Palestine Polytechnic University

College of Engineering

Design and Implementation an Apnea Detection System for Infants

By

Renad S. Turman Alia M. Taradeh

Supervisor: Dr. Abdullah_Irman

Submitted to the College of Engineering

In partial fulfillment of the requirements for the

Bachelor degree in Biomedical Engineering

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الإهداء

السلام عليكم ورحمه الله وبركاته

أشكر الله العلي القدير الذي أنعم عليَّ بنعمة العقل والدين القائل في محكم التنزيل "وَفَوْقَ كُلِّ ذِي عِلْمٍ عَلِيمٌ"

وقال رسول الله محمد (ﷺ):"من صنع إليكم معروفاً فكافئوه، فإن لم تجدوا ما تكافئونه به فادعوا له حتى تروا أنكم كافأتموه"

نهدي هذا العمل المتواضع

إلى وطننا أرضنا فلسطين

إلى أرض الشهداء .. والأسرى .. والجرحى

إلى القدس ، سيدة العالم ، عاصمة فلسطين الأبدية التاريخية

إلى كل أساتذتنا من علمونا حرفاً أصبح سنا برقه يضيء الطريق أمامنا

أنتم من أضأتم بعلمكم عقل غيركم ... و هديتم بالجواب الصحيح حيرة سائليكم

فأظهرتم بسماحتكم تواضع العلماء ... وبرحابتكم سماحة العارفين.

إلى أبائنا الأفاضل

الذين لم يبخلوا علينا يوماً بشيء ... من علمونا النجاح والصبر

إلى أمهاتنا الغاليات

اللواتي لم يدخرن جهداً في تربيتنا وتوجيهنا ... من تحمَلن الصعاب لنصل إلى ما نحن عليه

وإلى إخوتنا وأسرتنا جميعاً

أنتم من وهبتمونا الحياة والأمل والنشأة على شغف الاطلاع والمعرفة

إلى زملائي وزميلاتي الذين سرنا معهم بهذا الطريق

أهدي هذا البحث المتواضع راجياً من المولى-عز وجل- أن يجد القبول والنجاح

رناد، عليا

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الملخص

يُعتبر التنفس علامة حيوية مهمة في جسم الإنسان وانقطاعها يؤدي إلى مضاعفات قد تؤدي أحيانا للوفاة، فنظراً لتزايد الطلب على الأجهزة المتنقلة خاصة أجهزة المراقبة تم تصميم هذا المشروع المتنقل،يتمركز هذا التصميم على فئة عمرية من يوم إلى عامين حيث أن ٦% من هذه الفئة تتعرض لمرض Apneaوهو عبارة عن مرض انقطاع التنفس إما مزمن أو مؤقت نتيجة لمشاكل في الدماغ أو مشاكل في إنغلاق مجرى التنفس.

تكمن فكرة هذا المشروع تكمن حول مرض Apnea الذي قد يؤدي أحيانا إلى وفاة الرضيع إذا لم يتم ملاحظته فوراً وهو عبارة عن تصميم حزام يوضع بداخله المستشعر flexiforce sensor قادر على مراقبة التنفس للرضيع وإعطاء إنذار للممرضين أو الأهل في حال تعرض الطفل لنوبة Apnea اعتماداً على خاصية حركة الصدر للرضيع أثناء التنفس ينتج عنه تغير الإجهاد من خلال مجس Flexiforce sensor، حيث يتغير حجم صدر الرضيع أثناء التنفس بناءا تغير حجم الرئتين وحركة الحجاب الحاجز فإذا حدثت نوبة apnea يبدأ الصدر بالحركة بقوة لأخذ أكبر قدر من الأكسجين ثم تبدأ بالإختفاء تدريجياً بعد ٢٠ ثانية تقريبا، تتم مقارنة هذه القراءات مع قيمة مرجعية لمعرفة إذا تعرض الرضيع لانقطاع التنفس ليتم إعطاء إنذار ضوئي وسمعي ومن ثم يتم اتخاذ الإجراء المناسب من قِبل المسؤولين.

Abstract

Breathing is an important sign of vitality in the human body and its interruption leads to complications that can be fatal. Due to the increasing demand for portable devices, especially monitoring devices, this portable project is designed to focus on patients one day to two years of age suffering from apnea. Apnea is a chronic or temporary cessation of breathing caused by problems in the brain or problems in the closure of the respiratory tract.

This project is concentrated on apnea, which can lead to death in infants if not immediately observed. Our design uses a strap that can monitor the infant's breathing rate and give a warning to nurses or parents if the child has an apnea spell. This monitoring is based on chest movement of the infant during breathing, which leads to a change in strain through Flexiforce sensor prompting an alarm. The amount of change in an infant’s chest during breathing depends on the amount of the lungs compliance. In the case of an apnea spell, the chest begins to move strongly to intake the maximum oxygen and then gradually disappears after about 20 seconds. These readings are compared with a reference value to determine if the infant is experiencing respiratory failure. If such a situation is detected, a visual and audible warning is produced so that appropriate action can be taken by the officials.

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Chapter One

Introduction

1.1 Introduction

Monitoring respiration rate is important when evaluating a human's health. Respiration rate monitoring devices can be classified in a number of ways depending on the manner of their use and operation. Apnea is suspension of breathing. During apnea, there is no movement of the muscles during inhalation and exhalation, although the volume of the lungs initially remains unchanged. Depending on the patency of airways, or how blocked the airways are, there may noa a flow of oxygen between the lungs and the environment, effecting cellular respiration Apnea. Is currently diagnosed using polysomnography (PSG) at sleeping labs. This diagnostic technique is both expensive and inconvenient, it requires an expert human to observe the patient overnight and detect sleep apnea. If apnea is left undetected, it can result in a growing number of health problems, including high blood pressure, heart attacks, diabetes, headaches and potentially death. In recent years there has been increasing interest in wearable health monitoring devices. Here we present an apnea detecting system for infants and newborns in hospitals that warns the nursing staff about emergency conditions through a non-invasive method. This idea came from observing an accident during one of our trainings in the hospital. An infant was lying in bed and the ventilator seemed to be working, but it was actually not giving any oxygen to the infant. He began to suffocate and none of the nursing staff noticed until just in time to him.

1.2 Project Idea Description

The design is a medical device to monitor the respiration rate of an infant. Consist a strap is placed around the infant's chest and contains a FlexiForce sensor which depends on chest and diaphragm movement to detect apnea spells when they occur. A box beside the patient contains the conditional circuits of the device including an alarm system and an LCD display for observations.

1.3 Project Objectives

This project will achieve the following objectives:

1) Design a non-invasive medical alarm system that has the ability to detect and monitor apnea spells for infants and newborns in hospitals, warning the nursing staff and doctors in case of an emergency situation.
2) Design a portable alarm system to assist nursing staff and doctors in observing patients.

1.4 Project Importance

This project is important because:

1) It provides an easy and convenient way to detect the infant's apnea spells.
2) The costs associated with this design are specially low
3) It saves time and effort for nurses in the patient monitoring process.
4) It protects infants from suffocation and apnea complications.

1.5 Literature Review

Polysomnography is based on laboratory or ambulatory monitoring that usually includes continuous and simultaneous recording of several physiologic variables during sleep. These variable, all of which are more challenging for infants and young children, include EEG, EOG, EMG, ECG, snoring, thoracic and abdominal movements, SaO2 and airflow Therefore, derived measures can be unrepresentative of natural sleep of specific children. Because polysomnography is a costly and inconvenient procedure, it is often done only for one or two nights, which further compromises the representativeness of the data. Finally, infants and young children often spend a significant amount of time sleeping during daytime hours, sometimes with an irregular schedule. Under such circumstances, capturing all natural sleep episodes with polysomnography is practically impossible, furthermore this technique requires an expert human to observe the patient overnight and detect sleep apnea.[1]

There are several ways to monitor apnea through impedance monitoring with EKG electrodes which detect changes in electrical impedance as the size of the thorax increases and decreases during respiration. The problem with this method is that is unable to detect obstructive apnea. Heart rate may not decrease with an apnea episode and sensitivity levels usually set so the monitor will sound in the presence of shallow respiration resulting in a false alarm. Another application is pulse oximetry using continuous measurement of oxygen saturation in hemoglobin. The problem with this method is decreased accuracy during hypoperfusion, hypothermia, and active movement.[2]

Students at Palestine Polytechnic University have worked on methods to detect apnea spells. One of these method is based on placing electrodes on the chest and measuring changes in human body resistance based on changes during breathing and non-breathing. Another method uses pressure modules for measuring inhalation and exhalation.

1.6 Time Schedule

Table1.1 Illustrate the tasks that we performed and how long it took weekly toper form each task

Task \ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Project Idea	■	■													
Proposal		■	■	■											
Collecting data		■	■	■	■	■	■	■	■						
Documentation			■	■	■	■	■	■	■	■	■	■	■	■	
Preparing for presentation													■	■	■
Print documentation															■

1.7 Project cost

Table 1.2 Project cost.

Component	cost₪
Flexi force sensor	65
LCD	30
Arduino "Nano"	45
AD822 IC	30
Strap	25
Switches	8
Led/s	2
Buzzer	5
Battery	10
Outer cover "Box"	35
Resistors & Capacitor	5
Wires	10
Total	270

Chapter Two

Anatomy and Physiology

2.1 Human Respiratory System

In anatomy, the form of the organs of the body is studied; the basic question is “What does it look like?” Inphysiology, their function is studied; the basic question is “What does it do?”The respiratory system consists of all the organs involved in breathing. These include the nose, pharynx, larynx, trachea, bronchi and lungs. The respiratory system does two very important things: it brings oxygen into our bodies, which we need for our cells to live and function properly; and it helps us get rid of carbon dioxide, which is a waste product of cellular function. Anatomically, the respiratory system can be divided into the upper and lower respiratory tract. The upper respiratory tract includes the organs located outside of the chest cavity (thorax) area, it is the nose, oral cavity, pharynx, larynx, all work like a system of pipes through which the air is funneled down into the lower respiratory tract includes the organs located almost entirely within chest cavity, it is trachea, bronchi and lungs**.** There, in very small air sacs called alveoli, oxygen is brought into the bloodstream and carbon dioxide is pushed from the blood out into the air. When something goes wrong with part of the respiratory system, such as an infection like pneumonia, it makes it harder for us to get the oxygen we need and to get rid of the waste product carbon dioxide. Common respiratory symptoms include breathlessness, cough, and chest pain.

2.1.1 Upper Respiratory Tract

The nose is the only visible part of the respiratory system, protruding from the face, at the base of the nose are two openings called the nostrils the nose and its internal nasal cavity provides a passageway for the air to pass through to the lungs, warms and moistens (humidifies) the inhaled air, filters and cleans the inhaled air from any foreign particles and heating and conditioning of the inspired air occurs through a network of thin-walled veins that sits under the nasal epithelium. The superficial location and abundance of the blood vessels causes a natural heat transfer process to the colder inspired air.

The pharynx (throat) is a tube like structure that connects the posterior nasal and oral cavities to the larynx and oesophagus. It extends from the base of the skull to the level of the sixth cervical vertebrae, the pharynx serves to provide a passageway for both the digestive system and respiratory system since food and air pass through it. The food or air is directed down the correct passageway, either the oesophagus or the trachea, by being controlled by the epiglottis. The epiglottis is a flap of elastic cartilage tissue that acts as a lid to cover the trachea when food is swallowed in order to prevent objects entering the larynx during swallowing. Some disease of the pharynx that may have an effect on the airway geometry and airflow includes Pharyngitis, Tonsillitis and Pharyngeal Cancer.

The larynx is commonly known as the voice box as it houses the vocal folds that are responsible for sound production, it transmitting air from the oropharynx to the trachea and also in creating sounds for speech. It is found in the anterior neck, connecting the hypopharynx with the trachea, which extends vertically from the tip of the epiglottis to the inferior border of the cricoid cartilage. The ciliated mucous lining of the larynx further contributes towards the respiratory system's ability to remove foreign particles and to warm and humidify the inhaled air. A diseases of the larynx that may have an effect on the airway geometry and airflow is Laryngomalacia which is a common condition during infancy, where soft, immature cartilage of the upper larynx collapses inward during inhalation, causing airway obstruction.[3]

2.1.2 Lower Respiratory Tract

Alveoli is the main sites of gas exchange while the Lungs is Composed primarily of alveoli and respiratory passageways. Stroma is fibrous elastic connective tissue, allowing lungs to recoil passively during expiration, and it is the house respiratory passages smaller than the main bronchi. Pleurae is serous membranes. Parietal pleura lines thoracic cavity; visceral pleura covers external lung surfaces it Produce lubricating fluid and compartmentalize lungs.

The trachea bronchial tree is the structure from the trachea (air passageway; cleans, warms, and moistens incoming air), bronchi, and bronchioles that forms the upper part of the lung airways. It is referred to as a tree because the trachea splits into the right and left main bronchi, which further bifurcates or branches out into more progressively smaller airways. It is an asymmetric dichotomous (splitting of a whole into exactly two non-overlapping parts) branching pattern, with the daughter bronchi of a parent bronchus varying in diameter, length, and the number of divisions.

The trachea bronchial tree conducts the inspired air to and from the alveoli. During gas exchange oxygen is brought into the body and is exchanged with carbon dioxide that is produced from cell metabolism. This occurs in the alveolar-capillary network which consists of a dense mesh-like network of the respiratory bronchioles, the alveolar ducts, the alveoli, and the pulmonary capillary bed. At the gas exchange diffuse across and into plasma and red blood cells. The diffusion occurs between the alveolar gas and blood in the pulmonary capillaries within less than one second.[3] Figure 2.1 shows Schematic of the respiratory system displayed by the upper and lower respiratory tract region

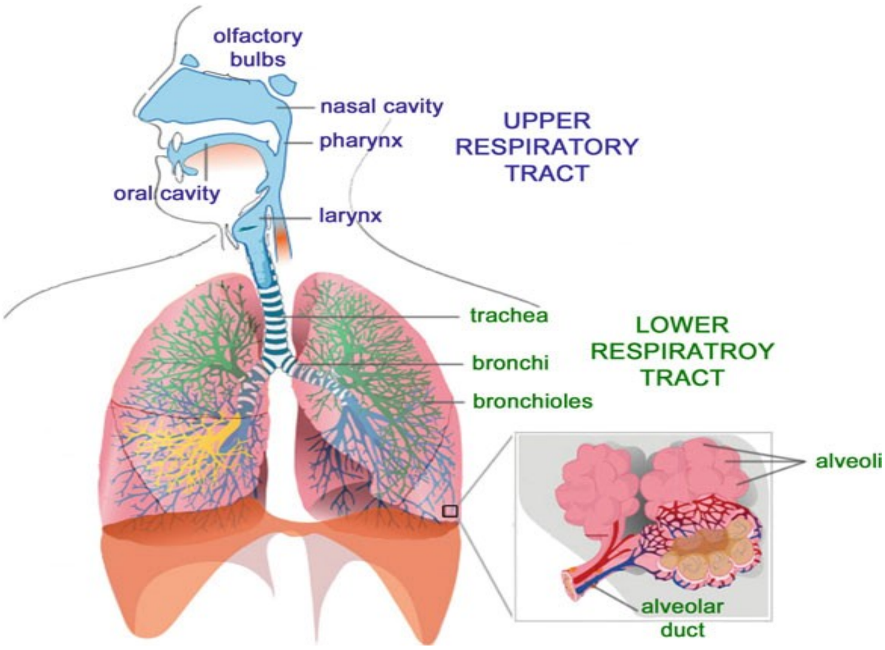


Fig.2.1: respiratory system.[3]

2.2 Respiration Physiology

The respiratory system is made up of a gas-exchanging organ it is lungs and a pump that ventilates the lungs. The pump consists of the chest wall; the respiratory muscles, which increase and decrease the size of the thoracic cavity; the areas in the brain that control the muscles; and the tracts and nerves that connect the brain to the muscles.

2.2.1 Lung Volumes and Capacity

Normally lung volumes are measured with a spirometer, and its lung capacity is then inferred from the measurements. Figure 2.2 illustrate Static lung volumes and capacity tracing measured by a spirometer. The vertical axis is the volume and the horizontal axis is time.[4]

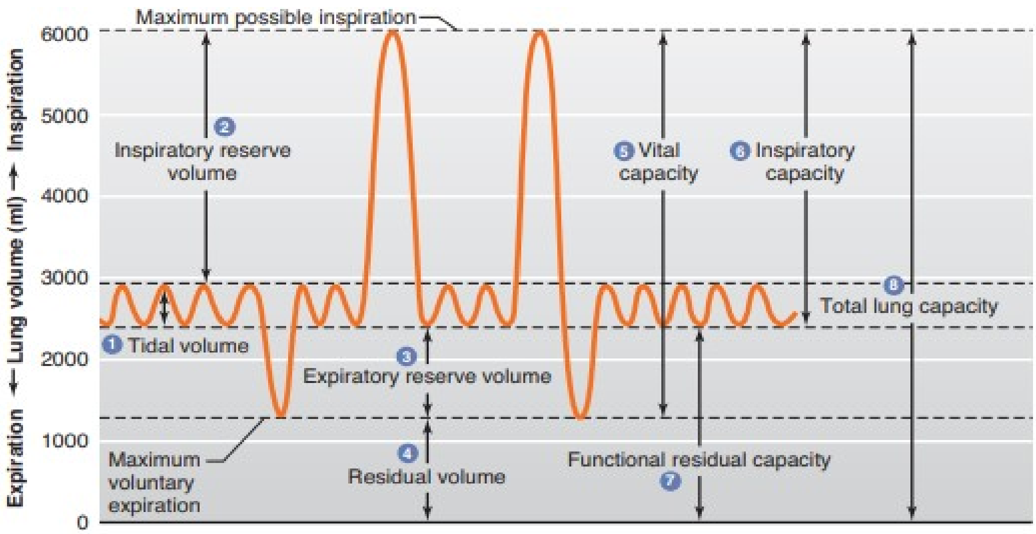


Fig. 2.2 a typical tracing measured from a spirometer. [4]

There are five volumes and four capacities used to define the lung space. [3] **They are:**

1) **Respiratory Volumes**

1.1 Tidal Volume (TV): is the amount of volume that is inspired and exhaled during normal quiet breathing. 7–9 mL/kg of ideal body weight ~8–10% of TLC

1.2 Inspiratory Reserve Volume (IRV): is the maximum volume that can be inhaled above the tidal volume.

1.3 Expiratory Reserve Volume (ERV): is the maximum volume that can be expired after the expiration of a tidal volume.

1.4 Residual Volume (RV): is the volume left in the lungs after maximum expiration.

2) **Respiratory Capacities**

2.1 Vital Capacity (VC): is the volume of maximum inhalation and exhalation.

2.2 Inspiratory Capacity (IC): is the volume of maximum inhalation.

2.3 Functional Residual Capacity (FRC): is the volume of air left in the lungs that can be exhaled after normal expiration.

2.4 Total Lung Capacity (TLC): is the maximum volume in the lungs. [4]

2.2.2 Respiratory Muscles

Movement of the diaphragm accounts for 75% of the change in intrathoracic volume during quiet inspiration. Attached around the bottom of the thoracic cage, this muscle arches over the liver and moves downward like a piston when it contracts. The distance it moves ranges from 1.5 cm to as much as 7 cm with deep inspiration show figures 2.3 and 2.4.

The diaphragm has three parts: the costal portion, made up of muscle fibers that are attached to the ribs around the bottom of the thoracic cage; the crural portion, made up of fibers that are attached to the ligaments along the vertebrae; and the central tendon, into which the costal and the crural fibers insert. The central tendon is also the inferior part of the pericardium.

When human breathe in inspiration, his muscles need to work to fill his lungs with air. The diaphragm, a large, sheet-like muscle which stretches across his chest under the ribcage, does much of this work. At rest, it is shaped like a dome curving up into his chest. When he breathe in, the diaphragm contracts and flattens out, expanding the space in his chest and drawing air into his lungs. Other muscles, including the muscles between his ribs the intercostal muscles also help by moving his ribcage in and out. Breathing out expiration does not normally require his muscles to work. This is because his lungs are very elastic, and when his muscles relax at the end of inspiration his lungs simply recoil back into their resting position, pushing the air out as they go.[4]

Fig.2.3 X-ray of chest in full expiration.[4]

Fig.2.4 The dashed white line is an outline of the lungs in full expiration.[4]

2.2.3 Mechanics of Breathing

Inhalation is initiated by the contraction of the diaphragm which contracts and descends about 1 cm during normal breathing and up to 10 cm on forced breathing. The diaphragm lines the lower part of the thorax, sealing it off air-tight from the abdominal cavity below. Its contraction causes muscles in the thorax to pull the anterior end of each rib up and outwards enlarging its volume. As a result, the pressure inside the thorax (intrathoracic pressure) and inside the lungs (intrapulmonary pressure) decreases relative to the outside atmospheric air pressure. The pressure difference induces the inhaled air from a higher pressure to a lower pressure in order to equalize the pressure. During exhalation the lung and chest wall return to its equilibrium position and shape. The thoracic cavity volume is reduced and the pressure builds up to release the air from the lungs. In quiet breathing only the elastic recoil of the lung and chest walls is needed to return the thorax to equilibrium (a passive process). However in forceful expiration additional muscles (inter costal) in the thorax and abdomen are also used to further increase the pressure.[3]

2.2.4 Gas Exchange

Gas exchange during the respiration process takes place in the alveolus at its surface that separates the alveolus with the capillary. In addition each alveolus is smaller than a grain of salt, in which there are approximately 300 million in the lungs. Each alveolus is optimized for gas exchange by having a thin moist surface and a very large total surface area in total. The surfaces of the alveoli are covered with a network of capillaries which are narrow blood vessels. Oxygen is passed from the alveoli into the surrounding capillaries that contains oxygen deprived, carbon dioxide rich blood passed from the heart. Gas exchange takes place where the oxygen is dissolved in the water lining of the alveoli before it diffuses into the blood while carbon dioxide is removed from the blood and into the alveoli where it leaves the body during exhalation. After leaving the lungs, the refreshed blood is now oxygen rich and returns back to the heart before it is redistributed to tissues in the human body see figure2.5. [3]

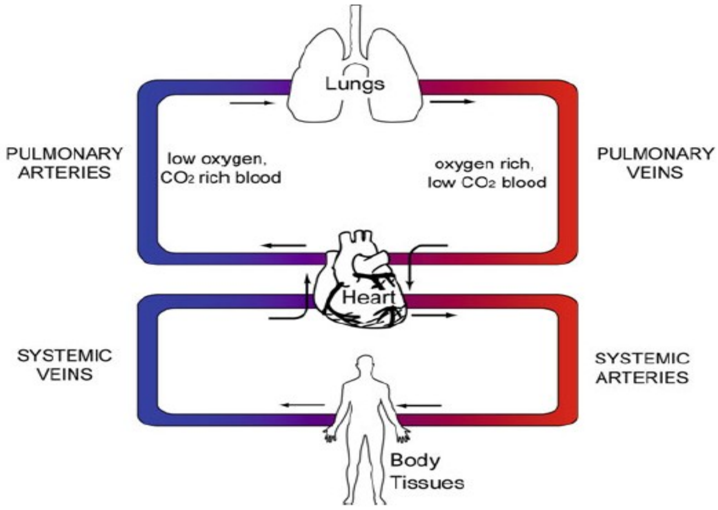


Fig. 2.5 Schematic of blood flow from the body through the heart and lungs. [4]

2.3 Respiratory Rate

The number of breaths per minute or, more formally, the number of movements indicative of inspiration and expiration per unit time. In practice, the respiratory rate is usually determined by counting the number of times the chest rises or falls per minute. The aim of measuring respiratory rate is to determine whether the respirations are normal, abnormally fast (tachypnea), abnormally slow (bradypnea), or nonexistent (apnea).[5]

2.3.1 Normal respiratory rate by age

Table 2.1 Normal Respiratory Rate by Age (breaths/minute)
Reference: PALS Guidelines, 2015

Age	Normal Respiratory Rate
Infants (<1 y)	30-53
Toddler (1-2 y)	22-37
Preschool (3-5 y)	20-28
School-age (6-11 y)	18-25
Adolescent (12-15 y)	12-20

2.4 Apnea for Infants

Babies breathe much faster than older children and adults. A newborn's normal breathing rate is about 40 breaths each minute. This may slow to 30 to 53 breaths per minute when the baby is sleeping, but on general. The pattern of breathing in a baby may also be different. A baby may breathe fast several times, then have a brief rest for less than 10 seconds, then breathe again. This is often called periodic breathing and is a normal occurrence. Babies normally use their diaphragm (the large muscle below the lungs) for breathing.

Respiratory problems will be mentioned two are breathing increases of 60 beats per minute, and breathing that stops longer than 20 seconds is called apnea syndrome.

Changes in a baby's breathing rate or pattern, using other muscles and parts of the chest to breathe, or changes in color may mean the baby is having respiratory distress and needs immediate medical attention.[6]

2.4.1 Infant defined

The World Health Organization (WHO) defines a term infant as one who is greater than 37 weeks' gestation. Recent evidence, however, has demonstrated that infants born at 37 weeks' gestation behave differently from infants delivered at 39 and 40 weeks' gestation. The more mature term infant (39 or 40 weeks) has fewer respiratory problems. The mean birth weight of a term infant is approximately 3400 grams. Mean length, which is sometimes difficult to measure accurately, is approximately 52 to 53 centimeters, and head circumference averages 34 centimeters.[7]

2.4.2 Apnea Spells

An apneic spell is usually defined as a cessation of breathing for 20 seconds or longer or a shorter pause accompanied by bradycardia (<100 beats per minute), cyanosis, or pallor. In practice, many apneic events in preterm infants are shorter than 20 seconds, because briefer pauses in airflow may result in bradycardia or hypoxemia. On the basis of respiratory effort and airflow, apnea may be classified as central (cessation of breathing effort), obstructive (airflow obstruction usually at the pharyngeal level), or mixed. The majority of apneic episodes in preterm infants are mixed events, in which obstructed airflow results in a central apneic pause, or vice versa.

Some factors contributing to apnea is a respiratory distress like an airway obstruction, cardiovascular disorders like a congestive heart failure, gastrointestinal disorders like a vomiting, central nervous system disorders incompletely growth and etc.

Cessation of respiratory effort with cyanosis, pallor, hypotonia, or bradycardia is noted. Frequent swallowing-like movements in the pharynx during apnea can be a problem, because swallowing directly inhibits the respiratory drive.[2]

Chapter Three

Theoretical Background

3.1 Introduction

Observations are made either continuously or in intervals, of minutes or hours. This type of patient monitoring is performed in hospital sittings, usually in intensive care units (ICU), and is warranted in crisis situations.

Because it is the respiratory function of living individuals that is being evaluated, measurement must be minimally invasive cause minimal discomfort and be acceptable for use in a clinical environment. For the sake of discussion, it is convenient to divide respiratory functions into two categories:

1. Gas transport in the lungs
2. Mechanics of the lung and chest wall

The mechanics of the lung and chest wall in relation to pressure as well as the incorporation of FlexiForce technology into designs of medical devices is shown in this chapter.

3.2 Stress and Strain

The relationship between stress and strain is one of the most fundamental concepts from the study of the mechanics of materials and is of paramount importance to the stress analyst.

In the general case, stress is the force an object generates inside by responding to an applied external force when a body deforms, this deformation is called strain. In our project note, we will be more specific and define the term strain to mean deformation per unit length or fractional change in length and give it the symbol,(ε), and stress analysis to mean when we apply a given load and then measure the strain on individual members of a structure or machine. Then we use the stress strain relationships to compute the stresses in those members to verify that these stresses remain within the allowable lim.

about figure 3.1 shows the relation between stress and strain of different materials.

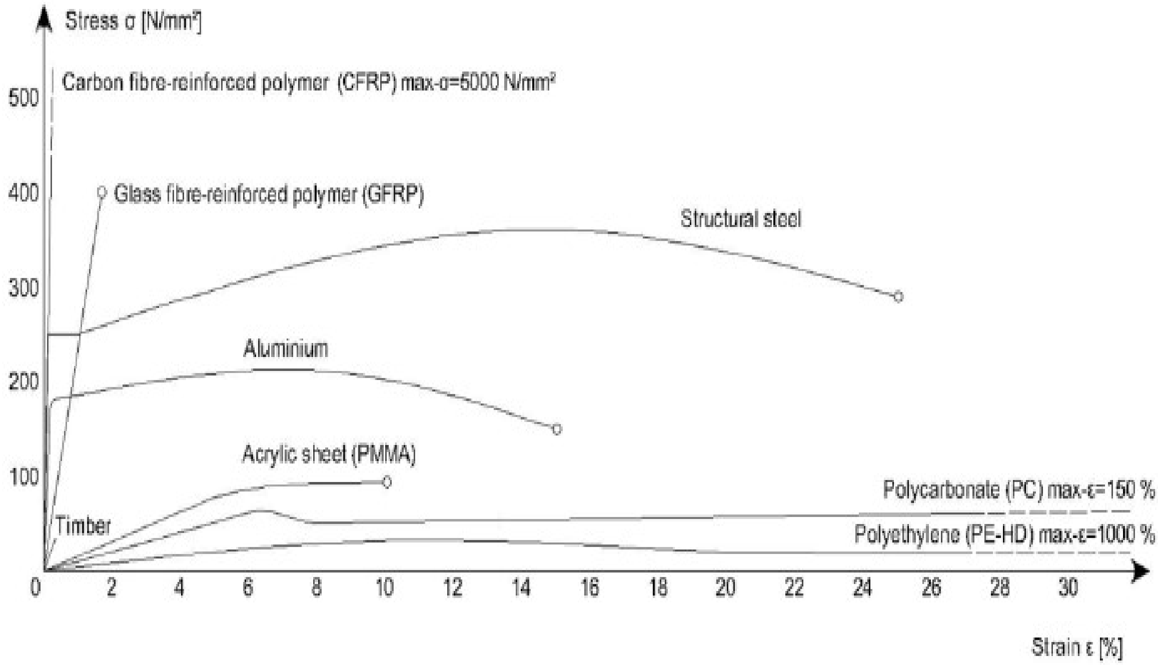


Fig 3.1 Stress strain relationships of different materials. [8]

3.2.1 Hooke's law (law of elasticity)

In most materials, a proportional relation is found between stress and strain borne, as long as the elastic limit is not exceeded. This relation was experimentally revealed by Hooke in 1678,{1} and thus it is called "Hooke's law" or the "law of elasticity." The stress limit to which a material maintains this proportional relation between stress and strain is called the "proportional limit" (each material has a different proportional limit and elastic limit), let's briefly learn about stress and strain and strain gages.

Stress is the force an object generates inside by responding to an applied external force, if an object receives an external force from the top, it internally generates a repelling force to maintain the original shape. The repelling force is called internal force and the internal force divided by the cross-sectional area of the objects called stress, which is expressed as a unit of Pa (Pascal) or N/m^2.

Suppose that the cross-sectional area of the column A (m^2) and the external force is P (N, Newton). As shown in figure.3.2.

$$\sigma = \frac{P}{A}(PaorN/m2) \qquad 3.1$$

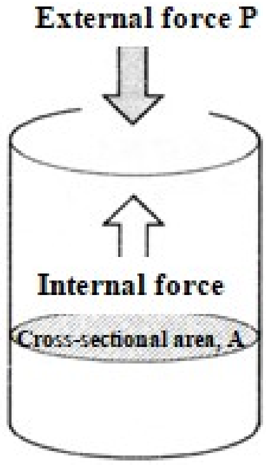


Fig.3.2 Simple expression of stress. [9]

When an object is pulled it elongates by ΔL and thus Fig.3.1 it lengthens to L+ ΔL (change in length). The ratio of this elongation (or contraction) ΔL to the original length L is called **strain**, which is expressed in Ɛ (epsilon): see figure3.3

$$\varepsilon_1 = \frac{\Delta L(\text{change in length})}{L(\text{original length})} \qquad 3.2$$

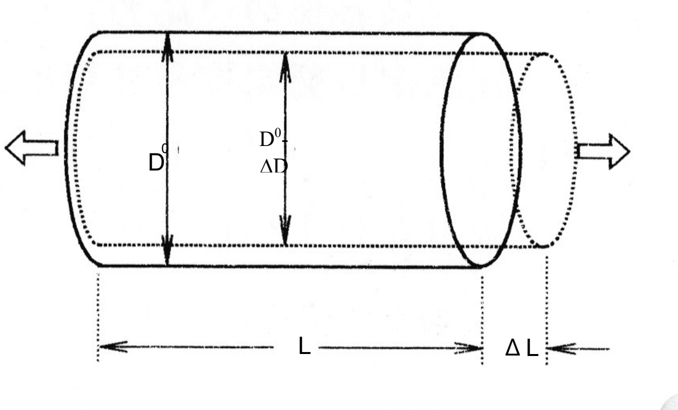


Fig.3.3 Expression strain deformation.[9]

The pulled object becomes thinner while lengthening, the pulled object becomes thinner while lengthening. Suppose that the original diameter, D^0, is made thinner by ΔD. Then, the strain in the diametrical direction is:

$$\varepsilon_2 = \frac{-\Delta d}{d_0} \qquad \textbf{3.3}$$

Strain is the same tensile (or compressive) direction as the external force is called longitudinal strain. Since strain is an elongation (or contraction) ratio, it is an absolute number having no unit. Usually, the ratio is an extremely small value, and thus a strain value is expressed by suffixing $x10^{-6}$ strain (µm/m) or (µε).

Strain in the orthogonal direction to the external force is called lateral strain. Each material has a certain ratio of lateral strain to longitudinal strain. This ratio is called Poisson's ratio, which is expressed in: [9]

$$v = \left|\frac{\varepsilon_2}{\varepsilon_1}\right| \qquad \textbf{3.4}$$

3.2.2 Polarity of Strain

Show in fig3.4, there exist tensile strain (elongation) and compressive strain (contraction). To distinguish between them, a sign is prefixed as follows:

1) Plus (+) to tensile strain (elongation).

2) Minus (–) to compressive strain (contraction).[9]

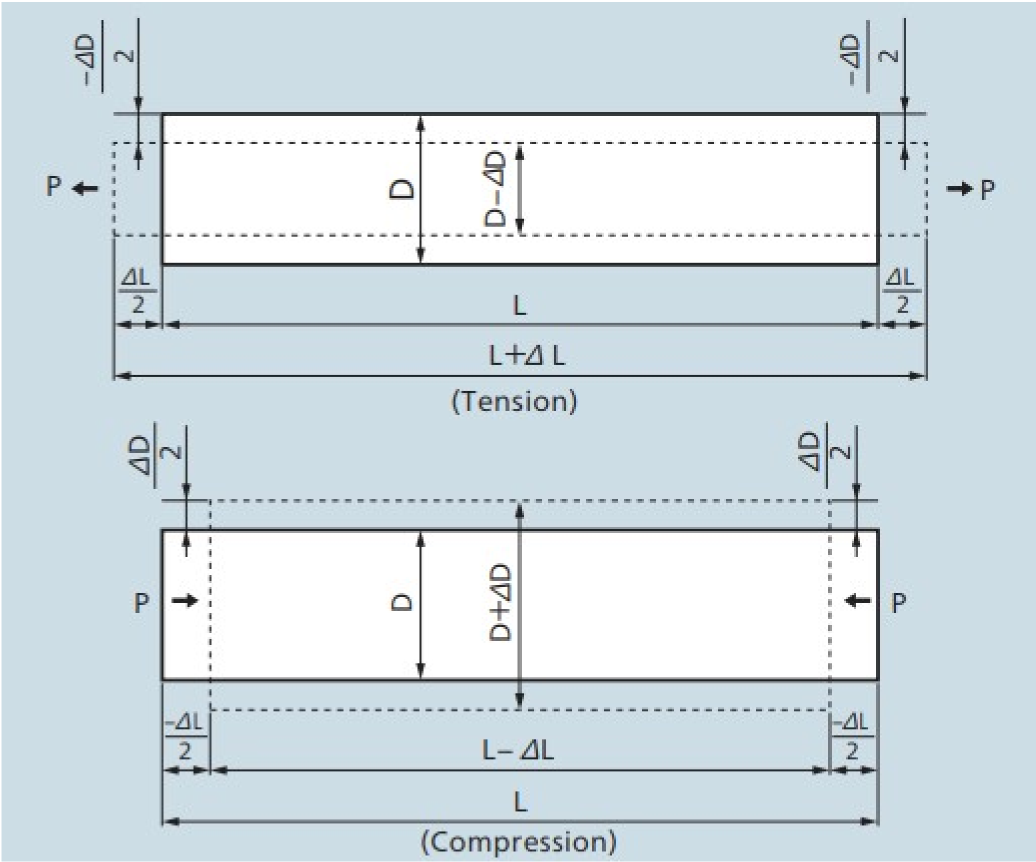


Fig.3.4 Tensile and compression strain.[10]

3.3 Strain Gages

A strain gage detects a minute dimensional change (strain) as an electric signal. By measuring strain with the gage bonded to a material or structure, the strength or safety will be known. Thus, the strain gage is used in various industries including machinery, automobile, electric, civil engineering, medical, and food.

The strain gage is also adopted as a sensing element of force, pressure, acceleration, vibration, displacement, and torque transducers used for various purposes including measurement and control of production lines.

$$R_0 = \rho \frac{L_0}{A_0} \qquad 3.5$$

$$R_1 = \rho \frac{L_1}{A_1}$$

$$\frac{\Delta R}{R_0} = \frac{R_1 - R_0}{R_0}$$

$$\frac{\Delta R}{R_0} = \frac{R_1}{R_0} - 1$$

$$\frac{\Delta R}{R_0} = \frac{\rho \frac{L_1}{A_1}}{\rho \frac{L_0}{A_0}} - 1$$

$\frac{\Delta R}{R_0} = \frac{L_1 A_0}{L_0 A_1} - 1$Dimensional effect

3.3.1 Structure of Strain Gages

There are many types of strain gages. Among them, a universal strain gage has a structure such that a grid-shaped sensing element of thin metallic resistive foil (3 to 6μm thick) is put on a base of thin plastic film (15 to 16μm thick) and is laminated with a thin film, as shown in figure3.5

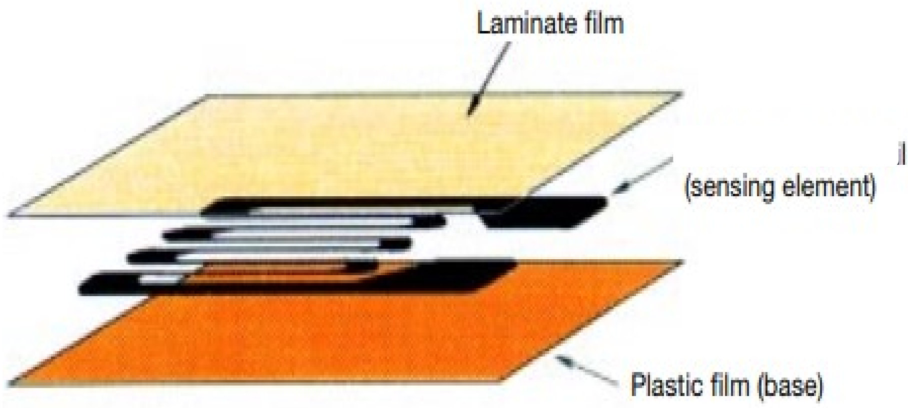


Fig.3.5 Strain gage structure. [9]

3.3.2 Principle of Strain Gages

The strain gage is tightly bonded to a measuring object so that the sensing element may elongate or contract according to the strain borne by the measuring object. When bearing mechanical elongation or contraction, most sensing element undergo a change in electric resistance. The strain gage applies this principle to strain measurement through the resistance change. Generally, the sensing element of the strain gage has a rate of resistance change proportional to strain with a certain constant.

Expressing the principle as follows:

$$\Delta R = \frac{K.\varepsilon}{R} \qquad \textbf{3.6}$$

where,

R: Original resistance of strain gage, Ω (ohm).

ΔR: Elongation- or contraction-initiated resistance change, Ω (ohm).

K: Proportional constant (called gage factor).

ε: Strain.

The gage factor K differs depending on the sensing element materials. A strain gage enables conversion of mechanical strain to a corresponding electrical resistance change. However, since strain is an invisible infinitesimal phenomenon, the resistance change caused by strain is extremely small.

3.4 FlexiForce Sensor

The FlexiForce sensor is an ultrathin and flexible printed circuit, which can be easily integrated into most applications. With its paper thin construction, flexibility and force measurement ability, the FlexiForce force sensor can measure force between almost any two surfaces and is durable enough to stand up to most environments. FlexiForce has better force sensing properties, linearity, hysteresis, drift, and temperature sensitivity than any other thin film force sensors. The sensors are constructed of two layers of substrate. This substrate is composed of polyester film (or Polyimide in the case of the High-Temperature Sensors). On each layer, a conductive material (silver) is applied, followed by a layer of pressure sensitive ink. Adhesive is then used to laminate the two layers of substrate together to form the sensor. The silver circle on top of the pressure sensitive ink defines the “active sensing area.” Silver extends from the sensing area to the connectors at the other end of the sensor, forming the conductive leads. The sensor acts as a variable resistor in an electrical circuit. When the sensor is unloaded, its resistance is very high (greater than 5 Mega ohm); when a force is applied to the sensor, the resistance decreases. Connecting an ohmmeter to the two pins of the sensor connector and applying a force to the sensing area can read the change in resistance. The FlexiForce sensor reads forces that are perpendicular to the sensor plane.[11]

3.4.1 Advantages of Using a FlexiForce Sensor vs. a Strain Gauge

Strain gages and FlexiForce sensors are1 resistance based technology available in a variety of shapes and sizes but FlexiForce sensor is:

1. Direct force measurement measures load directly as opposed to correlating strain of an assembly with load.
2. Larger dynamic range (resistance range from MΩ to KΩ).
3. Simpler Electronics simply measured with multimeter or integrated with inexpensive circuitry.
4. Lower cost, standard sensors are available off the shelf in packs of four and eight to satisfy limited budgets or low-volume requirements. High volume discounts are also available.
5. Easier to integrate and simple mounting process.

3.4.2 Comparison between force sensors

The 406 sensor as shown in figure 3.5 is chosen according to its suitable properties for this device, it has a suitable shape and square sensing area (43.69mm x 43.69mm) that covers target area of chest wall comparing with similar thin force sensors as A401 as illustrate in figure 3.6 it's sensing area (25.4 mm diameter) and A201 in figure 3.7 it's sensing area (9.53 mm diameter).

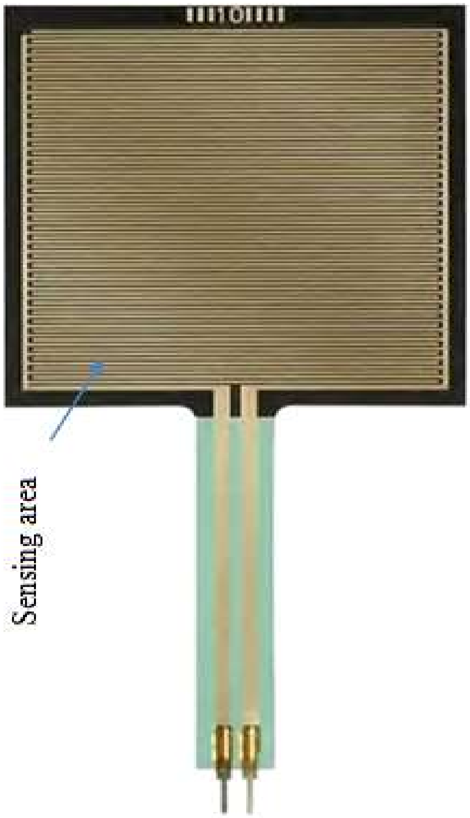


Fig3.6 FlexiForce Sensor 406 [11]

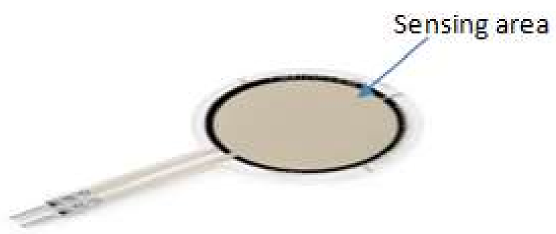


Fig3.7 FlexiForce Sensor A401 [11]

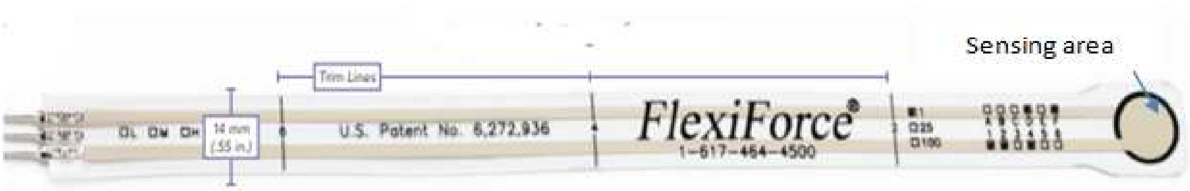


Fig3.7 FlexiForce Sensor A201[12]

3.4.3 Physical properties of 406 FlexiForce sensor

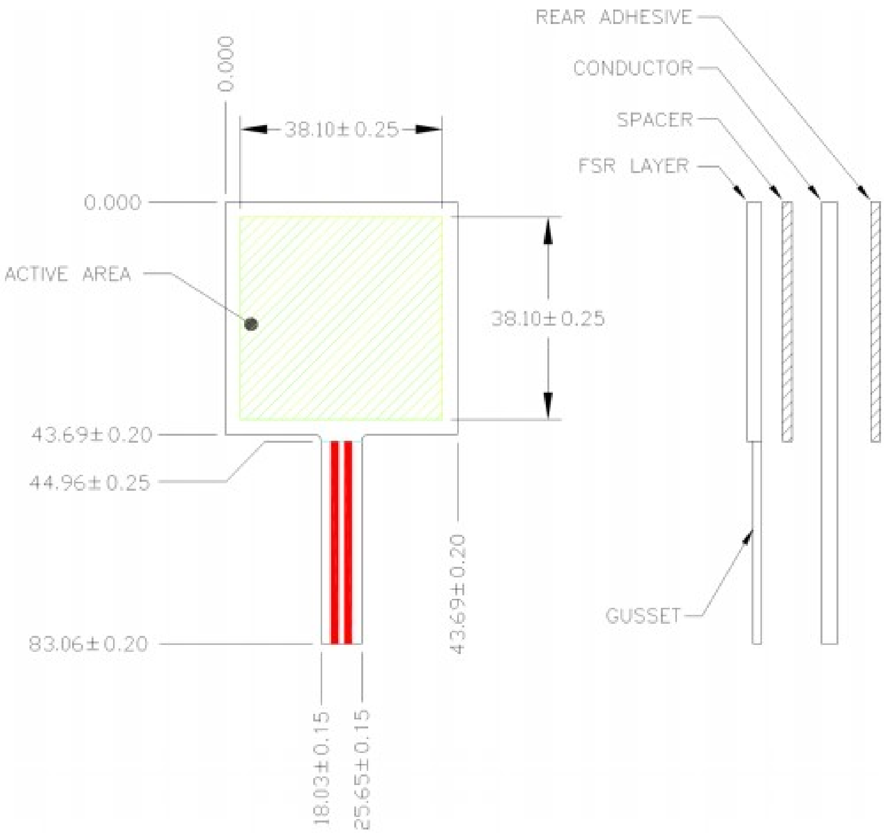


Fig.3.8 Part No. 406 **in Appendix A**

3.4.4 Typical performance of 406 FlexiForce sensor

1. Linearity (Error) < ±3% of full scale
2. Repeatability < ±2%
3. Hysteresis < 4.5 % of full scale
4. Drift < 5% per logarithmic time scale
5. Response Time < 5µsec
6. Operating Temperature -30°C to +70°C (-22°F - 185°F). **in Appendix A**

Chapter Four

Apnea Detection system Design

4.1 Apnea Detection System Block Diagram

In this chapter, a general process for designing the system is described. A system consulting of interconnected components is designed to achieve a desired purpose, a general block diagram of an embedded system is shown in figure (4.1)

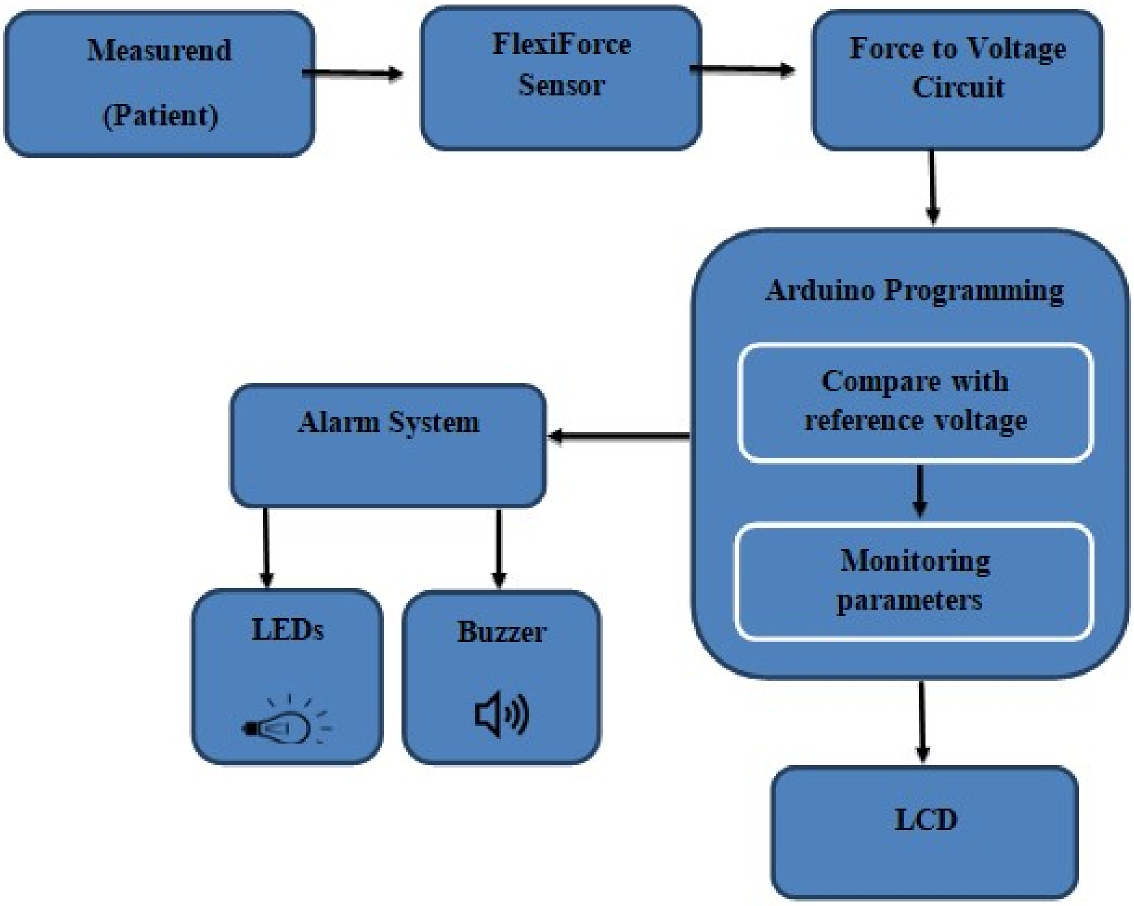


Fig.4.1 Block Diagram

4.2 Block Diagram Description

The goal of this project is to investigate an apnea detection system by designing and implementing a chest muscle signaling processing system. The following depicts how all components of the hardware system are connected to each other, including a Flexiforce sensor and an alarm output.

The alarm output is generated by a signal transfer through each hardware component, starting with the Flexiforce sensor and ending with the alarm system. When the apnea spell begins, the infant's chest movement changes that consequently changes that sensor deformation. The Flexiforce sensor then converts this change in movement to change in resistance and on to voltage.

This voltage quality is small so it will need amplification. This value of voltage will enter an Arduino device for comparing operations with a reference value to judge whether or not the infant is suffocating. If it is suffocating, the alarm will be triggered giving off sound and light and displaying the infant's health situation on an LCD screen.

4.3 Measurand

Monitoring respiration rate is an important task when evaluating a human's health and the method of measuring breathing is many. This project is depend on chest movement for detecting apnea spells using strap around infant's chest contains a Flexiforce sensor. Chest moving distance ranges from 1.5 cm to as much as 7 cm with deep inspiration.

Babies breathe much faster than older children and adults. A newborn's normal breathing rate is about 40 breaths each minute (Previously mentioned in chapter II).

4.4 FlexiForce Sensor

The FlexiForce sensor single element force sensor acts as a force sensing resistor in an electrical circuit. Force Range of the 406 FlexiForce sensor is available in a 0.1-10 N (0.022-2.24 lb) range. Force Range can be increased in custom sensors, Interlink Electronics have designed and manufactured sensors with operating force larger than 50Kg. When the force sensor is unloaded, its resistance is very high. When a force is applied to the sensor the output resistance decreasing, the resistance can be read by connecting a multimeter to the two sensor's pins then applying a force to the sensing area. The conductance for this sensor distinguishes that it has a linear relationship with the applied force Linearity (Error) $< \pm 3\%$ of full scale, see tables (4.1 and 4.2). [13]

Fig4.2 406 FlexiForce Sensor

Table 4.1 Force-Resistance Relation

Force(lbs)	Resistance(KΩ)
0.5	924.57
1	711.21
5	390.24
10	206.16
20	103.08
30	68.72
34	59.8
40	51.42

Note, 1lb=0.45kg **And**1lb=4.448N

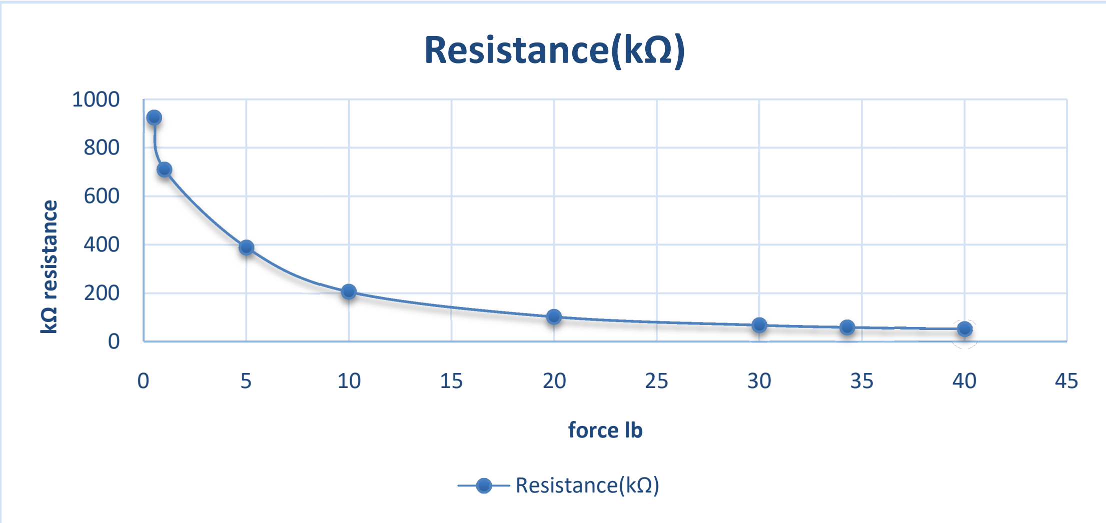


Fig 4.3 Force-Resistance Relatio

Table 4.2 Force-Conductance Relation

Force(lbs)	Conductance(μS)
0.5	1.08
1	1.41
5	2.56
10	4.85
20	9.70
30	14.55
34	16.72
40	19.45

Note, 1lb=0.45kg **And**1lb=4.448N

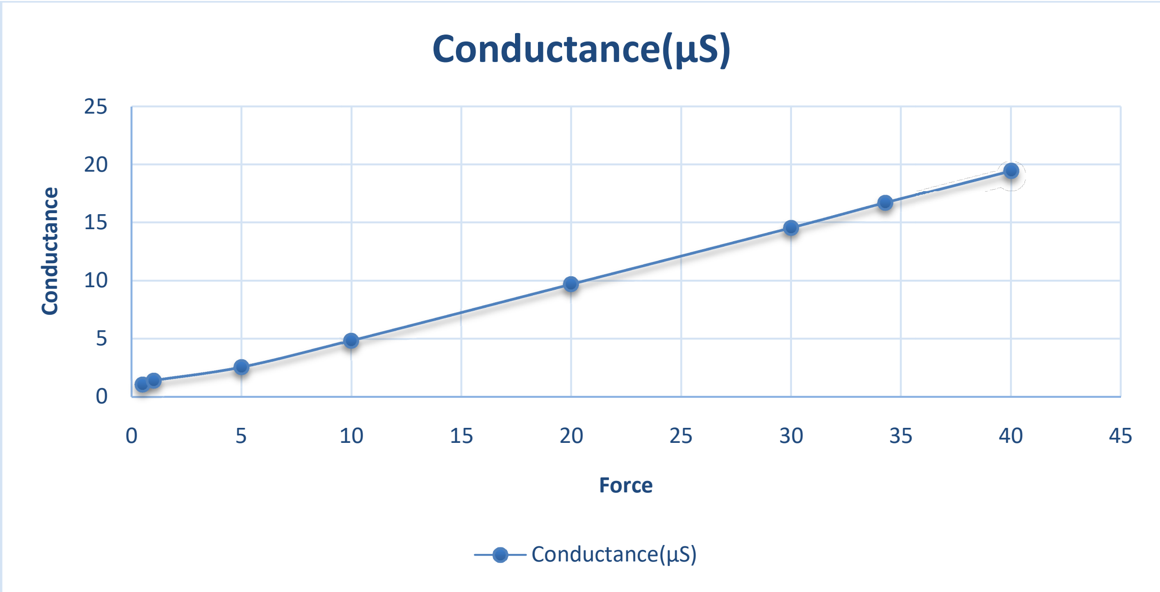


Fig 4.4 Force-Conductance Relation

4.5 Force to Voltage Circuit

According to the performance of the FlexiForce sensor and since it's a variable resistance that changes in accordance with input applied force. The force to voltage circuit it used to deal with force to another signal type which is voltage that easy to use, the circuit that shown in figure 4.2 contains of AD822AN op-amp, this amplifier is chosen because of its advantages, Rs is a FlexiForce sensor resistance. At first to amplify the output voltage from the sensor the maximum and suitable output voltage from the sensor will be calibrated at 5 DC voltage since it is a valid voltage input to the Arduino.

Since the output voltage is DC, a positive single supply op-amp is an appropriate choice. Also this eliminate the necessity to connect a negative supply voltage (-VCC) and reducing hardware component & cost.

AD822AN is chosen for its wide input voltage range (3-36 V) and a several acceptable features as power supply rejection ratio, common mode rejection ratio, Output Swings Rail to Rail, one of its application is medical instrumentation and other characteristics as illustrate in **Appendix B**.

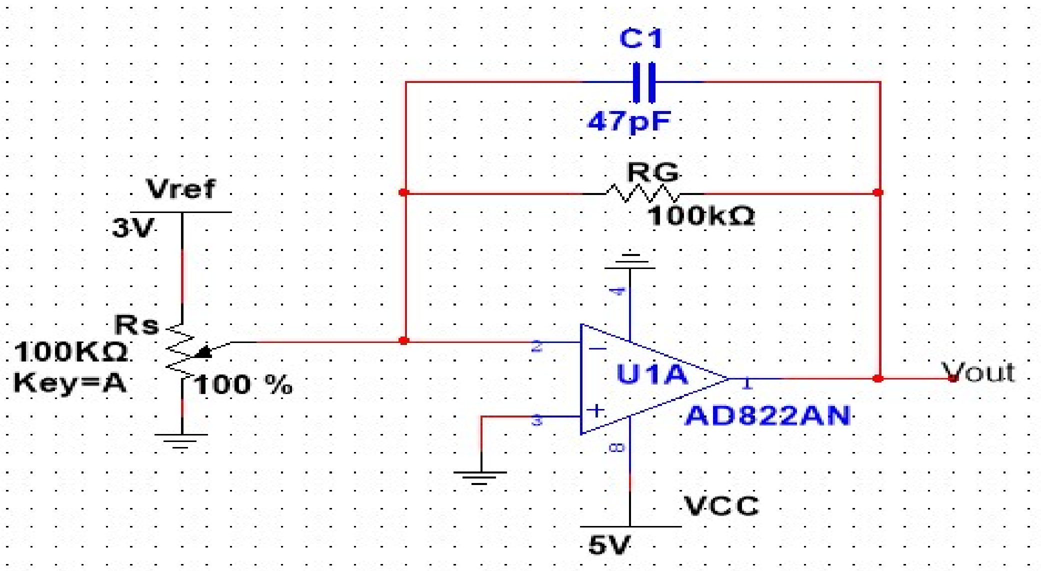


Fig 4.5 Force to Voltage Circuit

AD822AN was connected as inverting op-amp to produce more linear output voltage than non-inverting op-amp, to obtain 5 volt as maximum output voltage, feedback resistance should be adjusted as (RG= 100KΩ), see equation 4.1

To calibrate 5 output voltage at maximum load (34Ib) with an input of (-3 volt), the sensor resistance will reach approximately (60KΩ) as illustrate in table 4.1

<u>Calculation</u>

For inverting op-amp

$$Vout = -Vin * \frac{RG}{Rs} \qquad \textbf{4.1}$$

$$RG = Vout * \frac{RS}{-Vin}$$

$$RG = 5\,V * \frac{60K\Omega}{-(-3V)}$$

$$RG = 100K\Omega$$

Where Vin=-3 volt, RG= 100KΩ, and Rs as shown in table 4.1, the output voltage can be calculated, see table 4.3

Table 4.3 Force-Output Voltage Relation

Force(lbs)	Vout (volt)
0.5	0.324
1	0.423
5	0.768
10	1.455
20	2.910
30	4.365
34	4.981
40	5.835

Note, 1lb=0.45kg **And**1lb=4.448N

4.6 Microcontroller (Arduino)

Arduino is an open source electronics platform based on easy to use hardware and software. Arduino boards are able to read inputs, voltage, a finger on a button, or message, and compared values with reference value can programmed then monitoring parameters on serial monitor as illustrate in **Appendix C**

The Arduino Nano as illustrate in figure 4.6 can be powered via 9V regulated external power supply (pin 27). The power source is automatically selected to the highest voltage source, each of the 14 digital pins on the Nano can be used as an input or output. They operate at 5 volts.

Each pin can provide or receive a maximum of 40 mA and has an internal pull up resistor (disconnected by default) of (20-50) KOhms.

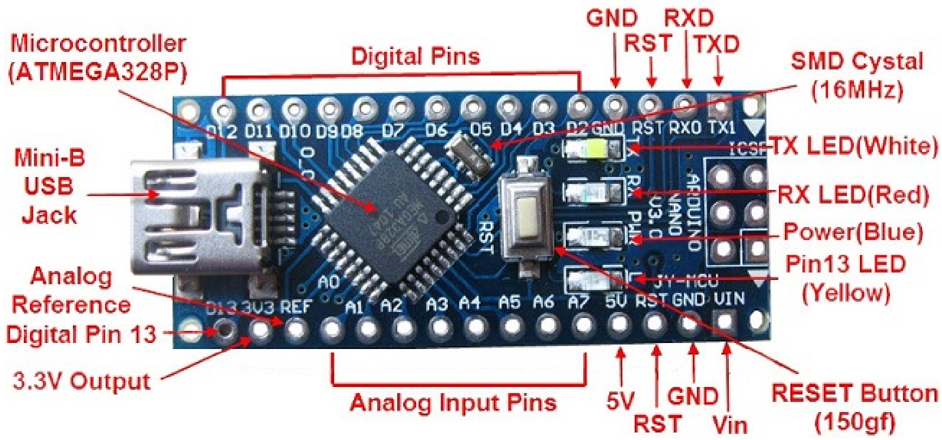
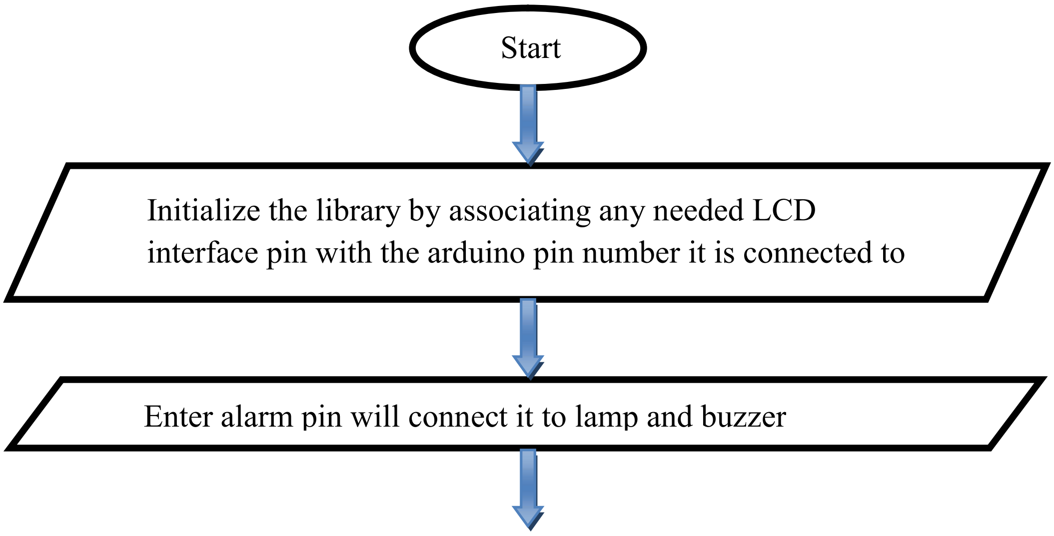
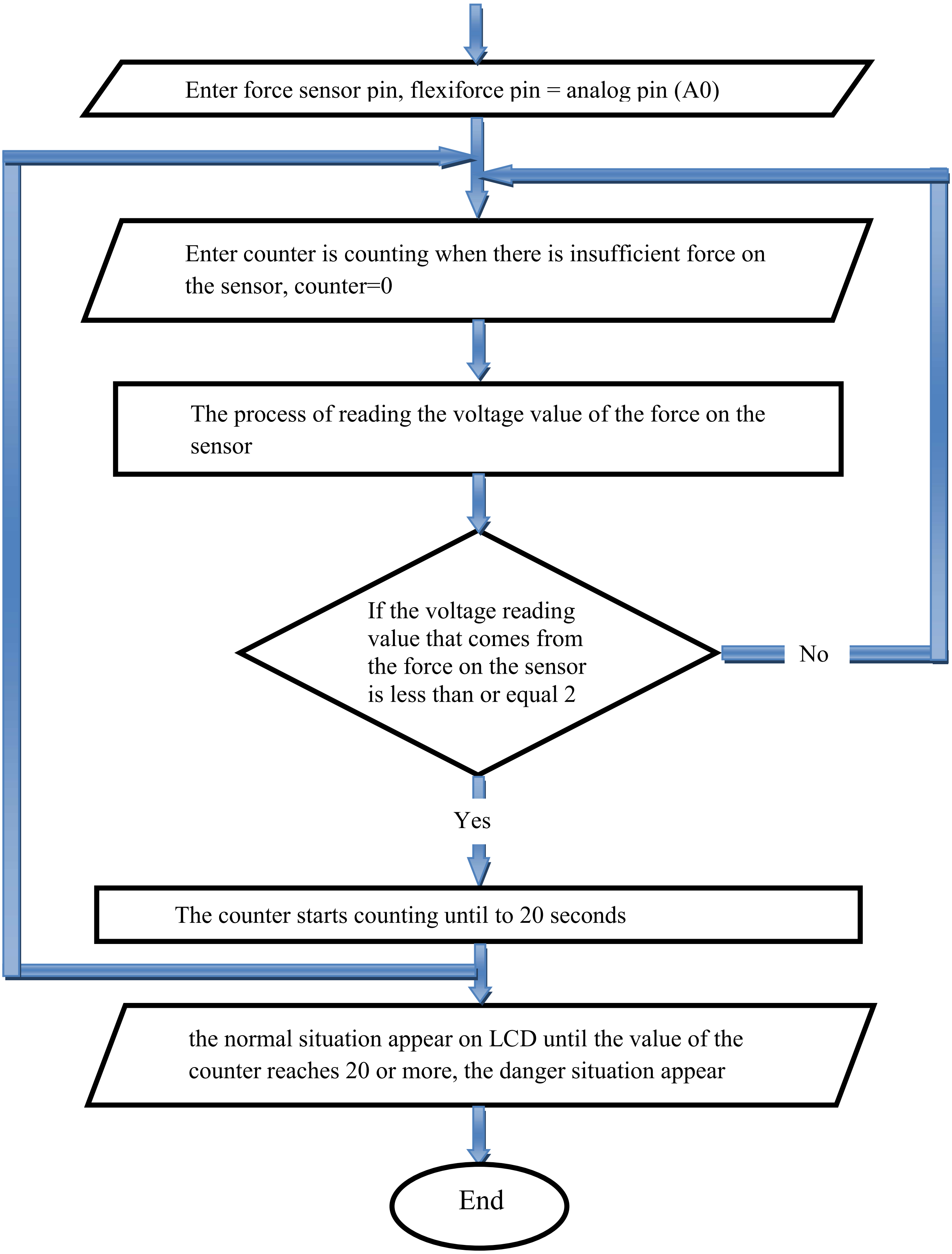


Fig4.6 Arduino Nano

After receiving the output voltage signal from the force to voltage circuit, this signal will inter the Arduino hardware to compare it with a reference voltage value. This value will define an approximate standard for infant breathing. If the input voltage is greater or equal to the reference voltage, a programming code will define this as a normal situation simultaneously showing status of this situation on the LCD display. But if the input voltage is less than the reference voltage the code will trigger an alarm system using a buzzer, LEDs lights and simultaneously showing the situation of the infants, if they are at risk or not, on the LCD . Furthermore the respiration rate will display on LCD.

4.6.1 Algorithm and Arduino programming steps




Enter force sensor pin, flexiforce pin = analog pin (A0)
Enter counter is counting when there is insufficient force on the sensor, counter=0
The process of reading the voltage value of the force on the sensor
If the voltage reading value that comes from the force on the sensor is less than or equal 2
No
Yes
The counter starts counting until to 20 seconds
the normal situation appear on LCD until the value of the counter reaches 20 or more, the danger situation appear
End

4.7 Alarm System

Alarms are intended to draw attention to a problem before it becomes harmful. Most stand-alone monitors can generate an alarm when a monitored variable crosses fixed or adjustable limits

Alarms with this design are used to warn people, especially doctors in hospitals, that an infant is experiencing an apnea spell requiring resuscitation from suffocation.

4.7.1 Buzzer

A buzzer or beeper is an audio signaling device, which may be mechanical, electromechanical, or piezoelectric. Typical uses of buzzers and beepers are as alarm devices. A buzzer is an integrated structure of electronic transducers, a DC power supply, widely used in computers, printers, copiers, alarms, electronic toys, automotive electronic equipment, telephones, timers and other electronic products needing sound devices. Here it is used when an infant had an apnea spell and is suffocating. In this situation the buzzer is chosen with the criteria of the sound not being too high and its voltage trigger must also be suitable for the output voltage Arduino hardware(see figure 4.7) a voltage is 5 volt DC. TMB12A05 Buzzer Datasheet **in Appendix D**

Fig 4.7 Active Buzzer 5V

4.7.2 LEDs

Light Emitting Diode is a very important metric of the conversion of electrical energy into emitted optical energy. LEDs produce more light per watt than incandescent bulbs; this is useful in battery powered or energy saving devices, LEDs can emit light of an intended color without the use of color filters that traditional lighting methods require. This is more efficient and can lower initial costs. LEDs can have a relatively long useful life. LEDs has a life time of about 50,000 hours, whereas Fluorescent tubes typically are rated at about 30,000 hours, and incandescent light bulbs at 1,000–2,000 hours. In this project two color used red for danger situation when the apnea happened and green color for normal situation. Figure 4.8 shows several LEDs.[14]

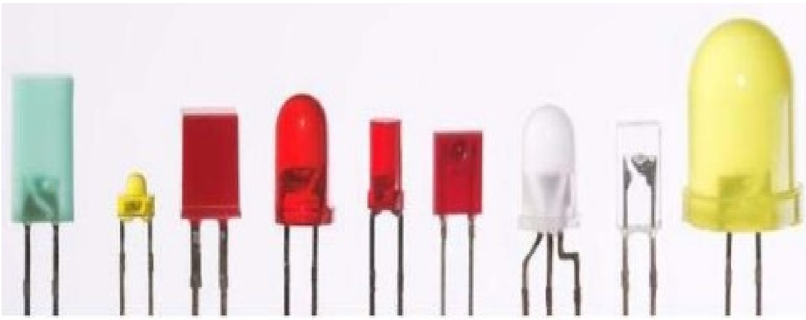


Fig.4.8 Types of LED[14]

4.8 Liquid Crystal Display

LCD screen is an electronic display module and had a wide range of application. MTC-s16204 LCD 16x2 display is very commonly used because of its features see figure 4.9, easy to interface of 4-bit or 8bit, power supply voltage range : 2.7 ~ 5.5 volt, low power consumption and more characteristic shown in **Appendix E.**

Fig4.9 16x2 LCD

4.9 Power Supply

Our project needs power supply to power up the hardware component because of the system is portable, a battery that has the following characteristics is required:

1. Has relatively long life
2. Provide needed power
3. Small and not heavy

The system intended to operate using rechargeable (9Volt) battery to power the Arduino and the other components its working power will take from Arduino because of Arduino can give 5 volt from each output, the AD822AN IC will supply from Arduino and that’s will reduce the hardware component and cost.

Chapter Five

Test and Implementation

5.1 Overview

Throughout this chapter the implementation working will discuss in both parts a strap and a box although the test for used sensor and the reference value that depended.

5.2 System Implementation

This implementation of this system for the project and its external design of two parts:

5.2.1 Strap

Is a first stage is near the patient's infant is a strap, that is placed around a patient's chest, fitted with a sensor to sensitivity the movement of the chest. The strap must has important properties, which it must be biocompatible with the body so we used antibacterial cloth type and comfortable, this cloth is put on the beds in hospitals. As it does not harm the patient, even if he sleeps for hours on end. Show in fig5.1 and fig5.2.

The circumference of the strap is customized according to the infant's circumference to suit it, the body of a normal newborn is essentially cylindrical; head circumference slightly exceeds that of the chest. For a term baby, the average circumference of the chest is 30–33 cm (12–13 inches).[15] And according to these data in table 5.1.

Table 5.1 Baby Size chest [16]

Baby's size	**cm**
3 months	40.5
6 months	43
12 months	45.5
18 months	48
24 months	50.5

Fig5.1 Implemented Strap

Fig5.2 The strap contains Flexiforce sensor.

5.2.2 Hardware Module

The second part of the project is a box contains conditional electrical circuit for processing data that comes from the strap, this data is a resistance signal converted from chest force on the sensor during breathing.

- **Box Designing**

The outer shape of this device is made a wooden box showing all the outputs on a front panel, the LED green if the device is working normally, 4-LEDs red and the buzzer if the case is detected of apnea . Finally, the LCD screen shows by writing in case of apnea or natural state.

From the side of the box there is an input to the wire coming from the first stage of this design is the flexiforce sensor to connected with its circuit, and the switch to control the closure and operation of the device. show in fig5.3.

Fig5.3 outer shape of a box.

From inside, the box contains the electrical circuit that consist of (Arduino nano, IC, Resistors, capacitors etc) as illustrate in figure 5.4.

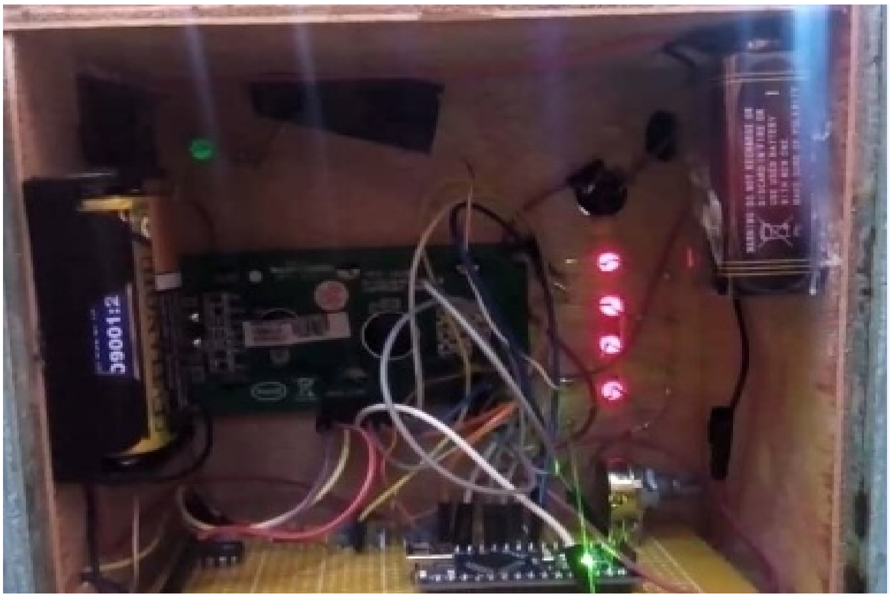


Fig 5.4 Box from inside

5.3 FlexiForce Sensor Test

At no load the sensor impedance measurement is described open loop "high impedance"

While applying device on infant in multiple areas of his body the impedance and output voltage as following table5.2, It has been observed that in the inhalation, the sensor is affected by a certain force and shows a change in resistance and then show a change in voltage and then return of the sensor to its natural state as if there is no effect in the exhalation. And it has been found that the back abdomen is the area that gives greater impact on the sensor.

Table5.2 Tested find an area that gives greater impact.

Area	Vout
Chest	1.492
Back abdomen	4.371
diaphragm	2.950

5.4 Reference Value Test

When the device was tested on newborn and infant, it was found that the voltage varies according to the strength of breathing for each person.

When doctors were asked about the state of apnea in newborns, they said that the state of apnea in newborn comes from incomplete brain growth cells. They do not feel it or give any breathing movement.

So when it was applied to newborns, apnea was sudden and sensor resistance became high impedance, show in fig5.4

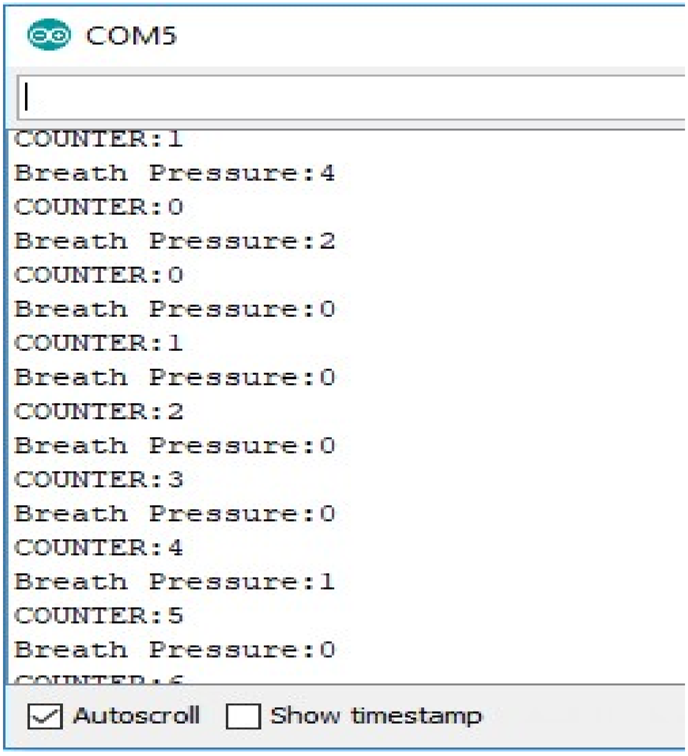


fig5.4 Test on newborn

when apnea occurs in infant, they try to breathe deeply at the beginning but the movement is few because of their inability to breathe and then gradually decrease movement until disappears forever show in fig5.5

Therefore the reference voltage value is set to be less than 2.

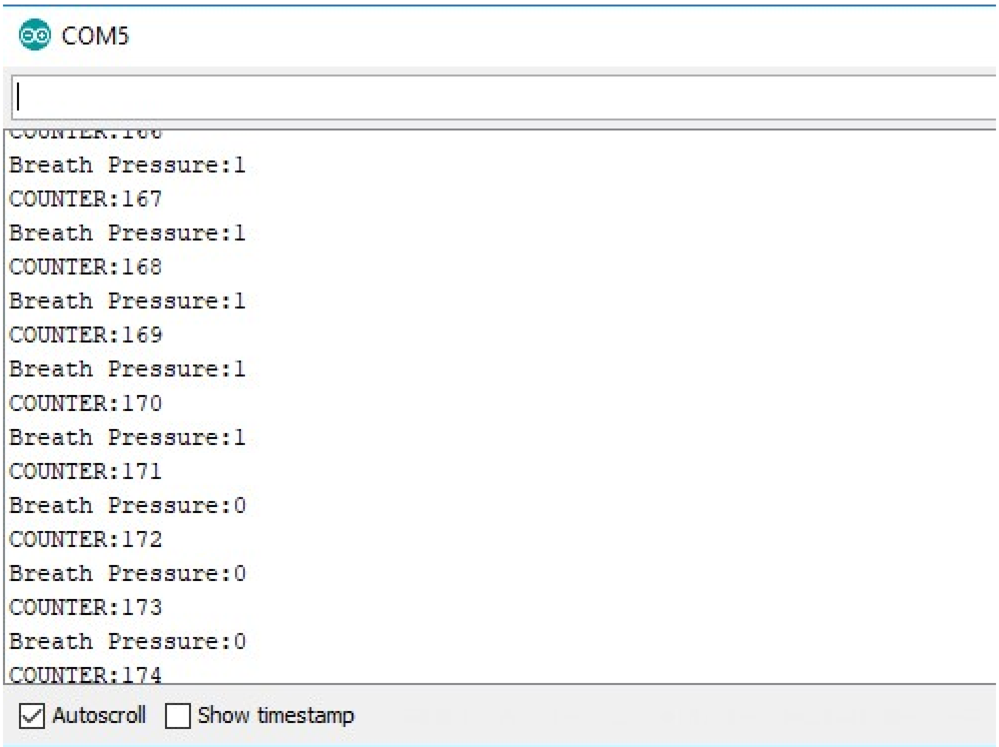


fig5.5 Tested on infant for to determine the reference Vref

Chapter Six

Result and conclusion

6.1 Overview

This chapter presents the results of apnea detection system and the conclusions of the project described in the document. The idea description and objectives of the research, outlined in chapter one, are reviewed. Then indicates extra suggestion for future work.

6.2 System Result

Project results are the changes or effects expected to take place after implementing the project. The results are generally positive improvements to the lives of the beneficiaries. At the end of the project period, the following results are expected to be achieved:

6.2.1 Normal Situation

This project contain two types of result for the patient, when the infant breathing good and no suffocation happen, the smart strap that contain the Flexiforce sensor detecting chest movement that makes circuit box giving an normal output, including green light and displaying (Normal Situation) on LCD screen, furthermore output voltage of input force pressing is displayed in range of (2 to 5) volt at normal situation for infant respiration. that's above reference voltage value, figure 6.1illustrate normal outcomes from apnea detection system.

The system output can be either followed on a serial monitor of the arduino program for monitoring the project parameters and signals, here the monitor observe the counter of breathing time, breath pressure in a voltage value and working time, the breath pressure mean the chest force applying on the Flexiforce sensor. Figure 6.2 shows background of the monitor in a normal infant situation.

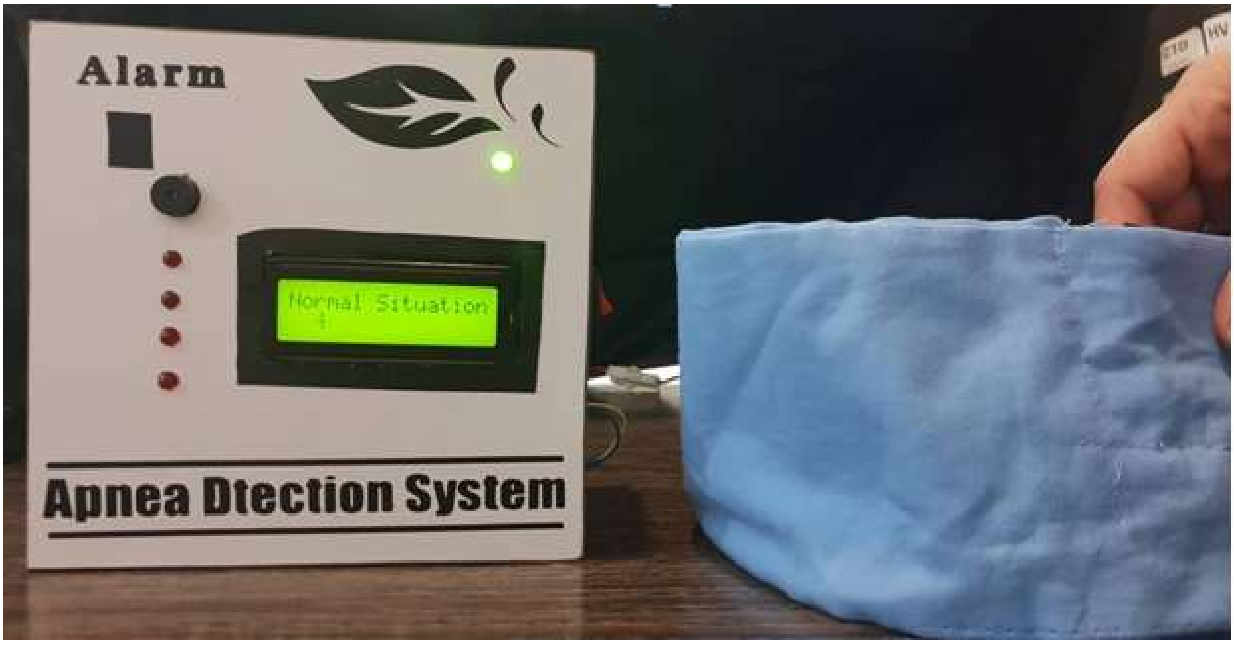


Fig6.1 Normal breathing situation

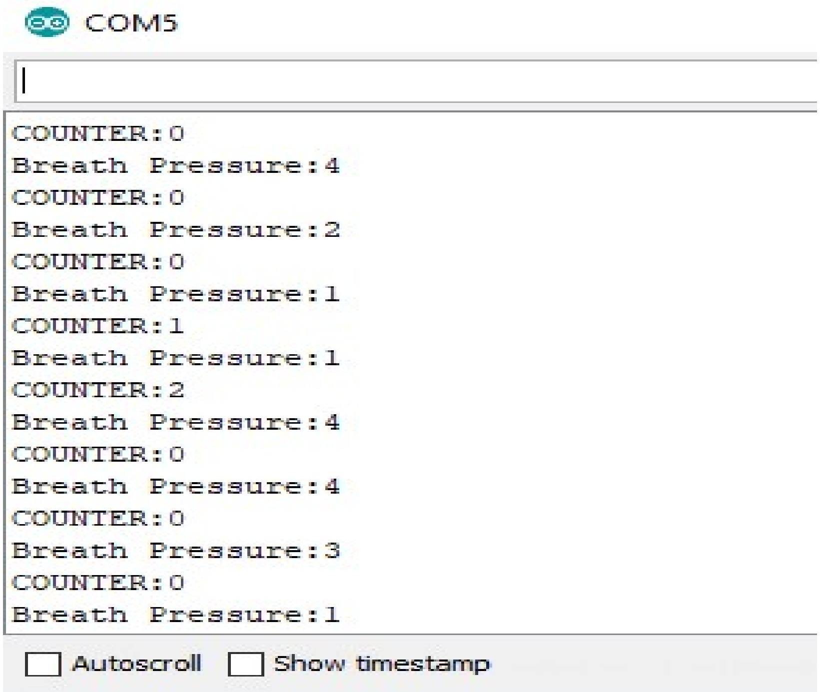


Fig 6.2 Serial monitor at normal situation

6.2.2 Danger Situation

The second type of result is when the apnea spell happen and infant suffocates, that's mean the chest muscles aren't moving, the sensor of the strap not detecting any deformation then the circuit box triggers alarm output include red lights, buzzer sound and displaying (Danger Situation) on LCD display, although voltage value at no movement of chest muscles at range of (0 to 2) volt that's mean less than the reference value. Figures 6.(3,4) shows the alarm outputs from apnea detection system.

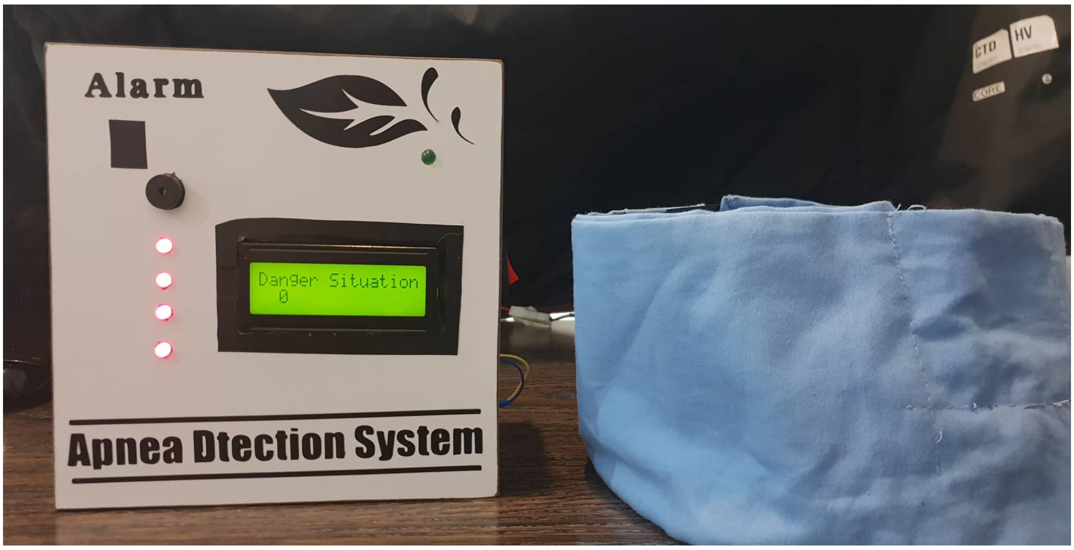


Fig.6.2 Danger breathing situation

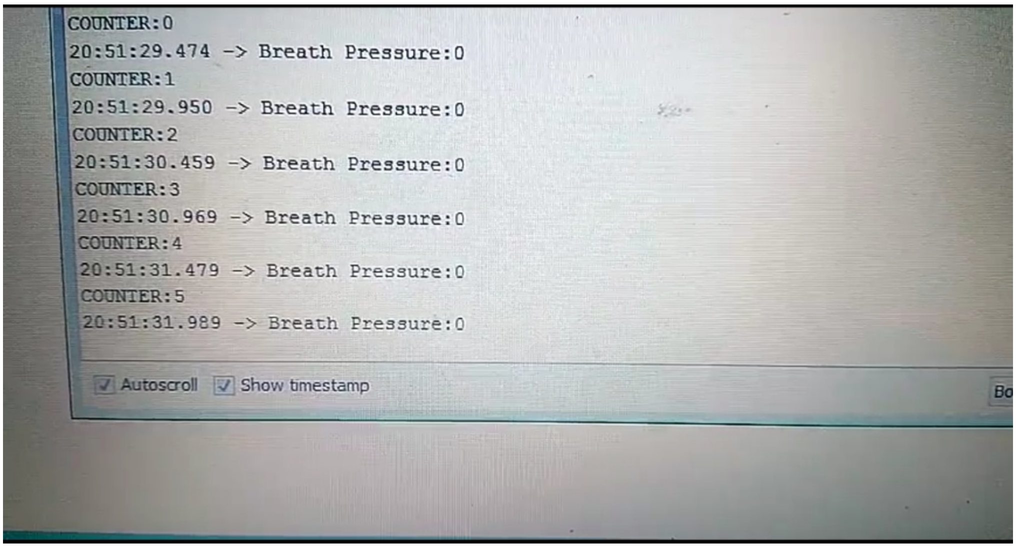


Fig 6.4 Serial monitor at danger situation

6.3 Conclusion

Our hypothesis was that through designing and implementing this project a system could be set up to detect apnea through a chest muscle signaling processing. Apnea is suspension of breathing. During apnea, there is no movement of the chest muscles during inhalation and exhalation. If left undetected, apnea can result in an increasing number of health problems and possibly lead to death. The breathing of an infant should monitored to ensure safety and health of the child. This project provided a more complete understanding of the physiological processes occurring during breathing. The results ultimately support our hypothesis and intended results, as the tests we conducted went smoothly and without problems. In preparation significant components of the device were collected in order to implement the apnea detection system starting with the smart strap and ending with the alarm system. The end result was that the alarm will be triggered when apnea spell like conditions occur, giving off sound and light and displaying the infant's health situation on an LCD. The objectives of the project are listed in chapter one, were all completed throughout out study. Furthermore, the results obtained through meeting these objectives are stated.

We conclude that we have the ability to detect and monitor apnea spells for infants in an easy and convenient way by designing a non-invasive portable smart strap and alarm system to warn people in case of an emergency situation, benefitting and protecting infants from suffocation and apnea complications.

6.4 Future Work

Interesting future studies might involve:

1. Sending SMS messages to the parents in order to provide information of the infant's situation
2. Developing another technical circuit to display more vital parameters on the LCD monitor.
3. Including a selection key for the reference value for various age groups, this is requires a Changing the construction and design: instead of customize the design for infants it could be for different age groups.
4. Changing the design to accommodate with rechargeable batteries.

6.5 Programming code

This project is programed using Arduino the code bellow is what we did

```
#include <Wire.h>+

// define LCD libariy

// include the library code:

#include <LiquidCrystal.h>

// initialize the library by associating any needed LCD interface pin

// with the arduino pin number it is connected to

const int rs = 11, en = 10, d4 = 4, d5 = 5, d6 = 6, d7 = 7;

LiquidCrystal lcd (rs, en, d4, d5, d6, d7);

// define Force sensor pin

int flexiForcePin = A0; //analog pin 0

// define alarm pin we can connect it to  lamp or  bazzer

int AlarmPen=9;

int Alarmb=2;

int Normal=3;


int c =0;


void setup()

{
```

```
  // set up the LCD's number of columns and rows:
  lcd.begin(16, 2);
lcd.setCursor(2,2);
pinMode(9,OUTPUT);
pinMode(2,OUTPUT);
pinMode(11,OUTPUT);
pinMode(10,OUTPUT);
pinMode(4,OUTPUT);
pinMode(5,OUTPUT);
pinMode(6,OUTPUT);
pinMode(7,OUTPUT);
pinMode(3,OUTPUT);
Serial.begin(9600);
}

void loop()
{

  int flexiForceReading =(5.0/1023)* analogRead(A0);

lcd.setCursor(2,2);
```

```
lcd.print(flexiForceReading );
Serial.print("COUNTER:");
Serial.println(c);
Serial.print("Breath Pressure:");
Serial.println(flexiForceReading);
digitalWrite(3,HIGH);
digitalWrite(9,LOW);
digitalWrite(2,LOW);
if (flexiForceReading<2)
  c++;
else if (flexiForceReading>2)
c=0;


if (c>=0 && c<19)
{
digitalWrite(3,HIGH);
digitalWrite(9,LOW);
digitalWrite(2,LOW);
lcd.setCursor(0,0);
lcd.print("Normal Situation");
}
```

```
else if (c>=20)
{
digitalWrite(3,LOW);
digitalWrite(AlarmPen,HIGH);
digitalWrite(Alarmb,HIGH);
lcd.setCursor(0,0);
lcd.print("Danger Situation");
}
delay(500);
    }
```

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