

SLEEP APNEA DETECTION USING ECG SIGNAL AND AUTOMATED NON- INVASIVE VENTILATION USING A LOW- COST CPAP DEVICE

Submitted in partial fulfilment of the requirements for the award of Bachelor of Technology
degree in Biomedical Engineering

By

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**DEPARTMENT OF BIOMEDICAL ENGINEERING
SCHOOL OF BIO AND CHEMICAL ENGINEERING**

SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **ANEESHWAR M (38240005) AND STEPHIN BRITTO A (38240038)** who carried out the project entitled **"Sleep Apnea Detection using ECG signal and automated non-invasive ventilation using a low-cost CPAP device"** under our supervision from **October 2021 to March 2022.**

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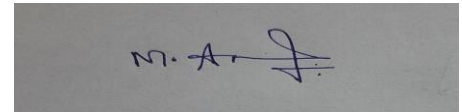
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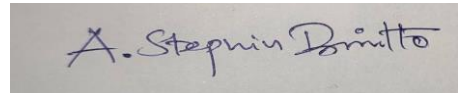
DECLARATION

We **ANEESHWAR M (REG. NO.38240005)** and **STEPHIN BRITTO A (REG. NO. 38240038)** hereby declare that the Project Report entitled “**Sleep Apnea Detection using ECG signal and automated non-invasive ventilation using a low-cost CPAP**” device done by us under the guidance of **Dr. Bethanne Janney J, M.E., Ph.D.** at **MedCuore Medical Solutions Pvt. Ltd.** at **Royapuram** submitted in partial fulfilment of the requirements for the award of **Bachelor of Technology** Degree in **Biomedical Engineering**.

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ABSTRACT

Sleep apnea is potentially a serious sleep disorder in which the breathing pattern repeatedly stops and starts. In the initial condition, the healthcare practitioner will suggest some medications or recommend patients to use CPAP, APAP, or BiPAP devices, which use compressed air to open and support the airway during sleep, and those require to be operated manually by the patient or physician. A new method is presented to detect sleep apnea and a low-cost CPAP device is further built for automatic non-invasive ventilation. At first, sample ECG signals are collected from sleep apnea patients and processed on MATLAB. Moreover, techniques like interpolation, filtration, Time-domain analysis, Frequency vs Power spectrum, and Frequency domain analysis were used to detect the distance between R peaks, as irregular R peaks lead to the presence of apnea. A low-cost CPAP instrument is constructed further for ventilation support. Initially, a blower (which p continuously provides pressurized air) is utilized by connecting an adaptor to produce a power supply. A pressure sensor is used then to sense the pressure produced by the blower. Arduino UNO microcontroller is utilized by consuming a 5V power supply from the board, an LCD is connected along with the microcontroller to show the output values on the screen. A relay is used as a switch that electronically opens and closes the circuit to facilitate automatic switching on/off CPAP. After detecting sleep apnea through MATLAB, the signals are transferred to the Arduino board through PC. So, if sleep apnea is detected the Arduino will enable the relay to function. When the relay is ON the power supply will enable the blower to operate. The blower produces air, so a tube is attached to the blower to deliver pressurized air to the patient. A small tube was then inserted to measure the pressure produced by the blower. So a pressure sensor is used for measuring the value of the air pressure produced by the blower. Finally, the output is displayed on the screen.

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LIST OF ABBREVIATIONS

ABBREVIATIONS	EXPANSIONS
CPAP	Continuous Positive Airway Pressure
APAP	Automatic Positive Airflow Pressure
BiPAP	Bi-level Positive Airway Pressure
ASV	Adaptive servo-ventilation
OSA	Obstructive Sleep Apnea
CSA	Central Sleep Apnea
ECG	Electrocardiogram
LCD	Liquid Crystal Display
LPF	Low Pass Filter
LMICs	Low-/ Middle-Income Countries

CHAPTER 1

INTRODUCTION

Sleep apnea is imaginably a serious sleep disorder, in which the breathing process stops and starts continuously. Each interruption can last for a few seconds to a few minutes and they usually occur at night. The tests to diagnose sleep apnea include Polysomnography, a comprehensive test that records the brain waves, eye movements, heart rate, breathing patterns, blood oxygen level, body position, chest abdominal, and limb movements, snoring, and related noise when an individual makes while sleeping. Home sleep apnea testing may also be done under certain circumstances when a physician provides a simplified home version kit for the measurement of sleep apnea.

1.1 NON-INVASIVE TREATMENTS FOR SLEEP APNEA

Several procedures are used to treat sleep apnea some of them are mentioned below:

1) Continuous Positive Airway Pressure (CPAP):

It is a machine that is programmed to send pressurized air at a steady level into your nose and mouth. It is most commonly recommended for patients suffering from sleep apnea. The working of this device is a motor in the CPAP that generates pressurized air which travels via an air filter to a flexible tube. The tube then supplies purified air to a mask that is sealed around the patient's mouth. There are different types of CPAP masks available based on the patient's needs: 1) Nasal pillow mask which has a small cushion that covers the nostril area, the advantage of using this, is it helps individuals to wear glasses and also suits for patients with huge facial hair, 2) Nasal mask- These masks that cover the whole nasal region. It delivers airstream at high pressure, 3) Full mask- This kind of mask covers both nose and mouth, these sort of masks are recommended when patients breathe through the mouth during their sleep. The benefits of using this machine include stability in the level of sleep reduces risk rate of heart attack and stroke, reduced blood pressure, and lessened sleepiness during the daytime. The drawbacks might be disturbed and complications falling asleep, nasal congestion, irritation of the skin, and nose bleed.

2) Automatic Positive Airflow Pressure (APAP):

Automatic positive airflow pressure is a machine that checks the breathing level of the patient and automatically adjusts the airflow settings using the software. APAP has a mask and has connections to a device that advances air into the patient's throat. The advantage of using this machine is that it offers both continuous and auto-adjusting modes, adapts pressure with different positions during sleep, increases comforts during sleep due to delivery of high pressure, and pressures according to the patient's needs. The Cons are these devices are costlier and in certain situations, the adjustments of the device might take time, so this may lead to disturbances in sleep.

3) Bilevel Positive Airway Pressure (BiPAP):

BiPAP devices are used for individuals who can't tolerate CPAP. It delivers pressurized air into the lungs and the air pressure can be delivered in two different modes, one for inhaling where the BPAP machine delivers a large amount of air pressure to the patients this is also known as inspiratory positive airway pressure, and another for exhaling where the machine decreases the air pressure while breathing out this is known as expiratory positive airway pressure. A BPAP contains a face mask and a nasal mask attached to the machine by a tube. The motor in the device blows the air and the air enters the body with the help of the masks. Certain BPAP machines can have a programmed timer that will maintain the number of breaths per minute. The usage of BiPAP can cause some mild side effects like bloating, running nose, sinus, mouth dryness, and nasal dryness.

4) Adaptive servo-ventilation (ASV):

It is the latest approved device that measures the breathing patients' breathing patterns and scores them in an inbuilt computer. After the patient falls asleep, the machine utilizes the pressurized air to normalize the breathing pattern. It utilizes a non-invasive ventilator to therapize central sleep apnea by providing servo-controlled inspiratory support. The positives of using this device are it is easier and more comfortable to use. This device can also be life-threatening for someone with central sleep apnea and chronic heart failure. Moreover, it usually costs more than CPAP.

1.2 SURGICAL TREATMENTS FOR SLEEP APNEA

If the other treatments have failed surgery is the only procedure to treat sleep apnea. Various surgical procedures include:

1) Upper Airway Surgery:

The common surgery performed is known as Uvulopalatopharyngoplasty (UPPP). It is the most usual surgical method for Obstructive Sleep Apnea. This method includes the removal of excess tissue from the soft palate and pharynx in which common blockages occur for many patients. This surgery may require hospitalization and rehabilitation may take several weeks. The side effects may include changes in voice and difficulty while swallowing fluids.

2) Nasal Surgery:

Nasal surgery is done by removing the nasal polyps or straightening the deviated nasal septum for increasing the airflow through the nose. It is not a complete cure for apnea but can improve breathing.

3) Maxillomandibular Advancement:

Here upper and lower jaws are fractured surgically, and both jaws advance for the airway enlargement. This procedure is more critical than UPPP, and it can take some time for recovery.

4) Tracheostomy:

A tracheostomy is a surgical procedure where an opening is created at the front of the neck so a tube can be inserted into the trachea for breathing assistance. A tracheostomy might be carried out for individuals who require oxygen support after an injury or accident, it can also allow the patients to breathe if the throat region is blocked. Furthermore, it reduces the risk of food or fluid entering the lungs. The complications of this medical procedure include bleeding, mucus & fluid formation in the tracheostomy tube.

5) Hypoglossal Nerve Stimulation:

Here a stimulation electrode is placed on the branches of the hypoglossal nerve during surgery and a sensing electrode is placed on the chest wall. Both electrodes are connected to a neurostimulator. The sensing electrode detects the beginning of the breath and transfers the signal to the neurostimulator. After transmission, the stimulation electrode activates the hypoglossal nerve which controls the tongue movement. The tongue then moves forward after activation. In Obstructive Sleep Apnea this will prevent the backward collapsing of the tongue thereby preventing obstruction of the airway. This method is quite effective and produces better results for patients suffering from Obstructive Sleep Apnea.

6) Radiofrequency volumetric tissue reduction:

If a person can't wear a breathing device, a physician might recommend this surgical procedure that uses radiofrequency waves for opening up the airway by shrinking or removing the tissues at the back of the throat.

7) Maxillomandibular advancement:

This procedure is also known as jaw repositioning where the jaw is moved forward to create some space behind the tongue that can open the airway.

8) Anterior inferior mandibular osteotomy:

Here the patient's tongue moves forward by dividing the chin bone into two parts. The recovery time is shorter when compared to other surgical methods, but it's less effective.

9) Genioglossus advancement:

In this procedure, the tendons are tightened slightly in the front of the tongue. This can avoid the tongue from rolling back and interfering with breathing.

10) Lingual tonsillectomy:

Here both of the patient's tonsils and tonsillar tissue is removed near the back of the tongue. The physicians might recommend this to help them open up the lower part of their throat for breathing easily.

11) Septoplasty and turbinate reduction:

The nasal septum is a combination of bone and cartilage that separates nostrils. If the nasal septum is bent, it may damage the breathing patterns, so septoplasty is done for straightening the nasal septum and nasal cavities which can make individuals breathe easier.

The curved bones alongside nasal passage are called turbinates, which can sometimes interfere with breathing, so a turbinate reduction is done to reduce the bones' size and help the patients open up the airway.

1.3 TYPES OF SLEEP APNEA

The main types of sleep apnea are Obstructive apnea and Central apnea.

1.3.1 Obstructive Sleep Apnea

Obstructive sleep apnea (OSA), occurs due to airway collapse during sleep as the effort taken by the patient to breathe become foiled, the oxygen level in the blood drops due to unsuccessful breathing, lastly, the amount of oxygen reaching the brain decreases, and the brain signals triggers the body to wake up to take the breath. The individual awakens with shortness of breath but it will disappear after one or two deep breaths. The fascinating fact is that only 10% of the individuals with OSA patients get treatment, whereas the remaining patients go undiagnosed as they might not be aware of their interrupted sleep. The symptoms of obstructive sleep apnea include loud snoring, excessive daytime sleepiness, awakening with a dry mouth or sore throat, headache in the morning, change of moods, concentration lapse during the day, high blood pressure, etc. Individuals with excess weight, older age, a Narrowed airway, High blood pressure, chronic nasal congestion, smoking, diabetes, asthma, and a family history of sleep apnea have greater chances of experiencing Obstructive sleep apnea. The side effects of this include daytime fatigue and sleepiness, cardiovascular problems, eye problems, etc. Patients with obstructive sleep apnea might also experience COVID-19 and requires excess assistance from the physician than those who don't have obstructive sleep apnea. The test to detect Obstructive sleep apnea is Polysomnography and Home sleep apnea testing. Patients can change their lifestyle habits like losing weight, exercising

regularly, quitting smoking, and avoiding consuming alcohol for milder cases. The therapy for this condition includes delivering positive airway pressure that reduces the number of respiratory events during sleep and improves the quality of life. The most common instrument used here is CPAP. Another approach to treating sleep apnea is delivering air through an oral device (mouthpiece). This procedure is used for individuals who have mild or moderate obstructive sleep apnea mildly or moderately, and also for patients who can't use CPAP. If the above procedures don't go well, the patient has to undergo some types of surgeries for getting rid of the apnea. The first type is the removal of tissue from the back of the patient's mouth and top of the throat by performing surgeries. Another approach is to implant a small impulse generator in the upper chest underneath the skin. The device detects the patients' breathing patterns and sends stimulation to the nerve to control the movements of the tongue if required. Other types of surgery include Jaw surgery, where the upper and lower parts of the jaw are moved forward. This can likely reduce the obstruction as there will be huge space between the tongue and soft palette after the surgery. Tracheostomy, where the surgeon makes an opening on the neck and inserts a tube to send air to the lungs. Scientists predicted that Obstructive sleep apnea is going to upset about 19 percent of the total population in the upcoming years.

1.3.2 Central Sleep Apnea

Central sleep apnea (CSA) happens when the muscles, which control breathing, don't receive proper signals from the brain. It is less common than Obstructive sleep apnea as the tolerant can't breathe properly due to obstruction of the upper airway. The symptoms of central sleep apnea include abnormal breathing patterns during sleep, sudden awakenings due to shortness of breath, insomnia, hypersomnia, difficulty in concentration, change of moods, snoring, and headaches in the morning. Central sleep apnea occurs when the brain fails to pass on the signals to the breathing muscles. The causes can vary depending upon the type of central sleep apnea a patient has. Types include. Cheyne-Stokes breathing, whicost commonly associated with stroke or heart failure. It is the gradual increase and then decreases in the breathing patterns. Drug induce apnea is one of the causes that occur due to the consumption of certain medications like opioids. It can cause irregular breathing

patterns. Another cause of central sleep apnea is High-altitude periodic breathing, here a Cheyne-Stokes breathing pattern occurs when the individual is under high altitude. Treatment-emergent sleep apnea- here some patients with obstructive sleep apnea expand to central sleep apnea during the usage of CPAP for the treatment. It is a combination of obstructive and central sleep apnea. Certain factors like sex, age, heart disorders, stroke, brain tumor, high altitude, opioid usage, and CPAP can put people at the risk of experiencing central sleep apnea. The complications include fatigue and cardiovascular problems. To diagnose this disease, doctors recommend that the patients undergo polysomnography and imaging of the heart and brain for evaluation. Trained neurologists and cardiologists solved the evaluation process. For treatment, instruments like CPAP and BiPAP are most commonly used. Adaptive servo-ventilation can also be used to treat this condition. Transvenous phrenic nerve stimulation is the new approach that delivers an electric impulse to the nerve during sleep to provide a steady breathing pattern

CHAPTER-2

LITERATURE SURVEY

Onintza Garmendia et al. (2020) had implemented a low-cost, easy-to-build non-invasive pressure support ventilator for under-resourced regions: open-source hardware description, performance, and feasibility testing. The project aims to design and test an affordable and easy-to-build non-invasive bilevel pressure ventilator to allow a reduction in the serious shortage of ventilators in low-/middle-income countries (LMICs). The ventilator was built using a high-pressure blower, two pressure transducers, and an Arduino Nano controller with a digital display. The designed ventilator provided inspiratory/expiratory pressures up to 20/10 cmH₂O, respectively, with no faulty triggering or cycling; both in the bench test and in volunteers. The low-cost, easy-to-build non-invasive ventilator performs similarly to a high-quality commercial device, with its open-source hardware description, which will allow for free replication and use in LMICs, facilitating the application of this life-saving therapy to patients who otherwise could not be treated.

Sindu Divakaran et al. (2021) constructed an intelligent detection and therapeutic device to support sleep apnea in infants to help infants to overcome sleep apnea disorder. They have utilized various sensors by placing them on the infant to measure parameters such as heart rate, SPO₂, breath rate, and temperature. These vital parameters are read continuously and the live data is sent in through a microcontroller through a serial port. This data is then processed and extracted. The values are then compared with the database that contains standard values. The decision model makes a decision and concludes whether the condition of the infant is abnormal (sleep apnea) or not. If abnormal, the decision-making model sends a trigger to the flow sensor whose one end is connected to the oxygen supply and the other end is connected to the mask on the patient's mouth. Once the trigger is given, the oxygen supply reaches the patient's mask. The therapy unit is stopped only when the condition turns normal.

Ms .S. Jayachitra et al. (2021) developed a prototype for the treatment of Sleep Apnea using CPAP. The main objective is to construct a low-cost CPAP. Thus they had collected real-time data and transferred the data via IoT. In their proposal, they

have designed a compact CPAP kit based on the IoT environment. The kit will detect the snoring rate of a patient. Because of its low price, this will help people to reach in the best way. Portable in size and easily rechargeable. A controlled pressure airflow system is used to protect and maintain the air level. There are two modes of operation one is the auto mode and another one is timer mode or manual mode. They also added a temperature sensor and a heart rate sensor. Temperature sensor which continuously detects the temperature of the patient. Also, the heart sensor monitors the beating rate of the heart.

André Pinho et al. (2019) had built a device towards accurate sleep apnea detection based on ECG signals. This is a reliable and simplified method to detect sleep apnea using an ECG signal. ECG signal was modeled to obtain the Heart Rate Variability (HRV) and the ECG-Derived Respiration (EDR). The feature extraction was processed along with the HRV and the EDR signals. On the one hand, the time interval from one R wave is considered the HRV. On the other hand, the EDR is a signal processing technique for deriving respiration signals from ordinary electrocardiograms. The area of the R wave was obtained using a trapezium. Since the database classification was provided for one-minute segments of data, features were extracted from these segments. In total, 50 features were extracted from the HRV and 34 from the EDR signal, giving a total of 84 features. The results evidence that the best accuracy was 82.12%, with a sensitivity and specificity of 88.41% and 72.29%, respectively

P. Janbakhshi et al. (2018) had assembled a device for Sleep Apnea Detection from Single-Lead ECG Using Features Based on ECG-Derived Respiration (EDR) Signals. In this paper, two EDR extraction methods are proposed, and their application in automatic Obstructive Sleep Apnea detection using single-lead ECG is investigated. EDR signals are extracted based on new respiration-related features in ECG beats morphology, such as ECG variance (EDRVar) and phase space reconstruction area (EDRPSR). The results indicate that an ECG-based OSA detection system can classify OSA events with high accuracy and suggest a promising, non-invasive, and efficient method for apnea detection.

Alaa Sheta et al. (2021) had established a device for diagnosis of Obstructive Sleep Apnea from ECG Signals Using Machine Learning and Deep Learning Classifiers.

The proposed system follows the following steps including noise from the ECG signal using a Notch filter, extracting nine features from the ECG signal, and using thirteen ML and four types of DL models for diagnosing sleep apnea. Analyzing the ECG signal using CAD systems based on data mining methods leads to a robust system that can recognize OSA inside ECG signals. pictorial diagram for a CAD system to diagnose ECG signal. The proposed system consists of three steps which are: Preprocessing, Feature extraction, and classification. The experimental results show that the proposed approach offers a good performance of DL classifiers to detect OSA. The proposed model achieves an accuracy of 86.25% in the validation stage.

Mehmet Aksahin et al. (2020) developed a prototype for Sleep Apnea Detection with Respiratory Modulated ECG signal. Since ECG is a respiratory modulated signal because of the location of the heart, they, firstly determined respiratory signals from the ECG series. For this purpose, they have utilized a low-pass filter with a 1Hz cutoff frequency. Secondly, different features were calculated from the determined respiratory signals using energy, power spectral density, and continuous wavelet transform. Patient data used in the study were obtained from the MIT-BIH Polysomnographic database. And this study was evaluated retrospectively. The sampling frequencies of the ECG data are 250 Hz. The analyzes were performed by evaluating the data of 3 ECG signals obtained from different patients for 1 hour of night sleep recording. The data were processed in 30 seconds of epochs. A total of 348 epochs were analyzed.

Rishab Kincha et al. (2020) constructed a system for ECG Signal Analysis on an Embedded Device for Sleep Apnea Detection. There were various problems while using CPAP and it's remained untreated. Their motto is to find out a solution for the inconvenience and make this a low-cost portable one for sleep apnea detection. Thus they'd collected real-time data with the help of a designed one. The obtained data is then transferred via IoT. Their method combines steps including dataset extraction, segmentation, signal cleaning, filtration, and finally apnea detection using Support Vector Machines (SVM). Their method combines data segmentation, signal filtering, and feature generation from RR intervals to predict the occurrence of sleep apnea. This system is portable, customizable, and would be an ideal solution for a continuous monitoring device for sleep apnea.

Ahmad Akbar Khatami et al. (2020) had built a device for Obstructive Sleep Apnea Detection using ECG Signal: A Survey to detect obstructive sleep apnea. OSA detection is carried out using several biological signals such as EEG, ECG, or EMG. In this article, several studies of OSA detection using ECG signals are presented. From the calculation of the RR interval on the ECG signal, it can be seen the condition of a person's respiration, known as ECG-derived respiration (EDR). In this review, they had discussed the feature extraction method and classifier used in OSA detection using ECG signals. In addition, they briefly described the potential and its development in the future.

Remalli Rohan et al. (2020) assembled various methods for identification of Obstructive Sleep Apnea using Electrocardiogram features to detect obstructive sleep apnea using ECG signals. Abundant algorithms and models have been designed, proposed, and developed using Electrocardiogram features to detect sleep apnea syndrome. The ECG signal represents the electrical activity of the heart. Mostly cardiac diseases can happen due to sleep apnea which needs to be diagnosed in the critical stage. This survey paper aims to bring the different techniques to identify sleep apnea syndrome by using the ECG features because ECG features have been found most effective and efficient to detect sleep apnea disorders. In this paper, a comparative analysis has been prepared between the different techniques used

CHAPTER 3

AIM & SCOPE

3.1 AIM

This project aims to detect sleep apnea by processing the sample ECG signals on MATLAB and to build a low-cost CPAP device for delivering automatic non-invasive ventilation to individuals suffering from sleep apnea. This method reduces the manual work of the patient or physician, enabling the device for assistance.

3.2 EXISTING METHODS

Several existing methods may detect or therapize sleep apnea, techniques include:

- Detection of sleep apnea using signal processing on MATLAB.
- Machine Learning and Deep Learning techniques are also used for the detection of sleep apnea.
- A low-cost CPAP device is built in an IoT environment.

The main difference between the existing method and the proposed methodology is that the existing methods use manual work for non-invasive ventilation after the detection of sleep apnea. However, our work, after detection, includes automatic non-invasive ventilation using a CPAP device.

3.3 PROPOSED SYSTEM

Sample ECG signals are collected from sleep apnea patients and processed on MATLAB. Moreover, techniques like interpolation, filtration, Time-domain analysis, Frequency vs Power spectrum, and Frequency domain analysis were used to detect the distance between R peaks, as irregular R peaks lead to the presence of apnea. After detecting sleep apnea through MATLAB, the signals are transferred to the Arduino board through PC. So, if sleep apnea is detected the Arduino will enable the relay to function. When the relay is ON the power supply will enable the blower to operate. The blower produces air, so a tube is attached to the blower to deliver pressurized air to the patient. A small tube was then inserted to measure the pressure produced by the blower. So a pressure sensor is used for measuring the

value of the air pressure produced by the blower. Finally, the output is displayed on the screen.

3.4 SCOPE

The main theme of this project is to detect sleep apnea in a simplified way and to deliver automatic non-invasive ventilation to patients. This is a cost-effective method to diagnose and therapize sleep apnea with high accuracy. These techniques can be used in smart cities, as they would boost up the development process of the Healthcare market of their country.

CHAPTER 4

MATERIALS AND METHODOLOGY

4.1 APNEA DETECTION ON MATLAB

- The sample ECG waveforms are simulated and the distance between RR intervals is calculated by using techniques like interpolation, filtration, time-domain analysis, frequency vs power spectrum, and frequency domain analysis.
- Thus the graphical representation of the distance between the RR intervals will help us detect sleep apnea. Furthermore, these signals are processed to a microcontroller through PC and are processed to the CPAP prototype for delivering automatic non-invasive ventilation.

4.2 TECHNIQUES USED FOR R PEAKS DETECTION USING MATLAB

4.2.1 ECG Waveform

Firstly, four hours of sample ECG data had been collected from sleep apnea and processed on MATLAB. The sampling frequency was then extracted from the ECG data to obtain a graphical waveform.

4.2.2 Interpolation

It is a method that is used to add new data points within a range of a group of known data points. Using Interpolation data can be smoothened, fill in the missing one, make predictions, etc. Here new sampling frequencies are created using interpolation and interpolating frequency from 100 Hz to 500 Hz. Two seconds of data before and after interpolation had been plotted in the form of a graph.

4.2.3 Filtration

This technique processes the data and can remove the high-frequency fluctuations. Raw and Filtered data are analyzed using filtration. Filtration is done by designing a low-pass filter (LPF). Two seconds of data before and after filtration had been plotted.

4.2.4 Time-Domain Analysis

Time-domain analysis analyses the physical signals in terms of time. Here ECG data has been read for every 60 seconds for four hours. RR values and subsequent heart values were measured. Also, heart rate information was added, additionally, into corresponding arrays. Time axis and arrays are created to store the ECG data in the form of numbers to detect sleep apnea. i.e. assigning 50 for non-apnea and 100 for apnea. Plotting the average heart rate and sleep apnea in the form of the graph.

4.2.5 Frequency VS Power Spectrum

Frequency Spectrum is the distribution of phases and amplitudes of each frequency component against the frequency. It is the representation of the signal in the frequency domain. Power Spectrum states the distribution of power into frequency by composing the signal. It is used to determine the degree of noise associated with the signal. Here new sampling frequency for 4 Hz is assigned. Data has been resampled and 60 seconds of data extracted. Applying FFT and storing power spectral density. The graph was thus obtained.

4.2.6 Frequency-Domain Analysis

Frequency Domain Analysis analyses the signal concerning frequency. Signals are converted from the time domain to the frequency domain using Fourier Transform. It shows the distribution of signals over a range of frequencies. Thus the power density graph is analyzed and sleep apnea is detected. Performing the analysis for every 60 seconds in the 4 hours. Appending the Power Spectral Density array and color plotting the information. Algorithm design and efficiency calculation is done and the final efficiency is displayed in percentage.

4.3 CONSTRUCTION OF A CPAP MACHINE

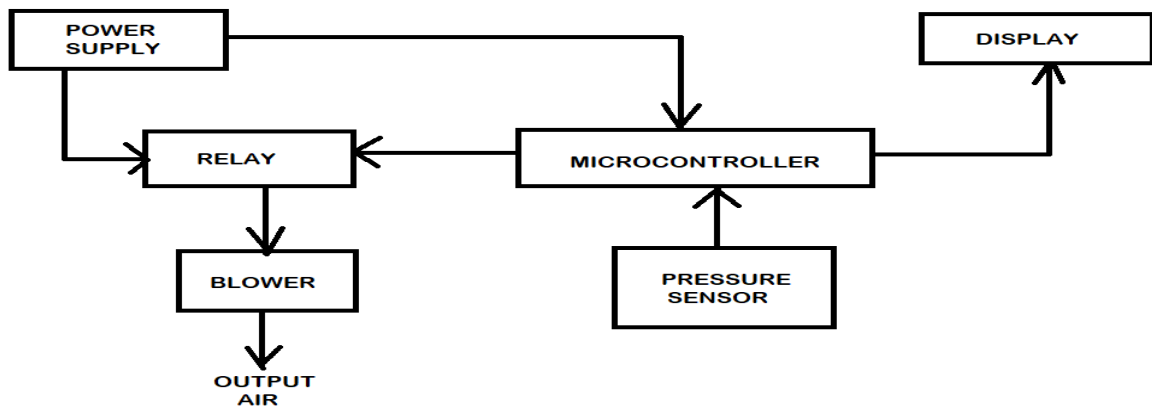


Fig: 4.1: Block diagram of a CPAP machine

4.3.1 Blower Fan

A Blower is a device that pushes pressurized air by imparting energy. The blower utilized here was PGSA2Z™ DC12V 4500RPM Cooling Brushless Turbine Air Blower Fan which produces high velocity as a special feature.

Specifications:

- Model: BFB1012VH
- Fan Type: Axial
- Dimensions: Height: 97 mm Depth: 94 mm Width:33 mm
- AC/DC: DC Blower Fan
- Voltage: DC 12V
- Working Voltage: 6.0-13.2v
- Power: 32.4
- Current: 2.70A
- Speed: 4500 RPM

Dimensions:

- Height: 97 mm Depth: 94 mm Width:33 mm
- Air Flow 38 CFM (1.08 m³/min)
- Static Pressure: 1.952 in H₂O
- Noise: 60 DBA
- Bearing: Double Ball Bearing
- Bearing Type: Ball

Weight & Wire:

- Weight: 180 gms
- Frame: Plastic
- Colour: Black
- Yellow Wire Positive (+)
- Black Wire Negative (-)
- Blue Wire PWM



Fig: 4.2: DC Brushless BFB1012VH Blower

4.3.2 Arduino NANO

Arduino Nano is a small, compatible open-source electronic development board based on an 8-bit AVR microcontroller. Two versions of this board are available, one is based on ATmega328p, and the other on Atmega168. Arduino Nano can perform some functions similar to other boards available on the market, however, it is smaller

in size and is the right match for projects requiring less memory space and fewer GPIO pins to connect with. All Arduino boards can be programmed using Arduino IDE Software – An official software introduced by Arduino. All you need is a code to burn into the board to make it work as per the instructions fed into the board. Additionally, the board features a built-in Bootloader which sets you free from getting an external burner to burn the Arduino program. The unit supports a USB interface with a mini USB port. The USB cable is used to connect the board with the computer. The Arduino Nano Pin descriptions mentioned below:

Digital Pins: There are 14 digital pins on board which is used to connect external component.

Analog Pins: 6 analog pins on board that is used to measure voltage in a range from 0 to 5V.

LED: The unit comes with a built-in LED connected to pin 13 on the board.

VIN: This is an input voltage to the Arduino board when using an external power source (6-12V).

3.3V: It is a minimum voltage produced by the voltage regulator on the board.

5V: Regulated power supply used to power up the controller and other components on board.

AREF: It is an Analog Reference that is applied to the unit as a reference voltage from an external power supply.

GND: Two ground pins are available on the board.

Reset: Two reset pins are integrated on the board. These pins are used to reset the controller internally through software.

External Interrupts: Pin 2 and 3 are used to trigger external interrupts. These pins are used in case of emergency.

USART: The board supports USART serial communication that carries two pins i.e. Rx which is used for receiving the serial data and Tx which is a transmission pin used to transmit serial data.

SPI: The device also supports SPI (serial peripheral interface) communication protocol where four pins (SS, MISO, MOSI, SCK) are used for this communication. This protocol is used to transfer data between the microcontroller and other peripheral devices.



Fig: 4.3: Arduino UNO

4.3.3 Pressure Sensor

A pressure sensor is a device that measures the pressure of gases or liquids. These sensors act as a transducer. HX710B Air Pressure Sensor is used here for the measurement of air pressure produced by the blower. 5V of power is utilized by the pressure sensor from the Arduino board. The features and specifications of the sensor used here are mentioned below.

Features:

- Two Selectable Differential Input Channels.
- On-Chip Active Low Noise PGA.
- Selectable Gain of 32, 64, and 128.
- On-Chip Power Supply Regulator and ADC Analog Power Supply.
- On-Chip Power-ON-Reset, Simple Digital Control and Serial Interface.

Specifications:

- Model: HX710B
- Interface type: Serial
- Data Output Type: 10SPS/ 80SPS
- Max Operating Current: 1.5 mA
- Operating Temperature Range: -45 to 85 degree celsius
- IC Package: 16 Pin SOP
- Gain: 32 / 64/ 128
- Length: 18 mm
- Width: 17 mm
- Height: 2 mm
- Weight: 2 gm



Fig: 4.4: Pressure Sensor

4.3.4 Relays

The relay usually acts as a switch that converts small electric stimuli to larger currents by using electromagnetism. Relays are utilized as they use highly versatile components that are just as effective in complex circuits as in simple ones. They can be used in the place of other forms of switches, or they can be specifically designed based on factors such as required amperage.

Working of a Relay:

Relays differ in size, capacity, and corresponding uses. However, although they may differ in these respects, all relays function in essentially the same way: one circuit is

used to power another. The specific manner in which this occurs depends on whether the relay is normally open (NO) or normally closed (NC).

Normally Open Relays:

Most relays are normally open; the second, larger circuit is in the off position by default. Power flows through an input circuit in a normally open relay, activating an electromagnet. This generates a magnetic field that attracts a contact to join with the second, larger circuit, allowing current to flow through. When the source of power is removed, a spring draws the contact away from the second circuit, stopping the flow of electricity and turning off the end device.

Normally Closed Relay:

The fundamentals of an NC relay are the same as an NO relay: there are two circuits, with the second being larger, and an electromagnet moves physical contact between two positions. But in the case of an NC relay, the default states are reversed. When the first circuit is activated, the electromagnet draws the contact away from the second circuit. NC relays to keep the larger circuit in the *on* position by default.

A 2 channel 5V relay module with an Optocoupler is used as a switch for the CPAP device and the specifications are mentioned below.

Specifications:

- 1 channel relay board
- Operating Voltage 5V
- Max Current : 20mA
- Relay Contact Current Capacity at AC250V: 10A
- Relay Contact Current Capacity at DC5V: 10A
- One normally closed contact and one normally open contact
- Triode drive, increasing relay coil



Fig: 4.5: Relay

4.3.5 Display:

The Liquid Crystal Display has a parallel interface, meaning that the microcontroller has to manipulate several interface pins at once to control the display. The interface consists of the following pins:

- A register select (RS) pin that controls where in the LCD's memory you're writing data to. You can select either the data register, which holds what goes on the screen, or an instruction register, which is where the LCD's controller looks for instructions on what to do next.
- A Read/Write (R/W) pin that selects reading mode or writing mode
- An Enable pin that enables writing to the registers
- 8 data pins (D0 -D7). The states of these pins (high or low) are the bits that you're writing to a register when you write, or the values you're reading when you read.

The Liquid Crystal Display mentioned below indicates the operation of a CPAP device and shows the level of the air pressure produced by the blower.

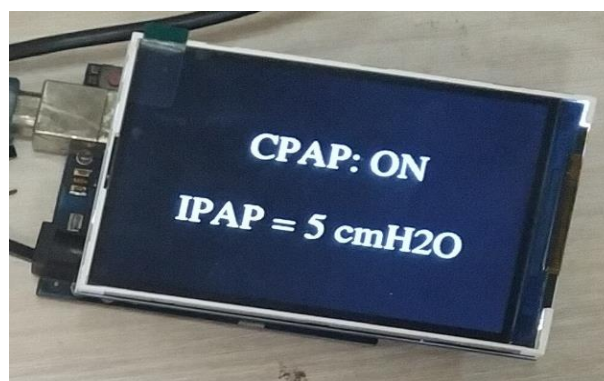


Fig: 4.6: Display

CHAPTER 5

RESULTS AND DISCUSSION

5.1 RESULTS

We had collected two sets of sample ECG signals from the sleep apnea and non apnea patients and loaded them individually on MATLAB for signal processing, as we measured the distance between R peaks for the detection of sleep apnea and after detection the signal is sent to the relay which enables the blower to operate and this will further turn on the display which indicates the operation of the prototype. Absence of apnea will not allow the relay to operate and will not enable the blower for air production. Firstly, the sampling frequency is obtained from the sample ECG signals. To add new data points for further process, we used interpolation. The obtained frequency is interpolated from 100 Hz to 500 Hz. Now, the signals are in raw form, so noises have to be removed to extract the required data for further process. Filtration is utilized here by designing a low-pass filter, thus noises were removed and the ECG waveform is obtained. RR values and heart rate values are measured in terms of time by using Time domain analysis to detect the presence or absence of apnea. The graphical waveform of Frequency vs Power Spectrum is plotted to assign a new sampling frequency of 4 Hz. Data has been resampled by sampling 60 seconds of the data and Power Spectral Density is stored to quantify and compare different vibration environments. The last step of signal processing is frequency domain analysis. Here signals are converted from the time domain to the frequency domain using Fourier Transform. Finally, sleep apnea and non apnea is detected by adding a power spectral density array. Final efficiency is displayed in percentage. The graphical waveforms obtained from MATLAB are mentioned below. Fig 5.1 to 5.7 indicates the outputs of sample ECG signal of Apnea Patient and Fig 5.8 to Fig 5.14 indicates the outputs of Sample Non Apnea ECG signals.

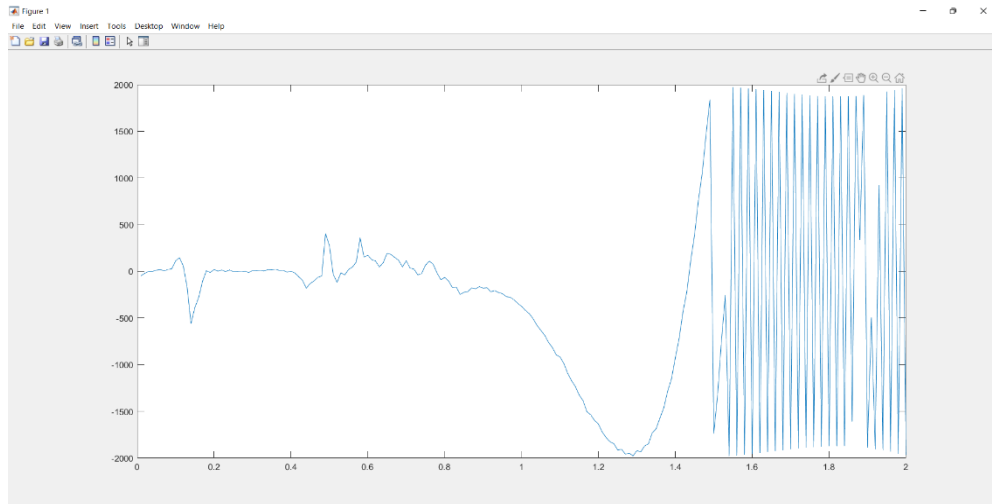


Fig: 5.1: Sample ECG signal of Apnea Patient-1

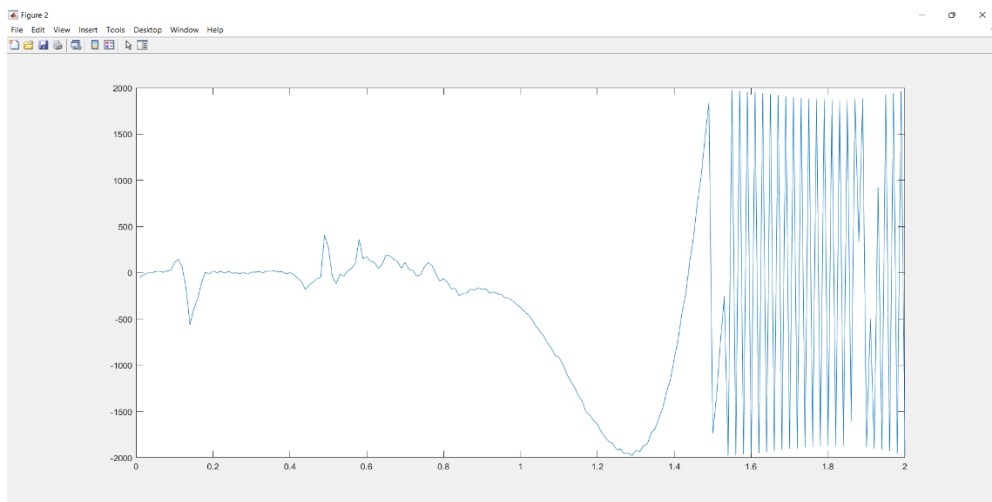


Fig: 5.2: Sample ECG signal of Apnea Patient-2

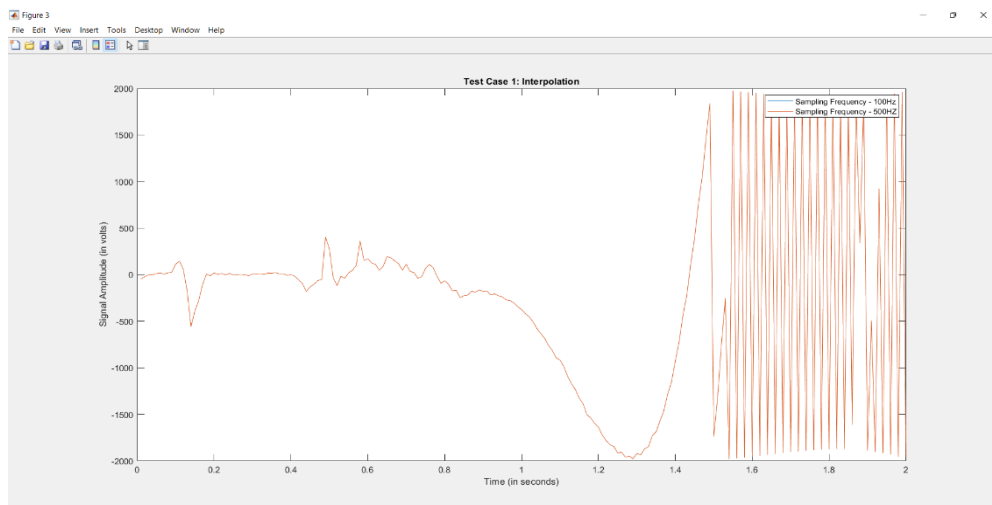


Fig: 5.3 Interpolation of Sample Apnea Signal

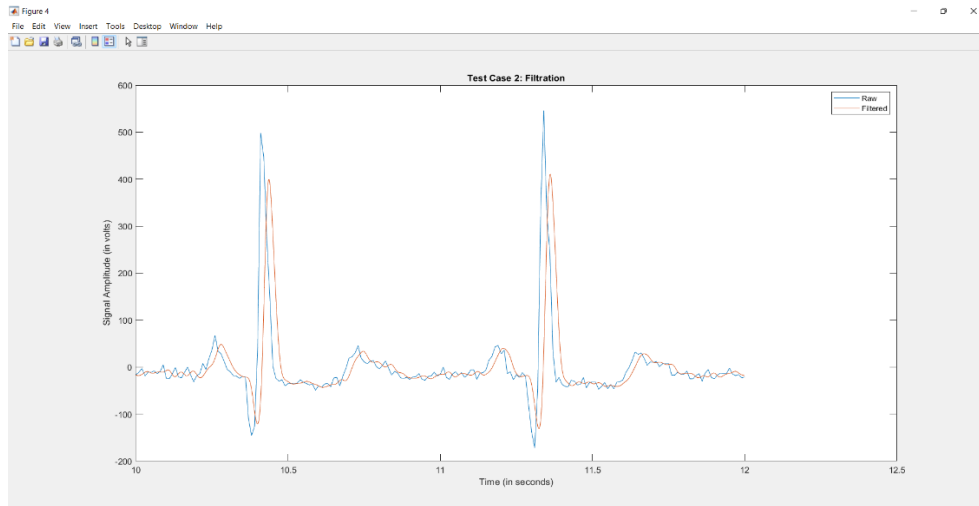


Fig: 5.4: Filtration of Sample Apnea Signal

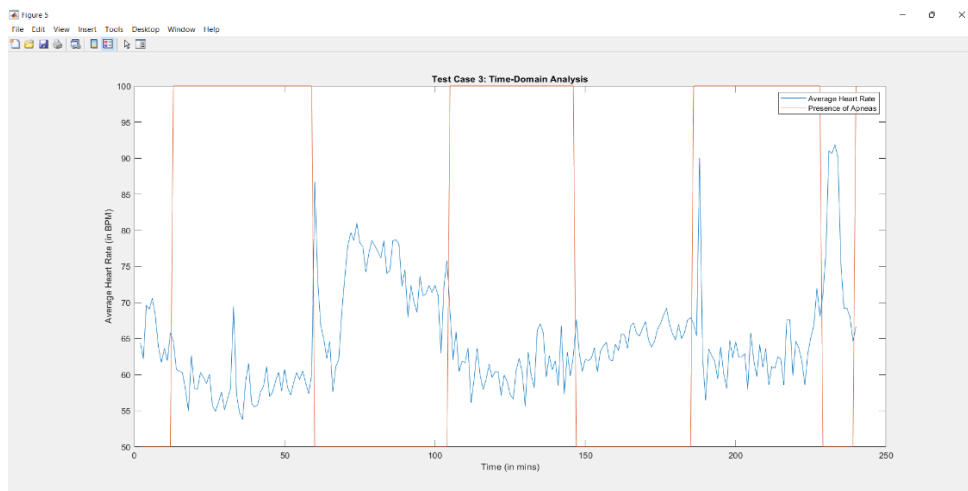


Fig: 5.5: Time-Domain Analysis of Sample Apnea Signal

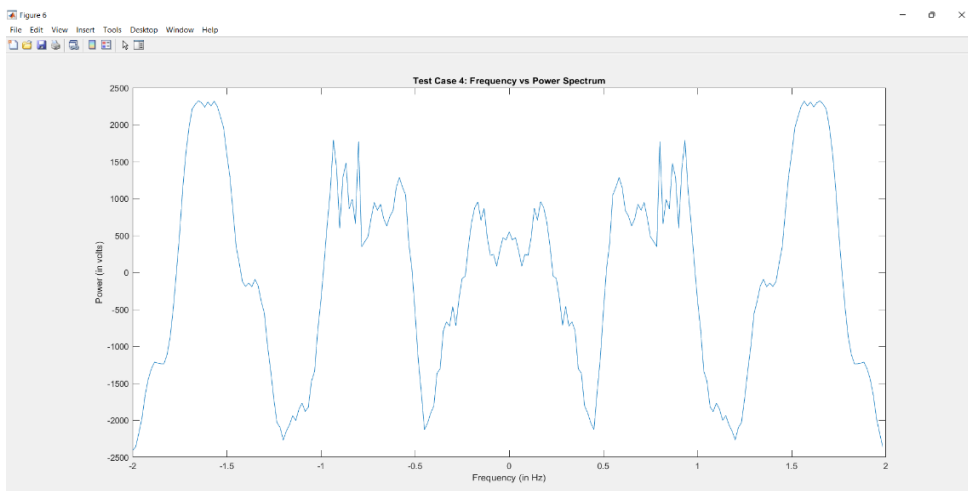


Fig: 5.6: Frequency vs Power Spectrum of Sample Apnea Signal

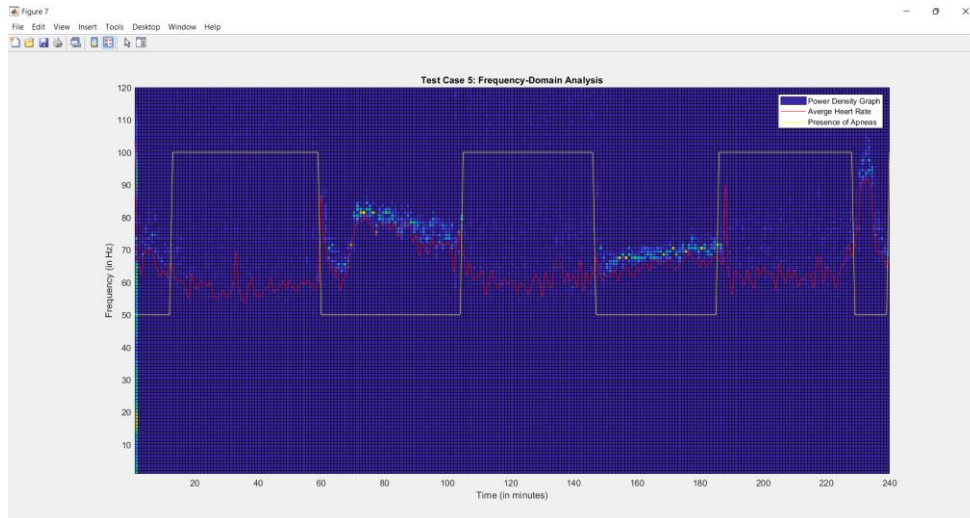


Fig: 5.7 Frequency Domain Analysis of Sample Apnea Signal

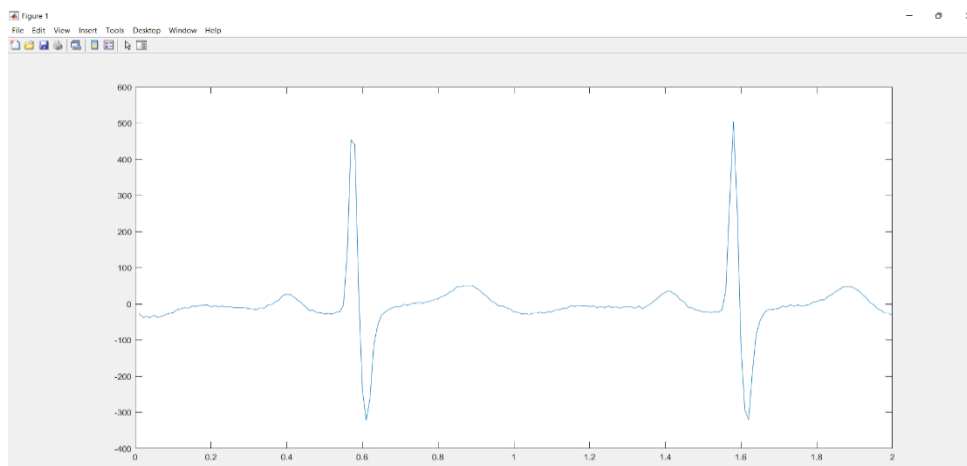


Fig: 5.8 Sample ECG signal of Non Apnea Patient-1

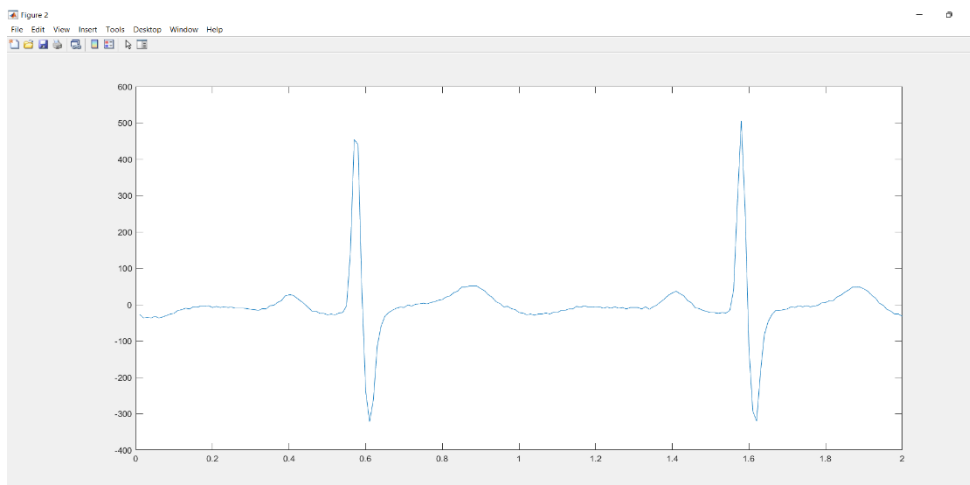


Fig: 5.9 Sample ECG signal of Non Apnea Patient-2

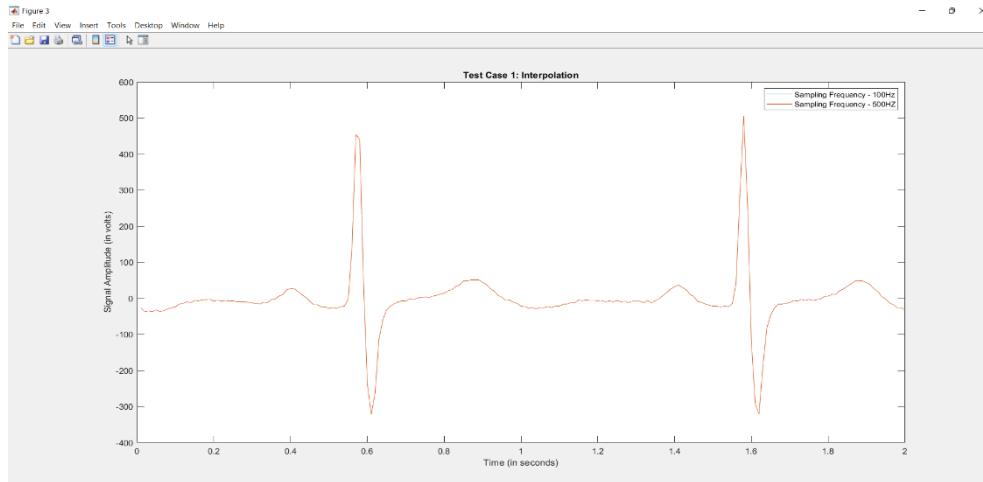


Fig: 5.10 Interpolation of Non Apnea Signal

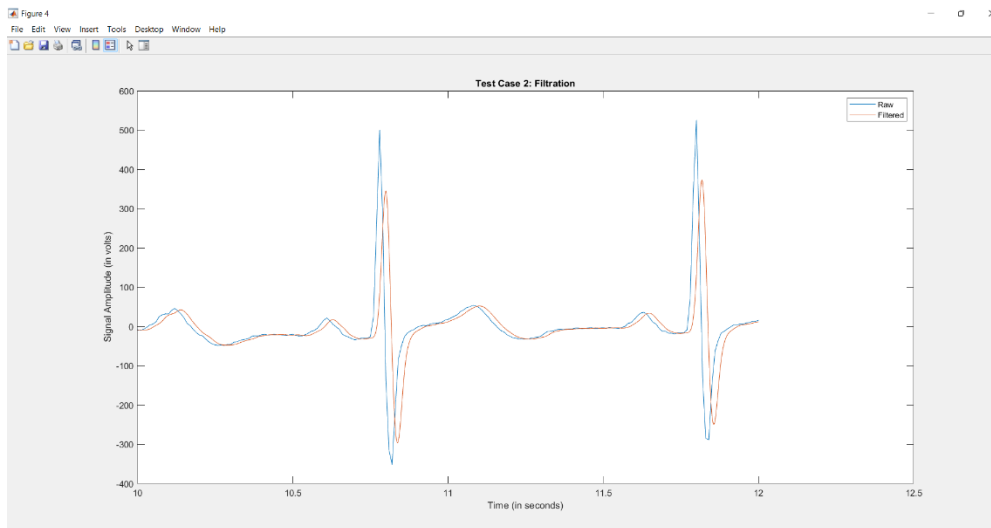


Fig: 5.11 Filtration of Non Apnea Signal

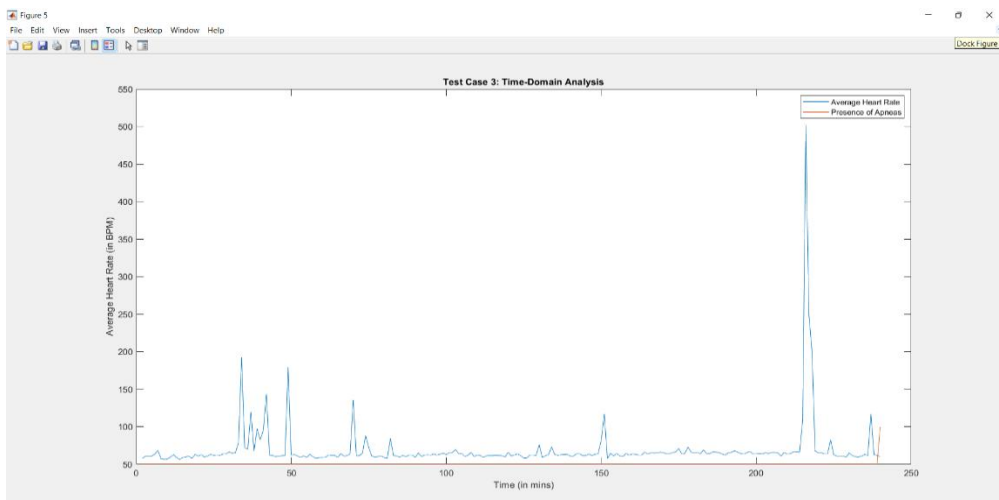


Fig: 5.12 Time-Domain of Non Apnea Signal

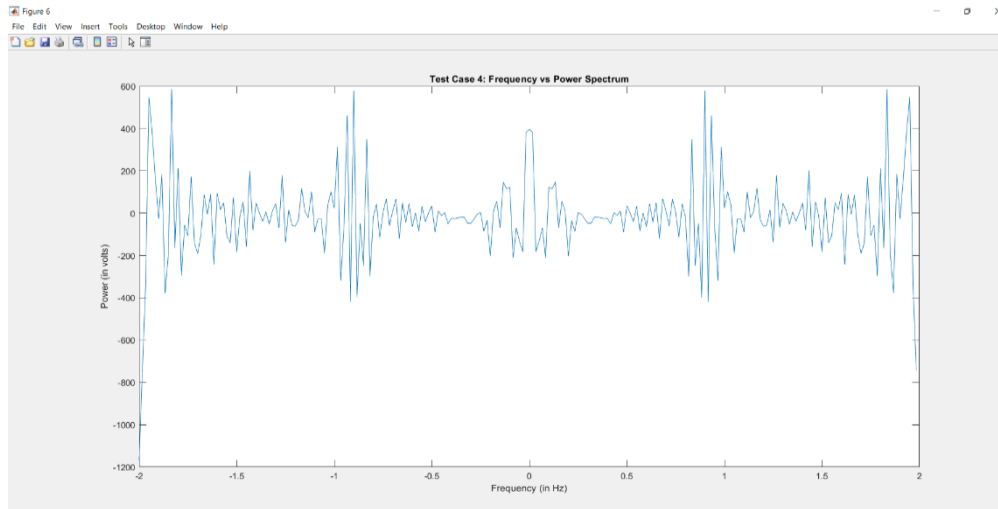


Fig: 5.13 Frequency vs Power Spectrum of Non Apnea Signal

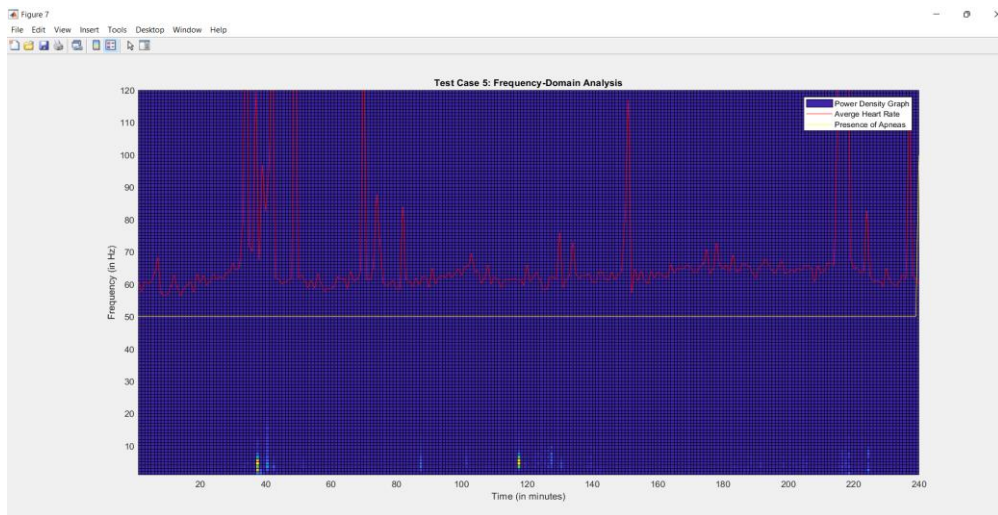


Fig: 5.14 Frequency Domain Analysis of Non Apnea Signal

5.2 DISCUSSIONS

In this project, we have processed sample ECG signals on MATLAB to find the distance between R peaks for detecting the presence of apnea. After detection, we have processed the MATLAB codes to the Arduino UNO through PC for further operation. A low-cost CPAP prototype is constructed further for automatic non-invasive ventilation to keep the trachea open for breathing. This model can come out as a product in the healthcare market in the future, as it will be a labor-saving

device that assists in automatic enabling of the CPAP machine. However, some modifications need to be done to establish a whole prototype model in the market. As we used a PC to transfer the codes to the Arduino board, however, a software called Raspberry Pi in which we can simulate the codes for the detection of sleep apnea and then process the codes directly from raspberry pi to the CPAP model to obtain an individual prototype. Moreover, an ECG acquisition system is yet to be built using voltage followers, amplifiers, and filters to obtain live ECG signals for processing to CPAP, as we had used sample ECG signals for the measurement of R peaks.

5.3 FUTURE WORK

5.3.1 ECG Acquisition System

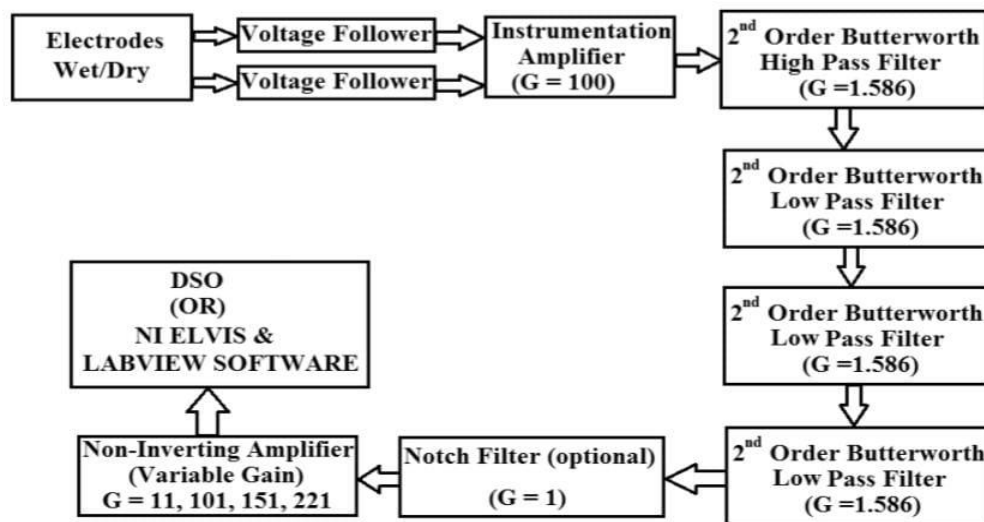


Fig: 5.15: Block diagram of ECG acquisition system

5.3.2 Explanation of the block diagram

- Firstly, two voltage followers are assembled on the breadboard, and the outputs of both voltage followers are connected to the one end of the instrumentation amplifier that provides low-level signals for a large number of gains

- The output of the instrumentation amplifier is then connected to the second-order Butterworth high pass filter, used to sharpen the image with the frequency domain.
- Furthermore, three second-order Butterworth low pass filters are constructed for image smoothing in the frequency domain. It preserves low-frequency components and removes high-frequency noise from a digital image.
- After assembling three low pass filters, a notch filter is constructed, as it rejects the transmission of frequencies within a specific frequency range.
- Lastly, a non-inverting amplifier is built, which is an op-amp circuit that produces an amplified output signal, the final output is measured by wet/dry electrodes and the signal is extracted using AT Mega328 microcontroller.

5.4 CPAP PROTOTYPE MODEL

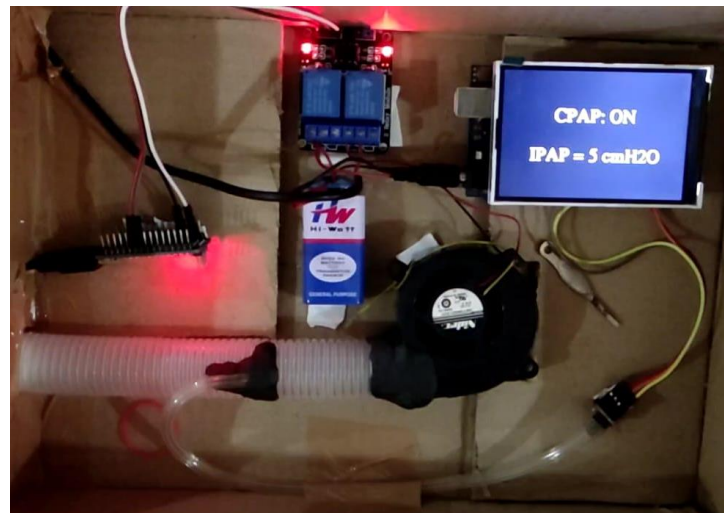


Fig: 5.16: Prototype of our CPAP device

After detecting sleep apnea through MATLAB, the signals are transferred to the Arduino board through PC. So, if sleep apnea is detected the Arduino will enable the relay to function. The relay here acts as a switch. When the relay is ON the power supply will enable the blower to operate. The blower produces air, so a tube is attached to the blower for delivering pressurized air to the patient through a mask. A small tube is then inserted to measure the pressure produced by the blower. So a pressure sensor is used for measuring the value of the air pressure. The above-

mentioned figure is the prototype of our CPAP device, where the CPAP device is enabled which can be seen on the display and the value of pressurized air is also displayed on the screen which is connected to the Arduino.

CHAPTER 6

SUMMARY AND CONCLUSION

6.1 SUMMARY

Overall, a new technique is analyzed to detect sleep apnea by measuring the distance between R peaks from the sample ECG signals from the sleep apnea patients as irregular R peak distance leads to the presence of apnea. Furthermore, a low-cost CPAP device is constructed for automatic non-invasive ventilation. Sample ECG signals are processed by using techniques like interpolation, filtration, Time-domain analysis, frequency vs power spectrum, and frequency domain analysis. A low-cost CPAP is built using a blower, relay, pressure sensor, Arduino UNO, and a display for displaying the output.

6.2 CONCLUSION

To conclude, this prototype can help physicians or nurses by delivering automatic non-invasive ventilation to patients suffering from sleep apnea. This model needs to be improved to launch this prototype as a product in the healthcare market, as a lot of sleep apnea patients from low-/middle-income countries can be benefitted if this device comes into the market for sale since the cost of a mechanical ventilator is too high and so it restricts the availability of the device for the low-/ middle-income countries (LMICs). The low-cost, easy-to-build non-invasive ventilator performs similarly to a high-quality commercial device, with its open-source hardware description, which will allow for free replication and use in LMICs, facilitating the application of this life-saving therapy to patients who otherwise could not be treated by availing the device.

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APPENDICES

PROGRAM USED FOR R-PEAK DETECTION:

```
clear all;

global a;

%%Reading Data from the file
%Opening the header files
fheader = fopen('a05.heg','r');
test = fscanf(fheader, '%s',2); %To skip values
%Opening the ECG data file
fid = fopen('a05.dat','r');
ECG = fread(fid, 'int16');
%Extracting the sampling frequency
samplingfreq = fscanf(fheader, '%f',1);

%%Extracting four hours of information and Interpolating

%Extracting 4 hours of data from the ECG data
nECG = ECG(1:1440000);

N = samplingfreq; %Storing the sampling frequency in N
t = 1/N: 1/N: 14400;
t = t.';

N2 = 500; %Creating new Sampling frequency for interpolation
t2 = 1/N2: 1/N2: 14400;
t2 = t2.';
rECG = interp1(t, nECG, t2); %Interpolating from 100Hz to 500 Hz

%Plotting two seconds of data before and after interpolating
```

```

figure
plot (t(1:200),nECG(1:200));
figure
plot (t2(1:1000),rECG(1:1000));
figure
plot (t(1:200),nECG(1:200));
hold on;
plot (t2(1:1000),rECG(1:1000));
title('Test Case 1: Interpolation')
xlabel('Time (in seconds)');
ylabel('Signal Amplitude (in volts)');
legend('Sampling Frequency - 100Hz','Sampling Frequency - 500HZ');
hold off;

```

%%Filtering the data using a low-pass filter

%Designing a low pass filter

```

d = designfilt('lowpassfir', 'Filterorder', 20, 'CutoffFrequency', 11, 'SampleRate',
N2);

```

```

fECG = filter(d, rECG); %Applying the low pass filter

```

%Plotting two seconds of data before and after filtering

```

figure
plot (t2(5000:6000),rECG(5000:6000));
hold on;
plot (t2(5000:6000),fECG(5000:6000));
title('Test Case 2: Filtration')
xlabel('Time (in seconds)');
ylabel('Signal Amplitude (in volts)');
legend('Raw','Filtered');
hold off;

```

%%Time-Domain Analysis

```

%Creating empty arrays
avghr = [];
maxhr = [];
minhr = [];

HR = [];
Peaks = [];

%Setting start and end points
s = 1;
e = 1;

for i=1:30000:720000

    %Reading through each 60 seconds of data for the four hours
    newArr = fECG(i:i+29999);
    for j=2:length(newArr)-1
        %Condition for calculating peaks
        if (newArr(j)>100 && (abs(newArr(j) - newArr(j-1)) >= 0.5) &&
(newArr(j)>newArr(j+1)) && (newArr(j)>newArr(j-1)))
            Peaks = [Peaks, j];
            e = e+1;
        end
    end

    for k = s+1:e-1
        %Measuring the RR-values and the subsequent Heart Rate values
        diff = Peaks(k) - Peaks(k-1);
        HR = [HR, 60/(diff*0.002)];
    end
end

```

```

%Appending heart rate information into corresponding arrays
avghr = [avghr, mean(HR)];
maxhr = [maxhr, max(HR)];
minhr = [minhr, min(HR)];

%Emptying the HR array
HR = [];
%Assiging new start point
s=e;

end

%Creating time axis
t3 = [1:240];
t3 = t3.';

%Reading data from annotated files
apnf = fopen('a05.apn.txt', 'r');
if(apnf == -1)
    error('File couldn"t be opened');
end
%Skipping data
data= fscanf(apnf, '%s',3);

%Creating array to store annotated values in forms of numbers
apnea = [];
for i = 1:240
    data= fscanf(apnf, '%s',1);
    if(data == 'N')
        apnea = [apnea, 50]; %Assigning 50 for non-apnea
    end
    if(data == 'A')
        apnea = [apnea, 100]; %assiging 100 for apnea
    end
end

```

```

end
data = fscanf(apnf, '%s',1); %Skipping values

end

%plotting the average heart rate graph and the apnea data graph
figure
plot(t3(2:240),avghr(2:240));
hold on;
plot(t3(2:240), apnea(2:240));
title('Test Case 3: Time-Domain Analysis')
xlabel('Time (in mins)');
ylabel('Average Heart Rate (in BPM)');
legend('Average Heart Rate','Presence of Apneas');
hold off;

%%Downsampling and Frequency vs Power Spectrum

%Assigning new sampling frequency of 4Hz
nfs = 4;
r2ECG = resample(nECG, nfs, N); %Resampling the data
r2ECG60 = r2ECG(1:240); %extracting 60 seconds of data
ff60 = fft(r2ECG60); %applying fft
Num1 = length(ff60);
freq = -nfs/2:nfs/Num1:nfs/2-nfs/Num1; %defining the x-axis
%Storing power spectral density info
PSDX = (1/nfs*Num1)*abs(ff60).^2;
PSDX = PSDX(1:Num1/2);

%plotting the graphs
figure
plot(freq,ff60);
title('Test Case 4: Frequency vs Power Spectrum')

```

```

xlabel('Frequency (in Hz)');
ylabel('Power (in volts)');

%%Frequency-Domain Analysis
PSDarr = [];
%Performing the analysis for every 60 seconds in the 4 hour period
for i=1:240:57600
    newFreq = r2ECG(i:i+239);
    ffn = fft(newFreq);
    NumN = length(ffn);
    freqN = -nfs/2:nfs/NumN:nfs/2 - nfs/NumN;
    PSDn = (1/nfs*NumN)*abs(ffn).^2;
    PSDn = PSDn(1:NumN/2);
    PSDarr = [PSDarr,[PSDn]]; %appending the PSDn array into the PSDarr
end

%Colour Plotting the information
figure
pcolor(PSDarr);
hold on;
plot(t3,avghr,'r');
plot(t3,apnea, 'y');
title('Test Case 5: Frequency-Domain Analysis')
xlabel('Time (in minutes)');
ylabel('Frequency (in Hz)');
legend('Power Density Graph','Averge Heart Rate','Presence of Apneas');
hold off;

%%Algorithm Design and Efficiency Calculation

check =[];
threshold = 63; %threshold value for apnea detection based on observation

```

```

for i=1:240
    if avghr(i)<=threshold
        check = [check, 100];
    else
        check = [check, 50];
    end
end

%Algorithm efficiency
eff = 0;
for i=1:240
    if apnea(i) == check(i);
        eff = eff+1;
    end
end
%Diplaying final efficiency in percentage
finaleff = eff*100/240

a = arduino;
apneadetec = mean(apnea);

if apneadetec > 60
    disp('Sleep Apnea events detected')
    writeDigitalPin(a,'D6',0);
    writeDigitalPin(a,'D7',0);
    pause(20);
    writeDigitalPin(a,'D6',1);
    writeDigitalPin(a,'D7',1);
else
    disp('No Sleep Apnea events detected')
end

```

PROGRAM USED FOR ARDUINO NANO:

```
#include "HX710B.h"

#include <Adafruit_GFX.h>
#include <MCUFRIEND_kbv.h>

int Pressure;
int FinalPressure;

const int DOUT = 2; //sensor data pin
const int SCLK = 3; //sensor clock pin

#define BLACK 0x0000
#define RED 0xF800
#define WHITE 0xFFFF
#define STATUS ON, OFF

#include <Fonts/FreeSans24pt7b.h>
#include <Fonts/FreeSerif24pt7b.h>

MCUFRIEND_kbv tft;
HX710B pressure_sensor;

void setup() {
  Serial.begin(57600);
  pressure_sensor.begin(DOUT, SCLK);
  uint16_t ID = tft.readID();
  tft.begin(ID);
  tft.fillScreen(BLACK);
  tft.setRotation(1);
}
```

```

void loop() {
  if (pressure_sensor.is_ready()) {
    Pressure = pressure_sensor.mmHg();
    FinalPressure = Pressure * 1.36;
  } else {
    Serial.println("Pressure sensor not found.");
  }

  tft.setFont(&FreeSerif24pt7b);
  tft.setCursor(135,125);
  tft.setTextSize(1);
  tft.setTextColor(WHITE,BLACK);
  tft.print("CPAP: ", STATUS);
  tft.setCursor(75,225);
  tft.setTextSize(1);
  tft.setTextColor(WHITE,BLACK);
  tft.print("IPAP = ", FinalPressure);
  delay(1000);
}

```