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Design and Development of a Wearable Wireless Health Monitoring System: A Smart Watch Approach

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Design and Development of a Wearable Wireless Health Monitoring system: A Smart Watch Approach

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Abstract

According to Statistics, every year, about 610,000 people die because of heart disease in United States of America. (i.e. 1 in every 4 deaths.*) Heart disease is common for both men and women. Annually, about 370,000 people die because of coronary heart disease, which is the most common type of heart disease [1]. About 735,000 Americans have heart attack every year. In this, 210,000 people gets heart attack who already has heart problems and 525,000 people get heart attack for the first time [2]. Not many people know that they have heart problems. Around 47% of the people in United States of America have sudden cardiac arrests outside the hospitals [3].

To reduce the probability of death and to analyze the data of the body condition for the betterment of life, A wireless health monitoring system can be introduced. This health monitoring system is required for all ages of the people. In this fast moving busy world, wearable wireless health monitoring system is the most important system, which can continuously monitor the health of the patients/people. In this thesis, a wireless health monitoring system (A smart watch approach) can be developed which includes pulse and oxygen saturation.

The health monitoring system is designed with the wearable (smart watch) approach, through which the above parameters are monitored that shows the variation from which the disease can be detected and diagnosed initially. For this, the sensor modules are implanted in the daily wearable like watch that can monitor the body condition in real time and can send the data to the computer via Bluetooth and to the medical centers via Global System for Mobile (GSM) Long-Term Evolution (LTE) where the doctors can monitor their patients and act when they are in an emergency.

Here, the proposed prototype is implemented in the watch by which the data are collected from the wrist. In the engineering point of view, this watch that consists of pulse sensor will help in monitoring the patient’s body condition. The reflectance pulse sensor module consists of the IR led, the RED led and the photodiode. The sensor that takes up the PPG signal, process and sends it via Bluetooth to a receiver station with the help of an application and shows up the data on the screen. These signals can also sent to the medical centers using Wi-Fi and Cellular networks with LTE, through which the doctors can analyze the body condition of the patients.

With this engineering technology (both hardware and software), the health monitoring has been made easy and initiates the decrease in number of death caused by the cardiac arrest.

Acknowledgements

I would like to express my greatest and deepest gratitude and appreciation to my Inspiration, Professor and Advisor, Dr. Vijay K. Varadan, who gave me an opportunity to work under him and extended his phenomenal guidance. His exceptional guidance and his motivation towards the research made my way through this thesis. He is a prodigious, perceptive, marvelous, motivational, eccentric and sagacious advisor and mentor. His consistent and anomalous guidance and questions towards my work would be my one of the reason to become successful in my life.

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Last but not the least, I would like to express my heartiest gratitude to my parents whom I consider as GOD, for their support, guidance and motivation in all aspects in my life. Their efforts to make my dreams, my wishes and aim to become true is unexplainable. From my heart,

I am really grateful to them for everything they gave in this life and I dedicate this thesis to my GOD, who are my parents.

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Chapter 1: Introduction

Oxygen is one of the most important components needed to sustain life. Most of us, don't take breathing functionality more serious till they get some respiratory difficulties, heart problem or an organ failure. In the human body, the oxygen deficiency is one of the problems and linked to each and every major failure or illness including heart disease, organ failure, respiratory disease, and cancer. In the red blood cells, there are two types of hemoglobin, Oxy hemoglobin (HbO2) and De-Oxy hemoglobin. The Oxy hemoglobin (HbO2) that is bounded with O2, delivers 98% of the oxygen to the cells. The Oxygen saturation (SpO2) is measured by the calculation of amount of HbO2 in the arterial blood [19].

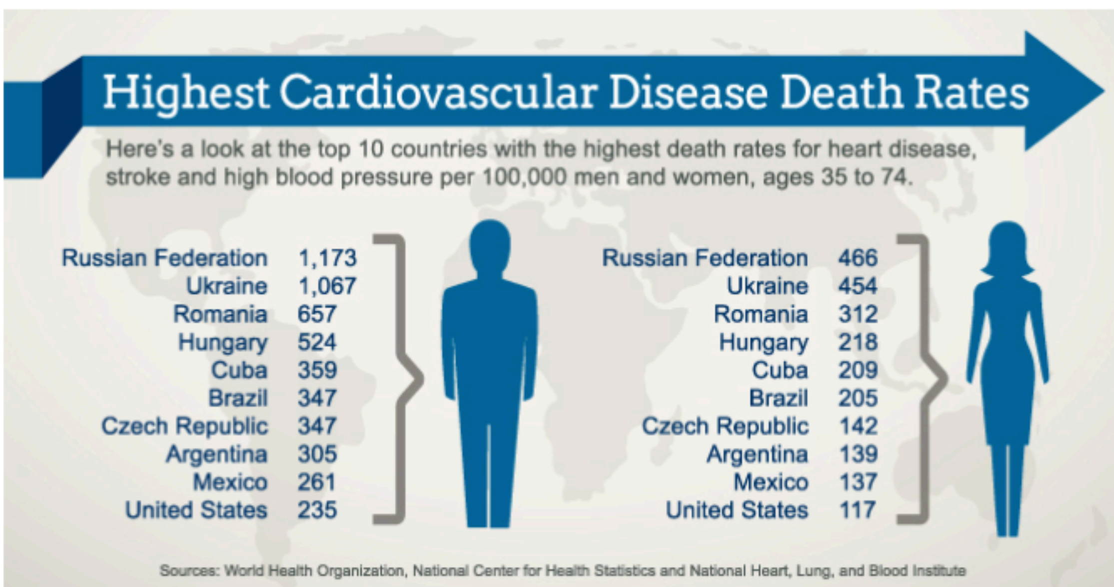
In olden days, the SpO2 was measured invasively by taking the blood samples and measuring the O2 levels in it. This method was invasive and real time monitoring was not possible at that time. Until the non-invasive method was introduced, the SpO2 measurement was not recognized as important [20].

The development of pulse oximetry was the result of need for the non-invasive method of measuring SpO2. The pulse oximetry obtains the SpO2 and the pulse rate from the Photoplethysmogram (PPG signal). The IR led and Red led are used to obtain the PPG signal. The PPG signal is obtained by the light absorbed by the light. The IR led and Red led are used because the wavelength of these light helps them to travel through the tissues. The SpO2 values are calculated from the ratio of the Infrared light and the red light. There are two types of pulse oximetry, one is Transmittance based and the other is reflectance based.

1.1 Statistical report on cardio vascular disease

A report by American Heart Association says that According to "Heart Disease and Stroke Statistics – 2015 Update : A Report from American Heart Association", the heart disease remains the No. 1 reason for the global cause of death which was compiled over from more than 190 countries with 17.3 million deaths per year and the current figure is expected to rise to 23.6 million by 2030 [5].

The same report says that stroke remains No. 2 as the reason for death. The report from American Heart Association says that the stroke death rate, which is the number of deaths per 100,000 people went down between 1990 an 2010. But, the number of people getting first and recurring strokes each year went high, touching 33 million in 2010 [5].



Sources: World health Organisation, National Center for Health Statistics and National Heart, lung, and Blood Institute
Figure 1.1: Cardio Vascular Disease Death Rates by American Heart Association [6]

1.2 Respiratory Disease

The respiratory problems are also based on the oxygen saturation in the blood. A research group in 1996 reported that the red blood cells acts the biosensors that can finely tune themselves to have optimum amount of oxygen to the organs and the tissues by adjusting the blood flow. The blood cells carry s-nitrosothiol (SNO) in the blood stream along with the oxygen. The blood flow is adjusted by changing the shape of the blood cells and releasing SNO. When the oxygen level is high in the blood, the hemoglobin has excess oxygen and NO, which reduces the blood flow. When the oxygen level in low in the blood, NO is released to expand the blood vessels and to improve the blood flow. So, if there is prolonged oxygen shortage (hypoxia) in the blood cells, SNO is completely depleted, which results in asthma and other breathing diseases. This may also lead to the heart diseases and organ failure [7].

1.3 Congenital Heart Defects

The defects in the heart's structure that are present at birth are referred to as the Congenital Heart Disease. There are many types of congenital heart disease. At this point, the defects may be present in the interior walls of the heart, the valves inside the heart or the arteries and veins near or around heart that carry the blood throughout the body. These types of defects affect the normal flow of blood through the heart. The level of defects various from low to high. Some of the newly born babies or adults with these defects need cardio care throughout their life for a continuous diagnosis and treatment.

For the above reasons, the below proposed system would be useful and convenient for the people [8].

1.4 Proposed system

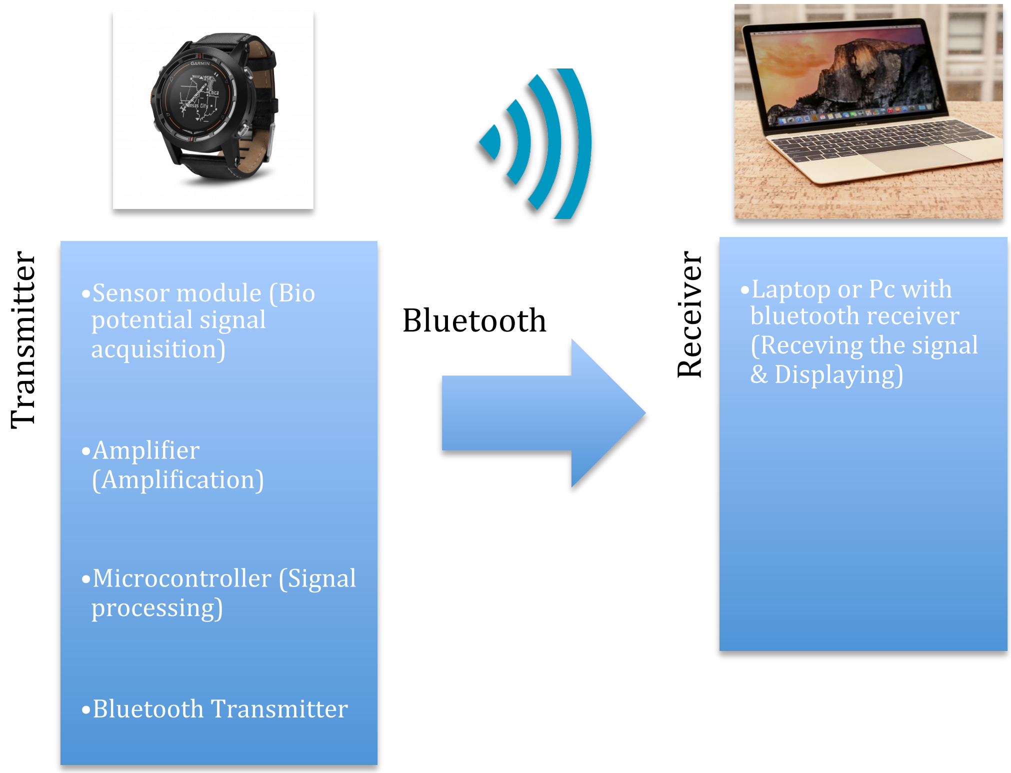


Figure 1.2: Block diagram of the proposed system

To diagnose the above-mentioned problems, the system is proposed. In this proposed system, the transmitter end (watch) includes the sensor module, amplifier, microcontroller and the Bluetooth transmitter, and the receiver end includes the laptop or PC with software module and the Bluetooth receiver. The bio-potential signal, PPG is acquired to monitor the oxygen saturation and the heart. To attain the PPG signal from the wrist, the sensor module is designed with the IR LED, Red LED and photo diode. Then the raw data from the sensor module is amplified using the amplifier that is design and fabricated, then the signal is fed into the microcontroller to be processed. The microcontroller converts the analog signal to the digital signal with the help of A/D converter. Then the processed data is transmitted to the receiver end by the Bluetooth wireless communication module enabling real time monitoring of the pulse.

The lithium-ion battery powers up the whole transmitter end modules, which is rechargeable. The receiver end consists of the Bluetooth receiver station and the software is programmed to extract the transmitted data from the transmitter end and display the same on the screen. This proposed system is explained in detail in the 5th chapter.

Chapter 2: Literature Review

There are several research groups who are currently working on Wireless Health Monitoring systems across the world. The health care is one of the most important factors in today's life. The real time monitoring from a remote place is needed for the patients care in this fast moving world.

2.1 Health Monitoring System

A health monitoring system consists of ECG, Pulse rate, SpO2, blood pressure, etc., These equipment are already available in commercial markets for the hospital setups and many researches are currently being held to improve the efficiency and accuracy.
These equipment are massive in size that can be used only in hospitals and clinics and could not be used by the patients outside the hospitals. Since the production cost is high due to several factors, it is also expensive. Due to the above reasons, we started working towards the health monitoring system that is affordable and portable for patients to monitor their health outside the hospitals.

2.2 Wireless Technology implemented on Health Monitoring System

Working towards the accessibility to patients, the wireless technology was implemented. This wireless technology made the pathway for the upcoming technology to overcome most of the disadvantages faced before. Even though the wireless technology was implemented, still the size was big for the patients to male it portable and the still the cost was expensive.

2.3 Wearable Technology implemented on Health Monitoring System

Currently, several research groups are involved with the wearable and wireless technology implemented on the health monitoring system for the ease of the patients. The monitoring unit would be implanted on daily wearable. This can reduce the size of the monitoring system and the production cost can also be reduced.

2.4 Commercially available technology

There are commercially available wearable systems to monitoring the health for the fitness purpose. The companies like Fitbit, Garmin etc., have already launched their products with reference to the fitness, which tracks the daily motions of the human. There are products which measures the heart rate with simple and single led which acts as the sensor that used only for the fitness purpose.

2.5 Conclusion

The proposed health monitoring system prototype would be the initiative to the health care sector to monitor the patient's health wirelessly and analyze it in a hospital environment, which avoids the situation for the patients to be present at the hospital each and every time for the check up and emergency.

Chapter 3: Bio potentials

Bio potentials are the electric potentials caused by the chemical reaction in the body. It is defined as the potential difference between two points in the body (ie. Tissues, living cells and organisms). The required information are extracted from these bio potentials which accompanies the whole biochemical processes in the body. Bio-potentials illustrates the transfer of information (electric potentials) within the cells and between each and every cells [9] [10].

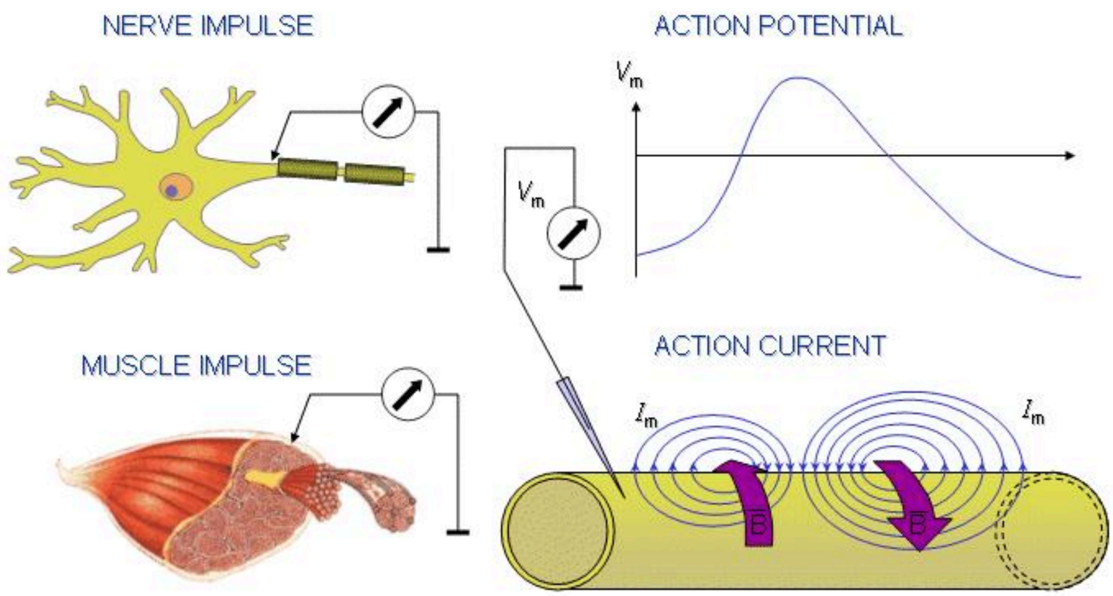


Figure 3.1: Nerve responses with a change in potential [9] [10].

The Bio-potentials are classified into ECG, EEG, PPG, EMG, EOG, etc., In the proposed prototype, Electrocardiography (ECG) and Photoplethysmography PPG are studied and analyzed.

3.1 Electrocardiography (ECG)

Electrocardiography is a non-invasive process of recording and analyzing the electrical signal from the heart over the time period. This recording is made using different kinds of electrodes that are placed at a particular place, on the patient's body. These electrodes helps in detecting the very small electrical changes in mV in the body that are due to the dramatic electrical changes in the heart muscle cells during each and every heart beat [11].

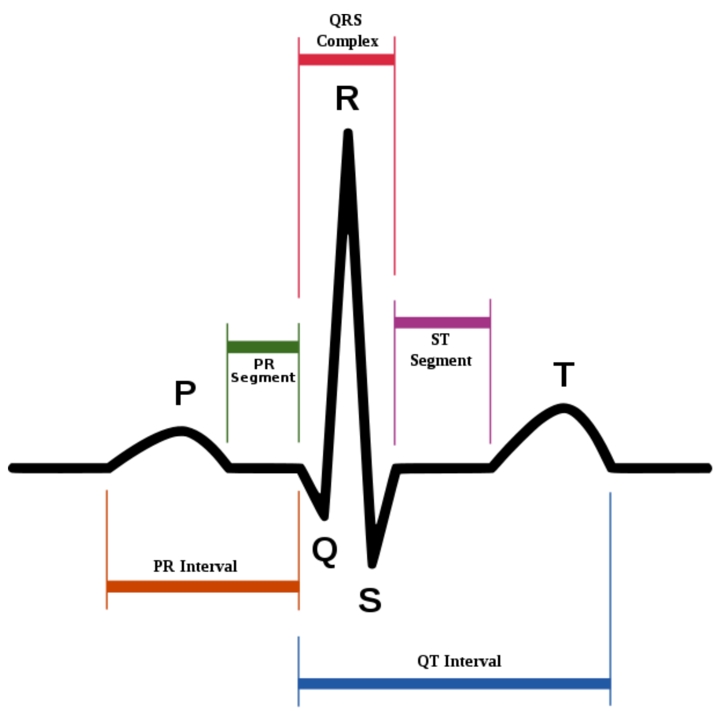


Figure 3.2: ECG Waveform [11]

During the cardiac cycle, the direction and the magnitude of the electrical depolarization are captured. By this, the graph of voltage and time is plotted which is known as Electrocardiogram. The ECG waveform would be like the figure 3.2 above, which has P, Q, R, S and T waves. The Electrocardiography helps in conveying a large amount of data about the heart and the functions of electrical conduction of the heart. It also provides information like heart rate, size of the heart chamber, structure of the heart, blocks in the arteries and veins of the heart, damages to the heart muscles, etc., [11].

3.2 Photoplethysmography (PPG)

Photoplethysmography is the process of volumetric measurement that are obtained using optical method. The PPG is measured by a device called pulse oximeter that calculates the volume of oxygen with the help of change in absorption rate of light sent into the body. It helps in monitoring the breathing level, and other circulatory conditions of the blood. The heart rate can also be calculated with the help of the peaks in the signal [12] [13].

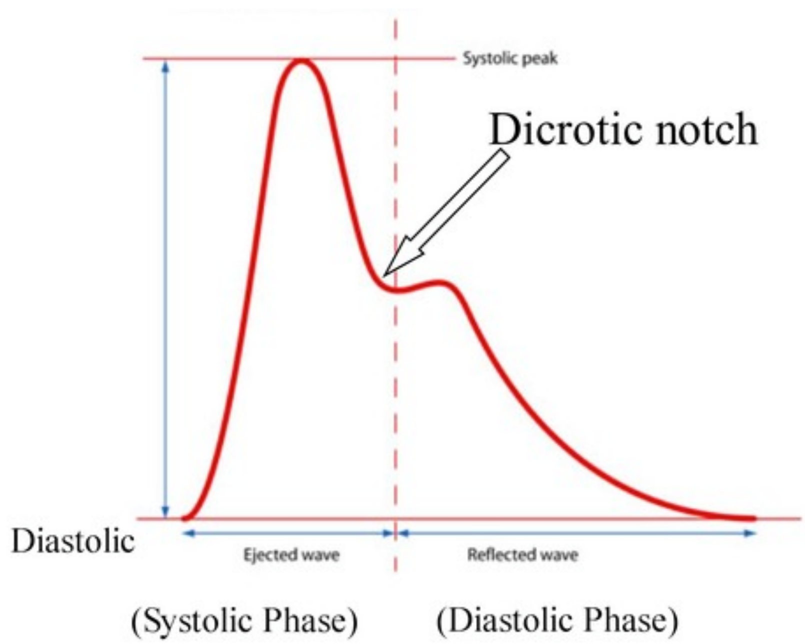


Figure 3.3: PPG Signal [12] [13].

PPG signal gives a optical representation of the volume of blood in the vessels and the cardiac cycle. The amount of blood in the tissues is proportional to the heartbeat and it varies accordingly. This gives the distinguishable AC component. The PPG signal data is usually taken from the finger, ear and the forehead. This is possible because of the perfusion of blood in the skin and tissues. In the PPG signal, the DC component of the signal refers to the skin tissue absorption and the AC component of the signal refers to the volume of the blood content that varies according to the heartbeat during the cardiac cycle [15] [16] [17].

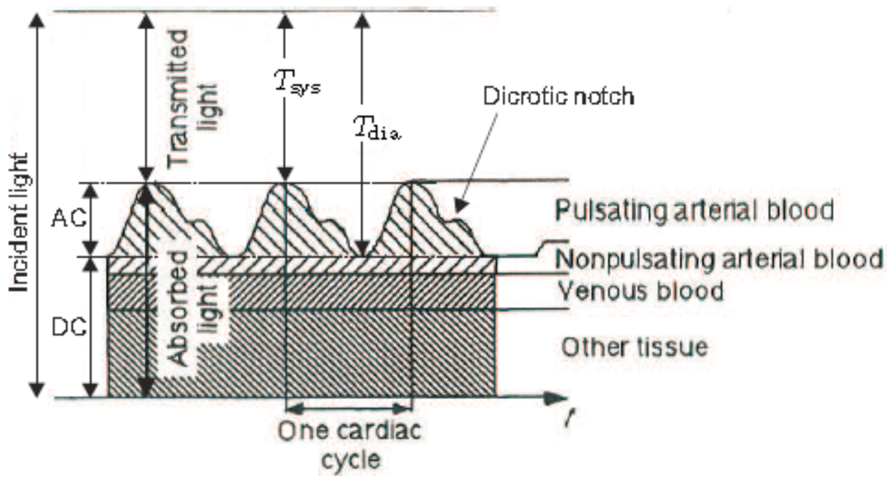


Figure 3.4: PPG signal with AC and DC Component [18]

Chapter 4: Wireless Communication Systems and Standards

In today's life, Wireless communication plays the dominant role in each and every technology that is in use. The advancement in technologies, made the telecommunication world evolve with wireless communication. The wireless communication standards such as Wi-Fi, Bluetooth, ZigBee, GSM(Mobile communication), Satellite communication has eliminated the need of wired communication. Wireless communication standards that support the technologies are demanded by the need of the society. Firstly, these wireless standards, where introduced in the electronics gadgets like mobile phones, laptops, computers, etc., and then slowly to all the day-to-day life amenities with technology. These wireless standards are also used in health care, transport, security, and many more. So, this chapter briefly describes about the different wireless systems and standards, their specifications and applications that are to be used for the health care monitoring system prototype [14].

4.1 Wi-Fi

Wireless LAN (Wi-Fi) has captured an important place in Local Area Network, in jus few years, as it can connect many devices simultaneously to the Internet and Intranet. WLANs based on the IEEE 802.11 standard gives the solution for the low cost, mobility and flexibility of the network connection [14].

4.1.1 Architecture

A WLAN is a data transmission system which is the wireless extension of the wired, fixed infrastructure, and not the system which depends on the wireless links. WLANs are the final link between the wired network and a group of devices such as computers, laptops, Tablets, Smart phones, and other smart devices that gives access to the external resources wirelessly [14].

In the past few years, WLANs are introduced and enabled in the public zones such as airports, shopping malls, railway station, café shops, etc., to give access to any individuals who as smart devices to the external resources (Internet) and services available through this wireless infrastructure [14].

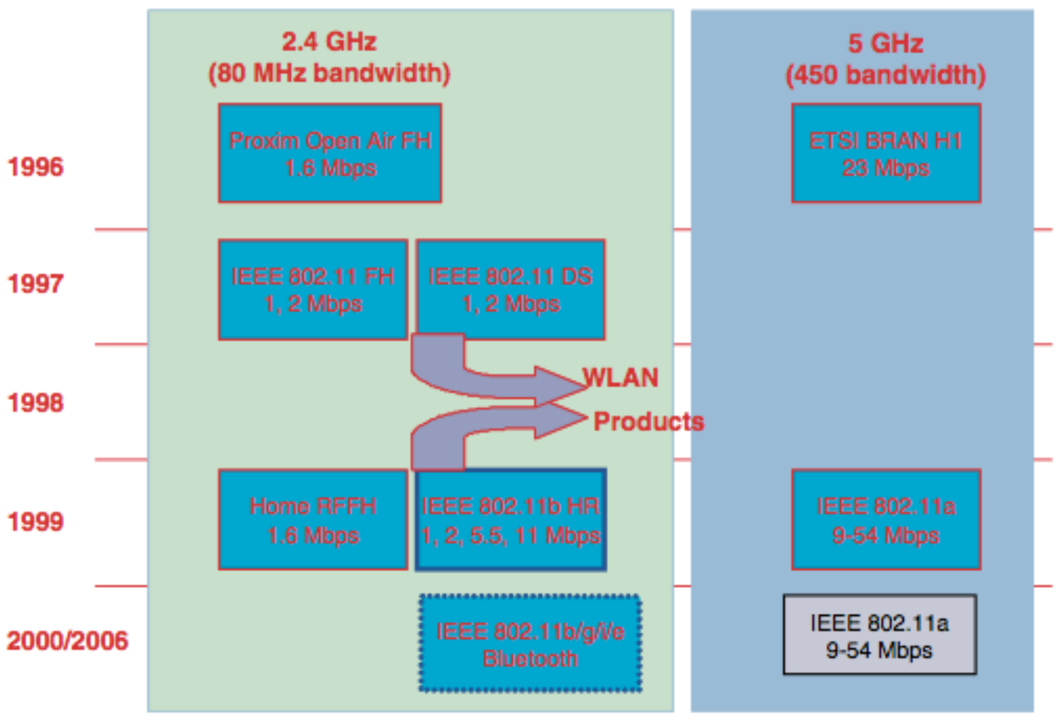


Figure 4.1: Evolution of WLAN standards [14].

4.1.1.1 Three Basic Operational Mode

The IEEE 802.11 standard consists of types of components, a wireless client station known as station(STA) and an access point (AP) which is sometime known as wireless relay, which acts as a bridge and a relay point between the wireless network and the fixed network.

This access point consists of network card (Ethernet 802.3), radio transceiver and a software for bridging [14]. The access point acts as the basic wireless network station, linking the multiple wireless stations with the fixed network. These wireless stations also include IEEE 802.11 network access cards or adapters that are available in different formats such as PCI, PCMCIA, USB, and Wi-Fi chips. The IEEE 802.11 standard consists of three modes, an infrastructure mode, an ad hoc mode and a mesh mode [14].

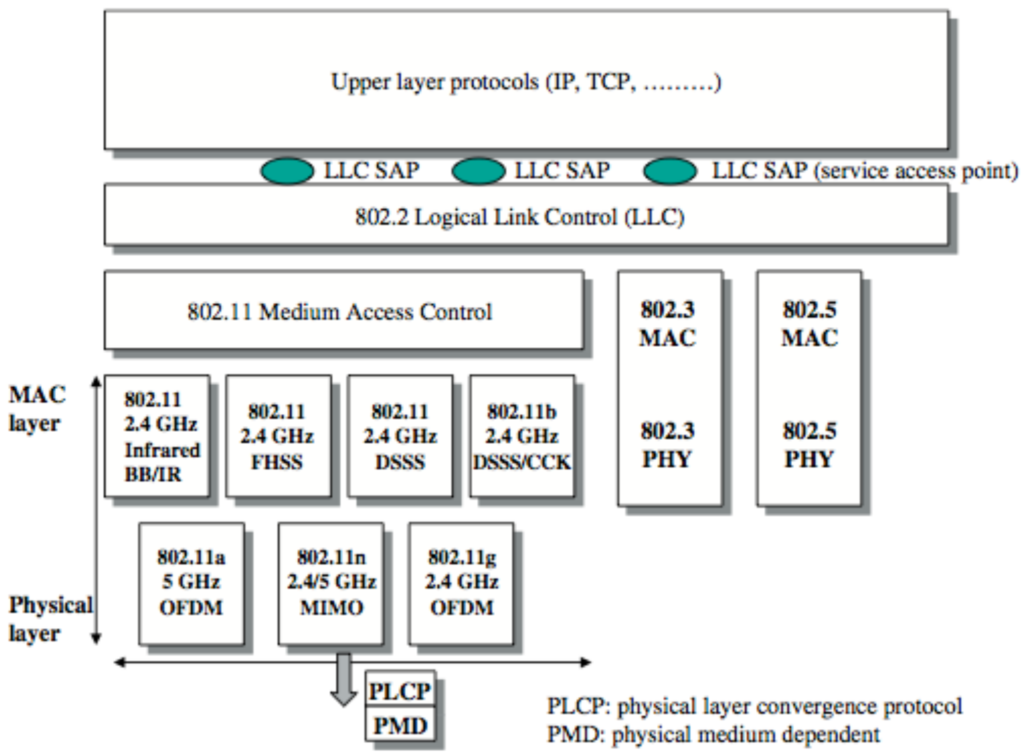


Figure 4.2: OSI reference model of IEEE 802.11 and 802 Family [14].

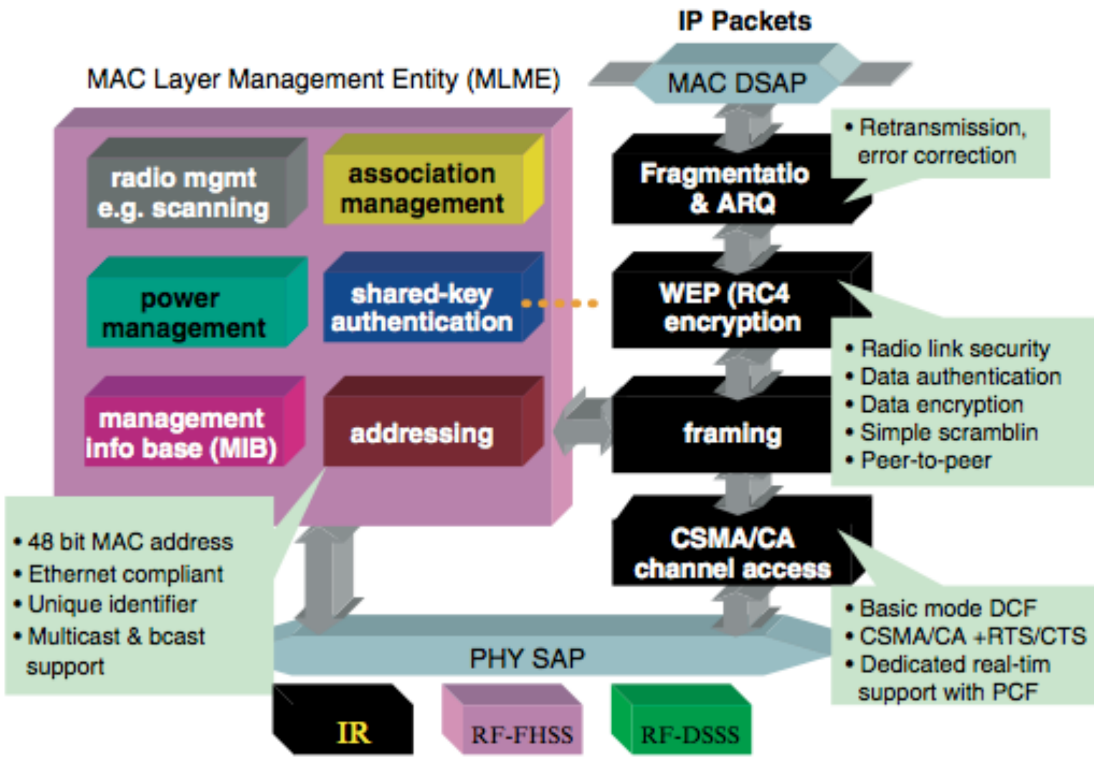


Figure 4.3: A view of IEEE 802.11 MAC layer [14].

4.1.1.2Infrastructure Mode

In the infrastructure mode, At least an access point connected to the fixed network and a set of wireless client stations will form the wireless network. In IEEE 802.11, this is based on the cellular architecture and the system is divided into cell known as BSS (Basic Service Set) and is controlled by the base station known as Access Point [14].

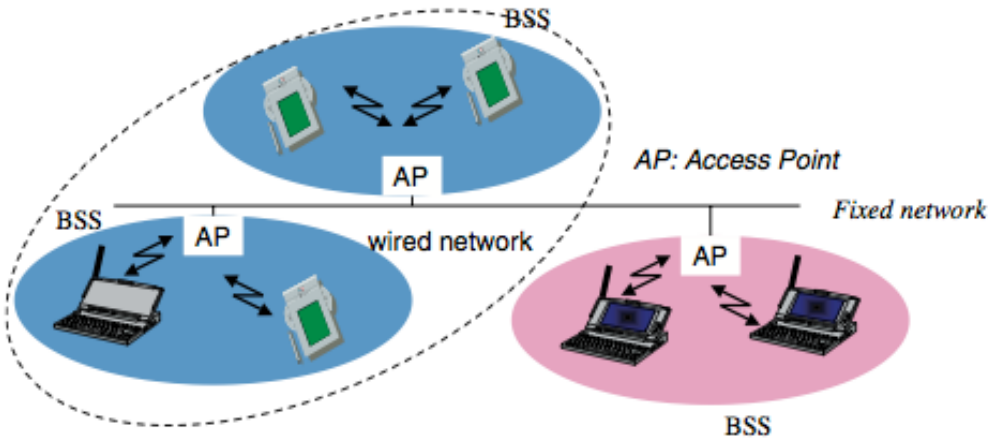


Figure 4.4: Infrastructure Mode (IEEE 802.11) [14].

4.1.1.3Ad Hoc Mode

The ad hoc mode is a group of IEEE 802.11 wireless stations, which communicate between them avoiding or without having any connections with the access point or the fixed network through the distribution system. This mode or configuration is generally referred to as peer-to-peer configuration [14]. In this mode, any station can communicate with any stations wirelessly within the cell that is known as Independent Basic Service Set (IBSS). These networks are also known as Packet Radio Networks. Within the infrastructure mode, SSID identifier identifies this ad hoc mode [14].

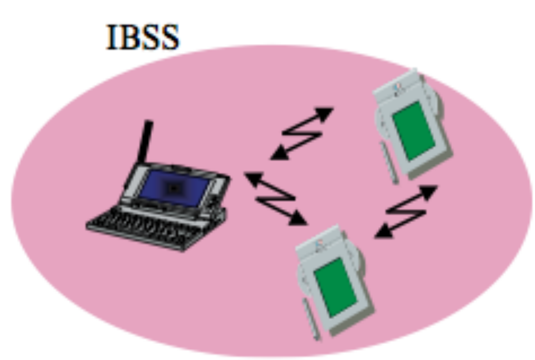


Figure 4.5: Ad Hoc Mode [14].

4.1.1.4Mesh Mode

Mesh mode configuration is the combined configuration of both the infrastructure mode and the ad hoc mode [14].

4.1.2Conclusion

In conclusion, the WLAN (Wi-Fi) based on IEEE 802.11 standards paved the way for the solution of mobility, flexibility and low cost technology that are used on all smart devices for easy wireless communication with the particular network which have access to an external resources or to a private network [14].

4.2Bluetooth

This Bluetooth technology concentrates on the short-range wireless communication among the smart devices. Bluetooth technology was originally developed by Ericsson and was maintained and developed by the Lobby Special Interest Group (SIG) through the evolution of its technology and is standardized by the IEEE with the reference IEEE 802.15.1. The main idea of Bluetooth technology is to communicate with other devices using very low energy consumption and thus making it low cost [14].

Ericsson Mobile Communications launched a feasibility study of low cost and low consumption radio in 1994, to interface the technology between the mobile phones and their accessories. In February 1998, several companies such as IBM, INTEL, Nokia and Toshiba joined hands with the Swedish company and created the SIG in the month of May. During 2000, the SIG got a upper hand by the arrival of 3Com, Microsoft, Motorola and many more who were the expertise in cellular communication, portable computers, and digital processing. And now, The SIG has more than 2500 manufactures in its group [14].

4.2.1 Architecture

There are two important things in Bluetooth communication. First is the devices to be discovered nearby and the second is the pre-established circuit to communicate with. This Bluetooth communication is based on the master-slave principle. In this technology, A cell known as piconet is formed by the group of equipment. A piconet consists of a master and seven slaves at the maximum. Many piconet can overlap to form a “Scatternet” [14].

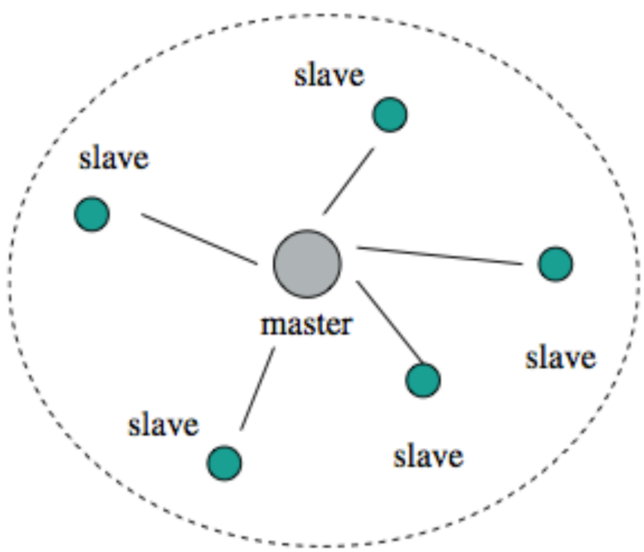


Figure 4.6: Master/Slave architecture [14].

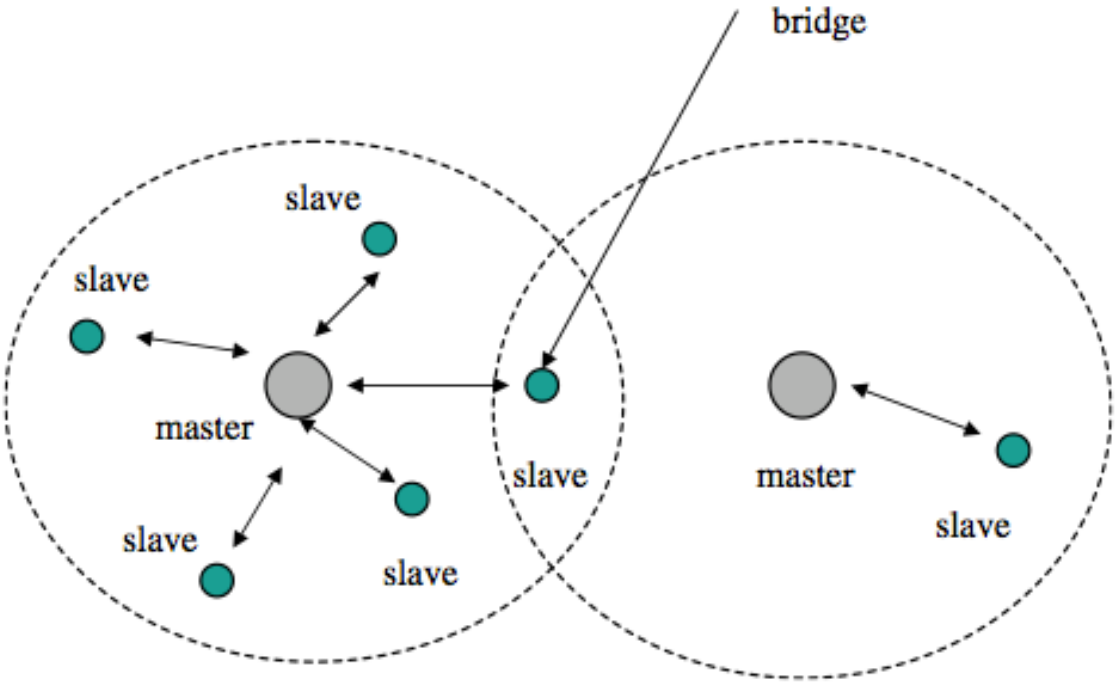


Figure 4.7: Scatternet [14].

In a Scatternet, the two slaves cannot communicate directly to each other without the master except during the discovery mode. Master controls everything including allocation of channels and the establishment of the communication [14].

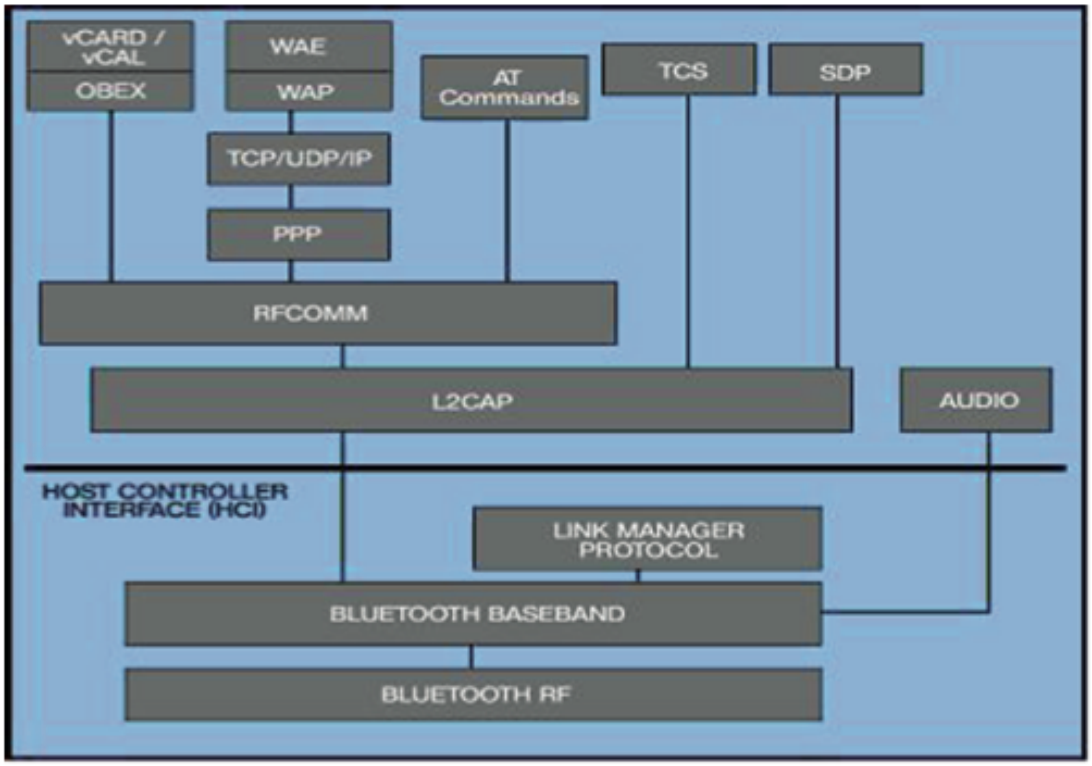


Figure 4.8: Bluetooth Architecture [14].

One of the main advantage is that the Bluetooth doesn't work depending on the IP. Several protocols were identified in Bluetooth [14]:

- Lower Layer Protocols
- Interfacing Protocols
- Applicative Control Specifications
- Applicative Protocols

The first version of Bluetooth was developed with a maximum bandwidth of 1 Mbps for a range of about 10 m. The second version of Bluetooth was developed with maximum bandwidth of 2 Mbps to 3 Mbps. The latest version of Bluetooth has the maiximum bandwidth of 24 Mbps. The frequency range of the Bluetooth in which it is operating is 2.4 GHz ISM Band [14].

4.2.2 Conclusion

The Bluetooth is the short distance communication technology that has low power consumption, no IP involved, high level of integration and the master-slave technology. The new version of Bluetooth has a high level bandwidth, which even supports high quality videos and audios. This advancement in this Bluetooth technology has paved the way to use this mode of communication for the real-time data transfers from the bio-potential sensor module to the smart devices like mobile phones, computer, laptops and even servers [14].

4.3 Zigbee

In WPANs, there are generally three trends that are as follows: Low data rate, medium data rate and high data rate. In short-range situation like this, there is no need to have a low or high throughput because different applications operate at different conditions. So, IEEE 802.15.4, which is referred as ZigBee, has the low data rate, whereas the Bluetooth is considered as the medium data rate. It is designed accordingly to provide the MAC protocols which gives space for the designer to focus more on the costumer needs[14].

4.3.1 Architecture

ZigBee is one of the wireless communication system which is powerful. The architecture based on the IEEE 802.15.4 reference model takes full advantages on the physical layer. The alliance between the ZigBee and the IEEE 802.15.4 is becoming strong with continued work to ensure the completed and integrated solution for especially the sensor based applications. It also provides discovery, security and so on for the layers given by the IEEE [14].

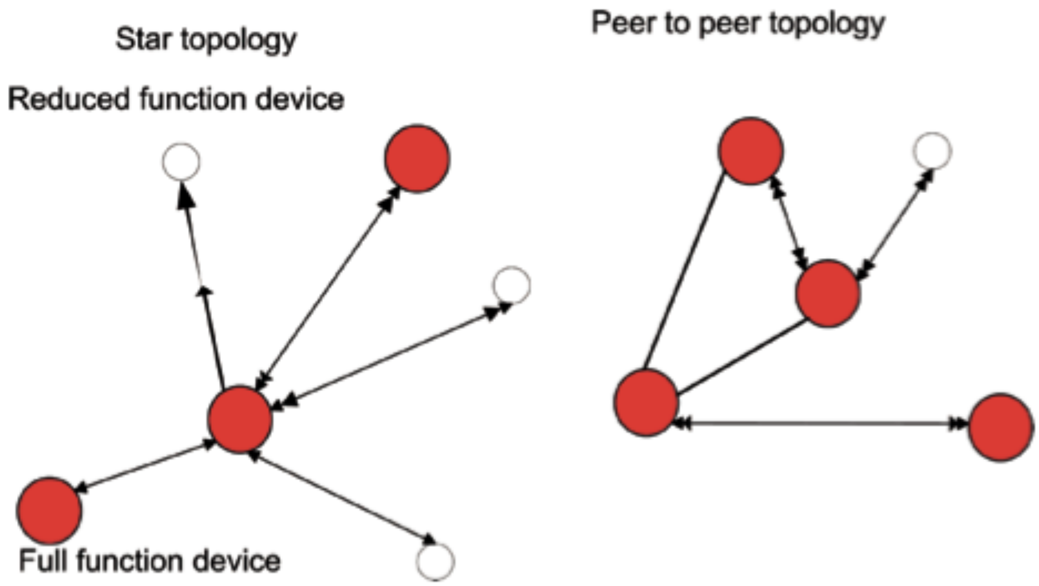


Figure 4.9: Basic topologies and node categories [14].

IEEE 802.15.4 is a low rate wireless communication system. It is just designed for the low power and light weighted devices. ZigBee helps in long battery life, but the throughout is not as expected [14].

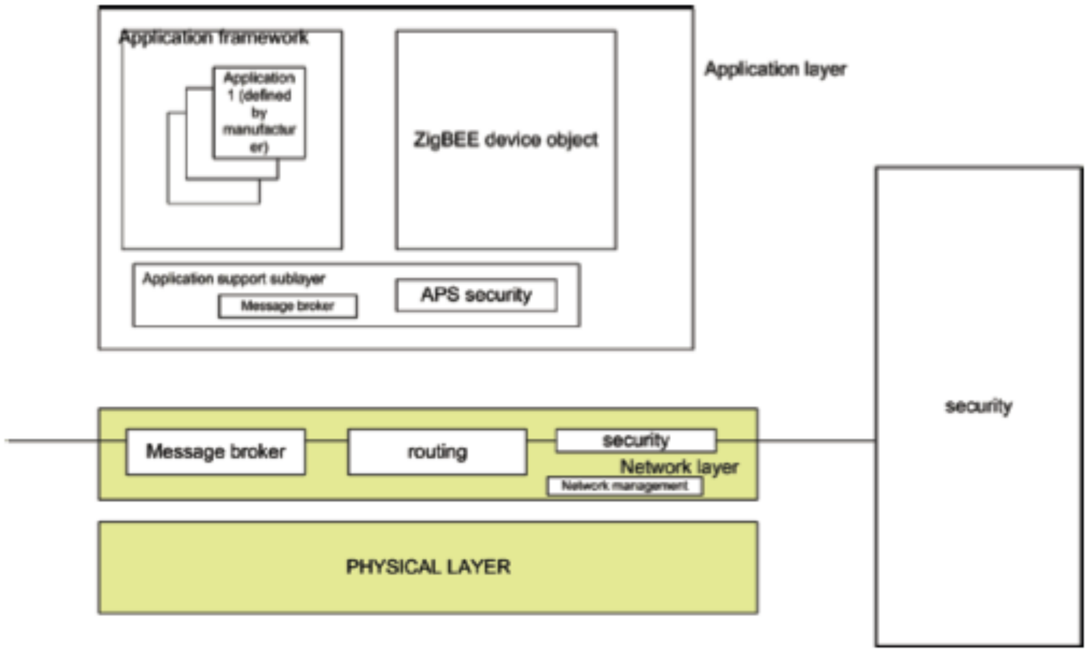


Figure 4.10: ZigBee Stack [14].

It defines only some functionalities in the layers on top of the IEEE 802.15.4 which is defined previously that satisfies the costumer needs with the set of programming tools for the applications. The three main formulae for ZigBee are [14]:

1. Service discovery
2. Binding
3. Security

4.3.2 Conclusion

ZigBee is the low data rate technology interface when compared to the other technologies available. But, It has the complete technology, which covers several applications with long battery life [14].

4.4 Discussion and comparison of all three wireless communication standards

Standard	Bluetooth	Zigbee	Wi-Fi
IEEE spec..	802.15.1	802.15.4	802.11a/b/g
Frequency band	2.4GHz	868/915 MHz; 2.4 GHz	2.4 GHz; 5 GHz
Max signal rate	1 Mb/s	250kb/s	54Mb/s
Nominal range	10 m	10-100 m	100 m
Nominal TX power	0 - 10 dBm	(-25) - 0 dBm	15 - 20 dBm
Number of RF channels	79	1/10;16	14(2.4GHz)
Channel bandwidth	1MHZ	0.3/0.6 MHz; 2 MHz	22MHz
Modulation type	GFSK	BPSK (+ ASK), O-QPSK	BPSK, QPSK COFDM, CCK, M-QAM
Spreading	FHSS	DSSS	DSSS, CCK, OFDM
Coexistence mechanism	Adaptive freq. hopping	Dynamic freq. selection	Dynamic freq. selection transmit power control (802.11h)
Basic cell	Piconet	Star	BSS
Extension of the basic cell	Scatternet	Cluster tree-mesh	ESS
Max number of cell nodes	8	> 65000	2007
Data protection	16-bit CRC	16-bit CRC	32-bit CRC

Table 4.1: Comparison table of Bluetooth, Zigbee and Wi-Fi [14].

Chapter 5: Wireless Health Monitoring System – A smart watch Approach

5.1 System design

The proposed system of wearable wireless health monitoring system consists of watch, which includes sensor module, data acquisition module and transmission module. The acquired signal is transmitted to the receiver end through Bluetooth communication. The receiver end (laptop or PC) that contains the Bluetooth receiver and the software module receives the signal and displays the data on the screen. The hardware and the software implementation are explained below.

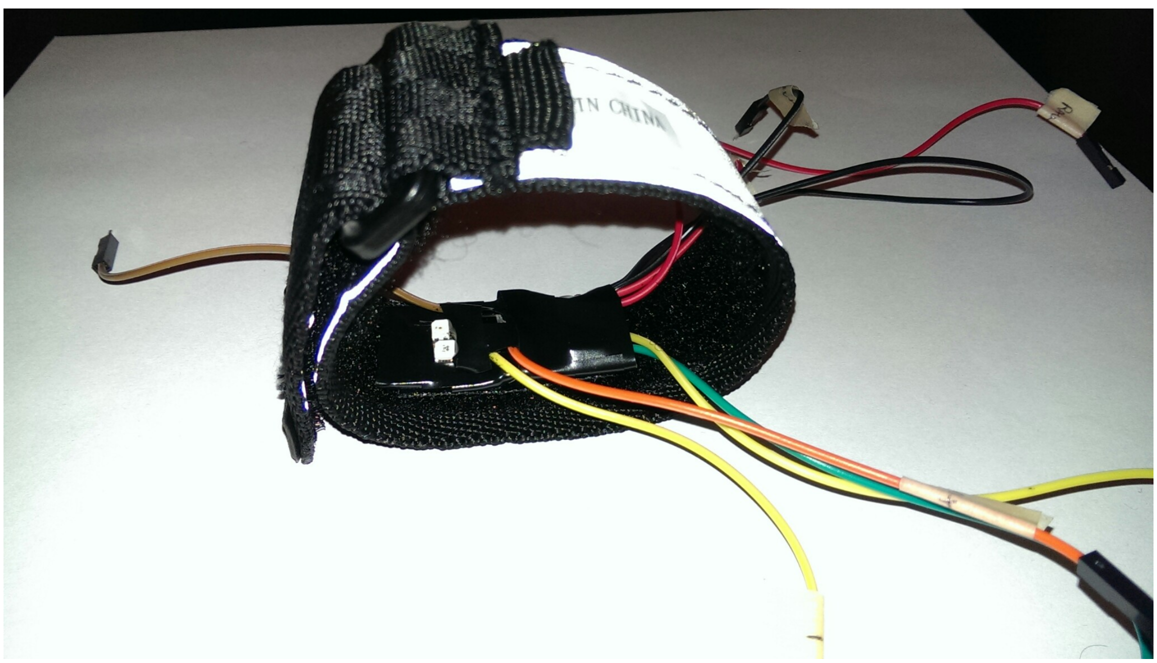


Figure 5.1: Developed Prototype with sensor module

5.2 Hardware Description

The hardware system consists of the watch, which include sensor module that is used to detect the bio potential signals from the wrist, the amplifier to amplify the acquired signal, microprocessor to digitalize and process the signal, and the Bluetooth communication module to transmit the processed signal from the microcontroller to the receiver end for monitoring. The complete hardware module is designed and fabricated in a way such that, it can be mounted on the strap of the watch. Since, the hardware unit can be mounted on the watch, the user can use it as one of the daily wearable.

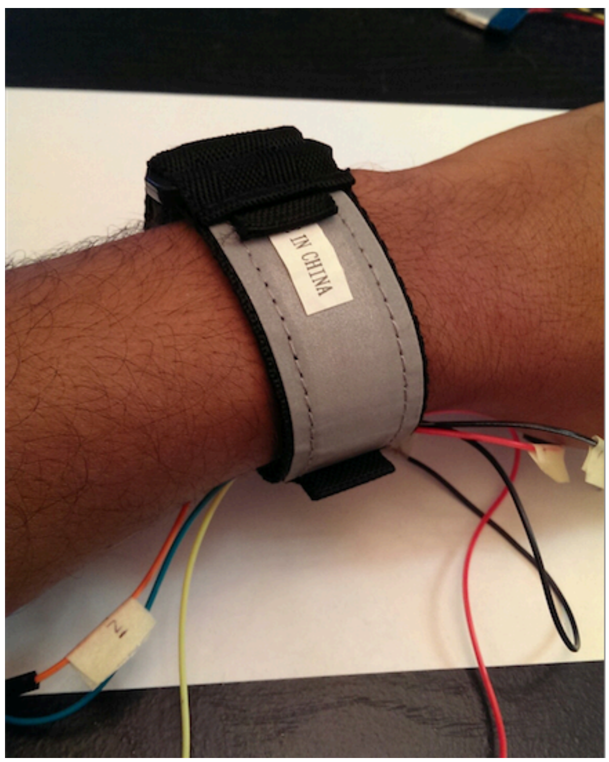


Figure 5.2: Developed prototype worn as a watch

5.2.1 Sensor Module

The sensor module is equipped with the IR LED and Red LED to incident the light into the wrist, and the photo diode for capturing the reflected signal with data in it. The driver IC L293DD was added for driving the LEDs. This acquired signal from the photodiode is transmitted to the amplification and processing module and are then transmitted to the receiver through Bluetooth communication.

5.2.2 Amplification module

Generally, the bio potential signals acquired from the sensor module are in the range of microvolts to millivolts. Since the signals acquired are very small, the amplification of the signals is needed. It also contains some noise signal with it due to the internal and external source. To avoid those noise signals, filters are used. Therefore, to obtain a good quality signal, the signals are amplified and filtered with the particular gain for further processing.

The amplification module is designed for a single channel. This single channel amplification module consists of three stages: Instrumentation amplifier, and the operational amplifier with high pass filter with non-inverting amplifier and third stage with high pass filter and second order low pass filter. INA114 was used for the instrumentation amplifier that has high common mode rejection ratio (CMRR) and TLC 272 was used for the operational amplifier. This is how, the acquired PPG signal is amplified and filtered which is to be processed on the next stage.

5.2.3 Processing module & Power Management

The processing module consists of the Microcontroller unit. The amplified and filtered signals from the amplifier are sent to microcontroller for processing and analog to digital conversion. The microcontroller is used for the data acquisition and data conversion (A/D). The microprocessor used for processing the signal is AT mega 328P, manufactured by Atmel. AT mega328P microcontroller is the high performance, Low power consuming, 8 – bit microcontroller. Some of the features of this microcontroller are: Low power consumption, Advanced RISC Architecture with high endurance Non-volatile memory segments, power on reset and programmable brown=out detection and many more. The operating voltages ranges from 1.8V to 5.5V. The temperature range is from 40°C to 85°C. The operating voltage used in this system for this microcontroller is 5V. The microcontroller digitalizes the acquired analog signal from the amplifier and sends it to the receiver module through Bluetooth communication. The amplified and the filtered data from the amplifier are transmitted to the microcontroller. In the microcontroller, A/D conversion takes place and the digital data are used to calculate the SpO2 values with the mathematical calculation in the programming. The peaks of the IR led and Red led are detected, compared and the SpO2 values are obtained. These SpO2 values are sent to the receiver module using Bluetooth communication.

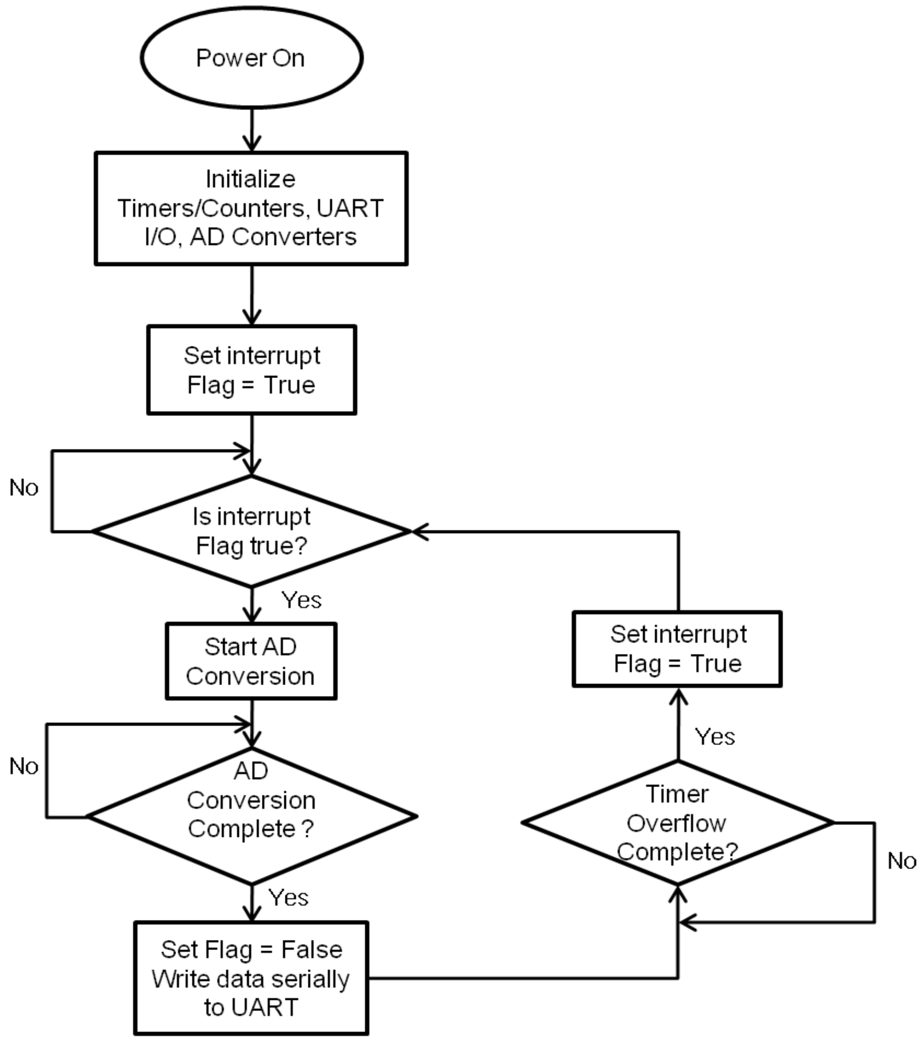


Figure 5.3: Microcontroller Algorithm Implementation

The microcontroller is powered by the battery. The algorithm initializes the timer, UART, i/o ports and the A/D converters. The interrupt flag is set. If the interrupt flag is set, the A/D conversion takes place. After the A/D conversion, it writes the data serially to the UART. Then it checks whether the timer overflow is completed. If it is completed, it sets the interrupt flag and the procedure repeats with next data for the A/D conversion. This is how, the A/D conversion takes place with the help of Algorithm implementation.

A lithium-ion battery of 3.7V and 220 mA as the voltage and current capacity powers the whole unit at the transmitter end respectively. A shunt voltage reference, LM4041 and the charge pump is used to step-up the voltage to 5V for some of the components used in the module.

5.2.4 Wireless Communication module (Bluetooth)

The acquired and processed signal from the sensor module in this system is transmitted to the receiver end through the Bluetooth communication, since the short distance communication is preferred for this system. The Bluetooth module along with the sensor and processing module is mounted on the strap of the watch, which makes it easier as a wearable. The Bluetooth communication standards is chosen from various wireless communication standards according to the requirements and best suitable for the system with low power consumption. The Bluetooth works at the frequency of 2.4 GHz. The Bluetooth transceiver at the transmitter end transmits the acquired signal to the receiver end that has the Bluetooth transceiver. The below flowchart explain the implementation and the working of Bluetooth communication.

During the Bluetooth communication, The Bluetooth module from the sensor broadcast the SPP after the power is switched on. At the data receiver end (smart phone or PC), the discovery protocol is introduced to discover the sensor module. Then, the discovery is successful. Now, the service protocol is introduced. Then, the serial port service is identified. The handshaking is successful. After this, the sensor module is paired with the receiver device. The Bluetooth module in the sensor requests for a 4 digit pin to authorize the pairing. Then, the pairing is successful. After successful pairing, the device requests for the SPP connection. After the successful SPP connection, the device start receiving data from the sensor. This is how, the Bluetooth communication initiates and sends data to the device wirelessly.

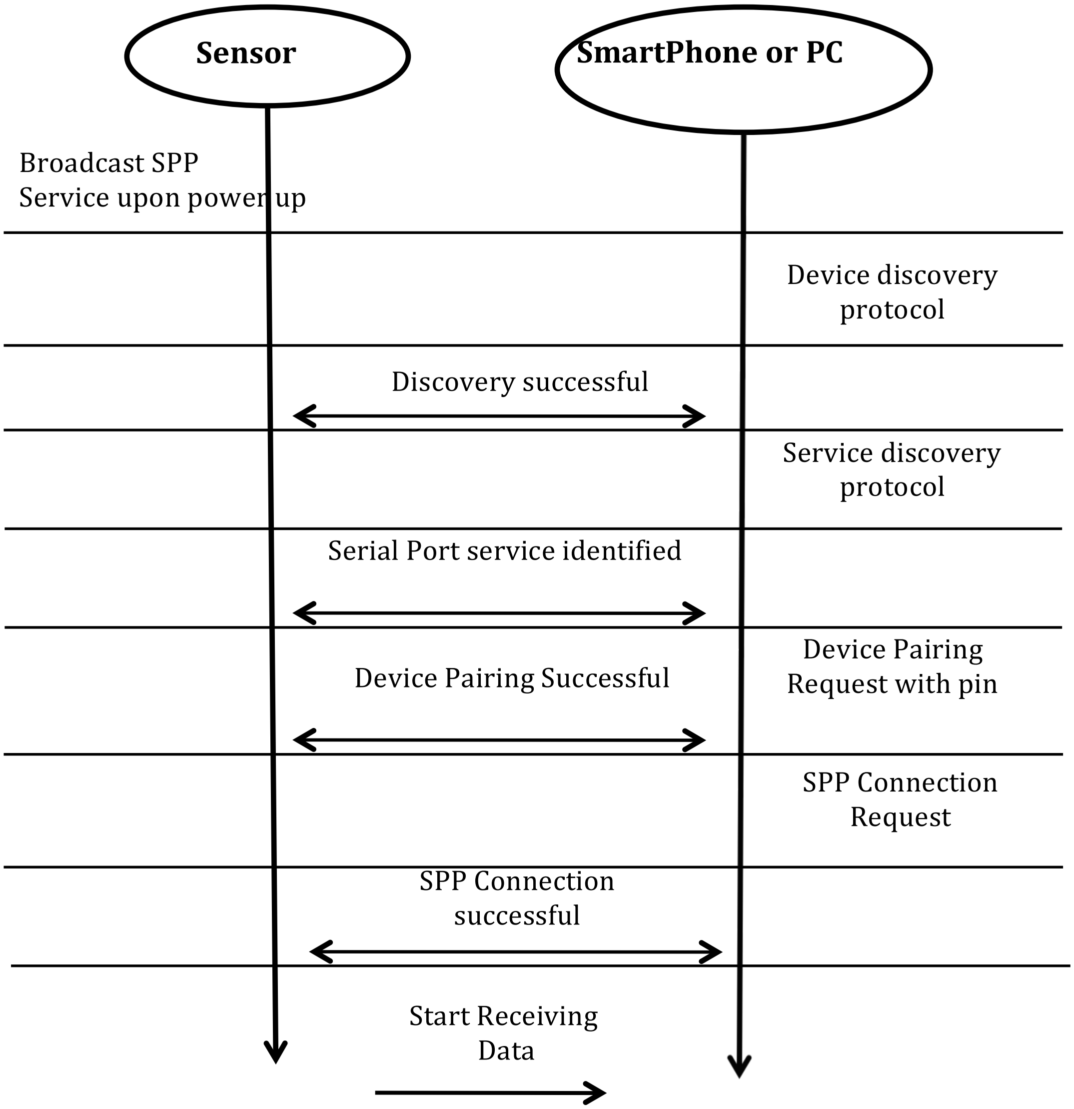


Figure 5.4: Working of Bluetooth Communication

5.3 Software Description

At the receiver end, the software implementation is done for the processed and transmitted data from the transmitter side, using MATLAB programming platform. The software implementation is done for the data acquisition, data management and the display of the expected output of the PPG signal with calculated oxygen saturation level in the blood. The algorithm for the Bluetooth is also added to the program to acquire the transmitted data. This helps to display the expected output on the screen of the laptop or PC.

At the software end, the Bluetooth communication takes place by initializing the connection between the sensor module and the receiver device. Then the data are received from the senor module. These calculated SpO2 data from the microcontroller are displayed on the screen of the Laptop or PC.

Chapter 6: Tests and Results

The above prototype is designed, developed and then the tests and experiments were performed. Below are the test procedures, results, discussions and the validation of the prototype.

6.1 Test procedure, Results and Discussions

The prototype is wired and powered by a lithium-ion battery. Then the prototype is connected to the computer through Bluetooth. The handshake is made and the data are transferred and displayed on the computer monitor. The raw data from the amplifier is taken to the oscilloscope. Comparing the raw data with the calculation for the oxygen saturation and the actual displayed output on the computer monitor, results on the screen and the raw data signal are validated. The data points of the result from the oscilloscope are saved and are plotted using excel. Below are the obtained sample results from the oscilloscope.

From the below figures 6.1, 6.2, and 6.3, PPG signal of the IR led and Red led can be observed. The waveform above the reference point indicates the IR led PPG signal and the inverted waveform below the reference point indicates the Red led PPG signal. The SpO2 values are calculated comparing these two PPG signal of IR led and Red led.

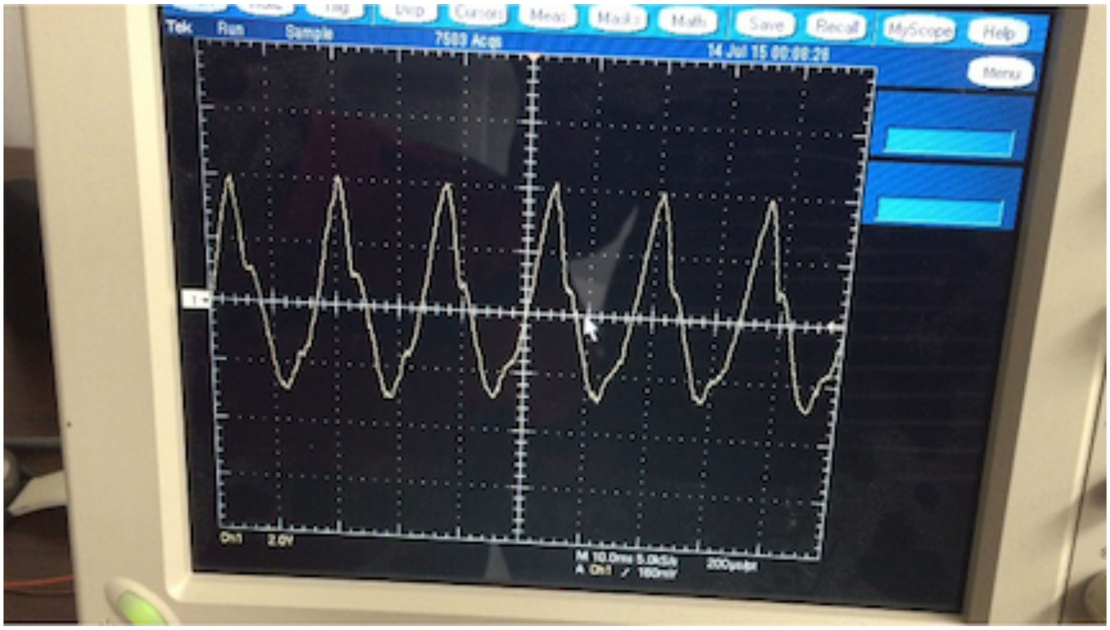


Figure 6.1: Oscilloscope SpO2 Waveform signal-1 from the developed prototype

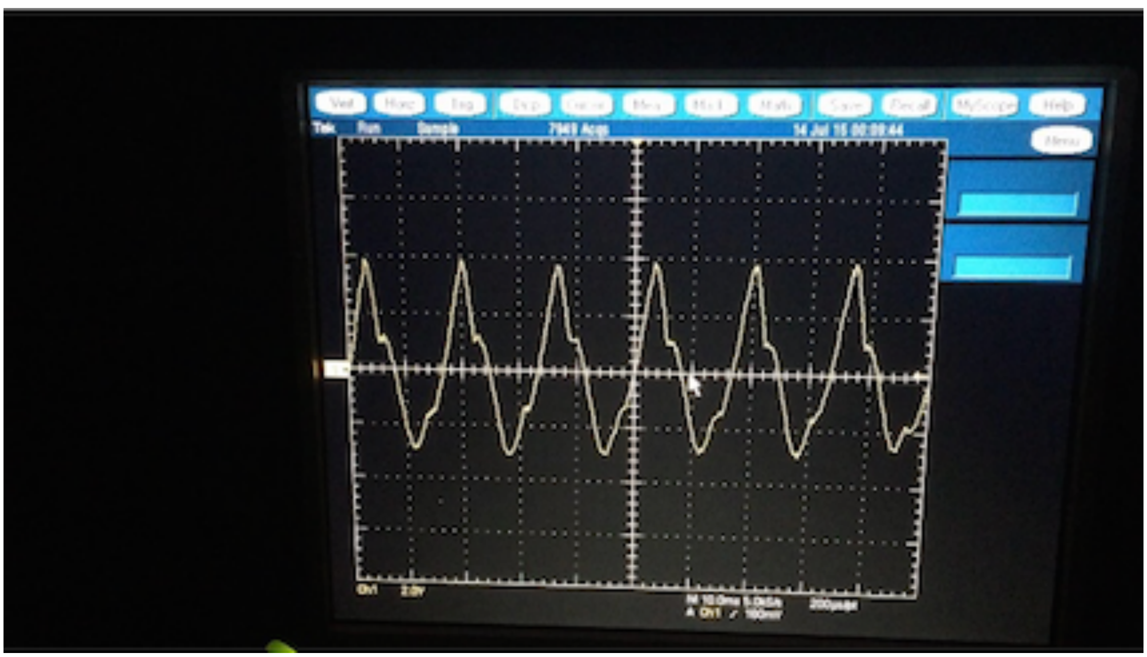


Figure 6.2: Oscilloscope SpO2 Waveform signal-2 from the developed prototype

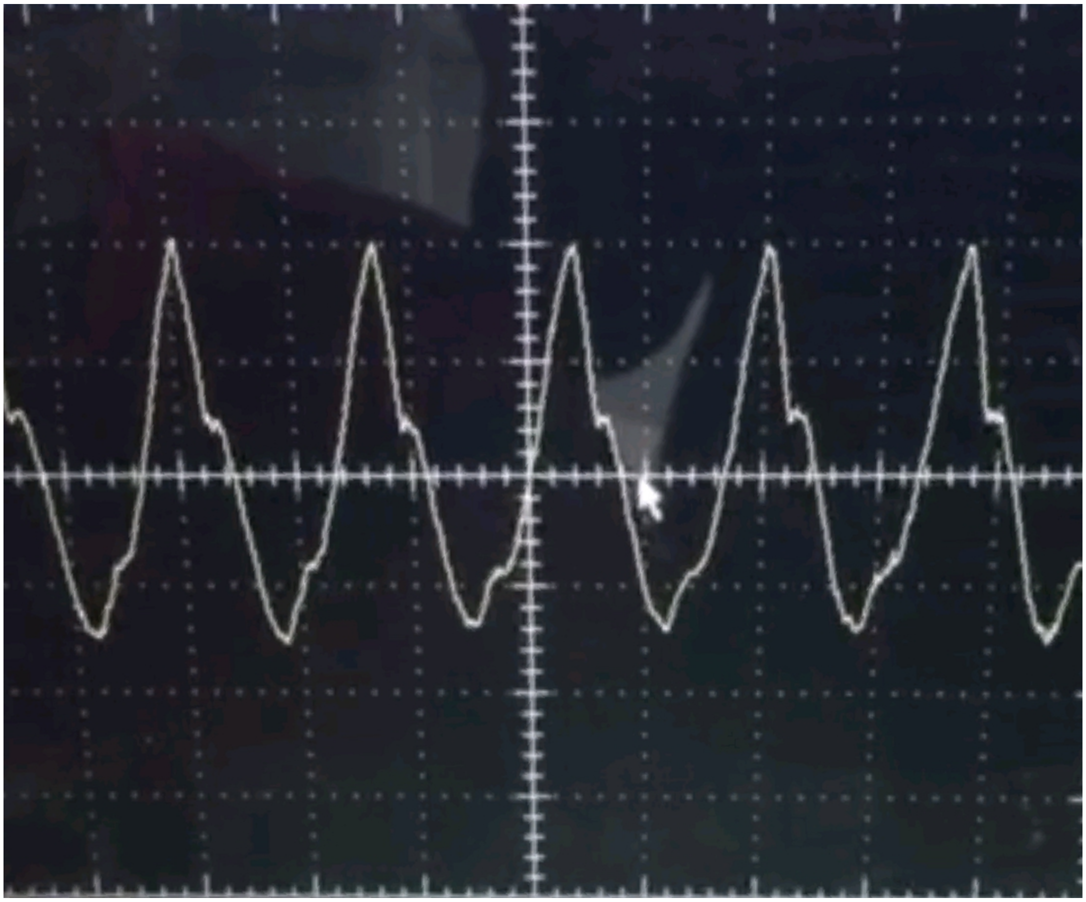


Figure 6.3: Oscilloscope SpO2 Waveform signal-3 from the developed prototype

From this waveform, various parameters are taken and used for the calculation.

The below formulae are used to obtained the value of SpO2.

$$\Delta X = \log\ (IR/(IR - \Delta IR) \ldots (1)$$

$$\Delta Y = \log\ (R/(R - \Delta R) \ldots (2)$$

$$\emptyset = \Delta X/\Delta Y \ldots (3)$$

$$SpO2\ \% = \left(\frac{IRm}{IRm+Rm}\right) * \emptyset * 100 \ldots (4)$$

Where,

- IR refers to the maximum amplitude of the infrared led signal
- R refers to the maximum amplitude of the red led Signal.

- ΔIR *and* R refers to the minimum amplitude of the infrared and red led signal respectively.
- ΔX *and* ΔY refers to the difference between the maximum and the minimum amplitude of the infrared and red signal respectively.
- $\emptyset$ is the absorbing light constant.
- IRm and Rm refers to the average of the infrared and red pulse signal respectively.

This is how the SpO2 value is calculated from the infrared and red led pulse signal.

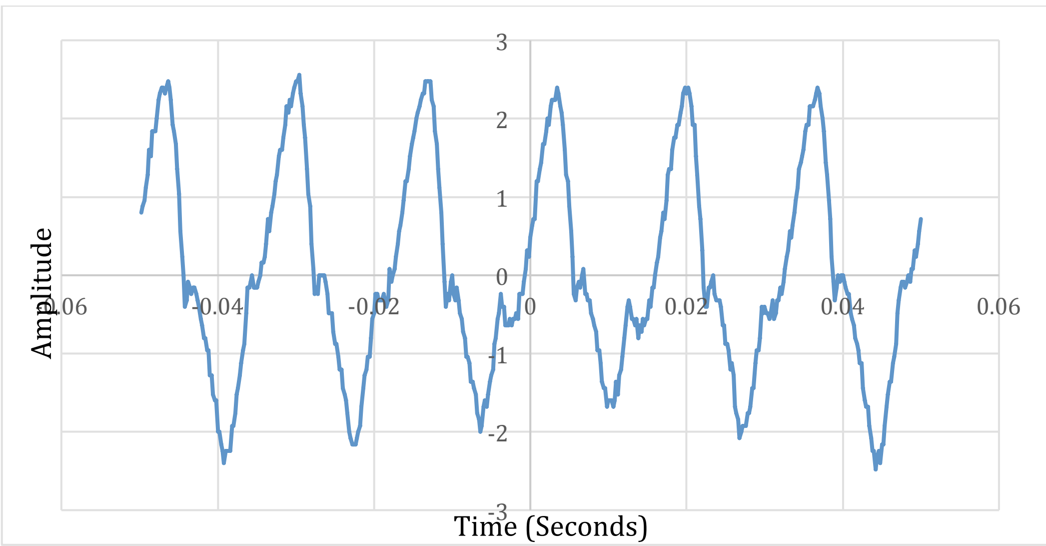


Figure 6.4: Excel plotted SpO2 waveform signal from Oscilloscope

From the above plotted signal, the SpO2 value is calculated.

$\Delta X = \log\ (IR/(IR - \Delta IR)$ --- (1)

$\Delta X = \log (2.56 / (2.56 – 2.4))$

$\Delta X = \log 16 = 1.20$

$\Delta Y = \log (R/(R - \Delta R)$-- (2)

$\Delta Y = \log (2.3 / (2.3 – 1.8))$

ΔY = log 4.6 = 0.66

$\emptyset = \Delta X / \Delta Y$ -- (3)

$\emptyset$ = 1.818

$SpO2\ \% = \left(\frac{IRm}{IRm+Rm}\right) * \emptyset * 100$ --- (4)

SpO2 % = (2.45 / (2.45+2.08)) * 1.818 * 100

SpO2 % = 98.3 %

From the mathematically calculated result, SpO2 % = 98.3%.

The average processed value from the microcontroller that appeared on the display is 98.6%

This negligible difference is because of the rounding-off the value while calculating manually.

6.2 Validation

The obtained results are validated by, comparing the results obtained with the clinically validated pulse oximeter for accuracy. The pulse oximeter used for validation is '**Reli On™ Pulse Oximeter**' device.

The measurement accuracy given in the Operator's manual is 70% - 100% $\pm$ 2 digits.

No. of Tests	Reli On™ Pulse oximter (SpO2 %)	Developed Prototype (SpO2 %)	Percentage Difference (%)
1	99	98.5	0.5
2	98	98.2	0.2
3	99	98.9	0.1
4	98	99	1
5	98	98.6	0.6

Table 6.1: Comparison table of clinically validated device and the developed prototype for validation

From the above-tabulated results, the percentage difference varies from 0.1% to 1%, being the measurement accuracy of the clinically validated pulse oximeter has $\pm$ 2 digits.

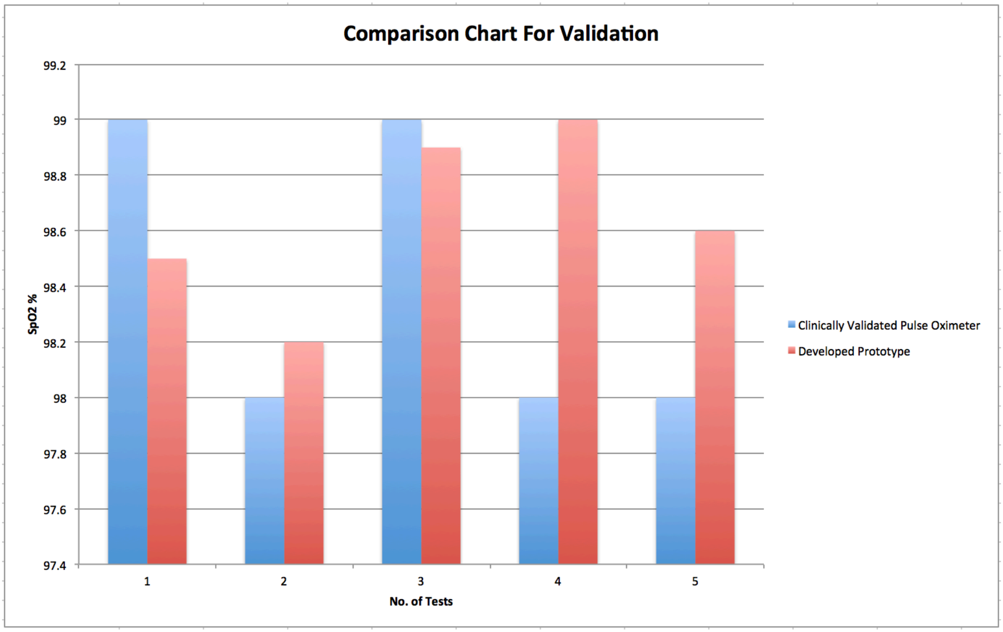


Figure 6.5: Comparison Chart for Validation I

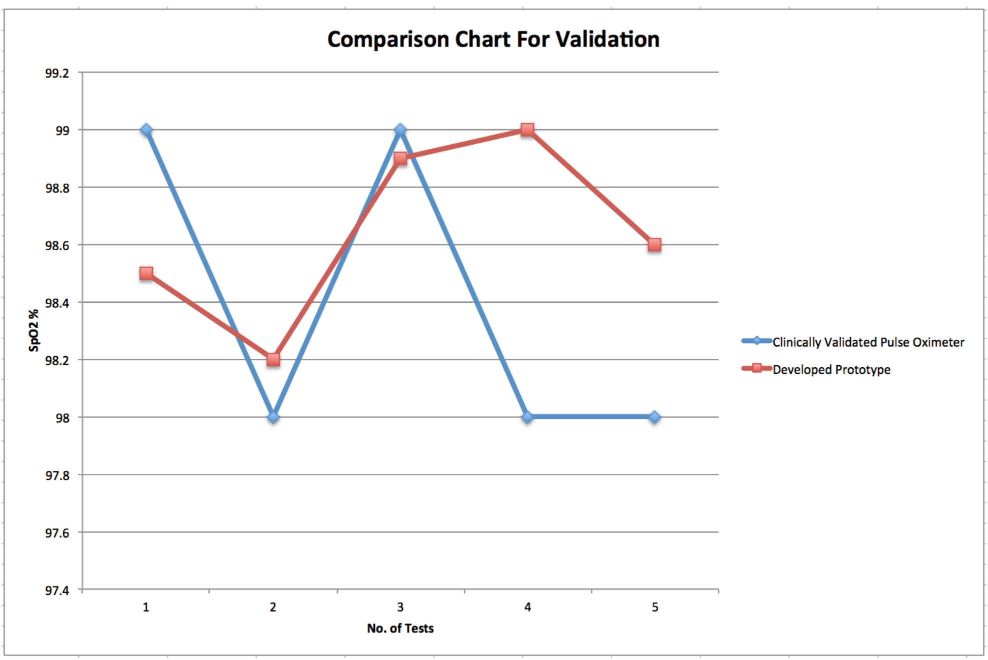


Figure 6.6: Comparison Chart for validation II

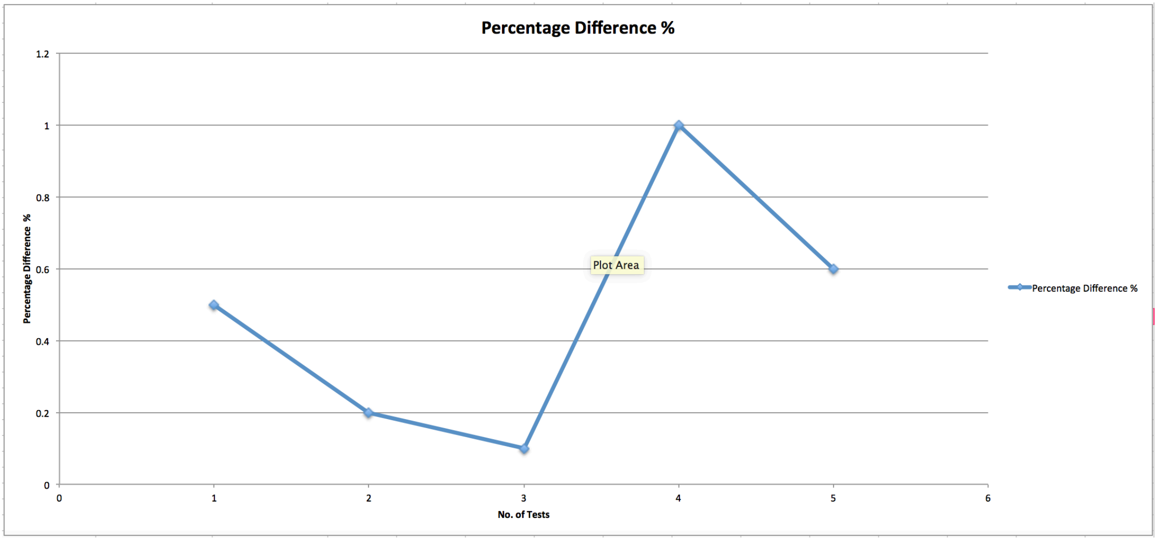


Figure 6.7 Graphical presentation of the Percentage Difference.

There are many factors like motion artifacts, placement of sensors, etc., to be worked on in the future that would bring up the completely accurate and clinically validated device of this developed prototype. The conclusion and future work is explained in the forthcoming chapters.

Chapter 7: Conclusion & Future Work

7.1 Conclusion

As an outcome of the pursued research work, the real time wireless health monitoring (Pulse Oximeter) monitoring is depicted in this thesis. This prototype of Real time health monitoring system was designed and built to monitor the people's health wirelessly at any time and make precautionary measures to avoid death or illness. The wearable technology is implemented with this system for the people to feel comfortable without any add-ons to there daily wear that would not make them feel conscious. The modules, which include watch with sensor, amplifier, microcontroller and software, were designed and developed to implement the proposed prototype, practically by carefully analyzing the abstract and the research method done by other research groups to give the improved version of the monitoring system available currently. During this research, several methods and technique were studied and implemented.

Firstly, to get a better understanding of the concept, a detailed study of researches and the commercially available devices that are similar to my thesis were studied to give a state of art knowledge. By doing the above, it was helpful to design and develop this prototype with considerable improvement and solving some of the drawbacks of the previously done research.

Secondly, the bio-potentials part was concentrated to get the basic idea for evaluating the human's health. The classifications of bio-potential signal were studied and the waveforms of each and every bio-potential signal were analyzed to get the exact person's body condition. Then the principle and the method of measurement of bio potentials were studied and given in thesis as a chapter for a better understanding of the concept used for the prototype.

Thirdly, for the communication of the extracted data from the human body to be displayed wirelessly, the wireless communication standards were studied and compared. With the comparison of the wireless standards, the Bluetooth technology was implemented for the proposed prototype, as it satisfies the short distance communication, low power consumption and the other specification required for the prototype.

Fourthly, with all the studies made above, the proposed prototype was design and developed with the sensor module that acquired the signal, processed it with the amplifier and the microcontroller and displayed it on the computer using the software. To acquire the PPG signal, the sensor module that includes IR LED, Red LED and a photodiode were used. Then for processing the acquired signal through the sensor module, the amplifier circuit was designed and microcontroller was used for digitalizing the acquired analog signal. To power up the whole module, the rechargeable, lithium ion battery was used which excluded external power supply. The Bluetooth module is placed, for the wireless communication with the computer or laptop for displaying the acquired signal and the expected output for the user's convenience. For displaying the measured oxygen saturation (SpO2) and the pulse signal, MATLAB is used as a software module.

Lastly, with the developed prototype, several tests were performed to analyze and validate the results of the system. The results were displayed and the analyses were discussed in previous chapter. With the above results and discussion, it is showed that the heath of the humans can be monitored with this developed prototype.

7.2 Future Work

Finally, the proposed concept of the wireless health monitoring system- A smart watch approach has been developed and tested. However, this system can be used for the future research to improve the performance and modify the system according to the trend at that period. There are several suggestions for the future work to be done on this thesis as follows:

- With the reference of the developed prototype, the sensor module can be fabricated separately to improve the placement of the special sensors in the module and the accuracy even if the watch is not tight enough.
- The motion artifact can be included to the system, for better results when there is a movement of the hand or wrist.
- The GSM module can be added to the system to communicate with other devices or server for monitoring by other people such as relatives and doctors and notifying the same people if there is an emergency.
- The GPS system can be added to the system, so that if in case of emergency, the person using this system can be located and emergency backup can be sent to the place immediately.

This chapter gives some suggestions for the improvement of the system as the future work.

References

[1] CDC, NCHS. Underlying Cause of Death 1999-2013 on CDC WONDER Online Database, released 2015. Data are from the Multiple Cause of Death Files, 1999-2013, as compiled from data provided by the 57 vital statistics jurisdictions through the Vital Statistics Cooperative Program. Accessed Feb. 3, 2015.

[2] Mozaffarian D, Benjamin EJ, Go AS, et al. Heart disease and stroke statistics—2015 update: a report from the American Heart Association. *Circulation*. 2015;131:e29-322.

[3] CDC. State Specific Mortality from Sudden Cardiac Death: United States, 1999. *MMWR*. 2002;51(6):123–126.

[4] CDC. Disparities in Adult Awareness of Heart Attack Warning Signs and Symptoms—14 States, 2005. *MMWR*. 2008;57(7):175–179.

[5] Heart disease and stroke statistics—2015 update: a report from the American Heart Association [published online ahead of print December 17,2014]. Circulation. doi: 10.1161/CIR.0000000000000152.

[6] http://blog.heart.org/american-heart-association-statistical-report-tracks-global-figures-first-time

[7] Duke University Medical Center. (2005, October 10). Discovery Links Blood Cell Defect To Common Lung Disorder, Leads To Novel Treatment.*ScienceDaily*. Retrieved November 28, 2015 from www.sciencedaily.com/releases/2005/10/051007094528.htm

[8] *"What Are Congenital Heart Defects?". National Heart, Lung, and Blood Institute. July 1, 2011. Retrieved 10 August 2015.*

[9] Webster, J. (1999). *The measurement, instrumentation, and sensors handbook*. Boca Raton, Fla.: CRC Press published in cooperation with IEEE Press.

[10] Malmivuo, J., & Plonsey, R. (1995). *Bioelectromagnetism: Principles and applications of bioelectric and biomagnetic fields*. New York: Oxford University Press.

[11] https://en.wikipedia.org/wiki/Electrocardiography

[12] http://hematoxylineosin.tumblr.com/post/45199333388/arterial-pulse-and-its-variants

[13] http://medcaretips.com/different-types-of-abnormal-pulses/

[14] Labiod, H., Afifi, H., & De Santis, C. (2007). *WI-FI TM, BLUETOOTH TM, ZIGBEE TM AND WIMAX TM*. Dordrecht: Springer.

[15] Shelley K. and Shelley S., "Pulse Oximeter Waveform: Photoelectric Plethysmography," Clinical Monitoring, Carol Lake, R. Hines, and C. Blitt, Eds.: W.B. Saunders Company, (2001): 420-428. Print.

[16] Shelley K. H., Jablonka D. H., Awad A. A., Stout R. G., Rezkanna H., and Silverman D. G., "What Is the Best Site for Measuring the Effect of Ventilation on the Pulse Oximeter Waveform?" Anesth Analg, (2006): vol. 103, 372-377. Print.

[17] Reisner A, Shaltis. P. A., McCombie D., and Asada, H. H., "Utility of the Photoplethysmogram in Circulatory Monitoring, Anesthesiology," Anesthesiology, (2008): vol. 108, pp. 950-958. Print.

[18] http://produceconsumerobot.com/biosensing/

[19] Mendelson, Y. "Pulse Oximetry." Wiley Encyclopedia of Biomedical Engineering (2006): vol. 5. Hoboken, NJ: John Wiley & Sons, Inc. Print.

[20] Pole, Yash. "Evolution of the Pulse Oximeter." International Congress Series 1242 (2002): 137-44. Print.

[21] http://spectrum.ieee.org/biomedical/devices/injectable-optoelectronics-for-brain-control

[22] http://www.medgadget.com/2014/04/flexible-skin-worn-patch-monitors-eeg-ecg-sends-recorded-data-via-wireless-video.html