WBAN Characterization, Simulation and Analysis

A Dissertation submitted towards the partial fulfilment of
the requirement for the award of degree of

Master of Technology in
Microwave and Optical Communication Engineering

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DELHI TECHNOLOGICAL UNIVERSITY

Established by Govt. of Delhi vide Act 6 of 2009

(*Formerly Delhi College of Engineering)*

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CERTFICATE

This is to certify that the work which is being presented in the dissertation entitled " **WBAN Characterization, Simulation and Analysis**" is the authentic work of **SHASHANK** under my guidance and supervision in the partial fulfilment of requirement towards the degree of Master of Technology in Microwave and Optical Communication Engineering jointly run by Department of Applied Physics and Department of Electronics and Communication in Delhi Technological University during the 2014-16.

As per the candidate declaration this work has not been submitted elsewhere for the award of any other degree.

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DECLARATION

I hereby declare that all the information in this document has been obtained and presented in accordance with academic rules and ethical conduct. This report is my own, unaided work. I have fully cited and referenced all material and results that are not original to this work. It is being submitted for the degree of Master of Technology in Microwave and Optical Communication Engineering at Delhi Technological University. It has not been submitted for any degree or examination in any other university.

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ABSTRACT

Due to over busy schedule and unhealthy lifestyle, the modern generation is facing continuous health problems. For proper healthcare of current generation, a regular health check up is the must but the constraint being over busy schedule and long queues of physicians which develops a necessity of such a system that monitors health parameters at regular intervals and transfers the critical information to the physician.

The current wireless sensor technology utilized for the same can serve the purpose. The protocol designed for such purpose is called Wireless body area network that has a sensor body area network sensing and transmitting information wirelessly.

The idea is to design a system capable of sensing desirable body parameters and transmit the information wirelessly to a processing system capable of understanding the value and comparing it with the limits of critical conditions. The system must have an active internet or messaging service to communicate with the physician whenever required. The transmission to the physician must be only confined to critical conditions. The same design can be utilized for athletes but the information is completely transmitted to the observer without any comparison so that the overall performance analysis can be done.

The WBAN prototype proposed is capable of sensing body parameters and transmitting the information via Bluetooth to the processing unit where a comparator block is designed to compare the values obtained to the critical data for the same. Another conditioning block is designed for large data information so that the critical data information can be compressed and encrypted before transmission over the internet in order to minimize the bandwidth required for transmission and to improve the security of transmission. For the compression, discrete cosine transform and for encryption Gyrator transform is proposed.

The expectation is to characterize a WBAN prototype, design its hardware, transmit the information wirelessly to processing unit, analyze the values and compare them with critical limits using a comparator specially simulated for the same, compress and encrypt the critical data and transmit it to the concerned authority using active internet or messaging service.

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At first, I owe my deepest gratitude to my mentor **Prof. P.R.CHADHA**, whose guidance, continuous support and positive criticism enabled me to become familiar with the subject. It would have been merely a dream to finish this work without his continuous support and motivation.

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I am indebted to my family and friends for their trust in me that made me confident enough to complete this work. Their support in a number of ways must also be acknowledged here.

Above all, the infinite grace of almighty God is of essential importance and I solemnly offer my regards for His grace which enabled peace and harmony for this work.

LIST OF ABBREVIATIONS

BAN – Body area network

BP- Blood pressure

BPSK - Binary phase shift keying

BSN – Body sensor network

COM - Computer

CSMA-CA - Carrier sense multiple access-collision avoidance

DC- Direct current

DCT - Discrete cosine transform

ECG – Electro-cardio graph

EEG – Electro-encephalogram

EMG- Electromyography

FCC- Federal communications commission

GFSK - Gaussian frequency shift keying

GPS- Global positioning system

GSM – Global system for mobile communication

GT - Gyrator transform

GUI - Graphical user interface

IC - Integrated circuit

IDCT - Inverse discrete transform

IEEE- Institution of electrical and electronics engineers

IFT - Inverse Fourier transform

I/O - Input output

ISM - Industrial scientific and medical

K-map – Karnaugh map

Kbps - Kilo bits per second

LCD - Lead crystal display

LED - Light emitting diode

Mbps - Mega bits per second

OFDM - Orthogonal frequency division multiplexing

PAN – Personal area network

PC - Primary communication circle

PD - Personal device

PPU - Primary processing unit

QPSK - Quadrature phase shift keying

RFID - Radio frequency identification

SC- Secondary circle

SPU - Secondary processing unit

SMS - Short message service

TC- Tertiary circle

TTL - Transistor-transistor logic

USB -Universal serial bus

UWB - Ultra wide band

WBAN - Wireless body area network

WLAN -Wireless local area network

LIST OF TABLES

TABLE NO. **TITLE** **PAGE NO.**

LIST OF FIGURES

FIGURE NO. **PAGE**

CONTENTS

CHAPTER 1: INTRODUCTION

1.1 HISTORY

In the past two decades, the growth in sensor development and integrated circuits miniaturization has been surprisingly high with new developments in sensor network technologies and inventions of useful technologies with innovative ideas that make completion of daily tasks easier and much quicker. As the technology is progressing, physiological sensor development is also improving with low power consumption of integrated circuits and inter-operability of different technologies which made it possible to develop anything desired as per the requirement of situation. With combination of wireless communication with emerging technologies like sensor network technologies, new achievements like monitoring of traffic, air and water pollution control, health monitoring of critical patients with chronicle diseases , monitoring and improvement of quality of crop etc. could be possible. A similar emerging idea is the development of WBAN also referred as wireless body area network or BAN i.e. body area network or BSN i.e. body sensor network.

In 1995, the WBAN technology concept initiated with the idea of using personal area network (PAN) around close proximity with the human body in order to achieve communication link on or around the body for observing critical details about changes in external environmental conditions and reaction of human body senses to those changes. About six years later in 2001, BAN achieved existence as a sensor network with complete operability under close vicinity of a human body. Since then, there have been tremendous modifications and upgrades to the technology for achieving the optimum results out of it. As this technology links body sensor network with wireless communication, there is a huge list of challenges and scope of improvement in the technology that makes WBAN even more eye catching for those who wish to contribute towards advancements in technology.

1.2 CONCEPT

The idea behind a WBAN design may vary according to the requirements of the system using WBAN but the basic concept remains real time sensing of desired parameters on the body and transmitting it wirelessly to a node where it can be connected to the internet so that the information can be transmitted in minimum time. There might be a low complex to moderate complex processing and comparing of the data obtained in order to filter the critical data for more prior transmission. The widely used model consists of different tiers of communication between the sensors and the node that connects the internet. The following figure will help in developing a basic concept about the basic concept and functionality of WBAN and to understand about the problems and scope of improvement in the technology. Also, the discussion will help in developing an understanding of the vast area of application and the domain of possibilities associated with associating WBAN with different technologies.

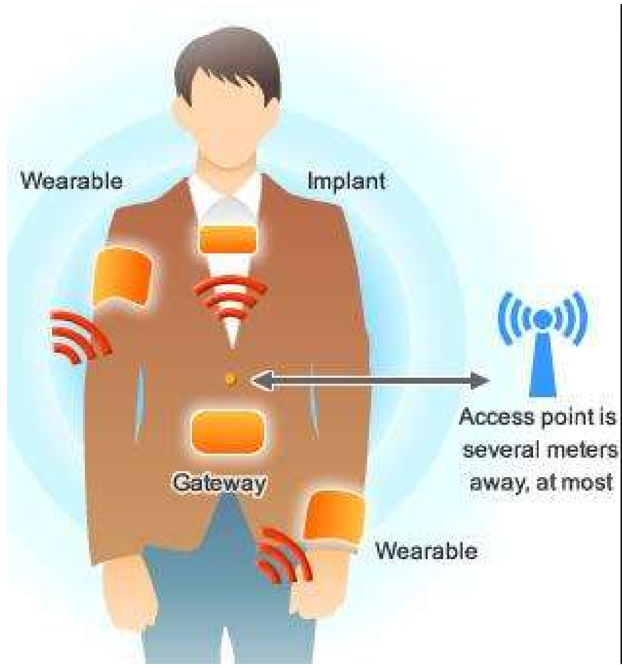


Figure 1.1 WBAN basic model

The above figure shows WBAN basic model with some wearable sensor nodes and some implants. All these sensors sense in real time and communicate with the gateway where small amount of pre transmission signal processing is done due to constraint of low power consumption as present on the human body. The conditioned signal is then transmitted to the node connected to the internet where signal comparison and proper processing can be done because it is separate from the body and hence external power source can be used. The pre processing and comparison of signal done at the node connected to the internet decides the online transmission criteria according to the priorities set up by the user.

If only a single sensor parameter is sensed by WBAN, the use of gateway node can also be avoided as the transmission can be directly done at the sensor node between the sensor node and the processing node with internet access as there is no requirement of combining different data from different sensors. For such conditions, a small amount of pre transmission processing is an option at the sensor node.

The design of WBAN may differ according to the application of the network e.g. the WBAN with critical patient's condition may employ a GSM module attached right at the gateway that saves processing time before transmission. A healthy person must have a process with complete transmission after comparing the data obtained at the processing node. Similarly WBAN associated with performance monitoring of an athlete might have a monitoring and transmission rate higher than the normal patient's data transmission as it is more critical for performance evaluation. Similarly the technologies employing gesture and movement control operations also require very high data transmission as no lag is permissible in such cases.

The figure given below shows WBAN used for health monitoring in case of a critical patient. All the sensors communicate to the base unit i.e. the gateway that wirelessly transmits to the processing unit. The processing unit is linked to the physician, ambulance and primary care provider units via internet as well as using GSM network. Thus a quick action can be taken as soon as there is an emergency for the patient under observation.

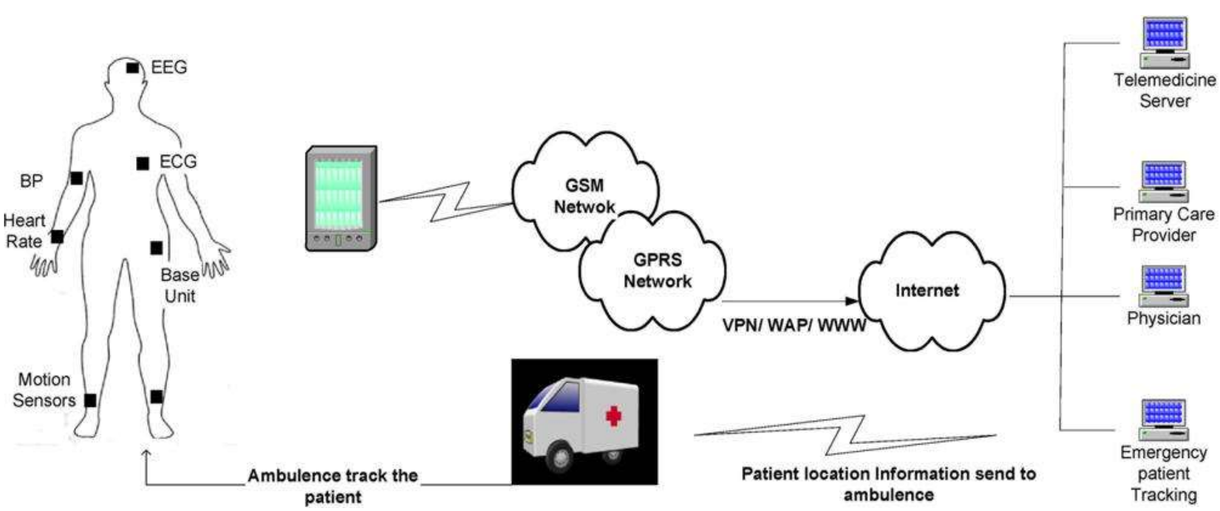


Figure 1.2 WBAN critical environment.

1.3 ADVANTAGES AND APPLICATIONS

WBAN being a sensor network associated with wireless communication of body parameters in real time thus it gives a huge advantage [11] in continuous health parameter monitoring with minimal disturbance in daily schedule. Also WBAN provides a wire-less communication link between critical patients and physician thus it is possible for a physician to diagnose a patient as soon as the critical emergency occurs. It also makes the continuous health care less expensive as a personal physician is not required always. Thus WBAN has a wide range of advantages in terms of flexibility of working and cost of monitoring.

The WBAN has a vast range of applications out of which some of the most popular ones are listed below:

1.3.1 People having continuous health issues:

WBAN for health monitoring links patient with physician and attending care along with ambulance in no time at the critical situations for patients who have serious health issues and at very frequent intervals of time thus, using a continuous check on health related parameters will help them with a quick attention from physician so that the case can be handled in time. This application can be very effective in saving some precious lives if treated in time. Some healthcare channels even use automated drones for immediate supply of essential life saving medicines with location tracked by GPS system enabled on the WBAN itself. Also it provides a free and mobile environment to patients. WBAN is highly advantageous for old and infants who are generally more prone to illness.

1.3.2 WBAN used in gesture control application and motion sensing application:

With the gestures and motions controlling the operations, the daily work has become very easy and interesting. Motion sensors attached to human body are used to make applications and most importantly games feel like real life situations and more interesting. The WBAN has been the major part of motion and gesture controlled gaming as this provides the information in real time.

1.3.3 WBAN for over busy people:

In today’s busy life, everyone is busy working hard and struggling for fulfilling their basic requirements. As the schedule for work is becoming tougher and tougher, avoidance towards personal health care has increased. This application can be quite much helpful for those who wish to have their regular health checkups done but can't spare time for it without any wired bonds or any harm.

Figure 1.3 WBAN applications.

1.4 CHALLENGES

As WBAN is a vast domain containing sensor network in association with wireless communication thus the challenges [11] and scope of modifications and improvement is also vast. specially the custom design of WBAN makes the options infinite as per different applications with which WBAN can be used. Amongst all there are some common and basic challenges that should be taken into consideration while developing a WBAN for any particular system although all these challenges are independently a complete project to deal with on their own. Some of the challenges that are commonly faced in WBAN are listed below:

1.4.1Interoperability:

The present standard for WBAN I.E.E.E. 802.15.6 that provides low power, highly reliable communication link for short ranges with multiple ranges of data rate as per required by different applications. The allowed frequency allotted for WBAN ranges in wide area radio link ranging from 2360MHz to 2400MHz providing a total of 40MHz for the low power medical BAN as per allocated by FCC(federal communications commission). A variety of other technologies also work in the same frequency range such as Bluetooth, ZIGBEE, WLAN using the same ISM band 2400MHz frequency thus, it is very much required for WBAN to operate with all the different technologies for successful information exchange as per the requirement of the system employing WBAN.

1.4.2 System devices characterization:

The characterization of the system employing WBAN is also very much of importance. The sensors used in WBAN are the most tedious to be made as they are required to be smaller in size, energy consumption , form factor and complexity also the association of a transmission technology with sensors is also of equal importance. The processing node in the system must also consist of a storage capacity to store the data to be transmitted and must be linked to the internet for active transmission of data as per the requirement of the system. A data management system must also be used for storing, handling and managing data obtained for processing and transmission in case of transmission failure at the internet end.

1.4.3Security:

Security has been a major challenge for WBAN systems as a secure data is the basic requirement of any transmission. Data of one person employing WBAN must not be misunderstood or exchanged with other one. Although a lot of work has not been done in security domain of WBAN due to the constraint of low power consumption and low complexity of the system at the sensor node, still a data can be processed and secured at the processing node that can be secured before transmitting through the internet.

1.4.4 Interference mitigation:

As the frequency allotted for transmission to WBAN by FCC clashes with that used by different other technologies, there is a fair chance of interference if another device is trying to transmit within the boundaries of WBAN thus producing interference and corrupted data transmission which can be a major challenge when multiple WBAN networks and different technologies are used in close proximity to each other. This problem can however be limited by mitigation of interference. One of the most emerging concepts that can be utilized in solving this problem is by understanding the behavior of the transmission channel and by channel sensing and utilizing the concept of cognitive radio. Although it is nearly impossible to employ cognitive channel sensing at the sensor node, still we can try to utilize it at the gateway node between sensors and processing node.

1.4.5 Cost and power consumption:

The cost and power consumption are also some of the major challenges in WBAN as the quality of sensors and conditioning of signal at gateway level must be very much accurate. As the signals in WBAN are mostly fetched from or through the body, mostly signals are corrupted and deformed by huge noise present on the body thus a very effective still lower in cost filter and sensor system must be utilized in WBAN.

CHAPTER 2 LITERATURE REVIEW

2.1 CHARACTERSTICS OF WBAN

2.1.1 Fundamental blocks

Nodes are the basic communication blocks in WBAN, basically those units which communicate within the network. Sensors, gateway, processing unit etc. all are referred to as nodes. Classification of nodes can be done on the basis of their functionality and implementation that nodes play in the WBAN internal and external network.

On the basis of functionality [2], nodes can be broadly classified in four types:

- Sensor node: This node basically functions in gathering information from the body about a desired parameter. The main function of sensor node is to sense the parameter from the body in terms of a signal or a value that is obtained in response to a physical stimulus by the body and transmit the data to the next operating node for further processing. According to the requirement of parameters there may be different types of sensors like blood pressure sensor, body temperature sensor, heart pulse sensor, skin sensitivity sensor, EMG, ECG, EEG imaging sensors etc.
- Actuator node: this node is present as a feedback system in WBAN with basic functionality of providing feedback to the signal transmitted by the sensor node. This node can be avoided in case where risk of multiple transmission interferences is very low.
- Gateway node: Sometimes also called as the personal device (PD) node, the gateway node is responsible for obtaining signals from different sensor nodes and combining all the signals as one before transmitting it to the external processing node. Sometimes actuator node can also be taken as a part of gateway node as a feedback from gateway to sensor node.
- External node: this is the node basically outside the WBAN which can be within the range of 5meters from the gateway node that receives the cumulative data from gateway node and processes and compares it before transmitting it. This node is usually connected with internet and other emergency transmission services in order to transmit the critical information in time. The maximum processing and data encryption and

compression is done at this node as it is external to the body thus can be used with external power supply option. All the other nodes have negligible processing capability due to power usage constraints.

On the basis of implementation of the nodes, the nodes in WBAN can be classified [2] into the following types by IEEE802.15.6:

- Implant node: when a node is implanted inside the body surface surgically, then such kind of a node is referred to as implant node. Mostly sensor nodes are implant nodes as some signals can be fetched more accurately beneath the skin as compared to sensors being over the body.
- Body surface node: the nodes present on the body are referred to as body surface nodes. Basically sensor nodes, actuator node and gateway node all can be body surface nodes. According to IEEE 802.15.6 a node placed within the distance of 2cm from the body surface is referred to as a body surface node. This node can be seen in form of wearable devices may it be sensor node or communication nodes.
- External node: those nodes which are present in the range from 2cm to 5 meters of the body surface are called external nodes. These nodes are not in direct contact with the body.

The communication frequency of the sensors depends upon the type of implementation of the sensors.

2.1.2 Communication scenarios in WBAN

According to the implementation and positioning of the sensor node while communication in WBAN different scenarios have been defined by IEEE802.15.6. Different scenario is allotted a different communicating operational frequencies and different channel models. A brief about the communication scenarios is as given in the table below:

Table 2.1 Communication scenarios.

Scenario	Frequency	Communication description	Channel model
S1	402-405 MHz	Implant node to implant node	CM1
S2	402-405 MHz	Implant node to body surface	CM2

		node	
S3	402-405 MHz	Implant node to external node	CM3
S4	13.5MHz, 50MHz, 400MHz, 600MHz, 900 MHz,2.4GHz, 3.1-10.6 GHZ(UWB)	Body surface to body surface (line of sight)	CM4
S5	13.5MHz, 50MHz, 400MHz, 600MHz, 900 MHz,2.4GHz, 3.1-10.6 GHZ(UWB)	Body surface to body surface (no line of sight)	CM5
S6	900 MHz 2.4GHz, 3.1-10.6 GHZ(UWB)	Body surface to external node (line of sight)	CM6
S7	900 MHz 2.4GHz, 3.1-10.6 GHZ(UWB)	Body surface to external node (no line of sight)	CM7

2.1.3 Topology of nodes

According to IEEE 802.15.6 standard the appropriate topology for WBAN network is the star topology [3] with the gateway node present in the centre of the topology and all the sensor nodes at the corners although if only a single sensor is used in WBAN the sensor can directly transmit to the external node making it similar to a modified bus topology. In general the star topology can be a one hop star topology or two hop star topology. The star topology has the advantage of minimum power consumption although it limits the transmission distance that is not a concern in WBAN transmission.

The one hop star topology [3] similar to the bus topology is used when only a single sensor is used in WBAN whereas the two hop topology is used in case of multiple sensors present in WBAN.

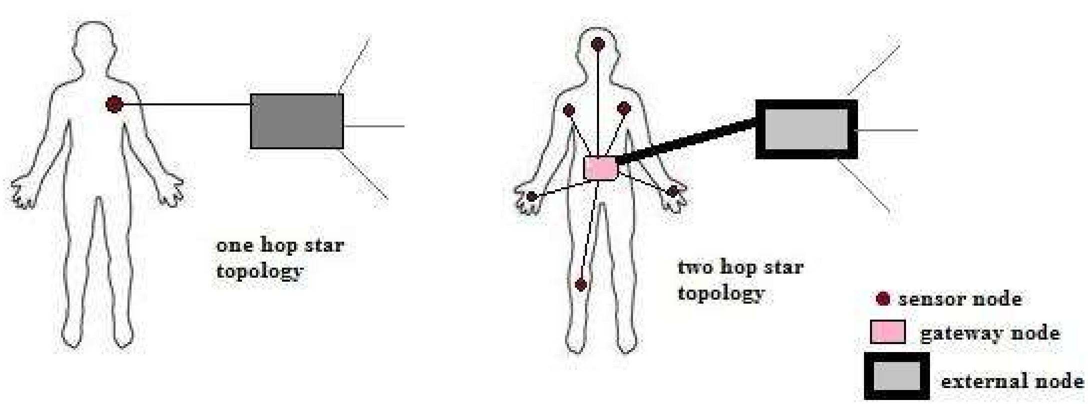


Figure 2.1 One hop and two hop star topology

There exist two modes of communication in WBAN:

- Beacon transmission mode [3]: In this transmission mode the gateway node or the coordinator node controls the transmission pattern between the sensors and the gateway. It sends periodic beacons that regulates transmission pattern. A beacon is transmitted after a regular interval of time to the transmission channel which is accepted by one of the sensor nodes that starts transmitting. After the transmission is complete, another beacon is sent to the channel and hence the communication between the sensors and gateway completes without any internal network interference. It is necessary in this mode that the beacon transmission is complete before the next sensing session at the sensor nodes start.

- Non beacon transmission mode [3]: In this transmission mode usually CSMA-CA (carrier sense multiple access collision avoidance) is used. The nodes are required to power up and poll the gateway for transmission.

2.1.4 WBAN architecture

WBAN basic architecture basically consists of multiple staged communication network [11]. The stages are:

Stage 1: Intra WBAN communication circle (primary circle)

Stage 2: Inter WBAN communication circle (secondary circle)

Stage 3: beyond WBAN communication circle (tertiary circle)

The figure below illustrates the arrangement of communication circles in WBAN network.

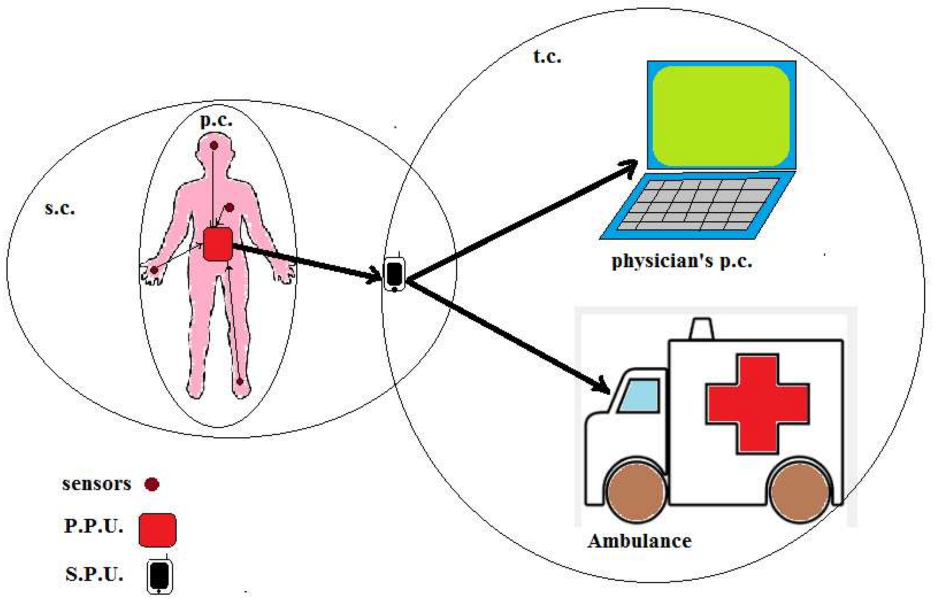


Figure 2.2 WBAN architecture

The primary communication circle (PC) i.e. the intra WBAN communication [7] refers to the communication between sensor nodes and the intermediate gateway node. The permissible range of transmission is about 2 meters from the human body. Intra WBAN interference is present in this communication circle due to communicating sensor nodes in a WBAN.

The data obtained from all the sensors at the gateway is then transmitted to the secondary communication circle (SC) i.e. inter WBAN communication circle which is within the range of 2-5 meters from the human body. This circle corresponds to communication between the gateway and the processing node as well as the communication between different networks operating in the same frequency range. Inter WBAN interference is present in this circle due to different WBAN and similar transmission technologies.

The data obtained at the processing node is then conditioned, processed and compared with critical values. The processing node is linked to various nodes like the ambulance, the physician's laptop and distant attendants via internet, GSM messaging and GPRS services. This communication between the processing node and the linked nodes is considered to be tertiary communication circle (TC) i.e. beyond WBAN communication circle.

2.1.5 Technologies used in WBAN

One of the basic requirements of WBAN is interoperability and freedom to use different technologies in WBAN transmission network [2]. As mentioned above there are some frequencies allotted by IEEE 802.15.6 to implants and on body transmission. The technologies used widely in this communication are as detailed below in the table [2]

Table 2.2 Technologies used in WBAN

Technology	Data rate	Operational frequency	Topology used	Modulation schemes	Coverage area
Bluetooth	780KBps(V1) 3MBps(V2) 3-24MBps(V3)	2.4GHz	Star	GFSK	10 m
ZIGBEE	20Kbps 40Kbps 250Kbps	868 MHz, 915 MHz, 2.4GHz (ISM)	Star Mesh Cluster Tree	QPSK BPSK	10m-100m
UWB	110-480Mbps	3.1-10.6 GHz	Star	OFDM DSUWB BPSK QPSK	5m-10m
ANT	1 Mbps	2.4 GHz ISM	Star Mesh Tree	GFSK	30 m
RFID	10 to 100Kbps	860 to 960 MHz	peer to peer	FSK PSK ASK	20 cm
Zarlink (ZL70101)	200-800 Kbps	402-405 MHz 433-434 MHz	peer to peer	2FSK 4FSK	2 m

Bluetooth, ZIGBEE and ANT [4] operate in license free ISM band. As per requirement of data rate, topology and modulation technique, these technologies can be used for communication from on body sensors to the gateway as well as to the external nodes.

RFID on the other hand has a very less communication range of only 20cm thus it is rarely used. RFID is mainly used in communication between sensors and actuator node and sometimes between inter sensor communication.

Zarlink is the only technology used for transmission between implants and other nodes as the operational frequency suits that decided for implants. Moreover due to all such reasons like implantation of sensor inside the body and low availability of technologies in comparison to the ob body wearable sensor technology, implants are sparingly used.

2.2 SECURITY ISSUES IN WBAN

Security has been a major challenge in WBAN as there is almost negligible scope of processing in the inter WBAN communication circle due to low power, low computation capability, less memory and communication constraints at primary WBAN level. The following are some requirements that are needed to be considered in WBAN transmission security:

- Availability of information: WBAN network security system must have information about the availability of the data to be transmitted at all times. A separate memory allocation or buffer memory can be used at lower level of processing whereas a memory block can be used at higher levels of processing to ensure that the system data flowing from one level to other is present unless the data is refreshed and next real time data is obtained from sensor nodes.
- Data authentication: The WBAN system must be capable to identify if the data is authenticated in form before transmitting it to the next level. This step is much required in case any interferer data gets mixed which can be easily identified by this.
- Data integrity: At the lower levels of transmission from the sensor node to the gateway node, there is a high risk that the data can be altered because lack of system capabilities due to constraint of simplicity of system at that level, thus a proper system is very much required for data integrity at the authentication level where the altered data can be distinguished.
- Management unit security: A secure management is required for proper encryption of data at the transmission end to ensure confidentiality of the critical data.

All these requirements are necessary to be employed in WBAN system but due to constraints, all these can be achieved at the processing node.

IEEE802.15.6 has categorized the security levels in WBAN as given below:

- Unsecured communication (level 0): This is the lowest security level in WBAN where data is transmitted in unauthenticated and unsecure frames. There is no data authentication by the system or integrity in data and no management security as well. No data masking or encryption is possible at this security level in WBAN
- Partially secured communication (level1): In this security scheme, data integrity is possible due to active authentication of data but masking is not available hence data can't be encrypted at this level.
- Completely secured communication (level 2): This level of security provides all the features discussed above. It has an active data authentication management system as well as an effective encryption scheme [5][8] for masking of critical data before transmitting for maintaining data confidentiality.

2.3 OVERVIEW OF IEEE 802.15.6 TASK GROUP

The IEEE 802.15.6 has set up some standards [2][3] for WBAN communication some of which are listed below:

- The communication link must support a bit rate of 10Kbps to 10Mbps
- The network must have a capability to handle 256 nodes in it.
- If not required a node can be disconnected within 3 seconds.
- A reliable communication link must be present even if the person is moving. The body postures must not affect the signal and the data should not be lost.
- A maximum jitter of 50ms is permissible whereas latency of 125ms for medical applications and 250ms for non medical applications is critically decided.
- Interoperability must be possible in heterogeneous environment.
- Power saving mechanism must be employed at lower level of communication.
- Quality of service must be set up to self healing priority.

CHAPTER 3 METHODOLOGY

3.1 WBAN PROCESS

Wireless body area network basically consists of three major processes being:

- Communication
- Comparison
- Conditioning

3.1.1 Communication

The basic and most important process in WBAN is the communication between different stages of WBAN. Sensors nodes sense parameters and transmit them to the next node. For testing the functionality of WBAN a prototype is designed with simple single on body sensor node, hence there is no requirement of a gateway node.

The sensor node is interfaced with the Bluetooth module utilizing ARDUINO MEGA. The ARDUINO is programmed to receive signals at each minute of sensing and pass it over to the Bluetooth module. The Bluetooth module receives the signal and transmits it over to the processing node directly using Bluetooth 2.4GHz ISM band frequency. Due to power constraint the prototype is kept in its simpler form thus utilizing unsecured communication at the sensor node. A GSM module is also employed along with which is subject to transmit the data directly to the physician in case of critical health problems. The GSM module functionality can also be controlled by programming it to the interfaced ARDUINO MEGA.

The designed WBAN prototype contains blood pressure sensor utilized at the arm and the data is transmitted to a Bluetooth enabled device i.e. laptop used at the processing node.

3.1.2 Comparison

The signal transmitted by the Bluetooth module to the processing node i.e. laptop is received at the serial port of the system. This data is then fed into the comparator circuit which contains comparator blocks to determine the value of systolic and diastolic blood pressure from the data received. The comparator is designed using LABVIEW software by NATIONAL INSTRUMENTS. Maximum and minimum values can be set in the comparator for both the systolic and diastolic values of blood pressure independently and if the observed value lies outside the boundaries defined, an alert signal is assigned to each condition that displays the type of abnormal blood pressure (i.e. systolic low /high or diastolic low/high) and stores the signal value to a MICROSOFT WORD document. This MS WORD document is then linked to the GOOGLE ONLINE SPREADSHEET via the Internet hence all the critical blood pressure values for a patient are shared on the online GOOGLE storage cloud that can be accessed by the physician.

3.1.3 Conditioning

This stage is the signal processing stage of the critical abnormal data before transmission. Usually blood pressure, body temperature, skin sensitivity, moisture content on skin etc are the parameters that are contained in numeric values thus easy to be transmitted but some complex signals like ECG, EEG, EMG are present in the form of graphs and thus they require more masking and compression as they transmit more data than the data utilized by transmitting numeric values. The ECG for instance is taken up every minute and the data is transmitted to the processing unit in form of a signal or a graph or a picture. The received signal if found abnormal is transmitted to the physician in the same form received. To minimize the bandwidth and data carriage required to transmit the critical information, the signal is compressed using different compression techniques. The one used in this study includes compression of ECG signal using discrete cosine transform (DCT) along with run length encoding for compression. For encryption of the image, Gyrator transform technique which is an extension of fast Fourier transform is used on ECG sample graph. Both the compression using DCT and encryption using Gyrator transform are done using MATLAB.

The DCT quantized critical information in compressed form is encrypted before transmitting. The active links possible for communicating over the internet and active SMS service adds an additional advantage to the system design. The communication services can be chosen as per the condition and requirement of the patients.

The block diagram given below will show the progress flow in WBAN prototype:

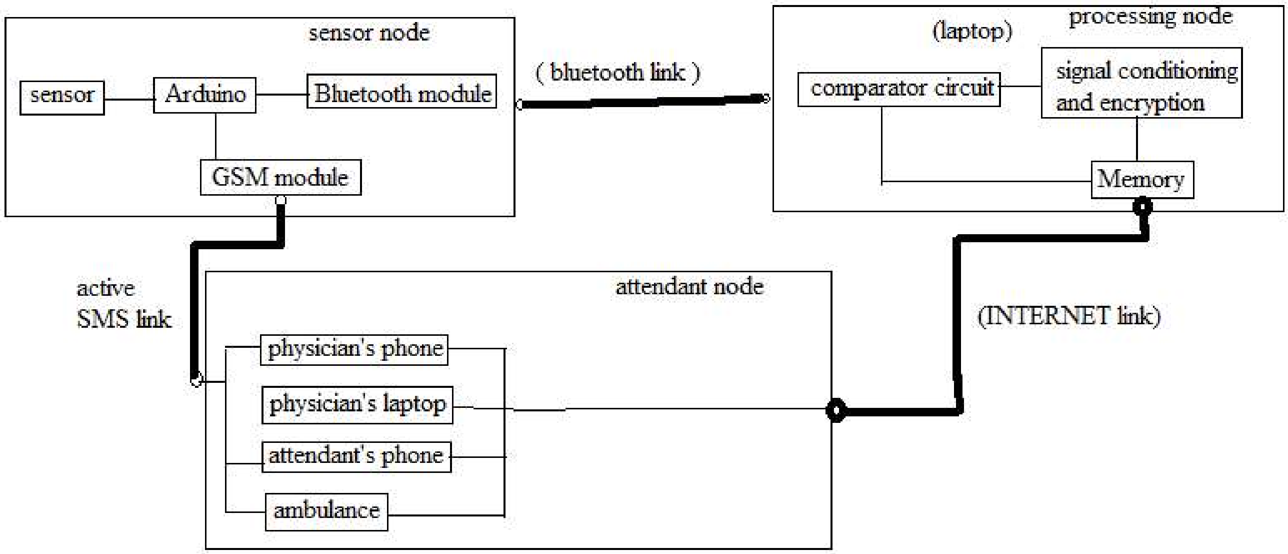


Figure 3.1 Block diagram of the WBAN prototype proposed

CHAPTER 4 HARDWARE IMPLEMENTATION

4.1 COMPONENTS USED

The basic hardware used is at the sensor node of the WBAN that consists of a blood pressure sensor that senses the blood pressure of the patient. The hardware basically consists of the following blocks:

- Power supply
- Blood pressure sensor
- LCD display
- MAX-232
- Bluetooth module
- GSM module
- ARDUINO MEGA

4.1.1 Power supply

The power supply block consists of a battery, a regulator IC and capacitors. Also to indicate the proper working of power supply, one LED in series with a resistor is utilized. The block diagram of the power supply is as shown in the figure below:

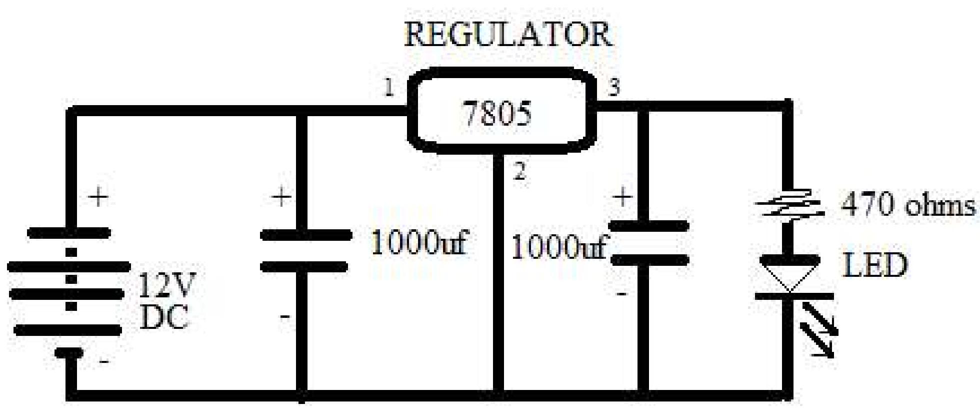


Figure 4.1 Power supply block

The idea is to operate all the components by a single power source, hence a 12V power supply is utilized in accordance to the ARDUINO utilized as the components require around 5 volts DC voltage. The 12V DC can either be obtained by using a battery of 12 V or by using special adapter. Both the provisions are possible in WBAN prototype designed. The battery used is a 12 V, 1.3 Ah rechargeable battery that is sufficient for at least 10 hours of continuous power supply. A diode is utilized at the positive terminal of the battery in order to save the hardware if in case the battery terminals are wrongly attached.

A regulator IC 7805 is used to provide an accurate 5V output from the 12V DC obtained from the battery. For the proper functioning of hardware components it is very much essential that all the fluctuations and ripples are removed from the power utilized by each component so that all components get the desires smooth power to operate. For suitable output as 5V two capacitors of 1000uf are used in parallel in the power supply circuit with the input i.e. pin1 and the output i.e. pin3 of IC 7805 .pin2 is connected to ground. The IC and internal block diagram of 7805 is as shown below

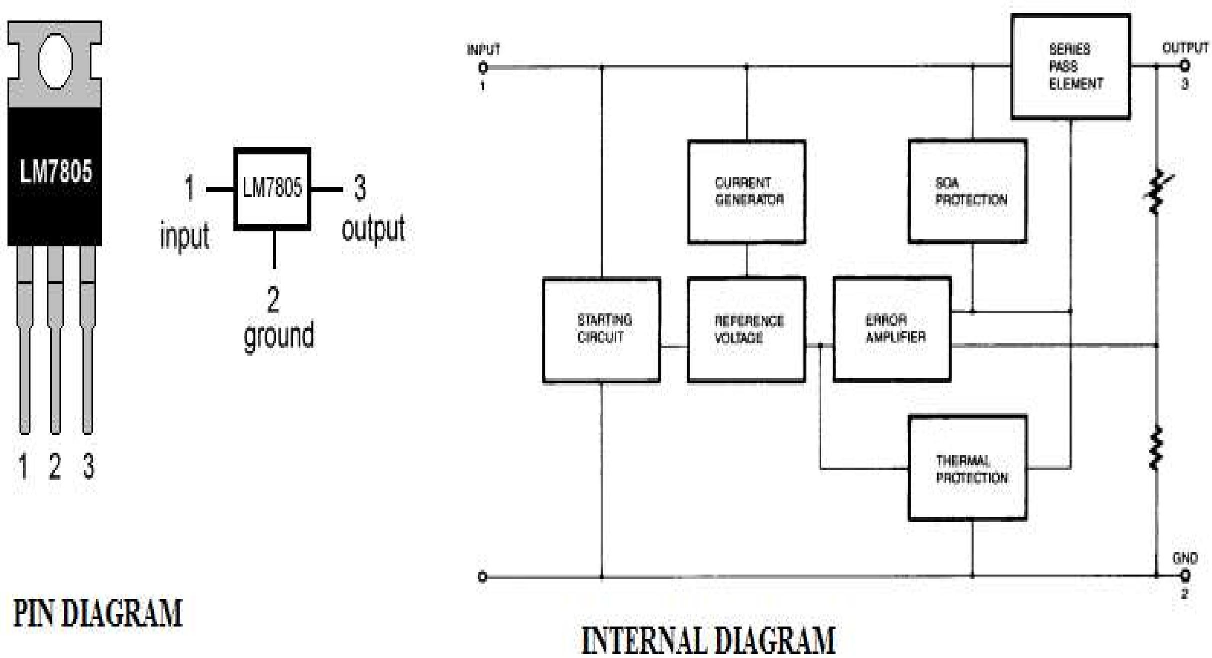


Figure 4.2 Pin diagram and block diagram of voltage regulator IC 7805

4.1.2 Blood pressure sensor

The blood pressure sensor used for WBAN prototype is to be linked to ARDUINO and the sensed blood pressure values are to be transmitted to Bluetooth module and GSM thus a special blood pressure sensor with serial output with similar baud rate to that of other devices is used. As the baud rate for Bluetooth module and GSM module is 9600 hence a similar baud rating is essential for BP sensor too. Also the sensor must be operable on +5V in order to use the same power supply for the entire circuit thus the sensor must be chosen accordingly. For all the above desired specifications and operability with ARDUINO MEGA, sunroom 4118 blood pressure sensor with serial communication is used.

The sensor used is as shown in the figure below

Figure 4.3 BP sensor with ARDUINO operability and serial communication.

The sunroom 4008 consists of 4 pins to the board. The pin 1 and pin 2 are for supply i.e. pin 1 for supply voltage (5V) and pin 2 for ground. This enables the sensor to draw operational power from the same source as all the other components do. Pin3 is for transmission to ARDUINO and pin4 for reception from ARDUINO. The blood pressure data obtained is transmitted via pin3 and the operating time from ARDUINO is communicated via pin 4.

4.1.3 LCD display

The LCD display used is a 16x2 display with operability along ARDUINO. The LCD is programmed to display according to the programming done at ARDUINO processor. This display is preferred over the seven segment display because it is much economical, easily programmable and it can easily display special characters and custom signs which are issues with the traditional seven segment display. A 16x2 LCD display unit is capable of displaying 2 data lines of 16 characters. Each character is prepared by a pixel matrix of 5x7 independent pixel values. The LCD display consists of two registers:

- Command register: This register stores information about instructions like execution of instruction, clearing any instruction, clearing the screen or pointing the cursor to a certain desirable position so that the display can make sense.
- Data register: This register stores data values mainly obtained from the driving controller to be displayed.

The LCD display consists of total 16 pins. The function of all the pins is as given in the table below:

Table 4.1 LCD display pin function

PIN	FUNCTION	NAME
1	Ground (0V)	Ground
2	Supply voltage; 5V (4.7V – 5.3V)	Vcc
3	Contrast adjustment; through a variable resistor	V_{EE}
4	Selects command register when low; and data register when high	Register Select
5	Low to write to the register; High to read from the register	Read/write
6	Sends data to data pins when a high to low pulse is given	Enable
7	8-bit data pin	DB0
8	8-bit data pin	DB1
9	8-bit data pin	DB2
10	8-bit data pin	DB3
11	8-bit data pin	DB4
12	8-bit data pin	DB5
13	8-bit data pin	DB6
14	8-bit data pin	DB7
15	Backlight V_{CC} (5V)	Led+
16	Backlight Ground (0V)	Led-

A variable resistance is used with the pin 3 of LCD display to adjust the brightness and contrast of the display. Pin 4,6,11,12,13,14 are attached to the ARDUINO MEGA according to their functionality and use. An LED is used between pin 15 and 16 that indicated proper power supply to the LCD display block. The LCD display used works on 4.3V and the supply is 5V thus we use a Indium IN4007 diode that causes the voltage drop of 0.7V and effectively makes 4.3V available for the display unit. The LCD display block diagram as used in WBAN prototype is as given in the figure below:

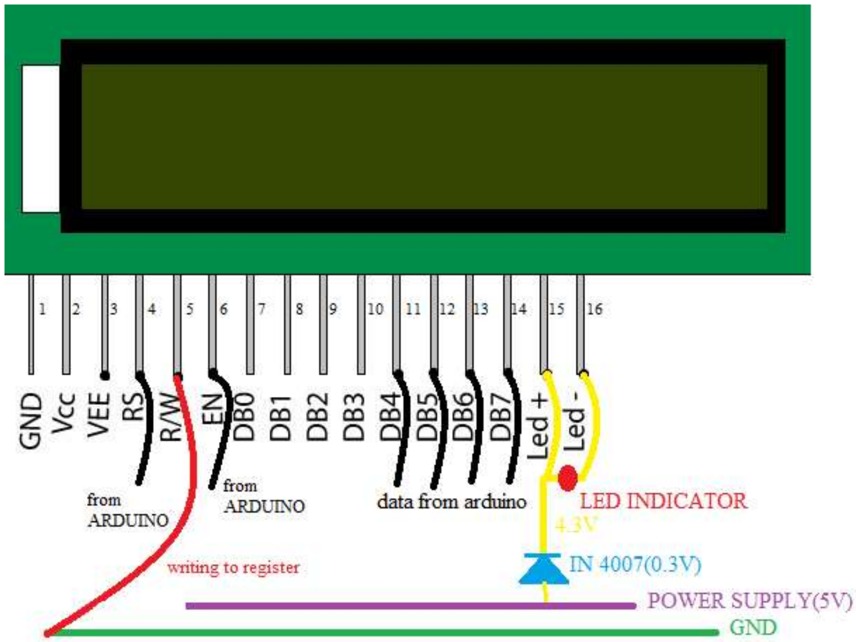


Figure 4.4 Connections on LCD display

4.1.4 MAX -232

The MAX 232 is an IC that converts signal from RS 232 to TTL compatible logic. It is an essential interfacing block between GSM module and ARDUINO MEGA. If GSM module is used in an interfering environment, the 5V signal from ARDUINO is more likely to be corrupted and lost hence a boosting mechanism is obtained by using five capacitors with MAX 232 in order to amplify the signal received from ARDUINO. When a MAX 232 receives a TTL signal to convert to RS 232 signal, the TTL logic is changed from +3V to +15v for logic 0 and from -3V to -15V for logic 1 and vice versa for the change of RS 232 signal to TTL logic.

The pin connection diagram of MAX 232 is as shown below:

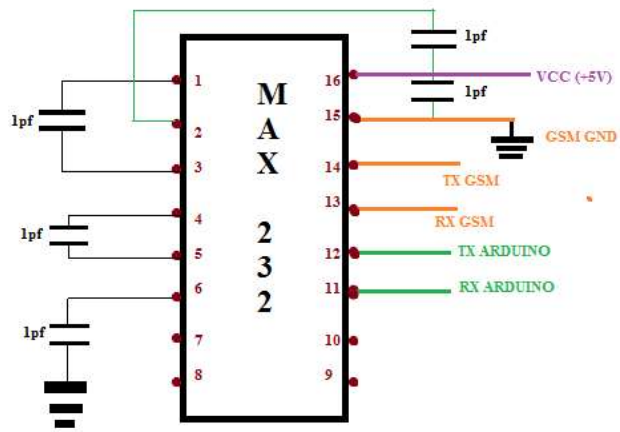


Figure 4.5 Pin connection of MAX 232.

4.1.5 Bluetooth module

The WBAN wireless transmission from the sensor node to the processing node is done using Bluetooth 2.4GHz ISM frequency [4] as on body blood pressure sensor is used. For the same, a Bluetooth module containing HC-05 IC is used. The Bluetooth module works at 3.3V DC hence two indium diodes are used in series to attain a similar voltage supply from the power supply used for all the blocks. The Bluetooth module consists of a 6 pin interface although it has an embedded 32 pin HC-05 IC. The signal through transmitter of the Bluetooth module is amplified using PNP transistor amplification in common base configuration.

The pin configuration is as shown below:

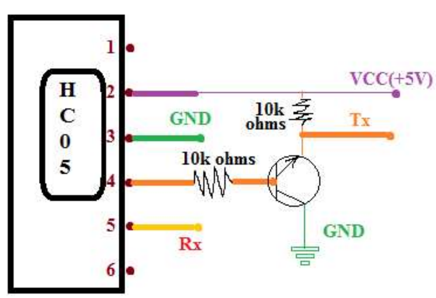
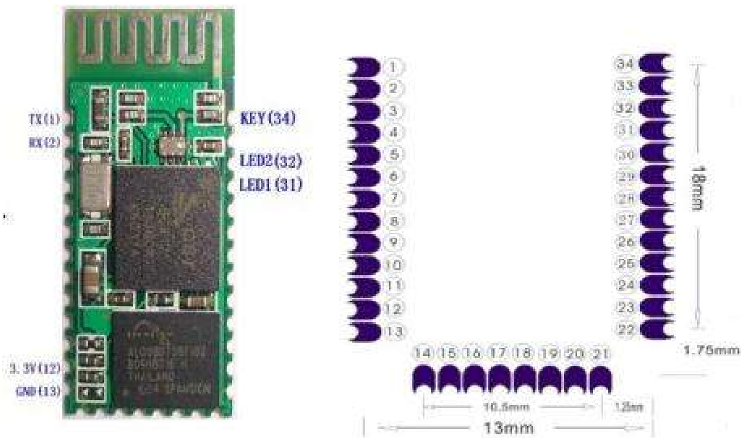


Figure 4.6 Bluetooth pin configuration.

The HC-05 is chosen because this chip has programmable master-slave definition. The Bluetooth at the sensor node i.e. at the data transmitting node is set to the master configuration and that used at the processing node is set as slave configuration. The default operating mode however is slave for HC-05 but can be changed using AT+ROLE=1 command at the ARDUINO. The actual IC and its pin description is as given below:



NO	PIN NAME	NO	PIN NAME
1	TX	20	USB D+
2	RX	21	GND
3	CTS	22	GND
4	RTS	23	PIO0
5	PCM CLK	24	PIO1
6	PCM OUT	25	PIO2
7	PCM IN	26	PIO3
8	PCM SYNC	27	PIO4
9	AIO0	28	PIO5
10	AIO1	29	PIO6
11	RESET	30	PIO7
12	3.3V	31	PIO8
13	GND	32	PIO9
14	NC	33	PIO10
15	USB D-	34	PIO11
16	CSB		
17	MOSI		
18	MISO		
19	CLK		

Figure 4.7 HC-05 IC description

4.1.6 GSM module

A GSM module is utilized in WBAN prototype for transmitting the blood pressure values directly via active messaging service without even comparing to the threshold. This feature is applicable for those conditions where the data observed is all critical and all the data is to be transmitted. A switch is utilized along the GSM switch that decides whether the GSM module should transmit or not. The switched is programmed with ARDUINO in order to work in association with the GSM module. An active RS-232 IC i.e. MAX- 232 is utilized before the GSM module so that the TTL logic can be interfaced with RS-232 logic so that the GSM can be associated and controlled by the ARDUINO.

SIM900 GSM module which is a quad band cell phone module working at 800, 900,1800 and 1900MHz is used in WBAN prototype. This is the simplest module with just voice calling and SMS services possible. Internally, the module is managed by an AMR926EJ-S processor, which controls phone communication, data communication (through an integrated TCP/IP stack), and (through an UART and a TTL serial interface) the communication with the circuit interfaced with the cell phone itself. The pin description of SIM900 used in the GSM module is as given in the figure below:

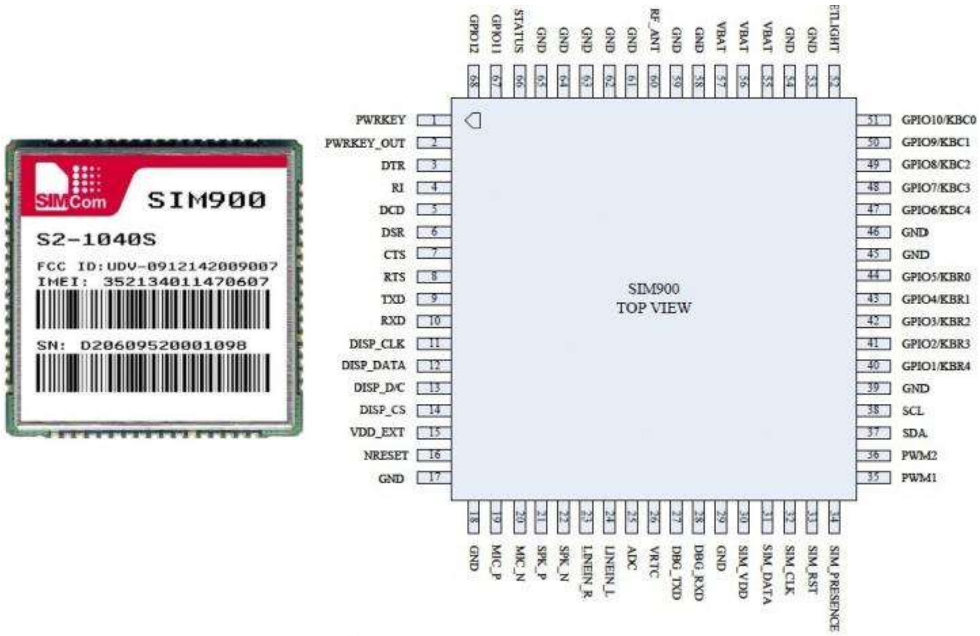


Figure 4.8 SIM-900 pin description

The overall GSM module looks as in shown given below:

Figure 4.9 GSM module used in WBAN prototype

4.1.7 ARDUINO MEGA

For the interoperability of all the blocks used at the sensor node of WBAN, there is a requirement of a controller that completes the connections between different components used as well as controls the functionality of the blocks. ARDUINO is one such controller that can be easily interfaced with all the modules and can control their functionality as per requirement of the programmer. There are many different versions of ARDUINO like UNO, MEGA etc. As WBAN required more number of components to communicate with the ARDUINO hence MEGA version of ARDUINO is utilized as it has 4 UART serial ports i.e. more Tx-Rx ports than that present in UNO. The MEGA consists of a USB portability option for programming and providing power supply from USB. A continuous and ripple free power supply is a necessity for ARDUINO to perform correctly.

The ARDUINO MEGA 2560 consists of 54 digital I/O pins, 16 analog pins with 10 bits of resolution which makes the resolution to have 2^{10} i.e. 1024 different values. It is enabled with 4 serial UART ports for Tx and Rx of TTL serial data.

The serial communication pins in (Rx,Tx) form are as follows:

- pins (0,1) as serial 0,
- pins (19,18) as serial 1,
- pins (17,16) as serial 2
- pins (15,14) as serial 3 .

The interrupt pins are as follows:

- Pin2=interrupt 0
- Pin 3=interrupt1
- Pin 21= interrupt 2
- Pin 20= interrupt 3
- Pin 19=interrupt 4
- Pin 18=interrupt 5

These interrupts can trigger on low level, a rising or falling edge.

- Pin 2-13 and pin44,45 and 46 are used for 8 bit output.

➢ Pin 13 is used for LED indicator, high level indicated LED is ON and low level indicates OFF state of LED.

The physical diagram of ARDUINO MEGA is as shown below :

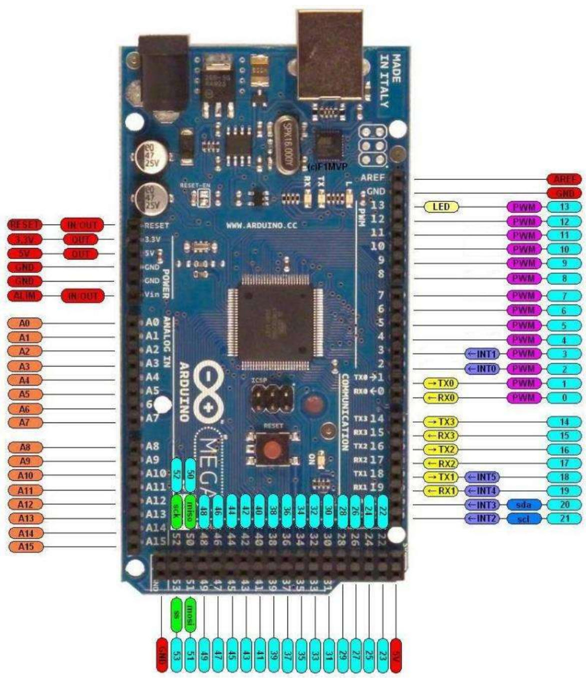


Figure 4.10 ARDUINO MEGA 2560 pin description

The programming algorithm of ARDUINO is as follows:

➢ Pin 8,9,10,11,12,13 are assigned to the data communication between LCD display as they are connected to the Rs, enable, D4, D5, D6, D7 of LCD display respectively.
➢ The LCD display is defined to be 16x2.
➢ Serial 0 port assigned to LCD display unit with 9600 baud rate.
➢ Serial 1 port assigned to incoming BP sensor with 9600 baud rate.
➢ Serial 2 port assigned to Bluetooth module with 9600 baud rate.
➢ Serial 3 port assigned to GSM module with 9600 baud rate.
➢ Initialize a display message at the LCD display till the sensor senses blood pressure.

- Assign the different digits of BP values obtained from sensor to different variables and display the values on the LCD.
- Assign the message to be transmitted over the Bluetooth using variable values assigned from the BP measurement.
- Assign a phone number to the GSM module as the recipient of the message.
- Create a body of the message to be transmitted including the variables that will convey the measured values in text message.
- As the GSM module is conditionally used only for critical cases, a switch is assigned with GSM transmission and only if the switch value is set high, the transmission command is executed.
- This switch variable is physically operated by a switch connected to the ARDUINO that decides the functionality of GSM module.

4.2 FUNCTIONALITY OF HARDWARE

A 12V DC power supply is used for the supply to all components used at WBAN prototype hardware circuit. The power supply is regulated and lowered to a perfect ripple free 5V for operation of most of the blocks and the controller ARDUINO MEGA. Bluetooth module operates at 3.3V and LCD at 4.3V hence a suitable voltage drop is obtained by using IN4007 diodes with the power supply. The controller is so chosen because it has 4 UART serial TTL Tx-Rx connections possible that communicate with the ARDUINO. Serial 0 is connected to the LED, serial 1 pins connected to Blood pressure sensor Tx-Rx, serial 2 to Bluetooth and serial 3 to GSM module. An LCD display unit is used to display the data obtained from the sensor node. The data pins of LCD display are connected to the PWM 8 bit data pins of ARDUINO along with enable and restart pin of LCD. To communicate with the GSM module, the ARDUINO is interfaced with MAX 232 IC as an intermediate that converts the TTL logic signal to RS-232 and vice versa hence operation between GSM and ARDUINO becomes possible. The Bluetooth module is also linked with the ARDUINO, a PNP transistor amplification circuit is attached in series with the transistor pin of the module to amplify the Bluetooth signal. The ARDUINO is programmed for the desired functionality of all the blocks of WBAN prototype hardware in order to obtain the desired communication between sensor node and processing node.

The physical hardware model designed is as given below:

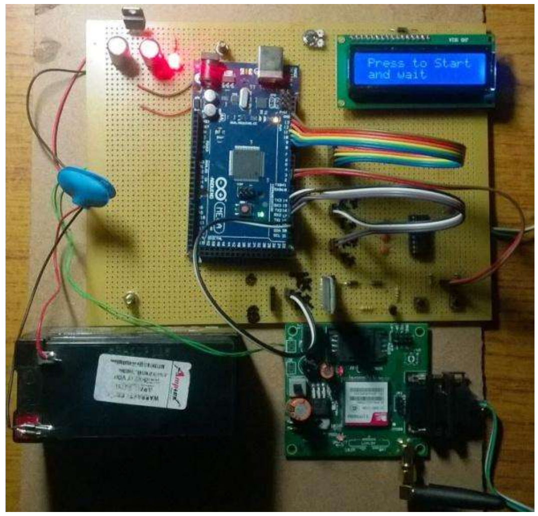


Figure 4.11 Hardware for WBAN sensor node transmission.

The circuit diagram at the sensor node is as shown below:

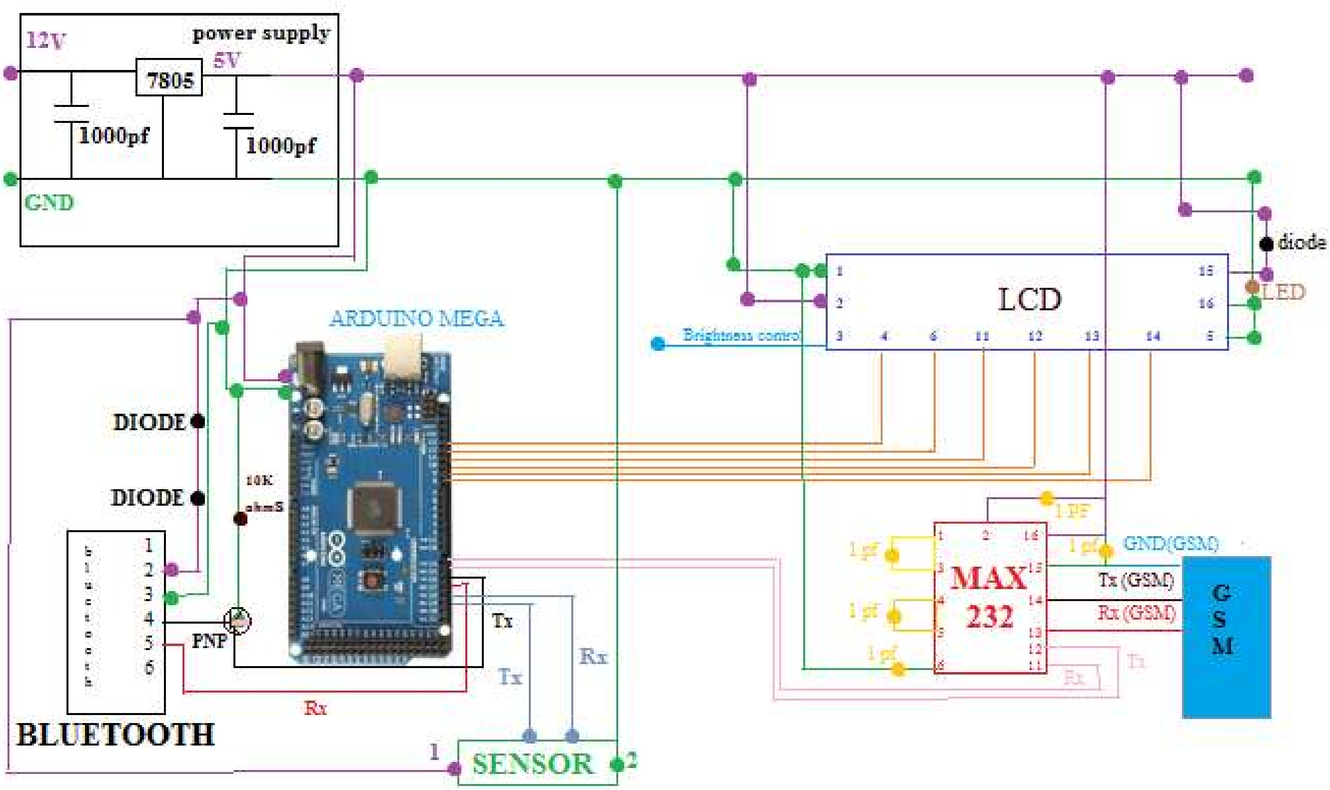


Figure 4.12 WBAN sensor node Circuit diagram.

CHAPTER 5 SOFTWARE IMPLEMENTATION

5.1 SOFTWARE ENVIRONMENT

The signal transmitted by the hardware at the sensor node is received by the serial COM port of the processing unit. The signal is then fed to the comparator block to check whether the data received is normal or critical. The comparator block basically is designed to check whether the received values lie in the normal limits. If not, the data is transmitted to the physician over the internet.

LABVIEW 2014 is used for the designing of comparator block. It is virtual instrumentation software ideal for conditional digital block designing, software developed by NATIONAL INSTRUMENTS capable of acquiring real time inputs from external hardware. LABVIEW is ideal software to deal with the testing and processing of signals. The advantages of LABVIEW over any other software are quite impressive like

- The ability to simplify complexity by using huge number of readily available functional blocks to be directly used.
- Multithread processing with different programming units and different platforms operability that makes LABVIEW very powerful multithread execution software where almost all the platforms can be used for logic designing as per the ease and comfort of the designer.
- Custom user interface that can be defined in any way as demanded and designed by the user to add a look and feel to the execution unit as per its function. The user interface can be designed with limitless possibilities as per the innovation of designer.

LABVIEW is the best in accepting data from any external ports and storing and sharing measurements and results hence the best for WBAN comparator design.

After the comparison a memory unit contains all critical measurement values to be transmitted to the physician or concerned person over the internet. A conditioning and encryption of signal is very important before transmission. As the data to be transmitted can take higher bandwidths in case of ECG, EEG, EMG data transmission, it is very much required to compress the data in order to minimize the bandwidth used without disturbing the information contained by the signal. Also as the transmissions can be very confidential sometimes hence an encryption decryption scheme must be employed in order to mask the information. An ECG signal graph image is used for compression and encrypted and similarly can be done on all other sensed data like EMG, EEG etc in a similar fashion.

Discrete cosine transform is proposed for compression and gyrator transform is proposed for encryption of data at the processing end. Inverse gyrator transform recovers the data at the physician's end. Hence a secure data is transmitted over the internet with masked information. This conditioning is done using MATLAB software. Matrix laboratory commonly known as MATLAB is a multi-paradigm numerical computing software and also referred to as the fourth generation programming language developed by MATHWORKS. This is best suited environment for numerical computing and developing and applying functions. As for the conditioning part a huge mathematical computing is required hence MATLAB is chosen as it is the best known to deal with such operations with ease. Implementing mathematical algorithms with the minimal user input is one of the salient feature of MATLAB. An additional add on SIMULINK integrated with MATLAB enables graphical multi domain simulation and model based designs.

5.2 COMPARATOR

The data is transmitted by the Bluetooth module in form of alphabets without any meaning which is received at the serial COM port at the processing node. This information is extracted using LABVIEW and is processed to get the value equivalent to that meant to be referred by the data received. The values of blood pressure are fed as inputs to the comparator circuit. As the value of the blood pressure cannot exceed 256 in systolic or diastolic case even in most critical case, the maximum value that can be received is assumed to be 255 hence it can be easily expressed in 8 binary bits with possible 0 or 1 state. The basic blocks designed and used in a successful and functional comparator are as follows:

- Decimal to binary converter
- Eight- bit binary comparator
- Logical select function key
- Display message block
- Access time block

➢ Number to decimal string
➢ Concatenate strings block
➢ Memory block

5.2.1 Decimal to binary converter

Decimal to binary converter block is basically designed to convert the data to be processed into simplest binary form so that the data can be handled by any machine used at the processing node. The value of the data received at the COM port is given a decimal form using number to decimal string. This decimal value is then converted into binary 8 bit number using decimal to binary convertor to be used at convertor block. Each input to the converter block should be in form of binary7 bits hence a decimal to binary converter is utilized prior to all converter blocks. Using the basic algorithm of decimal to binary converter, the steps involved are:

- Dividing the decimal value by 2 and obtaining the remainder each time.
- The remainder is stored in an array and the values of array are used from bottom to top manner.

The basic circuit diagram of the block designed in LABVIEW is as shown below:

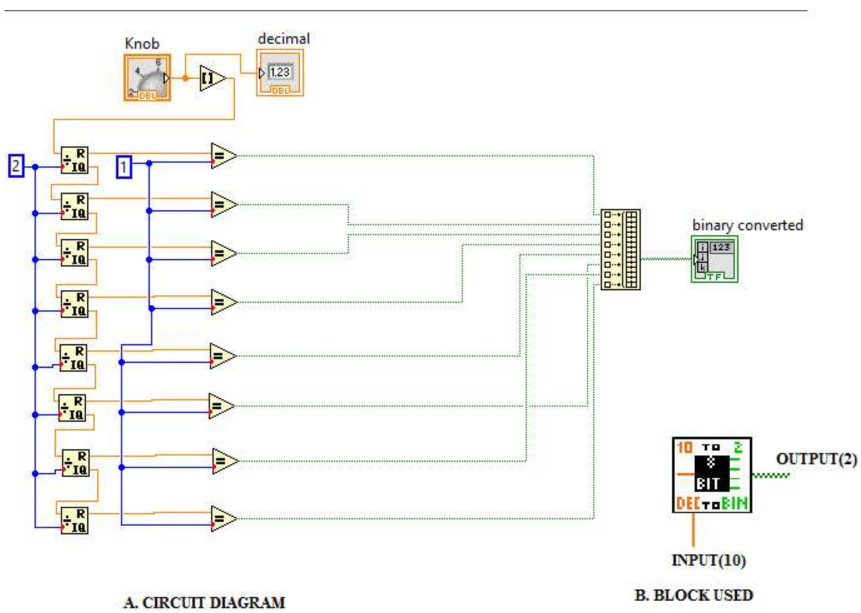


Figure 5.1 Decimal to binary converter block using LABVIEW.

5.2.2 Eight-bit magnitude comparator

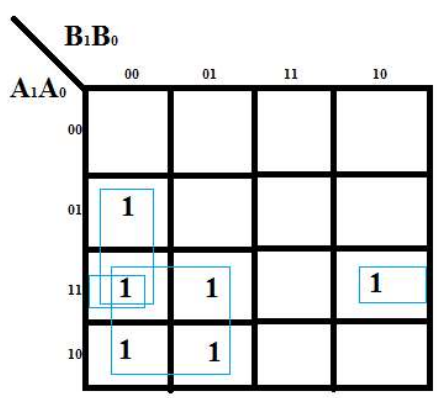
An 8 bit binary magnitude comparator is designed to difference between higher and lower of values input to it. As a maximum of 8 bit positive data values from blood pressure are compared hence an 8 bit comparator is designed. For designing the magnitude comparator the bits are assigned priority according to their place in binary notation and simple comparing is executed. An example of 2-bit magnitude comparator is illustrated to obtain the basic idea about the logic of magnitude comparator. The steps involved are as follows:

A. Prepare a truth table

A_1	A_0	B_1	B_0	A>B	$\overline{A>B}$
0	0	0	0	0	1
0	0	0	1	0	1
0	0	1	0	0	1
0	0	1	1	0	1
0	1	0	0	1	0
0	1	0	1	0	1
0	1	1	0	0	1
0	1	1	1	0	1
1	0	0	0	1	0
1	0	0	1	1	0
1	0	1	0	0	1
1	0	1	1	0	1
1	1	0	0	1	0
1	1	0	1	1	0
1	1	1	0	1	0
1	1	1	1	0	1

Figure 5.2 Truth table of 2 bit magnitude comparator

B. Draw the K-map corresponding to the desired condition. Here say the desired condition is A>B



$$Y = A_1\overline{B_1} + A_0\overline{B_1B_0} + \overline{B_0}A_1A_0$$

Figure 5.3 K-map of A>B condition

In the similar way the logic of P > Q for P and Q being 8 bit binary numbers is found to be .The circuit diagram for 8 bit comparator conditional to A>B to be true is as given in the figure below:

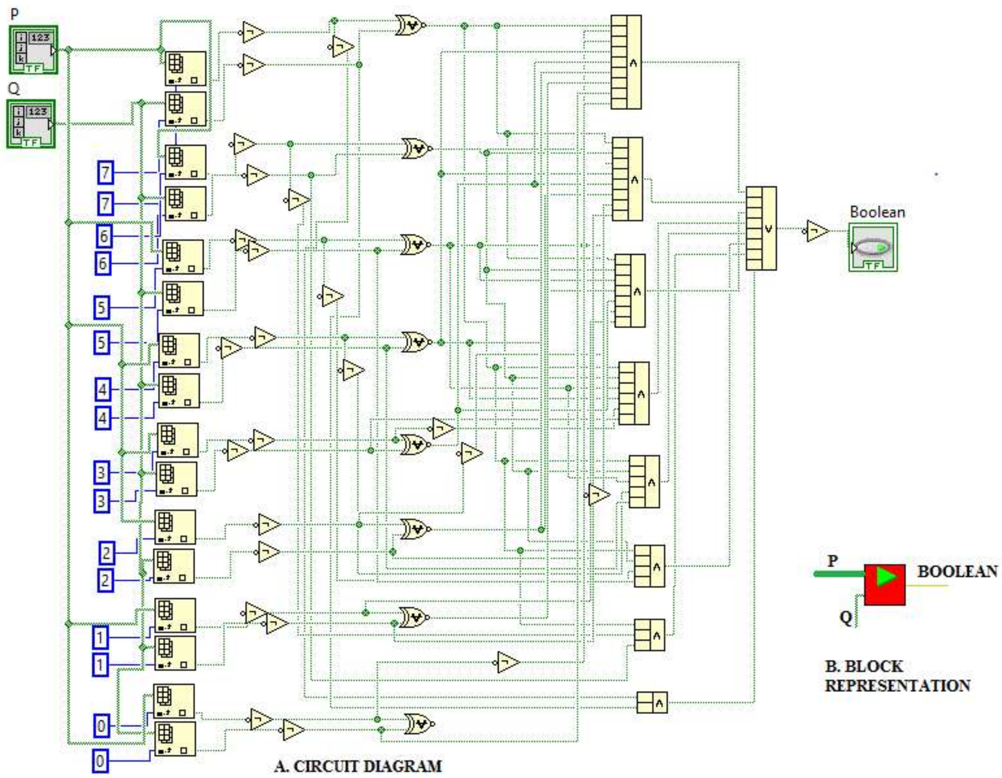


Figure 5.4 8-bit magnitude comparator circuit diagram subjected to P>Q.

The above Boolean results a high or 1 value when P>Q and low or 0 value when P<Q or P=Q.

5.2.3 Logical select function key

This function returns the value from one of the two inputs fed, the **t** input or **f** input is carried forward depending on the Boolean value of signal **s** fed. If **s** is at TRUE state, function returns the value wired to **t**. Conditional to the **s** value if FALSE, logical select key returns the value wired to **f**. The figure below displays the functional block used for logical select function key.

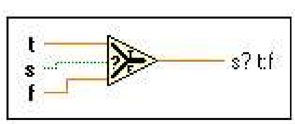


Figure 5.5 Logical select key.

5.2.4 Display message block

This block is basically used for alerts. A similar function is also served in comparator of the WBAN prototype designed. The block consists of 3 inputs namely message, enable and error. Message to be displayed for alert is fed and the same is displayed if the block is enabled. The enable is generally connected to the conditional Boolean, if the condition for alert is fulfilled, the enable is activated and the message input to the block is displayed to the user. The figure below displays the display message block.

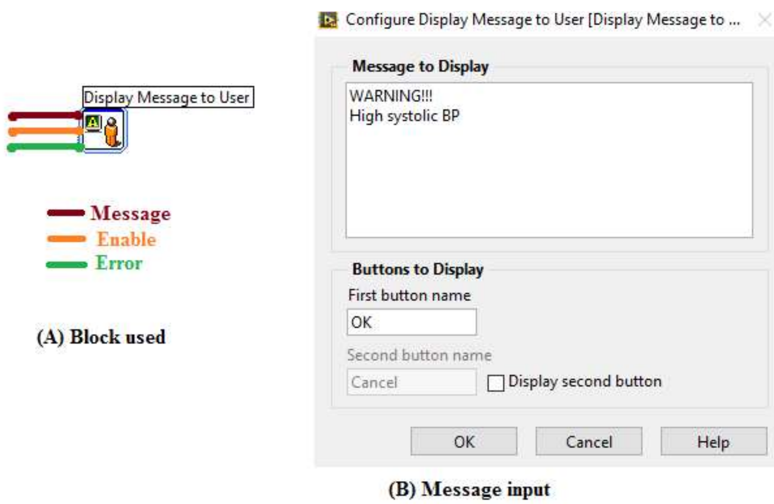


Figure 5.6 Display message block and input message

5.2.5 Access time block

This block is used to access date and time and use it as text in the WBAN prototype. As the details of measured blood pressure if found outside the normal range should be noted with the date and time. This block contains two components:

- Date/time fetch block: This functional block returns a time stamp of the date and time accessing it from the system. The datum is set to universal time 12am, January 1, 1904 i.e. Friday. LABVIEW calculates the number of seconds from the datum to the present hence giving an accuracy of even less than one millisecond.
- Format date/time block: This function is useful in displaying the values obtained from the time stamp into desired time format using some predefined codes.

The access time block is basically used to extract the existing real time date/ time information in form of numbers so that it can be used in form of a message to be transmitted in critical cases.

Access time block is given in the figure below:

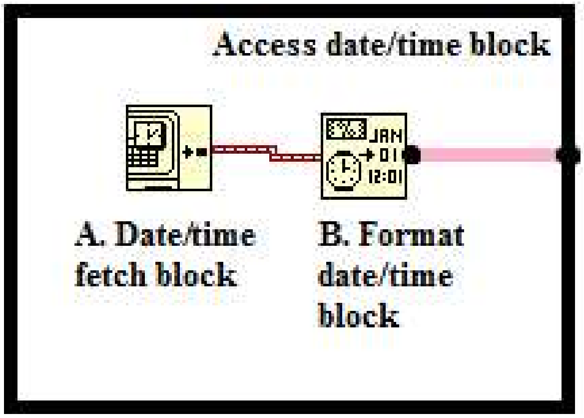


Figure 5.7 Access date/ time block

5.2.6 Number to decimal string

This block converts the numerical value from a signal to decimal string of at least one character width or more depending upon the type of numerical value possessed by the signal. If the signal possesses a floating point value or a fixed point value then in such cases rounding off is done prior to conversion. The example below will illustrate the functionality of this block

Number	Width	Decimal string	Comments
2.6	2	_3	Rounding floating and fixed points to most appropriate integral value
5.0	4	_ _ _5	If width is more than required for the integral decimal notation then spaces are added at the front of string
-479	3	-479	If width is inadequate, then the integral decimal string value automatically corrects the width value as large as necessary to represent the number correctly.

Table 5.1 Number to decimal string functionality

The block for number to decimal string is as shown below:

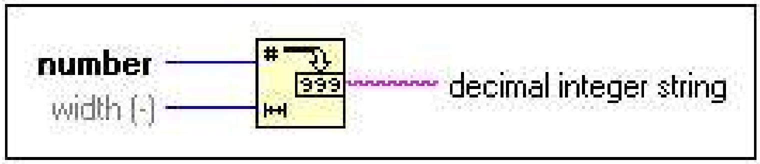


Figure 5.8 Number to decimal string block

5.2.7 Concatenate strings block

This block is used for concatenation of many strings or arrays of strings input to it to form one output string. In WBAN comparator, this block is used to create the desired message format containing all the information like date/time, signal value of blood pressure, and the message string that indicates the issue about the critical case. The block contains multiple inputs and single output. The inputs can be added and arranged in desired manner to represent meaningful message at the output. The LABVIEW concatenate strings block is as shown below:

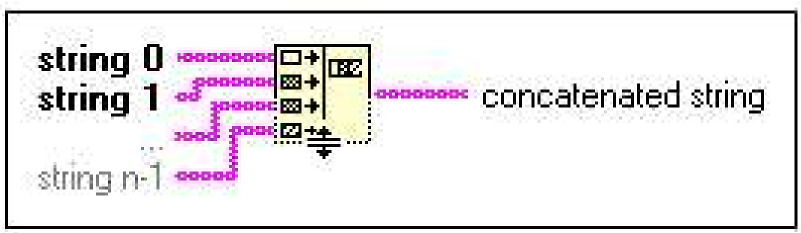


Figure 5.9 Concatenate strings block in LABVIEW.

5.2.8 Memory block

The memory block also called write to text file block serves in writing the information by the concatenate string block to a suitable file as per the type of data. The text based measurement files are stored in (.lvm) format stored in notepad, the binary based measurement file in (.tdms), or (.tdm) format file and MS excel file in (.xlsx) format in MICROSOFT EXCEL. The properties of data type and location of storage along with different options can be configured as shown in the figure below:

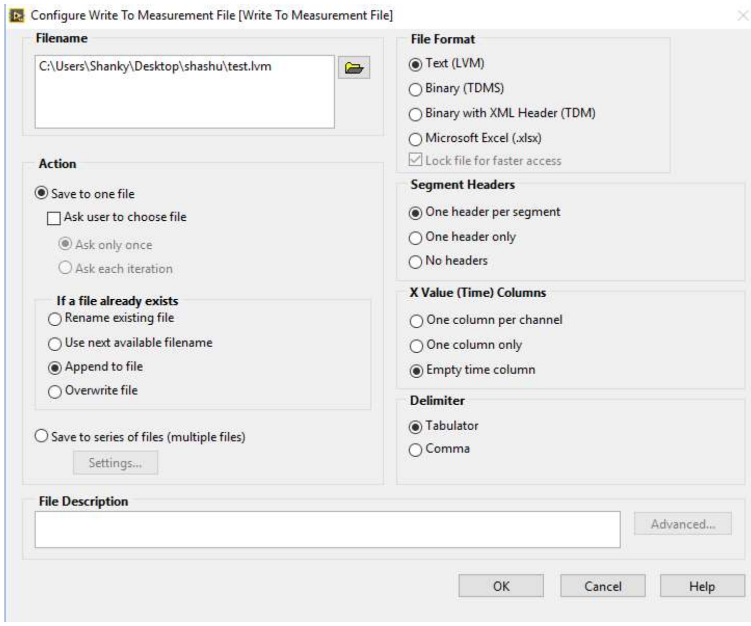


Figure 5.10 Properties configuration of memory block.

The block representation is given in the figure below:

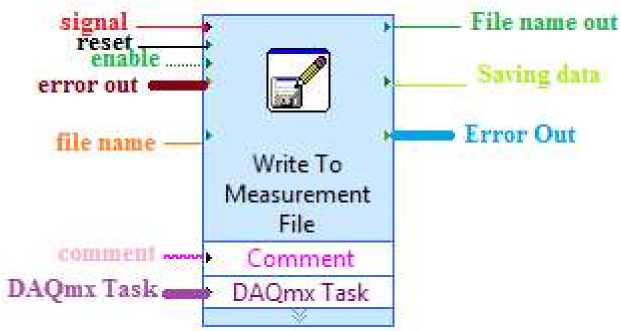


Figure 5.11 Memory block

5.3 COMPARATOR ALGORITHM

The steps involved in comparator are as follows:

- ➢ The Blood pressure signal values are obtained at the serial COM port of the system that is a wireless transmission port using Bluetooth for communication.
- ➢ The values of blood pressure signals can be viewed to be received using port details of ARDUINO software.

- The values obtained at the COM port are in the form of characters which is imported using LABVIEW.
- The data imported is arranged and separated into two variables P and Q.
- The value of P and Q are converted to binary to be used in 8 bit binary magnitude comparator.
- The binary value of P and Q are input to the magnitude comparator, the higher of two is set as systolic and the lower as diastolic.
- Maximum and minimum variable values are assigned to set up normal limits for both systolic and diastolic B.P. values.
- Again using the binary converter and then 8 bit magnitude comparator, the systolic and diastolic values are compared to their maximum and minimum values assigned.
- If the values are found more than the maximum value permissible, the blood pressure condition is critically high. Similarly if the value is lower than the minimum value in respective comparison, the condition is critical low blood pressure.
- According to the type of critical condition, different messages are allotted to each condition using display message block.
- For the formation of message with date and time information along with the message and the critical value of blood pressure obtained, a clock with date/ time information is used using access date/ time block.
- The various data are merged together to form a meaningful information to be sent using Concatenate string block.
- The concatenate string block produces a complete information message that is fed to the memory block to store the messages corresponding to all critical conditions.
- The format and tools for storing the information depends on type of data to be stored as a message.
- The memory unit is linked online hence an updated list of messages is transmitted over the internet with all details of critical cases of blood pressure observed.

The following diagram briefs the path flow of process:

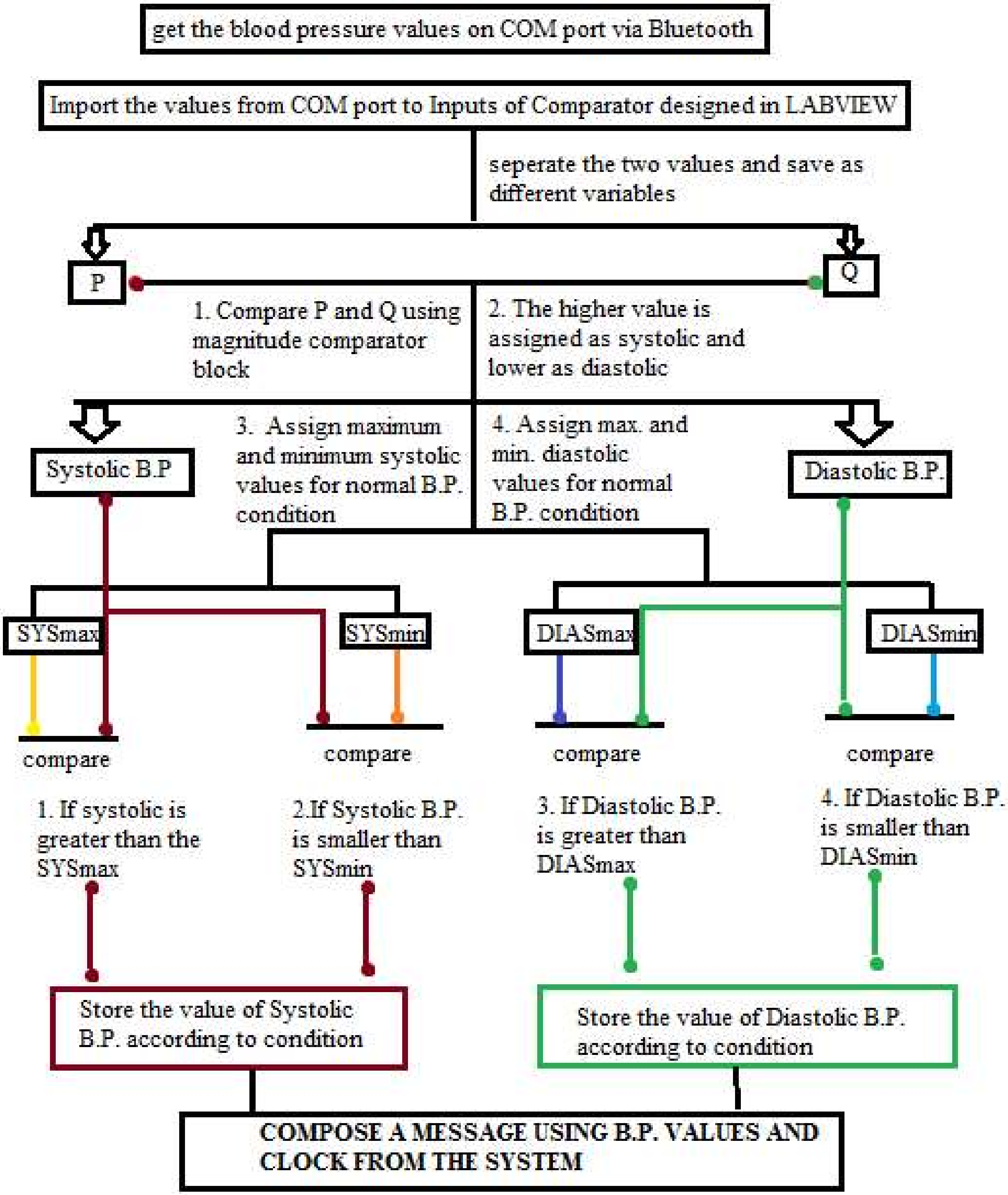


Figure 5.12 Flow diagram of Comparator process.

5.4 LABVIEW CIRCUIT USED

The LABVIEW virtual instrumentation circuit for comparator is as shown below:

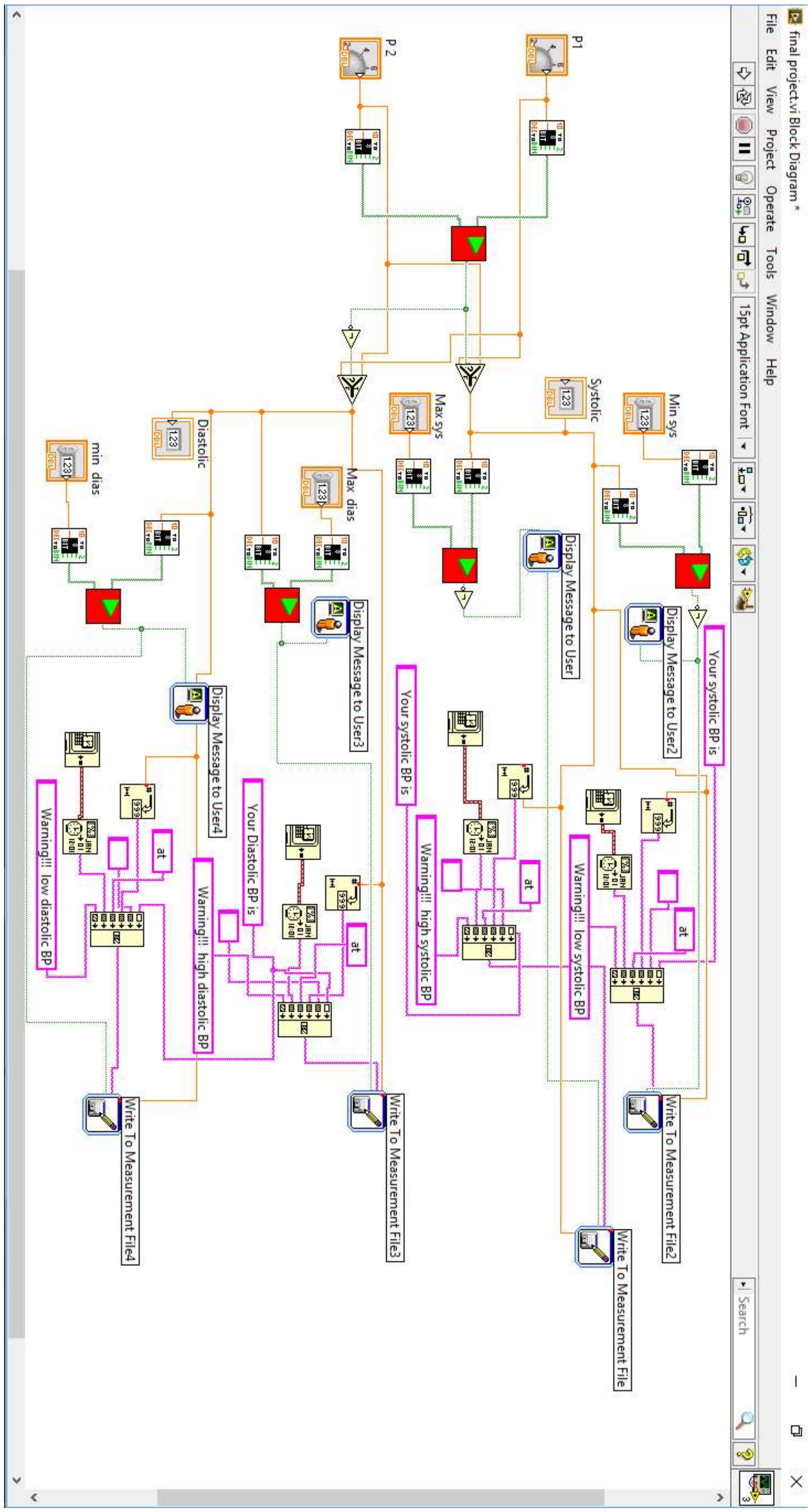


Figure 5.13 LABVIEW circuit designed for Comparator.

CHAPTER 6 SIGNAL CONDITIONING

6.1 INTRODUCTION TO CONDITIONING

The signal conditioning refers to pre-processing at the data to be transmitted via internet. Conditioning at transmission end comprises of two steps:

- Compression
- Encryption

The blood pressure values and critical messages to be transmitted using a very small data space hence compression is not an issue in this case however, if ECG [10] [12, EEG, EMG etc sensors are utilized in WBAN, they produce results in form of graphs and images in form of signals which are to be transmitted at regular intervals hence it is very much required that the data to be sent over internet should be compressed and conditioned so as to reduce the bandwidth utilization for transmission. For such analysis, an ECG signal is used and the graph is taken at regular intervals of time to be transmitted.

6.2 Compression

Suppose an ECG sensor is utilized at the sensor node that transmits data in form of graph at the processing node. The signal must be continuously uploaded over the internet hence if the bandwidth is to be utilized properly, the images to be transmitted must be compressed before transmission. The compression used for ECG image compression is DCT [13] [14] [15]. The algorithm used in compression is as shown in the figure below:

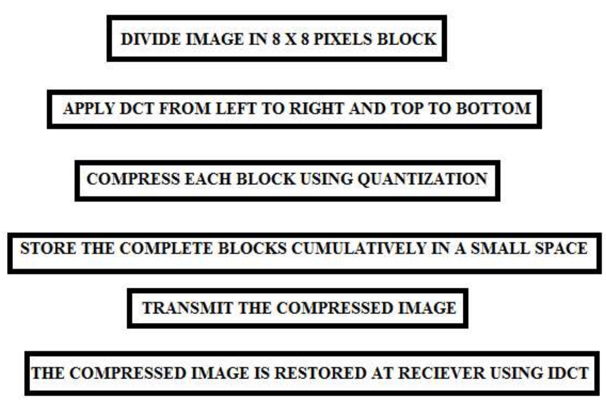


Figure 6.1 DCT compression process

The DCT of each element can be calculated using the equation [14] given below:

$$S(u,v) = \frac{1}{\sqrt{2n}}\ C(u)\ C(v)\ \sum_{y=0}^{n-1} \cdot \sum_{x=0}^{n-1} s(x,y) \cos\frac{(2x+1)u\pi}{2n} \quad \cos\frac{(2y+1)v\pi}{2n} \qquad (1)$$

Where $C(p) = 2^{\frac{-1}{2}}$; for p=0 (2)

$= 1$; otherwise (3)

The steps involved in DCT compression [15] are as given below:

1. Read the image cameraman.tif.
2. Load the size of the image in rows and columns.
3. Convert the image to double precision.
4. Subtract each pixel value of the image by 128.
5. Display the desired quality of the compressed image.
6. Make a 8*8 quality matrix.

   $Q_{ij} = 1/(N)^{1/2}$; if $i = 0$ (4)

   $=(2/N)^{1/2} \cos\{[(2j+1)i\pi]/2N\}$; if $i > 0$ (5)

   Q = [16 11 10 16 24 40 51 61
   12 12 14 19 26 58 60 55
   14 13 16 24 40 57 69 56
   14 17 22 29 51 87 80 62
   18 22 37 56 68 109 103 77
   24 35 55 64 81 104 113 92
   49 64 78 87 103 121 120 101
   72 92 95 98 112 100 103 99]

7. Create an array of all ones of 8*8 matrix and name it Q1.
8. If desired quality of the compressed image is more than 50, take value of $QX = \left(\frac{100-\text{Quality}}{50} \times Q1\right)$. Multiply this matrix with Q and round it to nearest integer. Convert it to unsigned 8bit integer.

9. If desired quality of the compressed image is less than 50, take value of $QX = \left(\frac{50}{Quality} \times Q1\right)$. Multiply this matrix with Q and round it to nearest integer. Convert it to unsigned 8bit integer.
10. If desired quality of the compressed image is equal to 50, take value of QX =Q.
11. Formulating forward DCT matrix and inverse DCT matrix makes a matrix DCT_matrix8 by DCT of identity matrix into it and put it in IDCT_matrix8.
12. For jpeg compression, create an array of zeroes and put rows and columns in it and take it as dct_restored.
13. Take double precision of QX.
14. For forward discrete cosine transform, take two 'for' loops, i1varying from 1 to number of rows and i2 i1varying from 1 to number of columns.
15. Put i1 to i1+7 in rows and i2 toi2+7 in column of zBlock.
16. Now multiply DCT_matrix8 with zBLOCK and IDCT_matrix8.
17. The output will work as dct_domain.
18. Now for quantization of DCT coefficients, two 'for' loops are defined at i1 from 1 to rows and i2 from 1 to columns.
19. Put the value of dct_domain in another element win1 and divide it with QX
20. This value is put into dct_quantized.
21. For decoding we need to dequantize the DCT coefficients. Put for loop at i1 from 1to row and i2 from 1 to column
22. Multiply put value of dct_quantized matrixin win2 and multiply it with QX which will now serve as the dct_dequantized matrix.
23. Now taking inverse discrete cosine transform, take for loop at i1 from 1 to row and i2 from 1 to column.
24. Put dct_dequantized matrix in win3.
25. Multiply it with iDCT_matrix8 and DCT_matrix8 to get the restored matrix.
26. The restored matrix is actually the restored image. Convert it into an image.

6.3 Encryption

The security of transmission is one of the very important domains that must be taken proper care of before transmission of information over the internet. For improving security of transmission a number of ways are utilized, one of the most effective ways is by encrypting the data before transmission that can be reverted back using decryption at the receiver end. For this purpose a very new tool namely Gyrator transform is used. It is a linear canonical integral transform.

6.3.1 Gyrator Transform:

It is a two dimensional function which introduces the rotation in position−spatial frequency planes of phase space. The two dimensional input function $f_i(x,y)$ with a parameter called transformation or rotation angle α .[4]

$$f_o\,(p,q) = G^{\alpha}\,[f_i\,(s_i\,)](\,s_o\,) = \iint f_i(x,y)k_{\alpha}\,(x,y,p,q) \qquad (6)$$

$$= \frac{1}{|\sin\alpha|}\int\int_{-\infty}^{+\infty} f(x,y)\,\exp\,(i2\pi\,\frac{(pq+xy)\cos\alpha-(xq+py)}{\sin\alpha})dxdy \qquad (7)$$

Where f_o (p,q) is a two dimensional output function

Symbol G denotes the gyrator operator

(x,y) are the input coordinates whereas (p,q) are the output coordinates.

The presence of rotation angle α enlarges the key space and thus helps in improving the security of the system. When $\alpha \in [0, 2\pi]$ the gyrator transform can be realized by using an optical system containing plano-convex cylindrical lenses.

$\alpha = \frac{m\pi}{2}$ where $0 \le \alpha < 2\pi$ and $0 \le m < 4$, [5]

when m=0 then α=0 then the gyrator transform is reduced to identity transform.

when m=1 then $\alpha = \frac{\pi}{2}$ then the gyrator transform is reduced to direct Fourier transform (FT). The coordinate (p,q) are rotated by an angle of $\frac{\pi}{2}$.

When m = 2 then α= π then the gyrator transform is reduced to reverse transform.

When m= 3 then $\alpha = \frac{3\pi}{2}$ then the gyrator transform is converted to inverse Fourier transform (IFT). The coordinate is rotated by an angle of $\frac{\pi}{2}$.

The rotation angle of $-\alpha$ corresponds to inverse gyrator transform transforming G^{α} to $G^{-\alpha}$. It is both periodic and additive

i.e. $G^{\alpha 1} . G^{\alpha 2} = G^{\alpha 1 + \alpha 2} = G^{\alpha 2} G^{\alpha 1}$ and $G^{\alpha + 2\pi} = G^{\alpha}$ is the fractional Fourier transform

$G^{2\pi - \alpha}$ is also the inverse of G^{α} as they are reciprocal transforms. It can be used in experimental realization for the process of encryption and decryption of an image thus enhancing the security.

The advantages of using gyrator transform are as listed below:

- The presence of rotation angle α enlarges the key space and thus helps in improving the security of the system. When $\alpha \in [0, 2\pi]$ the gyrator transform can be realized by using an optical system containing plano-convex cylindrical lenses. It can be used for information processing which can optical, digital or quantum. It can also be used for holographic recording and mode transformation.
- It is a universal mode converter as it generates different structurally stabled Gaussian modes. The Gaussian modes can be obtained by the integral canonical transform using Hermite-Gaussian modes.
- It also provides application in space variant filtering, encryption of images and hyperbolic noise reduction.
- It represents image in a phase domain, can be used for hyperbolic wave detection, shift-variant filtering, encryption, beam characterization, generation of stable modes with specific properties.

Gyrator transform [1] can be defined as:

$$G_{\alpha}(p,q) = k^{\alpha}[g(x,y)] = \frac{|\csc\alpha|}{2\pi} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} exp\left(\frac{(pq+xy)cos\alpha-(py+qx)}{sin\alpha}\right) g(x,y)\, dxdy \quad (8)$$

Here x and y are the input coordinates of the input image where as p and q are the output coordinates of the transformed image. Let us take the sampling interval to be Δ_s in space domain where as Δ_w to be in frequency domain [8]. Since the image is divided in pixels the analysis can be done taking the image as a matrix of discrete pixels. Hence,

$$g1[x,y] = g(x\Delta_s , y\Delta_s) \quad (9)$$

and

$$G_{\alpha,1}[p,q]= G_\alpha(p\Delta_w , q\Delta_w) \quad (10)$$

Using the above formula, this can also be written as:

$$G_{\alpha,1}(p,q) = \Delta_s^2 \, |\csc\alpha|/ 2\pi \times \sum_x \sum_y exp\left(\frac{(pq\Delta_w^2 + xy\Delta_s^2)\cos\alpha - (py+qx)\,\Delta_s\,\Delta_w}{\sin\alpha}\right) g1(x,y) \quad (11)$$

Also an important condition [5] is $\Delta_s\Delta_w = 2\,\pi \sin\alpha/ N$ (12)

Where N is some integer which should be more than values of x and y coordinates i.e. number of sampling points in the input coordinates. Since the ECG image in every sample taken for transmission has 256 x 256 pixels, x=y=256, N is more than 256. For simplicity in calculation and keeping the image input and output pixel count same $\Delta_s = \Delta_w$. There are three steps to implement the transform.

Step 1: Multiply the image matrix g1[x,y] with $e^{jxy\Delta_s^2 \cot\alpha}$ to obtain a matrix g2[x,y]

$$g2[x,y]= e^{jxy\Delta_s^2 \cot\alpha} \, g1[x,y] \quad (13)$$

Step 2: Now we take the Discrete Fourier Transform of the output matrix.

$$G_{\alpha,2}[p,q]= \sum_x \sum_y exp(-j2\pi \frac{px+qy}{N}) g2[x,y], \text{ (by DFT)} \quad (14)$$

Step 3: Taking $G_{\alpha,3}[p,q]$ as the transpose of $G_{\alpha,2}[p,q]$ and multiplying it with $\Delta_s^2 \frac{|\csc\alpha|}{2\pi} e^{jpq\Delta_w^2 \cot\alpha}$ we obtain the transformed image $G_{\alpha,1}[p,q]$

$$G_{\alpha,1}[p,q] = \Delta_s^2 \frac{|\csc\alpha|}{2\pi} e^{jpq\Delta_w^2 \cot\alpha} \, G_{\alpha,3}[p,q], \quad (15)$$

Where $G_{\alpha,3}[p,q] = G_{\alpha,2}[q,p]$ (16)

The process flow diagram is as shown below:

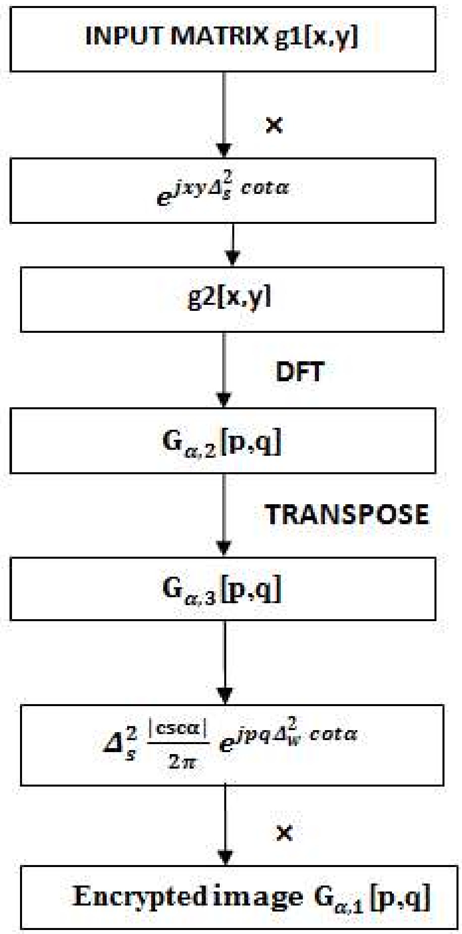


Figure 6.2 Process of Gyrator transform.

The image is encrypted at the transmitter side of internet using a specific rotation angle (α) value using Gyrator transform and the inverse of it gives back the decrypted image at the receiver. The inverse gyrator transform can be easily obtained by using the Gyrator transform with negative rotation angle as used at the transmission side (-α). Hence the image can be transmitted safely over internet.

CHAPTER 7 RESULTS AND CONCLUSION

7.1 RESULTS

According to the age group and type of body behavior of the patient, the datum and limits will be assigned .The typical values of normal blood pressure values for reference are given below [6] which are used to set up limits for comparison to WBAN observed BP values :

Table 7.1 Human blood pressure indifferent life stages

Stage	Age (years)	Systolic range(mm)	Typical systolic(mm)	Diastolic Range(mm)	Typical diastolic(mm)
Infants	0-1	75-100	85	50-70	60
Toddlers	1-3	80-110	95	50-80	65
Preschoolers	3-5	80-110	100	50-80	65
School age	5-13	85-120	110	55-80	70
Adolescence	13-18	95-135	120	60-90	75

Table 7.2 Adult blood pressure

Category	Systolic (mm of Hg)	Diastolic (mm of Hg)
Hypotension	< 90	< 60
Desired	90 – 119	60 – 79
Pre-hypertension	120 – 139	80 – 89
Stage-1 Hypertension	140 – 159	90 – 99
Stage-2 Hypertension	160 – 179	100 – 109
Hypertension Crisis	> 180	>110

The comparator is fed with appropriate limits as per the values from the tables so that the crisis of blood pressure can be observed.

7.1.1 Results from WBAN hardware

The designed WBAN hardware has the blood pressure sensor that senses blood pressure and transmits the values via Bluetooth to the COM port. The observed results are as shown below:

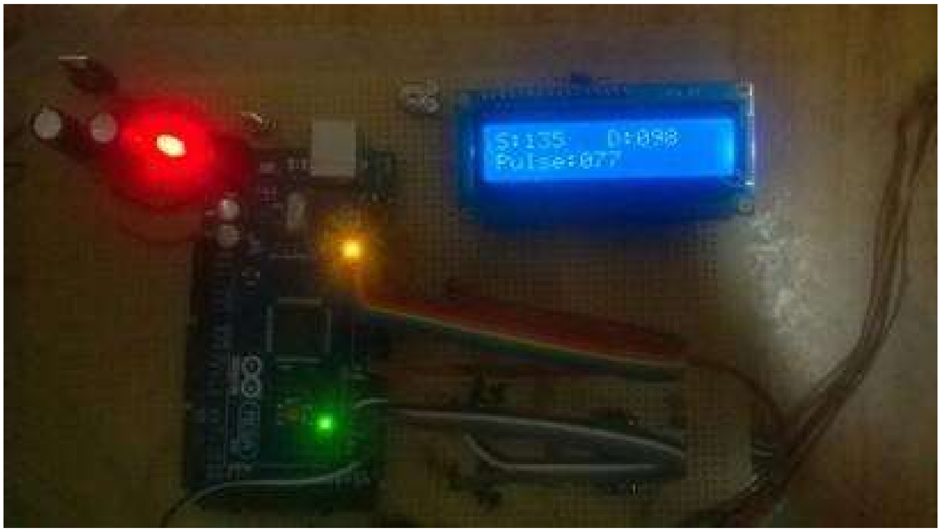


Figure 7.1 Observed Blood pressure and pulse values

The blood pressure values observed are then transmitted to the processing node using Bluetooth module and can be traced at the serial COM port 4 as shown below:

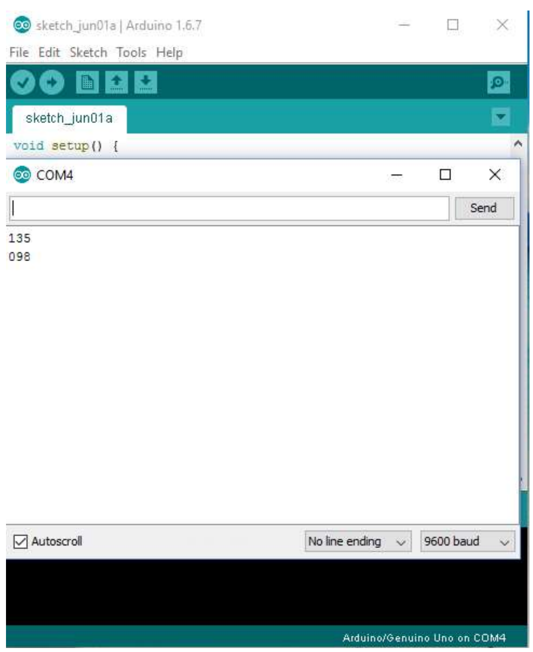


Figure 7.2 Signal values received at serial port of processing node.

7.1.2 Results from WBAN comparator software

The limits of systolic and diastolic normal blood pressures are set so that the data obtained can be analyzed. The values are then used as inputs by the Comparator block in LABVIEW as shown below:

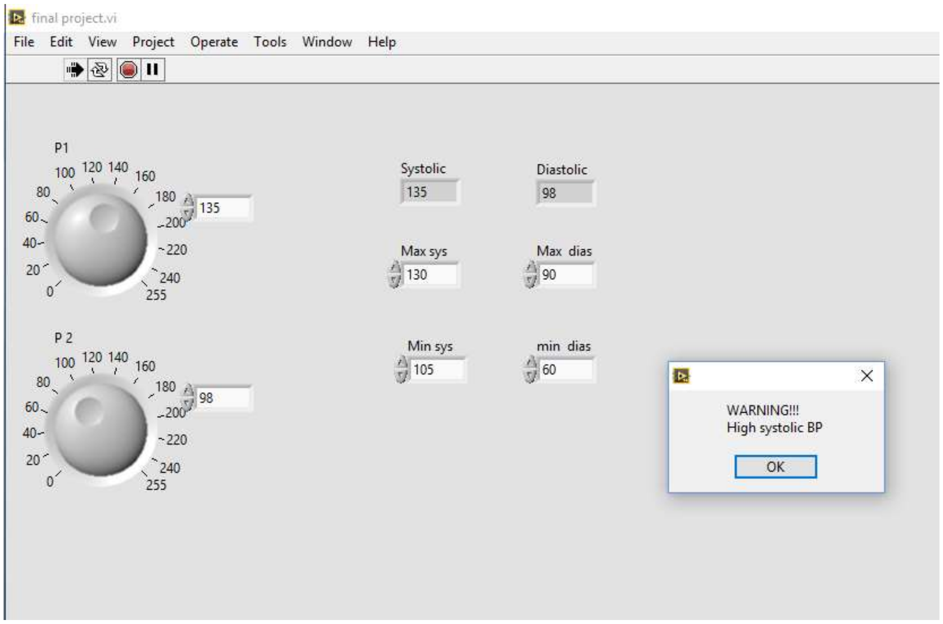


Figure 7.3 GUI for comparator displaying High Systolic B.P. message as per limits set.

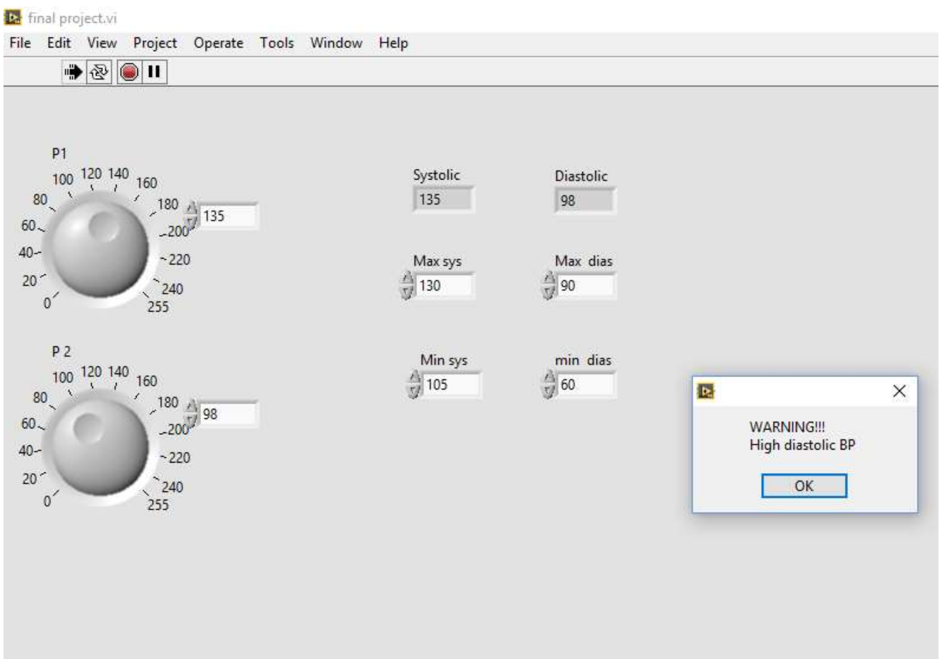


Figure 7.4 GUI for comparator displaying High Diastolic BP message as per limits set.

Similarly corresponding to different conditions like low systolic BP or low Diastolic BP, messages are displayed on the screen. The critical message is then created with the faulty B.P. values and corresponding time details as shown below:

```
test - Notepad
File  Edit  Format  View  Help

Channels        1
Samples 1
Date    2016/06/01
Time    22:15:59.3774199485778808594
X_Dimension     Time
X0      0.0000000000000000E+0
Delta_X 1.000000
***End_of_Header***
X_Value Untitled        Comment
        98.000000            Your Diastolic BP is        98    at    6/1/2016 10:15:59 PM      Warning!!!  high diastolic BP

Channels        1
Samples 1
Date    2016/06/01
Time    22:15:59.3774199485778808594
X_Dimension     Time
X0      0.0000000000000000E+0
Delta_X 1.000000
***End_of_Header***
X_Value Untitled        Comment
        135.000000           Your systolic BP is        135    at    6/1/2016 10:15:59 PM      Warning!!!  high systolic BP
```

Figure 7.5 Critical message for transmission over internet for observed BP values

The above message generated is uploaded from time to time using the internet and hence the critical information can be transmitted to the physician and the concerned people.

7.1.3 Results from conditioning

The compressing and encryption is carried out on an EEG image of 256 x 256 pixels which is transmitted at regular intervals of time. The results of conditioning are as shown below:

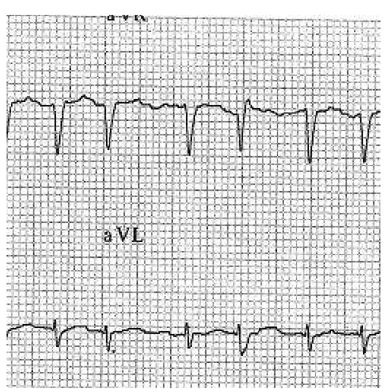


Figure 7.6 Actual ECG image input for conditioning

The image is encrypted using Gyrator [5] transform at different rotation angles for improving security at the time of transmission. The results of encryption areas shown in the figure below for different values of α:

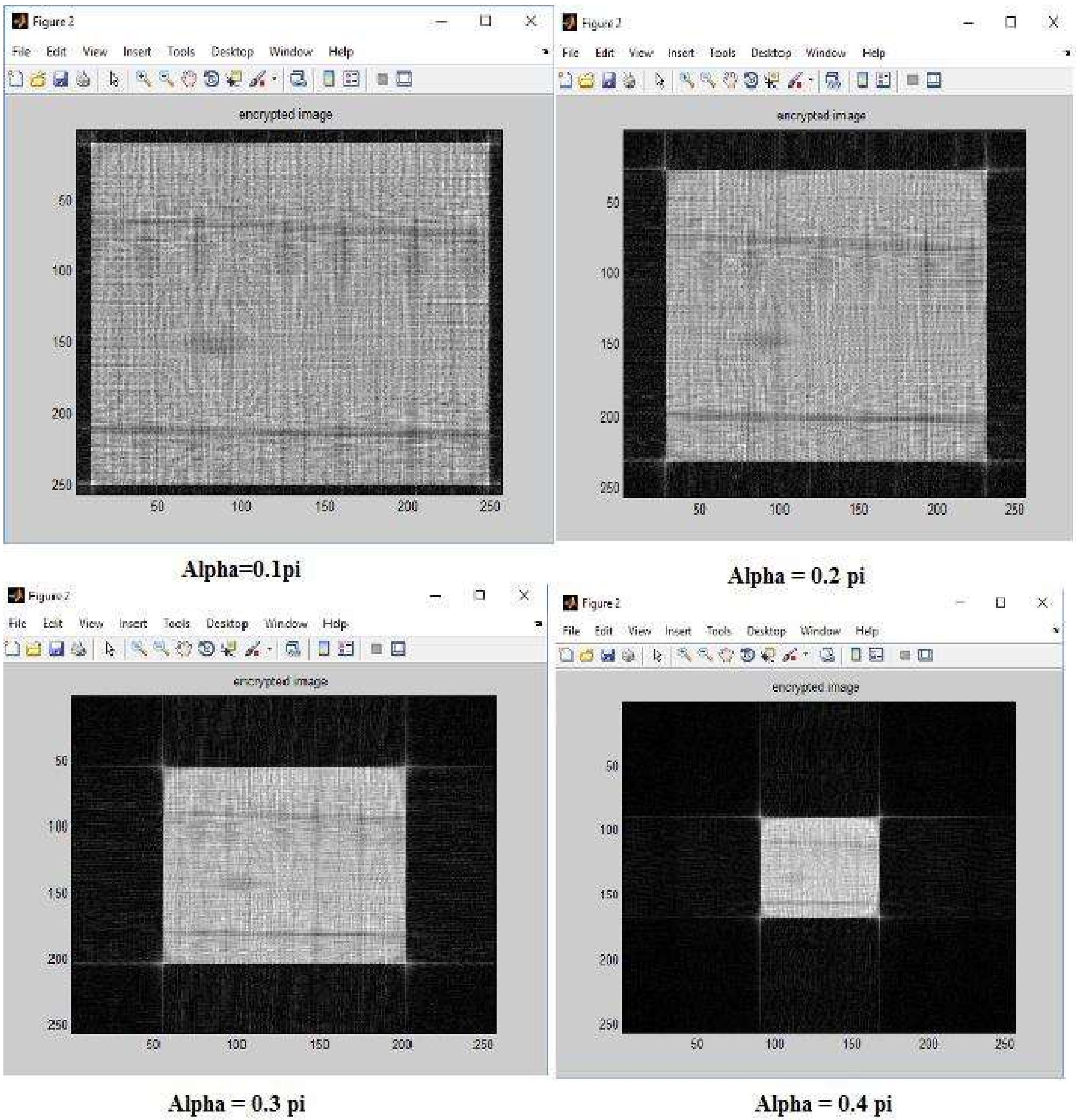


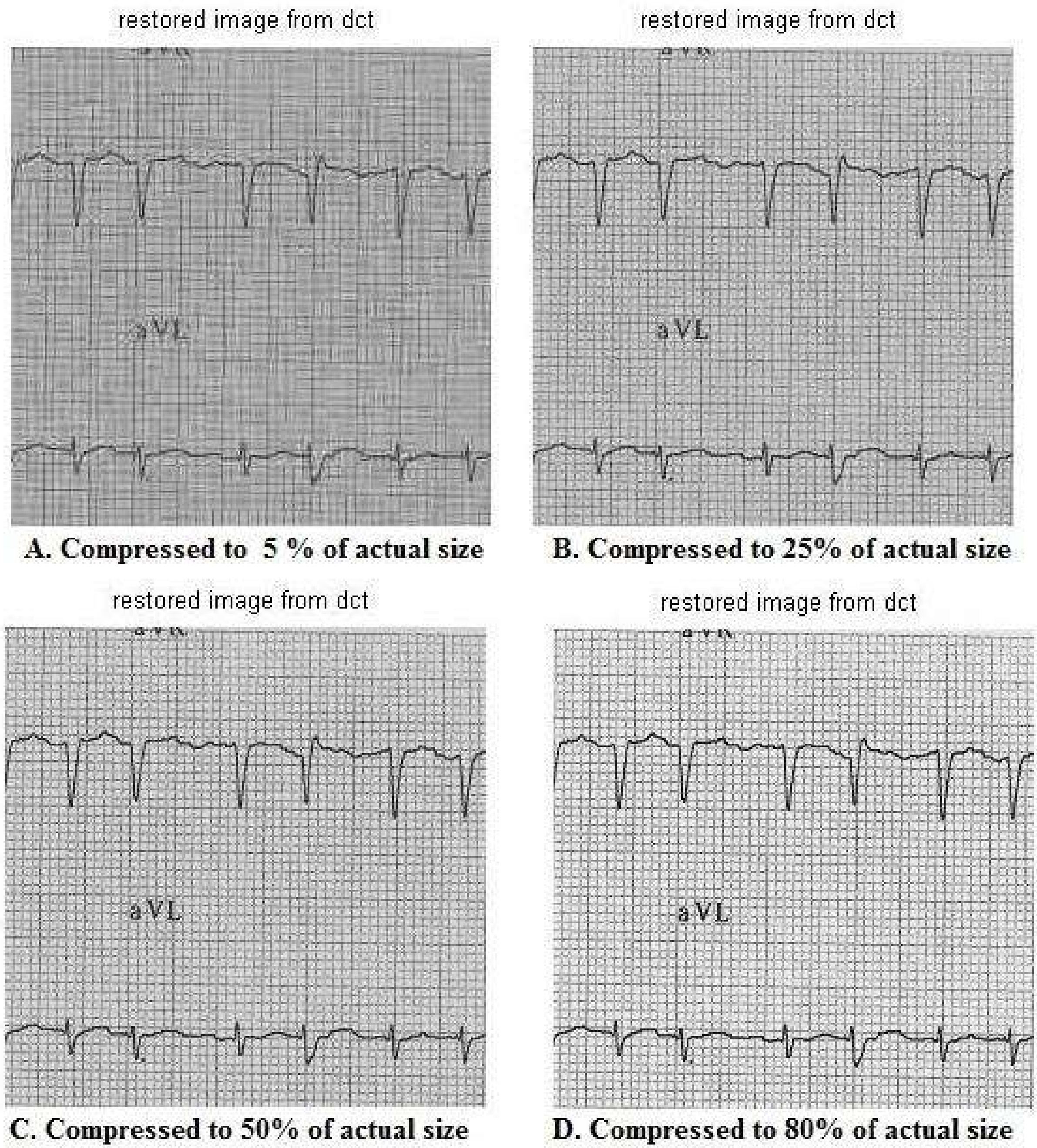
Figure 7.7 Encrypted images using different rotation angles.

The decrypted image can be obtained by using rotation angle of (-α) in the Gyrator transform at the receiver's end. The decrypted original image obtained is as given below:

Figure 7.8 Image at the receiver using (-α) rotation angle GT to transformed image

The input image to be transmitted can be compressed prior to transformation to reduce the transmission bandwidth. Discrete cosine transform is utilized for compression and the compression ratio can be set as per the available bandwidth or the minimum size or maximum compressed value with which the actual image can be retrieved at the receiver without interference of noise and distortions.

The compressions of ECG signals prior to transmission and transformation with different compression efficiencies are as shown below:



A. Compressed to 5 % of actual size

B. Compressed to 25% of actual size

C. Compressed to 50% of actual size

D. Compressed to 80% of actual size

Figure 7.9 Compression at different efficiencies.

7.2 CONCLUSION

The WBAN prototype designed is capable of commuting critical information wirelessly to the concerned person utilizing the existing technologies with enhanced transmission performance using signal conditioning using compression for efficient bandwidth utilization and encryption for improved transmission security. As there is a vast scope of miniaturization of the system using new and effective technologies in future, hence it concludes to contribute more and more in future using more efficient emerging technologies for optimum system performance.

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