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This report with the title

"Design and Implementation of a Wireless Sensor Network based health monitoring System for Hypertensive Patient"

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Has satisfied the regulations governing the award of degree of

BACHELOR OF ENGINEERING (B.Eng)

Federal University Oye-Ekiti, Ekiti State.

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DEDICATION

This work is dedicated to God Almighty, who made everything possible. To the Department of Computer Engineering, Federal University, Oye-Ekiti, Ekiti State, to my parents who support me wholly on everything and my friends who have provided support all through.

ACKNOWLEDGEMENTS

I humbly wish to appreciate every member of staff of the Computer Engineering Department of the Federal University, Oye-Ekiti, Ekiti State for their invaluable time, efforts and insights. I appreciate every academic and non-academic staff for the priceless contributions over time. Without them, none of this would have been possible.

Exceptional acknowledgement goes to my supervisor, Mrs B. A. Omodunbi who steered and counselled the projection of the entire project. Special recognition to Dr. I. A. Adeyanju, Dr A. S. Falohun, Dr M. O. Olaniyan who provided a great deal of support and insights that massively amended this work.

I must also thank my devout colleagues who have all stimulated everything I have gained from our time together. Adewale, Deji, Samuel, Mutolib, Olisa, Joshua, Dimeji, Timi, Bright, Gbenga and Yemi, I cannot appreciate you all enough for your understanding.

My parents, Alhaji Babatunde Fatai Raheem and Mrs Olabisi Serifah Raheem, my siblings, deserve endless thanks for their guidance, patience, wishes and support.

Not forgetting Warriz Adelabu, Adeola Yusuf and Bright Ubani for making me comfortable and providing diverse resources during the process. Also, to those friends and people in my life who have skillfully, morally and socially contributed to my sojourn so far. I thank you all for supporting and inspiring me.

ABSRACT

Hypertensive-patient monitoring usually requires the use of non-invasive sensors that are hardwired to bedside monitors. This set-up is cumbersome, forcing the patient to be confined to his hospital bed thereby not allowing him to move around freely within the hospital premises. Presently, in order to continuously track a patient's Blood Pressure (BP) remotely over a period of time, physicians hand over specialized devices to patients. Most of these devices are cuff-based that are worn on the arm or wrist, and store patient data on their local memory over a period of time. The patient then takes the device back to his physician who downloads the data from the device for analysis. Such systems, although extremely useful and necessary, suffer from lack of real-time monitoring.

The design of this project comprises of hardware components such as blood pressure sensor, Bluetooth serial communication circuit, sensor node for base station interfaces and softwares programmed in two languages, Arduino for the microcontroller section and Android for the Patient Monitor app.

The designed system addresses situations such as routing data in real-time from a patient's sick bed to a personal digital assistant (PDA) where the data can be accessed by the physician without any time lag. In this case, any dangerous situation can be avoided because the technology will generate a notification to alert the physician rather than requiring the patient to inform his physician of the situation. Bluetooth communication can be used to design a robust mesh network that routes patient data to a remote base station, a hospital care giver can have access to this data at any point in time and doesn't have to be physically present in the patient's room to review the readings.

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LIST OF ACRONYMS

ACRONYM	MEANING
ECG	Electrocardiogram
BP	Blood Pressure
WSN	Wireless Sensor Network
WHO	World Health Organization
HBP	High Blood Pressure
HTTP	Hypertext Transfer Protocol
NTP	Normal Temperature and Pressure
IMAP	Internet Message Access Protocol
DHCP	Dynamic Host Configuration Protocol
PDA	Personal Digital Assistant

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Recent advances in sensor, communication and information technologies have enabled the development of novel vital signs monitoring systems by which various vital health parameters can be measured, like electrocardiogram (ECG), body temperature, heart rate, blood pressure and oxygen saturation. In particular, healthcare related applications using wireless sensor networks may assist residents to avoid falling victims of deadly health conditions such as Hypertension. 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%. Also in the United States, about a third of people over the age of 20 years has been diagnosed with hypertension, based on high blood pressure assessments (McGill, 2016). A research by the British Heart Foundation also shows that as many as eleven million people in the United Kingdom are living with undiagnosed high blood pressure, without knowing they are at risk. Control of hypertension has become a key national priority in the United States and WHO for the immediate future.

Hypertension, also known as high blood pressure (HBP), is a long term medical condition in which the blood pressure in the arteries is persistently elevated. Hypertension is defined as blood pressure higher than 140 over 90 mmHg (millimetres of mercury). A diagnosis of hypertension may be made when one or both readings are high: systolic (the pressure as the heart pumps blood around the body), given first; or diastolic (pressure as the heart relaxes and refills with blood), given second. The number of people living with hypertension (high blood pressure) is predicted to be 1.56 billion worldwide by the year 2025. (Lancet, 2015). Hence, control and monitoring of hypertension has become a key International priority in the most western countries and a global challenge. Diagnosis of hypertension is made by measuring blood pressure over a number of clinic visits, using devices which are analogue such as the sphygmomanometer - the familiar upper-arm cuff device or other related devices. An isolated high reading is not taken as proof of hypertension. Rather, diagnosis can be made after elevated readings are taken on at least three separate days.

A lot of work has been done by engineers and researchers to tackle hypertension globally. While some of the works focused on developing health monitoring systems for hypertensive patients, some focused on monitoring health vital signs and a few focused on both. However, monitoring hypertensive patients is a continuous process of observing closely the situation of patient's blood pressure and alerting the appropriate personnel in case of any anomaly. In this project, an accurate and energy efficient real-time system is proposed to monitor high blood pressure based on wireless sensor network.

A wireless sensor network (WSN) is a wireless network consisting of spatially distributed autonomous devices using sensors to monitor physical or environmental conditions such as temperature, sound, pressure, etc. and to cooperatively pass their data through the network to a main location (Akyildiz and Kasimoglu, 2004). It incorporates a gateway that provides wireless connectivity back to the wired world and distributed nodes. These sensor nodes leverage the strength of collaborative effort to provide higher quality sensing in time and space as compared to traditional stationary sensors, which are deployed in positions far from the actual physical process (Raghavendra et al, 2014). This project aims to design and implement a WSN-based health monitoring system for hypertensive patients.

1.2 STATEMENT OF THE PROBLEM

Health is something which changes on a daily basis, even if not unaware or it isn't really apparent. In a hospital, constant monitoring of patient's health status is important. Health monitoring is an informal, non-statutory method of surveying for symptoms of ill health. Hospitals and Health Institutions need to constantly check patient's status, health vital signs and monitor their responses to treatment and pattern of the health condition at regular intervals. Sensors, strategically placed on the human body, create a wireless *body area network* (BAN) that can monitor various vital signs while providing real-time feedback to the user and medical personnel (McGrath and Dishongh, 2012).

Moreover, there is need for a real time system which can meet up with immediate demands of emergency cases. Existing systems also face the problem of energy dissipation and exhaustion i.e. with time, the system performance becomes unreliable and ultimately non-functional in most cases (Omodunbi, 2013). Also, there is need for patient data to be stored in structured information format for ease of access when needed (Alan, 2014).

1.3 MOTIVATION

A research by the British Heart Foundation shows that as many as eleven million people in the UK are living with undiagnosed high blood pressure, without knowing they are at risk. A recent survey taken all over the United States shows that about a third of all people over the age of 20 years had hypertension, based on high blood pressure assessments and the number of people taking antihypertensive medications (McGill, 2016). The condition increases the risk of heart attack, heart failure and sudden cardiac death. Heart failure. Over time, the strain on the heart caused by high blood pressure can cause the heart muscle to weaken and work less efficiently. Control of hypertension has become a key national priority in the US and WHO for the immediate future.

1.4 AIM and OBJECTIVES

The aim of the project is to design and implement a wireless sensor network system for hypertensive-patient monitoring. The specific objectives are to:

i. Design a system that periodically monitors hypertensive patient vital signs.
ii. Implement the designed hypertensive-patient monitoring system and;.
iii. Evaluate the developed system in terms of performance.

1.5 SIGNIFICANCE OF THE STUDY

Monitoring patient vital signs help hospital attendants to know patient health status and shows progress in their health status or dwindling health conditions. A network of sensors (worn, carried, and/or environmental) is an ideal technology platform for detecting and responding to health-relevant parameters such as movement, breathing, ECG, and social activity. Raw data is collected on this vital signs by the hypertensive-patient monitor device and it is sent to authorized personnel's phone for viewing. It also sends notification when viewing of such data is due since it is a regular process that is done continually on a hypertensive patient.

Furthermore, wireless sensors can be deployed in a patient's home environment to provide real-time and extended monitoring of activity and wellbeing. When coupled with communications technologies such as mobile phones and the Internet, the sensor network can keep family, caregivers and doctors informed, while also establishing trends and detecting variations in health.

Wireless Sensor Networks can deliver long-term datasets to assist in diagnostics and patient response to interventions (Mainwaring et al, 2002). The data collected by a WSN can be stored and integrated into a comprehensive health record of each patient, which will allow identification of subtle changes in a person's health.

High Blood Pressure medical condition does not require a patient to be bed-ridden, hence, such patients have the freewill to move around freely. Such patient usually has regular occasional visit to their physician. This births the necessity for remote monitoring. Patient's status can be remotely monitored easily with this system since doctors can have access to their vital sign data acquired. Also, if there is any unstable condition or dangerous status of a patient blood pressure according to the system, it sends a notification of this for an emergency response.

1.6 SCOPE OF STUDY

This project is aimed at checking the blood pressure and heart rate in hypertensive patients. These vital parameters include heart rate, respiratory pulses and blood. Though, a number of health monitoring systems exist and are optimal, the final evaluation to be carried out in this project work will be limited to hypertensive patients and are intended to be Wireless Sensor Network based. The efficiency and energy consumption are the metrics that will be considered for performance evaluation. The data for the implementation will be obtained from different teaching hospitals around.

1.7 METHODS OF STUDY

The procedures that would be adopted in the research and implementation of the project include:

i. The review of existing and available related systems.

ii. Circuitry design and making of design decisions and acquisition of components.

iii. Implementation of the System and development of required software.

iv. Analysis and Evaluation of the System.

CHAPTER TWO

LITERATURE REVIEW

2.1 OVERVIEW OF HYPERTENSION

Hypertension, also known as high blood pressure (HBP), is a long term medical condition in which the blood pressure in the arteries is persistently elevated. Blood pressure is the force exerted by the blood against the walls of blood vessels, and the magnitude of this force depends on the cardiac output and the resistance of the blood vessels. Hypertension results from a complex interaction of genes and environmental factors. Numerous common genetic variants with small effects on blood pressure have been identified as well as some rare genetic variants with large effects on blood pressure.

Humans have a range of values for most health vital signs such as heart rate, blood pressure, body temperature which can help denote a normal health status or an abnormality. For a sound health, most of these vital signs are sizable and relatively constant although subject to environmental conditions, age and special conditions such as pregnancy and presence of a health condition like diabetes. The increasing prevalence of the condition is blamed on lifestyle and dietary factors, such as physical inactivity, alcohol and tobacco use, and a diet high in sodium (usually from processed and fatty foods). A diagnosis of hypertension may be made when one or both readings are high: systolic (the pressure as the heart pumps blood around the body), usually first or numerator in a blood pressure analysis or evaluation; or diastolic (pressure as the heart relaxes and refills with blood), given second or denominator.

2.2 TYPES OF BLOOD PRESSURE

Blood pressure is experienced using two measurements; Systolic pressure which is the pressure as the heart pumps blood around the body and Diastolic pressure which is the pressure as the heart relaxed and refills with blood. The systolic and diastolic pressure can lead to Hypotension or Hypertension when it becomes alarming.

a) **Hypotension** is low blood pressure, especially in the arteries of the systemic circulation. A systolic blood pressure of less than 90 millimeters of mercury (mm Hg) or diastolic of less than 60 mmHg is generally considered to be hypotension. However, in practice, blood pressure is considered too low only if noticeable symptoms are present. Hypotension is the opposite of hypertension, which is high blood pressure. It is best understood as a physiological state, rather than a disease. Severely low blood pressure can deprive the brain and other vital organs of oxygen and nutrients, leading to a life-threatening condition called shock. Though often associated with shock, hypotension is not necessarily indicative of it.

b) **Hypertension:** Hypertension is defined as blood pressure higher than 140 over 90 mmHg (millimetres of mercury). Normal blood pressure at rest is within the range of 100–140 millimeters mercury (mmHg) systolic and 60–90 mmHg diastolic. High blood pressure is present if the resting blood pressure is persistently at or above 140/90 mmHg for most adults. Different numbers apply to children.

2.2.1 TYPES OF HYPERTENSION

There are two major types of hypertension: primary and secondary, a description of each is as follows:

A. PRIMARY HYPERTENSION

This type is also called essential hypertension, defined as high blood pressure due to nonspecific lifestyle and genetic factors, and it is by far the most common type of hypertension, and is diagnosed in about 95% of cases. Essential hypertension has no obvious or yet identifiable cause. Lifestyle factors that increase the risk include excess salt, excess body weight, smoking, and alcohol. The remaining 5–10% of cases are categorized as secondary high blood pressure, defined as high blood pressure due to an identifiable cause, such as chronic kidney disease, narrowing of the kidney arteries, an endocrine disorder, or the use of birth control pills.

B. SECONDARY HYPERTENSION

Secondary hypertension results from an identifiable cause. Kidney disease is the most common secondary cause of hypertension. Hypertension can also be caused by endocrine conditions, such as Cushing's syndrome, hyperthyroidism, hypothyroidism, acromegaly, Conn's syndrome or hyperaldosteronism, hyperparathyroidism and pheochromocytoma. Other causes of secondary hypertension include obesity, sleep apnea, pregnancy, coarctation of the aorta, excessive eating of liquor ice, excessive drinking of alcohol, and certain prescription medicines, herbal remedies and illegal drugs. Arsenic exposure through drinking water has been shown to correlate with elevated blood pressure.

2.3 BLOOD PRESSURE MONITORING

In medicine, monitoring is the observation of a disease, condition of one or several medical parameters over time. Monitoring of hypertensive patients can be classified by the target of interest of physician, such as:

i. Cardiac monitoring, which generally refers to continuous measurement of contraction of the heart with assessment of the patient's condition relative to their cardiac rhythm. A small monitor worn by an ambulatory patient for this purpose is known as a Holter monitor.

ii. Hemodynamic monitoring, which monitors the blood pressure and blood flow within the circulatory system. Blood pressure can be measured either invasively through an inserted blood pressure transducer assembly, or noninvasively with an inflatable blood pressure cuff. This is also done manually by counting the blood flow and pulse in the vein mostly through the veins of the wrist.

iii. Respiratory monitoring, blood glucose monitoring, Body temperature monitoring through an adhesive pad containing a thermoelectric transducer.

Monitoring of hypertensive patient vital parameters can include several of the ones mentioned earlier, and most commonly include at least blood pressure, temperature and heart rate, and preferably also pulse oximetry and respiratory rate. Some monitors can warn of pending fatal cardiac conditions before visible signs are noticeable to clinical staff, such as atrial fibrillation or premature ventricular contraction. (Daniel, 2009)

Monitoring of clinical parameters is primarily intended to detect changes (or absence of changes) in the clinical status of an individual. For example, the parameter of oxygen saturation is usually monitored to detect changes in respiratory capability of an individual. When monitoring a clinical parameter, differences between test results (or values of a continuously monitored parameter after a time interval) can reflect either (or both) an actual change in the status of the condition or a test-retest variability of the test method.

2.4 WSN-BASED PATIENT MONITORING SYSTEM FOR HYPERTENSIVE PATIENTS

Patient monitoring can be done with the conglomeration of several relevant body sensors which can be accorded through Wireless Sensor Networks. A Wireless Sensor Network incorporates a gateway that provides wireless connectivity back to the wired world and distributed nodes. Wireless sensor networks (WSNs) are finding applications in many areas, such as medical monitoring, emergency response, security, industrial automation, environment and agriculture, seismic detection, infrastructure protection and optimization, automotive and aeronautic applications, building automation, and military applications. Healthcare is always a big concern, since it involves the quality of life a given individual can have. It is always better to prevent an illness than to treat it, so individual monitoring is required as a periodic activity.

WSNs carry the promise of drastically improving and expanding the quality of care across a wide variety of settings and for different segments of the population. For example, early system prototypes have demonstrated the potential of WSNs to enable early detection of clinical deterioration through real-time patient monitoring in hospitals (Das et al, 2010), enhance first responders' capability to provide emergency care in large disasters through automatic electronic triage (Gao and Pesto, 2008), improve the life quality of the elderly psychologically through remote monitoring (Wood et al, 2006), and enable large scale field studies of human behavior and chronic diseases (Patrick, 2007).

Sensor networks applications in healthcare also have potential for large impacts. These can be realized through real-time, continuous vital monitoring to give immediate alerts of changes in patient status (Welsh et al, 2004). The data can also be relayed to the hospital or correlate with patient records and so on. Remote monitoring applications (from homes) for chronic and elderly patients which can be used to collect periodic or continuous data and be uploaded to a physician and can allow long-term care and trend analysis. It can also reduce length of hospital stay. Manual tracking of patient status is difficult. Collection of long-term databases of clinical data can be used in future diagnosis.

Patient monitoring systems are systems that facilitate in the checking, computation, processing and evaluation of health signs. Wireless sensors network enables dense spatio-temporal sampling of physical, physiological, psychological, cognitive, and behavioral processes in spaces ranging from personal to buildings to even larger scale ones. Wireless sensing technology helps address various drawbacks associated with wired sensors that are commonly used in hospitals and emergency rooms to monitor patients (Ko et al, 2010). The clutter of wires attached to a patient is uncomfortable for patients leading to restricted mobility and more anxiety, but is also hard to manage for the staff. Besides, cables have the tendency to be internally broken after time causing inefficiency in such systems. Quite common are deliberate disconnections of sensors by tired patients and failures to reattach sensors properly as patients are moved around in a hospital and handed-off across different units. Wireless sensing hardware that are less noticeable and have persistent network connectivity to back-end medical record systems help reduce the tangles of wires and patient anxiety, while also reducing the occurrence of errors.

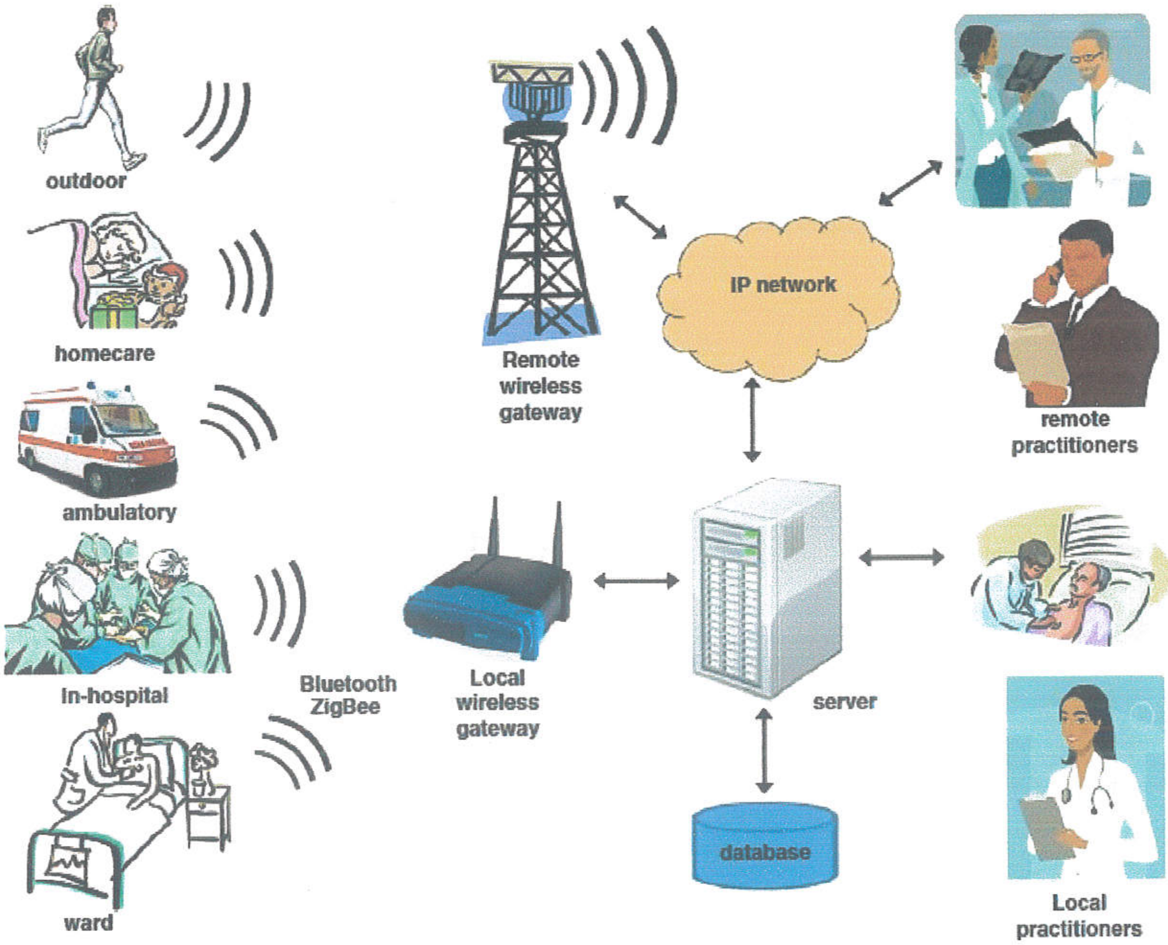

Figure 2.1: WSN architecture in healthcare monitoring (Tan et al, 2006).

2.5 COMPONENTS OF WIRELESS SENSOR NETWORK

A wireless sensor network consists of a large number of wireless-capable sensor devices working collaboratively to achieve a common objective. A WSN has one or more sinks (or base-station) which collect data from all sensor devices. These sinks are the interface through which the WSN interacts with the outside world. The basic premise of a WSN is to perform networked sensing using a large number of relatively unsophisticated sensors instead of the conventional approach of developing a few expensive and sophisticated sensing modules. The potential advantage of networked sensing over the conventional approach, can be summarized as greater coverage, accuracy and reliability at a possibly lower cost.

"WSNs are composed of individual embedded systems that are capable of

i. interacting with their environment through various sensors,
ii. processing information locally, and
iii. communicating this information wirelessly with their neighbors.

A sensor node (embedded system) usually consists of three components which are:

I. Wireless modules or motes – key components of the network which consists of a microcontroller, transceiver, power source, memory unit, and may contain few sensors. Examples: Mica2, Cricket, MicaZ, Iris, Telos, SunSPOT, and Imote2.
II. A sensor board which is mounted on the mote and is embedded with multiple types of sensors. Examples: MTS300/400 and MDA100/300.
III. A programming board (gateway board) – provides multiple interfaces including Ethernet, WiFi, USB, or serial ports for connecting different motes to an enterprise or industrial network or locally to a PC/laptop. These boards are used

to program the motes or gather data from them. Example: M1B510, M1B520, and M1B600.

2.5.1 HARDWARE COMPONENTS

For hardware design, these requirements can be grouped into three different categories. The first part is WSN connection mechanism. Smart gateway has to receive data from sensor nodes and gives commands to them. To achieve this goal, smart gateway has to provide mechanism to join into the WSN. Through this part, smart gateway provides connection to WSN in both hardware and software ways. At hardware way, smart gateway has to handle interface compatible and signal translation and rate conversion. For software, it has to translate the protocol using in WSN and extract the valuable data which can be used by the program using in smart gateway.

There are many WSN modules that can be chosen to connect the sink node. Sensor nodes commonly used is MICAz MPR2400 manufactory by Crossbow Company. Crossbow Company provided three basic interface boards with different types of connecting port to connect with MPR2400 node. They are MIB510 Serial Interface Board, MIB520 USB Interface Board and MIB600 Ethernet Interface Board. It is fast and easy to match the existing WSN to one of these three interface board as WSN module.

Comparing MIB520 and MIB510, the former one use USB interface while the later one uses serial port. Relatively, USB have these better characters like: higher data transfer rate, plug-and-play, smaller size, and larger number of ports. MIB600 provides Ethernet connectivity to LAN connected to host device. But if we use MIB600, the host device, which means the smart gateway in our situation, must include the DHCP function. This will take more memory space, making the system structure more complicated and consumption of more power.

There are two steps to connect to internet and WLAN. First step, smart gateway uses the IP address provides by the server in the internet. Second, smart gateway provides DHCP to build up WLAN with an extra wireless AP. These two steps can be implemented by center control unit or a powerful wireless router. When this task is completed by center control unit, system will have a higher integration and the wireless AP can be simpler and smaller size. If a powerful wireless router is used, center control unit will have simpler OS structure and can focus on data processing more.

This can also reduce the design duration time for prototype building up. The disadvantage is an extra router will have bigger size and consumes more power. In order to speed up the calculation time and shorten the design duration time, D-Link Company's DIR 301 wireless router can be used as wireless AP in smart gateway prototype design. Wireless medical sensors attached to the user send data to a PDA, forming a short-range wireless network (e.g., IEEE 802.15.1 or 802.15.3/4). The PDA equipped with a WLAN interface (e.g., IEEE 802.11a/b/g) transmits the data to the central server. The hospital server, already connected, can establish a secure channel to the medical server and send periodic updates for the user's medical record. The medical sensor nodes and the network coordinator form a wireless personal area network. By excluding the PDA, this can reduce system cost. However, this setting is likely to require more energy spent for communication due to an increased RF output power and lower Quality of Service (QoS), requiring frequent retransmissions. This configuration illustrates monitoring applicable any time, this application runs on a Wireless Wide Area Network enabled PDA/cell phone that connects directly to the medical server.

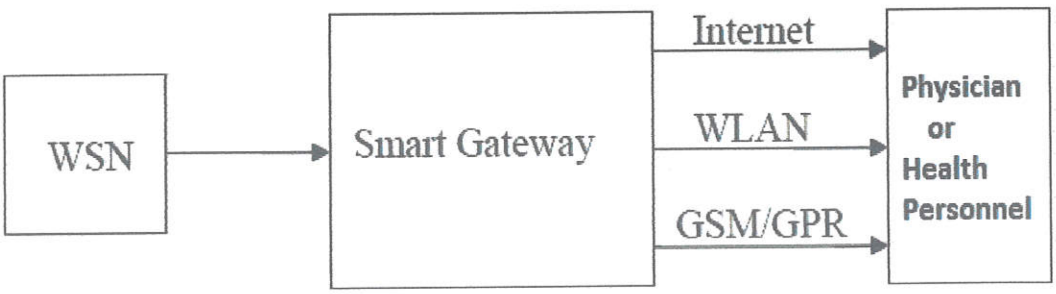

Figure 2.2: WSN hardware architecture

2.5.2 SOFTWARE COMPONENTS

The operating system (firmware) of the wireless sensor node plays a vital role in the overall capabilities and performance of the platform. The limited node resources such as computational capability, available memory normally in the range of kilobytes power consumption, and the application characteristics of wireless sensor networks place specific requirements on the operating system. Early research into operating systems for sensor networks lead to the development of TinyOS by researchers at UC Berkeley. It is based on a structured event-driven execution model and component-based software libraries that provides a high level of hardware abstraction with a small memory footprint and excellent power management.

An open source project, TinyOS has become the de facto industry-standard operating system for sensor network research and applications. TinyOS is written in nesC, which is a dialect of the C programming language. nesC supports the event-driven processing that is typical of many wireless sensors, which remain "asleep" until sensors acquire data or receive messages. The TinyOS developers decided to leave out some features commonly found in larger operating systems, such as multithreading and run-time module loading, though TinyOS provided a mechanism for tasks that run to completion but can be interrupted by higher priority tasks and then resumed. Exclusion of multiple execution threads has led to the development of alternative operating systems for wireless sensor applications that provide this capability; these include MANTIS, SOS, and Contiki. (Bhatti et al, 2003).

Another approach, which employs a distributed model, is implemented by MagnetOS. MagnetOS provides a single system image of a unified Java virtual machine to applications over an ad hoc collection of heterogeneous nodes. It treats the whole sensor network as one computational device. It automatically partitions applications into components and places them on appropriate nodes within the adhoc network. MagnetOS consists of a static code partitioning service and a local runtime that supports the partitioned applications. Squawk VM is a Java Virtual machine being developed for small platforms by Sun Microsystems. The virtual machine approach brings a number of potential advantages to the developer, such as the means to run diagnostics procedures remotely and to debug and modify code remotely (Barr et al, 2002).

2.6 WIRELESS NETWORK PROTOCOLS

All WSNs use sensors to collect data and then aggregate this data for analysis and subsequent use. In the healthcare context, aggregated data may be transmitted to a clinician or may prompt an actuator to respond to the patient. While they share this commonality of function, wireless sensor network solutions may utilize a range of different network architectures. The ultimate goal of collecting sensed data at an aggregation point can be achieved by autonomous ad hoc networking, by star networking, or by classical end-to-end network configurations.

In an ad hoc *network,* a large number of devices are broken down into clusters, within which the devices act as data relays with dynamic traffic routing; as a result of this arrangement, ad hoc networks are tolerant of individual device failures. Data travels to neighboring devices and eventually passes through an aggregator in the cluster to a target location, where it can be processed. In a *star configuration* the devices communicate directly with either a repeater hub or a data aggregator without communicating with each other. When the data collected from all the devices is aggregated on a particular device, this device may either process the data locally or relay it to backend infrastructure.

2.6.1 TCP/IP AND WSNs

In recent years, implementations of the TCP/IP network stack have appeared on WSN devices, devices to be connected directly into the Internet. This means that data can travel directly from its source—the sensor—to its ultimate destination in what is, in the application layer, a single step. This capability opens a range of new possibilities for WSNs, including the provision of a platform for higher-level communications protocols such as Telnet, SIP, HTTP, IMAP, NTP, and DHCP. An access point is necessary to support TCP/IP-enabled WSNs; implementations of 6LOWPAN, the IPv6 protocol over 802.15.4 will combine the cluster advantages of an ad hoc network with the auto configuration of IPv6, bundling the entire WSN into the global IP network in the presence of reach-back provided by a bridge or router.

2.7 WIRELESSS COMMUNICATION TECHNOLOGIES AND STANDARD

In a sensor network, dozens, hundreds, or even thousands of tiny, battery-powered computing devices are scattered throughout a physical environment. In a WSN, each device is capable of monitoring—sensing—and/or displaying—actuating information. Sensing may include data collection, such as temperature, humidity, vibration, electrocardiogram, pulse, gait information, or other health- related parameters. An actuating device may cause an LED to blink, turn on lights, change colors on a display, display textual information, or any other action that prompts a response or informs a human.

A WSN device is a node in a wireless sensor network that is capable of gathering sensory information, processing it in some manner, and communicating with other nodes in the network. The majority of wireless sensor platforms share a common set of system components:

i. Microcontroller: provides the computational capabilities to the platform;
ii. Radio transceiver: provides low-power wireless communications;
iii. Sensor interfaces: hardware interfaces to external sensors;
iv. Actuator interfaces: provide human interaction interface (LED, displays, etc.);
v. Antenna;
vi. Power: through batteries, capacitors, or solar arrays.

Often these devices for business or engineering reason are broken down into modules. These modules are themselves broken into a sensing or display module and a transceiver module. Transceiver modules are convenient in a design because they provide a common radio stack and embedded processor for a cluster of different WSN devices. Common examples of transceiver devices include the WINS (Rockwell), Mica/Mica2/Mica2DOT (Berkeley/XBOW), the GNOMES (Rice), BTNode (ETH Zurich), and the MANTIS Nymph (Colorado).

These transceiver modules often will have sensing or actuators on them like the LEDs on the Crossbow Mica2 or the temperature sensors on the Berkley Telos Mote. An example of another transceiver module is the SHIMMER platform, which is examined in detail later in this book. Many of the commercial devices have an operating/development environment such as TinyOS, but few have the resources to run a true multithreaded operating system. WSN devices also have some memory (often an SD card) and a power supply (commonly a Li-ion battery). Modules may or may not have an antenna built onto the device, depending on design constraints.

Correct antenna design, and configuration are important for data reliability and integrity—crucial characteristics for WSNs in healthcare applications.

2.7.1 BLUETOOTH

Bluetooth is a low-cost, low-power, robust, short-range wireless communication protocol. It was first developed as a cable replacement between mobile phones, headsets, PDAs, laptops, and so forth, but it has evolved to solve more general applications in the personal area network (PAN) domain. The Bluetooth stack is quite complex, giving it a rather large footprint, which means that it cannot be used in devices constrained in terms of processing-power and memory. A collection of devices communicating using Bluetooth is referred to as a piconet.

Bluetooth operates in the license-free 2.4-GHz ISM band. It uses 79 1-MHz channels to transmit data. Interference between other ISM band devices (802.11 and 802.15.4 devices) and other Bluetooth piconets is minimized using frequency hopping spread spectrum (FHSS), where the carrier is rapidly switched (hops) among the 79 available channels. The frequency hopping sequence is controlled by the master device within the piconet. Other Bluetooth interference reduction techniques include adaptive power control, channel quality driven data rate (CQDDR), and adaptive frequency hopping (AFH). The Bluetooth core system consists of an RF transceiver, baseband, and protocol stack. The system is usually implemented partly in hardware and partly in software running on a microprocessor.

2.7.2 IEEE 802.11 (WiFi)

Wireless local area networks based on the IEEE802.11 series of standards can provide a high capacity link with reasonable latency for ranges up to 100 meters. They operate in unlicensed bands, and are therefore subject to interference. Later versions of the standard include a form of dynamic channel assignment to allow access points to shift frequency in the event of interference or jamming signal blocking the channel. Wireless LANs are suitable for connecting sensors with high bandwidth requirements (e.g., video sensors), and are also ideal as a traffic conduit

from an aggregator to the wider Internet. However, high-power consumption makes 802.11 less suitable for use with small, low-power sensors. Higher component costs may also make 802.11 an inappropriate choice for many WSN deployments.

2.7.3 802.15.4/ZIGBEE

802.15.4/ZigBee is built on the IEEE 802.15.4 standard and specifies the MAC and PHY (physical) layers. "ZigBee" comes from higher-layer enhancements developed by a multivendor consortium called the ZigBee Alliance. For example, 802.15.4 specifies 128-bit AES encryption, while ZigBee also specifies how to handle encryption key exchange. 802.15.4/ZigBee networks are designed to run in the unlicensed frequencies, including the 2.4-GHz band in the United States. IEEE 802.15.4/ZigBee is intended for uses such as the control of lights, security alarms, motion sensors, thermostats and smoke detectors, and environmental monitoring. There are plans for ZigBee integration with residential network gateways that merge traffic onto a broadband Internet connection. ZigBee has specific advantages over other short-range protocols such as 802.11 and 802.15 for WSN applications; devices based on these latter protocols use too much power and the protocols are too complex (and thus more expensive) to be embedded in devices on very large scales. Unfortunately, the ZigBee Alliance has not yet made its protocol available as an open standard; additionally, it adds another protocol between the device and the global IP-based network.

2.8 WSN DESIGN CONSIDERATION

What differentiates healthcare from other WSN technology application is the criticality of reliable data transmissions. In wireless communication of patient data, several concerns may arise about the potential effects of RF wireless technology in and around medical devices. These concerns relate to the ability of the devices to function properly and the resultant impact on the safety of patients and operators. In all stages of the solution development and product life cycle the engineer should implement best design practices. Some of the prioritized considerations include:

i. Cost: Each element in the design of the system carries with it a sensitivity to cost, particularly in scenarios where many such elements are needed.

ii. Scalability: An attractive aspect of most WSN systems is the flexibility to use as many nodes as necessary in various configurations. However, when the numbers of nodes in the system increases, the radio frequency bandwidth may become clogged, resulting in system latencies or data loss.

iii. Fault Tolerance: For healthcare applications, the data being transmitted in the system is often critical and must be prioritized to ensure proper medical care. Wireless sensor networks offer a "best effort" delivery of data delivery service but do not explicitly provide transmission verification methods for critical data. It may be necessary to provide higher-level error correction and data validation functionality.

iv. Location: In clinical and institutional settings, the location of sensors and actuators may be chosen to reflect user needs or the physical constraints of an architecture.

v. Energy efficiency: One reason that healthcare systems architects are attracted to WSNs is that many sensors do not require external power. As such, at least some devices in the system rely on battery power or renewable sources such as solar panels. Systems software and firmware solutions exist which, when combined with energy efficient hardware, allow devices to go into low power modes or be shut off when not in use.

vi. Medical regulatory: Unlike other applications of WSN technology, medical regulatory issues impact not only the end product but also the very manner in which the system is designed. Appropriate design practices should comply with the requirements of the local applicable medical legislation and regulations.

2.9 HEALTH MONITORING SYSTEMS.

HealthGear is a real-time wearable system for monitoring, visualizing and analyzing physiological signals. It is a product of Microsoft Research. It consists of a set of physiological sensors connected via Bluetooth to a cell phone which stores, transmits and analyses the physiological data, and present it 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. Non-intrusive, at-home monitoring allows for constant access to the user's vital signs, both day and night. This enable computing the user's baselines for each physiological signal, making the detection of anomalous events more meaningful and accurate. As data is being analyzed in real-time, HealthGear could take an active role. For example, in the sleep apnea application, HealthGear could wake up the user during a severe apnea event, or suggest changing sleep positions. Instead of being limited to a specific sensor or manufacturer, an important goal in HealthGear's architecture is to allow the use of heterogeneous sensors in a unified hardware and software platform. (Oliver and Flores-Mangas, 2006).

CodeBlue, a wireless infrastructure intended for deployment in emergency medical care, integrating low-power, wireless vital sign sensors. It is a research project at Harvard University. It integrates sensor nodes and other wireless devices into a disaster response setting. It is designed to work across various network densities and a wide range of wireless devices (Malan et al, 2004). From a tiny small sensor mote to more powerful devices can be combined in CodeBlue. It provides protocols and services for node naming, discovery, any-to-any *ad hoc* routing, authentication, and encryption. The use of *ad hoc* networking will allow the "mesh" of connectivity to extend across an entire building or between multiple, adjacent facilities. Additional coverage, if necessary, will be possible with placement of fixed nodes in hallways, rooms, or other areas. No matter the topology, the network will be self-organizing: loss of a given node or network link can be rapidly detected and data re-routed accordingly. CodeBlue also provide for reliable transmission of critical data through content-specific prioritization and dynamic scaling of transmission power. CodeBlue is based on a publish/subscribe model for data delivery, allowing sensing nodes to publish streams of vital signs, locations, and identities to which PDAs or PCs accessed by physicians and nurses can subscribe.

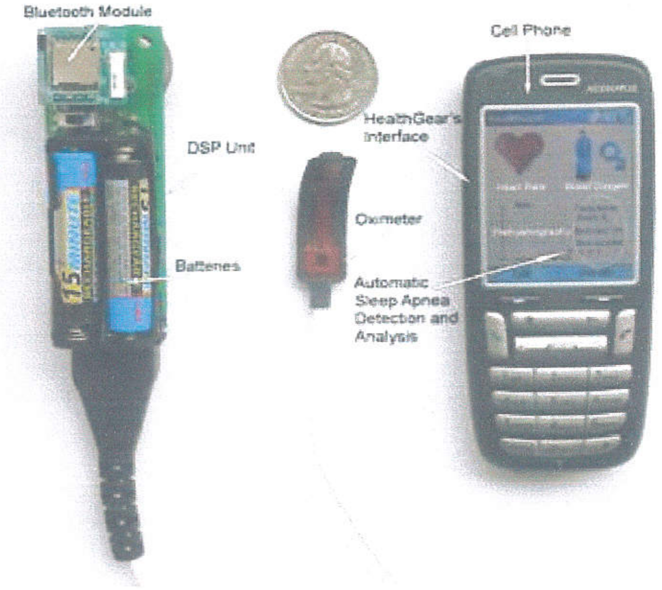

Figure 2.3 : HealthGear

Ko *et al.* proposed MEDiSN to address similar goals as CodeBlue (e.g., improve the monitoring process of hospital patients and disaster victims as well as first responders), but using a different network architecture (Ko *et al*, 2010). Specifically, unlike the ad-hoc network used in CodeBlue, MEDiSN employs a wireless backbone network of easily deployable relay points (RPs). RPs are positioned at fixed locations and they self-organize into a forest rooted at one or more gateways (i.e., PC-class devices that connect to the Internet) using a variant of the Collection Tree Protocol (CTP) (Gnawali et al, 2009) tailored to high data rates. Motes that collect vital signs, known as miTags associate with RPs to send their measurements to the gateway. The dedicated backbone architecture that MEDiSN incorporates significantly reduces the routing overhead compared to a mobile ad-hoc network architecture and results in two major benefits. First, it allows the network's operator to expand its coverage and engineer its performance by altering the number and position of RPs in the backbone. Second, since miTags do not have to route other nodes' data, they aggressively duty cycle their radio to conserve energy. The Washington University's patient monitoring has adopted a similar wireless backbone network to take advantage of similar benefits (Chipara *et al,* 2009)

MobiHealth aims to advance medical diagnosis, treatment, and patient care through application of wireless communications, mobile computing and sensing technologies. The emergence of high bandwidth public wireless networks and miniaturized personal mobile devices give rise to new mobile healthcare services. To this end, the MobiHealth system provides highly customizable vital signs tele-monitoring and tele-treatment system based on a body area network (BAN) and a mobile health care (m-health) service platform utilizing next generation public wireless networks. The developed system allows the incorporation of diverse medical sensors via wireless connections, and the live transmission of the measured vital signs to healthcare providers as well as real-time feedback to the patient (Wac *et al*, 2009). It is a mobile healthcare project funded by the European Commission. It is a multi-tier approach, going from in-body sensor devices to ubiquitous patient monitoring environments. It allows patients to be fully mobile while undergoing continuous health monitoring by utilizing UMTS and GPRS networks. Its interdisciplinary nature, with original contributions cutting across boundaries but all within the ambit of the application of mobile communications (technologies, standards, solutions, methodologies) aiming at the betterment of human health.

Ubimon from the Department of Computing, Imperial College, London. A ubiquitous monitoring system was presented for continuous monitoring of patients under their natural physiological states. The system provides the architecture for collecting, gathering and analyzing data from a number of biosensors. Particularly, the concept of BSN node is implemented which could form 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 aim of this project was to address the issues related to using wearable and implantable sensors for distributed mobile monitoring. Two areas under consideration are the management of patients with arrhythmic heart disease and the follow-up monitoring of post-operative care in patients who have had surgery.

A typical home healthcare system based on WSN is Alarm-Net an assisted-living and residential monitoring network for pervasive, adaptive healthcare. AlarmNet is a system based on an extensible, heterogeneous network architecture targeting ad-hoc, wide-scale deployments. It includes custom and commodity sensors, an embedded gateway, and a back-end database with various analysis programs. The system includes protocols such as context-aware protocols informed by circadian activity rhythm analysis for smart power management. It supports real-time on-line sensor data streaming and an inference system to recognize anomalous behaviors as potential indicators of medical problems (Wood *et al*, 2008). Privacy control is based on access control lists and all queries are logged. Future work is planned to use data mining on the query logs to detect privacy attacks. All messages are encrypted to ensure data confidentiality.

Georgia Tech built an Aware Home as a prototype for an intelligent space. This space provides a living laboratory that is capable of gathering information about itself and the different types of activities of its inhabitants. The Aware Home combines context-aware and ubiquitous sensing, computer vision-based monitoring, and acoustic tracking all together for ubiquitous computing of everyday activities while remaining transparent to its users (Kidd *et al,* 1999).

The Massachusetts Institute of Technology came up with the PlaceLab initiative which is a part of the House n project. The mission of House n is to conduct research by designing and building real living environments— "living labs"— that are used to study technology and design strategies in context (Intille *et al*, 2006). The PlaceLab is a one-bedroom condominium hundreds of sensing components are installed in nearly every part of the home, which is a one-bedroom condominium. These sensors are being used to develop innovative user interface applications that help people easily control their environment, save resources, remain mentally and physically active, and stay healthy. The sensors are also being used to monitor activity in the environment so that researchers can carefully study how people react to new devices, systems, and architectural design strategies in the complex context of the home. Some occupants may be studied living in their own home environments as well using a portable toolkit of sensors that has been developed by MIT researchers. These devices make remote monitoring of people in their own homes possible for some period of time before and after they enter the PlaceLab in order to investigate pre and post-occupancy behavior changes.

eWatch is a wearable sensor and notification platform developed for context aware computing research. It fits into a wrist watch form making it highly available, instantly viewable, and socially acceptable. eWatch provides tactile, audio and visual notification while sensing and recording light, motion, sound and temperature (Maurer *et al,* 2006). The eWatch system can sense if the user is in distress and then query to confirm that it is an emergency. If the user does not respond, then the eWatch could use its networked abilities to call for help. eWatch communicates wirelessly using a Bluetooth module and an infrared data port for control of devices. (Rowe *et al*, 2006)

The vital jacket is a mobile device which is an intelligent wearable garment that is able to continuously monitor electrocardiogram (ECG) waves and Heart Rate for different fitness, high performance sports, security and medical applications. Vital Jacket is an easy-to-wear garment, very comfortable and reliable cardio monitor which that can be worn by the patient allowing at least 72 hours of continuous exams enables physicians to do a correct assessment of cardiac problems in an everyday life environment. The data can be sent via Bluetooth to a PDA and stored in a memory card at the same time.

The Humon hex allows endurance athletes to train smarter by monitoring the way their muscles are using oxygen in real-time and providing them with real-time personalized insights for immediate performance improvement. Humon started as a research project at MIT Sloan on the premise that technology and biology were on a collision course.

University of Rochester is building the Smart Medical Home, which is a five-room "house" outfitted with infrared sensors, computers, bio-sensors, and video cameras for use by research teams to work on research subjects as they test concepts and prototype products (Liao *et al*, 2005). Researchers observe and interact with subjects from two discreet observation rooms integrated into the home. Their goal is to develop an integrated personal health system that collects data for 24 hours a day and presents it to the healthcare professionals.

The Visi Mobile is a wearable device worn around the wrist which allows clinicians to be in touch with their patients and check on their vital signs at any given moment. ViSi Mobile is a comprehensive monitoring system, designed to enhance patient safety, allowing early detection of patient deterioration and connecting clinicians with their patients anywhere, any time. The Visi Mobile is capable of monitoring ECG, heart rate, pulse rate, blood pressure, respiration rate and body temperature. a platform for comprehensive vital signs monitoring that keeps clinicians connected to their patients, whether in bed, in transport or while ambulating – "monitoring in motion." Featuring comfortable body-worn sensors that allow for freedom of movement, the system enables accurate, continuous monitoring of all core vital signs with the future addition of beat-to-beat, non-invasive blood pressure, as well as patient activity and posture. In addition, this technological device is able to transmit data in a wireless manner, so vital signs can be analyzed on a remote computer or portable tablet. By monitoring health-related indicators, Visi Mobile can be used to alert doctors and nurses if patients require urgent care.

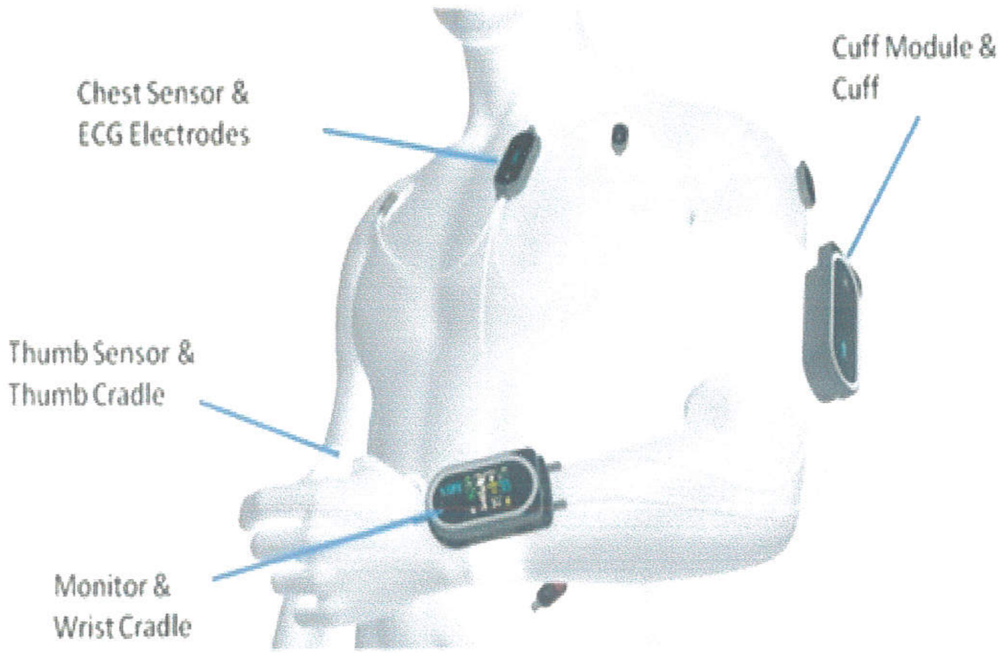

Figure 2.4: Visi Mobile

GoBe is a wearable activity monitor that automatically measures calorie consumption by reading the glucose levels in the cells, through the user's skin. GoBe is compatible with all iOS and Android smart phones, providing the user with a convenient way to keep track of their calories intake and burn rate. Furthermore, the wearable device can accurately measure the heart rate using the pressure sensor from HealBe Flow technology. GoBe can be used to improve safety in the workplace thanks to heart rate analysis, which can potentially prevent heart problems to occur. Collection and study of bodily data can also help in preserving physical health of workers. Also, as healthier and rested worker can potentially provide work in greater quantity and/or quality, the device can ultimately maximize productivity.

LifeShirt is a miniaturized, ambulatory version of an in-patient system, and is available as a commercial prescription medical device. The system consists of the LifeShirt garment with embedded sensors, data recorder, and the VivoLogic analysis and reporting software. LifeShirt functionality includes respiratory function, ECG, accelerometer, blood pressure, blood oxygen saturation, EEG, EOG (electrooculography), periodic leg movement, core body temperature, skin temperature, end tidal CO2, and cough. The system collects and analyses the data, and integrates subjective patient input from an on-board digital diary. A PDA continuously encrypts and stores the patient's physiologic data on a memory card. Data can be uploaded via the Internet or read from data cards even clinical research.

Multi-Electrophysiological System, the transformation of the periphery spontaneous nerve can indicate the state of human emotion. Using biological and medical signal (BMS) measurement technology, wireless sensor networks technology, and wearable calculation technology, the system can operate without disturbing human activities. A wireless sensor network captures signals from the subject, and sends the data to the signal conditioning circuits. Finally, data is sent to the remote host system. multi-electrophysiological equipment can also be used in emotion recognition experiment. The ECG data is recorded and transferred to the computer and then heart rate is calculated. In order to classify different emotion states, they analyze heart rate variability, and pick-up the eigenvalue of the power spectrum density.

2.10 RELATED WORKS

There are various wireless health monitoring systems currently deployed which monitor different parameters using different methods. These systems are deployed in different forms; some are deployed in positions far from the actual physical process or perception, a number of recent projects have focused on wearable health devices. Some of the major indoor/outdoor application projects are mentioned here. These applications work on both real time and non-real time modes.

Traditionally, personal medical monitoring systems, such as Holter monitors, have been used only to collect data for off-line processing. A Holter monitor is a battery-operated portable device that measures and tape records heart's activity or electrocardiogram (ECG) continuously for 24 to 48 hours or longer depending on the type of monitoring used. It has wires with silver electrodes that attach to the patient's skin. Systems with multiple sensors for physical rehabilitation typically feature many wires between the electrodes and the monitoring system. These wires may limit a patient's activity and level of comfort, thus potentially affecting the reliability of the measured results. Therefore, there has been an increasing interest in health monitoring in the wearable computing community. (Martin et al, 2000)

Cheng et al, described a Bluetooth-enabled health monitoring system is described, where the authors present a PDA-based ECG monitoring system with the sensors embedded in a shirt. The analysis of the data would be done in a central computer (Cheng et al, 2004). However, the authors neither report algorithms to process the data nor experiments with real users. A wearable health-monitoring device using a Personal Area Network (PAN) or Body Area Network (BAN) could be integrated into a user's clothing (Park and Jayaraman, 2004) such as Foster-Miller's health monitoring garment for soldiers. Along these lines, a garment with embedded ECG sensors for continuous monitoring of the heart. Jovanov and Park presented a wireless BAN with motion sensors for computer-assisted physical rehabilitation and ambulatory monitoring.

Husemann *et al* (2009) proposed a Personal Area Hub to manage interactions between wearable devices and act as a proxy for these devices. The authors developed an architecture for logging and subscribing to events occurring in the system and have implemented it on a Sony Ericsson P900 smart phone. Their testbed is a health care application for tracking patient compliance in taking blood pressure medication (Husemann et al, 2004).

Another application domain for WSNs in healthcare is high resolution monitoring of movement and activity levels. Wearable sensors can measure limb movements, posture, and muscular activity, and can be applied to a range of clinical settings including gait analysis (Pentland, 2004), (Russmann et al, 2004) activity classification, athletic performance and neuromotor disease rehabilitation (Patel et al, 2007). In a typical scenario, a patient wears up to eight sensors (one on each limb segment) equipped with MEMS accelerometers and gyroscopes. A base station, such as a PC-class device in the patient's home, collects data from the network. Data analysis can be performed to recover the patient's motor coordination and activity level, which is in turn used to measure the effect of treatments.

For millions of patients suffering from asthma in the world, sudden allergic morbidity may cause severe threat to their lives (Kolbe et al, 1999). They require administration of Terbutaline in minutes, in order to ease symptoms of rapid-onset asthma attacks, or the attacks may become fatal (Sur et al, 1999). A wireless sensor network can help them by having sensor nodes that can sense the allergic agents in the air and report the status continuously to the physician and/or to the patient himself. Hsueh-Ting Chu *et al*, developed a portable GPS-based device that continuously consults a remote server and reports whether the current air condition will threaten user's health. The server also collects information from the network of national air quality monitoring stations. Then, if it finds anything allergic to the patient, an alarm to the patient and/or physician can be triggered.

Currently, one of the most important issues in medical grounds is preventing medical accidents caused by human error. Approximately 98'000 people die every year due to such errors. Many deaths occur in hospitals because of medical accidents caused by human errors. The "E-nightingale project" uses wearable environmental sensors as components of a sensor network to reduce medical accidents by understanding the nurses' activities. By maintaining a log of previous medical accidents, the sensor network can notify the nurses in case of the occurrence of the same accident, thus many medical accidents can be reduced that can save many human lives. (Naya et al, 2006) cause a large number of deaths in developed countries. Many of the deaths can be avoided, had the physician known beforehand about the current health status of the patient. Some proposals use smart sensor nodes that can be installed on the patient in an unobtrusive way. The corresponding medical staff receives the vital information regarding heart rate and irregularities of the heart, treatment preparation beforehand while monitoring the health status of the patient (Jafari et al, 2005).

As the world population ages, the number of elderly people increases. Alzheimer is a common disease in elderly people who often feel lonely and depressed and has little or no interest in physical activity and social contact. Wireless sensor networks offer a means to counteract this outcome with home automation integration, detection of abnormal situations (e.g., a fall), or even alerting neighbors, family or the nearest hospital. Burchfield and Venkatesan discussed an accelerometer-based approach for abnormal movement detection is described, that can be used to detect seizures, in a non-invasive, non-intrusive manner (Burchfield and Venkatesan, 2007). The authors developed an algorithm using ZigBee protocol devices that detect brush, wash and shave activities. Another proposal is presented by Dagras et al. The authors used a mobile phone and a wireless sensor network based approach to help homebound people. The system is able to use a ZigBee or Bluetooth enabled wireless sensor network and provides real-time alerts and notifications.

Heart Rate Monitoring is a research domain that saves many lives. It is well known that every year 40% to 45% of firefighters die of heart attacks compared to 25% for the normal population. Monitoring the firefighter's vital signs and the environment could revolutionize the way they train, are selected for each job assignment, and allowed to work on some high-risk assignments. Current heart rate monitors require time and attention for their placement such as the chest straps with electrodes that need moist skin contact. There are also wrist watches with electrodes that take non continuous measures and act only when triggered, or photoplethysmographic sensors for the finger that are very sensitive to motion artifacts and loose accuracy specially when doing manual work. However, there is currently no practical monitoring system a person can easily wear while on the job (Grajales and Nicolaescu, 2006).

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 RESEARCH APPROACH

In designing and implementation of a WSN based system for hypertensive patient monitoring, the research approach is as follows.

I. Design an architecture of the system that must conserve power. Its power supply must be flexible and allows for long term supply without losing efficiency.

II. The implementation of a real-time, light-weight wearable health monitoring architecture, to wirelessly send hypertensive patient vital sign data to a cell phone through its nodes.

III. The visualization and analysis of the data on a cell phone;

IV. The validation of the complete system (hardware and software) in a study with several willing participants.

3.2 SYSTEM COMPOSITION

The architecture of the hypertensive patient monitoring system was built based on the Wireless Sensor Network method and this is composed of both software and hardware resources; The system composes of four sections namely: sensing, transmission, displaying/alert/notification and storage/database sections. All sections are to be configured with both software and hardware resources.

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 the Bluetooth communication. This is referred to as Tier 2. The communications links used between the WBASN and the android application uses bluetooth according to circumstances or chosen communication link.

The caregiver connects over the serial communication for communications protocols to various Tier 3 services. 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 is now ready to receive commands from the sensor node. Next, the sensor node would issue a command to take a measurement. The data harvested is sent over the Bluetooth protocol to the caregiver's PDA software which allows for access to the data in a proper format.

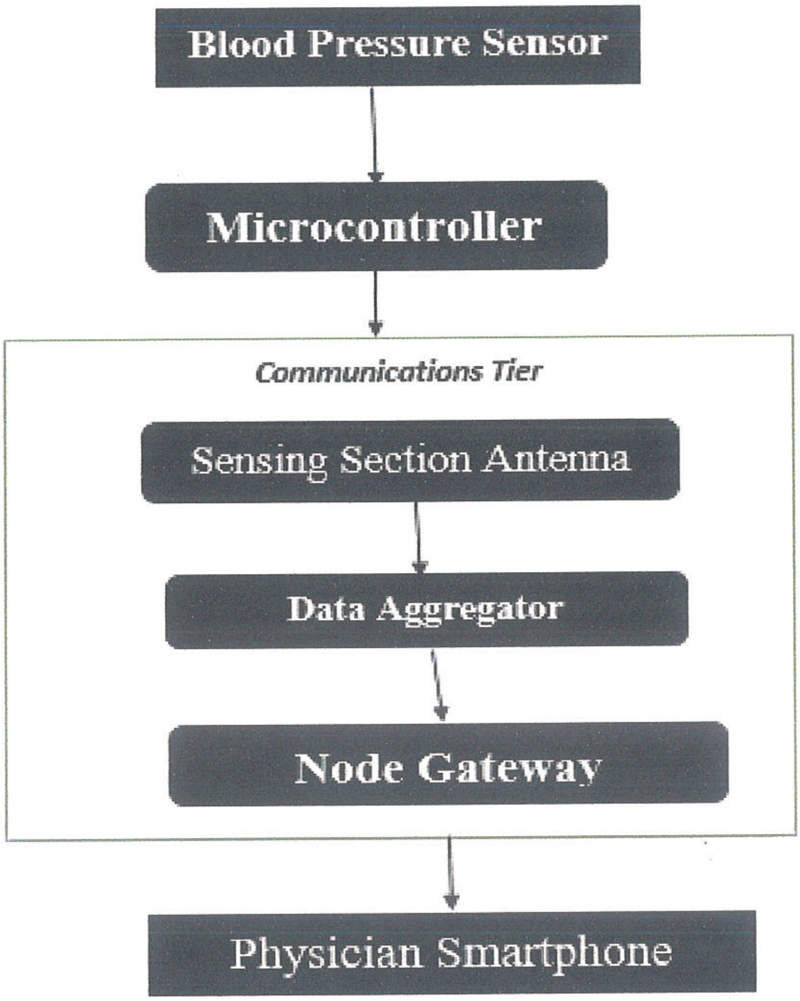

Figure 3.1: System Block Diagram

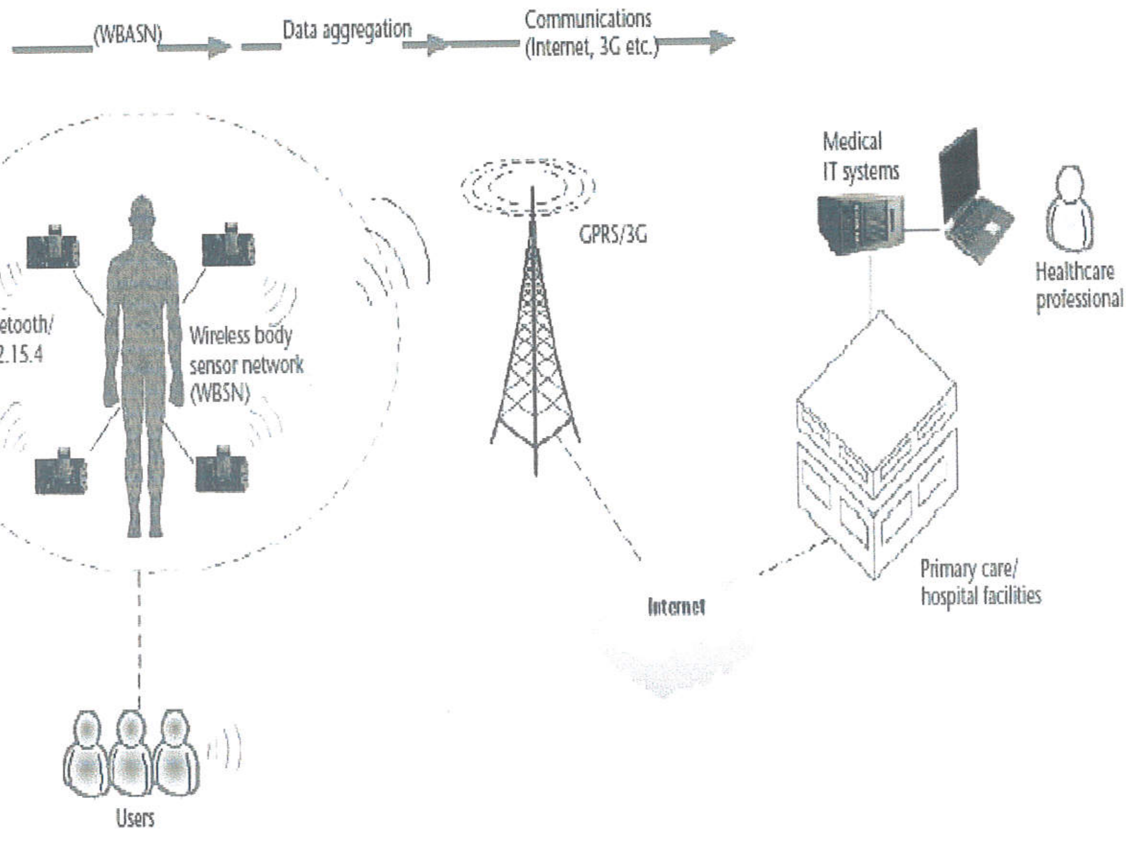

Figure3.2: System Architecture of the Hypertensive-Patient monitoring system

3.3 HARDWARE COMPONENTS:

The choice of technologies for wireless sensor network based hypertensive patient monitoring system is broad, with a range of options available across microcontrollers, firmware, operating systems, radios, sensors, and so forth. Selecting the optimum combination of technologies to address a blood pressure monitoring is not trivial. The objective is to select the best technology combination to collect and analyze the relevant data and to provide feedback as appropriate to the patient, and to deliver information to the clinician.

There are wide range of hardware technologies available for WSNs. The choice of hardware must reflect the solution objectives, environment, patients, and so forth (Dishongh and McGrath, 2012). The Hardware components include:

i. The *devices,* including sensors and/or actuators, embedded processor, and radio;

ii. The data *aggregator* for the WSN (This was outsourced to software)

iii. The hardware for the *backend* data analysis/visualization services (This was outsourced to software).

Selection of off-the-shelf devices and of modules which can be combined to create the blood pressure monitoring devices is more cost-effective, saves time and usually provide technical help during integration from data sheets and documentation of such components. The off-the-shelf blood pressure monitor used is the CK-101 blood pressure cuff. The Blood Pressure and Heart rate sensors are used to compute the patient data and then processed by the microcontroller. The microcontroller used in this project is an Arduino Mega 2560 which holds the firmware program and manages computing resources of the system.

The microcontroller is also responsible for the processing of data computed, its recipient from the sensing section and its transmission using Bluetooth. The hardware section then sends the patient data to the caregiver's PDA for viewing by the Physician or medical personnel connected.

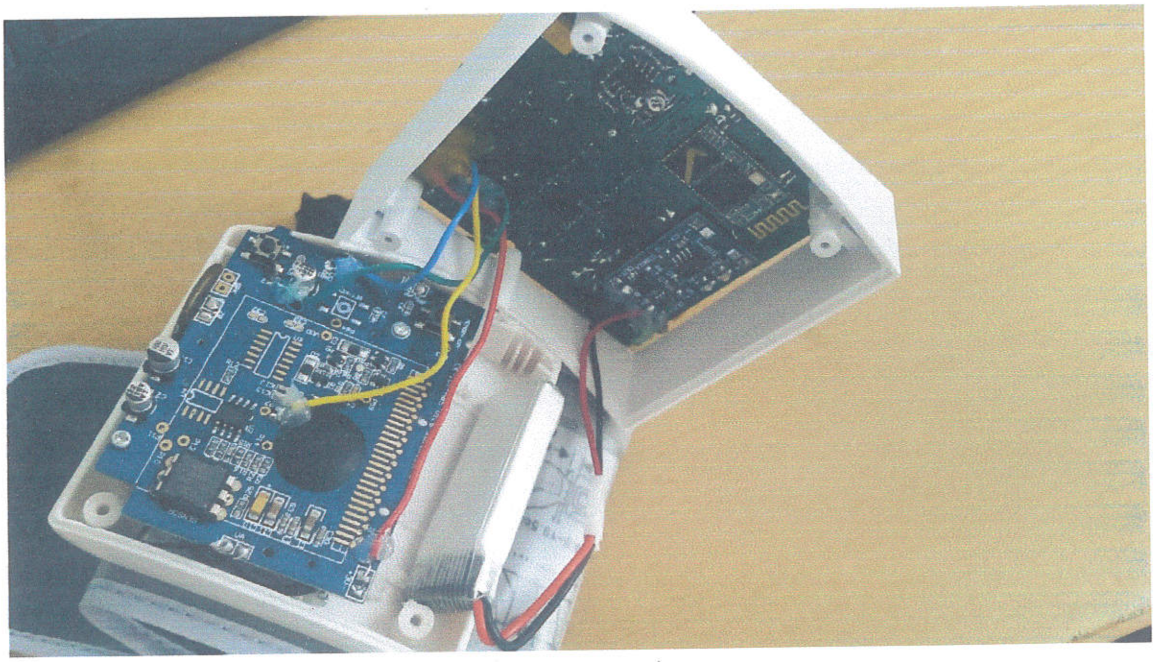

Figure 3.3: The Patient Monitor hardware.

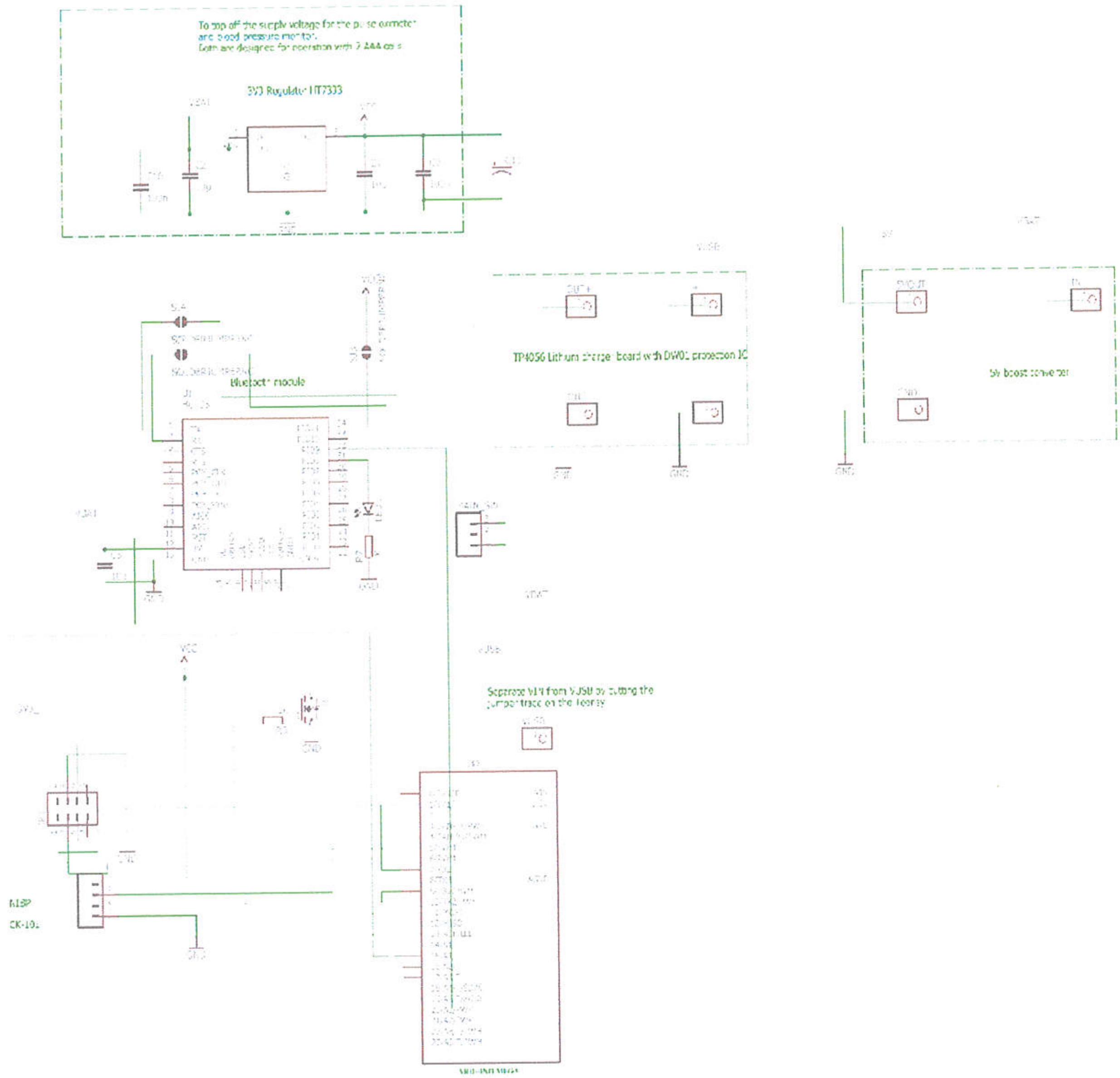

Figure 3.4: System Circuit Schematic

3.3.1 BLOOD PRESSURE MONITOR (CK-101)

An off-the-shelf blood pressure sensor which has a combination of few fully piezo resistive silicon pressure sensor for use in invasive blood pressure monitoring also known as CK-101 was used for the sensing section. The blood pressure sensor integrated in the monitor is designed to be used with automated assembly equipment and can be dropped directly into a customer's disposable blood pressure housing. The sensor is designed to meet the requirements as described in the Association for the Advancement of Medical Instrumentation (AAMI) specification for Blood Pressure Transducers.

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 BP monitor and protection for the sensing element.

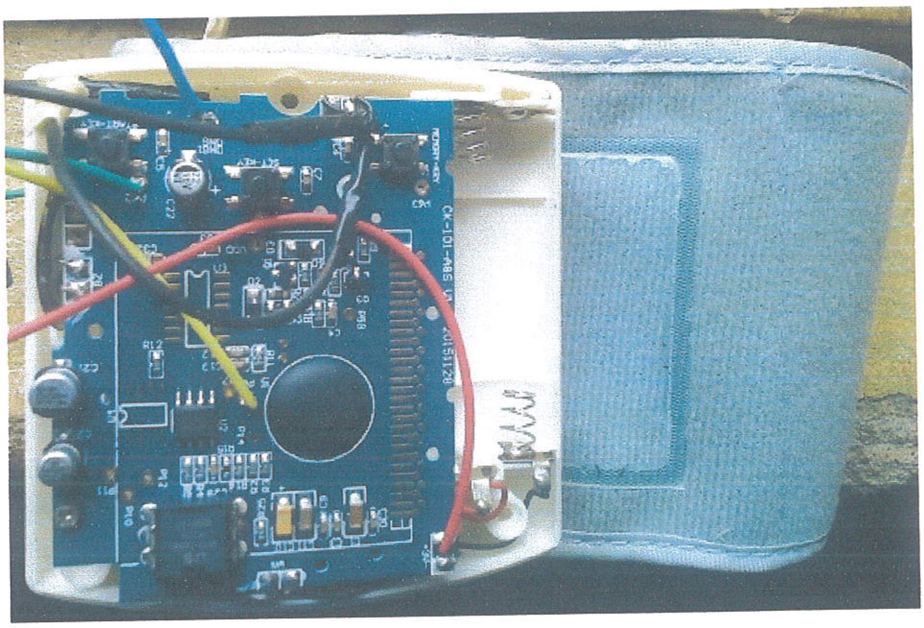

Figure 3.5: Blood Pressure Cuff

3.3.2 ENERGY HARVESTING AND POWER MANAGEMENT

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 harvesting module would 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 ultracapacitors.

3.3.3 SENSOR NODE AND BASE STATION INTERFACES

The Blood Pressure Monitor (BPM) would provide patient blood pressure and heart-rate readings for the system. It includes a serial port that facilitates bi-directional communication at 9600 bps. A Bluetooth module (HC-06) is programmed as the sensor node to communicate with the BPM on this serial link to start the reading process and receive the patient's BP and heart-rate readings. Once the readings were received, the sensor node would communicate with the network and transmits them to the base station.

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 is now ready to receive commands from the sensor node. Next, the sensor node would issue a command to take a measurement.

When the reading process has 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 to the base station.

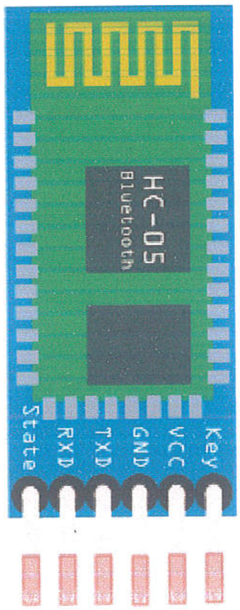

Figure 3.6: Bluetooth module.

3.4 SOFTWARE COMPONENTS

Working closely with the hardware, the firmware which manage the resources of the embedded processor and an Android application used by the caregiver or physician to access patient data.

3.4.1 FIRMWARE PROGRAM

Some low-cost embedded processors do not support real-time operating systems as such, but rely on a loop program running continuously with interrupts to program the device. Some embedded IC devices are restricted to lower level assembly languages, although the most popular processors support higher-level programming language like C. In such higher-level language compilers, a suite of validated subroutines for the embedded device are included. While designing the firmware, there is a need to augment these libraries with additional assembly language routines.

When building the hypertensive patient monitoring system, this required more complex resources, such as a gateway, a RTOS is indispensable. In order to build support for Bluetooth protocol, for USB mass storage devices or to provide parallel execution of software tasks, a RTOS is necessary. This is provided by the Arduino platform.

The Arduino project provides the Arduino integrated development environment (IDE), which is a cross-platform application written in the programming language Java. It originated from the IDE for the languages *Processing* and *Wiring*. It includes a code editor with features such as text cutting and pasting, searching and replacing text, automatic indenting, brace matching, and syntax highlighting, and provides simple *one-click* mechanisms to compile and upload programs to an Arduino board. It also contains a message area, a text console, a toolbar with buttons for common functions and a hierarchy of operation menus.

The Arduino program which harvest 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

3.4.2 ANDROID PROGRAM (Patient Monitor)

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 pushing the "START SYSTEM" button of the Start Activity. On starting the system, the start activity layout is opened, its only purpose is to start the system to access patient data.

The "START SYSTEM" is only activated if the application is connected to the sensing node through Bluetooth communication, else communication cannot be established.

Figure 3.7: Patient Monitor App Start Activity.

When the "START SYSTEM" button is triggered, it starts another app activity that discover 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 displaying the data sensed in the dynamic plot showing 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.

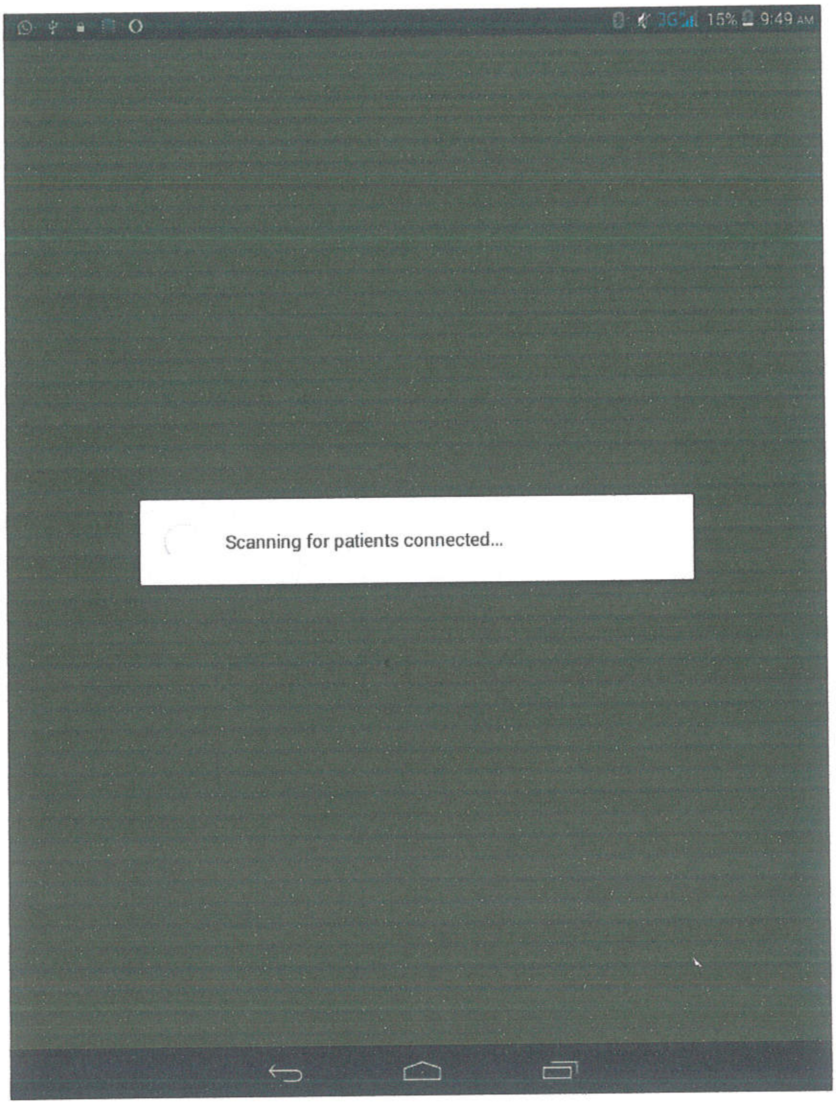

Figure 3.8: Discovering connected patients

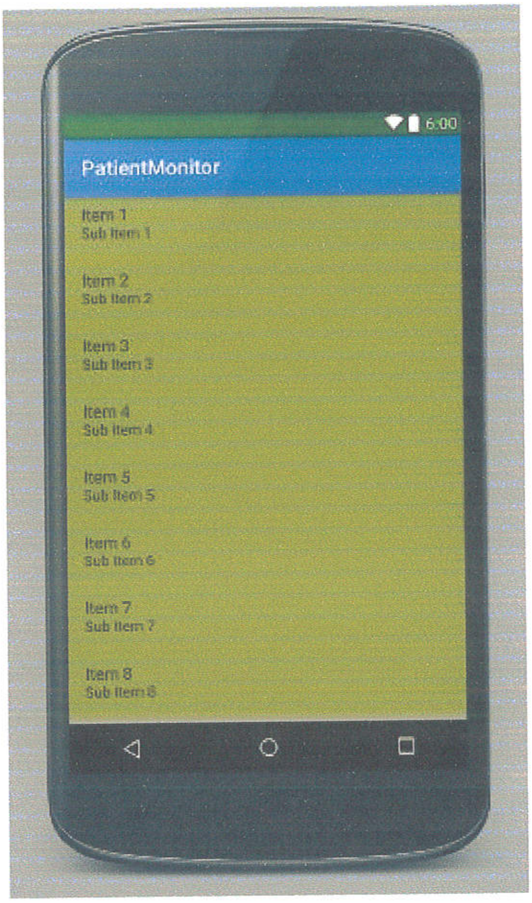

Figure 3.9: List of Patients available for connection.

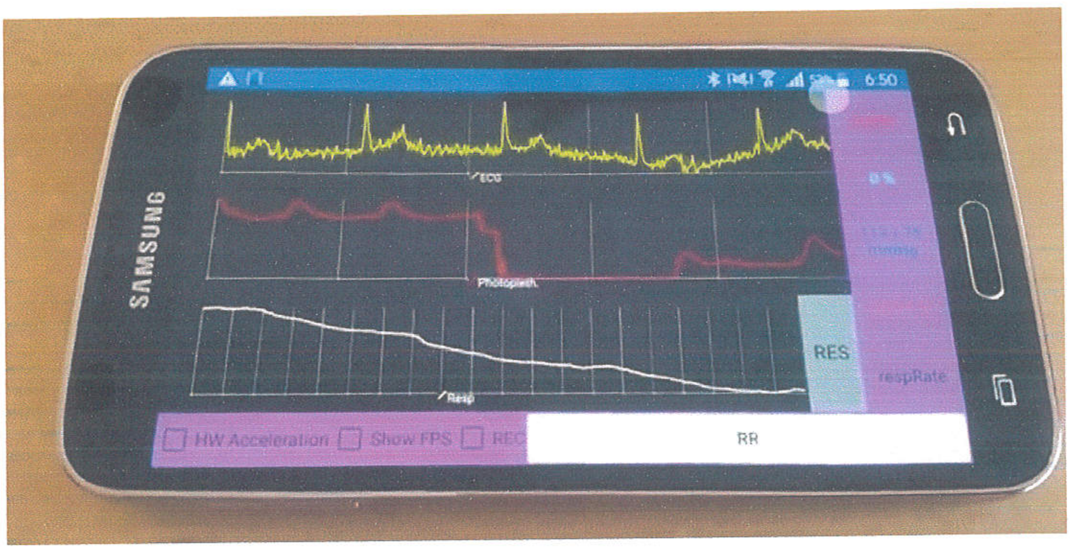

Figure 3.10: Display patient data.

3.5 ALGORITHM

1. Start
2. Sense Patient Blood Pressure
3. Send serial value sensed to the microcontroller
4. Process and Compute BP reading as variable blood_pressure
5. Send Patient data to Patient Monitor (on Caregiver's PDA)
    a. If blood_pressure is severe:
        i. Notify the physician – mobile app

    Else:

        Continue measurement.
6. Save Blood pressure value for records and analytics
7. Go to Step 2.

3.6.1 FLOWCHART

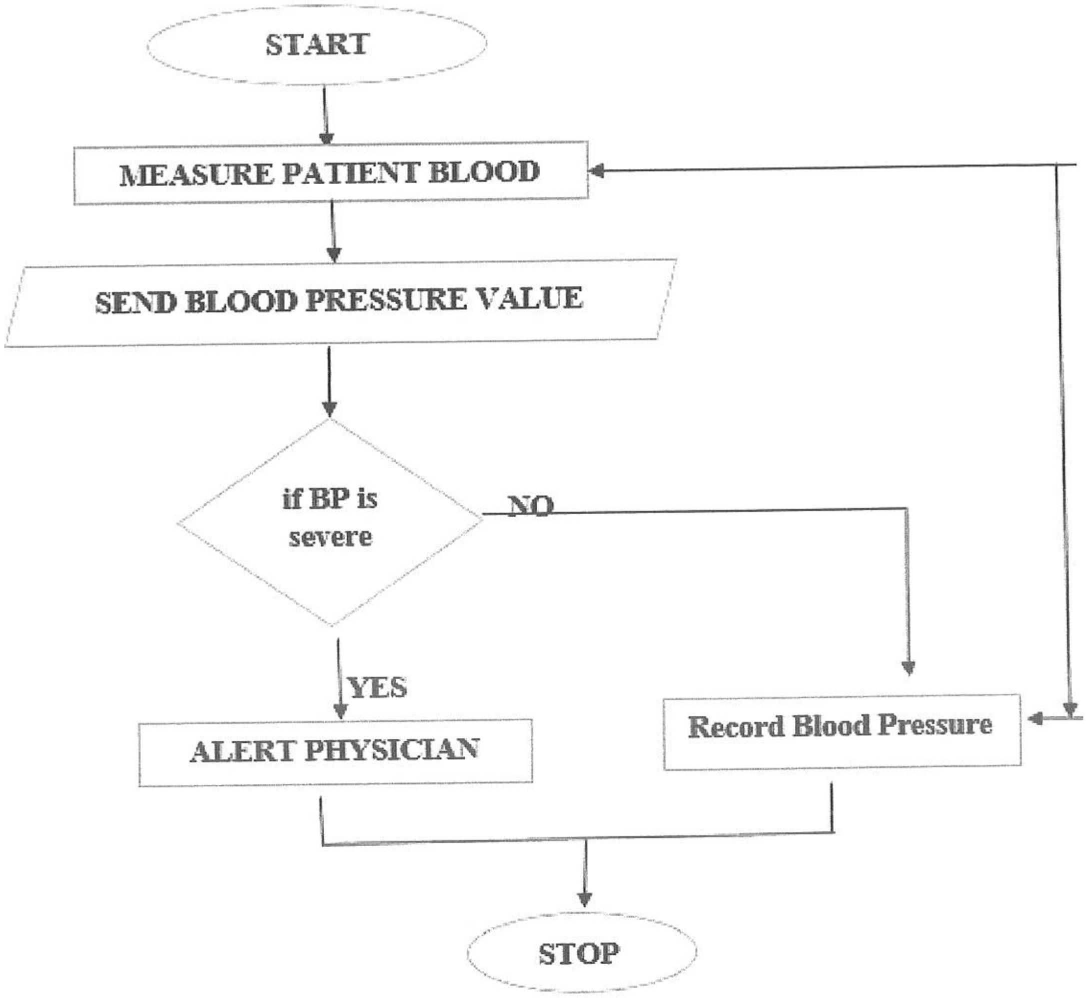

Figure 3.11: System Flowchart

3.7 METHOD OF EVALUATION

The system is evaluated based on three metrics namely: Accuracy, Energy utilization and Scalability.

Accuracy: The accuracy of the system is calculated by comparing the measured blood pressure with analogue readings taken concurrently. The actual error, percentage error (PE) and mean percentage error (MPE), and Percentage Accuracy (PA) are computed as below:

$$Actual\ Error = Blood\ Pressure\ readings - \ manual\ (or\ analog)\ readings$$

$$PE = \frac{Actual\ Error}{Actual\ BP} * 100$$

$$Mean\ Percentage\ Error = \frac{Total\ BP\ for\ 20\ samples}{20}$$

$$Percentage\ Accuracy = 100 - Mean\ Percentage\ Error$$

Energy consumption: The energy consumed by the processor and radio during the transmission of one packet in joules can be measured and the efficiency of the energy harvest. Continuous monitor the ultra-capacitor voltage and obtain a voltage reference for the router node microcontroller. Due to possible variation in supply voltage (VL), a fixed 1.223 VDC voltage reference can be used to determine the router node VL and microcontroller 10-bit A/D reference voltage (VREF). This voltage reference would consist of a 1.223 VDC zener diode.

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 must be able to accommodate as many nodes as possible and be ascendable. The system proved to be quite scalable 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.

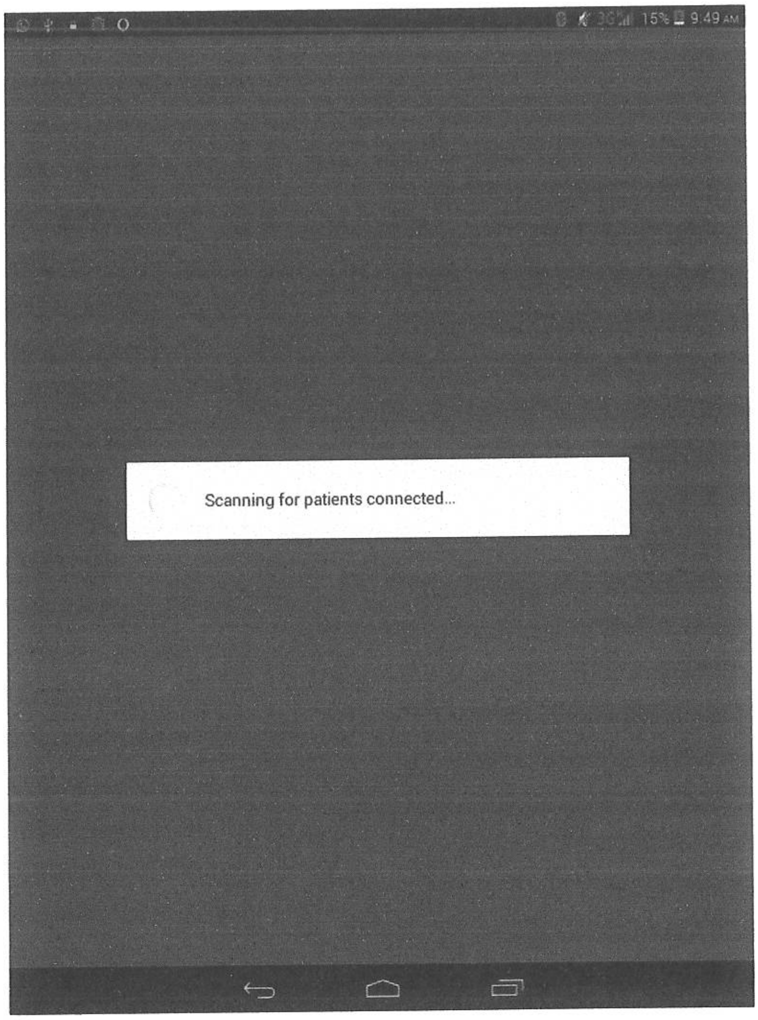

Figure 3.8: Scanning for connected patients

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 RESULTS

The system developed was used to measure blood pressure of 20 patients and the patients' measurements were compared to blood pressure readings using conventional sphygmomanometer. The patients' data taken are of twelve (12) male patients and eight (8) females patients. Using the system setup of the patient monitoring system designed, it was discovered that blood pressure taken by the system is nearly same as the patients' data from manual measurements taken by a traditional sphygmomanometer. It should be noted that the designed system measured efficiently the blood pressure and heart rate under ten (10) seconds as compared to a traditional sphygmomanometer which takes almost twenty (20) seconds to take the same measurements.

Blood pressure measured with the developed system is quick and reliable since there isn't access to the data by unauthorized personnel who may manipulate such data, it integrity can be ascertained as exact.

The result of the readings of the patients' data are shown in the table 4.1 below:

Table 4.1: Comparison of Designed System data with manual Sphygmomanometer

Subjects	Gender	System Systolic Pressure Measured	Sphygmomanometer Systolic Pressure measured	System Diastolic Pressure measured	Sphygmomanometer Diastolic Pressure measured
1	M	114	110	75	74
2	M	108	107	71	72
3	M	107	103	65	65
4	M	120	118	72	71
5	M	122	122	78	77
6	M	117	115	66	68
7	M	120	117	69	68
8	M	122	123	61	62
9	M	118	115	65	64
10	M	123	120	74	72
11	M	119	118	70	71
12	M	124	122	63	63
13	F	117	118	67	66
14	F	112	111	70	71
15	F	129	127	72	74
16	F	125	124	68	67
17	F	118	116	62	62
18	F	122	121	65	64
19	F	120	121	74	72
20	F	112	110	64	66

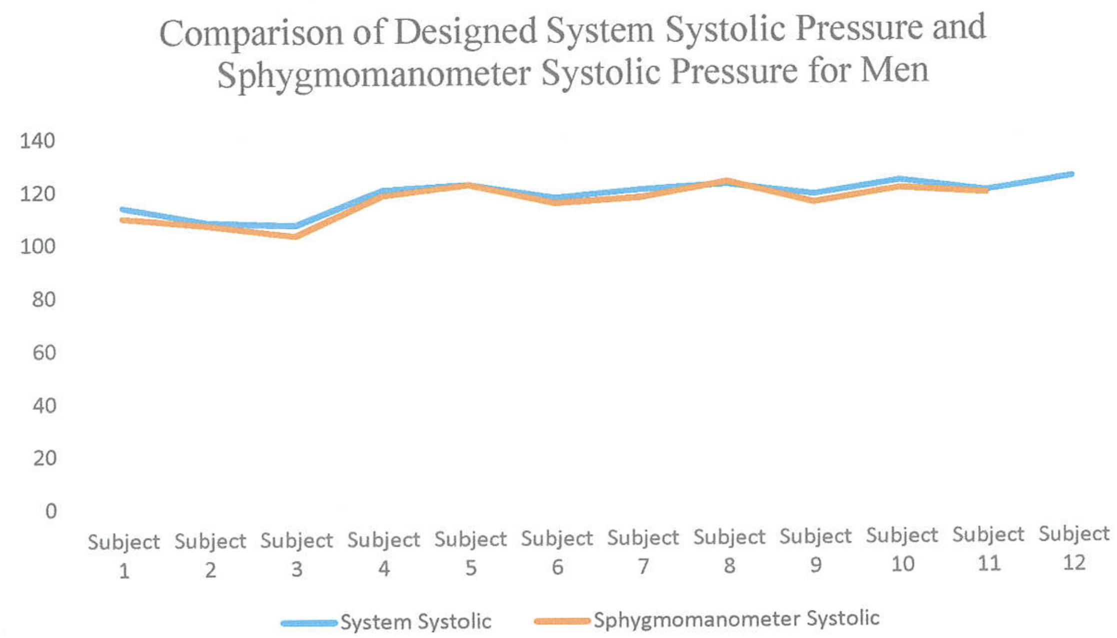

Figure 4.1: Comparison of Systolic Pressure in men from Designed System and Manual Sphygmomanometer.

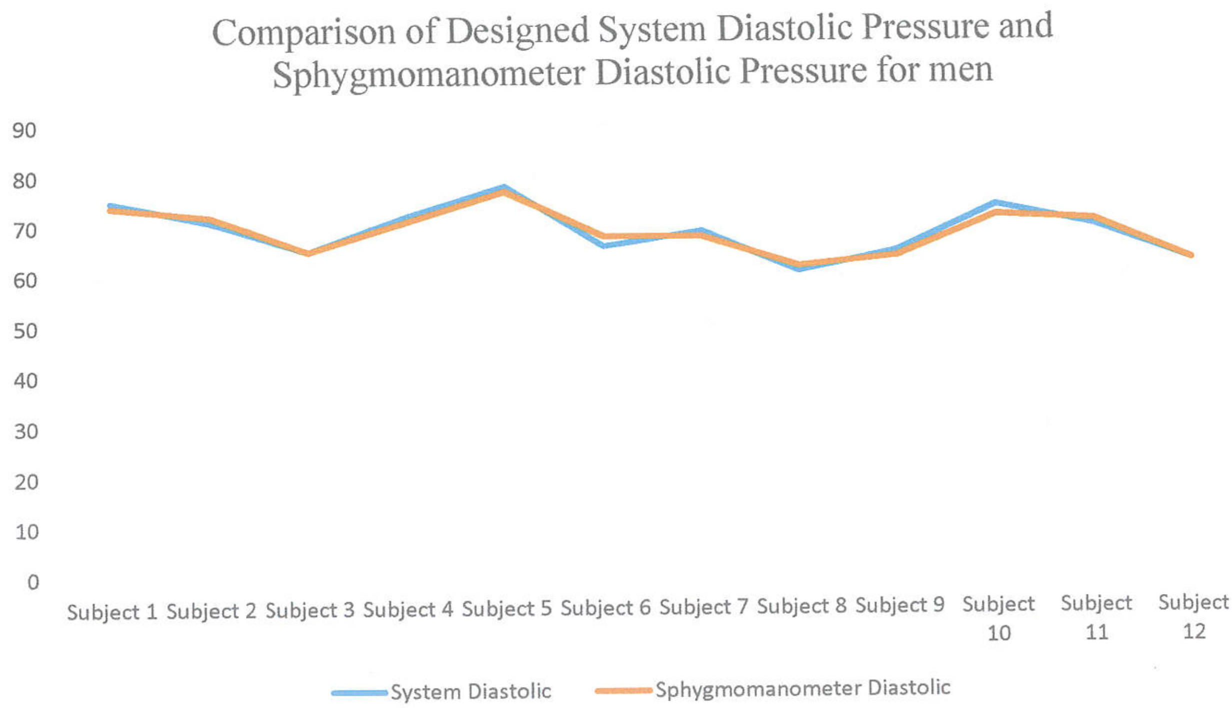

Figure 4.2: Comparison of Diastolic Pressure in men from Designed System and Manual Sphygmomanometer

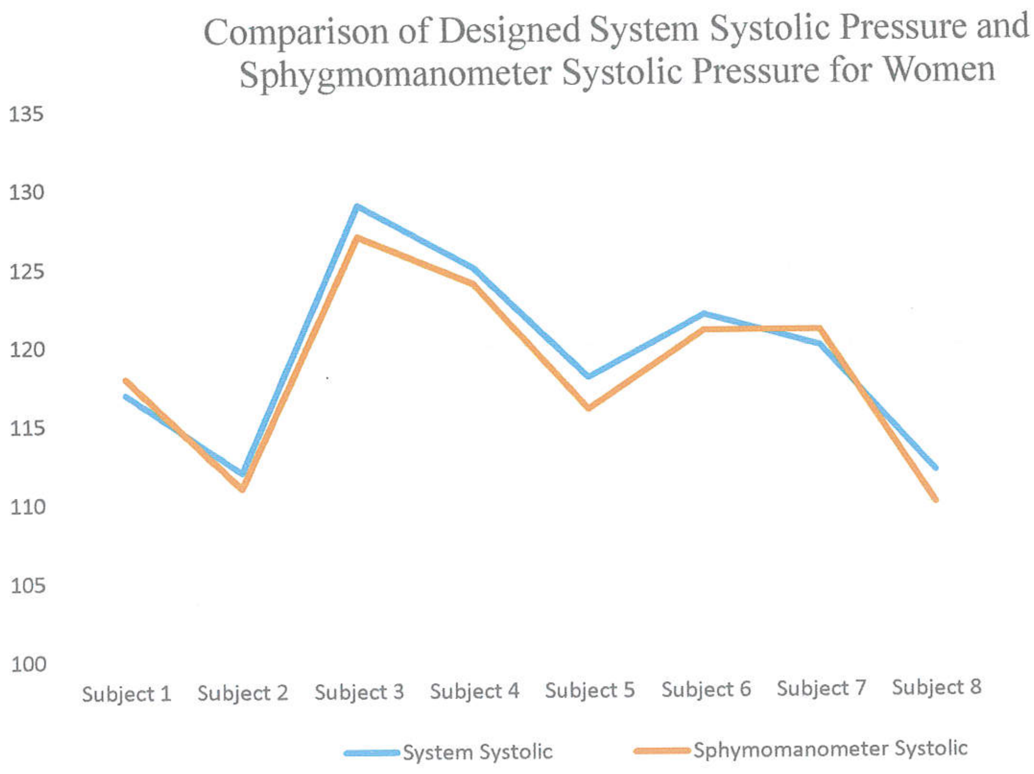

Figure 4.3: ***Comparison of Systolic Pressure in women from Designed System and Manual Sphygmomanometer***

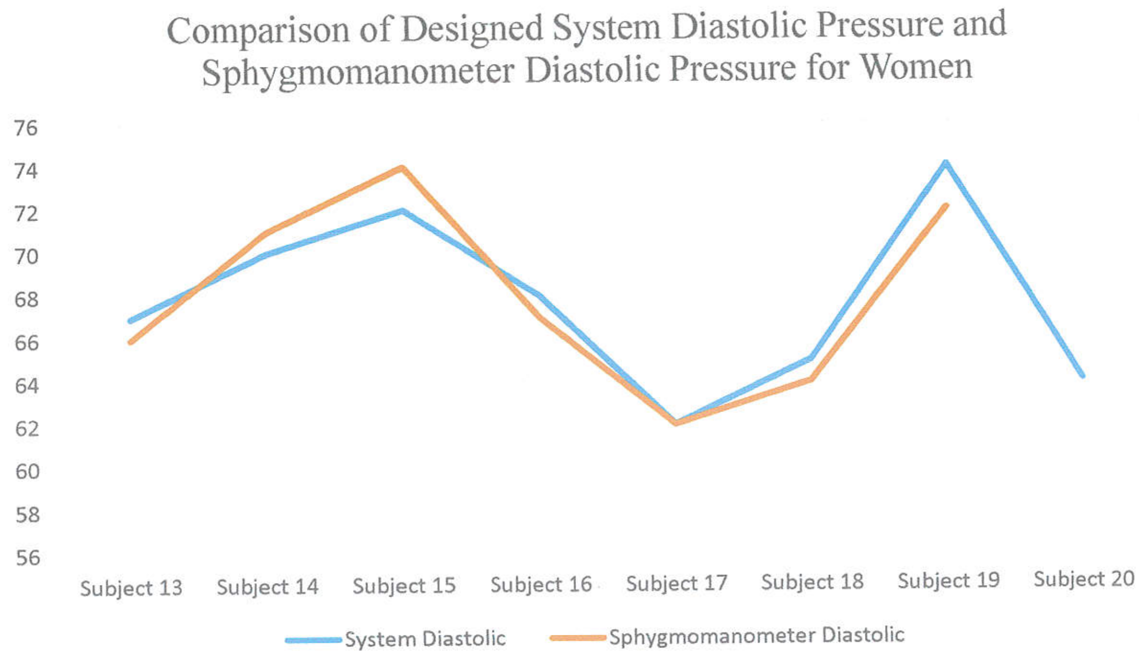

Figure 4.4: *Comparison of Diastolic Pressure in women from Designed System and Manual Sphygmomanometer*

4.2 DISCUSSION OF THE RESULT

It could be inferred from the table 4.1 and graphs shown above that the system designed measures systolic and diastolic blood pressure effectively. The data harvested is also efficient to monitor hypertensive patient health status and know the progress made. All this can be done remotely without caregivers' or health personnel having to take the readings which gives room for error.

One of the core advantages of using the system is that traditional prior informed consent is not adequate when sensors may capture data in unanticipated situations and the sheer amount and nature of sensor data makes information integrity more acceptable instead of heightened data from foreseen measurement process which gives patients unnecessary fright. Collecting patients' data continuously means that it is impossible to anticipate upfront, and accordingly inform patients about, the complete nature of information that the sensor data may reveal.

The system is monitoring and collecting patient data that is subject to privacy policies. Having health personnel take the patients' data may give room to access such information by unauthorised personnel. 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, some of these results indicate that the designed system blood pressure measurements slightly overestimate blood pressure and that the between-site difference may vary from subject to subject but this is quite minute.

4.2.1 ENERGY CONSUMPTION

There is a relation between energy consumption and lifetime of the network. A challenge of WBSN is patient quality of life during the monitoring. Sensing node has an important role in the network such as aggregation of sensory data, data packaging and transmitting them to the caregiver's PDA. Therefore, we have to prolong the lifetime of coordinator node. If the lifetime is short, the patient has to recharge the battery of coordinator node in short intervals, and if the patient forgets to recharge the battery, it may be dangerous for the patient.

Assuming that the sensing node's battery is 5000 mJ and the interval of data transmission is once every three hours. In normal case, the battery can continue to work for three days. But, in burst transmission, where the patient (subject or health personnel) has to trigger measurement at certain times of the day, the battery lifetime will be upgraded and prolonged about five times, hence reducing energy consumption.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSIONS

Wireless BSN technology is emerging as a significant element of next generation healthcare services. In this project, a remote mobile monitoring of admitted hypertensive patient was proposed, which is able to continuously monitor the patient's heart beat and blood pressure. The entire 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 is equipped with an emergency notification when the blood pressure or heart rate is becoming pernicious.

This was achieved through an appropriate real-time firmware programmed to sensing node composed of an Arduino Mega 2560 microcontroller, with CK-101 integrated to a Bluetooth module. The microcontroller makes the sensed data available to the Bluetooth connection which transmits to the caregiver's PDA. On receiving, the patient's data, an activity is created by an Android developed application to further process the data and convert the data into a graph plotted to signify the level of the peril and virulence.

Also, the system was evaluated with accuracy to a sphygmomanometer and have compared results on same subject and assess the differences (based on gender), energy consumption and other differences.

From the performance results obtained, the system achieved a percentage accuracy of 98.7% in blood pressure monitoring. It also recorded a 480% reduction in energy consumed if interval of measurement and data transmission is made 12 hours (twice a day) instead of 3 hours' interval of transmission.

5.2 LIMITATIONS AND CHALLENGES

While the project can benefit the health sector, it has a few limitation and challenges. The limitations of the project are as follows:

i. Unavailability of Project components and the need to ship components which takes a long time.
ii. Coverage of the project is not wide since it uses Bluetooth for communication.
iii. Slight difference in the reading compared to the traditional sphygmomanometer.

The project challenges are as follows:

i. Extra cost for shipping project components.
ii. When a component got destroyed, it warrants a need to ship another thereby causing a delay for another time usually running into a month or two for arrival of a replacement.
iii. Data integrity. When the data association mechanisms are not sufficient, or integrity is considered critically important, some functionalities of the system can be disabled. This preserves only the data which can claim a high degree of confidence. In an environment where false alarms cannot be tolerated, there is a trade-off between accuracy and availability.