pressure, pulse rate and body temperature need to be monitored periodically (usually once an hour). Currently, hospitals in Sri Lanka maintain a chart for every patient indicating how these vital parameters change periodically.

The purpose of this research is to design and develop a wireless sensor node to monitor a person's vital health parameters periodically in real time and display the results on the screen of a mobile phone. The phone also produces alerts whenever it detects an abnormal condition. This system is most suitable for monitoring patient in clinical environment and monitoring elder peoples at home.

A. Recent Work

The UbiMon project [4] developed prototypes of motion sensors that are worn at different places on the body, while the wearer performs certain activities of interest (such as walking, sitting down, running, climbing stairs, cycling, etc.). The datasets recorded with these platforms are important for characterizing optimal sensor types and their corresponding locations. Once determined, only a minimal number of sensors needs to be deployed for monitoring patient activity for context aware body sensing applications.

A technique to capture ECG data on a smart phone is described in [4] in which prototypes of motion sensors that are worn at different places on the body are developed. While the wearer performs certain activities of interest (such as walking, sitting down, running, climbing stairs, cycling, etc.), the device measures and records ECG data. This system requires only a minimal number of sensors to be deployed for real time monitoring patients.

A cellular phone based online ECG processing system for ambulatory and continuous detection is revealed in [8]. It aids cardiovascular disease (CVD) patients to monitor their heart status and detect abnormalities in their normal daily life. This system provides solutions to overcome the limitations observed in conventional clinic examination such as the difficulty in capturing rare events, off-hospital monitoring of patients' heart status and the immediate dissemination of physician's instruction to the patients.

A miniaturized and autonomous sensor system that enables people to carry their personal body area network is presented in [9]. The network provides medical, lifestyle, assisted living, sports or entertainment functions by combining the expertise in wireless ultralow power communications, packaging, 3D integration technologies, MEMS energy scavenging techniques and low power design techniques. A first generation EEG transmitter occupies a volume over $500cm^3$ and its operational life time is 3 days. To improve the convenience of the patient, an in-house 3D stack technology is used that reduces the volume of the system to $1cm^3$.

II. METHODOLOGY

As in Fig.1 the system is divided in to four sections, namely, the device section, communication section, mobile section and the web server section. The device section consists of a pressure sensor, temperature sensor and all other electronic components. The system uses Bluetooth as a communication link between the device and mobile phone. The vital sign monitor, an Android application, receives the pressure signal and temperature to calculate systolic, diastolic and pulse rate. The application allows synching these parameters with an external web server.

A. Design of Wireless Device

The ARduino-uno development kit is used as the main hardware platform for the device. It is a microcontroller board based on the ATmega328 chip having 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analogue inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header and a reset button. As we used two sensors and a Bluetooth module, we can easily power up the equipment without an additional power source. However, in this project, we used a 6 V air pump and 6 V air release valve which cannot be directly connected to the Arduino board. As such, a separate motor driver and a 6 V power source is required to power up the motor drivers.

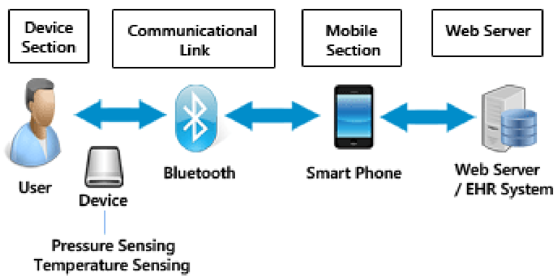

Fig. 1. System Topology

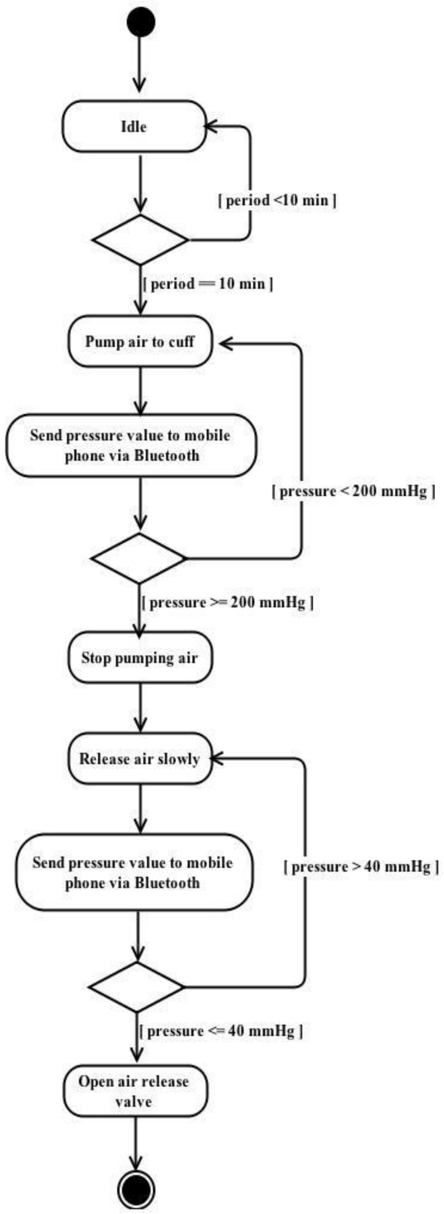

Fig. 3. Activity Diagram- process of obtaining blood pressure readings

B. Temperature Sensor

A DS18B20 temperature sensor is used to take axillary temperature that uses a 1-Wire bus protocol to make a connection to the Arduino board. The main feature of the DS18B20 is its ability to operate without an external power supply as power is supplied through the 1-Wire pull up resistor via the DQ pin when the bus is high. The high bus signal also charges an internal capacitor (CPP) which then supplies power to the device when the bus is low. This method of deriving power from the 1-Wire bus is referred to as "parasite power."

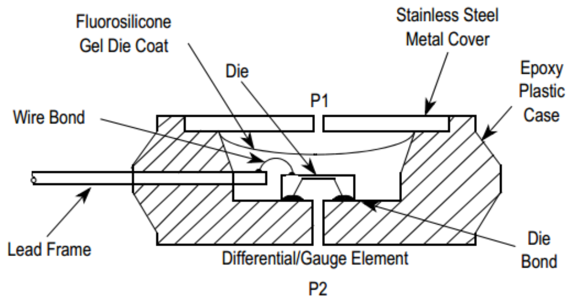

Fig. 2. Cross section of the of the pressure sensor.

C. Pressure Sensor

There are various kinds of pressure sensors in the market made for different purposes. When selecting a pressure sensor for this project, we need to consider which type of pressure sensor is required with parameters such as the supply voltage and pressure range. We used a cuff that can be wrapped around the arm easily to take raw blood pressure measurements to be transmitted to a mobile phone in real time.

The proposed device uses an MPX5050 silicon gauge pressure sensor, as depicted in Fig. 2, which is compatible with the Arduino-uno. Its supply voltage is 5 V and has a pressure range of 0 - 375 mm Hg.

Fig. 3 shows the process of obtaining blood pressure readings from the sensor. As in this flow chart, we need to pump air until the pressure reaches its maximum. This maximum limit is derived using the patient's blood pressure history (the default maximum limit is 180 mmHg). After the pressure reaches its upper limit, the cuff is slowly deflated using a small air inject valve until the pressure reaches to 40 mmHg. Then, the cuff is deflated fast using the air release valve.

D. Bluetooth Transceiver Module

The HC-06 Bluetooth RS232 serial module is used to establish the communicational link between the Arduino and the Android application [21]. Connecting the HC-06 Bluetooth module with Arduino in RX ->TX combinations is trivial. The HC-06 Bluetooth module acts as a slave device while the mobile phone initiates the communication link. Once the mobile phone sends a command to the device, it starts sending data continuously via the Bluetooth interface.

Fig. 4 shows how the sensors, the Bluetooth module, the motor drive, the air pump and the air release valve are connected to the Arduino board.

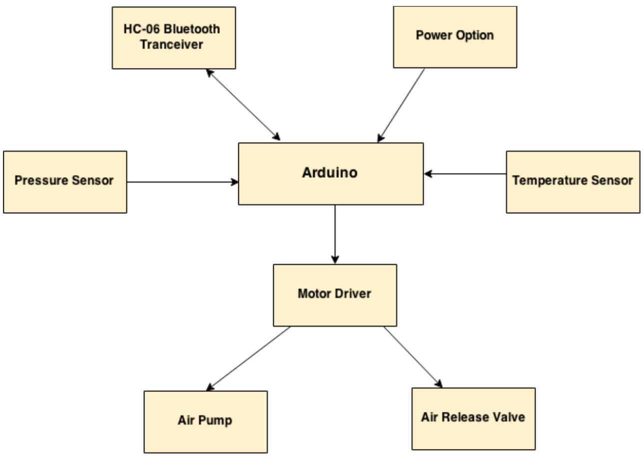

Fig. 4. Overall design of the system.

E. Receiving Sensor Data

Our wearable device is capable of capturing and transmitting sensor data through the Bluetooth communication channel. When the device starts measuring the blood pressure, the user can view the current pressure of the cuff on the Android application. In order to display sensor data in real time, Android handlers, observers and threading technologies are used. The following steps must be executed to transfer data between the sensor devices and the Android application:

- Check whether the device supports Bluetooth and whether Bluetooth is enabled in the phone.
- Search for the Bluetooth device, recognizes device and pairs it with the device using pass codes.
- Open a socket to obtain the input stream and output stream.
- Retrieve sensor data as a byte stream in a runnable threads.

F. Detecting Systolic, Diastolic and Pulse Rate using Oscillometric Method

In this project we used the oscillometric method to find the blood pressure. In this method, the cuff which is wrapped around the arm (at wrist or upper arm level), is inflated up to about 200 mmHg (26 kPa) pressure. At this pressure, the cuff is sufficiently constrictive to block blood circulation to the arm. In addition to measuring the pressure in the cuff, the sensor is sufficiently sensitive to obtain an audible signal of the characteristic pulsations of the heart.

At 200mmHg, the blood flow is constricted and a heart beat is not detected. When the cuff is slowly deflated, at the systolic pressure (around 120mmHg), the heart will be able to overcome the cuff pressure. The pressure sensor will be able to detect a small pulsing variation in the cuff pressure. The cuff continues to deflate until a point is reached where no heart beat is detected. This is known as the diastolic pressure.

The recorded cuff pressure (series of raw pressure values) are shown in Fig. 5 (left), band-pass-filtered to observe the pulsatile oscillations as the cuff is slowly deflates. Fig 5 (right) shows the derived oscillation diagram. It has been determined only recently that the maximum oscillations actually occur when the cuff pressure is equal to the mean arterial pressure (MAP) [22].

The systolic pressure is located at the point where the oscillations, Os, are a fixed percentage of the maximum oscillations, Om. The following systolic and diastolic detection ratio are used in the proposed application to detect the blood pressure.

The systolic detection ratio is = Os/Om = 0.7.

Similarly, the diastolic pressure can be found as a fixed percentage of the maximum oscillations, as Od/Om = 0.6. It must be noted that there can be variations in mean arterial pressure algorithm and also systolic & diastolic ratios are not fixed [23].

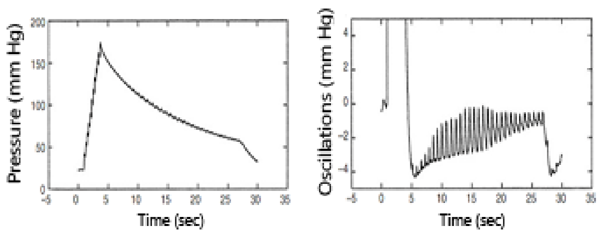

Fig 5. Sample recording of cuff pressure during oscillometric blood pressure measurement (left) and oscillations in cuff pressure obtained by high pass filtering above 1/2 Hz.

The proposed system can be successfully deployed to detect vital signs of dengue patients in real time. Each node can send these vital signs to central machine using WiFi communication. Medical practitioners can monitor each patient using a single computer and also remote monitoring can be done using a smart phone. Fig. 6 shows a typical network architecture of the proposed system.

The alerting system in the central machine is based on following criteria,

- Increasing diastolic pressure
- Narrowing of pulse pressure ≤ 20 mmHg
- Postural drop ≥ 20 mmHg of systolic blood pressure
- Hypotension (from patient's baseline)

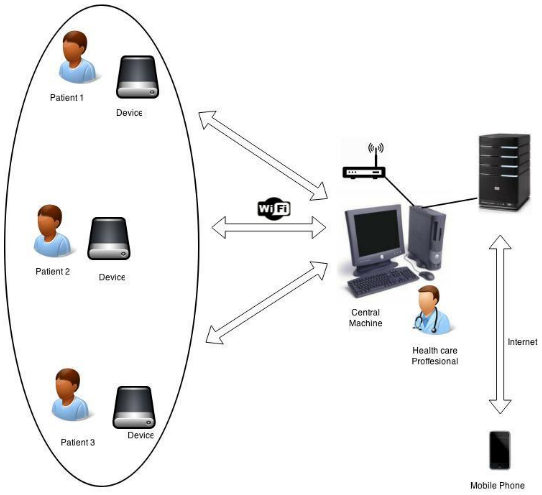

Fig. 6. Network architecture of the proposed sensor network

Fig. 7. Device setup of the sensor node. 1 – Arduino uno with atmega328 microcontroller, 2- Air pump (6V), 3- MPX5050 pressure sensor, 4- Small air outlet valve, 5- DC6V Solenoid exhaust valve, 6- L9110 Stepper Motor Driver, 7- HC-06 Bluetooth module, 8- DS18B20 temperature sensor probe, 9- Pressure cuff, 10- power switch for motor drive, 11- 9V Battery and 12- 6V power source.

III. Results and Discussion

The hardware device setup of the proposed system is shown in Fig. 7. To evaluate the accuracy of temperature measurements, we use a standard Bio-plus digital thermometer with the DS18B20 digital temperature sensor. Temperature readings are obtained under different environmental conditions such as room temperature, body temperature of different people and temperature of cool water. We obtained 10 readings to calculate the accuracy of temperature sensor as given in Table I.

TABLE I
COMPARISON OF RESULTS FOR TEMPERATURE SENSOR AND STANDARD PROBE.

No :	Temperature (^{o}F) measured using DS18B20 sensor probe	Temperature (^{o}F) measured using standard probe	Error Rate (%)
1	86.6	86.3	0.35
2	95.4	95.8	0.41
3	95.1	95.3	0.20
4	94.1	94.1	0
5	85.6	85.3	0.35
6	72.5	72.3	0.27
7	96.1	96.4	0.31
8	96.1	96.3	0.20
9	95.9	96.1	0.20
10	96.0	96.1	0.10

Based on the results in Table I, the accuracy of the temperature sensor is 99.76%.

For validating the blood pressure, we used five healthy volunteers (4 of males and 1 female) in the 20 to 50 years age group. The standard sphygmomanometer and a stethoscope is used with an experience medical practitioner to pre-validate systolic, diastolic and heart rate.

Three measurement are taken with both devices for each person under the following conditions.

- After lying down for 5 minutes.
- After running for 5 minutes.
- After inserting the right hand in an ice water bucket for 1 minute.

With above conditions we try to simulate daily events like, a person at rest, a person after some physical activity and a person under a stressful condition, respectively. The results obtained for the blood pressure and heart rate are depicted in Table II. Based on the results, the following can be derived.

Error rates of: systolic blood pressure = 11.04%, diastolic blood pressure = 12.17% and heart rate = 7.30%

Accuracy level of: systolic blood pressure = 88.96%, diastolic blood pressure= 87.83% and heart rate= 92.70%

A. *Mobile Phone Connectivity*

The Android application is also an important part of the project where all the signal processing of the blood pressure, warning and alerting system is carried out.

TABLE II
RESULTS OBTAIEND FOR BLOOD PRESSURE

Prototype Device			Standard Device		
Systolic (mmHg)	Diastolic (mmHg)	Heart Rate	Systolic (mmHg)	Diastolic (mmHg)	Heart Rate
125	83	72	114	78	78
90	60	83	100	70	81
90	77	75	100	70	78
126	90	82	130	88	79
104	65	72	110	75	76
130	79	79	124	85	72
100	70	80	110	80	81
95	70	83	115	75	79
130	87	85	135	90	81
110	67	82	115	70	81
131	90	81	125	85	84
95	63	79	105	75	82
90	65	71	100	70	75
125	90	84	130	85	78
110	70	74	105	75	80

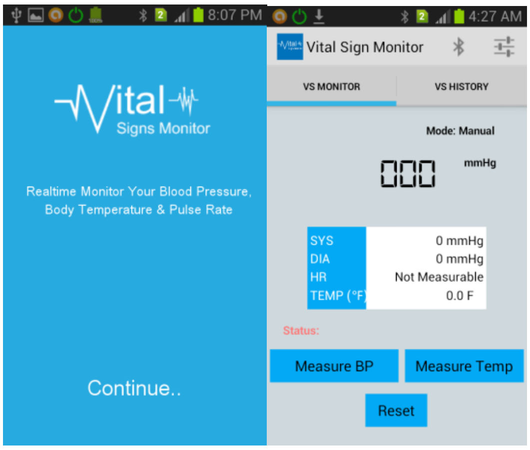

Fig. 8. Welcome screen (left) and functional buttons (right).

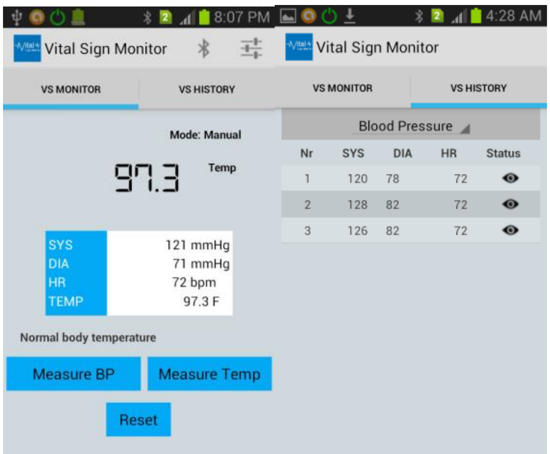

Fig. 9. Screenshots of measuring blood pressure and body temperature (left) and history records of vital signs (right).

As in Fig. 8 (right), the "*Measure BP"* button is clicked to start reading pressure data in real-time. Similarly, the temperature is measured by clicking on the "*Measure Temp"* button. At this stage, the blood pressure and the body temperature are taken simultaneously by the sensor node.

Fig. 9 shows the result after measuring the blood pressure and the temperature.

The prices of standard digital blood pressure monitors are

TABLE III
HARDWARE COMPONENTS AND COST

Hardware Components	Price (US $)
Arduino Uno R3	14.00
MPX5050GP pressure sensor	28.00
HC-06 Bluetooth module	10.00
DC 6V air pump	6.00
DC 6V air release valve	4.00
L9110 stepper motor drive	5.00
DS18B20 temperature sensor	5.00
Pressure cuff	5.00
Resisters, wires & etc.	2.00
Total	**79.00**

within US $ 100.00 – 200.00. However, we are able to design and develop the proposed device by spending approximately US $ Rs. 79.00 as seen in Table III.

IV. CONCLUSIONS

The proposed wearable device enables a person to measure his/her blood pressure, heart rate and body temperature in real time. The current trend is to continuously monitor vital signs or any other health parameters in real time. However, it is very impractical to use oscillometric method for measuring blood pressure in a continuous manner. Also, there can be allergies caused by the blood pressure cuff itself if worn for a prolonged time. One solution is to approximate the blood pressure by calculating the pulse transfer time (PTT) using ECG sensors.

As our device has a modularize architecture, new sensors can be connected and reprogrammed accordingly. Moreover, the system can used to monitor vital signs (blood pressure, heart rate and body temperature) periodically especially in elderly people and patients with white coat hypertension.

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