IoT ENABLED VITAL SIGN MONITOR

A PROJECT REPORT

Submitted by

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BONAFIDE CERTIFICATE

Certified that this project report **"IoT ENABLED VITAL SIGN MONITOR"** is the bonafide work of "**ANBUMANI R (2014505504), VIGNESHWARAN SA (2014505561)"** who carried out the project work under my supervision. Certified further that to the best of my knowledge the work reported herein does not form part of any other project report on the basis of which a degree was conferred on a earlier occasion on this or any other candidate.

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ABSTRACT

Chronic heart failure (CHF) affects a large segment of population, and it is one of the major causes for the hospitalization of elderly people. But there is a high probability of re-hospitalization owing to the low efficiency of out-of-hospital treatment model designed to be administered to the patient after discharging from the hospital. This can be alleviated by integrating Information and Communication systems, enabling the CHF patients to collect vital signs at home on daily basis and automatically send them to the Hospital Information System or some remote server accessible to the doctors, allowing the physicians to monitor their patients at distance and take timely actions in case of necessity. A minimum set of vital parameters has been identified, consisting of Electrocardiogram, SpO2 and body temperature are measured using non-invasive biomedical sensors. The Sensor interfacing is done using Atmega 2560. Signal acquisition, preprocessing, signal conditioning is carried out by an algorithm on MATLAB and the processed Signal Parameters are sent using IoT interface to the physician’s server or any remote server so that, the physician can take timely actions required for his patient. The proposed telemedicine platform would prove to be a valid support to detect the alterations in vital signs that precede the acute syndromes in advance, allowing early home interventions thus reducing the number of subsequent hospitalizations.

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LIST OF SYMBOLS & ABBREVIATIONS

CHF	-	Chronic Heart Failure
BP	-	Blood Pressure
L	-	Liter
Kg	-	Kilogram
ICT	-	Information and Communication Technologies
SpO2	-	Peripheral Capillary Oxygen Saturation
ECG	-	Electrocardiogram
SPI	-	Serial Peripheral Interface
SCk	-	Serial Clock
MISO	-	Master In Slave Out
MOSI	-	Master Out Slave In
DRDY	-	Data Ready
UART	-	Universal Asynchronous Receiver Transmitter
Tx	-	Transmission
Rx	-	Reception
USART	-	Universal Synchronous Asynchronous Receiver Transmitter
UBRR	-	USART Baud Rate Register
UCSR	-	USART Control and Status Register
ADC	-	Analog to Digital Converter
COM	-	Communication
IoT	-	Internet of Things
Hz	-	Hertz
HW	-	Hardware
SW	-	Software
MODWT	-	Modulated Wavelet Transform
CWT	-	Continuous Wavelet Transform

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Remote monitoring is one modality of structured care in chronic heart failure. CHF is a complex clinical syndrome of symptoms and signs that suggest impairment of the heart as a pump supporting physiological circulation and it is considered to be very serious condition [1]. While CHF occurs when the pumping power of the heart weakens gradually, Heart Attack occurs when the coronary artery supplying the heart muscle with blood becomes blocked. Chronic heart failure happens when heart muscle gets damaged, then becomes weak and doesn't pump properly. The damage can be caused by a heart attack, or long-term health problems like high blood pressure, diabetes or heart disease. It can also be caused by cardiomyopathy, a disease of the heart muscle. Figure 1.1 gives the general schematics of the system.

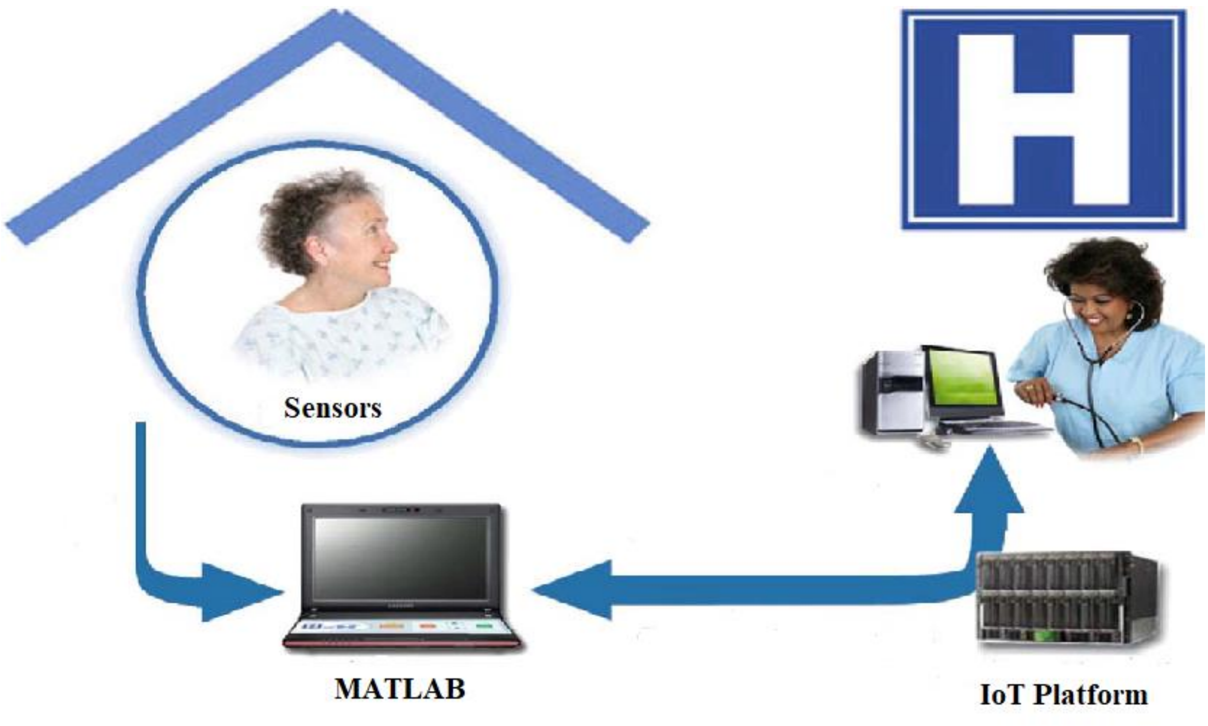

Fig. 1.1 System Block Diagram

1.2 MANAGEMENT

Unfortunately, there’s no cure for CHF, because if the valves get hardened once, it cannot be healed, but doctor or health practitioner can help the victim manage the problems it causes and improve the quality of life. Chronic heart failure can make everyday activities exhausting, but by following the advice of the doctor or health practitioner one can improve the symptoms of heart failure.

Past studies have shown that multidisciplinary treatments can improve compliance and reduce admission rates in patients with chronic HF. Some of these studies have included home monitoring with self-reported or electronically transmitted daily measurements of vital signs.

Frequent occurrences of decompensated chronic HF, which can be related to multiple factors, are a major problem in the outpatient treatment of these patients. Once patients with HF undergo decompensation, HF requires movement of clinical management from the outpatient to the costlier inpatient hospital setting. However, we believe most HF decompensation episodes are preceded by changes in vital signs in the previous days that, if detected early, might have easily led to intervention while the patient was at home and avoided an inevitable hospital readmission.

1.3 CAUSES

A heart attack might have damaged the heart. *High BP* may put pressure on the heart walls while pumping blood. Over a period of time this might cause the cardiac muscles to wear down. When the Coronary artery becomes clogged with fat or cholesterol, the volume of oxygenated blood that the heart muscles receive reduces. Over time, this might even lead to localised death of the cardiac muscles and scarring. Lung disease, diabetes, and other conditions can also lead to chronic heart failure.[5]

1.3.1 COMMON CAUSES OF CHF

- Ischaemic Heart Disease where the heart is not getting enough oxygen.
- Previous heart attack
- Essential hypertension (high blood pressure) makes it harder for the heart to get blood and makes coronary artery disease worse.
- Diabetes doubles the risk of developing chronic heart failure in men and increases risk five times for women

1.3.2 LESS COMMON CAUSES OF CHF

- Dilated Cardiomyopathy a condition where the heart just gets bigger and wider, without a known cause.
- Valvular Heart Disease especially aortic stenosis, where blood has trouble getting past one of the major valves in the heart.

1.3.3 UNCOMMON CAUSES OF CHF

- Valvular Heart Disease
- Alcoholic Cardiomyopathy
- HIV - related cardiomyopathy
- Restrictive cardiomyopathy

1.3.4 LIFESTYLE CAUSES OF CHF

- Smoking
- Obesity
- Excess alcohol consumption
- High salt intake
- High fat, low nutrient diet

1.4 PROGRESSION OF CHF

Some patients who have heart failure are not even aware of the problem until it progresses to a more serious form, called congestive heart failure. The term “congestive” refers to a fluid build-up that happens when the heart gets behind in its work. Because the heart is not efficient in pumping blood out, there is less blood leaving the heart and thus the blood that returns to the heart gets backed up. This results in an increase in pressure causing seepage into surrounding tissue. Very often it is at this stage that patients start noticing symptoms and seeking help.

1.5 PROGNOSIS OF CHF

The outlook for heart failure depends to some extent on the underlying cause of the problem and on the presence or absence of an obvious problem causing the heart failure. If an obvious cause can be identified and removed, the outlook is better. Generally, chronic heart failure carries a poor prognosis. Approximately 50% of patients with severe heart failure due to left ventricular dysfunction will die within 2 years. It should be pointed out that this is only in extremely severe cases however, and most people will live for many years.

1.6 LIFESTYLE CHANGES

Along with seeing your doctor or health practitioner regularly and taking the medicines as prescribed, lifestyle factors make a big difference in managing heart failure.

What we can do:

- Two of the most important things to do are to restrict our fluid intake to 1.5 L/day and to weigh yourself daily. If weight increases by 2 kgs over 2 days we need to see our local doctor immediately.
- Be smoke free: Smoking reduces the amount of oxygen in our blood and damages the walls of our arteries. Stopping smoking is one of the most important things that we can do to improve your condition.

- Eat less salt: Salt causes our body to retain fluid. Make sure we eat low salt, no salt, or reduced salt foods. Don't add salt to your food at the table or during cooking.
- Limit saturated fat, and avoid trans fats. Replace these unhealthy fats with the healthier monounsaturated and polyunsaturated fats.
- Limit alcohol: Alcohol can cause more damage to your heart. Talk to your doctor about what’s right for you.
- Limit caffeine and soft drinks: they can cause high blood pressure and make our heart race and not pump properly.
- Exercise every day. Talk to your doctor or health practitioner about what exercise might suit us.

1.7 ORGANIZATION OF REPORT

This report is organized as follows and discusses the topics relating to Sensor and IoT interface of vital signs in CHF.

- Chapter 2 describes about literature survey.
- Chapter 3 discusses about the clinical significance of vital signs.
- Chapter 4 revolves around the hardware interfacing of sensors.
- Chapter 5 focuses on the software interfacing.
- Chapter 6 describes about the results and discussion of the project.

CHAPTER 2
LITERATURE SURVEY

2.1 EPIDEMIOLOGY

Chronic heart failure mostly tends to affect elderly people. It occurs in about 1% of people aged 50-59, but becomes more common in the age group 80-89 where its occurrence rate is over 50%, so it certainly is not uncommon. Lifetime risk for developing heart failure is 1 in 5 among both men and women. In Australia, nearly one in everyone hundred admissions to hospital is because of chronic heart failure, and it also accounts for 2% of all deaths. It is estimated that in the United States, almost five million people have heart failure and over 600,000 develop new heart failure each year [2].

There are few data on heart failure (HF) burden and none available on the community prevalence of HF in India. Heart failure patients in India had one of the highest mortality rates after one year of diagnosis at 23%. This was more than mortality rates of patients in Southeast Asia (15%), China (7%), South America (9%) and West Asia (9%) (May 2017). [3] The study also highlighted that heart failure patients in India, Africa and Southeast Asia were approximately 10 years younger than patients in the U.S. and Europe.

According to the survey conducted in North India among the rural adult population of 10,163 patients, CHF was present in 128. Therefore, the prevalence of CHF in this general community was 1.2/1000 [3].

Heart Failure (HF) is a clinical syndrome affecting nearly 5 million people in the United States. More than 400 000 new cases are diagnosed annually. Current mortality of HF is related to its severity, ranging from 5% to 10% in patients with mild symptoms to 30% to 40% in severe cases[4].

Available data indicate that HF may cost the US healthcare system from $20 billion to $40 billion annually, including hospitalizations, medications costs, and medical follow-up. In patients older than 65 years, HF is the most frequent indication for hospitalization and the most frequent discharge diagnosis submitted for Medicare reimbursement. Moreover, as the US population ages, the incidence and prevalence of HF is expected to increase. As HF rates continue to grow, so does the impact of HF on patients, families, and health care systems, and increased significance is placed on research demonstrating positive outcomes related to this devastating health problem.

Cardiovascular diseases were the most common cause of death in the world, claiming about 17.3 million lives. In the U.S., more than 1 in 3 adults (92.1 million adults) have cardiovascular diseases, accounting for 807,775 deaths. About 790,000 people in the U.S. have heart attacks each year. Of those, about 114,000 will die. In the U.S., about 795,000 adults experienced a new or recurrent stroke, accounting for nearly 133,000 deaths. There were more than 350,000 out-of-hospital cardiac arrests in the U.S., nearly 90 percent of them fatal.

2.2 DRAWBACKS OF EXISTING METHODS

The current healthcare model is mostly in-hospital based and consists of periodic visits. Previous studies pointed out that in patients with a discharge diagnosis of heart failure, the probability of a readmission in the following 30 days is about 0.25, with the readmission rate that approaches 45% within 6 months [6]. It is acknowledged that changes in vital signs often precede symptom worsening and clinical destabilization indeed, a daily monitoring of some biological parameters would ensure an early recognition of heart failure decompensation signs, allowing appropriate and timely interventions, likely leading to a reduction in the number of re-hospitalizations. Due to lack of resources at medical facilities to support this kind of follow-up, the use of Information and Communication Technologies (ICT) has been identified by physicians and administrator as a possible valid support to overcome this limit. Systems based on telephone calls or web portal to report symptoms and measures have to be discarded for scalability and usability issues. Similar commercial systems in terms of supported vital signs use proprietary data formats and dedicated databases limiting the degree of interoperability and integration with existing departmental HIS, while they rely on dedicated call centers. The user interfaces and the collection gateways (i.e., smartphone, etc) are in some cases quite complicated with respect to the patient's ability. All existing solutions do not include advanced signal processing functions in the home gateway for early warning of the remote system. Instead, they demand all processing to the remote host which may result in loss of signals, applying only noise removal on the acquired signals.

2.3 BENEFITS OF PROPOSED METHOD

There are some evidence in literature that a multidisciplinary management program [7], [8] including a home-based follow up strategy can improve outcome of heart failure patients, including a reduction in mortality, hospital readmissions, and lengths of hospital stays, and increase patient satisfaction [9]–[11]. Root perception for the executed project was explored from [12].

CHAPTER 3
CLINICAL SIGNIFICANCE OF VITALS

3.1 INTRODUCTION

Vital signs are an important component of patient care. They determine which treatment protocols to follow, provide critical information needed to make life-saving decisions, and confirm feedback on treatments performed. Accurate, documented vital signs are a very important part of Health Monitoring System. Electrocardiogram, SpO2 levels and Body temperature are the chosen vitals for the constant remote monitoring of the CHF patients.

3.2 ELECTROCARDIOGRAM

Electrocardiogram is an indication of the proper working of the heart and an important tool used for the diagnosis and treatment of various cardiac and other related diseases. The recorded tracing of the ECG waveforms produced by the heart can tell you basic information about a patient's condition. The ability to evaluate various ECG waveforms is an important skill for many health care professionals including nurses, doctors, and medical assistants. In addition, as a multiskilled health care employee you may be required to determine if an ECG is normal or abnormal and be able to respond to a cardiac emergency, if necessary. You will follow your scope of practice and the policy at your place of employment when evaluating and reporting dysrhythmias. ECG waveform has various components such as waves, segments, and intervals that are evaluated and classified based on their size, length of time, and location on the tracing. All these different components determine the type of cardiac rhythm. To evaluate a rhythm, you must first understand each component and its normal appearance. When these components differ from the expected norm, a dysrhythmia (or arrhythmia) is indicated. Remember, an abnormal ECG tracing may only be the result of artifact. The tracing must be evaluated for artifact prior to the evaluation of the heart rhythm. [13]

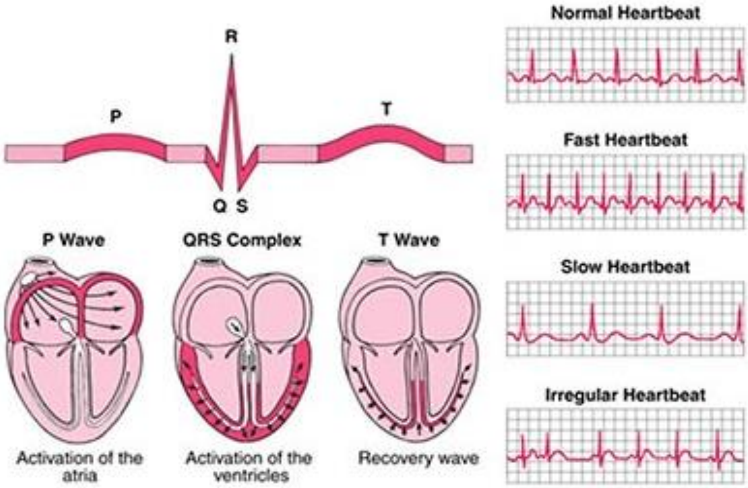

Fig 3.1: Normal vs abnormal ECG waves

From the figure 3.1, we are able understand the discrimination in normal and abnormal ECG waves.

3.3 SpO2

SpO2 stands for peripheral capillary oxygen saturation, an estimate of the amount of oxygen in the blood. More specifically, it is the percentage of oxygenated haemoglobin (haemoglobin containing oxygen) compared to the total amount of haemoglobin in the blood (oxygenated and non-oxygenated haemoglobin). Pulse oximetry is an important diagnostic and patient monitoring tool widely used throughout the hospital environment. Pulse oximetry is highly reliable when used on motionless and well-perfused patients.

Baseline oxygen saturation by pulse oximetry decreased progressively in relation to the presence and the severity of acute heart failure assessed by Killip classes 1 to 3 (mean: 95, 92 and 85, respectively; $P<.001$) or by radiology score 0 to 4 (95, 94, 92, 89 and 83, respectively; $P<.001$), with a correlation coefficient of 0.66 and 0.63, respectively. Receiver operating characteristic curves disclosed the cut-off of oxygen saturation by pulse oximetry<93 to have the greatest area, with a sensitivity of 65%, specificity 90%, and overall test accuracy 83%. Patients grouped according to lowest oxygen saturation by pulse oximetry showed significantly different rates of one-year mortality or rehospitalisation for heart failure. Table 3.1 gives the information about Oxygen Saturation levels in the blood.

Table 3.1: Oxygen Saturation Levels

Measurement	Critical	Notes
Spo2 > 95%	NO	Normal healthy individual
Spo2 91% - 95%	NO	Clinically acceptable, but low. Patient may be a smoker, or be unhealthy.
Spo2 70% - 90%	YES	Hypoxemia. Unhealthy and unsafe level.
Spo2 < 70%	YES	Extreme lack of oxygen, ischemic diseases may occur.

3.4 HEART RATE

Heart rate is negatively related to duration of life both across many animal species and in humans, and a high heart rate is a prognostic index for cardiovascular risk. It has been reported that a reduction in heart rate of 10 beats/min saves 5 kg adenosine triphosphate per day. In addition, an increase in heart rate of 5 beats/min corresponds to an increase in the atherosclerosis progression score of 0.21 and to an increase in the stenosis progression score of 0.27. Table 3.2 gives the information about resting heart activity.

Increased heart rate may be associated with increased mortality either because an accelerated heart beat itself favours mechanisms that lead to the occurrence of death or, alternatively, because it is a marker of pathophysiological alterations that, through other mechanisms, lead to death. [14] Table 3.3 and 3.4 gives knowledge about resting heart rate statistics of men and women respectively

Table 3.2: Resting Pulse Rate

Measurement	Critical	Notes
PR <40 BPM	YES	Below healthy resting heart rates.
PR 40-60 BPM	YES/NO	Resting heart rate for sleeping.
PR 60-100 BPM	NO	Healthy adult resting heart rate.
PR 100 BPM – 220 BPM	YES	Acceptable if measured during exercise. Not acceptable if resting heart rate.
PR > 220 BPM	YES	Abnormally high heart rate.

.

Table 3.3: Resting heart rate chart for men

Age in Years	Heartbeats Per Minute						
	Athlete	Excellent	Good	Above Average	Average	Below Average	Poor
18-25	49-55	56-61	62-65	66-69	70-73	74-81	82+
26-35	49-54	55-61	62-65	66-70	71-74	75-81	82+
36-45	50-56	57-62	63-66	67-70	71-75	76-82	83+
46-55	50-57	58-63	64-67	68-71	72-76	77-83	84+
56-65	51-56	57-61	62-67	68-71	72-75	76-81	82+
65+	50-55	56-61	62-65	66-69	70-73	74-79	80+

Table 3.4: Resting heart rate chart for women

Age in Years	Heartbeats Per Minute						
	Athlete	Excellent	Good	Above Average	Average	Below Average	Poor
18-25	54-60	61-65	66-69	70-73	74-78	79-84	85+
26-35	54-59	60-64	65-68	69-72	73-76	77-82	83+
36-45	54-59	60-64	65-69	70-73	74-78	79-84	85+
46-55	54-60	61-65	66-69	70-73	74-77	78-83	84+
56-65	54-59	60-64	65-68	69-73	74-77	78-83	84+
65+	54-59	60-64	65-68	69-72	73-76	77-84	84+

3.5 BODY TEMPERATURE

In CHF, a low body temperature at hospital admission predicts in-hospital mortality. Postdischarge reduction in body temperature predicts early CHF rehospitalization and death. The records of 198 patients discharged after CHF hospitalization were reviewed. Patients were categorized as hypothermic or normothermic (cutoff point, 36.3 degrees C/97.4 degrees F) according to body temperature at discharge. Classification of 2 groups-based temperature change between discharge and the first follow-up visit: normothermic/non-decreasing temperature (N+), normothermic/decreasing temperature (N-), hypothermic/non-decreasing temperature (H+), and hypothermic/decreasing temperature (H-).

Ninety-three patients (47%) had decreasing temperatures, and 105 patients (53%) had non-decreasing temperatures. Kaplan-Meier analysis revealed a significant intergroup difference in survival ($P = .01$) and rehospitalization time ($P = .005$). On logistic regression, a decreasing temperature was significantly associated with rehospitalization within 180 days (odds ratio, 4.01; 95% confidence interval, 1.63-10.02; $P = .003$). On Cox regression, the hazard ratios for death were 3.19 ($P = .07$), 6.49 ($P = .004$), and 5.17 ($P = .07$), for the N-, H+, and H- groups, respectively, versus the N+ group. For rehospitalization time, the hazard ratios were 7.02 ($P = .01$), 4.24 ($P = .08$), and 13.43 ($P = .005$) for the N-, H+, and H- groups, respectively, versus the N+ group.

Decreasing body temperatures can predict readmission, decreased time to rehospitalization, and (in combination with hypothermia) decreased survival.[8]

CHAPTER 4
HARDWARE INTERFACING

4.1 INTRODUCTION

The three vitals, Electrocardiogram, SpO2 and the Body Temperature are measured using three different non-invasive biomedical sensors. The ECG shield for Arduino made by protocentral is being used for the measurement of surface ECG. MOD PULSE board is used in association of Nellcor sensor for the measurement of SpO2. The standard LM35 temperature sensor is being used for temperature measurement.

4.2 INTERFACING ELECTROCARDIOGRAM

The protocentral ECG shield (shown in the figure 4.1) communicates with the Arduino through SPI interface. Three wire SPI is used for the purpose. SCK, MISO, MOSI pins are used. SPI is a synchronous serial data protocol used by microcontrollers for communicating with one or more peripheral devices quickly over short distances.

Fig 4.1: ECG Shield

With an SPI connection there is always one master device (usually a microcontroller) which controls the peripheral devices. Typically, there are three lines common to all the devices:

MISO - The Slave line for sending data to the master,

MOSI - The Master line for sending data to the peripherals,

SCK - The clock pulses which synchronize data transmission generated by the master

In Arduino Mega (shown in the figure 4.2) the pins 50, 51, and 52 are the SPI pins. A High baud rate of 115200 is being used by the ECG shield for the transmission of data to the Arduino Mega 2560.

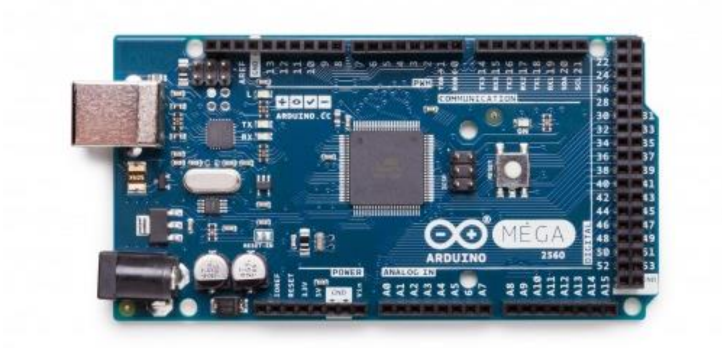

Fig 4.2: Arduino Mega 2560

4.2.1 DATA ACQUISITION AND SAMPLING

The sampling rate for the Protocentral ECG shield embedded with the analog to digital converter, ads1292, an TI product, has a sampling rate of 125 samples per second. Each sample is 8 bits long and each packet of data consists of 8 bytes. The first four bytes of the packet are of ECG signal and the next four bytes are of the respiration signal. Only the ECG signal is of significance to us and thus the redundant respiration signal is put to trash. The ECG signals are collected through a set of three electrodes. The signal noise is attenuated using a on board bandpass filter with a cutoff frequency of 150Hz. The analog signal is converted to digital format and then transmitted through SPI communication to the Arduino. Since the sampling rate is 125 samples per second, the ads1292 drives the DRDY pin “LOW” every 8ms. Whenever the arduino detects this DRDY pin to be LOW, it transfers the data from the SPI buffer of the ads1292 to its internal data buffer. Shift by 8 operations is done on the received data bytes to receive multiple bytes on the same data buffer without the need to initialise new buffer every time a new packet of data is ready. This ECG data acquisition is run as the main program in the arduino and hence it collects the data continuously over a period of specified time.

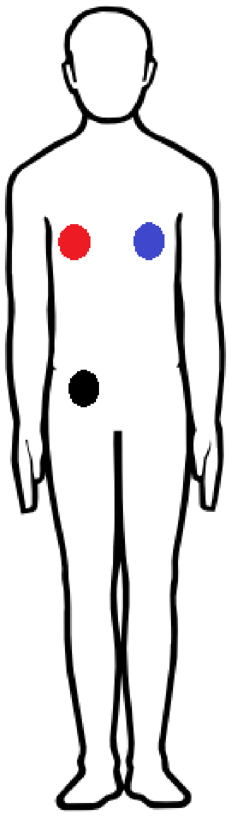

Fig 4.3 ECG Electrode Placement

4.3 INTERFACING SpO2

Nellcor Sensor, DS100 (shown in the figure 4.4) is being utilised as the SpO2 probe here. The data being collected from the SpO2 probe is transmitted to the TI Board, MOD PULSE (shown in the figure 4.5) using a DB-9 connector. MOD-PULSE is an instrument for monitoring the blood oxygenation of a human.

By measuring the oxygen level and heart rate, MOD-PULSE can display the levels of blood oxygenation and heart rate on it's LCD display. To perform it's functionality, MOD-PULSE requires external sensor connected to it via PROBE connector. MOD-PULSE board uses a ultra low power microcontroller MSP430FG439 from Texas Instruments. The MOD PULSE board is made to communicate with the master Microcontroller (Atmega 2560) through the UART. The Rx-Tx serial communication is used. The Mod Pulse board transmits the samples at the rate of 115200 baud rate.

Fig 4.4: DS 100A SpO2 sensor

4.3.1. DATA ACQUISITION AND SAMPLING

The MOD PULSE board was serially sending 3 samples per second to the arduino. A data packet consisted of 3 samples and each sample, a byte long. The Mod Pulse board was programmed to work on UART Interrupt. Everytime the Mod Pulse board was ready with a data packet in it’s Tx buffer, it sends a byte of data to the UART Rx buffer of the Arduino Mega 2560. Once the Rx buffer gets full, it generates a interrupt and the microcontroller responds to this interrupt, puts the main program on hold, waits for a few cycles so as to synchronize with the MSP430FG microcontroller on the MOD PULSE board and then reads the Rx buffer data for non-redundant data alone. Once 3 bytes of data is being read, i.e., a data packet has been read, the main program reading the ECG samples is continued. Since the MOD PULSE board sends only 3 samples per second, an interrupt occurs approximately every 300ms.

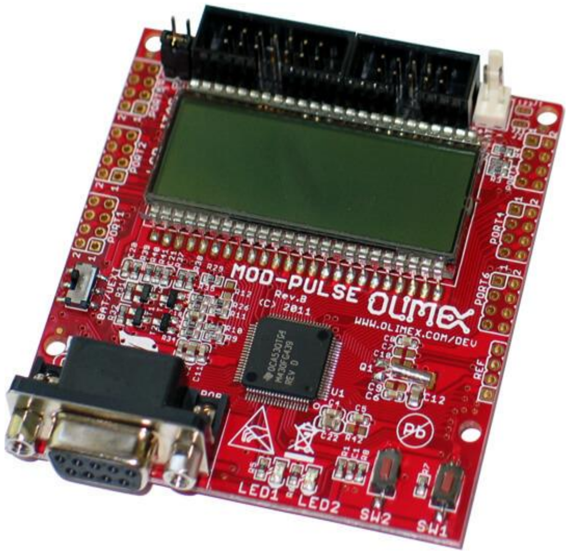

Fig 4.5: MOD-PULSE Board

4.3.2 INTERRUPT PROGRAMMING

USART1 RX_vect interrupt is beeng used here. The USART1 control registers, UCSR1A, UCSR1B, UCSR1C, UBRR1L, UBRR1H are written with a hex value to initialise them for the our required use. The UBRR value for a baud rate of 115200 is calculated to be written into the UBRR1L and UBRR1H registers. Using the frame format for the control registers, the status words are constructed. Figures 4.5, 4.6 and 4.7 details the frame format of UCSRA, UCSRB and UCSRC respectively.

- Before setting the baud rate, UCSR1B is reset.
- In USCR1A, we need the bit 1 to be ‘0’ so that the transmission is Asynchronous mode. Rest of the bits are left to stay in the initial value.
- Since each sample is a byte long, i.e., 8 bit long. Thus the bits 1 and 2 are set to ‘1’ in USCR1C.
- The Rx enable and Tx enable pins are set in the USCR1B after setting the UBRR value in the UBRR1L:UBRR1H registers.

- For a baud rate of 115200 and FOSC of 16000000, the UBRR value is calculated to hex value of 8.

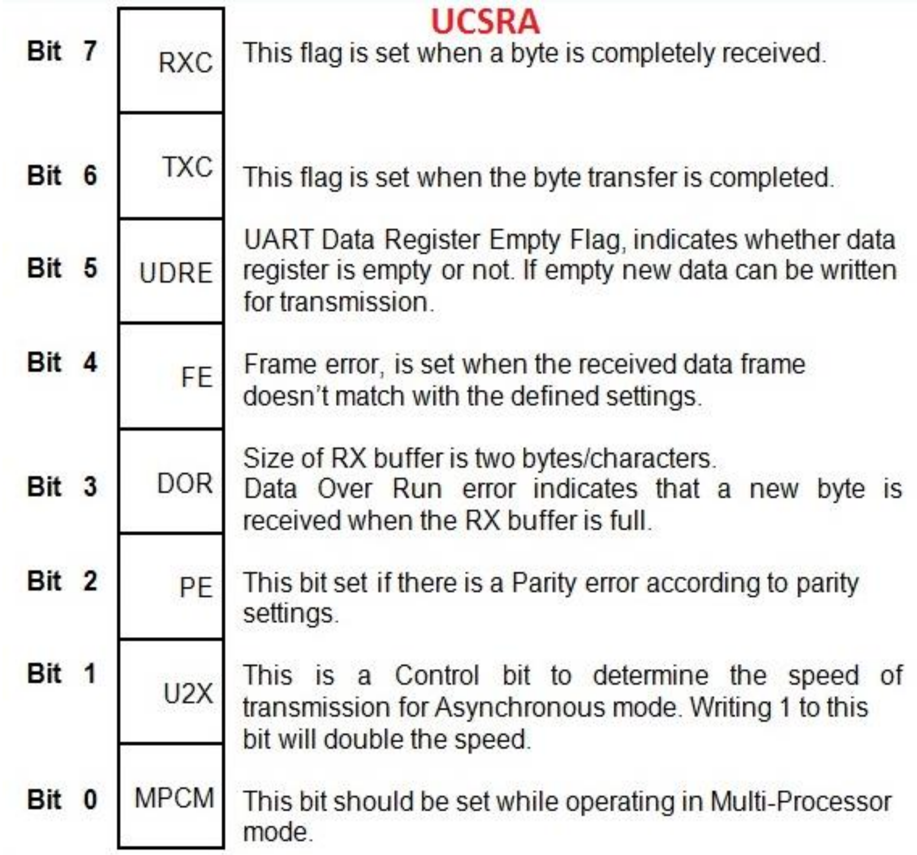

Fig 4.6: Frame format of UCSRA

Thus the values being written on all the control and status registers are:

UCSR1B = 0x00;

UCSR1A = 0x00;

UCSR1C = 0x06;

UBRR1L = 0x08;

UBRR1H = 0x00;

UCSR1B = 0x98;

UCSRB

Bit 7	RXCIE	This bit should be set, if an interrupt has to be generated after receiving a byte. Receive Complete Interrupt Enable bit.
Bit 6	TXCIE	Setting this to 1 bit will generate an interrupt after transferring the byte.
Bit 5	UDRIE	Generates an interrupt if the Data register becomes Empty.
Bit 4	RXEN	To enable receiving data, this bit must be set.
Bit 3	TXEN	Writing 1 to this bit will enable data transmission
Bit 2	UCSZ2	One of the bits to define the number of data bits.
Bit 1	RXB8	This bit holds the received 9^{th} bit during 9-Bit data mode. This bit must be read before reading the data register.
Bit 0	TXB8	The 9^{th} bit of the 9-Bit data is transferred through this bit. This bit must be written before writing to data register.

Fig 4.7: Frame format of UCSRB

Table 4.1: Baud rate and UBRR calculation

Operating Mode	Equation for Calculating Baud Rate[1]	Equation for Calculating UBRR Value
Asynchronous Normal mode (U2X = 0)	$BAUD = \frac{f_{OSC}}{16(UBRR + 1)}$	$UBRR = \frac{f_{OSC}}{16BAUD} - 1$
Asynchronous Double Speed Mode (U2X = 1)	$BAUD = \frac{f_{OSC}}{8(UBRR + 1)}$	$UBRR = \frac{f_{OSC}}{8BAUD} - 1$
Synchronous Master Mode	$BAUD = \frac{f_{OSC}}{2(UBRR + 1)}$	$UBRR = \frac{f_{OSC}}{2BAUD} - 1$

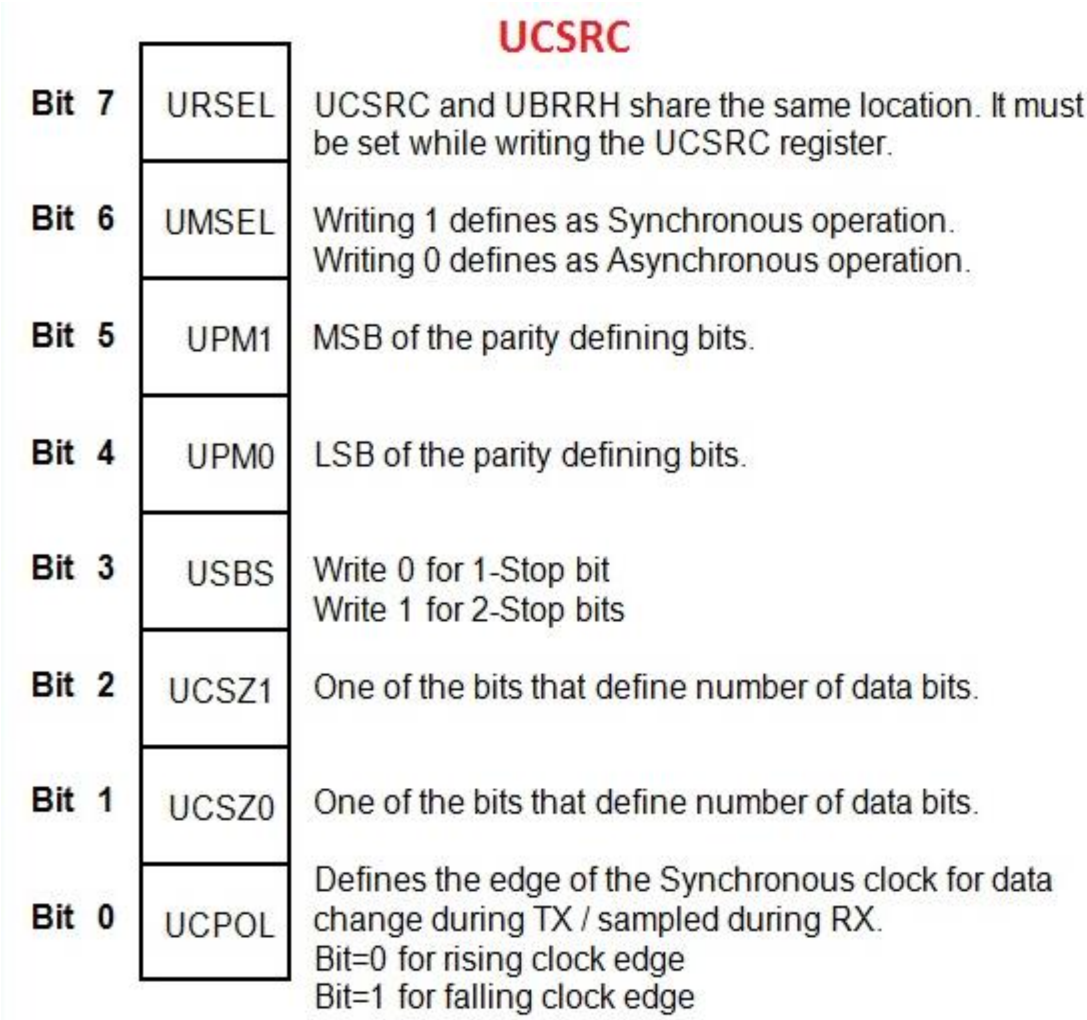

Fig 4.8: Frame format of UCSRC

4.4 INTERFACING LM35

The LM35 (shown in 4.9) series are precision integrated-circuit temperature devices with an output voltage linearly proportional to the Centigrade temperature. The LM35 device does not require any external calibration or trimming to provide typical accuracies of ±¼°C at room temperature and ±¾°C over a full −55°C to 150°C temperature range. The device is used with single power supplies, or with plus and minus supplies. As the LM35 device draws only 60 µA from the supply, it has very low self-heating of less than 0.1°C in still air. The LM35 device is rated to operate over a −55°C to 150°C temperature range. The output of the LM35 device changes 10mv for every degree change in temperature in degree Centigrade.

Fig 4.9: LM35

4.4.1 DATA ACQUISITION

Since, body temperature is one such vital parameter that does not tend to change significantly in a very short period, sampling of body temperature is not required absolutely. It is perfectly alright to acquire the temperature signal occasionally. LM35 device is a analog device and produces a analog voltage proportional to the temperature. A single channel of the 16 channels, 10-bit ADC of the Arduino Mega 2560 is used for analog to digital conversion of the output voltage of the LM35 device. The digital output of the ADC is read by the microcontroller.

4.5 DATA TRANSMISSION

ECG shield transmits data to the Arduino Mega at a rate of 115200 bits/second and the MOD PULSE board transmits the SpO2 data at the same rate to the Arduino Mega. With a combined speed of 230400 baud rate, the arduino is receiving data from SPI and Serial Communication interface. If it wasn't for this high speed of incoming data, other arduino models could have been chosen. Since Arduino Mega is one the popular devices capable of handling such high speeds, it was chosen as the master microcontroller. Though the speed of operation is really high, it is not necessary to operate at such high speeds. The ECG shield is transmitting 125 samples, each one byte long per second, meaning, it is transmitting just around 3200 bits/second, but is been programmed to operate at a speed of 115200 baud rate. Apart from the 3200 bits, all other bits is completely redundant. This is the similar case with the MOD PULSE device too. It transmits not more than 3 samples, each one byte long per second, i.e., 24 bits/second, but is transmitting them at a speed of 115200 baud rate. Such high speeds is trivial for the operation of the device, also the baud rate error is high at these speeds. A rate not higher than approximately 3300 bits/ second (3200 + 24) is necessary for the proper transmission of the data without incurring any loss. Thus the standard 9600 baud rate with a baud rate error of 0.2% is chosen as the speed of transmission of the signal to the PC for further processing. This data is communicated serially to the computer through the software serial COM Ports.

CHAPTER 5
SOFTWARE INTERFACING

5.1 INTRODUCTION

The Arduino Mega transmits the collected data to the PC at a standard baud rate of 9600. The serial port is opened in the PC and the data is received and stored in a buffer. The collected data is then processed here, decisions made based on predictions and the output is uploaded onto a cloud IOT platform.

5.2 DATA ACQUISITION

The serial port where the arduino is connected is opened and the serial incoming data is read for a set period. A Timer is set for this purpose. When the timer runs out, the serial port is closed, and the data collected is sent to processing.

Each packet of data being sent from is the arduino is been assigned with a header and footer. For instance, the header for ECG is 1101 while the header for SpO2 is 1001. The temperature data is not being given a specific header for the sake of simplicity. It is sent as such as the fourth byte in the SpO2 packet. This saves space in the transmitted data space.

Flags are being assigned and used for the purpose of non sequential data acquisition. If it were not for the flags, the data would be collected one unique packet after the other, as such for every SpO2 packet, we will be storing only one ECG packet and the rest will be discarded. With the proper utilisation of flags, all the 125 packets of ECG and 3 packets of SpO2 are properly captured.

5.3 PROCESSING ECG DATA

5.3.1 FILTERING DATA

Though there is an on-board band pass filter on the Protocentral ECG shield, there is a high risk of noise affecting the ECG signal during transmission from the Arduino Mega to the PC. The noise may be of different types like, DC Noise and Motion Artifacts. Butterworth Low Pass filter with a cut off frequency of 40 and a sampling frequency of 125 and order 5 is been designed for the purpose. The filter characteristics including the magnitude and phase angle plot is shown in the figure 5.1.

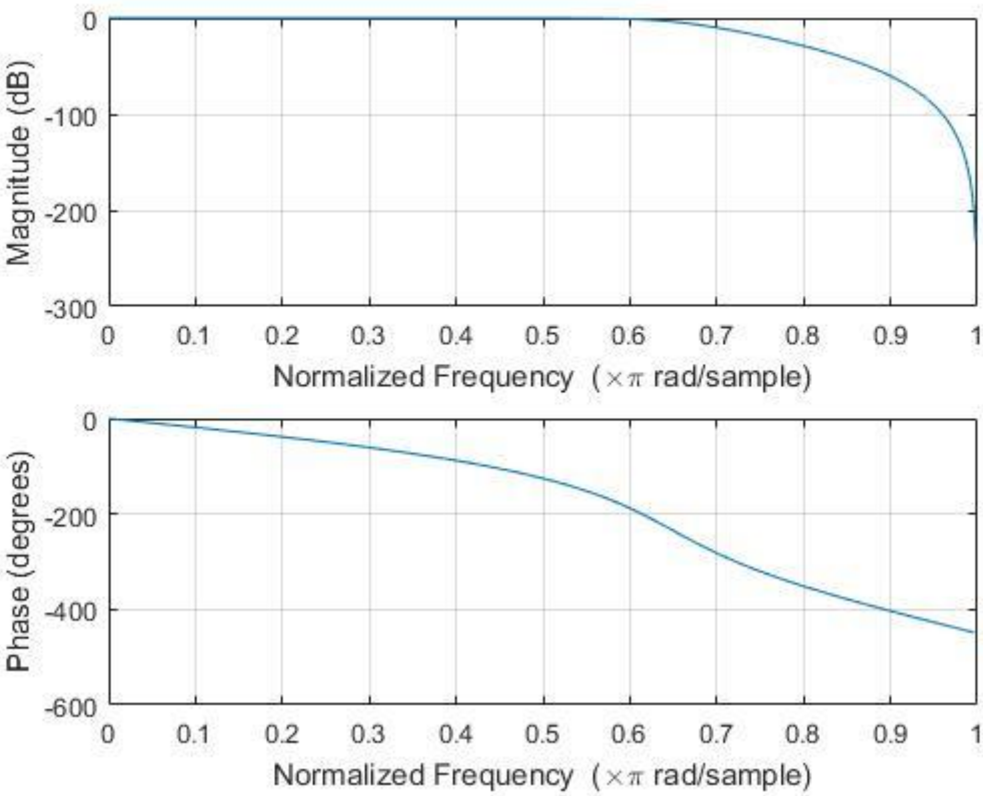

Fig 5.1 : Magnitude and phase compensation of ECG

Since the inherent non-stationary frequency of the ECG signal does not exceed 40 Hz, the cut off frequency is been chosen as 40 Hz.

5.3.2 MODULATED WAVELET TRANSFORM

The MODWT is a linear filtering operation that transforms a series into coefficients related to variations over a set of scales. It is similar to the DWT in that both are linear filtering operations producing a set of time-dependent wavelet and scaling coefficients. The filtered ECG signals are transformed using MODWT at a scaling rate of 4 and 5. The ECG signals are reconstructed using inverse modulated wavelet transform. The reconstructed signal which is devoid of any kind of noise is used for training, testing and validating the machine learning algorithm. 'Sym4' wavelet which closely resembles a single QRS complex is chosen as the wavelet of choice for the MODWT as shown in the figure 5.2.

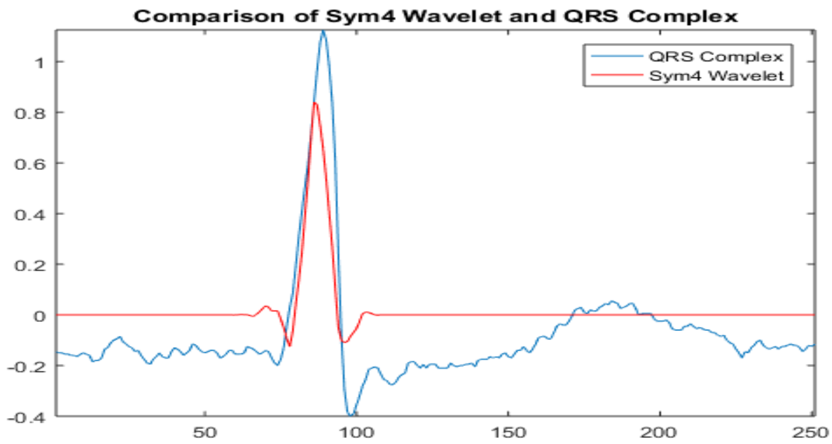

Fig 5.2: Comparison of Sym4 wavelet and QRS complex

The R peaks are clearly distinguishable in the reconstructed signal as depicted in the figures 5.3 and 5.4. The location and indices of occurence of the R peaks are noted down. The original signal, which is bipolar, is squared to get a new signal which is unipolar in nature. MODWT is applied to this signal.

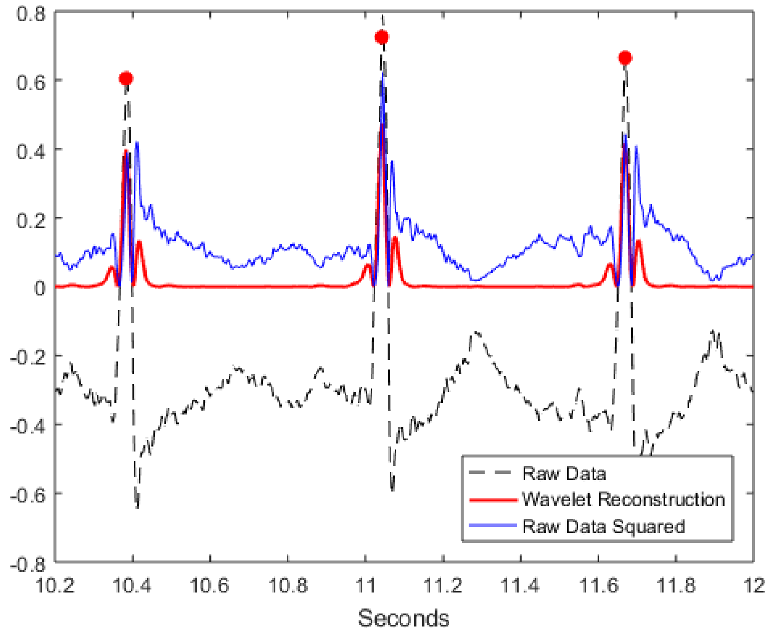

Fig 5.3: Comparison of Reconstructed signal, Raw data and Raw data squared values

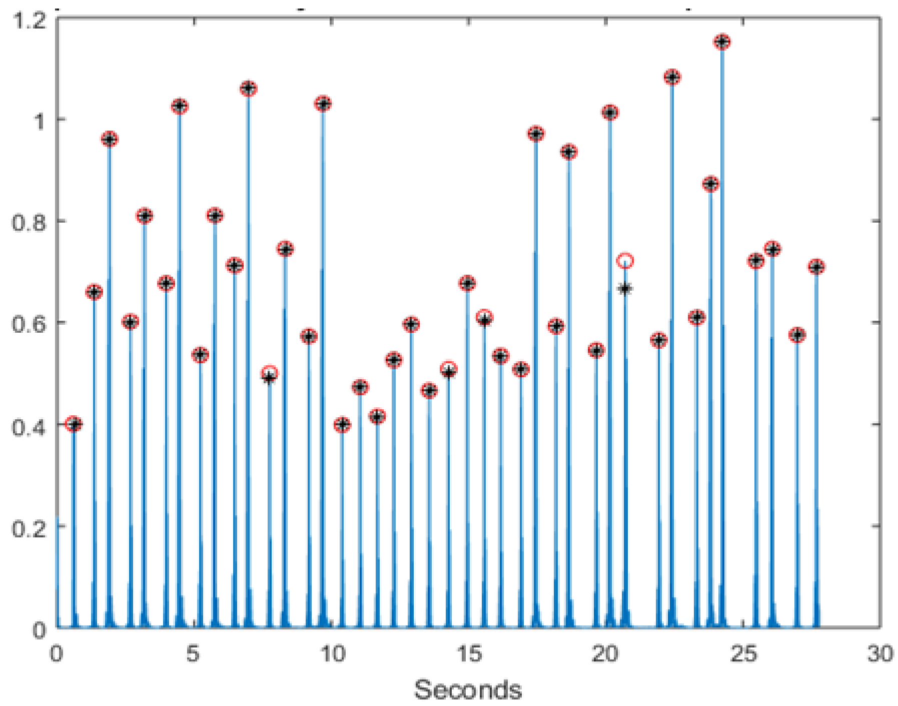

Fig 5.4: R peaks localized by Wavelet transform

5.3.3 CLASSIFICATION AND PREDICTION

The inverse MODWT signal is used for the training, testing and validation of data. A secondary dataset is used as the base for the abnormal ECG signal. A primary dataset collected from the students is used as the base for normal ECG signal. These datasets are combined into a single dataset and is split into test and training set with k-fold cross validation in the ratio of 70:30. The training set is used to train a simple Classification And Regression Tree. When the test set is been tested on the trained model, it is surprising to see a very high accuracy of about 99.95%. The instantaneous data collected from the patient, after going through the butterworth low pass filter and the inverse MODWT taken on the transformed filtered signal, is given to the trained model for the prediction of labels. Standard deviation, accuracy, loss, sensitivity, specificity are calculated based on the confusion matrix made from predicted labels and the original labels. Using this prediction output, the ECG of the patient is being diagnosed.

5.4 PROCESSING SpO2 AND TEMPERATURE DATA

The SpO2 and Temperature data are received as a single packet. Much processing is not required for these data. When the Oxygen Saturation and Heart rate per minute value is not in the punched range, the values are diagnosed to be abnormal. Similarly, if the body temperature of the patient is not the specified range, it is diagnosed to be abnormal.

5.5 UPLOADING TO IoT PLATFORM

A cloud IoT channel is created on a open source platform provided by Thingspeak. Knowing the proper channel ID and the correct API key for writing, it is possible to upload the diagnosed parameters into the cloud platform. These values are available for the physicians for their perusal and further remedial for the abnormal parameters. This Thingspeak Cloud platform is especially useful for the cloud computing of data on Matlab on a different server. So, as and when any of the vital parameter go abnormal, the physician is intimated about the same and he can take the necessary speedy remedial action. Real time data upload into the IoT platform Thingspeak is exhibited in figure 5.5.

Fig 5.5 Thingspeak Iot Platform

CHAPTER 6
RESULTS AND DISCUSSIONS

Exhaustive testing of HW/SW platforms is a key issue for their adoption in telemedicine systems. Each developed component passed the unit test. From the hardware point of view, the novel ECG-SpO2 module was subjected to the electrical certification, and the home gateway was tested after the replacement of the native keyboard with the custom membrane keypad. The operational correctness of the software elements has been verified using conventional software validation procedures. Both the sensor firmware on Arduino and software ad hoc executed on the MATLAB for home gateway have been heavily tested, with particular attention to the concurrence, accuracy and the responsivity. Interfacing of ECG, SpO2 and body temperature sensors are made effectively on the Arduino Mega board without any loss. Moreover, all the signal processing algorithms were tested for, using of arbitrary values. The integration test verified the end-to-end communication in the system, and the overall system-level interactions of the different HW and SW parts. Execution of the adhoc with healthy users as well as the CHF prone patients meet the expected behaviour. No connectivity and transmission problems, including no data lost occurred. The results show a very limited number of activity misses (around 0.05%), that is accuracy of the executed learning process is around 99.95%, confirming the property of such system can improve the therapy compliance. The measure of the estimated difference between the observed or calculated value of a quantity and its true value is not more than 0.005. When calculated for how much the predicted value deviates from the original value, we get a standard deviation of 0.3226. The proportion of truly positives cases that were classified as positive is as high as 0.9679, meaning, the Sensitivity of the classifier is really high. Apart from this, the classifier also identifies negative values perfectly at the rate of 0.9989, thus having a high Specificity too. All these parameters, accuracy, loss, sensitivity, specificity are all calculated based on the confusion matrix as shown in table 6.1.

Table 6.1: Confusion matrix

5231	10
23	693

With all this in mind, the number of false positive alarms is also negotiable. The system presents the physician, a valid means to access patient’s vital signs database at distance with the high quality of acquired signals as well as the high esteemed prediction capability.

CHAPTER 7
CONCLUSION

The developed system was tested on the normal subjects and the results were surprisingly perfect. The ECG diagnostics of the normal subject proved normal after rigorous filtering and transforming techniques. The SpO2 values like the oxygen saturation and the heart rate per minute was in the specified threshold and the diagnostic output was predicted to be normal, same as the expected outcome. The body temperature of our normal subjects were also in the punched range of values and the diagnostics came out as normal.

7.1 SCOPE FOR FUTURE DEVELOPMENT

- A minimal set of vitals were used here for the diagnosis of abnormality in CHF patients.
- The same principle can be used by adopting a completely different set of vital parameters or some other vital parameters in addition with the chosen ones, so that remote monitoring can be enabled for other chronic ailments as well.
- A different communication protocol not dependent on the internet connectivity can be used in addition to the IoT so that in times of low internet connectivity, the alternate method can be used to transmit the data to the physician.

CHAPTER 8

SUMMARY

- A brief introduction about Chronic Heart Failure is seen.
- A method to interface Protocentral ECG shield with Arduino is seen.
- A method to interface MOD PULSE board with Arduino is seen.
- A method to interface LM35 with Arduino is seen.
- Data Acquisition of vital signs from the body.
- Filtering ECG signal using higher order butterworth low pass filter.
- Application of Modulated Wavelet Transform to filtered ECG signal.
- Classification of the reconstructed ECG signal.
- Uploading the prediction output to a remote IoT platform.

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APPENDIX - 1

ARDUINO PROGRAM

```
#define F_CPU 16000000
#include<avr/io.h>
#include<avr/interrupt.h>
#include<util/delay.h>
#include <ads1292r.h>
#include <SPI.h>

ads1292r ADS1292;   // define class

volatile uint8_t  SPI_Dummy_Buff[30];
uint8_t DataPacketHeader[16];
volatile signed long s32DaqVals[8];
uint8_t data_len = 8;
volatile byte SPI_RX_Buff[15] ;
volatile static int SPI_RX_Buff_Count = 0;
volatile char *SPI_RX_Buff_Ptr;
volatile bool ads1292dataReceived =false;
unsigned long uecgtemp = 0;
signed long secgtemp=0;
int i,j;
byte k = 0;
byte tmpstr[5];
byte zsync = 0;
byte wait = 0;
byte cycle = 0;
char c;
```

```
float temp=0.0;

void setup()
{
 //USART1 INIT - SpO2 INIT
 UCSR1B = 0x00;
 UCSR1A = 0x00;
 UCSR1C = 0x06;
 UBRR1L = 0x08;
 UBRR1H = 0x00;
 UCSR1B = 0x98;
 //USART0 INIT - Data Transmission To PC
 Serial.begin(9600);
 //ECG Shield INIT
 pinMode(ADS1292_DRDY_PIN, INPUT);  //6
 pinMode(ADS1292_CS_PIN, OUTPUT);    //7
 pinMode(ADS1292_START_PIN, OUTPUT);  //5
 pinMode(ADS1292_PWDN_PIN, OUTPUT);  //4

 ADS1292.ads1292_Init();  //initalize ADS1292 slave
 //LM35 INIT
 pinMode(A0, OUTPUT);
 pinMode(A1, INPUT);
 pinMode(A2, OUTPUT);
```

```
 digitalWrite(A0, HIGH);
 digitalWrite(A2, LOW);
}

void loop()
{
  if((digitalRead(ADS1292_DRDY_PIN)) == LOW)      // Sampling rate is set to
125SPS ,DRDY ticks for every 8ms
  {
    SPI_RX_Buff_Ptr = ADS1292.ads1292_Read_Data(); // Read the data,point
the data to a pointer

    for(i = 0; i < 9; i++)
    {
      SPI_RX_Buff[SPI_RX_Buff_Count++] = *(SPI_RX_Buff_Ptr + i);
    }
    ads1292dataReceived = true;
  }
  if(ads1292dataReceived == true)      // process the data
  {
    j=0;
    for(i=0;i<6;i+=3)             // data outputs is (24 status bits + 24 bits Respiration
data +  24 bits ECG data)
    {

        uecgtemp = (unsigned long) (  ((unsigned long)SPI_RX_Buff[i+3] << 16) |
( (unsigned long) SPI_RX_Buff[i+4] << 8) | (unsigned long)
SPI_RX_Buff[i+5]);
```

```
        uecgtemp = (unsigned long) (uecgtemp << 8);
        secgtemp = (signed long) (uecgtemp);
        secgtemp = (signed long) (secgtemp >> 8);

        s32DaqVals[j++]=secgtemp;
      }
      DataPacketHeader[1] = s32DaqVals[1];          // 4 bytes ECG data
      DataPacketHeader[2] = s32DaqVals[1]>>8;
      DataPacketHeader[3] = s32DaqVals[1]>>16;
      DataPacketHeader[4] = s32DaqVals[1]>>24;

      DataPacketHeader[5] = s32DaqVals[0];          // 4 bytes Respiration data
      DataPacketHeader[6] = s32DaqVals[0]>>8;
      DataPacketHeader[7] = s32DaqVals[0]>>16;
      DataPacketHeader[8] = s32DaqVals[0]>>24;

      Serial.println("1101");
      for(i=1; i<9; i++)
      {
       Serial.println(DataPacketHeader[i]);     // transmit the data over USB
       }
     }
      ads1292dataReceived = false;
      SPI_RX_Buff_Count = 0;

      temp = (5.0 * analogRead(A1) * 100.0) / 1024;
  }
ISR(USART1_RX_vect)
```

```
{
  c = UDR1;
  if((byte)c == 0x00)
  {
    cycle++;  /* wait a few zero synch bytes */
    zsync = 1;
    i = 0;
  }
  if(zsync == 1 && cycle == 10)
  {
    if((byte)c != 0xFF)
    {
      tmpstr[i] = c;
      if(i == 3)
      {
        Serial.println(tmpstr[1]);
        Serial.println(tmpstr[2]);
        Serial.println(tmpstr[3]);
        Serial.println(temp);
        zsync = 0;
        wait = 1;
        cycle = 0;
      }
      i++;
    }
  }
}
```

APPENDIX -2

MATLAB CODE

```
ecg=0;
spo2=0;
resp=0;
yin=1;
yang=1;
yu=1;
boo=1;
i=0;
j=0;
k=1;
flag=0; % flag==1 ecg recorded flag==2 spo2 recorded

%ECG : header-1001  footer-1010
%SpO2: header-1101  footer-1110

data=0;
s = serial('com3');
set(s,'BaudRate',9600);

try
    fopen(s);
catch err
    fclose(instrfind);
    error('Select the correct COM Port where the Arduino is connected.');
end
Tmax=120; % time for running app
```

```
Ts=0.008;

tic
while toc<=Tmax

    out =strsplit(fgetl(s));
    data(k) =str2double(cell2mat(out(1)));
    data(isnan(data))=-1;

    pause(0.001);

    if (data(k)==1001 | flag==1 & data(k)~=-1) & i<=8
        flag=1;
        if(i>=1 & i<5)
            ecg(yin)=(data(k)/1024)*3.3;
            yin=yin+1;
        end
        if(i>=5)
            resp(yang)=(data(k)/1024)*3.3;
            yang=yang+1;
        end
        if i==8
            i=0;
            flag=0;
        else
            i=i+1;
        end
        j=0;
```

```
    end

    if (data(k)==1101 | flag==2 & data(k)~=-1) & j<=4
        flag=2;
        if (j>=1 & j<=3)
            spo2(yu)=data(k);
            yu=yu+1;
        end
        if (j==4)
            temp(boo)=data(k);
            boo=boo+1;
        end
        j=j+1;
        i=0;
    end

    t(k) = toc;
    if k > 1
        T = toc - t(k-1);
        while T < Ts
            T = toc - t(k-1)  ;
        end
    end
    t(k) = toc;
    k=k+1;


end
```

```
fclose(instrfind)


%Filtered signal
fs=500;
cutoff=150;
order=5;
fil_ecg=[];

fil_ecg = butterworth_lowpass_filter(ecg,cutoff,fs,order);
fil_ecg_2=[];
x=1;
a=1;
while (a<=int16(fix(length(ecg)/1024)))
    a=a+1;
    fil_ecg_2=[fil_ecg_2;fil_ecg(x:x+1023)];
    x=x+1023;
end
ecg=[];
ecg_sq=[];
i=1;
len=size(fil_ecg_2);
while(i<=len(1))
    f_ecg = fil_ecg_2(i,:);
    wt = modwt(f_ecg,5);
    wtrec = zeros(size(wt));
    wtrec(4:5,:) = wt(4:5,:);
    y = imodwt(wtrec,'sym4');
```

```
    ecg = [ecg; y];
    ecg_sq = [ecg_sq; abs(y).^2];
    i=i+1;
end

a=spo2(1:3:end);
b=spo2(2:3:end);
c=spo2(3:3:end);

spo2_2=[a;b;c];
spo2_2=spo2_2.';
IR_AC_heart_signal = sum(spo2_2(:,1))/length(spo2_2);
Heart_rpm = sum(spo2_2(:,2))/length(spo2_2);
O2_sat = sum(spo2_2(:,3))/length(spo2_2);

Temp = sum(temp)/length(temp);

if (O2_sat > 91)
    o2_sat_diag = 'acceptable';
else
    o2_sat_diag = 'unsafe';
end

if (Heart_rpm > 60 && Heart_rpm < 90)
    h_rpm_diag = 'normal';
else
    h_rpm_diag = 'abnormal';
end
```

```
if (Temp >=36.5 & Temp<=38)
    temp_diag = 'normal';
else
    temp_diag = 'abnormal';
end

chfdb = load ('chfdb_ecg.csv');
ndb   = load ('ndb_ecg.csv');

chf_size = size(chfdb);
ndb_size = size(ndb);
chfdb_label = zeros(chf_size(1),1);
ndb_label = ones(ndb_size(1),1);
features = [chfdb ; ndb];
labels   = [chfdb_label ; ndb_label];
dataset=[features labels];

p = .7  ;    % proportion of rows to select for training
N = size(dataset,1);  % total number of rows
tf = false(N,1);    % create logical index vector
tf(1:round(p*N)) = true;
tf = tf(randperm(N));   % randomise order
dataTraining = dataset(tf,:);
dataTesting = dataset(~tf,:);

XT = dataTraining(:,1:end-1);
yT = dataTraining(:,end);
```

```
Xt = dataTesting(:,1:end-1);
yt = dataTesting(:,end);

Mdl = fitctree(XT,yT);
L = loss(Mdl,Xt,yt);

pred = predict(Mdl,ecg);

i=1;
c0 = 0;
c1 = 0;
while(i<length(pred))
    if (pred(i) == 1)
        c1 = c1+1;
    else
        c0 = c0+1;
    end
    i = i+1;
end

if (c1>c0)
    ecg_diag = 'normal_ecg';
else
    ecg_diag = 'abnormal_ecg';
end

channelID = 447659;
writeKey  = '8NRFAUIWXQYN5EYP';
```

```
thingSpeakWrite(channelID,{O2_sat,Heart_rpm,Temp,ecg_diag},'WriteKey',writeKey)

csvwrite('ecg.csv',ecg);
csvwrite('ecg_sq.csv',ecg_sq);
csvwrite('resp.csv',resp.');
csvwrite('spo2.csv',spo2_2);
```