MICROCONTROLLER BASED WEARABLE HEALTHCARE MONITORING SYSTEM

A Dissertation submitted in fulfillment of the requirements for the Degree
of

MASTER OF ENGINEERING
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Submitted by

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Under the Guidance of
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DECLARATION

I hereby certify that the work which is presented in dissertation entitled, **"MICROCONTROLLER BASED WEARABLE HEALTHCARE MONITORING SYSTEM"**, in partial fulfillment of the requirements for the award of the degree of **Master of Engineering in Electronics Instrumentation And Control**, submitted to Electrical & Instrumentation Engineering Department of Thapar University, Patiala is as authentic record of my own work carried under the supervision of **Dr. MD Singh**. It refers others researcher's work which are duly listed in the reference section. The matter contained in this dissertation has not been submitted, neither in part nor in full to any other degree to any other university or institute except as reported in text and references.

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It is certified that the above statement made by the student is correct to the best of my knowledge and belief.

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Deepak Jain
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LIST OF ABBREVIATIONS

ADC	Analog to Digital Converter
ECG	Electrocardiogram
EEG	Electroencephalogram
EMG	Electromyogram
FSR	Force sensitive resistor
GSR	Galvanic skin response
GUI	Graphical User Interface
I2C	Inter IC communication
LabVIEW	Laboratory Virtual Instrument Engineering Workbench
MEMS	Micro Electro Mechanical System
NI	National Instruments
PCB	Printed circuit board
PCG	Phonocardiography
PPG	Photoplethysmograph
PPT	Pulse transit time
RTWPMS	Real time wireless physiological monitoring system
SPO_2	Blood oxygen saturation
TI	Texas Instruments
UART	Universal Asynchronous Receiver/Transmitter
WHMS	Wearable remote healthcare monitoring systems

ABSTRACT

Wearable remote healthcare monitoring systems have started to become one of the main building blocks of modern healthcare. It offers innovative and better ways to monitor chronic diseases or detect early deterioration. It acquires physiological signals using sensors and wirelessly transmits them to a remote healthcare station where they are monitored and analyzed for further diagnosis. This study presents the design and development of a healthcare system that monitors vital parameters namely heart rate, respiration rate, body temperature and orientation. The sensors used for them are pulse sensor, temperature sensor LM 35, a force sensitive resistor and MPU-9150 motion sensor. The sensors have been tested at different locations and the best location for each sensor has been used. The data has been sent wirelessly to a nearby laptop using Bluetooth and subsequently it has been displayed on the laptop using a graphical user interface (GUI) made in NI LabVIEW software. The proposed system has been compared with calibrated instruments and results are encouraging.

Dedicated to

My Parents

CHAPTER- 1
INTRODUCTION

Affordability of healthcare has started to become a bigger issue. Generally automation is the key to reduce costs. This automation is provided by the wireless medical embedded systems through ubiquitous patient monitoring and automated data analysis [1]. Wearable remote healthcare monitoring system (WHMS) is one of the main building blocks of modern healthcare. It is a promising new technology which is here to stay for a long time. Using MEMS (Micro Electro Mechanical System) based sensors, which are quite small in size, consume very less power and can detect physiological signals from the body. These sensor devices have the capability to sense the vital signal, process it and transmit them using wireless technology [2]. Most of the present WHMS are divided into three main parts: wireless sensor network, data acquisition network and remote monitoring station [3].

The main motivation behind this study is the millions of elderly people living alone in our country with no one to take care of them and the defense army personnel. The cost of commercially available systems is quite high and hence there is a need to make a system affordable to the common man. Not much work has been done in this field in our country.

The main challenges that have been faced are

- The selection of the parameters that need to be monitored.
- The location of the sensors to measure the parameters so that they don’t provide any discomfort to the user.
- The cost of the system has to be as low as possible.

So the main objective of the study is to design and implement a wearable system which monitors four parameters like heart rate, respiration rate, body temperature and orientation. It should be low in cost and aimed at the elderly people and the army personnel in our country. The system consists of four sensors measuring the four parameters, a microcontroller to perform acquisition and signal conditioning, a Bluetooth device to transfer the data wirelessly and finally a GUI on a laptop where the parameters are monitored.

Many conventional systems that have been developed are

- ‘Smart Vest’ or ‘Smart Shirt’ has been developed which uses conventional electrodes to acquire the physiological signals [4].
- A wrist worn wearable medical monitoring and alert system (AMON) has been developed to monitor physiological parameters such as ECG, heart rate, blood pressure, skin temperature [5].
- A system used to monitor the health status of astronauts called the ‘Life Guard’ has been developed by Stanford and NASA [6].

Many problems encountered with systems used in hospital are [7-14].

- There are number of hampering wires from the sensors to the data acquisition system.
- The signals acquired are affected with motion artifact and baseline wander as the electrodes float on the layer of gel.
- The sensors used in conventional monitoring systems are bulky and are not comfortable to wear for longer durations.
- Lack of system integration of individual sensors.
- Interference on a wireless communication channel shared by multiple devices.
- Nonexistent support for massive data collection and knowledge discovery.
- It is difficult to upgrade them or add components to existing system.
- The sensors locations cannot be changed once fixed.
- The power supply required is large because all the sensors and the processing unit draw the power from a single source of power supply.
- The conventional physiological monitoring systems are bulky to be used for wearable monitoring.
- The gels used in the electrodes dry out when used over a period of time.
- The gels used in the electrodes cause irritations and rashes when used for longer durations.

Nowadays there are a number of sensors that acquire different vital physiological signals and send them to a central processing unit. After processing the signals according to different requirements it then transmits the signal wirelessly to a remote healthcare monitoring station which keeps in check all the signals. If any anomaly is found in the signals then the close family members are informed and adequate health measures are taken to stop the condition from deteriorating any more.

1.1 GENERAL ARCHITECTURE OF WHMS

Fig. 1.1 illustrates a general block diagram of such system. The general architecture of wearable remote healthcare monitoring systems is a three tier system, the first tier consists of the sensors which are responsible for acquiring the physiological signals; the second tier consists of signal conditioning circuit and a microcontroller and the third tier consists of wireless communication from the person to a remote healthcare monitoring station.

1.1.1 Sensors

Wearable sensors have a monitoring capability. Their current potential includes physiological, biochemical and motion sensing [15-16]. They are used to acquire the physiological signals and transmit them to the signal conditioning circuit. Sensors are placed on the body of the patient according to their clinical use.

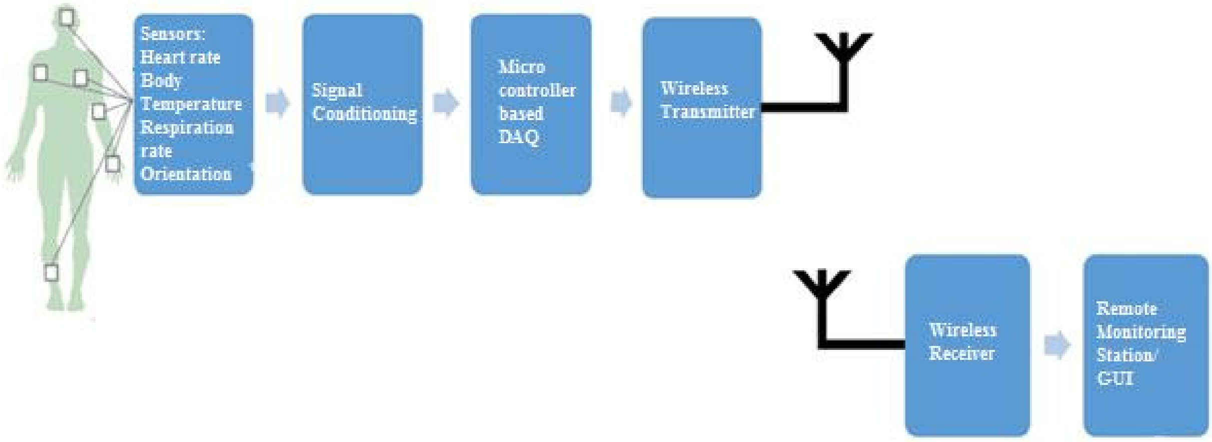


Figure 1.1 General Block Diagram of WHMS

For example if a person is suffering with congestive heart failure or chronic pulmonary obstructive disease, sensors to monitor heart rate and respiratory rate would be deployed at different locations on the body [17]. Sensors are small in size, are inexpensive and may or may not have a miniature battery along them. The biosensors are capable of measuring significant physiological parameters like heart rate, blood pressure, body and skin temperature, oxygen saturation, respiration rate etc. The specifications of some of the physiological signals that can be monitored are given in the Table 1.1.

Table 1.1 Physiological signals and their normal range

Physiological Parameter	**Range**
Heart rate	40-220 beats per minute
Body Temperature	32-40 degree Celsius
Respiratory Rate	2-50 breaths/minute Frequency: 0.1-10Hz
Orientation	Standing, Lying down

1.1.2 Signal Conditioning and Microcontrollers

The received physiological signal is conditioned and further processed to remove noises and make the signal voltage compatible with the Microcontroller. The circuit basically consists of a filter to remove out the noise signal and a circuit to amplify the physiological signal. Op-amp circuits are often used as they can act as a filter as well as an amplifier.

Microcontrollers are one of the main components of such systems. They play a key role in enabling portable and wearable medical equipments. They help in transmitting data wirelessly. They can perform analog to digital signal conversion. They are cheap and are easy to program. A microcontroller should accomplish all these goals and should meet some basic requirements. These are

- ADC’s (Analog to Digital Converter):- The AD-converter should have very fast conversion time and should be able to handle all the measurements, from the electrochemical or optical sensor to the temperature and power monitoring.
- Processor Speed: - The processor should be high enough as the system has to perform real time monitoring.

- Memory: - The microcontroller should have sufficient memory for the operations and it should be non volatile i.e. it should not be erased once the power is switched off.
- Connectivity: - The microcontroller under consideration should have wired and wireless connectivity. It should be compatible with USB, Bluetooth, radio frequency etc. modules. Power consumption, data rate and range are the three key considerations when selecting a wireless interface
- Power consumption: - Low power microcontroller applications are usually characterized by a continuous alternation of idle mode with minimal power consumption and very low power continuous functions (e.g. time keeping, low power LCD display) and run mode where microcontroller is active, executes application tasks.
- Peripherals: - The microcontroller should be ready to interface with LCD, speakers, capacitive touch display, USB controllers.

1.1.3 Wireless Communication & Remote Monitoring Station

Wireless communication is needed to transmit the signal from the micro controller to a central node which can be a mobile phone, a PDA, a laptop etc. and also from the central node to the remote monitoring station. A number of wireless communication standards that can be used for this purpose are discussed in Table 1.2.

Table 1.2 Wireless Communication Standards

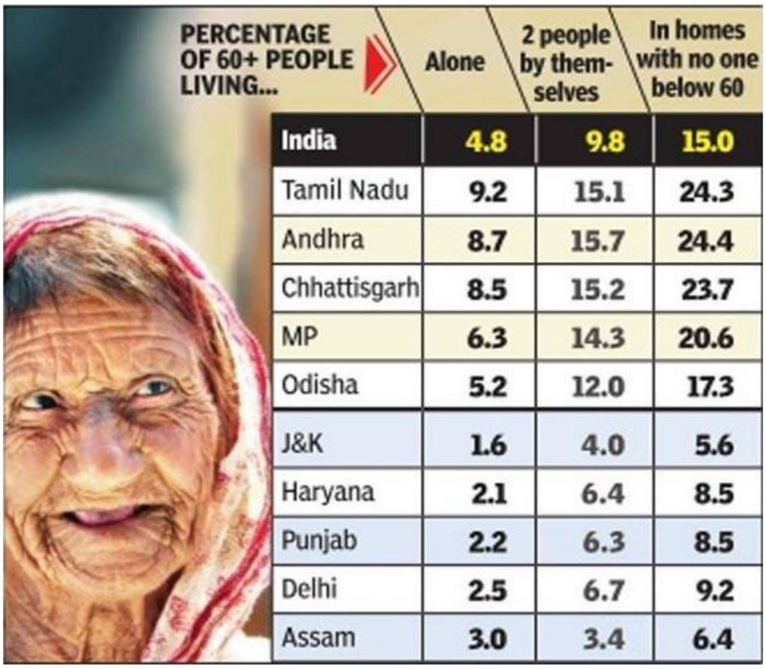
	Range	**Data Rate (max)**	**Power Consumption**	**Cost per Chip**	**Frequency**
Zigbee	10-75m	20kbps/ 40kbps/ 250kbps	30mW	$2	868MHz/ 915MHz/ 2.4GHz
Bluetooth	1-100m	1-3Mbps	2.5-100mW	$3	2.4GHz
IrDA	1m	16Mbps	-	$2	Infrared
MICS	2m	500kbps	25uW	-	402-405 MHz
802.11g	200m	54Mbps	1W	$9	2.4GHz

The signal is transmitted from the central node to a remote monitoring station where the vital signals are monitored continuously like a hospital. The physiological parameters are analyzed and alarms are generated accordingly. In case of emergencies an ambulance can be sent to the patient and close family members can be informed. Another use of this could be in case of soldiers. Their vital signs can be monitored in wartime without actually being at the war site.

1.2 NEED OF WHMS

Wearable health-monitoring systems (WHMS) have drawn a lot of attention from the research community and the industry during the last decade as it is pointed out by the numerous and yearly increasing corresponding research and development efforts [18-20]. As healthcare costs are increasing and the world population is ageing [21], there has been a need to monitor a patient's health status while he is out of the hospital in his personal environment.

All most 15 million elderly Indians live all alone. Figure 1.2 shows the percentage of elderly living alone in different states in India.



PERCENTAGE OF 60+ PEOPLE LIVING...	Alone	2 people by them-selves	In homes with no one below 60
India	4.8	9.8	15.0
Tamil Nadu	9.2	15.1	24.3
Andhra	8.7	15.7	24.4
Chhattisgarh	8.5	15.2	23.7
MP	6.3	14.3	20.6
Odisha	5.2	12.0	17.3
J&K	1.6	4.0	5.6
Haryana	2.1	6.4	8.5
Punjab	2.2	6.3	8.5
Delhi	2.5	6.7	9.2
Assam	3.0	3.4	6.4

Figure 1.2 People above age 60 living alone in India [22]

WHMS aims at providing real-time feedback information about one's health condition, either to the user or to a medical centre or straight to a supervising professional physician, while being able to alert the individual in case of possible imminent health threatening conditions. They enable early detection of deterioration reducing number of emergency department visits.

Keeping all the above things in mind, there is a need to make a wearable healthcare monitoring system which should be able to measure some vital parameters should be comfortable enough without irritating the person and should have wireless connectivity with a laptop/mobile which can be connected to the main server.

1.3 METHODOLOGY

The main aim of the present study is to design a wearable healthcare monitoring system which shall monitor 4 parameters like heart rate, body temperature, respiration rate and body orientation to send the data to a laptop wirelessly.

Continuous monitoring of vital signs can help identify a patient's risk for stroke, heart attack, heart failure etc. In this system heart rate has been measured using photoplethysmograph (PPG) technique which is a non-invasive and low cost method. Different locations have been studied for the PPG and the best location for optimal output shall be used to calculate the heart rate.

The monitoring of the respiration rate is one of the key aspects to detect early changes in the health status of critically ill patients. It has been done by using a force sensitive resistor whose value changes when force/pressure is applied on it. It has been pasted on a chest belt so that when a person inhales/exhales the force on the resistor changes and consequently the resistor value also changes. It is measured and calibrated to find the respiration rate.

Body Temperature is a vital sign as it can be used to detect infection, viral or an inflammation etc. So it is very important to monitor it. It has been monitored using the LM35 sensor which is quite accurate and pre calibrated. The sensor has been used to find temperature at different body locations and the optimal location in terms of comfort, sensitivity and least deviation has been chosen.

Body orientation in this system tells whether the person is lying down or standing/sitting. Orientation has been monitored using MPU9150 sensor. It has a very good application when used for army personnel and for the elderly which is explained subsequently.

The microcontroller that has been used is MSP430G2553.

Bluetooth communication has been used for transferring the data from the microcontroller to the laptop where a graphical user interface (GUI) helps the user to evaluate/ monitor the patient.

1.4 ORGANISATION OF THESIS

This thesis is divided into four chapters. Chapter 1 is introduction to the thesis and also gives a general idea about what WHMS are and its need in the modern world.

Chapter 2 is regarding the literature review about the chosen topic. It is further divided into 3 sections. First section is related to wearable sensors, section 2 is about microcontrollers used for WHMS, section 3 is regarding the concepts and technique used for measurement of vital signs.

Chapter 3 is about the materials used and the methodology regarding it. It describes in detail the sensors used and the techniques used for monitoring the vital parameters. It includes the concept and calibration of various sensors.

Chapter 4 is all about the observation tables of various vital signs monitored for different subjects and the results and conclusion inferred from them.

After that conclusion and future scope are discussed and in the end references have been mentioned.

CHAPTER 2
LITERATURE REVIEW

WHMS has been prepared first time in 1976 and since then a lot of work has been done in this area. This chapter presents a detailed review of the related work in chronological order. First section describes the literature survey on wearable sensors that have been made till now. Section 2 relates to the microcontrollers. Section 3 describes the literature on the techniques used for the measurement of physiological signals.

2.1 WEARABLE SENSORS

A medical wearable device which measured heart rate and SpO_2 (blood oxygen saturation) using pulse oximeter, breathing rate using a piezoelectric based sensor which was located on the chest belt and detected movement using 2-axis thermal accelerometer, was developed in 2003 and was targeted at brain-injured children's [23]. The data was sent to a PC using Bluetooth at defined regular intervals and was saved into a multimedia card before transmitting and finally data was transmitted to the medical service centre. It had many wired connections from the Bluetooth module to the sensors and hence had low wearability.

A wrist worn device, AMON (in 2004), was financed by the EUFP5 IST and was capable of measuring blood pressure, skin temperature, a one lead ECG and blood oxygen saturation [5]. It incorporated a two-axis accelerometer for correlating user activity with the measured vital signs. The main aim of AMON was to monitor patients with high risk cardiac/respiratory problems

LiveNet was developed in 2005 by Media Laboratory in Cambridge and was aimed to monitor health for a long term with real-time data processing [24]. It used a Linux-based PDA mobile device and an integrated physiological board (BioSense), which constituted of ECG, EMG, a 3-D accelerometer and galvanic skin conductance sensors which could interface with lots of commercially available sensors. It was aimed to extract features in realtime and classify medical conditions and closed-loop medical feedback systems also. It was used for monitoring the health of soldiers, automated detection of Parkinson's disease, epilepsy seizure detection etc.

LifeGuard was a multi parameter wearable physiological monitoring system for space and terrestrial applications developed in 2005. It was capable of measuring SPO_2, two ECG leads, breathing rate using impedance plethysmography, body temperature and movement, blood pressure and heart rate [6]. Sensors were connecting using wires to the data logger which sent the data to a base station using Bluetooth or recorded them continuously for 9 hours and saved it on a memory card. Collected data had acceptable accuracy and real time transmission was possible through satellites.

The Wearable Health Care System (WEALTHY) project was a part of the European Commission and had been developed in 2005 to target clinical patients during rehabilitation and other high-risk patients [25]. The sensing elements were integrated in fabric form (conducting and piezoelectric material). It was able to monitor a three-lead ECG, EMG, thoracic and abdominal breathing rate, body position and movement, skin and core temperature. The wearable garment also constituted of module capable of processing both analog and digital signals with Bluetooth wireless transmission capabilities.

A washable vest with embedded sensors was developed in 2005 in Milan known as MagIC. It had sensors for ECG and to monitor respiration rate weaved in the vest itself. An electronic board responsible for signal conditioning and data transmission using Bluetooth was also woven in the vest [8]. It was aimed at heart patients for in house monitoring. It accurately identified atrial fibrillation episodes.

Code blue was developed by researchers in Harvard University [26]. It was used for multi patient monitoring environments and was based on ZigBee. It had biosensor boards to monitor SpO_2, 3 lead ECG, motion activity and EMG. It used an RF-based system, to track the location of patients.

Another wearable device which was created was used for continuous monitoring of ECG, where the sensor continuously transmitted the signal to the hand held device (HHD) [27]. The HHD contained an algorithm which could detect arrhythmia events with a high accuracy. When an irregular signal was detected, the device recorded one min of the signal and sent the signal to the base station.

A wearable system for measuring emotion-related physiological parameters was developed at Fraunhofer IGD Rostock which used a glove as garment hosting a sensor unit that collected data from skin conductivity and skin temperature sensors and a conventional chest belt from Polar as a heart rate sensor [28].

A RTWPMS was described by Lin et al. [29] which measured heart rate, BP and temperature. It was too huge to be used for monitoring continuously.

A portable system with the ability of measuring ECG, phonocardiography (PCG) and body temperature was developed. It used a stethoscope consisting of a microphone for PCG detection, a three-lead ECG, a temperature sensor, a measuring board including a CPU and a Bluetooth device [30]. The system was impractical and not comfortable for long-term monitoring of a patient due to numerous large components.

My Heart project was supported by the European Commission and involved 33 partners from 10 different countries, including industrial partners such as Philips, Nokia, Vodafone, and Medtronic, aimed at fighting cardiovascular diseases (CVD) by prevention and early diagnosis [31] and adopted the use of smart clothes, where the sensing modules were either garment integrated or simply embedded on the piece of clothing. It relied on the use of tiny conductive wires knitted like normal textile yarns, hence it was comfortable for the user, and no wireless modules were needed and whole system needed centralized on-body power supply. The textile-sensors included an ECG and an activity sensor. An algorithm capable of classifying the activity into resting, lying, walking, running, and going up/downstairs had also been implemented.

The Medical Remote Monitoring of clothes (MERMOTH) was a European IST FP6 program [32] and was produced at low cost, knitted, was comfortable and was a stretchable garment. It enabled the measurement of ECG, body temperature, respiratory inductance plethysmography, and posture.

Microsoft had developed a Healthgear which included a noninvasive blood oximeter, a sensing board that provided the sampled oxygen saturation and heart rate signals, a Bluetooth module for wireless transmission of the measured signals, AAA battery power supply and a cell phone to provide the user interface [33]. It was used to detect sleep apnea. The system had been completely successful in detecting mild and severe obstructive sleep apnea (OSA).

AUBADE was a wearable system developed from the University of Ioannina in Greece that performed evaluation of the emotional state of individual targeting environments where human subjects operate at extreme stress conditions [34]. It consisted of a mask containing sixteen EMG textile fireproof sensors, a three-lead ECG and respiration rate sensors located on the chest of the subject and a textile sensor measuring electrodermal activity placed inside a glove.

Yuce et al. presented a wireless body sensor network hardware which used MICS band and consisted of a pulse rate and a temperature sensor, a central control unit (CCU), and a receiver station at a medical center [35]. Low power consumption was accomplished by keeping the sensor nodes in sleep mode most of the time i.e. one measurement every 5 or 10 min.

Another wearable ECG device was developed in 2007 to detect the motion artifacts (distortions) and classify the type of body movement activity (BMA) from the ECG signal itself [36]. It was used in situations where dynamic heart monitoring was required. The preprocessed ECG beat observations were used to train the BMA classifiers for sitting still, up and down, movement of left, right or both arms, walking on a level floor etc.

Pandian et al. [4] described a Smart Vest in 2009 which integrated sensors on the garment's fabric to simultaneously collect several biosignals in a noninvasive and unobtrusive manner and measures ECG, PPG, heart rate, blood pressure, body temperature, and galvanic skin response (GSR). It stated that the ECG can be recorded without the use of gel and blood pressure was calculated noninvasively via pulse transit time (PPT).

Leijdekkers and Gay [37] developed a heart attack self test application in 2008 implemented on a personal health monitor system that included a conventional mobile phone and a Bluetooth enabled ECG sensor. User interface on the phone was used to acquire feedback from the user about his symptoms and based on his answers; the emergency services were contacted.

HeartToGo was a cell phone-based wearable platform developed in 2009, capable of continuously monitoring the user's ECG signal via a wireless ECG sensor and possibly detecting any abnormal patterns pertaining to cardiovascular disease [38].

2.2 MICROCONTROLLERS USED FOR WHMS

Xu et al [39] used MSP430F1611 microcontroller to make a wearable vital signs monitoring system for pervasive healthcare which monitored the electrocardiogram (ECG) and photoplethysmogram (PPG) and calculated the heart rate oxygen saturation (SpO_2) and systolic blood pressure. This microcontroller had a fast 12 bit ADC, a wake up time of 6µsec and 48 I/O pins.

Chung et al [40] developed a wearable ubiquitous healthcare monitoring system using integrated electrocardiogram (ECG), accelerometer and oxygen saturation (SpO2). They used a micro controller of TI's MSP430 family as it had 10KB RAM, 48KB flash memory and 12-bit A/D converter with ultra low power consumption.

Li et al [41] designed a wireless health monitoring prototype which monitored the ECG in sleep apnea patients. They used a MSP430 based microcontroller as it is designed for low cost and low power embedded applications.

Yang et al [42] developed a wrist worn healthcare monitoring system which monitored body temperature, pulse rate, breath rate and waveform, blood pressure, electrocardiograph (ECG), electroencephalogram(EEG) and the level of blood glucose real-timely. They used two MSP430 based microcontrollers, one for storing monitored data, analyze physiological parameters and for transmissions while the second one were used for sampling the physiological signals.

Wang et al [43] presented a personal health monitoring system which monitored the ECG and the signal was sampled and transmitted using MSP430 based microcontroller.

Gnecchi et al [44] presented an ECG wearable sensor eHealth data acquisition system and used MSP430F2618 ultra-low power microcontroller which controlled the analog front end.

Rathore et al [45] presented a wireless system which enabled real time monitoring and monitored the heart rate and other such data of patient's body. They used an Atmel ATmega8 as it is a low power CMOS 8-bit microcontroller based on AVR RISC architecture. The AVR was one of the first microcontroller families to use on-chip flash memory for program storage

Smalls et al [46] created a health monitoring system that transmitted the vital signs of a patient through an ad-hoc wireless sensor network for a mass causality emergency application. They used MPR2400 which was based on the Atmel ATmega128L which was a microcontroller that runs Mote Works (free, open sourced, component operating system operates primarily with in the wireless sensor network motes) in its internal flash memory.

Isais et al [47] developed the ECGblood pressure homecare telemonitoring system which monitored the ECG and blood pressure. A PIC 16C774A microcontroller was then interfaced to the wearable blood pressure monitor and the ECG amplifier to collect the data from these devices, process them, store them and feed them to a transmitter.

Jubadi et al [48] proposed an alert system which monitors the heart beat using PPG. This signal is processed using PIC16F87 microcontroller to determine the heart beat rate per minute. Then, it sends sms alert to the mobile phone of medical experts or patient's family members, or their relatives via SMS.

Many microcontrollers have been used for making a health monitoring system. MSP430 based microcontroller family has been one of the best controllers used in such system due to its low cost, ultra low power consumption, inbuilt ADC's , a low operating voltage (ranging 1.8V to 3.6V) and a fast wakeup time (as low as 1 µsec).

2.3 TECHNIQUES USED FOR MONITORING PARAMETERS

The most popular technique used to monitor and calculate heart rate is the photoplethysmogram (PPG) as it is a low cost, easy to use and quite accurate [45,48-52].

LM35 is the mostly used sensor to measure the body temperature as it is quite accurate, is directly calibrated in centigrade and is a linear sensor [53-55].

2.4 SUMMARY AND GAP FINDINGS

A lot of work of work has been done in the field of wearable sensors. Many health monitoring systems have been made but only quite a few have made it to the commercial markets due to their complexity and cost. Some of the wearable sensors that have been developed can be seen in table 2.1.

Table 2.1 Summary of Wearable sensors

S. No.	Project Title/Institution	Communication Modules	Measured Signals	Medical Applications
1	LiveNet (MIT)	Wires, 2.4 GHz Radio, GPRS	ECG, BP, R, T, Sa02, EMG, GSR	Parkinson symptom & epilepsy seizures Detection, behave. modeling
2	AMON (EU IST FP5 program)	GSM link	ECG, BP, T Sa02,A	High-risk cardiac-respiratory patients
3	LifeGuard (Stanford Univ. & NASA)	Serial cables, Bluetooth	ECG, BP, R, T, Sp02, A	Medical monitoring in extreme Environments (space & terrestrial)
4	MyHeart (EU IST FP6 program)	Conductive yarns, Bluetooth, GSM	ECG, R, other vital Signs, A	Prevention and early diagnosis of CVD
5	WEALTHY (EU IST FP5 program)	Conductive yarns, Bluetooth, GPRS	ECG, R, T, EMG, A	Monitoring of rehabilitation & elderly Patients, chronic disease
6	MagIC (Un. Of Milan, Italy, Bioeng. Centre & Cardiac Rehab. Unit)	Bluetooth	ECG, R, T	Recording of cardio respiratory and motion Signals during spontaneous behavior in Daily life and in a clinical environment
7	MERMOTH (EU IST FP6 program)	Conductive yarns, RF link	ECG, R, T, A	General health monitoring
8	Smart Vest (National Pr. On Smart Materials, India)	Woven wires, 2.4 GHz ISM RF	ECG, BP, T, PPG, GSR	General remote health monitoring
9	CodeBlue (Harvard Univ.)	Zigbee	ECG, Sp02,A	Real- time physiological status monitoring With wearable sensors
10	Human++ (IMEC)	Zigbee	ECG, EEG, EMG	Enable autonomous wearable sensor Networks for general health monitoring
11	HealthGear(Microsoft)	Bluetooth	HR, Sp02	Monitoring users during their sleep to Detect sleep apnea events
12	HeartToGo (Un. Of Pittsburgh)	Bluetooth, GPRS	ECG, A	Individualized remote CVD detection
13	Personal Health Monitor (Un. Of Tech. Sydney)	Bluetooth, GPRS	ECG, BP, A	Heart-attack self-test for CVD patients
14	Wearable ECG, Arrhythmia detection (Eng. + Med. Dpts, Norway)	Wires, Bluetooth, Wi-Fi	ECG	Remote detection of cardiac arrhythmias

15	AUDABE (Dept. of Medical Physics, Ioannina, Greece)	Wires, Bluetooth, Wi-Fi	ECG, R, GSM, EMG	Evaluation of the emotional state of an Individual at environments where subjects Operate at extreme stress conditions

ECG: electrocardiogram (also implies the measurement of heart rate), HR: heart rate, EMG: electromyogram, BP: blood pressure, R: Respiration, T: temperature, P: posture, GSR: galvanic skin response, A: activity, PPG: photoplethysmography

WHMS will be one of the main building blocks of the modern healthcare systems. Many wearable systems have been developed but only quite a few systems have been aimed specifically at the elderly people or the army personnel. Only some of them have made it to the commercial markets but are quite expensive in the range of 400$. Most of the systems use complex methods to measure the respiration rate like measuring the amount of moisture when exhaled or finding it from galvanic skin resistance.

Almost 15 million elderly people live alone in our country. In this study a system is proposed aimed specifically for the elderly people and the army also. It's quite low in cost and utilizes the features of MSP430 based microcontroller and use Bluetooth communication for data transfer. A simple force sensitive resistor has been used to monitor the respiration rate. All the parameters have been displayed on a GUI made in LabVIEW, with an alarm system which goes high if a parameter is out of range.

CHAPTER 3
MATERIALS & METHODOLOGY

A wearable healthcare monitoring system is made which monitors 4 vital parameters which are heart rate, respiration rate, body temperature and orientation. Monitoring of each of the parameter would require individual sensors. One microcontroller would be needed to convert these analog signals into digital form one by one using an analog to digital converter (ADC), perform some signal processing on them to calculate the value of the given parameters and finally be able to communicate with the sensors using Inter IC communication (I2C) and compatible with Bluetooth to send the data to a laptop.

Once the data reaches the laptop it would be required to create a graphical user interface (GUI) so that the data can be interpreted easily.

3.1 CONCEPT

A basic block diagram of the wearable vital signs monitoring system is depicted in figure 3.1. It shows the location of pulse sensor on the index finger which is used to monitor heart rate, a force sensitive resistor on the chest belt for calculating the respiration rate, a LM35 sensor to measure the body temperature and the MPU9150 sensor, Bluetooth and the microcontroller on the upper arm. The signals are sent wirelessly to a laptop from where the data can be sent to the main server.

3.2 HARDWARE

Initially after all the sensors have been obtained they need to be individually checked, tested and calibrated first and then they are integrated together with the microcontroller and the circuit board.

3.2.1. Heart Rate

Continuous monitoring of vital signs can help identify a patient’s risk for stroke, heart attack, heart failure etc [56]. In this system heart rate was measured using photoplethysmograph (PPG) technique. It’s a low cost, non invasive technique to measure heart rate at skin surface [57].

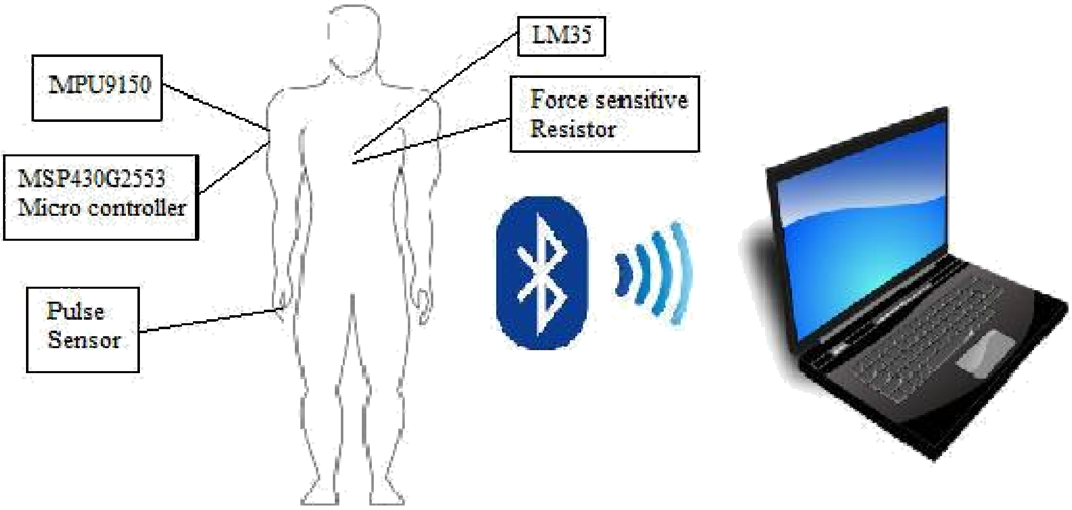


Figure 3.1 Basic Block Diagram of the wearable vital signs monitoring system

It uses a LED which illuminates the skin surface and a photo detector which detects the intensity of light reflected back which changes periodically with the heart rate. With each heart beat, a surge of blood is forced through the vascular system, expanding the capillaries in the finger, and changing the amount of light returning to the photo detector [58]. PPG was used to detect heart rate at different positions of the human body. Three different locations were chosen which were the ear, index finger and the palm. Figure 3.2 shows the PPG pulse sensor used at different locations. It operates on an input voltage of 3.3V.

Figure 3.2 Pulse Sensor

The wave that was obtained from the sensor was like a sinusoidal wave. The rate at which the peaks came was directly proportional to the number of times the heart was beating.

First of all a baseline was established by finding the least value of the sinusoidal waveform. The first 20 seconds were used the microcontroller to find the minimum value of the wave. Then an offset was added to find the approximate mid-value of the wave. After this the timer was turned on by the micro controller and whenever the waveform crossed that mid-value a heart beat was considered. The waveform can be seen in figure 3.3.

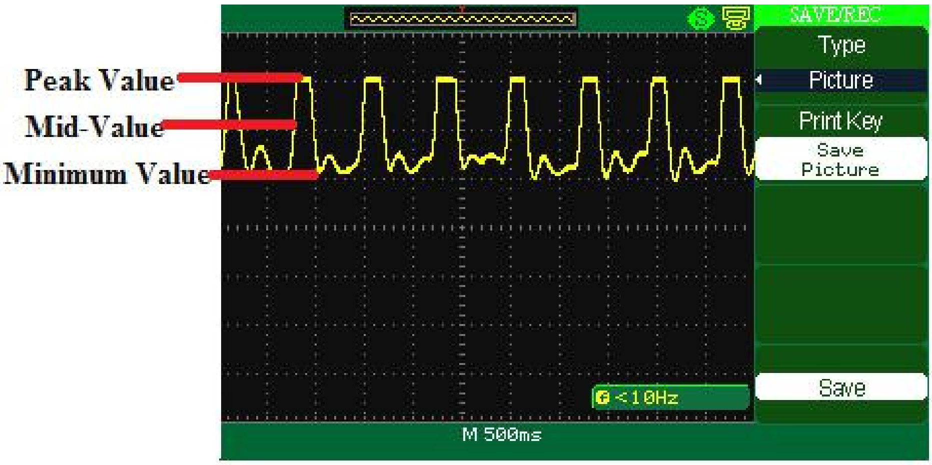


Figure 3.3 Waveform depicting different values

The algorithm used was that 5 heart beats were taken and averaged out to find the time taken for a single heart beat. This calculation was done 5 times and then the final result was obtained. A part of code used for this can be seen as follows:

```
if(LAST<MED && NEW>MED)
{
      J++;
      if(J==5)
      {
        HR=(int)((5*60)/(K*.05));
         J=0;
         K=0;
          if(HR<=120 && HR>=50)
         {
             M++;
             HRSUM+=HR;
             if(M==5)
```

```
            {
              TACTL |= MC_0;
             __disable_interrupt();
             HRAVG=(int)HRSUM/5;
             M=0;
             HRSUM=0;
             F=0;
            }
      }
  }
}
```

The output from this was the checked with the output of a pulse oximeter. Figure 3.5 shows the subject being tested with both the sensors simultaneously. Figure 3.6 depicts the output of both of them.

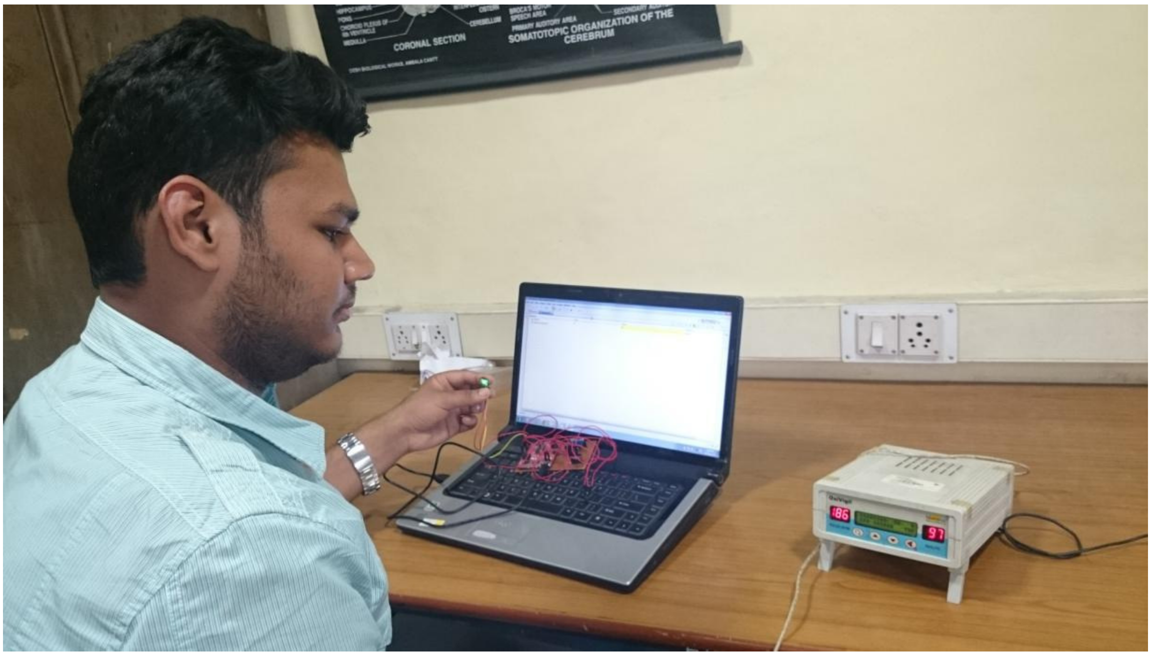


Figure 3.4 Subject being tested on both sensors simultaneously

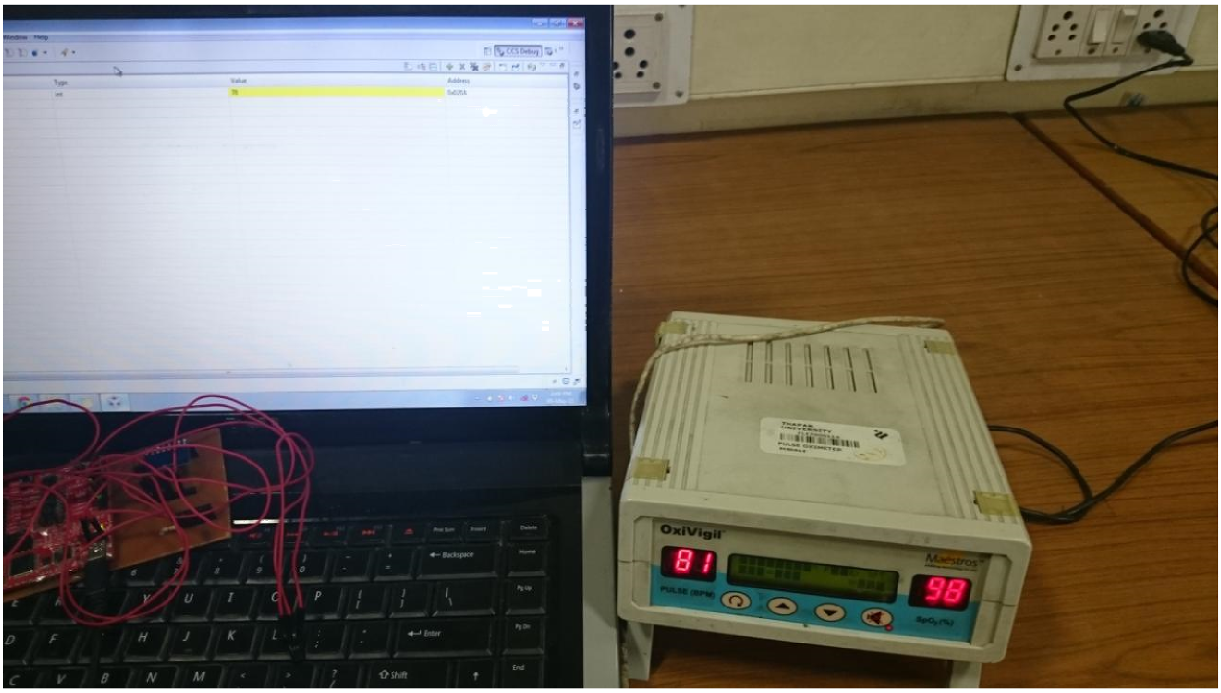


Figure 3.5 Output of pulse sensor=78, pulse oximeter=81

Figure 3.6 depicts the sensor being tested on the ear.

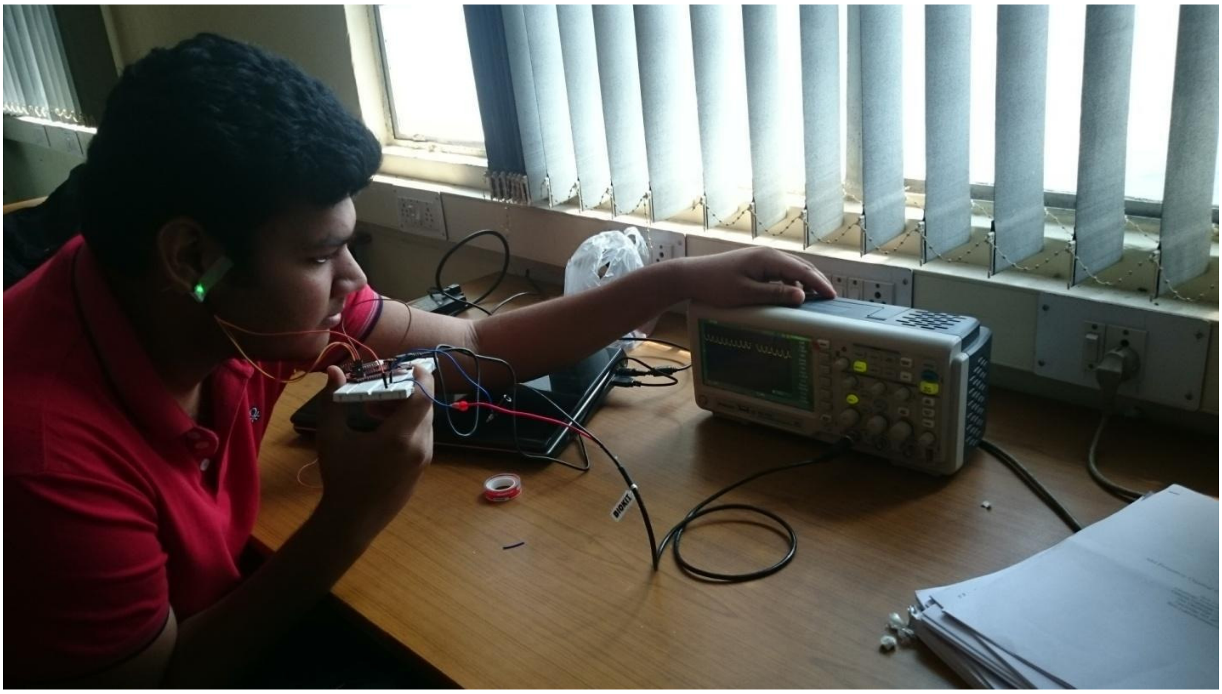


Figure 3.6 Pulse Sensor being tested on ear

3.2.2 Respiration Rate

The monitoring of the respiration rate is one of the key aspects to detect early changes in the health status of critically ill patients [59]. In this design it was monitored using a force sensitive resistor (FSR). It's a square resistor with sensing area of 1.75"x1.5". It was placed on the chest belt. It's one of the cheapest methods to monitor respiration rate. When a person inhales the chest expands and the resistor experiences force and consequently its resistance increases. When the person exhales the chest contracts and the pressure/force on the resistor reduces and the resistance decreases. A voltage divider was made with this resistor and a 22kΩ resistor with a voltage supply of 3.3V. The output voltage across the resistor changes periodically with the respiration rate. The peak voltage was about 1.7V. Figure 3.7 illustrates the FSR used in this system. Figure 3.8 depicts the waveform corresponding to the output voltage of the FSR. It is very easy to calculate the respiration rate from this waveform.

The algorithm used for respiration rate was quite similar to the heart rate algorithm. The only change in this was that instead of taking 25 (5x5) samples, a moving average filter was made using 9 samples (3x3).

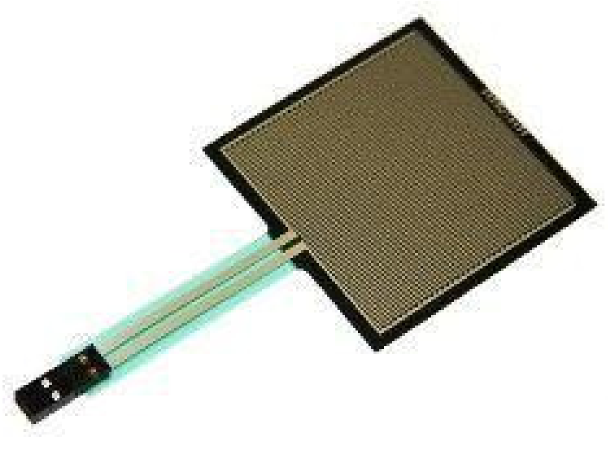


Figure 3.7 Force Sensitive Resistor

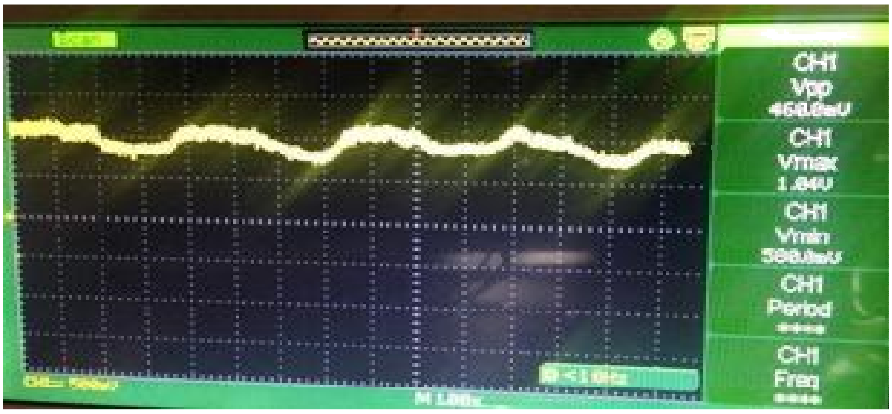


Figure 3.8 Output waveform of voltage across resistor connected in a voltage divider circuit

The sensor was calibrated with the help of a spirometer which also helps in finding the respiration rate. In spirometer with one hand you have to hold the sensor close towards a nostril and with the other hand you have to close the other nostril and breathe into the sensor. The output comes in the form of a graph.

Figure 3.9 depicts the subject being tested with both the FSR sensor and the spirometer.

Figure 3.9 Subject being tested to both the sensors

3.2.3 Body Temperature

Body Temperature is a vital sign as it can be used to detect infection, viral or an inflammation etc. So it is very important to monitor it. As the system has to made wearable, temperature was monitored at 4 different locations namely wrist, chest, anterior calf and axillary. The normal temperature is approximately within the range of 95.9-98.6° F /35.5-37.0° C [60].

The sensor used for these locations was LM35 by Texas Instruments. It is highly accurate at room temperature with an accuracy of ±1/4°C. It has a wide range from -55° C to 150 ° C. The operating input voltage can be anywhere between 4-20V. The output voltage is directly proportional to temperature in ° C with a scale factor of 10mV/° C. For example if the output voltage is 320mV then the temperature is 32° C.

Figure 3.10 depicts the different locations where temperature was monitored and Figure 3.11 shows LM35 sensor with its connections.

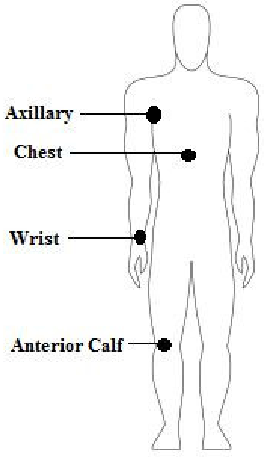


Figure 3.10 Different locations where temperature was monitored

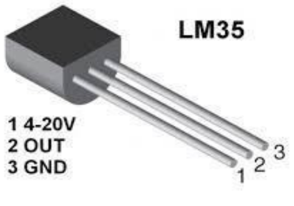


Figure 3.11 LM35 sensor with its connections

The temperature was taken at different body locations and simultaneously a digital thermometer was also used to simultaneously measure the temperature. The observation table can be found in the next section.

3.2.4 Body Orientation

Body orientation in this system tells whether the person is lying down or standing/sitting. Orientation is monitored using MPU9150 sensor. Its location was on the upper arm with the microcontroller. It is one of the finest 9-axis motion tracking device which has an inbuilt 3-axis accelerometer, 3-axis gyroscope and a 3-axis magnetometer. It has an inbuilt digital motion processor; 16-bit ADC's (Analog to Digital Converter) and can measure up to ±16g of force, ±2000°/sec rotation and ±1200μT magnetic field. Figure 3.12 shows the MPU9150 sensor which uses I2C (inter-IC communication) communication with the microcontroller.

Figure 3.12 MPU9150 sensor

It worked on an input voltage of 3.3V which could be given from the microcontroller itself. I2C communication is basically a two wire connection. SDA and SCL pins denote the data and clock pins respectively. Two pull up resistors are required to be put on both these lines. EDA and ECL are for auxillary I2C communication i.e. another sensor can be connected to MPU9150 where the MPU9150 acts as a master. When it is connected to a microcontroller MPU9150 acts as a slave. Initially the device is in power down mode and data has to be written in its register to make it come out of power down mode. First the address is sent to the slave and then any read/write operation can take place.

A sample code of write can be seen as follows:

```
void i2cread(char read)
{
                UCB0CTL1 |=UCTR+ UCTXSTT;
                 while(!(IFG2&UCB0TXIFG));
                 UCB0TXBUF=read;
                 while(!(IFG2 & UCB0TXIFG));
                 IFG2 &= ~UCB0TXIFG;
                 UCB0CTL1 &= ~UCTR;              // I2C RX
                 UCB0CTL1 |= UCTXSTT;
                 while(UCB0CTL1 & UCTXSTT); // Wait for start to
                 complete UCB0CTL1 |= UCTXSTP;
                 while(!(IFG2 & UCB0RXIFG));
                 Rx=UCB0RXBUF;
                 while (UCB0CTL1 & UCTXSTP);
                 IFG2 &= ~UCB0RXIFG;
}
```

Out of the 3 inbuilt sensors, accelerometer was used to deduce the orientation of the person i.e. whether the person is lying or standing/sitting. All the 3 axes were monitored simultaneously to detect the orientation.

Its location was on the upper arm near the shoulder with the circuit board and the micro controller.

3.2.5 Microcontroller

The microcontroller used was Texas Instruments MSP430G2553. Its launch pad kit was used which can be seen in Figure 3.13. It was chosen because of its low cost, it’s inbuilt 10 bit ADC, ability to handle 8 analog channels and having the ability to communicate through Universal Asynchronous Receiver/ Transmitter (UART) and Inter IC communication (I2C).It also acts as the data acquisition unit of the system.

Pulse sensor was connected on pin 1.0, FSR on pin 1.4, LM35 sensor on pin 1.5 and the MPU9150 was connected to the SCA and SDL pins of the microcontroller which were 1.6 and 1.7 respectively.

Figure 3.13 MSP430G2553 launch pad kit

The Bluetooth device was connected to pins 1.1 and 1.2 which were the designated pins for UART.

The MSP430 launch pad kit works on an input voltage of 5V. A voltage regulator IC is present which drops this voltage down to 3.3V for the microcontroller to work on. All the sensors take the power supply from the MSP board itself. LM35 takes 5V and the rest worked on 3.3V which was taken out of the board and on a printed circuit board (PCB) from where the rest of the sensors took their supply from. There was also a reset button present on the board in case there is some fault or error.

3.2.6 Wireless Communication

There are a number of wireless technologies available in the market. Mainly two of them are frequently used namely Bluetooth [61] and Zigbee [62]. Bluetooth was used in this system due to its popularity, low cost and ease of use. When Bluetooth is connected with the laptop it assigns a COM port to the Bluetooth and it can be used as UART. Basically it acts as a cabled serial port.

HC-05 was the Bluetooth device used in this system which can be seen in figure 3.14. It's portable, small in size and easily available in the market at a cheap cost. Bluetooth works on a frequency of 2.4GHz.

Figure 3.14 HC-05 Bluetooth module

3.2.7. Power supply

To make the circuit portable power bank was used to power the whole circuit and it gives a constant output of 5V. 5V was needed for the circuit to work. LM 35 works at 5V. Everything else works at 3.3V which was taken from the launch pad kit.

3.2.8 Chest Belt

FSR and LM35 were pasted on the chest belt shown in figure 3.15 which was made of elastic for flexibility with Velcro stitched on it for size variation.

Figure 3.15 Elastic chest belt with Velcro stitched on it

3.3 SOFTWARE

A couple of software’s were required to make the system successful. One was required for programming the microcontroller and the other for making a GUI.

3.3.1 Code composer studio 5.5.0 [63]

Code composer studio is an integrated development environment which was used to program Texas Instruments Microcontroller. It was also sometimes used to monitor the output of the serial port. It was quite easy to use and the programming was basically done in C language. One of the main benefits of this software was that the parameters could be monitored using a software breakpoint without stopping the program.

3.3.2 NI LabVIEW 2013

Laboratory Virtual Instrument Engineering Workbench (LabVIEW) by National Instruments is used for making a graphical user interface (GUI). Virtual Instrument Software Architecture (VISA) resource is used for connecting with the Bluetooth via COM port. It tells about the Heart Rate, Body Temperature, Respiration Rate and Orientation. Figure 3.16 shows the GUI.

First of all the visa resource name is chosen which is essentially the COM port assigned to the bluetooth from where the data enters. Then visa serial is configured. Baud rate is set to 9600, data bits to 8, parity bit to none, number of stop bits to 1 and time out time to 10000 milliseconds. An alarm button is also set up such that whenever any parameter goes out of its normal range, the alarm gets high and turns bright green.

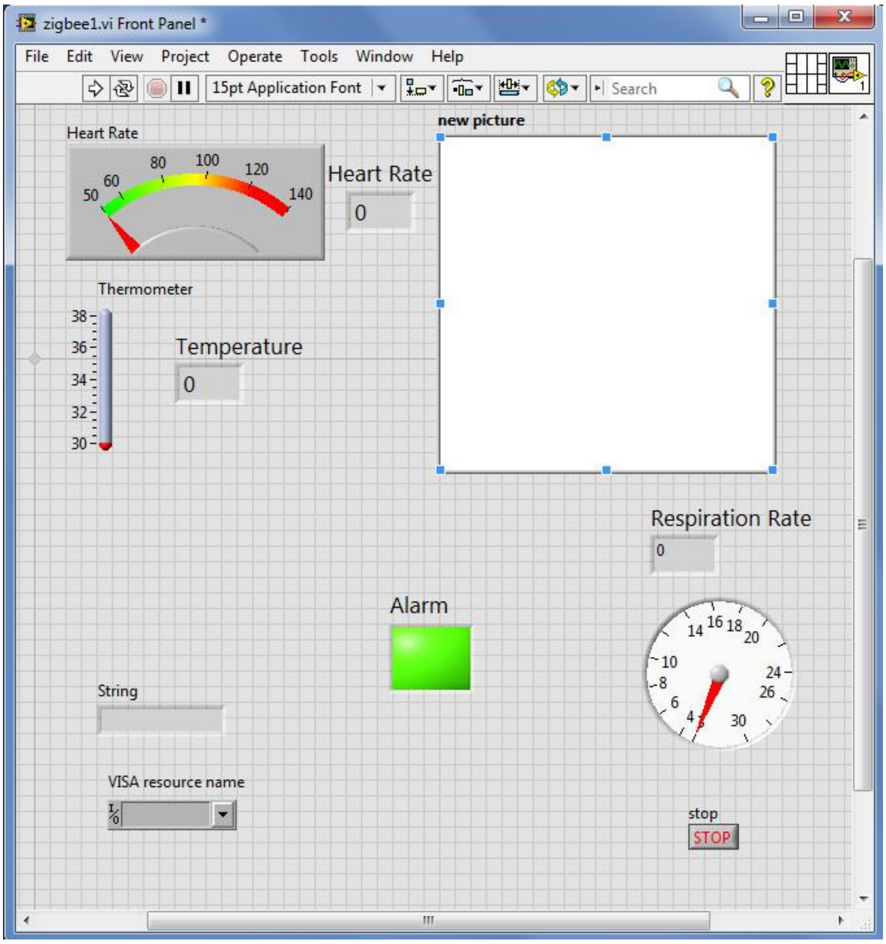


Figure 3.16 LabVIEW GUI

CHAPTER 4

RESULTS & DISCUSSION

A wearable health monitoring system has been made which monitors 4 vital parameters namely heart rate, respiratory rate, body temperature and orientation. Each was individually calibrated with standard instruments and was found to be quite accurate and the data was sent using a Bluetooth to the laptop where it was displayed on LabVIEW.

4.1 HEART RATE

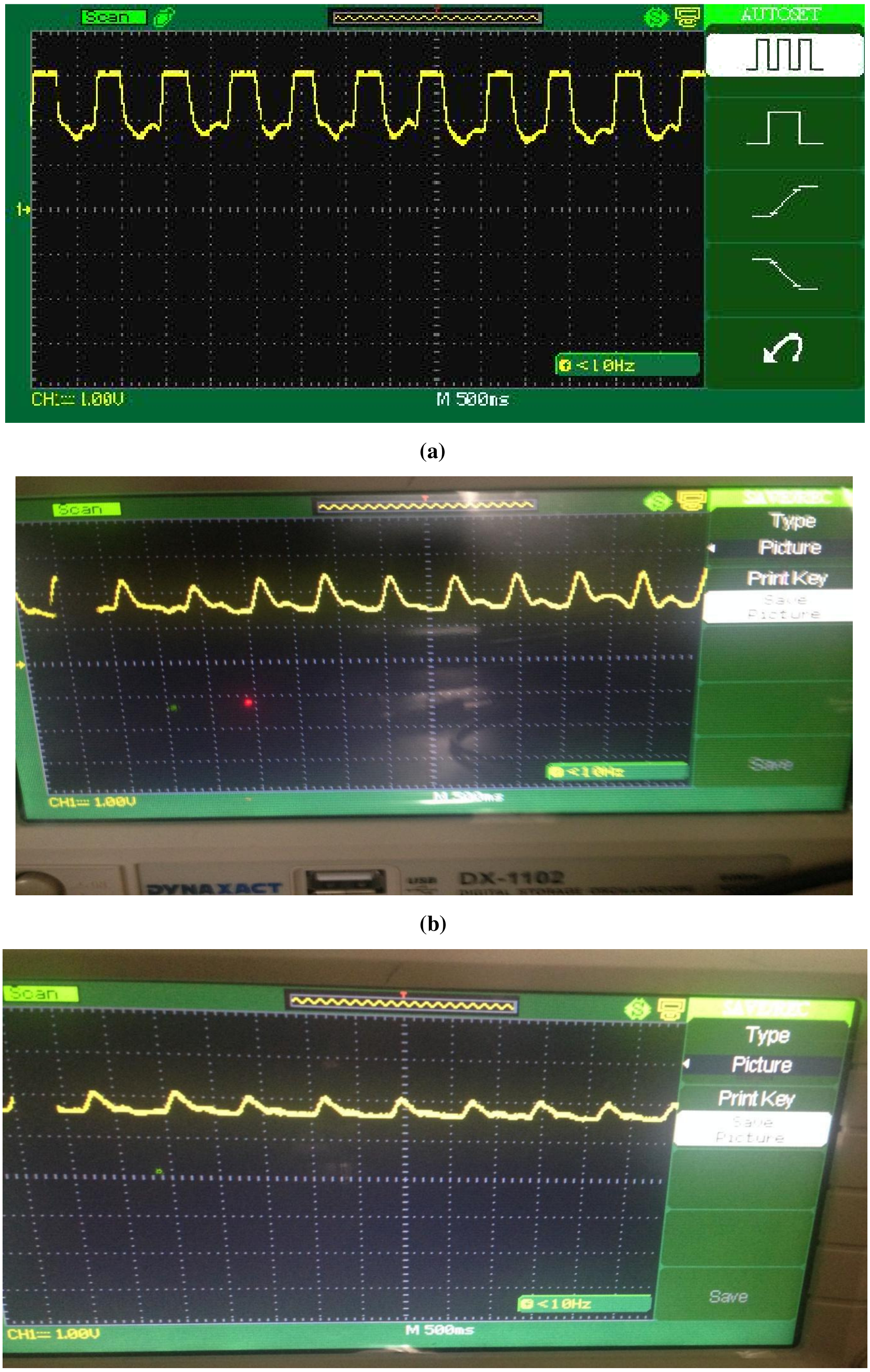
Heart rate is one of the main vital signs that should be monitored. PPG was used to detect heart rate at different positions of the human body. Three different locations were chosen which were the ear, index finger and the palm.

Figure 4.1a) represents the output waveform of PPG taken from the index finger, 4.1b) is from the palm and 4.1c) is from the ear. The peak values for the 3 output waveforms were 3V, 2.5V and 2V respectively. The most prominent peak came from the output of the index finger.

The index finger was considered the best position due to its best output. Positioning of the sensor at the palm was found to be quite uncomfortable and the output at ear was quite low, though it could be used as a probable position. The normal range of heart rate for adults is 60-100 beats per minute.

Table 4.1 shows the heart rate calculated using the pulse sensor on index finger and a pulse oximeter. It was calibrated with a pulse oximeter on the finger of the other hand.

It was observed from table 4.1 that the maximum error was found to be ±4.3% which is acceptable.



(a)

(b)

(c)

Figure 4.1 PPG output waveform from a) index finger, b) palm and c) ear

Table 4.1 Heart rate using pulse sensor and pulse oximeter

Subject Number	Pulse Oximeter (Heart rate)	Pulse Sensor(Heart Rate)	Error
1	85	82	3.5%
2	86	89	3.4%
3	97	99	2%
4	78	75	3.8%
5	66	64	3%
6	68	70	2.9%
7	95	95	0%
8	69	72	4.3%
9	83	82	1.2%
10	88	90	2.2%
		Average Error	**2.6%**

4.2 RESPIRATION RATE

In this design it is monitored using a force sensitive resistor (FSR). It is placed on the chest belt. It is one of the cheapest methods to monitor respiration rate. It was calibrated with a spirometer. Both the readings were taken simultaneously. Figure 4.2 represents the waveform of the voltage across the FSR connected in the voltage divider circuit.

Table 4.2 shows the respiration rate calculated using the sensor and a spirometer.

The FSR was pasted on the chest belt and changed its resistance with change of force on the belt when the person inhaled or exhaled.

It was observed from table 4.2 that the maximum error was found to be ±7.6% and average error is 4.1% which is acceptable.

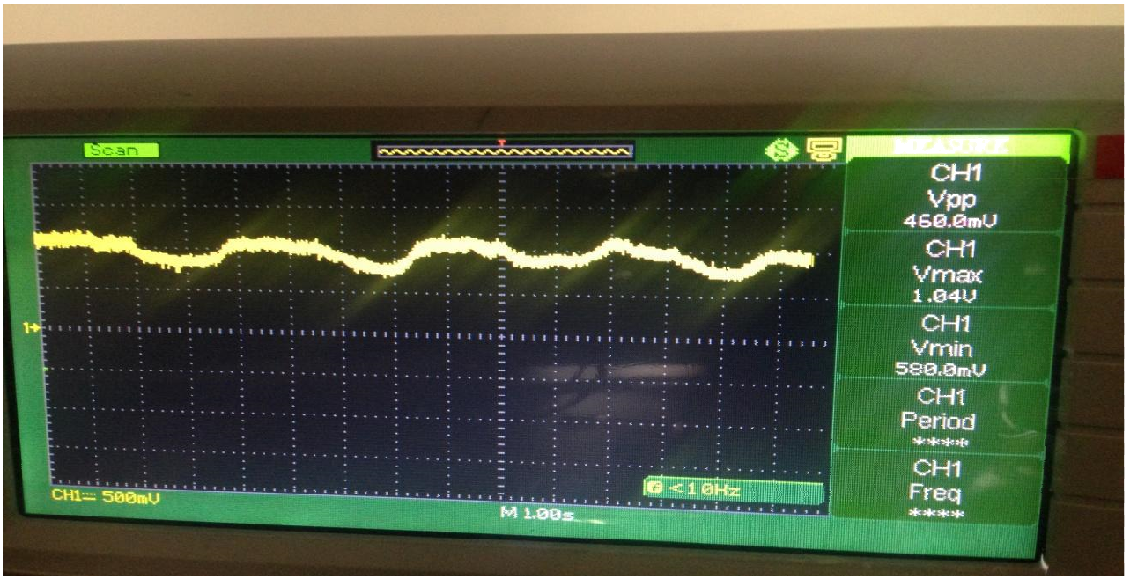


Figure 4.2 Output waveform of voltage across FSR connected in a voltage divider circuit

Table 4.2 Respiration rate using FSR and spirometer

Subject Number	**Spiro meter**	**Force Sensitive Resistor**	**Error**
1	14	14	0%
2	23	22	4.3%
3	28	29	3.5%
4	16	15	6.2%
5	15	15	0%
6	17	18	5.8%
7	25	26	4%
8	13	12	7.6%
9	17	18	5.8%
10	21	20	4.7%
		Average Error	**4.1%**

4.3 BODY TEMPERATURE

Temperature was monitored at 4 different locations namely wrist, chest, anterior calf and axillary. According to the level of comfort and the location where there was least variation was chosen. The normal temperature is approximately within the range of 95.9-98.6° F /35.5-37.0° C.

Table 4.3 shows the readings of the temperature of the participants at different locations with LM35 sensor and a digital thermometer.

Table 4.3 Temperature measurement at different locations with LM35 sensor and a digital thermometer

	Digital Thermometer (calibrated) (in ° C)	**LM35 (in ° C)**	**Error**
Indoor	18	17.7	1.6%
Outdoor	27	27.4	1.4%
	Subject 1		
Wrist	30	30.3	1%
Chest	33	33.2	0.6%
Axillary	32	32.4	1.2%
Anterior Calf	32.6	32.8	0.6%
	Subject 2		
Wrist	31.2	31.5	1%
Chest	33.2	33.4	0.6%
Axillary	31.6	31.4	0.6%
Anterior Calf	32	32.1	0.3%
	Subject 3		
Wrist	31.4	31.5	0.3%
Chest	32.9	33	0.3%
Axillary	31.7	31.1	1.8%
Anterior Calf	31	30.3	2.2%

The temperature of 10 subjects was monitored throughout the day at the 4 locations. One such reading of 3 subjects is shown in table 4.3. The standard deviation was found out for a subject whose temperature was monitored for half hour continuously at an interval of a minute which is shown in table 4.4 with the average error for all the readings taken at different locations.

Temperature is taken from the chest as the deviation is the least, it is least effected by external environment and won't affect the person during daily work. Hence the LM35 sensor was pasted on the chest belt itself. The error in the reading was found to be quite small.

Table 4.4 Average error and standard deviation

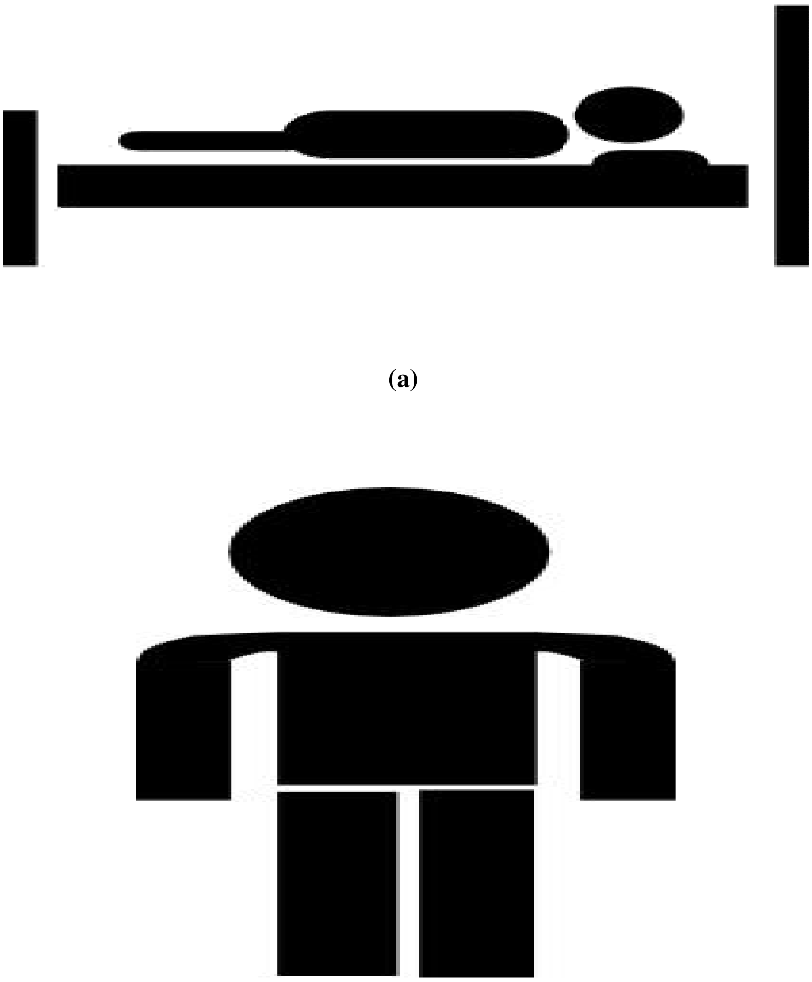
	Standard Deviation	**Avg. Error**
Wrist	0.496	0.77%
Chest	**0.116**	**0.5%**
Axillary	0.35	1.2%
Interior thigh	0.415	1.03%

4.4 BODY ORIENTATION

Body orientation was detected using MPU9150 sensor which is a digital motion processor. 25 participants were chosen irrespective of their age, sex, weight etc. This sensor was able to identify with an accuracy of 100% whether the person was lying down or not.

For a lying person figure 4.3(a) was seen on GUI else figure 4.3(b) was seen.

This parameter can be very useful in war time for military personnel. For example if a soldier gets separated from its group and is shot near the enemy line, then by checking its heart rate and position we call tell whether the person is alive or not and whether other soldiers should go and help him if alive or leave him if dead. If he is dead there will be no heart rate and his orientation will be of lying down whether face down or head down. It can also be used for monitoring elderly people. Orientation and heart rate together might be helpful. For example if the aged person has high heart rate and is lying down in resting position it might suggest some abnormal cardiac activity which could be fatal.



(a)

(b)

Figure 4.3 GUI picture seen when person (a) lying and (b) standing/sitting

4.5 SPECIFICATIONS AND WORKING OF THE PROTOTYPE DEVELOPED

The prototype made was small in size with dimensions of 10 x 7 cm. The cost of developing the prototype was around Rs. 3500 and was quite light weight, weighing only 125 gm.

First the temperature and orientation were found out by the micro controller which takes less than 1 second to do. Then the heart rate was calculated by the MSP430 which took anywhere between 30-45 seconds. Then again body temperature and orientation were found. Finally respiration rate was found which took time between 40-50 seconds. Then again body temperature and orientation were detected and the cycle went one. The sampling rate for each signal is about 125 kHz.

The input signals were anywhere between 0.3V to 2.5V. The inbuilt ADC was of 10 bit with a reference voltage of 2.5 V; hence the resolution was about 2mV which was quite sufficient. With each parameter value an alphabet was sent with it (4 alphabets for 4 parameters) so that each could be distinguished when data was transferred to LabVIEW.

Bluetooth was connected to those pins of MSP430G2553 which dealt with UART. Data was transferred from the controller to a nearby laptop wirelessly. It has a range of approximately 8 m without any obstruction in between.

Finally the data was received at the COM port. The same COM port was chosen as an input to the LabVIEW. Data was transferred with a baud rate of 9600 kbps and was differentiated using the alphabets before the value. Consequently the corresponding data could be seen on the GUI. The parameters retained their previous values until any change occurred.

The data received from the micro controller was displayed using LabVIEW. Each parameter was displayed separately. Until a new value of the parameter came to the software, it would show the last value only. If the parameter value is out of range of the normal values, then the alarm gets high else it remains low in a dull green position. The final wearable circuit can be seen on one of the subject in figure 4.4. Figure 4.5 shows how the GUI looked during the experimentation on one of the subjects.

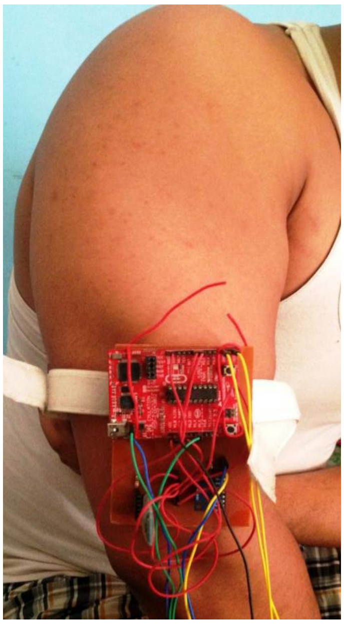
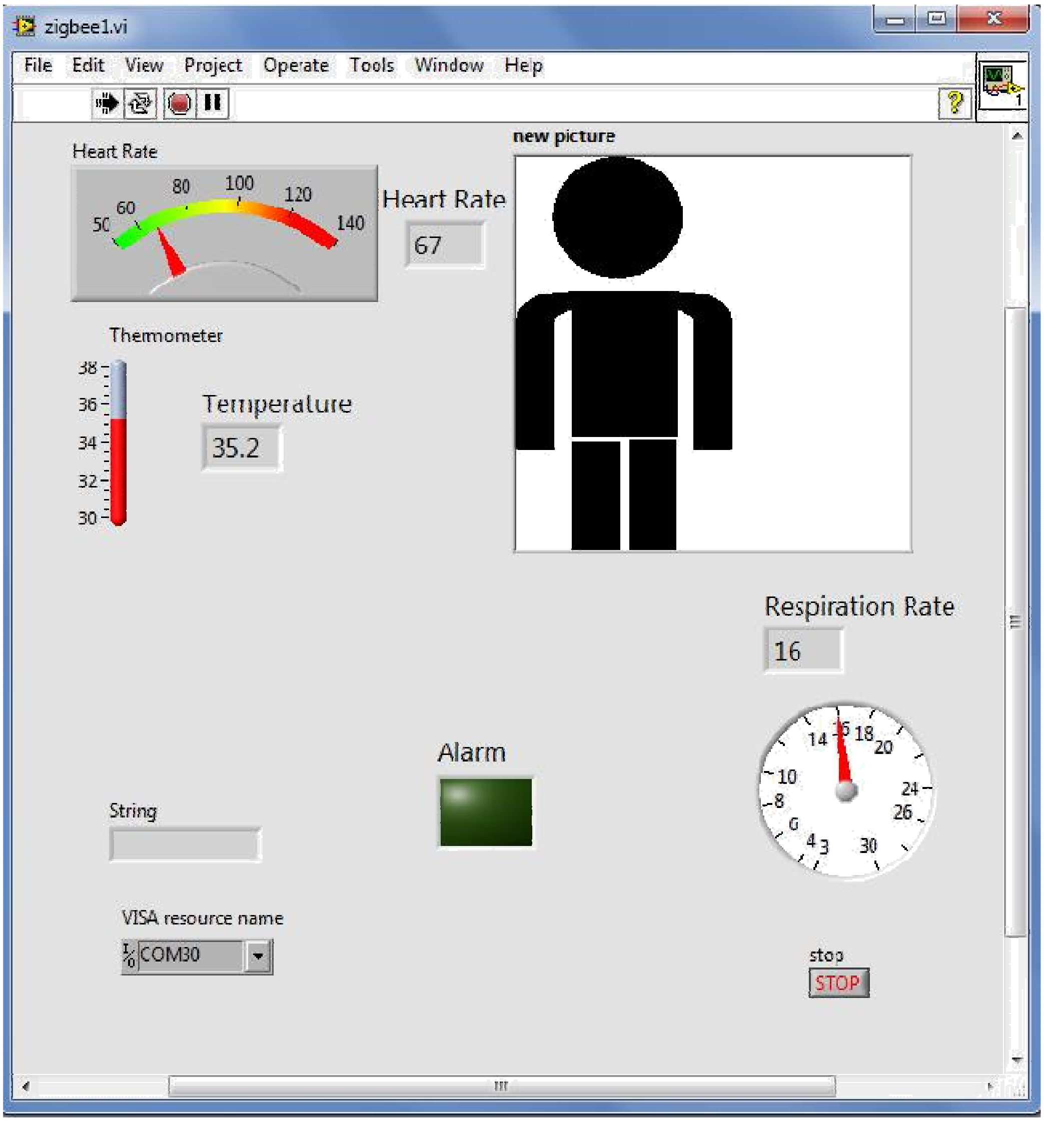


Figure 4.4 Person wearing Wearable Healthcare System Monitoring Vital Parameters



Heart Rate 67

Temperature 35.2

Respiration Rate 16

VISA resource name COM30

Figure 4.5 GUI during experimentation on one of the subjects

CONCLUSION

In this study a system is proposed which monitors 4 vital physiological parameters which are heart rate, respiration rate, body temperature and orientation. The prototype has been successfully developed using Texas MSP430 based microcontroller board. All the sensors were connected to the analog channels of the microcontroller. The microcontroller is connected to a Bluetooth device which sends the data wirelessly to laptop through LabVIEW where the status of the person can be monitored. The range of the prototype device is 10m. The GUI made is quite user friendly as it displays data in numeric value and as indicators also. An alarm button is also provided which goes high if any parameter goes out of normal range. The laptop is connected to the internet and the data can be sent to the close family members who can contact the doctor if necessary. It can be used to monitor the health of elderly people, patients who have just come out of hospitals, military personnel etc.

FUTURE WORK

This system can be improved in the future. The number of parameters to be measured can be increased. Additional sensors for body level hydration; blood pressure etc. can be incorporated. A wireless body area network can be made to remove the wires between the sensors and the acquisition unit. The range of the system can be increased by using Zigbee, Wi-Fi etc. The sensors can be provided with their individual batteries which should have a long life. The sensor can be placed at the chest belt itself rather than on the finger so that it does not interfere with daily work and improve comfort level. A mobile application can also be made for the data to be communicated to the mobile. In today's world most of the people have smart phones with internet connectivity and the data can be sent to a central server where if any abnormality is seen the closed ones can be informed and medical personnel can reach the person as quick as possible.

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