OSA PREDICTION BY SLEEP LEVEL CLASSIFICATION

GRADUATION PROJECT SUBMITTED TO THE BIOMEDICAL DEPARTMENT OF NEAR EAST UNIVERSITY

By

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Abstract

Some diseases are still ambiguous for scientists and researchers, despite of studies and researches that have been done to study and diagnose them. The effects of these diseases may be known, but the unknown is their causes, times, and signs. These unobvious causes and signs make scientists unable to detect, nor diagnose these diseases. One of these diseases is the **sleep apnea**, which is defined as breathing difficulties and pauses in breathing during sleep. Some studies concluded that there may be a relationship between Sleep apnea and snoring, in which snoring maybe a sign to get into a sleep apnea. In this context, the design of diagnostic devices for detecting OSA, and the data analysis tools employed in its quantification and classification are of paramount importance.

This research project aims to produce a diagnostic device for early prediction of **sleep apnea** through signal analysis of snoring. The idea is to establish an algorithm linking **sleep apnea** and snoring by the implementation of a device that measures the chest expansion during inspiration and expiration of subjects. Then, collect data from which snorers and apnea goers are pointed out so that we can provide the patient with quantitative measurements and statistics that end up with a classification of sleep disorders levels in terms of voltages interval of each level. When such levels of sleep being classified and known; it is then easy to find a voltage interval just prior to apnea occurrence. In such case, the machine is programmed to early predict and prevent the **Obstructive Sleep Apnea** occurrence by providing a buzzing sound in order to wake the patient up right before **OSA**. Furthermore, this project also diagnose and detect some medical conditions may happened through each sleep level; such as high blood pressure, low oxygen level and diabetes.

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The real spirit of achieving our goal is through the way of excellence. We would have never succeeded in completing this task, final year project, without the cooperation, encouragement, and help provided by various personalities.

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I shall be failing if deep sense of gratitude towards Near East University and its instructors is not explicitly expressed out; namely the head of the Faculty of Engineering, Prof. Dr. Ali Ünal ŞORMAN

I shall appreciate dearly the support I have had all along by my family who has been a constant source of inspiration throughout this work. Also, I thank them for bearing the brunt of my education and for being so patient, supportive, and spirit lifting.

Finally my greatest thanks go to all those who supported, and wished me success.

Problem Statement

Some researchers suggest that snoring may be a sign for sleep apnea and it is the first condition before getting into apnea, and that the excessive snoring may lead to sleep apnea [1]. On the other hand, other researchers suggest that not everyone who snores has sleep apnea and not everyone has sleep apnea snores [1]. Therefore, one of these two studies should be confirmed. The solution then, is to find the relationship between sleep apnea and snoring, if there is, and try to detect sleep apnea by monitoring and analyzing the snoring signal while sleeping. Whether or not if snoring is happening to patients as a result of any pulmonary obstructive disease or due to other unexplained conditions, still snoring not only presents a great level of danger to the sleeping person as he/she is being deprived of most needed oxygen to brain, but also presents annoyance and frightening situations to the immediate family members in the house as this may lead to a sudden stop of respiratory efforts, medically termed as **Sleep Apnea**. Apnea may last up to 40 seconds or even higher where brain and other tissue may be damaged due to lack of oxygen. Although many solutions ideas have been implemented to ease heavy snoring such as CPAP, Nose clips, apnea monitors etc…. but the medical field lacks the mostly needed type of equipment to further enhance an ideal warning system to patients.

This project aims to build a simple diagnostic system to measure the chest expansion and contraction in terms of voltages; as it inflates for inspiration and deflates for expiration. Collected measurements from snorers and snoring free people will be then studied thoroughly in order to:

1. Determine the onset of the respiratory expansion values of the chest.
2. Determine the voltages interval of the sleep different levels(Normal Sleep, Simple Snoring, Heavy Snoring and **Obstructive Sleep Apnea**)

3. Study statistically the reliability of the device to be made.
4. Analyze the collected data to create an algorithm for **OSA** detection
5. Employ an alarm system that will sound off prior to those onset values to warn the snorers that they would be going into apnea before it can actually occur.

Introduction

Biomedical Engineering is an exciting and emerging interdisciplinary field that combines engineering with life sciences. The relevance of this area can be perceived in our everyday lives every time we go to hospital, receive medical treatment or even when we buy health products such as an automatic blood pressure monitor device. Over the past years we have experienced a great technological development in health care and this is due to the joint work of engineers, mathematicians, physicians, computer scientists and many other professionals.

When the person sleeps and wakes up in the morning, he/she definitely doesn't know what problems occur within his/her internal body structure and organs. However, he/she should be careful, because these problems (if exist) may result in big and dangerous consequences. The sleep apnea is one of these dangerous and ambiguous problems that may face everyone without knowing and feeling because it happens while sleep. In other words, breathing difficulties and pauses in breath may happen to us during sleep and they may result in a high blood pressure, diabetes and even sudden death. To study and diagnose this disease, some researches had to be done. Some researchers suggest that a snoring may be a sign for a sleep apnea and it is the first condition before getting into apnea, and that the excessive snoring may lead to a sleep apnea. On the other hand, other researchers suggest that not everyone who snores has sleep apnea and not everyone has sleep apnea snores. Therefore, one of these two studies should be confirmed. The solution then, is to find the relationship between sleep apnea and snoring, if there is, and try to detect **sleep apnea** by monitoring and analyzing the snoring signal while sleep.

Snoring is a consequence of changes in the configuration and properties of the upper airway that occur during sleep. About 20 years ago some authors noted that habitual snoring might be related to obstructive sleep apnea (OSA) [3].

This project is divided into three essential parts:

1. Engineering work which led us to construct an electronic device that is simple, easy to use and low cost to measure the person's chest expansion using a Force Sensitive Resistor (FSR) sensor. This device also gives off a warning alert when apnea is about to occur.
2. Research work that is based on a set of hypothetical values. Collected data were further studied statistically using SPSS software by finding the mean, standard deviation, and correlation coefficients; and plotting some graphs in order to analyze and find the voltages variation of each sleep level.
3. Once statistical data and computations were obtained, an algorithm was established depending on the predetermined values of voltages and conditions found throughout the data analysis of voltages prior to get apnea.

In short, the hypothetical values and the established algorithm led us to set up the program that the micro-controller chip is operated on in order to alert the snorer of immediate apnea condition, and to display and diagnose the person's condition in terms of voltages.

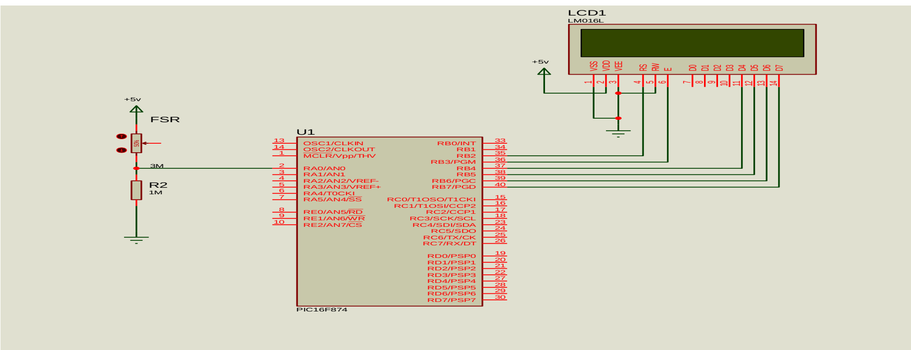

Figure 1: Primary circuit diagram

Chapter 1: Apnea-Snoring Relationship

This chapter is concerned with defining snoring and sleep apnea, as well as the symptoms and effects of each one. Furthermore, it discusses the apnea-snoring relationship and some researches related to that relationship.

Objectives:

1. **Snoring**
2. **Sleep Apnea**
   2.1.Types of sleep apnea
   2.2.Sleep apnea signs and symptoms
   2.3.Obstructive Sleep Apnea
3. **Is it just snoring or is it sleep apnea?**

1.1 Snoring

The noisy sounds of snoring occur when there is an obstruction to the free flow of air through the passages at the back of the mouth and nose. This area is the collapsible part of the airway where the tongue and upper throat meet the soft palate and uvula [3]. Snoring occurs when these structures strike each other and vibrate during breathing.

Figure 2: Snoring

Snoring is the vibration of respiratory structures and the resulting sound, due to obstructed air movement during breathing while sleeping. In some cases the sound may be soft, but in other cases, it can be loud and unpleasant. Snoring during sleep may be a sign, or **first alarm, of obstructive sleep apnea (OSA)**.Unless our bed partner is disrupting our sleep, most of us don't think of **snoring** as something to be overly concerned about. But frequent, **loud snoring may be a sign of sleep apnea**, a common and potentially serious disorder in which breathing repeatedly stops and starts as you sleep [2].

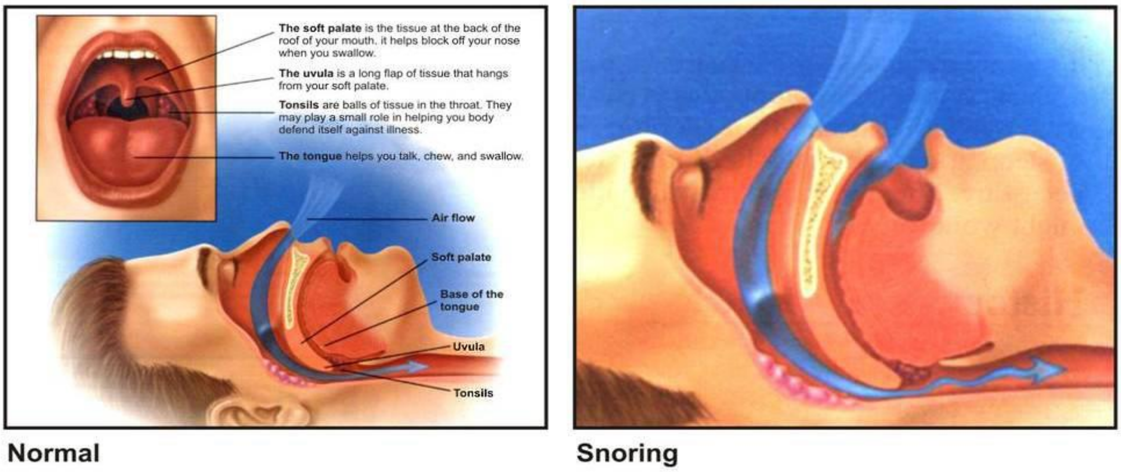

Figure 3: Normal Sleep VS. Snoring

1.2 Sleep Apnea:

1.2.1 Medical Background

DISTURBANCE of the normal breathing process can cause the development of severe metabolic, organic, central nervous, and physical disorders. Respiration monitoring allows the continuous measurement and analysis of breathing dynamics and, thus, the detection of various disorders. There are a number of breathing disorders, but ***sleep apnea syndrome* (SAS)** is probably the most common amongst them. Almost 5% of the total human population suffers from it, and its occurrence increases up to 30% in the population of males over 70 years old in the industrially developed lands [1]. The Greek word ***apnea means*:** without breathing. An episode of ***apnea*** occurs if someone's breathing ceases for a certain amount of time, by definition: if the magnitude of the respiration movements are decreased for at least 10 s to less than 5% of the physiological values [2]. A mild version of apnea is ***hypopnea,*** where the movements are decreased below half the normal values. The occurrence of sleep apnea episodes might be physiological; they would usually be regarded as being pathological only if more than 5 episodes of apnea occur per sleeping hour [3]. The origin of apnea can be ***central*** **(CA)**, caused by the lack of central moto-neural respiration drive, or can be ***obstructive*** **(OA)**, caused by the occlusion of the upper airways. The blood oxygen saturation falls during apnea, because no gas exchange can take place. This reaches clinical significance if the blood oxygen saturation decreases below 95% of the saturation level before the episode of apnea and this lasts for more than 10s. The desaturation event activates the sympathetic nervous systems. This results in increasing heart rate and blood pressure, which can stress and possibly injure aspects of the cardiovascular system.

1.2.2 State-of-the-Art Apnea Diagnosis

Today the only reliable diagnostic method for the detection of SAS is the ***polysomnographic*** **(PSG)** assay which is a multichannel signal record measured during the whole sleeping process. The standard diagnostic nocturnal PSG consists of the following vital parameters [5]: electroencephalogram (EEG), electro-oculogram (EOG), electromyogram (EMG), nasal airflow (NAF), abdominal and/or thoracic movements, body position, snore microphone, electrocardiogram (ECG), and blood oxygen saturation SaO . A limited-channel version of PSG is also frequently used for apnea screening, especially in portable devices, including only the following signal channels: NAF , abdominal and/or thoracic movements, SaO , and heart rate [6]. The diagnosis of SAS has several standardized methods and steps, including the detection of apnea and hypopnea, the determination of their type (CA/OA), and the calculation of the respiration disorder index (RDI), i.e., the number of apnea and hypopnea events per sleeping hour [1].

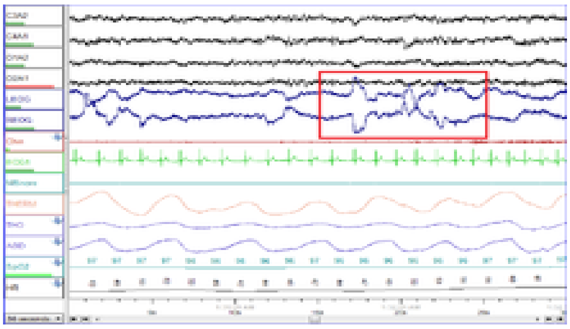

Figure 4: Polysomnogram

According to current accepted clinical criteria the episodes of apnea and hypopnea are detected in the respiration signals, while the arousals detected with EEG and the desaturation episodes in the SaO signal provide supportive evidence [7].

1.2.3 What is an Obstructive Sleep Apnea (OSA)?

People with OSA experience recurrent episodes during sleep when their throat closes and they cannot suck air into their lungs (apnea). This happens because the muscles that normally hold the throat open during wakefulness relax during sleep and allow it to narrow (see figure 5). When the throat is partially closed and/or the muscles relax too much, trying to inhale will suck the throat completely closed and air cannot pass at all.

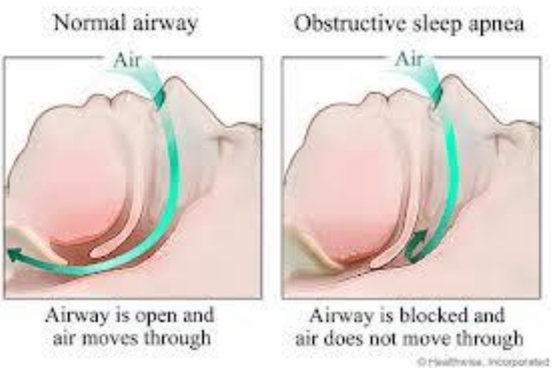

Figure 5: Normal VS. Blocked Airway

1.2.3.1 What are the cardinal symptoms?

a) Fatigue and tiredness during the day.

b) Loud snoring; if the loud snoring is repeatedly punctuated by brief periods of silence or choking sounds, the individual is certain to have obstructive sleep apnea.

1.3 Is it just snoring or is it sleep apnea?

Not everyone who snores has sleep apnea, and not everyone who has sleep apnea snores [1]. The biggest tell-tale sign is how you feel during the day. Some researchers believe in this theory but it is applied mainly on babies since babies may snore or have sleep apnea because of their enlarged tonsils, enlarged adenoids and obesity**.** On the other hand, some researchers believe that snoring may be a sign for sleep apnea since they happen successively; heavy snoring is followed by Obstructive Sleep Apnea if it lasts for long time.

1.3.1 Proposed Project

In fact, this project aims to produce an acceptable, logic and accurate answer for the previous question. Since fatigue and sleepiness during the day cannot be a measure of obstructive sleep apnea and snoring, there should be a device to study the sleeping quality and find the relationship between snoring and OSA by implementing a logic circuit, Collecting data from

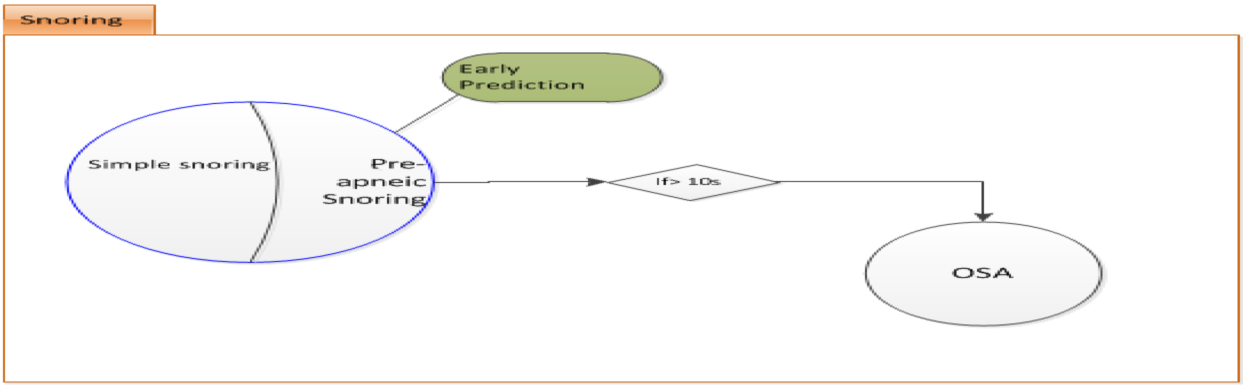

Figure 6: Sleep Levels Classification

both healthy and snorers, and performing statistical studies to try to pin point people who could be considered as potential sufferers from snoring and apnea as a result, and people who have apnea.

Chapter 2: Force Sensing Resistor

This chapter explains Force Sensing Resistor concept: Definition of FSR, Function and Description of it.

Objectives:

1. **What is a Force sensing resistor**
2. **How the Sensor Works**
3. **How To Test It**
4. **Proposed Circuit Design**
5. **FSR Description**

2.1 What is a Force sensing resistor

Force Sensing Resistor (FSR) is a polymer thick film (PTF) device which exhibits a decrease in resistance with an increase in the force applied to the active surface. Its force sensitivity is optimized for use in human touch control of electronic devices. FSRs are not a load cell or strain gauge, though they have similar properties.

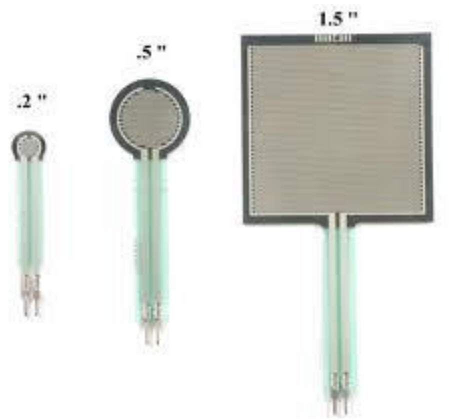

Figure 7: FSR Shapes

2.2 How the Sensor Works

The FSR sensor acts as a force sensing resistor in an electrical circuit. When the force sensor is unloaded, its resistance is very high. When a force is applied to the sensor, this resistance decreases. The resistance can be read by connecting a millimeter to the outer two pins, then applying a force to the sensing area. Figure 8 below shows both the Force vs. Resistance and Force vs. Conductance (1/R). Note that the conductance curve is linear, and therefore useful in calibration.

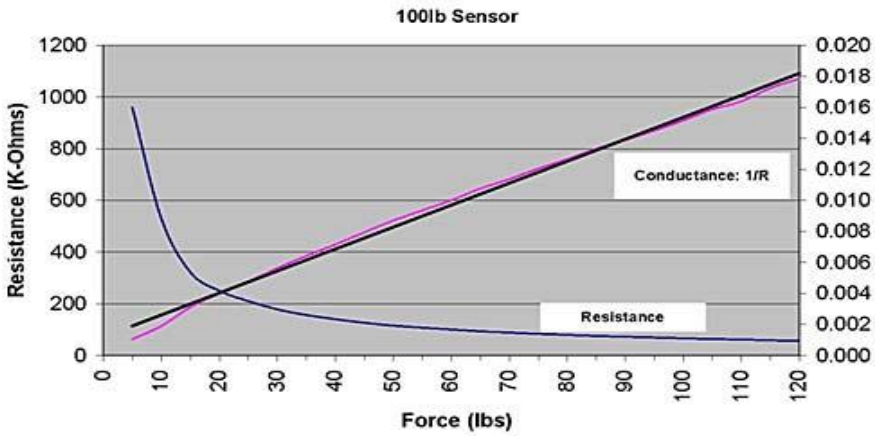

Figure 8: Force Vs. Conductance and Resistance

One way to integrate the FSR sensor into an application is to incorporate it into a force-to-voltage circuit. A means of calibration must then be established to convert the output into the appropriate engineering units. Depending on the setup, an adjustment could then be done to increase or decrease the sensitivity of the force sensor. Figure 9 below shows a typical sensor response.

2.3 How to Test It

An FSR is a variable force resistor, in which its large resistance is decreased as much as its active sensing area is subjected to pressure. Therefore; its resistance decreases as the applied pressure on its active area is increased. This characteristic of the FSR makes it easy to be tested by connecting its two pins to a multimeter, then applying force or pressure on its sensing area and measure its resistance.

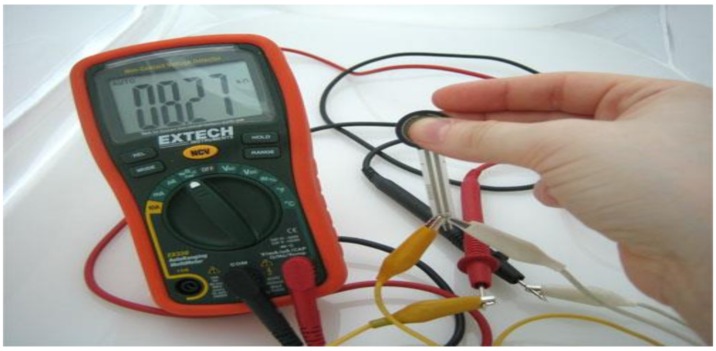

Figure 9: Testing the FSR

When there is no pressure, the resistance is a maximum resistance. Once a pressure is applied to the sensing area, the resistance decreases gradually in response to the applied pressure.

2.4 Proposed Circuit Design

Because the goal is to just take voltages out of someone's chest during sleep, we proposed a simple circuit layout (see figure 10) to perform this job. An FSR sensor (3Mohm) is located into a belt wrapped around chest. The FSR Sensor is placed in series with a 1k ohm or 1 M ohm resistor, and then a voltage divider is applied on that resistor to take voltages out. A voltage source of 5v is to supply the circuit.

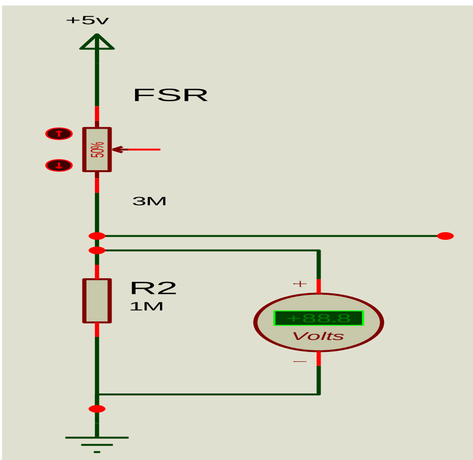

Figure 10: Proteus first layout circuit

Since the FSR has very a high resistance, it draws almost 4.95v of the 5v and the 1 kohm resistor draws the rest 0.05v. 0.05v is too small, therefore; it should be amplified using an instrumentation amplifier. We noticed that if we use a larger resistor (1Mohm), the drawn voltage will be larger (Ohm's law), and there will be no need for the instrumentation amplifier anymore; Therefore we replaced the 1 kohm resistor by 1 Mohm.

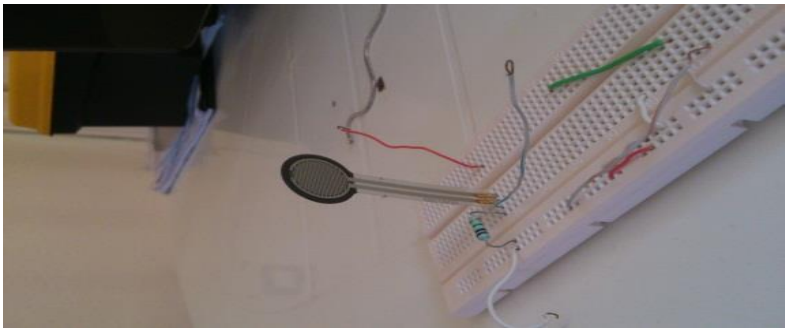

Figure 11: FSR in series with a resistor

2.5 FSR Description

The FSR sensor is not a strain gauge, load cell or pressure transducer. While it can be used for dynamic measurement, only qualitative results are generally obtainable. Force accuracy ranges from approximately ± 5% to ± 25% depending on the consistency of the measurement and actuation system, the repeatability tolerance held in manufacturing, and the use of part calibration. Accuracy should not be confused with resolution. The force resolution of FSR devices is better than ± 0.5% of full use force

Usually sensor size and shape are the limiting parameters in FSR integration, so any evaluation part should be chosen to fit the desired mechanical actuation system. In general, standard FSR products have a common semiconductor make-up and only by varying actuation methods (e.g. overlays and actuator areas) or electrical interfaces can different response characteristics be achieved.

2.5.1 Physical Properties

- Thickness 0.208 mm (0.008 in.)
- Length 25.4 mm (1 in.)
- Width 14 mm (0.55 in.)
- Sensing Area 9.53 mm diameter (0.375 in.)
- Connector 2-pin Male Square Pin
- Substrate Polyester (ex: Mylar)
- Pin Spacing 2.54 mm (0.1 in.)

Chapter 3: Design and Simulation

3.1 Introduction

The main purpose of this research project is to develop a low cost, low power, reliable, and non-invasive Obstructive Sleep Apnea Detector that processes the data acquired from the FSR sensor to determine if the apnea is imminent to occur, according to an accurate protocol and algorithm based on a detailed and predetermined research about sleep apnea and the sleep levels before it happens.

3.2 Project design

The Obstructive Sleep Apnea Detector needs the following components as listed in the table below:

Item #	Specification	Quantity	Description
1	FSR	1	Measure chest voltage
2	Resistors	1/2/2	1M/1k/10k
3	16F874	1	PIC-Microcontroller is used to generate digital outputs
4	LCD	2	Display output of modules
5	7805	1	Voltage regulator(9V to 5V)
6	Capacitors	1/1	1Uf/10Uf used with regulator
7	Potentiometer	2	10K for LCD contrast
8	2N222	1	Diode to give safety for buzzer
9	Push button	2	To reset and start test

3.3-Software requirements

This part presents the software used in design modeling

3.3.1-PROTON IDE

The PROTON IDE compiler takes full advantage of each type of PIC® micro available, and offers a friendly and intuitive language that allows very complex operations to be carried out with a minimum of fuss, and provides a flexibility and functionality that is unparalleled in the world of PIC® micro programming. The PROTON+ compiler is functionally compatible with the language of the Parallax BASIC Stamp modules and the PICBASIC Pro Compiler from micro Engineering labs. This offers the beginner a comfortable and familiar environment to gently move into the world of PIC® programming. The logo of the Proton + is shown in the figure 12.

Figure 12: PROTON IDE Logo

3.3.2-Proteus

Proteus is a Virtual System Modeling (VSM) that combines circuit simulation, animated components and microprocessor models to co-simulate the complete microcontroller based designs. This is the perfect tool for engineers to test their microcontroller designs before constructing a physical prototype in real time. This program allows users to interact with the design using on-screen indicators and/or LED and LCD displays and, if attached to the PC, switches and buttons. Proteus VSM comes with extensive debugging features, including breakpoints, single stepping and variable display for a neat design prior to hardware prototyping. Thus, Proteus is a computer aided design program. It is divided into two parts: The first is PROTEUS ISIS used for schematic design and simulation; it has a huge components library and easily used.

Figure 13: Proteus Logo

3.4-General description of the design

3.4.1 P16F874

The PIC is simply a microcontroller. It's a data processing unit by which we can add some internal peripherals that allow realizing our design without the need to add external components. The microcontroller used is PIC 16F874. The program on the microcontroller, reads the value of the Force Sensitive Resistor. The micro controller programming is done using Proton IDE, a miKrobasic language for control units. The PIC microcontroller PIC 16F874 has an operating speed Max 20 MHZ, voltage (2-5.5v). Memory consists of flash program RAM, EEPROM and Data Memory. Displayed data of chest voltage are transferred by the microcontroller to the LCD to be displayed as they are, as a first step Also the main task of the PIC is to monitor the input sensors, and generate a message that reflects the values of these inputs as a final step.

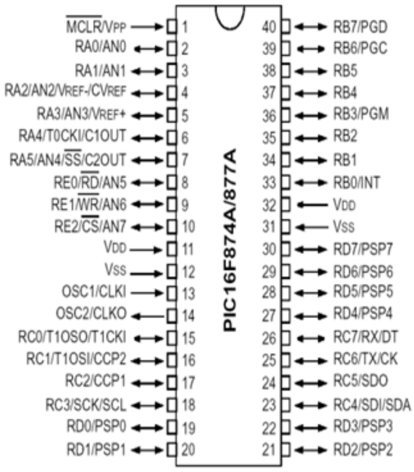

Figure 14: P16F874

3.4.2 LCD: LM 16*2

It is the abbreviation of liquid crystal display. LCD is an electronically-modulated optical device shaped into a thin, flat panel made up of any number of color or monochrome pixels filled with liquid crystals and arrayed in front of a light source (backlight) or reflector. It is often utilized in battery powered electronic devices because it uses very small amounts of electric power.

Figure 15: LCD

3.5 Design Process

The machine was designed progressively; so that each design process was simulated, tested then implemented on a breadboard. These are the design processes that were accomplished:

3.5.1 FSR circuit to read chest voltages

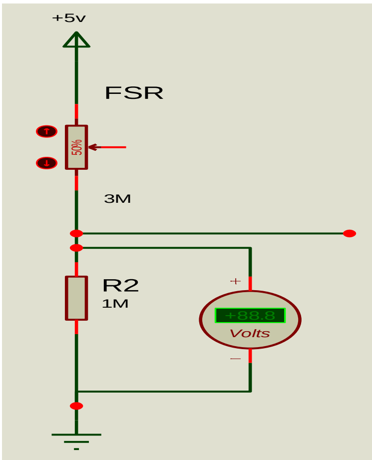

Figure 16: FSR in series with a fixed resistor

In order to take out voltages from the thorax using the **FSR**, different methods can be used. The most appropriate one is the voltage divider method which is done by connecting a smaller pulled down resistor (1Mohm) in series with the **FSR** and measure the voltage across that resistor. A power source of 5V is applied to the circuit; therefore, the **FSR** draws approximately 3.36V and the rest 1.64V will be drawn by the other smaller resistor when the FSR is not pressed.

The output was measured across the fixed resistor; so that it is increased as the **FSR** resistance is decreased. In other word, the output voltage is minimum when the **FSR** is not pressed (see figure 17); as far as the **FSR** is pressed, its resistance decreases, results in a voltage drop across it. This drop in voltage across the **FSR** results in a voltage increasing across the fixed resistor.

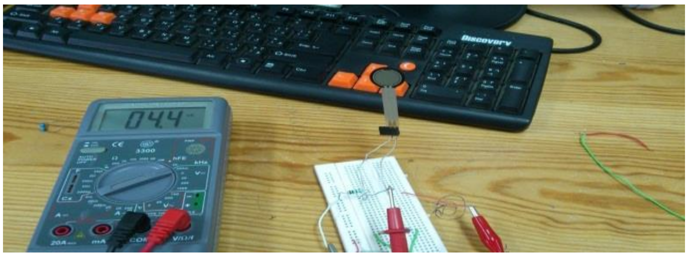

Figure 17: Primary Circuit Testing

3.5.2 PIC 16F874 interface with LCD and FSR output

The analogue voltage output produced by FSR circuit is an input for a PICmicro 16F874; nevertheless the PIC needs a program in order to be able to read analogue input and converts it into digital output. This was the most difficult task, and it made a delay by almost two weeks. I tried first to program the PIC microcontroller on **MPlab** using assembly codes but it was too difficult and didn't work out. I downloaded then the **Proton IDE** compiler which uses a miKroBASIC language and spent one week to learn its basics: how to interface PICmicro 16F874 to LCD and how to make the PIC reads analogue input and transforms it to digital output to be displayed on the LCD. Finally a created program was written on **Proton IDE** and it was simulated on **Proteus** and the result is shown below:

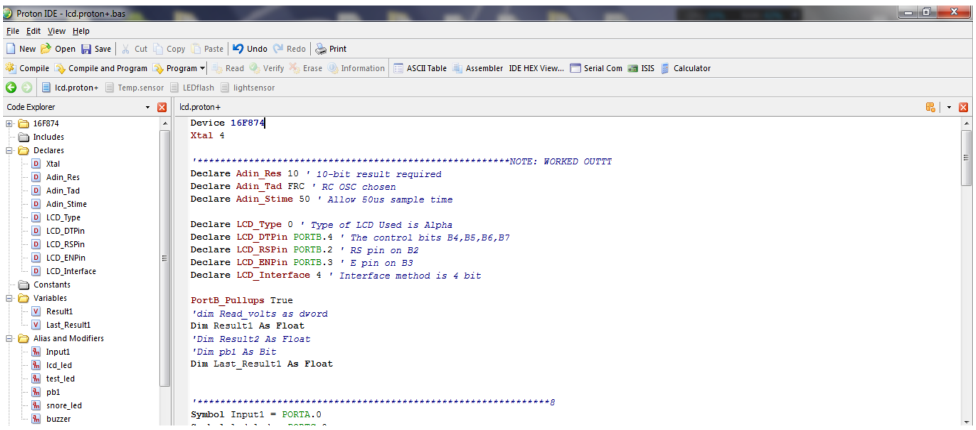

Figure 18: PIC Programing using Proton IDE

3.5.3 Design Simulation

After debugging and creating a PICmicro interface with LCD and FSR output using Proton IDE, the design was simulated using Proteus after adding all required features such as the buzzer and some leds to the design (see fig. 19).

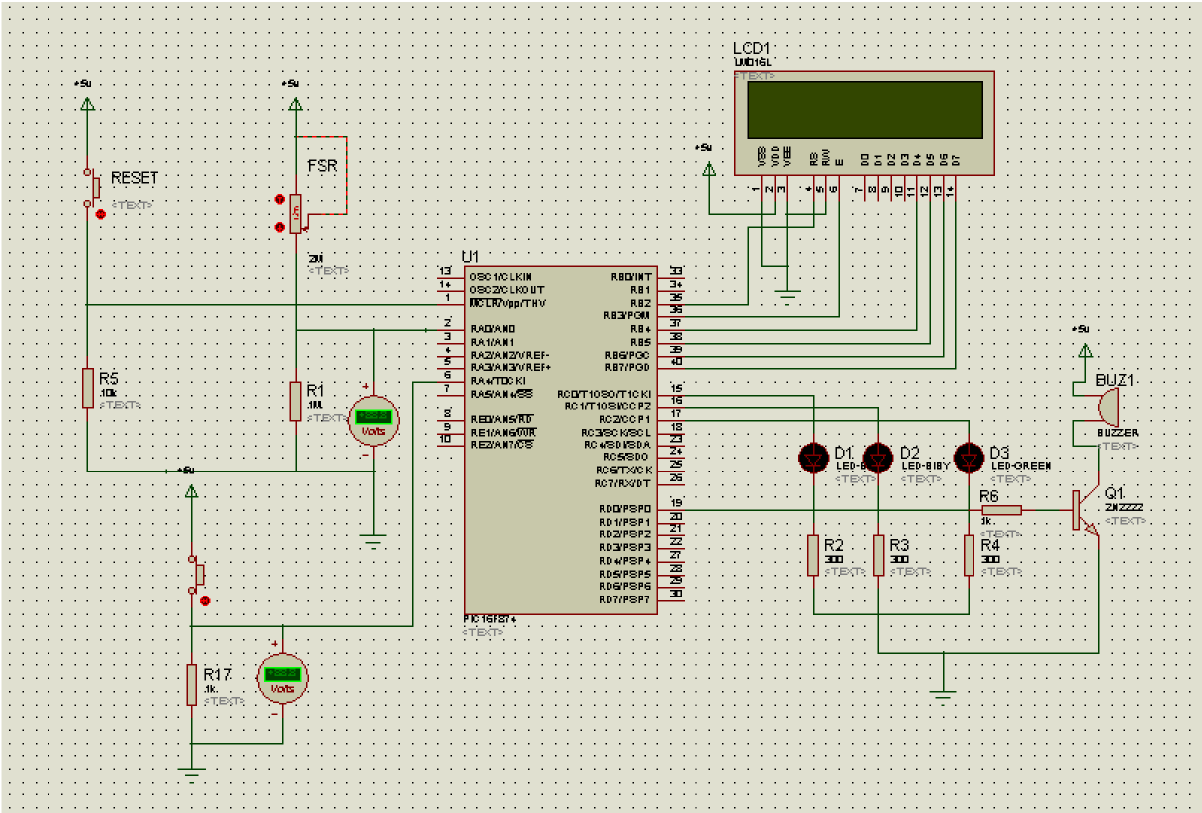

Figure 19: Design simulation using Proteus

Chapter 4: Implementation and Testing

As the FYP progressed from successful computer programming and simulation, it was time to move on to construct the electronic circuit PCB so that actual implementation could begin to cultivate our previous efforts. The following steps were implemented prior to the final circuit construction as follows:

4.1 Circuit Implementation on Breadboard

A full circuit was built on a breadboard as shown (see figure 20) below. It was then ready for initial testing trials to check if the simulation and preset values done on the PC could resemble and read the physiological values. The outcome of this circuit was promising.

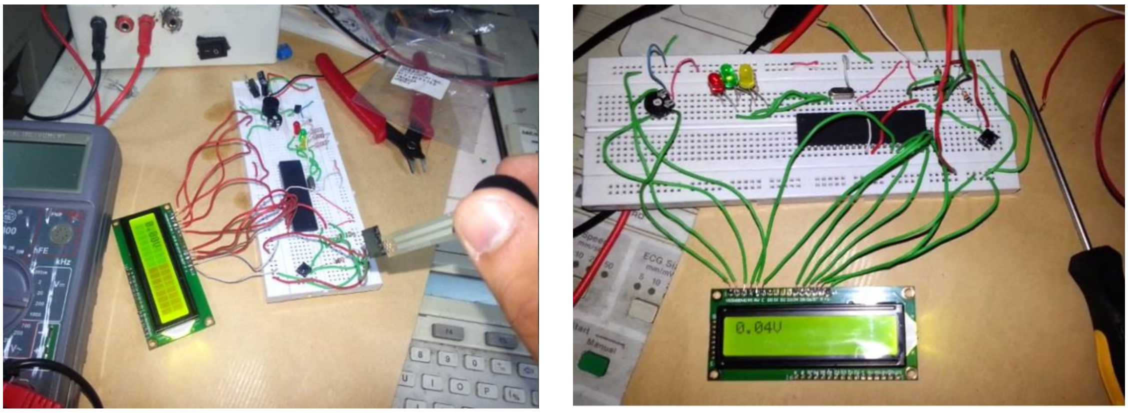

Figure 20: Circuit Implementation on breadboard

4.2 Circuit Implementation on PCB

After implementing the circuit and testing it on a breadboard, it was then implemented on a PCB as a final step. In order not to make mistakes, the implementation steps were done successively and the circuit was tested after each step.

4.2.1 Design a Power Supply

The circuit is supplied by 9V battery, but since the FSR circuitry needs 5V and the PICmicro can read only Voltages between 0V and 5V; we used a 7805 Regulator with two capacitors(1UF, 10UF) in order to transform from 9V to 5V (see figure 21).

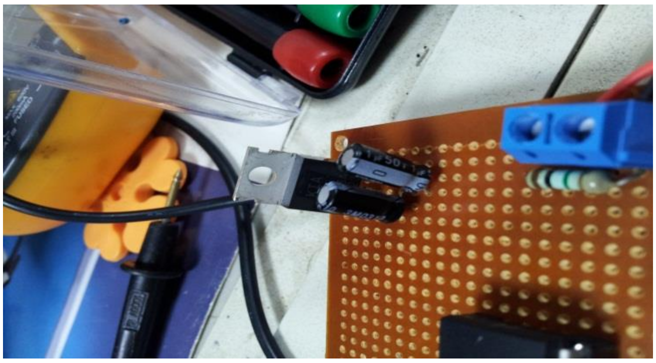

Figure 21: Regulator 7805

4.2.2 Build the sensor Circuitry

The first step was to implement the FSR sensor in series with a 1 Mohm resistor. The circuit was also feed by 5V and the output is measured across the 1 Mohm resistor.

Figure 22: FSR with a 1 Mohm resistor on PCB

The output was measured and the results were promising.

4.2.3 Interface PICmicro to LCD

Once the FSR sensor circuit produced the required results, the next step was to implement the PIC 16F874, the LCD and the buzzer.

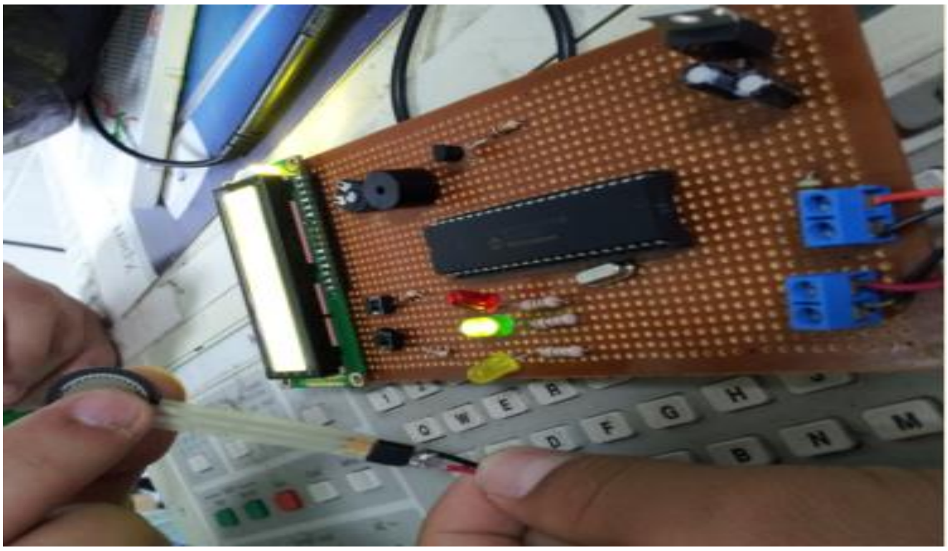

Figure 23: OSA Detector, Final Design

As this step was accomplished, the machine was tested and it was almost ready for starting tests. Whereas, certain readjustment to the microcontroller program can be made. Also some additional features to the circuit may be added such as additional Push buttons…

4.2.4 Belt and Sensor Placement

Since the FSR sensor is composed of a two conductive plates, it requires double side push to have a change in its resistance; that's why it was not easy to find the appropriate method and location to place the sensor; in which it is pushed up by the chest (Expiration) and at the same time pushed by an opposite direction by the belt.

Figure 24: Double side push on FSR

After many trials, we found out that the thorax (chest region) is the most appropriate region for the belt to be placed and for the sensor to be built in. Beside, we found out that one belt is not enough because two opposite forces should be applied to sensor to have variation in its resistance. Therefore the sensor should be placed between two belts in order to be pushed from its both sides (figure 26). The first lower belt should be a rubber one (figure 25), while the upper belt should be a rigid one. In the expiration phase, the chest contracts; which pushes the sensor from its lower side and at the same time the rigid non rubber belt produces an opposite force that pushes the other side of the sensor results in resistance decrease.

Figure 25: Belt on Abdominal Region

Figure 26: Belt on Thoracic Region

4.3 Testing Trials:

The **OSA Detector** was first tested using one rubber belt placed on the patient chest and the results were as following:

One rubber belt is used	**Output Voltages**		
	Test 1	**Test 2**	**Test 3**
	0.03	0.04	0.0
	0.6	0.07	0.37
	1.01	0.9	1.8

Table 1: Primary data using one belt

As noticed, the output voltage is not exceeding 1.8V which means that the FSR sensor is not pushed against on its both sides; data was not being precise. To solve that problem, another non rubber belt is placed just above the rubber one and the result is as following:

Two belts used	Output Voltages
	0.04V
	0.10V
	0.19V
	0.55V
	0.26V
	1.08V
	1.55V
	1.65V
	1.60V
	1.72V
	3.62V
	4.10
	3.76V
	1.6V
	0.03V

Table 2: Primary data using two belts

Chapter 5: Data Collection and Processing

5.1 Candidates Selections

A general criterion is considered to make selection of candidates; this criterion is a simple questionnaire to be filled out by each individual candidate in order to speed up the process of selection; (See Appendix **B**). After careful screening of the questionnaire, a policy has been placed to supervise the whole process from candidate selections to performing tests. The protocol of this research study says to include candidates from different age groups, so that wider data can be obtained. Therefore candidates of different categories were selected. Those categories are (See table 3):

- **Normal Respiratory Rhythm(NRR)** without snoring to establish standard voltage values
- **Simple snoring(SS)** to detect voltage values variation during snoring
- **Hypopnea (Heavy Snoring) (Hypo)**

Categories	Number of Candidates	Gender	Age Group (years)
NRR	4	Male	20-45
SS	4	Male	20-45
Hypo	2	Male	20-45

Table 3: Candidate categories

5.2 Data Collection

The following flowchart depicts the procedure of testing for the three different categories (**NRR, SS, and HS**) using **OSA Detector**:

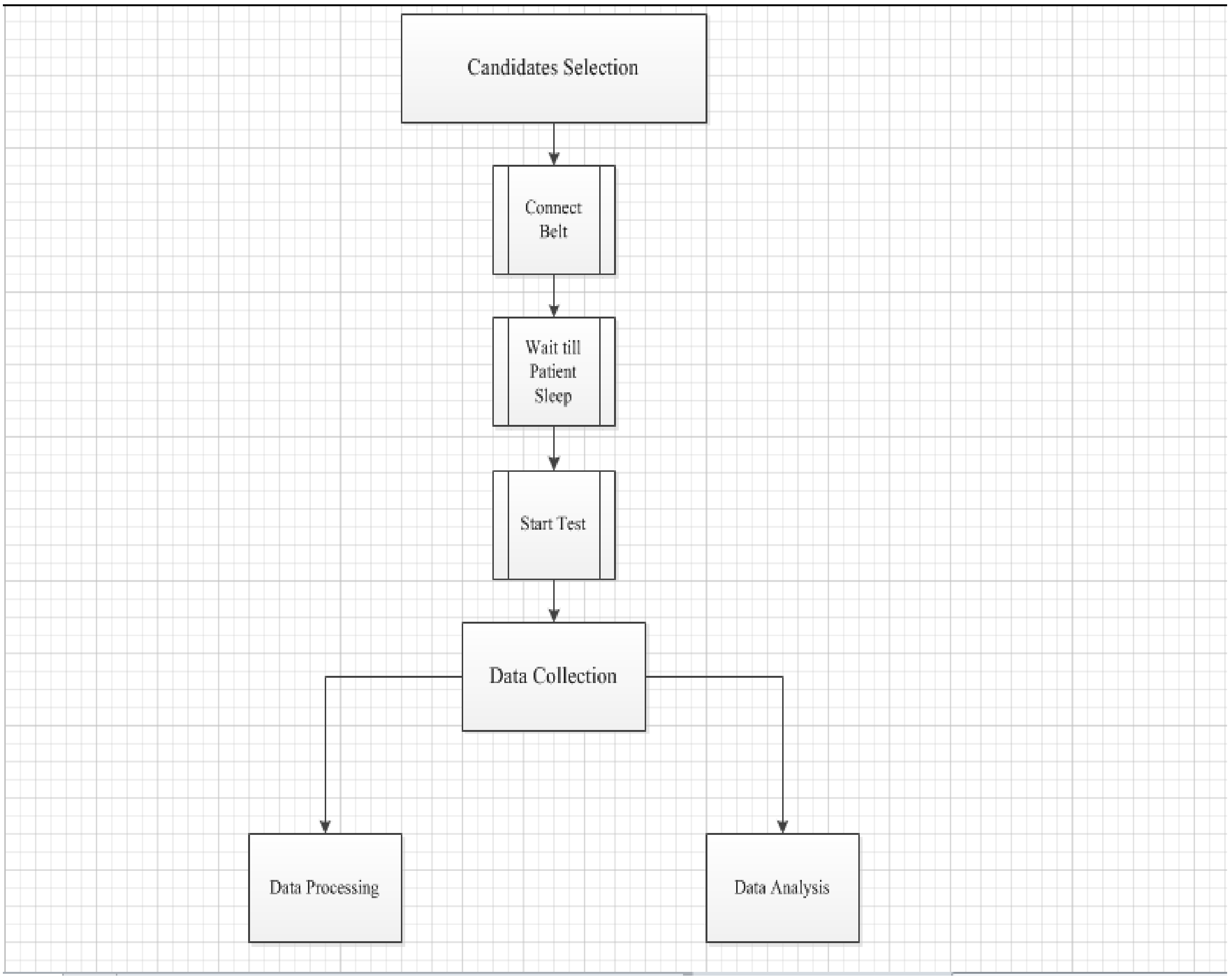

Figure 27: Testing Procedure

After collecting the data for each sleep level, data is directly filled out in tables using the **SPSS** software in order to be plotted as graphs and compared to other normal graphs to check for the accuracy and reliability for the designed machine (**OSA Detector**). The following tables are the data taken from the machine for the three levels of sleep levels (**NRR, SS and HS**):

5.2.1 NRR data:

subject	category	age	interval	voltages
1.00	NRR	23.00	1.00	.04
.	.	.	2.00	.10
.	.	.	3.00	.19
.	.	.	4.00	.55
.	.	.	5.00	.26
.	.	.	6.00	.24
.	.	.	7.00	1.08
.	.	.	8.00	.95
.	.	.	9.00	1.55
.	.	.	10.00	1.65
.	.	.	11.00	1.41
.	.	.	12.00	1.60
.	.	.	13.00	1.72
.	.	.	14.00	3.61
.	.	.	15.00	4.10
.	.	.	16.00	3.70
.	.	.	17.00	.03

Table 4: NRR Voltages for Candidate 1

subject	category	age	gender	voltages
2.00	NRR	25.00	Male	.01
.	.	.	.	.08
.	.	.	.	.14
.	.	.	.	.15
.	.	.	.	3.86
.	.	.	.	4.33
.	.	.	.	.00
.	.	.	.	.16
.	.	.	.	.27
.	.	.	.	3.67
.	.	.	.	3.89
.	.	.	.	.06
.	.	.	.	.00
.	.	.	.	.19
.	.	.	.	.15
.	.	.	.	4.10
.	.	.	.	4.18
.	.	.	.	.00
.	.	.	.	.18
.	.	.	.	3.35
.	.	.	.	4.01
.	.	.	.	.24
.	.	.	.	.00
.	.	.	.	.10
.	.	.	.	2.28
.	.	.	.	4.02
.	.	.	.	.00
.	.	.	.	.17
.	.	.	.	4.42
.	.	.	.	4.37

Table 5: NRR sample for Candidate 2

See Appendix **B** for complete table containing full data of four candidates

5.2.2 SS Data:

subject	category	age	gender	voltages
4.00	.	1.00	Male	.00
.	.	.	.	.23
.	.	.	.	4.34
.	.	.	.	4.41
.	.	.	.	2.94
.	.	.	.	4.26
.	.	.	.	4.51
.	.	.	.	2.93
.	.	.	.	4.45
.	.	.	.	2.79
.	.	.	.	3.35
.	.	.	.	4.43
.	.	.	.	3.16
.	.	.	.	4.84
.	.	.	.	4.90
.	.	.	.	4.75
.	.	.	.	4.80
.	.	.	.	4.41
.	.	.	.	3.20
.	.	.	.	4.36
.	.	.	.	4.27
.	.	.	.	4.62
.	.	.	.	4.90
.	.	.	.	4.95
.	.	.	.	4.82
.	.	.	.	4.25
.	.	.	.	4.43
.	.	.	.	4.76
.	.	.	.	4.79
.	.	.	.	4.67

Table 6: SS voltages for candidate 4

subject	category	age	gender	voltages
1.00	SS	21.00	Male	.00
.	.	.	.	.14
.	.	.	.	.18
.	.	.	.	.05
.	.	.	.	3.81
.	.	.	.	4.72
.	.	.	.	.72
.	.	.	.	.17
.	.	.	.	.00
.	.	.	.	3.94
.	.	.	.	4.00
.	.	.	.	.18
.	.	.	.	.00
.	.	.	.	.02
.	.	.	.	3.91
.	.	.	.	4.48
.	.	.	.	.00
.	.	.	.	.02
.	.	.	.	.08
.	.	.	.	4.01
.	.	.	.	4.70
.	.	.	.	1.49
.	.	.	.	.09
.	.	.	.	3.48
.	.	.	.	4.69
.	.	.	.	4.47
.	.	.	.	.00
.	.	.	.	.18
.	.	.	.	4.32
.	.	.	.	4.72

Table 7: SS voltages for candidate 1

See Appendix **B** for complete simple snoring table

5.2.3 Hypo (HS) Data:

subject	category	age	gender	voltages
3.00	Hypo(HS)	31.00	Male	.01
.	.	.	.	.08
.	.	.	.	.14
.	.	.	.	3.86
.	.	.	.	4.33
.	.	.	.	.00
.	.	.	.	.16
.	.	.	.	.27
.	.	.	.	3.27
.	.	.	.	3.86
.	.	.	.	3.90
.	.	.	.	2.06
.	.	.	.	3.45
.	.	.	.	1.90
.	.	.	.	2.30
.	.	.	.	3.16
.	.	.	.	1.82
.	.	.	.	3.60
.	.	.	.	2.50
.	.	.	.	1.69
.	.	.	.	3.20
.	.	.	.	1.78
.	.	.	.	2.60
.	.	.	.	3.69
.	.	.	.	2.36
.	.	.	.	2.00
.	.	.	.	3.50

Table 8: Hypo voltages for candidate 3

subject	category	age	gender	voltages
4.00	Hypo(HS)	28.00	Male	.09
.	.	.	.	4.42
.	.	.	.	3.90
.	.	.	.	3.50
.	.	.	.	2.70
.	.	.	.	3.60
.	.	.	.	3.25
.	.	.	.	2.18
.	.	.	.	1.96
.	.	.	.	2.36
.	.	.	.	3.59
.	.	.	.	4.00
.	.	.	.	3.20
.	.	.	.	1.89
.	.	.	.	2.25
.	.	.	.	3.03
.	.	.	.	.00
.	.	.	.	3.41
.	.	.	.	3.87
.	.	.	.	.14
.	.	.	.	.02
.	.	.	.	.20
.	.	.	.	3.92
.	.	.	.	3.94
.	.	.	.	4.25
.	.	.	.	.19
.	.	.	.	.00

Table 9: Hypo voltages for candidate 4

See Appendix **B** for complete Hypopnea table.

Chapter 6: Data Analysis

6.1 Introduction

The collected data were analyzed and interpreted on the same Software **(SPSS)** by plotting graphs represent the voltage variation with respect to the number of voltages read by the **OSA Detector**. The following are the analyzed data for each studied level of sleep:

6.1.1 Data analysis For NRR

Figure 31 represents Normal Breathing Rhythm obtained directly from a candidate as compared to a Normal Respiratory Waveform (figure. 30). **Figure 29** is a waveform drawing of voltages that are produced by full respiration (inspiration-expiration) versus time in 35 seconds. Normal respiratory rate of a healthy subject is between 15 Bpm which is one complete breath (cycle) per 4 seconds. The microcontroller is programmed to have a delay of 0.6 seconds between two consecutive readings due to sensitivity issues of the electronic circuit. The X-axis represents the number of voltages read by the device every 0.6s and it is automatically updated. One complete respiratory cycle repeats itself almost every seven voltage readings that is proportional to the normal respiratory timing cycle (4s per 1 cycle), this is derived as

Respiratory Rate = Readings*Delay = 7*0.6 = 4s

and by generating some descriptive statistics tables that calculate the mean, the standard deviation and the skew.

6.1.2 NRR Analysis:

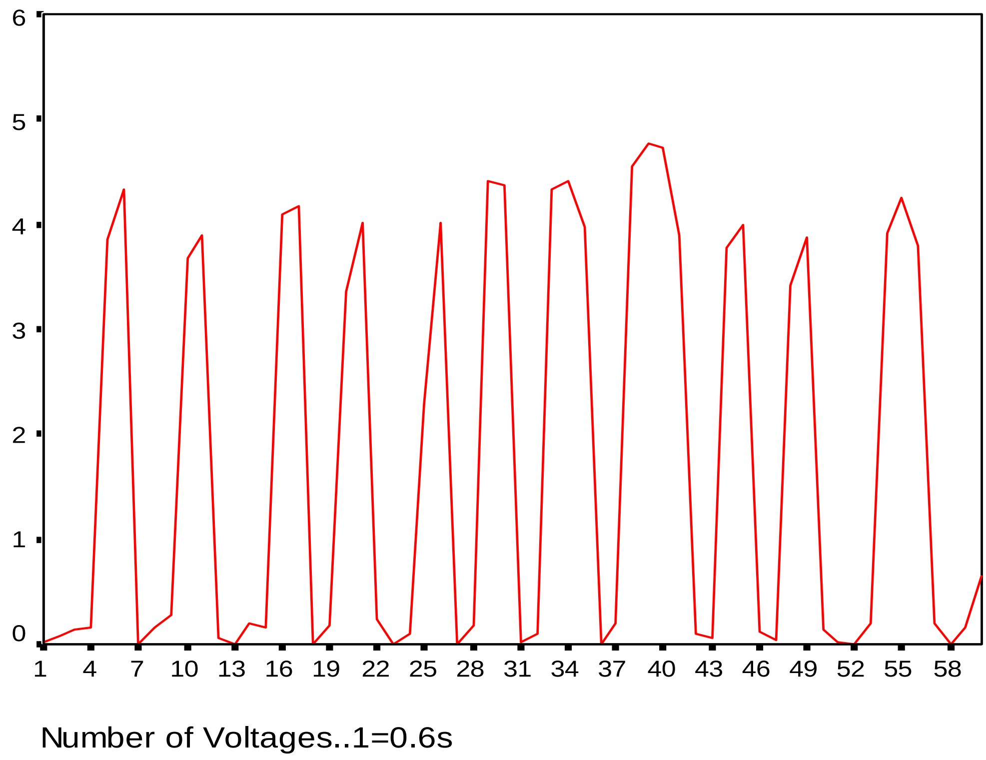

Figure 28: NRR using OSA Detector

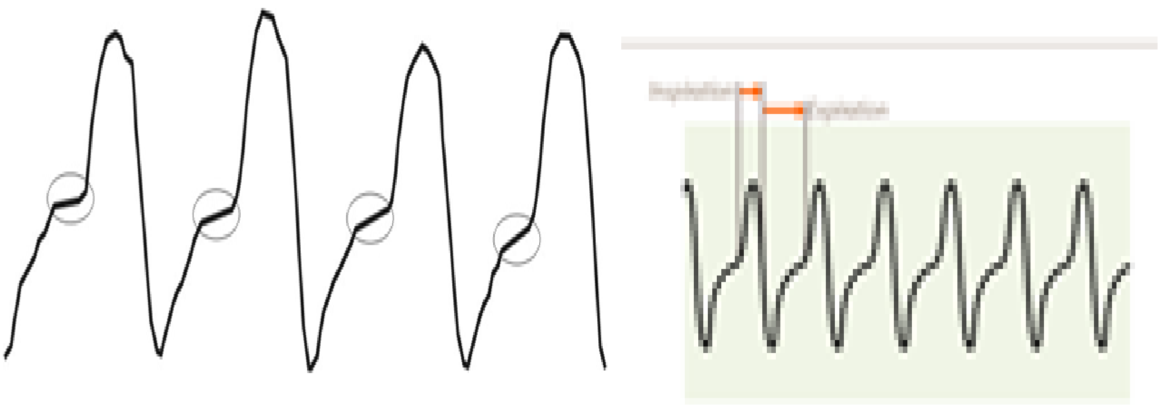

Figure 29: Normal Breathing Rhythm

6.1.3 SS Analysis

After finishing the **NRR** category and getting the required results, the next category to be tested was the **SS** category. The tests were performed for three minutes in order to monitor all the sleep levels happened during sleep, and then the sampling of the simple snoring pattern took place. The **SS** data were sampled, analyzed then compared to other normal snoring data and graphs to check the accuracy of the designed device and to determine the voltage interval of the **SS**. **Figure 31** represents **Simple Snoring** pattern obtained directly from a candidate using the **OSA Detector** compared to the **SS** pattern using other devices (see figure 32)

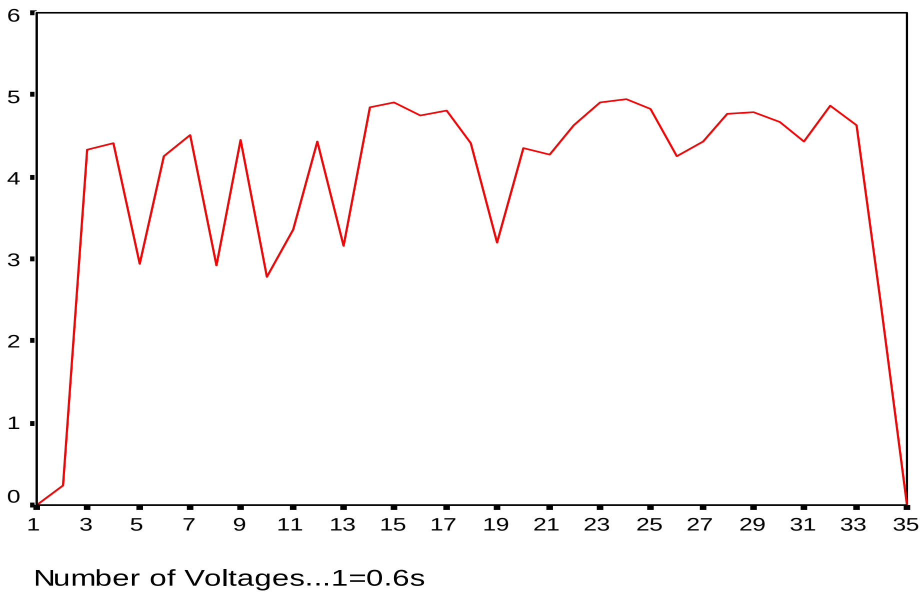

Figure 30: SS pattern by OSA Detector

Figure 31: SS pattern using different devices

6.1.4 HS analysis

As far as the candidate is tested by the device (**OSA Detector**), he may pass through different sleep disorders and levels. One of the most dangerous disorders is the **Hypopnea** or **Heavy Snoring. Hypopnea** is a medical term for a disorder which involves episodes of overly shallow breathing or an abnormally low respiratory rate. It is a partial blockage of the airway that results in an airflow reduction of greater than 50% for 10 seconds or more. It is less severe than **apnea** (which is a more complete loss of airflow). It may likewise result in a decreased amount of air movement into the lungs and can cause oxygen levels in the blood to drop. It more commonly is due to partial obstruction of the upper airway. **Figure 33** represents **Heavy Snoring** pattern directly from a obtained candidate using the **OSA Detector** compared to the **Heavy Snoring** pattern from other machine (see figure. 34).

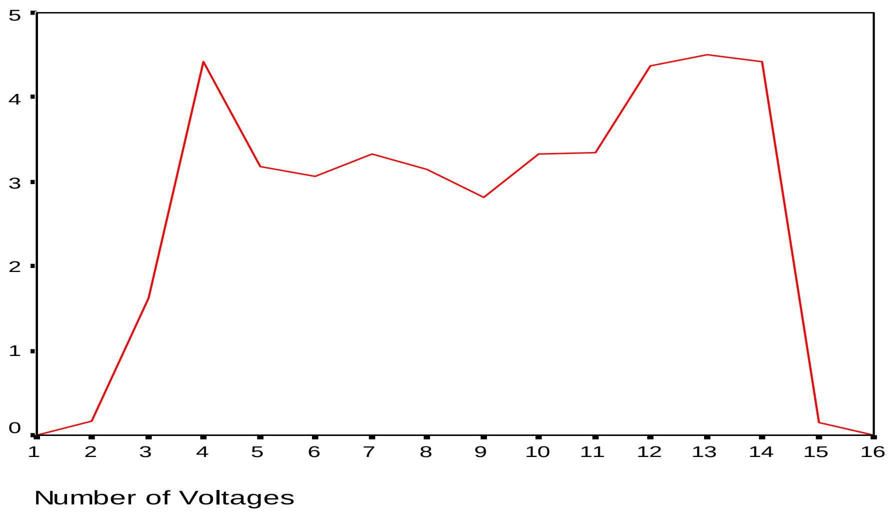

Figure 32: HS pattern using OSA Detector

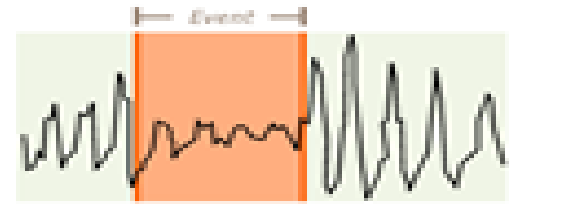

Figure 33: Normal HS pattern

Chapter 7: Data Interpretation

7.1 Introduction

The objectives of this chapter are to study statistically the data obtained of all measurements taken; **NRR, SS, HS and OSA**, and to determine exactly the distribution of such data about their mean values and standard deviation and other values as well, so that, to accurately program my **OSA Detector** to help predict **OSA** before it strikes.

7.2 Definition of Statistics Terminologies

The application of statistics to medical data is used to design experiments and clinical studies; to summarize, explore, analyze, and present data; to draw interference from data by estimation or hypothesis testing; to evaluate diagnostic; and to assist clinical decision making. **Quantitative** data are measured on a continuous or discrete numerical scale with some precision [10]. **Distributions** of data reflect the values of a variable or characteristic and the frequency of occurrence of those values. In this statistical study we used the following quantitative parameters:

- Measure of the middle, or the **central tendency**(the mean) $\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$ is the sum of the observed values divided by the number of the observations:

  $$\bar{X} = \frac{\sum_{i=1}^{n} X_i}{n}$$

- The **median** is the value for which half of the observations are smaller and half larger; it is used for skewed numerical data.
- The **range** which is the difference between the largest and smallest value is used to emphasize extreme values.
- The **standard deviation** is a measure of the spread of data around the mean

$$\sqrt{\frac{\Sigma(X - \bar{X})^2}{(n - 1)}}$$

where:

X = each score
$\bar{X}$ = the mean or average
n = the number of values
Σ means we sum across the values

7.3 Statistical Analysis

This section is solely made to take collected raw data from just being numbers to try to make meaningful conclusions beyond any doubt for precise determination of snoring and apneic events. This will not only produce a reliable medical device but also to increase its dependability and accuracy across a large number of populations. Thus, the following calculations and computations will determine if the main purpose of our research project is successfully or partially met. The collected data were analyzed and interpreted individually for each candidate and collectively for each category of candidates. In this regard, I have performed the followings:

7.3.1 NRR Interpretation

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
NRR Volts	180	.00	4.61	1.91-2	1.79835
Valid N (listwise)	180				

Table 9: NRR Descriptive Statistics

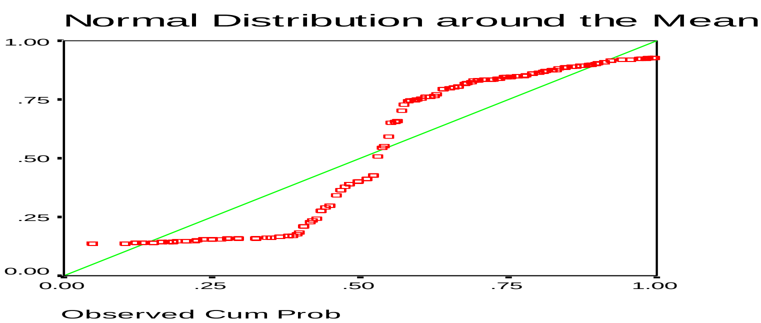

Figure 35: NRR Normal Distribution

7.3.2 SS Interpretation

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
SS Volts	148	2.37	4.91	4-4.1739	0.70938
Valid N (listwise)	148				

Table 10: SS Descriptive Statistics

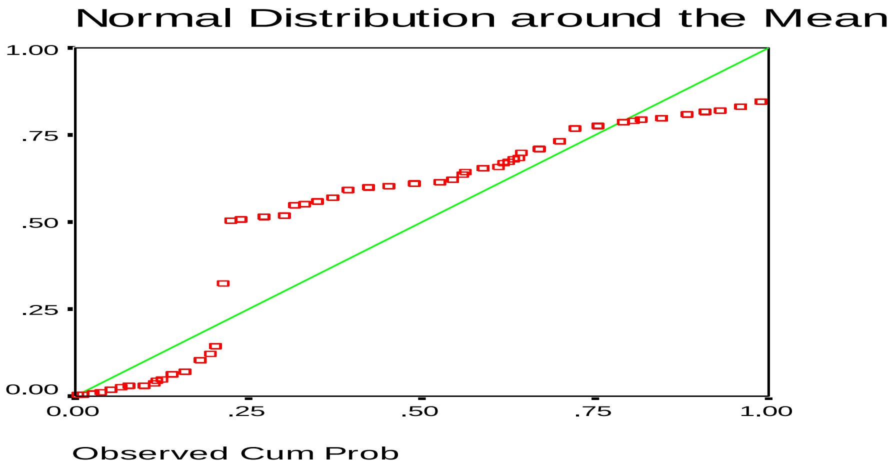

Figure 36: SS Normal Distribution

7.3.3 Hypo (HS) Interpretation:

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
HS Volts	73	2.50	3.50	3.1800	.38367
Valid N (listwise)	73				

Table 11: HS Descriptive Statistics

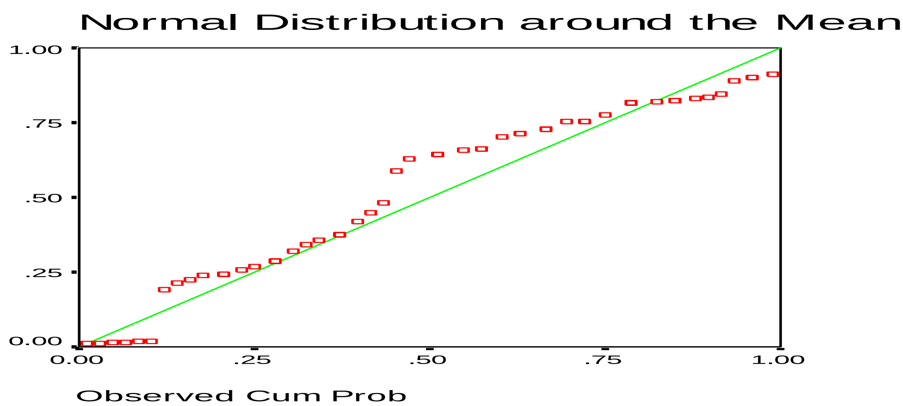

Figure 37: HS Normal Distribution

7.4 Results Discussion

A quick assessment of the above tables and recorded data is that each table contains voltage range (low/high) for each type of sleep level. The voltage interval of each sleep level is the range of voltages in between these two values (Low/high) including them. **NRR** voltage distribution is a symmetrical distribution which that the right and left side has equal distance to the mean (standard deviation). **SS** voltage distribution is a left skewed distribution since most of the voltages are greater than the mean. Also the voltages are getting closer to the mean since the standard deviation is 0.7. **HS** voltage distribution is also left skewed; however, the voltages are getting closer to the mean than the SS voltages which results in a low standard deviation (0.38).

Sleep Levels	NRR	SS	HS
Voltage interval	0.01-4.61	2.42-4.91	2.5-3.5
Standard Deviation	1.798	4.17	0.38
Mean	1.91	0.69-0.7093	3.1-3.30

Table 13: Sleep Levels Voltages Interval

7.5 OSA Prediction

OSA is a condition in which the airflow ceases despite continuing respiratory drive because of occlusion of the oropharyngeal airway. **OSA** cannot be overlooked because of its major and dangerous medical illnesses such as: **Hypertension**, **Congestive Cardiac Failure** and **Stroke. OSA** is not a condition that is suddenly happens, whereas it is a result of different sleep disorders such as **Simple Snoring** and **Heavy Snoring.** A sleeping person may pass through different sleep levels and stages during sleep pattern before getting into **Obstructive Sleep Apnea**; therefore, if these levels get classified and diagnosed by a device, then it is easy to predict the **OSA** occurrence by analyzing the sleep levels before that condition.

After analysis of the data collected using the designed machine (**OSA Detector**), and depending on the accurate results and determination of sleep levels voltage, we created an algorithm based on the analysis of **voltages interval** and **standard deviation** of the last sleep level (**Heavy Snoring**) before **OSA**. The **Hypopnea (HS)** is a sleep disorder in which a reduction of airflow of 50% and greater, and a 3% desaturation and lasting for at least **10 seconds.** After the 10 seconds the patient may either return to the Normal Respiratory Rhythm **(NRR) or** get into **OSA.** The algorithm consists of many conditions:

1. Check if the voltage interval is still in the range of **HS interval** or lower at the tenth and eleventh second.
2. Check if the standard deviation is still in the range of **HS standard deviation** (0.38-0.40) or lower, and also at the tenth and eleventh second.
3. If these two conditions were satisfied, this means that the patient is going into **OSA**; therefore the device will give off an alarm to wake the patient up. Otherwise, the patient is getting back to the **NRR**.

See appendix **A** for the algorithm programing

Conclusion

This research study has not passed without difficulties, but perseverance and upbeat determination to a successful conclusion have overcome such nuisance. An outcome of this research study has been revealed, and that is the prediction the sleep dangerous disorder: the **Obstructive Sleep Apnea**. This new method of prediction provides patients with quantitative measurements to uphold this and statistical analysis that has been employed to solidify the data obtained. These three diagnosed levels (**NRR, SS, and HS**) were studied and analyzed through measuring the chest voltages collected using a belt wrapped onto candidate chest with a built in sensor (**FSR**) and a simple circuit design to display voltages. The early prediction of **OSA** was a result of setting a voltage interval of each sleep level, and also a result of determining a standard deviation and a mean of each level depending on the voltages collected directly from candidates. Furthermore, snoring data (**SS, HS**) is sampled and extracted form a complete sleep pattern, then it is analyzed and plotted in order to reduce biases and errors. Finally, we can conclude that this research study has succeeded in fulfilling the objectives set forth in the introduction and our data is confirmed by earlier research studies done by other machines

Prospective

Future work is possible in so many ways to improve the diagnostic tools with this OSA Detector, Such improvements are:

- Select more candidates and perform more tests to get 100% accurate results.
- Introduce additional variables and parameters to improve the diagnosis of each Sleep level such as Temperature and spo2
- Create a machine-computer interface in order to monitor the sleep levels through a complete night.

References

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[4] http://ieeexplore.ieee.org › ... › Engineering in Medicine and BiomedicalEngineering in Medicine and Biology Society, EMBC, 2011 Annual International Conference of the IEEE, Aug. 30 2011-Sept. 3 2011, Jane, R. Dept. ESAII, Univ. Politec. de Catalunya (UPC), Barcelona, Spain Fiz, J.A.; Sola-Soler, J.; Mesquita, J.; Morera, J. pp. 8331 - 8333, Conference Publications http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=6092054&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D6092054,

[5] www.ni.com/white-paper/3642/en

[6] http://en.wikipedia.org/wiki/Obstructive_sleep_apnea

[7] www.omega.com/prodinfo/StrainGages.html

[8] www.eidactics.com/Downloads/.../NI_Strain_Gauge_tutorial

[9] www.efunda.com/.../strain_gages/strain_gage_theory.cfm

[10] Medical Instrumentation, Application and design (fourth edition), by John G. Webster, chapter 13.

Appendix A:

```
'****************************************************************
'*  Name    : OSA Detector.BAS                              *
'*  Author  : [Abdulkader Helwan...EDITOR OPTIONS]                *
'*  Notice  : Copyright (c) 2013  [select VIEW...EDITOR OPTIONS] *
'*          : All Rights Reserved                           *
'*  Date    : 8/6/2013                                      *
'*  Version : 10                                    *
'*  Notes   :                                       *
'*          :                                       *
'****************************************************************

Device 16F877
Xtal 4

'****************************************************************
Declare Adin_Res 10 ' 10-bit result required
Declare Adin_Tad FRC ' RC OSC chosen
Declare Adin_Stime 50 ' Allow 50us sample time

Declare LCD_Type 0 ' Type of LCD Used is Alpha
Declare LCD_DTPin PORTB.4 ' The control bits B4,B5,B6,B7
Declare LCD_RSPin PORTB.2 ' RS pin on B2
Declare LCD_ENPin PORTB.3 ' E pin on B3
Declare LCD_Interface 4 ' Interface method is 4 bit
```

```
PortB_Pullups True

Dim volts As Float

Dim rdgs As Byte

Dim HS  As Byte

Dim cycle As Byte

'*****************************************************************

Symbol Input1 = PORTA.0

Symbol lcd_led = PORTC.0

Symbol test_led = PORTC.1

Symbol pb1 = PORTA.4

Symbol snore_led = PORTC.2

Symbol buzzer = PORTD.0


TRISA = %00001001  ' Configure AN0(PORTA.0) and (PortA.1) as an input

TRISC = %00000000

ADCON1 = %10000000  ' Set analogue input, Vref is Vdd

'*******************************************************************


'********************************************************************************

 Cls

High lcd_led

'high portd

Print At 1,1, "1.System on"

DelayMS 2000

Print At 2,1, "2.Self Test"

DelayMS 2000

Print At 1,1, "3.Connect belt "
```

```
Print At 2,1, "on patient chest"

DelayMS 2000



'************************************************************************

loop:

Cls

 If pb1 = 0 Then

 Print At 1,1, "4.Press start"

 Print At 2,1, " to start test "

 DelayMS 3000

 GoTo loop

 EndIf

 If pb1 = 1 Then

 GoTo main

 EndIf


 '************************************************************************

   rdgs = 0

   cycle = 0

   HS = 0

'*************************************************************************

main:

Cls

High test_led

Low lcd_led
```

```
volts = ADIn 0 ' Grab A0's digital value

DelayUS 1 ' Allow internal capacitors to charge


volts = volts * 5 / 1023 ' Scale it to volts

 Cls

  'Cycle = rdgs*0.6  ;;;;;calculating cycle

  'If cycle = 7 Then

  'Print cycle 1

  'EndIf


Print At 1, 1, Dec2 volts, "V " ' If it has, display new data

rdgs = rdgs+1    """Reading number

DelayMS 600

Low buzzer

Low snore_led

Low lcd_led

If rdgs = 7 Then  """"""""7*0.6=4s

cycle = cycle + 1""""""""""cycle  number

rdgs = 0

EndIf


If volts = 5 Then

High buzzer

High snore_led

High lcd_led

Print At 1,1, Dec2 volts, "V"

Print At 2,1, "Relocate the FSR"
```

```
DelayMS 1500
Low snore_led
Low lcd_led
Low test_led
Low buzzer
EndIf
'**************************************************************************
'OSA Prediction

If volts >= 2.5 And volts <= 3.5 Then'''''Heavy snoring range
HS=HS+1
ElseIf volts< 2.5 And volts > 3.5 Then '''' back to normal sleep
HS = 0
EndIf
If HS = 17  Then ''''''''17  rdgs = 10s
High buzzer      '''''''wake up patient
Print At 1,1, " OSA Detected" '''''OSA detected
High test_led
High snore_led
High lcd_led
DelayMS 5000
EndIf

'******************************************************************************

 GoTo main ' Loop for ever
```

Appendix B

- **Normal Respiratory Rhythm table:**

subject	category	age	gender	voltages
2.00	NRR	25.00	Male	.01
.	.	.	.	.08
.	.	.	.	.14
.	.	.	.	.15
.	.	.	.	3.86
.	.	.	.	4.33
.	.	.	.	.00
.	.	.	.	.16
.	.	.	.	.27
.	.	.	.	3.67
.	.	.	.	3.89
.	.	.	.	.06
.	.	.	.	.00
.	.	.	.	.19
.	.	.	.	.15
.	.	.	.	4.10
.	.	.	.	4.18
.	.	.	.	.00
.	.	.	.	.18
.	.	.	.	3.35
.	.	.	.	4.01
.	.	.	.	.24
.	.	.	.	.00
.	.	.	.	.10
.	.	.	.	2.28
.	.	.	.	4.02
.	.	.	.	.00
.	.	.	.	.17
.	.	.	.	4.42
.	.	.	.	4.37

subject	category	age	gender	voltages
.	.	.	.	.01
.	.	.	.	.09
.	.	.	.	4.33
.	.	.	.	4.42
.	.	.	.	3.98
.	.	.	.	.00
.	.	.	.	.19
.	.	.	.	4.55
.	.	.	.	4.76
.	.	.	.	4.72
.	.	.	.	3.89
.	.	.	.	.10
.	.	.	.	.05
.	.	.	.	3.77
.	.	.	.	4.00
.	.	.	.	.11
.	.	.	.	.04
.	.	.	.	3.41
.	.	.	.	3.87
.	.	.	.	.14
.	.	.	.	.02
.	.	.	.	.00
.	.	.	.	.20
.	.	.	.	3.92
.	.	.	.	4.25
.	.	.	.	3.79
.	.	.	.	.19
.	.	.	.	.00
.	.	.	.	.15
.	.	.	.	.66

subject	category	age	gender	voltages
.	.	.	.	.04
.	.	.	.	.10
.	.	.	.	.19
.	.	.	.	.55
.	.	.	.	.26
.	.	.	.	.24
.	.	.	.	1.08
.	.	.	.	.95
.	.	.	.	1.55
.	.	.	.	1.65
.	.	.	.	1.41
.	.	.	.	1.60
.	.	.	.	1.72
.	.	.	.	3.61
.	.	.	.	4.10
.	.	.	.	3.70
.	.	.	.	.03
.	.	.	.	.01
.	.	.	.	.19
.	.	.	.	2.81
.	.	.	.	3.29
.	.	.	.	3.36
.	.	.	.	2.31
.	.	.	.	2.10
.	.	.	.	1.60
.	.	.	.	1.03
.	.	.	.	.75
.	.	.	.	.04
.	.	.	.	.10
.	.	.	.	.19

- **Simple Snoring Table:**

ss.cand1	ss.cand2	ss.cand3	ss.cand4
.	4.34	4.48	4.34
4.340	4.41	4.79	4.41
4.410	2.94	4.44	2.94
2.940	4.26	2.88	4.26
4.260	4.40	4.51	4.51
4.510	4.51	4.56	2.93
2.930	4.26	3.92	4.45
4.450	2.93	3.07	2.79
2.790	4.45	4.54	3.35
3.350	4.32	2.42	4.43
4.430	2.79	3.43	3.16
3.160	3.35	4.60	4.84
4.840	4.43	4.52	4.90
4.900	4.42	2.37	4.75
4.750	3.16	4.55	4.80
4.800	4.24	4.57	4.41
4.410	4.84	3.04	3.20
3.200	4.90	4.49	4.36
4.360	4.75	4.44	4.27
4.270	4.33	2.66	4.62
4.620	4.41	4.26	4.90
4.900	4.82	2.98	4.95
4.950	4.87	4.36	4.82
4.820	4.51	4.41	4.25
4.250	3.20	.	4.43
4.430	3.49	.	4.76
4.760	4.76	.	4.79
4.790	4.86	.	4.67
4.670	4.82	.	4.43
4.430	4.36	.	4.86

ss.cand1	ss.cand2	ss.cand3	ss.cand4
4.860	4.27	.	4.62
4.620	4.62	.	2.47
2.470	4.90	.	4.34
.	4.95	.	4.41
.	4.82	.	2.94
.	4.25	.	4.26
.	4.43	.	4.40
.	4.76	.	4.51
.	4.79	.	4.26
.	4.67	.	2.93
.	4.81	.	4.45
.	4.76	.	4.32
.	4.43	.	2.79
.	4.86	.	3.35
.	4.62	.	4.43
.	2.47	.	4.42
.	.	.	3.16
.	.	.	4.24
.	.	.	4.84
.	.	.	4.90
.	.	.	4.75
.	.	.	4.33
.	.	.	4.41
.	.	.	4.82
.	.	.	4.87
.	.	.	4.51
.	.	.	3.20
.	.	.	3.49
.	.	.	4.76
.	.	.	4.86

- **Heavy Snoring Table:**

hs.cand1	hs.cand2
.01	3.86
.08	4.33
.14	3.27
3.86	3.86
4.33	3.90
.00	2.06
.16	3.45
.27	1.90
3.27	2.30
3.86	3.16
3.90	1.82
2.06	3.60
3.45	2.50
1.90	1.69
2.30	3.20
3.16	1.78
1.82	2.60
3.60	3.69
2.50	2.36
1.69	2.00
3.20	3.50
1.78	2.36
2.60	2.00
3.69	3.50
2.36	3.50
2.00	1.00
3.50	.
.09	.
4.42	.
3.90	.

NRR Descriptive Statistics:

- **Candidate 1:**

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
VOLTAGES	27	.03	4.10	1.4907	1.28127
Valid N (listwise)	27				

- **Candidate 2:**

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std.
	Statistic	Statistic	Statistic	Statistic	Statistic
VOLTAGES	60	.00	4.76	1.7998	1.97412
Valid N (listwise)	60				

- **Candidate 3:**

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std.
	Statistic	Statistic	Statistic	Statistic	Statistic
VOLTAGES	76	.000	4.820	2.65263	1.949560
Valid N (listwise)	76				

- **Candidate 4:**

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
VOLTAGES	**104**	**.00**	**4.76**	**1.6442**	**1.71947**
Valid N (listwise)	**104**				

SS Descriptive Statistics:

- **Candidate 1:**

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
SS.VOLTS	32	2.470	4.950	4.23969	.719922
Valid N (listwise)	32				

- **Candidate 2:**

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
SS.VOLT2	46	2.47	4.95	4.3161	.64144
Valid N (listwise)	46				

- **Candidate 3:**

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
SS.VOLT3	24	2.37	4.79	3.9288	.81320
Valid N (listwise)	24				

- **Candidate 4:**

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
SS.V	102	2.37	4.95	4.2010	.71910
Valid N (listwise)	102				

HS Descriptive Statistics:

- **Candidate 1&2:**

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
STD	6	2.50	3.50	3.1800	.38367
Valid N (listwise)	6				

Appendix C:

- Are you a loud and/or regular snorer?
- Have you ever been observed to gasp or stop breathing during sleep?
- Do you feel tired or groggy upon awakening, or do you awaken with a headache?
- Are you often tired or fatigued during wake-time hours?
- Do you fall asleep sitting, reading, watching TV or driving?
- Do you often have problems with memory or concentration?

If you have one or more of these symptoms you are at higher risk for having obstructive sleep apnea.

Source: *American Sleep Apnea Association*