Wireless Sensor Network Based Health Monitoring System for Hypertensive In-Patients


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Abstract— Hypertensive-patient monitoring is a continuous process of observing closely the situation of patient's blood pressure and alerting the appropriate personnel in case of any anomaly. It usually requires the use of non-invasive sensors that arehardwired to bedside monitors. Although, present systems allow continuous monitoring of patient vital signs and limit the patient to the bed, the readings are mostly stored on the system local memory over a period of time before it is assessed for analysis. Hence, the need for a real time hypertensive patients' monitoring system which can meet up with immediate demands of emergency cases. This paper presents a Wireless Sensor Network (WSN)-based health monitoring system that addressed the aforementioned drawbacks for monitoring hypertensive in-patients. The design of the system comprises of hardware components such as blood pressure sensor, Bluetooth serial communication circuit, sensor node for base station interfaces and software components. Performance evaluation of the designed system gave an accuracy of 89.7% in blood pressure monitoring. The system is also cost effective, reliable and user friendly when compared with existing systems.

Keywords— Blood Pressure, Health monitoring, Hypertension, Wireless Sensor Networks

1 INTRODUCTION

Recent advances in sensor, communication and information technologies have enabled development of novel vital signs monitoring systems by which various important health parameters like body temperature, heart rate, blood pressure and oxygen saturation can be measured (McGrath and Dishongh, 2014). A Wireless Sensor Network (WSN) used for health application is usually named under body sensor network (BSN) (Andrew and Alfred, 2009). Sensors placed on the human body can monitor various vital signs while providing real-time feedback to the user and medical personnel (Xia et al., 2010). Continuous health monitoring is a key technology for realizing the transition of current health care systems to more proactive and affordable healthcare. It has tremendous potential to help address the issue of slow and challenging data collection process. It also helps hospital attendants to monitor patient health status and enhances quick discovery of dwindling health conditions which could results in deadly ailments such as hypertension.

Hypertension arises as a result of a persistent elevated blood pressure in the arteries over a long period of time. It is defined as blood pressure higher than 140 over 90 mmHg (millimetres of mercury) (Chipara, et al., 2009). Hypertension can be diagnosed when either the systolic or the diastolic pressure is high; the former is the pressure as the heart pumps blood around the body while the latter is the pressure as the heart relaxes and refills with blood. A recent study shows the prevalence of hypertension in Nigerians living in the urban parts of the country above the age of 40 to be 45.9 % (Akpan et al., 2015).

It is estimated that by the year 2025, the number of people living with hypertension worldwide will be up to 1.56 billion (Adeloye et al., 2014). Hence, control and monitoring of hypertension has become a key priority in most western countries and a global challenge for the World Health Organization (WHO) (British Heart Foundation, 2014). A lot of work has been done by engineers and researchers to tackle hypertension globally (Miller, 2017) (Wac et al., 2009). While some of the works focused on developing general health monitoring systems for hypertensive patients, some focused on monitoring vital signs and a few focused on both. In this work, an accurate and energy efficient real-time system is developed to monitor high blood pressure using wireless sensor network. The developed system addresses routing of data in real-time from a patient's sick bed to a personal digital assistant (PDA) device that permits the data to be accessed by the physician without any time lag.

2 RELATED WORK

Several efforts have been expended in the development of health care systems for monitoring vital signs that are needed in diagnosing ailments such as hypertension. Visi Mobile, a wearable device which can be worn around the wrist was developed by Sotera wireless incorporation (Miller, 2017). It enables physicians to be able to constantly monitor their patients’ vital signs at any given moment. It enhances patient safety and allows early detection of patient deterioration, It can also connect physicians with their patients anywhere, any time. The Visi Mobile can monitor ECG, heart rate, pulse rate, blood pressure, respiration rate and body temperature. It features comfortable body-worn sensors that allow for freedom of movement and enables accurate, continuous monitoring of all core vital signs.

Cunha et al., (2010) proposed a mobile and intelligent wearable device called vital jacket. It is capable of continuously monitoring electrocardiogram (ECG) waves and heart rate for different medical applications.

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It is an easy-to-wear garment, very comfortable and reliable cardio monitor that can be worn by the patient. The sensed data are transferred via Bluetooth to a PDA and stored in a memory card at the same time. However, the system needs an additional power source to prolong the lifetime of the battery.

MobiHealth, utilizes next generation public wireless network to provide a vital signs tele-monitoring and tele-treatment system (Wac et al., 2009). It is based on a body area network (BAN) and a mobile health care (m-health) service platform. Diverse medical sensors are incorporated into the system via wireless connections. It also allows the live transmission of the measured vital signs to healthcare providers who also give back a real-time feedback to the patient. MobiHealth employs UMTS and GPRS networks to enable patients be mobile while undergoing continuous health monitoring. However, the security of the system needs to be enhanced.

Microsoft Research group developed HealthGear, a system for monitoring, visualizing and analyzing physiological signals (Oliver and Flores-Mangas, 2006). It is a real-time wearable device that consists of a set of physiological sensors connected via Bluetooth to a cell phone which stores, transmits and analyzes the physiological data before it is presented to the user in an intelligible way. It was implemented using a blood oximeter to monitor the user’s blood oxygen level and pulse while sleeping. Heathgear analyses data in real time as can be seen in sleep apnea application where it could wake up the user during a severe apnea event, or suggest changing sleep positions. This system is not limited to a specific sensor or manufacturer, its architecture allows the use of heterogeneous sensors in a unified hardware and software platform, however the system is costly.

Ewatch developed by Maurer et al., (2006) is a system that senses a user in distress and then confirms if it is an emergency before employing its networked abilities to call for help. It is a wearable sensor that fits into a wrist watch form making it highly available, instantly viewable, and socially acceptable. Although, ewatch can communicate wirelessly using a Bluetooth module and an infrared data port for control of devices but the use of Bluetooth limits its range of communication.

An Ubiquitous monitoring environment for wearable and implantable sensors (Ubimon) was developed by the Department of Computing, Imperial College, London. Ubimon was developed for continuous monitoring of patients under their natural physiological states (Jason et al., 2004). The system employs a framework for collecting, gathering and analyzing data from a number of body sensors. It implements the concept of BSN which is the basis for wireless intelligent modules for wearable and implantable sensors. In addition to the physiological parameters, the context awareness aspect is also included in the system to enhance the capturing of any clinical relevant episode. The sensor data collected by the processing unit are transmitted to the mobile phone so that real-time ECG data can be displayed on the phone, including the retrieval of the patient record from the database.

3 Methodology

The hypertensive patient monitoring system is composed of four sections namely: sensing, transmission, display and database sections. All sections were designed with both software and hardware components. The architectural overview of the system is shown in Figure 1:

![Fig 1: Architecture of the Hypertensive-Patient monitoring system](image)

At the core of the system is the user, also referred to as the “subject” (in a research environment) and as the “patient” (in a clinical or therapeutic environment). The user is monitored by sensors and prompted by actuators, within wireless body area sensor network (WBASN). The information gathered by the components of the WBASN is sent to the android application (a smart phone), through Bluetooth communication. The communications links between the WBASN and the android application employs Bluetooth technology due to its cost effectiveness.

The caregiver connects over the serial communication with communications protocols to various services. In order to start the communication process with the monitoring system, the sensor node sends a start signal to the sensing section to switch it into communication mode and opens its communication port. The blood pressure monitor then receives commands to take measurement from the sensor node. The sensed data is transmitted through Bluetooth protocol to the caregiver’s PDA software where it can be accessed in a proper format.

3.1 Hardware Components

The choice of technology for the hypertensive patient monitoring system is broad, with a range of options available across microcontrollers(Okomba et al, 2015; Okomba et al, 2017), firmware, operating systems, radios, sensors (Okwor et al., 2016; Nuhu et al., 2016), and others. The objective is to select the best technology...
to collect and analyze relevant data, provide feedback as appropriate to the patient, and to deliver information to the clinician. The hardware components employed in this work include a blood pressure monitor (CK-101), teensy 3.2 microcontroller, Bluetooth module (HC-05) among others. The system is able to carry out a long-term monitoring on patient’s condition and is equipped with an emergency notification when the blood pressure or heart rate is becoming pernicious. This was achieved through an real-time firmware programmed to sensing node composed of a Teensy 3.2 with CK-101 integrated to a Bluetooth module.

### 3.1.1 Blood Pressure Monitor (CK-101)

The blood pressure monitor adopted in this work is the CK-101 blood pressure cuff. It is an off-the-shelf device which is cost-effective, time saving and easy to implement. The CK-101 consists of a pressure sensing elements such as pressure sensor, vibrators, and sensors mounted on a Printed Circuit Board (PCB). A plastic covering is attached to the printed circuit, pressure sensors and vibrators to provide an easy method of attachment to the Blood Pressure (BP) monitor and protection for the sensing element as shown in Figure 2. The blood pressure and heart rate sensors are used to compute the patient data and then processed by the microcontroller.

![Fig 2: Blood Pressure Cuff](image)

### 3.1.2 Microcontroller

The microcontroller employed in this project is Teensy 3.2 which holds the firmware program and manages computing resources of the system. Teensy is a breadboard-friendly development board which has a lot of desirable features: it comes pre-flashed with a boot loader that can be programmed using the on-board USB connection. The processor on the Teensy is good for USB projects because it has access to the USB and can emulate any kind of USB device. This 32 bit processor also has multiple channels of Direct Memory Access, several high-resolution ADCs and even an I2S digital audio interface. The microcontroller is responsible for the processing of data computed from the sensing section and its transmitted using Bluetooth.

![Fig 3: Teensy 3.2](image)

### 3.1.3 Communication Unit

A Bluetooth module (HC-05) is programmed as the sensor node to communicate with the BPM on the serial link to start the reading process and receive the patient’s BP and heart-rate readings. Once the readings are received, the sensor node would communicate with the network and transmits them to the base station. This is done through a serial port that facilitates bi-directional communication at 9600 bps. When the reading process is completed, the readings are sent to the patient monitor app on the caregiver’s PDA. Limited processing is performed by the sensor node on the data before transmitting it through the network.

![Fig 4: Bluetooth module (HC-05)](image)

### 3.1.4 Power Management

Energy is one of the most critical resources required for the smooth running of any WSN especially the BSN (Omodunbi et al., 2013). In order for the users to feel comfortable and acceptable to wear body sensors, they should be made as small as possible. This imposes critical constraints on the size of the batteries which implies that energy available to wireless body sensors becomes a very scare resources. The system consists of an adequate charging interface to charge the energy storage devices which in turn supply regulated power to the router node. The core of the energy module consist of a power management circuit which draws power from rechargeable batteries and manages energy storage and power routing to the node. The power management circuit would provide regulated power to the router node and also simultaneously store energy in ultra capacitors.

### 3.2 Software Components

The software works closely with the hardware. It is made up of the firmware which manages the resources of the embedded processor and an Android application used by the caregiver or physician to access patient data.

#### 3.2.1 Firmware Program

Some low-cost embedded processors do not support real-time operating systems but rely on a loop program running continuously with interrupts to program the device. While designing the firmware, there is need to augment these libraries with additional assembly language routines. In developing the hypertensive patient monitoring system, a gateway is required. An arduino platform was employed to build support for bluetooth protocol, USB mass storage devices and to provide parallel execution of software tasks. The Arduino program harvests the blood pressure and heart rate data and uses the Arduino MeetAndroid (For Amarino), I2Cdev, SPI, ADXL345 and Wire.h libraries.
for several of its operations. Arduino Wire library is required if I2Cdev I2CDEV_ARDUINO_WIRE implementation is used in I2Cdev.h

3.2.2 Android Program
The system is incomplete without a way to remotely access the patient data. The caregiver’s PDA also needs the installation of an android mobile app developed for the viewing of the harvested data in the format used by ECGs to access patient data. This was developed with the Android programming language and is the only way to access the patient data, hence, allowing for privacy and only caregiver privilege. The mobile application permits a caregiver to request real-time health conditions of the hypertensive patients connected. It uses a query management system distributed among the sensing section and PDA, The Android app is based on the Amarino platform which is a toolkit to connect Android-driven microcontrollers via bluetooth. The toolkit provides easy access to internal phone events which can be further processed on the arduino.

The Applications can trigger the sensing node to take new patient data immediately they are connected. This is done by pressing the “START SYSTEM” button of the Start Activity. On starting the system, the start activity layout is opened to start the system to access patient data. This system is only activated if the application is connected to the sensing node through Bluetooth communication, else communication cannot be established. When the “START SYSTEM” button is triggered, it starts another app activity that discovers connected patients in a list view. Caregiver can choose which patient data is needed for viewing.

On selecting the patient data to be viewed, it displays a new layout showing the data sensed in the dynamic plot with three plotted graphs which are Systolic data, Diastolic data and Heart beat rate. This is basically collected by sending redundant sequence of bytes containing all data collected in the sensing node to the PDA which serves as the data aggregator and separates each data into distinct constituents which make up the patient’s data. It also displays the raw numeric readings sensed in number format just beside the diastolic graph to make the readings parameters available for direct usage.

4 Results and Discussion
The system developed was used to measure blood pressure of 24 patients (12 males and 12 females) and the patients’ measurements were compared to blood pressure readings using conventional sphygmomanometer by a trained user.

4.1 Results
From the readings taken, it was discovered that the designed system measured efficiently the blood pressure and heart rate less than ten (10) seconds when compared to a traditional sphygmomanometer which takes almost twenty (20) seconds to take the same measurements. As shown in figures 7 and 8, the blood pressure measured by the designed system is a bit higher than the manual sphygmomanometer. This is because the blood vessel on the wrist where the designed system takes the blood pressure measurement is far away from the heart than the upper arm where the conventional sphygmomanometer is used (Willem, Alfons and Theo, 2011). Therefore, measuring blood pressure from the wrist requires the body to be positioned such that the arm and wrist must be at heart level.

Blood pressure measured with the developed system is quick and secure since there is no access to the data by unauthorized personnel who may manipulate such data, it integrity can be ascertained. The results of the readings of the patients’ data are shown in Table 1 and the graphs obtained from the comparison of the designed system with manual sphygmomanometer for both systolic and diastolic pressures for men are shown in Figures 7 and 8.

The following are some of the other evaluation metrics employed:

a) Accuracy: The accuracy of the system was calculated by comparing the measured blood pressure with analogue readings taken concurrently. The Actual Error (AE), Percentage Error (PE), Mean Percentage Error (MPE), and Percentage Accuracy (PA) are computed as:

\[
\text{Actual Error} = \text{Blood Pressure readings} - \text{manual (or analog) readings}
\]

\[
\text{PE} = \frac{\text{Actual Error}}{\text{Actual BP} \times 100}
\]

\[
\text{MPE} = \frac{\text{Mean Percentage Error}}{\text{Total BP for 20 samples}}
\]

\[
\text{Percentage Accuracy} = 100 - \text{Mean Percentage Error}
\]

b) Energy consumption: The energy consumed by the processor and radio during the transmission of one since it can connect to other sensing node in just a click thereby allowing it to connect to countless sensing nodes which can then be used to monitor other patients.
c) **Packet in joules**: Continuous monitoring of the ultra-capacitor voltage was done and a voltage reference for the router node microcontroller was obtained. Due to possible variation in supply voltage (VL), a fixed 1.223 VDC voltage reference was used to determine the router node VL and microcontroller 10-bit A/D reference voltage (VREF). This voltage reference consisted of a 1.223 VDC zener diode.

d) **Scalability**: The number of sensor nodes required to monitor certain events (such as all hypertensive patients admitted in a hospital) may be in the order of hundreds or even thousands depending on applications, hence designs of such systems should be able to accommodate as many nodes as possible and be ascendable. The system proved to be quite scalable.

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**Table 1. Comparison of Designed System data with manual Sphygmomanometer**

**Fig 7: Comparison of Systolic Pressure in men from Designed System and Manual Sphygmomanometer.**

**Fig 8: Comparison of Diastolic Pressure in men from designed system and Manual Sphygmomanometer.**

4.2 **DISCUSSION**

One of the main advantages of using the developed system is that the consent of the patients involved is not necessary before the blood pressure can be taken. This helps to avoid unnecessary fright from patients and enables the capturing of actual undisputable blood pressure values. The fact that only authorized personnel have access to the information gives the system more integrity since the system is monitoring and collecting patient data that is subject to privacy policies. This system eliminates the need for an interlocutor or manipulation of data by a middle contact hence protecting the integrity of the patient information and making it more reliable for the physician or caregiver. However, there is still need to extend the coverage of the system by using a more robust communication system that can cover a wider range than Bluetooth.
5 CONCLUSION

Wireless BSN technology is emerging as a significant element of next generation healthcare services. In this work, a remote mobile monitoring of in-patient blood pressure is proposed, which is able to continuously monitor the patient’s heart beat and blood pressure. The system consists of a sensing node to acquire the patient’s physiological data, a Bluetooth communication section to forward the data and a smartphone to collect the data, format it properly and allow for restricted access. The system is able to carry out a long-term monitoring on patient’s condition and it gives emergency notification when the blood pressure or heart rate is getting out of hands. The microcontroller makes the sensed data available to the Bluetooth connection which transmits it to the caregiver’s PDA.

The system was compared with a conventional sphygmomanometer and the metrics of evaluation employed were accuracy, energy consumed and scalability. The developed system can be improved upon using other communication protocols apart from Bluetooth to obtain a wider coverage area.

REFERENCES


