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School of Electrical and Computer Engineering

Ultrasonic Sensor Probe to Detect Early Signs of Lumbar Disk Herniation

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Declaration

I, the undersigned, declare that this thesis work is my original work, has not been presented for a degree in this or any other universities, and all sources of materials used for the thesis work have been fully acknowledged. It is a thesis submitted to School of Graduate Studies and Research in Partial Fulfillment of the requirement for the Master's Degree.

Name: Hanna Merid Signature: ______________________

Place: Addis Ababa, Ethiopia

Date of Submission: ___________________________

This thesis is submitted for examination with my approval as university advisor subject to the candidate incorporating the comments given by the advisor.

Advisor: Professor Mohammed Abdo Signature: ________________________

Acknowledgement

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Abstract

Medical imaging has advanced in remarkable ways since the discovery of X-rays 120 years ago. Today's radiologists can image the human body in intricate detail using computed tomography, magnetic resonance imaging, positron emission tomography, ultrasound, and various other modalities. Such technology allows for improved screening, diagnosis, and monitoring of disease, but it also comes with risks. Many imaging modalities expose patients to ionizing radiation, which potentially increases their risk of developing cancer in the future, and imaging may also be associated with possible allergic reactions or risks related to the use of intravenous contrast agents. In addition, the financial costs of imaging are taxing our health care system, and incidental findings can trigger anxiety and further testing.

In this thesis, the problem of lack of reachable alternatives for spinal imaging is addressed, to narrow the gap created between the potential victims of this disease and the imaging equipment which could only be accessed through a physician's order, and is expensive enough for people to dismiss their back pain and/or their neck pain.

Therefore another way to diagnose a lumbar disc herniation is required to make the best decisions when it comes to the better option a patient with a lower back pain comes along, which is, a makeshift Ultrasonic Sensor Probe (USP). This thesis depicts the overall design of the kit, which is an ensemble of a sensor, a microprocessor and the other components incased in one, simulation models of the components included in the probe, and the necessary methodologies used to make the modelling of the filters.

Table of Contents

List of Figures

List of Tables

Definitions, Abbreviations and Acronyms

The following table defines the acronyms and abbreviations used in this document

Term	**Definition**
SCI	Spinal cord Injury
LDH	Lumbar Disc Herniation
CT	Computed Tomography
MRI	Magnetic Resonance Imaging
USP	Ultrasonic Sensor Probe
SIMULINK	Matlab Platform
US	Ultrasonic Sensor
IC	Integrated Circuit
BPF	Band Pass Filter
PCB	Printed Circuit Board

Chapter 1

Introduction

Spinal disc herniation is an injury to the cushioning and connective tissue between vertebrae, usually caused by excessive strain or trauma to the spine. It may result in back pain, pain or sensation in different parts of the body, and physical disability. The most conclusive diagnostic tool for disc herniation is MRI, and treatment may range from painkillers to surgery. Typically, symptoms are experienced on one side of the body only [1]. Moreover, symptoms of a herniated disc can vary depending on the location of the herniation and the types of soft tissue involved. They can range from little or no pain, if the disc is the only tissue injured, to severe and unrelenting neck pain or low back pain that radiates into regions served by nerve roots which have been irritated or impinged by the herniated material. Often, herniated discs are not diagnosed immediately, as patients present with undefined pains in the thighs, knees, or feet [2].

The majority of spinal disc herniations occur in the lumbar spine (95% at L4–L5 or L5–S1). The second most common site is the cervical region (C5–C6, C6–C7). The thoracic region accounts for only 1–2% of cases. Lumbar disc herniations occur in the back, most often between the fourth and fifth lumbar vertebral bodies or between the fifth and the base of the spine. A herniation in the lumbar region often compresses the nerve root exiting at the level below the disc. Thus, a herniation of the L4–5 disc compresses the L5 nerve root [3].

Between 60% and 80% of people will experience lower back pain at some point their lives. Some of these people will have low back pain and leg pain caused by a herniated disk. Although a herniated disk can be very painful, most people feel much better with just a few weeks or months of nonsurgical treatment [4].

Diagnosis of spinal disc herniation is made by a practitioner on the basis of a patient's history and symptoms, and by physical examination. During an evaluation, tests may be performed to confirm or rule out other possible causes with similar symptoms. One of those examination techniques is spinal imaging. Although spinal imaging may be the most acceptable method so far, the availability and cost effectiveness of it can be easily arguable. Therefore an alternative method to detect and catch the early signs of spinal disc herniation is in need.

In this thesis, the problem of lack of reachable alternatives for spinal imaging is addressed, to narrow the gap created between the potential victims of this disease and the imaging equipment which could only be accessed through a physician's order, and is expensive enough for people to dismiss their back pain and/or their neck pain.

Therefore another way to diagnose a lumbar disc herniation is required to make the best decisions when it comes to the better option a patient with a lower back pain comes along, which is, a makeshift Ultrasonic Sensor Probe (USP). This thesis depicts the overall design of the kit, which is an ensemble of the sensor, the microprocessor and the other components incased in one, simulation models of the components included in the probe, and the necessary methodologies used to make the modelling of the filters etc.

1.1 Objectives

1.1.1 General Objective

- The general objective of this research is to design and Simulate an Ultrasonic Sensor Probe to detect early signs of Lumbar Disk Herniation

1.1.2 Specific Objectives

- Design a model for simulating the interaction of the sensors with the processors on Proteus

- To simulate the Ultrasonic Probe on Proteus and Matlab

- To simulate a relevant sensing environment for the system to be realistic enough to be applied in the real world

- To interpret the data collected during simulation and make a valid outcome in the form of a length measurement

- To analyze the output and draw conclusions based on it

1.2 Motivation

The main motivation behind this thesis work is the unfamiliarity of Lumbar Disc Herniation to the society and that it is a serious danger to health, yet not addressed in any significant way. This problem leads to having to go through harsh medical procedures, which may or may not be a cure or a fix because the damage is too severe that there is nothing to be done. This could have been prevented or could be caught early to take the less invasive approach to undo the damage that has been done to the spinal cord.

This thesis directly addresses this problem by narrowing the gap between the hospital, where all of the imaging equipment is located, and the patient who is unaware of the underlying problem in the first place. The targets of Lumbar Disc Herniation (LDH) are mainly people whose livelihoods depend on physical labor and jobs that require lifting and pulling heavy objects. This aggressive action is the major cause for LDH, but the people are unaware of it all along. If they do end up being informed of their problem, they are not willing to make the financial sacrifice to go to the doctor, get diagnosed properly and get their spinal cords checked under any medical imaging equipment. So, to alleviate this problem, a new approach has been introduced in this thesis, that is ruling out LDH out of all the symptoms of back-pain without having to go to the doctor's and no commitment financially.

1.3 Problem Statement

The problem of spinal disc herniation is not very known to major parts of society in Ethiopia. But it is a very real problem that affects many people who are unaware of the origins of their lower back pain. If these people were informed of the hazards and the simple solutions to this issue, they wouldn’t be so hesitant to seek help from physicians and get treated early on. Because more than 60 percent of the Lumbar Disc Herniation (LDH) cases are caused after adolescent age, and if caught on time could be treated in a non-invasive method without having to go under the knife.

The trend so far is for potential patients to experience a lower back pain and not reporting it or consult a physician about it because they don’t know that those symptoms are. This leads to the LDH worsening and their health at a higher risk because of it and by the time they realize that the symptoms are from a serious case, it is already too late for it to be fixed with just physical therapy or simple procedures. Therefore they will end up going under the knife for something that could have been prevented earlier. Addressing the underrated problem of spinal cord disk herniation will benefit people whose daily routines involve lifting heavy objects or bending over repeatedly or any activity that involves a heavy risk of lumbar disk herniation.

In this research, the effects of an Ultrasonic Sensor Probe applied to the spinal cord vertebrae for detecting the early signs of Disk Herniation will be simulated. This simulation mimics the real-life approach to the problem, as it is an ensemble of medical gadgets into one kit, that contains the sensor, processor and output or display, which is convenient for the user. The sensing environment of the system is also simulated in this thesis as fulfillment of the entire system so that it is more reliable. This makes the structure more realistic and represents the best approach to the problem of lumbar disc herniation.

1.4 Scope of the Thesis

The scope of this thesis is focused on the pre-diagnosis part of Lumbar Disc Herniation in the spinal cord of an average adult. It should be known that this medical kit is not meant to be used in a professional setting that it is able to produce accurate diagnostic data about LDH. Rather it is used in ruling out the primary problem of LDH in a day to day environment so that people that feel lower back pain don’t overlook the problem, and have a chance to at least rule out LDH among the many possible outcomes of symptoms of lower back pain. Therefore the scope of this thesis is limited to Pre-diagnosing and ruling out, than giving out accurate medical data to be used in the medical history of the patient.

1.5 Literature Review

There is no particular measurement for a lumbar herniated disc that would indicate the best treatment. Instead, physicians determine the best course of treatment by looking at the patient's clinical situation, including factors such as the amount of pain a patient has, the amount of disability, and the duration of the patient's symptoms [5]. The solution suggested in this thesis is a direct indication that finding other ways to get measurements for LDH is important in diagnosing and suggesting the best course of treatment for the patient.

A disc herniation or bulge is usually only clinically significant if it is pinching a nerve root. It matters more where the disc is herniated (e.g. midline disc herniation rarely pinches a nerve root) and how big the person's spinal canal is. If the canal is small, even a small disc herniation may pinch a nerve root. If the canal is large, even a sizable disc herniation may not cause any symptoms. [6]

Lumbar herniated discs commonly occur in patients 20-40 years of age, and result in acute symptoms of shooting and intractable pain in the low back and/or lower extremities. However, the prognosis of these patients is considered to be very good [5]. Moreover, 70% of these patients have been reported to be free from sciatica, a pain radiating along the sciatic nerve, at approximately 6 months after the first onset [7]. Magnetic resonance imaging (MRI) studies have described the spontaneous resorption process of herniated discs, which is a major cause of the reduction of symptoms in patients. New advancements in MRI have recently been developed that have facilitated the examination of nerve tract fibers and identification of symptomatic nerve tissue [8]-[10].

In the majority of cases, spinal disc herniation doesn't require surgery. A study on sciatica, which can be caused by spinal disc herniation, found that "after 12 weeks, 73% of people showed reasonable to major improvement without surgery."[11] The study, however, did not determine the number of individuals in the group that had sciatica caused by disc herniation. Non-surgical methods of treatment are usually attempted first, leaving surgery as the last resort [12]. Pain medications are often prescribed as the first attempt to alleviate the acute pain and allow the patient to begin exercising and stretching.

There are a variety of other non-surgical methods used in attempts to relieve the condition after it has occurred, often in combination with pain killers [13]-[14].

In [15], a study shows that the accuracy of computed tomography scans are essential in determining if the diagnosis of any spinal injury is accurate or not. It mentions that the Ultrasound-determined diameter measurements are more accurate than axial computed tomography (CT) measurements.

The Ultrasonic Probe, which is the subject of this thesis, is inspired by the medical ultrasound used in everyday diagnosis at the hospitals. The creation of an image from sound in a medical ultrasound probe is done in three steps: producing a sound wave, receiving echoes, and interpreting those echoes. A sound wave is typically produced by a piezoelectric transducer encased in a plastic housing. Strong, short electrical pulses from the ultrasound machine drive the transducer at the desired frequency. The frequencies can be anywhere between 1 and 18 MHz. Materials on the face of the transducer enable the sound to be transmitted efficiently into the body (often a rubbery coating, a form of impedance matching). In addition, a water-based gel is placed between the patient's skin and the probe [16]. This gel is used to prevent skin irritation caused by the vibration generated from the probe. It is due to the high frequency signal within the probe that affects the skin tissue and causes irritation and redness.

The return of the sound wave to the transducer results in the same process as sending the sound wave, except in reverse. The returned sound wave vibrates the transducer and the transducer turns the vibrations into electrical pulses that travel to the ultrasonic scanner where they are processed and transformed into a digital image [17].

As mentioned previously, the frequencies used for medical imaging are generally in the range of 1 to 18 MHz. Higher frequencies have a correspondingly smaller wavelength, and can be used to make sonograms with smaller details. However, the attenuation of the sound wave is increased at higher frequencies, so in order to have better penetration of deeper tissues, a lower frequency (3–5 MHz) is used [18]. Seeing deep into the body with sonography is very difficult. Some acoustic energy is lost every time an echo is formed, but most of it (approximately 0.5 dB per (cm depth MHz)) is lost from acoustic absorption.

1.6 Thesis Outline

In this research is included the simulation of the working principle of the Ultrasonic Sensor Probe (USP) to detect early signs of Lumbar Disc Herniation. It can be seen in two major parts, that is, the sensing environment for the probe and the measuring mechanism of the USP as it would be used in the hardware design. This thesis is outlined as follows.

Chapter one will have a brief introduction about the different medical imaging devices and how they work, as well as the differentiation between each of them. It also includes literature review concerning this pre-diagnostic device, with regards to other publications, articles, and research done in this field. The problem is stated clearly in this document along with why this area of study is chosen for this research, and the motivation behind raising an issue that is not known widely among the public especially in Ethiopia.

Chapter two includes some background information regarding this thesis. It includes some principles regarding common medical imaging devices and how they could be advantageous to the diagnosis of different medical conditions. Their disadvantages are also depicted under this chapter, which can be addressed within this thesis as a guideline in narrowing the gaps in medical imaging devices in recent times.

Chapter three is about the simulation procedures, modellings and the different approaches mentioned in this thesis to grasp the idea of what it would consist of if it was to be used in real life scenarios. This is a very crucial step, because if the system is not realistic, there wouldn't be a need to develop the idea in the first place as it is an outcome-based system. That is, if there is no feasible outcome, then the thesis would render invalid. The analysis in this thesis is also done in way it is easily understandable, hence making it simple to implement into the real world.

Chapter four of this thesis talks about the implementation of the methods mentioned in chapter three to realize the system in a more realistic way. That way the solution can be applied in real life, to be used by customers, solving real problems. This section is useful in understanding the engineering part of this thesis as it goes in depth in the design approaches and assumptions used in the methodologies part.

Chapter five is the section which includes the results found using the methodologies and implementation techniques discussed in chapters three and four. The result section is the data collection section of this thesis which is the output of the system depicted. It shows the outputs from the frequency filter and the piezoelectric effect, which is the model of the sensing environment. Discussions regarding the results obtained are also mentioned in this chapter.

Final, chapter six includes the conclusion of this thesis as well as recommendations for this thesis to better the output and many aspects of it later on. It contains what could be done in the future, and the shortcomings of this thesis as is.

Chapter 2

Background and Basics of Imaging Principles

Medical Imaging is the use of imaging modalities and processes to get pictures of the human body, which can assist diagnosis and treatment of patients. It can also be used to track any ongoing issues, and can therefore help with treatment plans. There are many different types of medical imaging techniques, which use different technologies to produce images for different purposes. Measurement and recording techniques that are not primarily designed to produce images, such as electroencephalography (EEG), magnetoencephalography (MEG), electrocardiography (ECG), and others, represent other technologies that produce data susceptible to representation as a parameter graph vs. time or maps that contain data about the measurement locations. In a limited comparison, these technologies can be considered forms of medical imaging in another discipline [22].

The origin of medical images is around the start of the 20th century, after the discovery of the x-ray. This started a growing interest in radiology, but it took off during the Second World War. Medical imaging initially started with x-rays that would be passed through the body onto some film, which would generate an image. They could take up to 11 minutes, and would subject the patient to 50 times more radiation than an x-ray today, which takes just milliseconds [23].

There were lots of improvements to this initial technique over the first half of the 20th century, but in the 1960s came ultrasound scanning. The development of sonar during World War II allowed this to become a reality, it works by sending a stream of high frequency, low wavelength sound waves to penetrate through the body and hit the organs inside, bouncing back to the detector. This can be used to generate an image under the skin, and also does not subject the body to harmful X-rays, and so is used for pregnant women [22].

Another big step was in the 1970s, when digital imaging techniques, such as the computed tomography scanner, more commonly known as the CT scanner, became widely available. After these new imaging techniques became more common, doctors realized they needed ways of analyzing these images in order to maximize the benefits of using them. This led to discoveries of new methods of medical image analysis [23].

It was in the 1960s that computer-based image analysis started to appear, meaning that it has been around for nearly 60 years. However, there have been many advances since they were first introduced, especially with the introduction of digitalization in the 1970s.

Medical images are not simple to understand, as they contain a lot of information, and therefore the idea of using computers to analyze them became apparent. There are many types of medical image, for example CT and magnetic resonance imaging (MRI), to more cutting edge types such as optical coherence tomography and magnetoencephalography (MEG), and they all produce differing images that need to be analyzed differently [23].

Spinal imaging plays a critical role in the diagnosis, treatment, and rehabilitation of SCI (Spinal Cord Injury) patients. In recent years there has been an increasing interest in the development of advanced imaging techniques to provide pertinent microstructural and metabolic information that is not provided by conventional modalities. Traditionally, these modalities have consisted of plain radiography (*Fig 2.1.*), computed tomography (CT) (*Fig 2.2.*), and magnetic resonance imaging (MRI) (*Fig 2.3.*). In combination, these techniques provide excellent macrostructural information regarding the classification and magnitude of the bone and ligamentous injury, which, coupled with the clinical examination, guides patient management [16]-[17].

2.1 Plain Radiography

Radiographic spine series typically include frontal and lateral radiographs of the cervical, thoracic, or lumbar region. Additional oblique radiographs may be added depending on the clinical indication.

Fig 2.1. : Plain Radiography of a 17 year old gentleman who noted upper extremity weakness after a fall

Plain radiographs have limited utility as a primary imaging tool in the evaluation of spinal cord but may demonstrate indirect evidence of underlying cord abnormalities and prompt performance of additional cross-sectional imaging [18]. Although some studies have concluded that CT should be the initial study in acute trauma screening [15], radiography continues to be the mainstay for screening patients with trauma [19].

2.2 Computed Tomography (CT)

A CT scan or computed tomography scan makes use of computer-processed combinations of many X-ray measurements taken from different angles to produce cross-sectional (tomographic) images or virtual "slices" of specific areas of a scanned object, allowing the user to see inside the object without cutting [20]. Like plain and contrast radiology, CT plays a limited role in direct spinal cord imaging.

However, CT has the advantages of speed, availability, improved contrast resolution compared with radiography, limited operator independence, and the capability for three-dimensional reformations.

It provides superior sensitivity and specificity in delineating bony irregularities compared with other modalities and can indicate the need for additional spinal cord imaging [21].

Fig 2.2.: A CT scan of the case mentioned in the figure above

2.3 Magnetic Resonance Imaging (MRI)

Magnetic resonance imaging (MRI) is a medical imaging technique used in radiology to form pictures of the anatomy and the physiological processes of the body. While the hazards of X-rays are now well controlled in most medical contexts, an MRI scan may still be seen as a better choice than a CT scan. MRI is widely used in hospitals and clinics for medical diagnosis, staging of disease and follow-up without exposing the body to radiation. MRI is in general a safe technique, although injuries may occur as a result of failed safety procedures or human error.

But still, since MRI does not use any ionizing radiation, its use is generally favored in preference to CT when either modality could yield the same information.

Fig 2.3.: An MRI scan showed a traumatic disc herniation on the C5-C6 area

Although the above paragraphs mentioned some of the ways to acquire a usable data from the spinal cord to detect not only LDH but other spinal injuries as well, it is also well depicted that they require a certain type of imaging mechanism. This gives way for a possibility to be exposed to radiation and may prompt the patient to undergo discomfort during imaging. Not to mention the cost to have those images taken are very high.

Chapter 3

Methodology

3.1. Background

Medical imaging is often perceived to designate the set of techniques that noninvasively produce images of the internal aspect of the body. The term "noninvasive" is used to denote a procedure where no instrument is introduced into a patient's body, which is the case for most imaging techniques used. In this restricted sense, medical imaging can be seen as the solution of mathematical inverse problems. This means that cause (the properties of living tissue) is inferred from effect (the observed signal). In the case of medical ultrasonography, commonly known as an ultrasound, the probe consists of ultrasonic pressure waves and echoes that go inside the tissue to show the internal structure. In the case of projection radiography, which is a type of medical imaging, the probe uses X-ray radiation, which is absorbed at different rates by different tissue types such as bone, muscle, and fat.

The piezoelectric effect of the system is demonstrated as a pre amplifier circuit and the dual operational amplifier is modelled separately in a subsystem in SIMULINK. The piezoelectric effect, is a model of the sensing environment of the sensor, and it is the equivalent of the sound producing transducer in the medical ultrasound probe. Ultrasonography (sonography) uses a probe containing multiple acoustic transducers to send pulses of sound into a material. Whenever a sound wave encounters a material with a different density (acoustical impedance), part of the sound wave is reflected back to the probe and is detected as an echo. The time it takes for the echo to travel back to the probe is measured and used to calculate the depth of the tissue interface causing the echo. The greater the difference between acoustic impedances, the larger the echo is. If the pulse hits gases or solids, the density difference is so great that most of the acoustic energy is reflected and it becomes impossible to see deeper [22].

Although it is the trend to use medical imaging during diagnosis, it is not easily available to potential patients so that they could rule out their lower back pain as not a Lumbar Disc Herniation. This is because these imaging devices are used upon prescription from a physician and when it is absolutely needed for medical history of a patient. Potential candidates are not included in this case, leaving them in a situation that they could not have their spine examined unless they develop severe symptoms of disc herniation.

Due to the above reasons and many more, an alternate is given in this project. This research mainly focuses on the simulation of the effect of the ultrasonic sensor probe (USP) on the determination of the measurement of the herniated disc. This is represented by the piezoelectric effect; the sensor used in this system is an ultrasonic sensor. The piezo electric effect is simulated in SIMULINK whereas the ultrasound and processing of the length measurement algorithm are simulated in Proteus. The design itself is limited by the fact that the sensor used is an ultrasonic sensor, because for the kit to be non-implantable and fully external, the input signal should be able to penetrate the skin, tissue under the skin, and the reach bone. But achieving that is difficult as the signal from the ultrasonic sensor is absorbed inside the tissue and is not reflected back for processing. Therefore, modelling the sensing environment, the mechanism for sensing and the output display is done in an ideal situation and it may not completely grasp the entirety of the human body condition, especially the spinal cord area.

3.2. Model and signal characteristic of the sensors in the USP

3.2.1 Measurement Mechanism

Keeping in mind the problems mentioned in the above section, this documentation introduces a solution to measure how much of the disc matter is bulged out of the original position. It is sufficiently shown in the SIMULINK model that the obstacles the ultrasound signal has to go through like skin, tissue, and ultimately reach the bone and onto the disc matter has been accounted for The Ultrasonic sensors are placed adjacently along the outer part of the probe to get the access to the patient. Afterwards, according to the circuitry, the rest of the components are aligned inside the plastic casing.

Fig 3.1.: Image of the 3 eyed fronts of the Ultrasonic Sensor Probe

The probe shown in figure 3.1 is what the physical appearance of the probe is supposed to look like. It is held against the target area, around the vertebrae to image the possible bulges on the spinal cord. Initially, the probe should have a water-based gel to prevent skin irritation. The skin is going to be irritated because the high frequency signal emitting from the probe might not be heard through the ear but it produces vibrations with the same frequency. This vibration causes a direct impact on the skin and the veins underneath the skin. The gel minimizes this impact by absorbing the energy of the signal onto itself. Not only does it absorb the vibration, it also reduces the amount of energy entering the skin surface while measurement [16]. That is, the residual energy accumulated after using the USP becomes significant overtime; that it causes other symptoms that are uncalled for in the future. The gel absorbs the energy from the incoming signal so that there will not be as much residual energy inside the skin as opposed to the one accumulated without the gel being applied.

3.3. System Design Architecture

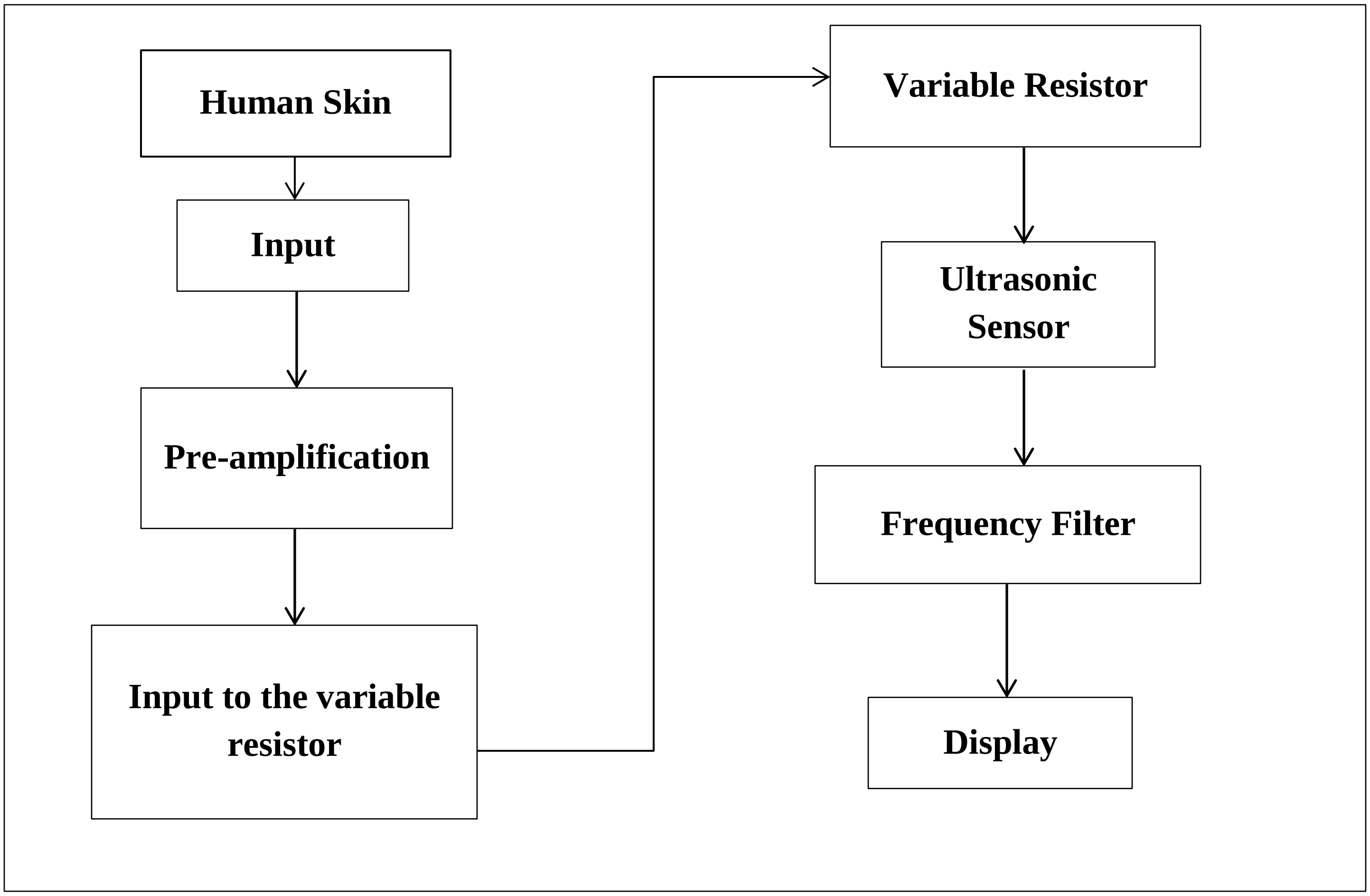

Fig 3.2.: System Architecture of the Ultrasonic Sensor Probe (USP)

Figure 3.2 shows the system design architecture of the Ultrasonic Sensor Probe. This design consists of the different stages a signal goes through to reach the output side of the system. Initially, the human body is applied with a water based gel to prevent irritation and it is ready to be exposed to the Ultrasound Probe. In the probe, there are one or more quartz crystals called piezoelectric crystals. When an electric current is applied to these crystals, they change shape rapidly. The rapid shape changes, or vibrations, of the crystals produce sound waves that travel outward. Conversely, when sound or pressure waves hit the crystals, they emit electrical currents. Therefore, the same crystals can be used to send and receive sound waves [16]. This process is done in the Pre Amplification stage of this design.

Then the electrical output from the piezo electric effect circuit (or the Pre-Amplifier circuit), goes to the variable resistor of the system. The variable resistor represents how much the spinal disc has bulged out from the vertebrae. Afterwards, the ultrasonic sensor transmits a sonar signal and receives an echo. The frequency filter circuits then comes in to make sure that the frequency isn't too low that the system cannot identify it, or too high for the human body to stay safe. This range is between 40 KHz – 20MHz. lastly, the display is connected so that the user is able to see the real time measurements of the spinal cord disc herniation.

3.3.1: The Ultrasonic Signal

The Ultrasonic sensor used in this thesis is the HC-SR04 Ultrasonic Sensor. It is the most widely available and mostly used US sensor, especially in the case of simulations. The US sensor is a 4 pin module, whose pin names are Vcc, Trigger, Echo and Ground respectively.

This sensor is a very popular sensor used in many applications where measuring distance or sensing objects are required. As can be seen from figure 3.3, the module has two eyes like projectors in the front which forms the Ultrasonic transmitter and Receiver. The sensor works with the simple formula that

$$\textbf{Distance} = \textbf{Speed} \times \textbf{Time}$$

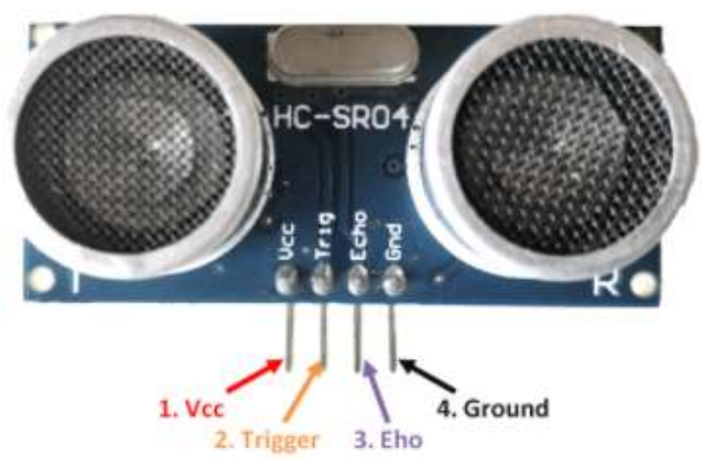

Fig 3.3: Ultrasonic Sensor HC SR04 Pin Diagram

To calculate the distance using the above formulae, the speed and time should be known. Since the Ultrasonic wave is being used, the universal speed of US wave at room conditions which is 330m/s is the right choice. The circuitry inbuilt on the module will calculate the time taken for the US wave to come back and turns on the echo pin high for that same particular amount of time, this way the time taken can also be identified. Then, the distance is simply calculated using a microcontroller or microprocessor.

Table 3.1: Ultrasonic Sensor Pin Configuration

Pin Number	**Pin Name**	**Description**
1	Vcc	The Vcc pin powers the sensor, typically with +5V
2	Trigger	Trigger pin is an Input pin. This pin has to be kept high for 10us to initialize measurement by sending US wave.
3	Echo	Echo pin is an Output pin. This pin goes high for a period of time which will be equal to the time taken for the US wave to return back to the sensor.
4	Ground	This pin is connected to the Ground of the system.

The Sensor is powered using a regulated +5V through the Vcc and Ground pins of the sensor. The current consumed by the sensor is less than 15mA and hence can be directly powered by the on board 5V pins. The Trigger and the Echo pins are both I/O pins and hence they can be connected to I/O pins of the microcontroller.

The electrical parameter of this specific sensor can be summarized in table 3.2 below:

Table 3.2.: Electrical parameters of the HC SR04 Ultrasonic sensor

Working Voltage	**DC 5 V**
Working Current	**15mA**
Working Frequency	**40Hz**
Max Range	**4m**
Min Range	**2cm**
MeasuringAngle	**15 degree**
Trigger Input Signal	**10uS TTL pulse**
Echo Output Signal	**Input TTL lever signal and the range in proportion**
Dimension	**45*20*15mm**

3.3.2.: Piezoelectric Effect

The transducer probe is the main part of the ultrasound machine. The transducer probe makes the sound waves and receives the echoes. It is the mouth and ears of the ultrasound machine. The transducer probe generates and receives sound waves using a principle called the piezoelectric (pressure electricity) effect. When an electric current is applied to the crystals found inside the transducer probe, they change shape rapidly. The rapid shape changes, or vibrations, of the crystals produce sound waves that travel outward. Conversely, when sound or pressure waves hit the crystals, they emit electrical currents. Therefore, the same crystals can be used to send and receive sound waves [16].

In this section, the piezoelectric effect of the ultrasound probe is modelled in SIMULINK. It consists of a Dual Operational Amplifier, and mainly a Pre-Amp circuit to demonstrate that the input signal is a proportional effect of the crystal movement and the electrical signal generated due to that is then pre-amplified. The Dual Operational Amplifier is needed to eliminate the use of two sources in the amplifier system, improve the noise and make the rest of the circuitry outside of the dual op-amp a lot easier and convenient.

Both the piezoelectric effect and the Op-Amp models are designed based on their respective datasheets provided by the manufacturer itself and they are shown in figure 3.4 below.

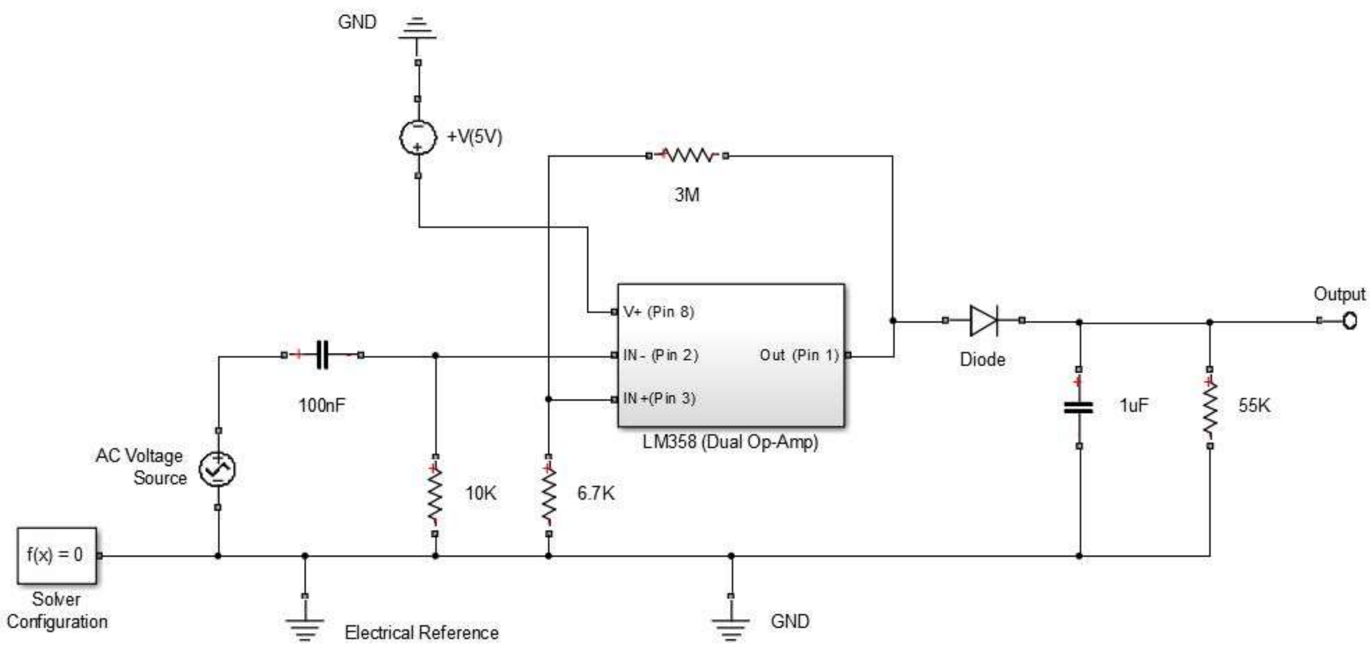

Fig 3.4.: Piezoelectric effect model of an Ultrasonic Sensor Probe

The above circuit can be divided into three parts simply for ease of understanding. The first part being the input circuit, which includes the voltage input of the model labeled as the AC voltage, and resistors and capacitors. The second part being the dual op-amp itself, it contains the subsystem that includes the model of the op-amp.

The third is the output circuit which has the power protection side (the diode) and the output itself. This output as mentioned before is supposedly the output signal that goes into the variable resistor in the proteus model.

The subsystem depicted in figure 3.4 above is the LM358 Dual Op-Amp. The LM358B op amp simplify the circuit design with enhanced features such as unity-gain stability, lower offset voltage of 3 mV (maximum at room temperature), and lower quiescent current of 300 µA per amplifier (typical). This device is the next generation version of the industry-standard operational amplifiers (op amps) LM358 and LM2904, which include two high-voltage (36-V) op amps. These devices provide outstanding value for cost sensitive applications.

Some of its features and applications include:

- Two Internally Compensated Op Amps
- Eliminates Need for Dual Supplies
- Allows Direct Sensing Near GND and Vout,
- Compatible with All Forms of Logic
- Power Drain Suitable for Battery Operation
- Can be applied in active Filters
- Used in General Signal Conditioning and Amplification
- Used in 4- to 20-mA Current Loop Transmitters

Generally, an Op-Amp is already modelled and ready to go in simulation platforms. But all kinds of Op-Amps might not be available in these platforms, Therefore either an external library or manual modelling might be required to use these components inside the platforms. The simulator software used in this thesis is the matlab SIMULINK. But in the case of SIMULINK, as it did not contain the dual operational amplifier, a representation of the component is necessary therefore modelled inside the subsystem of the piezoelectric effect model labeled LM358. It is done based on its functional diagram shown in figure 3.5 below where the diagram is provided by the component manufacturer datasheet. The model was achieved by replicating the layout of the diagram but using the components provided by SIMULINK. All of the I/O ports are labeled so that they fit the exact pin arrangement of a real life dual Op-Amp IC.

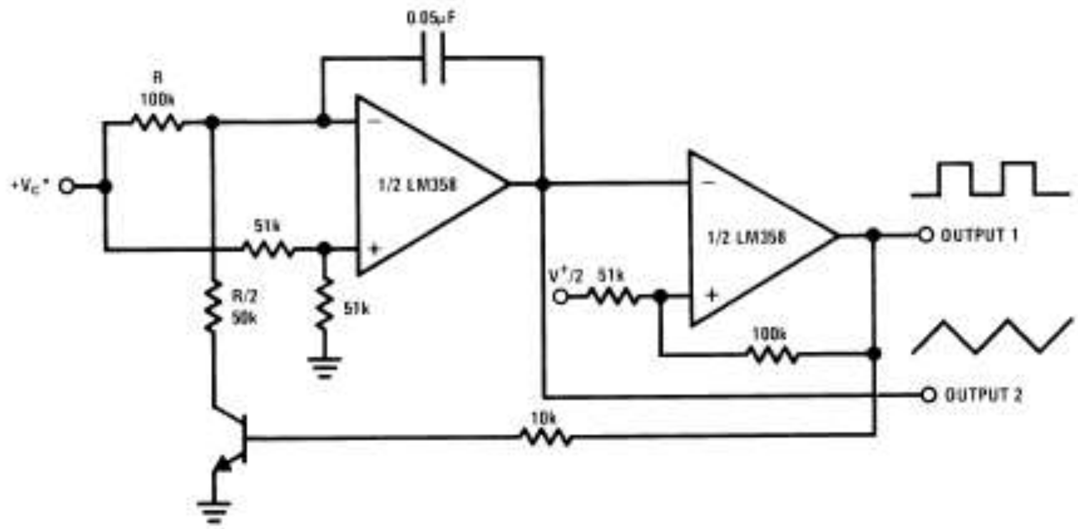

Fig 3.5.: Functional diagram of an LM358 dual OP-Amp

After assigning the appropriate pins to the ports in the diagram above, then it is ready to be connected to rest of the circuit as a subsystem. The modelling itself could not be done in proteus as proteus does not give the flexibility and simulation clarity needed for this component. Therefore, matlab's SIMULINK is deemed fit it this case hence used in this system as it was the better option.

Once the signal sensing side, and the modelling of sensing environment is simulated, the Ultrasonic sensor is in the next step. Afterwards, the Ultrasonic signal is then processed through a frequency filter to make the incoming signals safe for the human body using a band pass filter. Then, this signal reaches and passes through a microprocessor, which is Arduino in this case. After the algorithm is run into the processor, the output would be a length measurement of the herniated (bulged out spinal disc) disc from the vertebrae, which in turn tells us exactly how severe the protrusion is. The output data implementation will be discussed in the next section of this document.

The display mechanism used in this system is a virtual port display. This display is favorable over the other ones simply because it does not require any extra connection when attached unlike say, the LCD. It also has the ability to display outputs in real-time which is ideal when taking measurements multiple times as this. The virtual port used in this system is shown in fig 3.6 below.

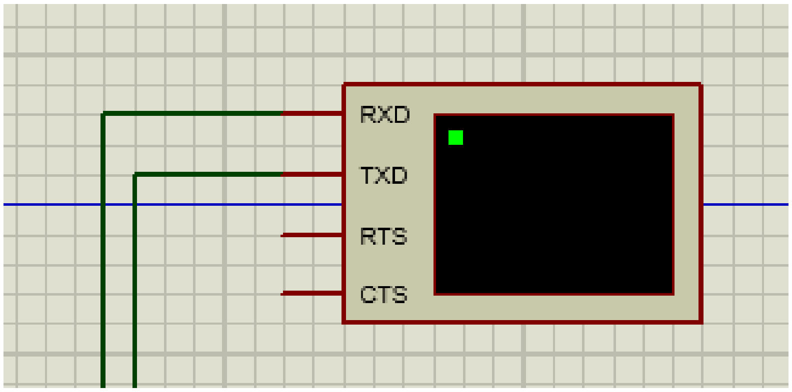

Fig 3.6.: Virtual terminal in Proteus simulation for Ultrasonic Sensor Probe design

3.4. Frequency Filtering

A band-pass filter is a device that passes frequencies within a certain range and rejects (attenuates) frequencies outside that range. An example of an analogue electronic band-pass filter (BPF) is an RLC circuit (a resistor–inductor–capacitor circuit). These filters can also be created by combining a low-pass filter with a high-pass filter. Unlike the low pass filter which only pass signals of a low frequency range or the high pass filter which pass signals of a higher frequency range, a Band Pass Filters passes signals within a certain “band” of frequencies without distorting the input signal or introducing extra noise. This band of frequencies can be any width and is commonly known as the filters Bandwidth. The upper and lower cut-off frequency points for a band pass filter can be found using the same formula as that for both the low and high pass filters,

$$fc = \frac{1}{2\pi RC}\ Hz$$

The signal from the Ultrasonic sensor might have a frequency outside of the safe range. If ignored the high frequency would damage our skin tissue, and eardrums, even though we might not be able to hear in that frequency range. Therefore, having a frequency filter is essential in the Ultrasonic Sensor Probe.

One of the ways to keep the hazardous frequencies out and setting a minimum frequency threshold so that the signal could actually be detected is introducing a band-pass filter. The filter used in this thesis is the RC band pass filter. Since the purpose of this filter in the system is to get the desired range of frequencies, a simpler version of it is used in the simulation as shown in figure 3.7 below.

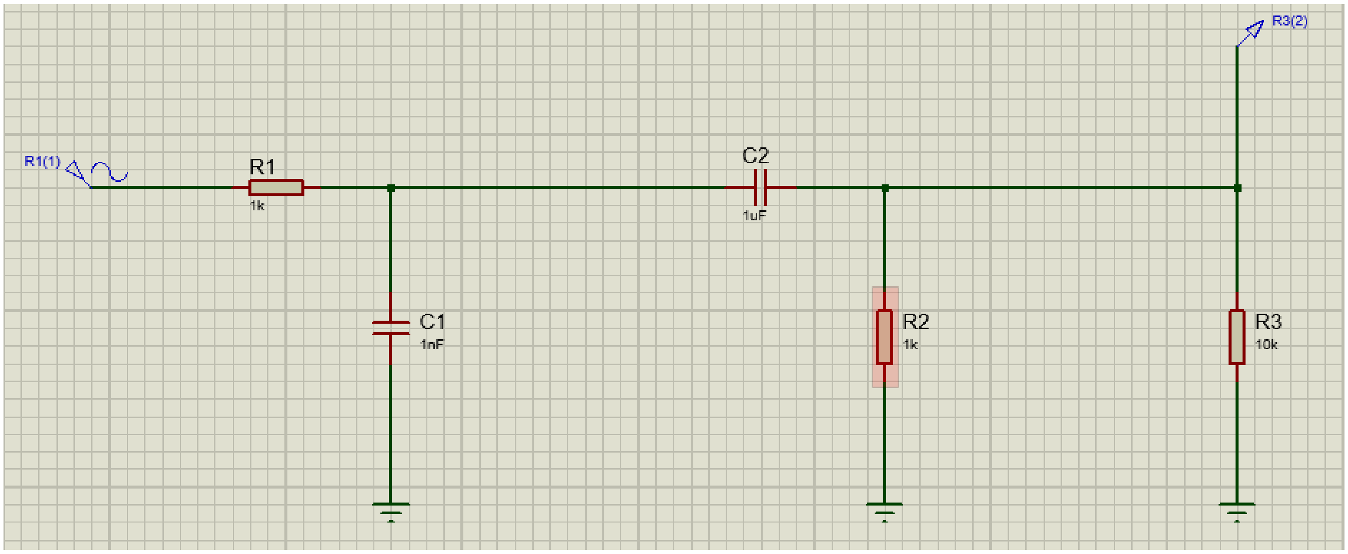

Fig 3.7.: Band-Pass filter in the simulation of the USP

The outputs and implementations of the components and systems mentioned in the previous sections will be discussed in the next chapter.

Chapter 4

Implementation

In this section, the detailed explanation of the simulation designs and their purpose is briefly explained. The simulation is done in two parts, the piezoelectric effect, which is done in matlab SIMULINK and the working principle of the system from the ultrasonic sensor side in Proteus.

Implementation of the techniques discussed so far requires setting up a simulation model for piezoelectric effect modelling in the measurement of Lumbar Disc Herniation (LDH), and protruded disc matter length measurement in real-time within the Ultrasonic Sensor Probe.

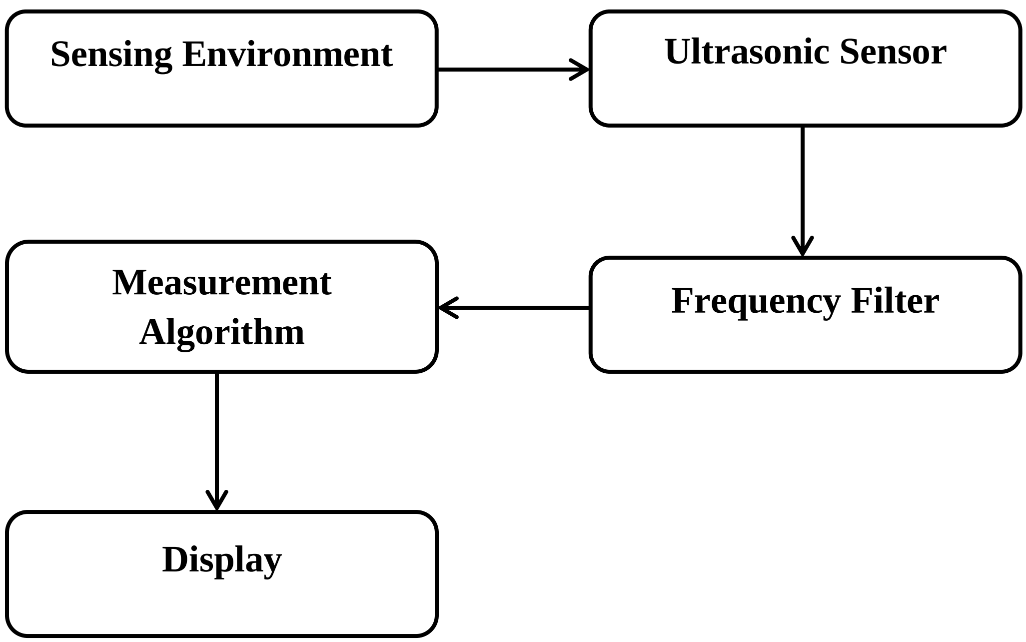

Figure 4.1: Block Diagram of the Ultrasonic Sensor Probe System Design

In the first part, the primary stages of the signal acquirement are simulated. This means that the environment where the probe would encounter inside the skin, the obstacles of the ultrasound signal is represented in the form of the piezoelectric effect. This effect is also useful in determining where to put the probe around the spinal area, so that the person measuring is not just taking a guess but doing a guided glide around the spine to find the spot where the herniated disc would reside.

This part is essential in the development of this USP, since the measurer is not a trained professional that knows the in and out of the spinal cord, it is a regular everyday person that might not be able to find the affected area easily. This step also gives this research a validation that it is not just a hypothetical scenario, but a real life application as well.

The second part of the simulation is the stage after the human body obstacle is demonstrated. It starts with the ultrasonic sensor which does the actual sensing of the herniated lumbar disc, and goes on with the filtering of the frequency. After these steps are done, then the signal is fed into the Arduino microprocessor, so that it is then interpreted with a length measurement. This step is done using the length measurement algorithm. Afterwards, the measurement is shown to the user using the virtual port placed on the simulation scheme.

4.1. Design Overview

Once components that fulfil the requirement of the designs are selected, a design is constructed representing the general operation mechanism of the signal acquisition system and the signal interpretation. The design incorporates individual parts (blocks) that the signals have to go through from detection through to conversion, conditioning and display.

4.2. System Simulation Models

The simulation model is done in two parts as it has been mentioned previously. At initial look at the first part, the first input is the AC input. This input is the equivalent of the electrical signal generated when the piezo electric signals are compressed and stretched. This is due to the fact that when these crystals are mechanically activated, they generate electrical signals. These signals are then further analyzed within the circuit.

Then, the Dual Op-Amp briefly explained in the previous section is biased through the input port labeled “Pin 8”. It does not use separate voltage supplies even though there are two op-amps inside the IC (see fig 4.2).

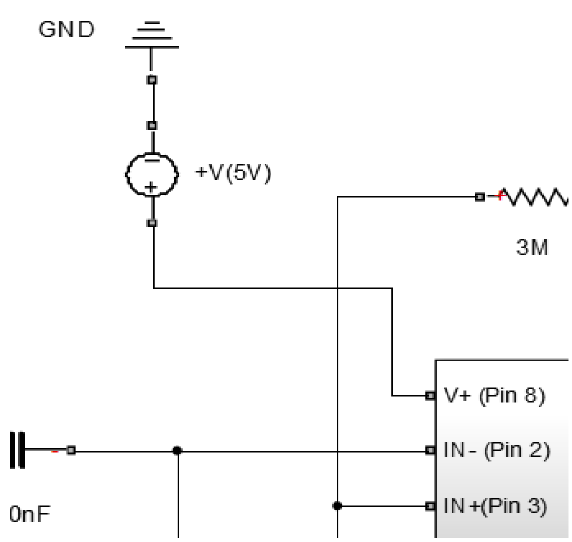

Fig 4.2.: Section of the circuit showing the bias input of the USP

Then, the input signal is connected through the inverting and the non-inverting sides of the Dual Op-Amp. This op-amp, is the LM358 as it has been mentioned in the previous sections. But, since there is no library for it in mat lab, modeling it using the data found in the datasheet is a necessity. It consists of two ideal op-amps cascaded to make the "dual" part of the circuit (see figure 4.2). These op-amps are each biased and connected to each other depending on the functional diagram shown in the previous section of this document (figure 3.5).

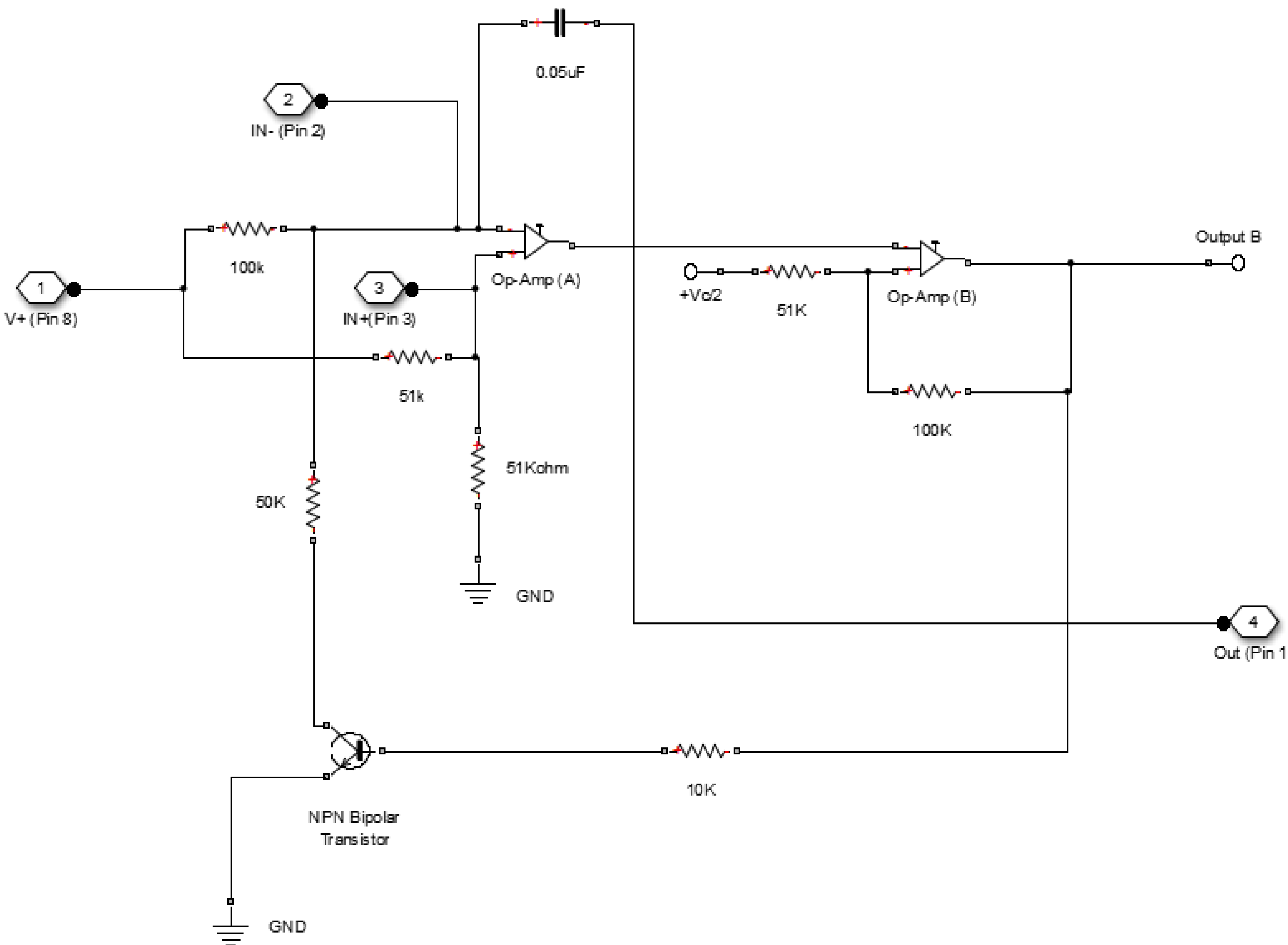

Fig 4.3.: Full circuitry of the LM358 Dual Op-Amp in mat lab SIMULINK

The pin configurations of the dual operational amplifier require it to have 8 pins which mean the two supplies for the separate op-amps are tapped together. The inverting and the non-inverting ports are also clearly shown so that one can benefit from both sides. Now, the bias voltage is not shown in the pin arrangement but since the op amp is voltage controlled, it is used to drive the entire circuit or the system as a whole.

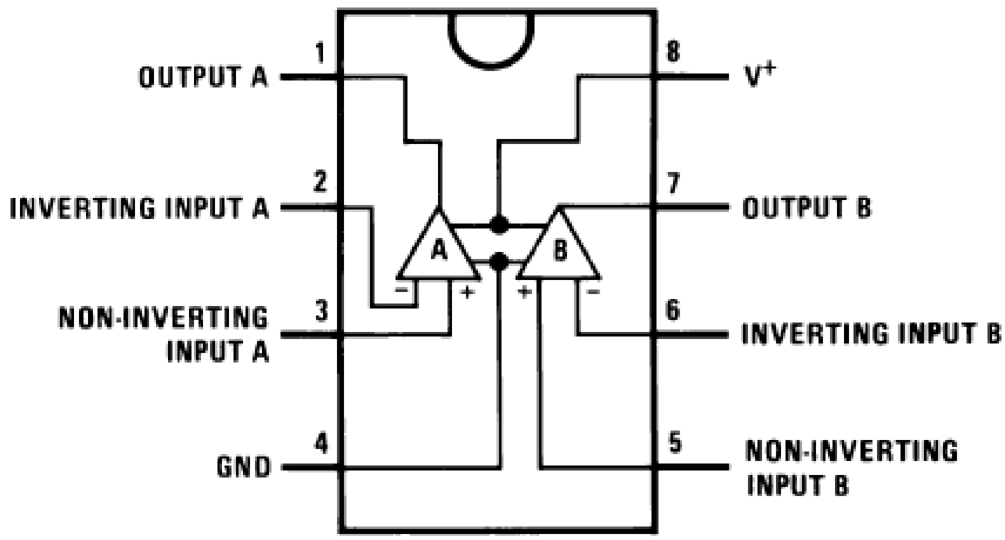

Fig 4.4.: Pin arrangement of the LM358 dual operational amplifier

Pin Functions

PIN			TYPE	DESCRIPTION
D/P/LMC NO.	DSBGA NO.	NAME		
1	A1	OUTA	O	Output , Channel A
2	B1	-INA	I	Inverting Input, Channel A
3	C1	+INA	I	Non-Inverting Input, Channel A
4	C2	GND / V-	P	Ground for Single supply configurations. negative supply for dual supply configurations
5	C3	+INB	I	Output, Channel B
6	B3	-INB	I	Inverting Input, Channel B
7	A3	OUTB	O	Non-Inverting Input, Channel B
8	A2	V+	P	Positive Supply

Table 4.1.: Pin Functions of the LM358 dual operational amplifier

A diode is included at the end of the circuit and the output is depicted with an open circuit (see figure 4.5). This is due to the fact that it is assumed that the output from this simulation is an input to the next one which is done in Proteus.

Since the circuit in the second part is a continuation of the one in the first, we are hypothetically assuming that the signals are of the same type. But the problem with this is not only that they are not compatible with each other, but also the fact that some other assumptions should be taken into consideration like the signal type, if any amplification is required, or the fact that these signals are representations of the human condition and it is not as simple as getting the obstacles to be shown in just these simulation. But for simulating the effects of a lumbar disc herniation and the measurements taken to solve the problem, the design depicted in this thesis is enough for the reader to understand the mechanisms and the general idea of the system. This makes it an easier version of the model therefore making it simpler to follow the grasp the idea that has been conveyed here.

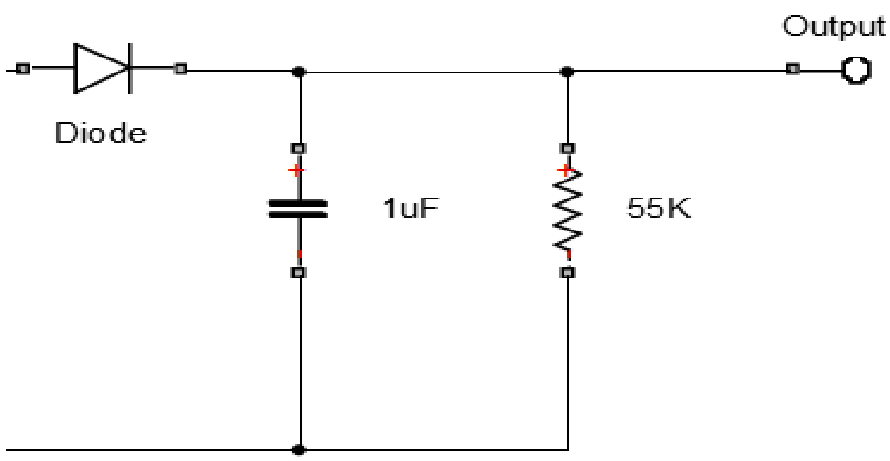

Fig 4.5.: Output side of the piezoelectric effect circuitry

When it comes to the second part of the simulation, which is done in proteus, the first section is the resistive potentiometer. This is a representation of the actual spinal disc matter that is about to bulge out. Changing the resistor value from 0.1 ohm to 1K ohm in the potentiometer means either the disc is slightly, bulged out or it is severely bulged out (figure 4.6). This is in turn fed into the ultrasonic sensor which is then calculated into a sound wave. Now, the sound wave generated might have unwanted frequencies and has to be filtered in the next stage.

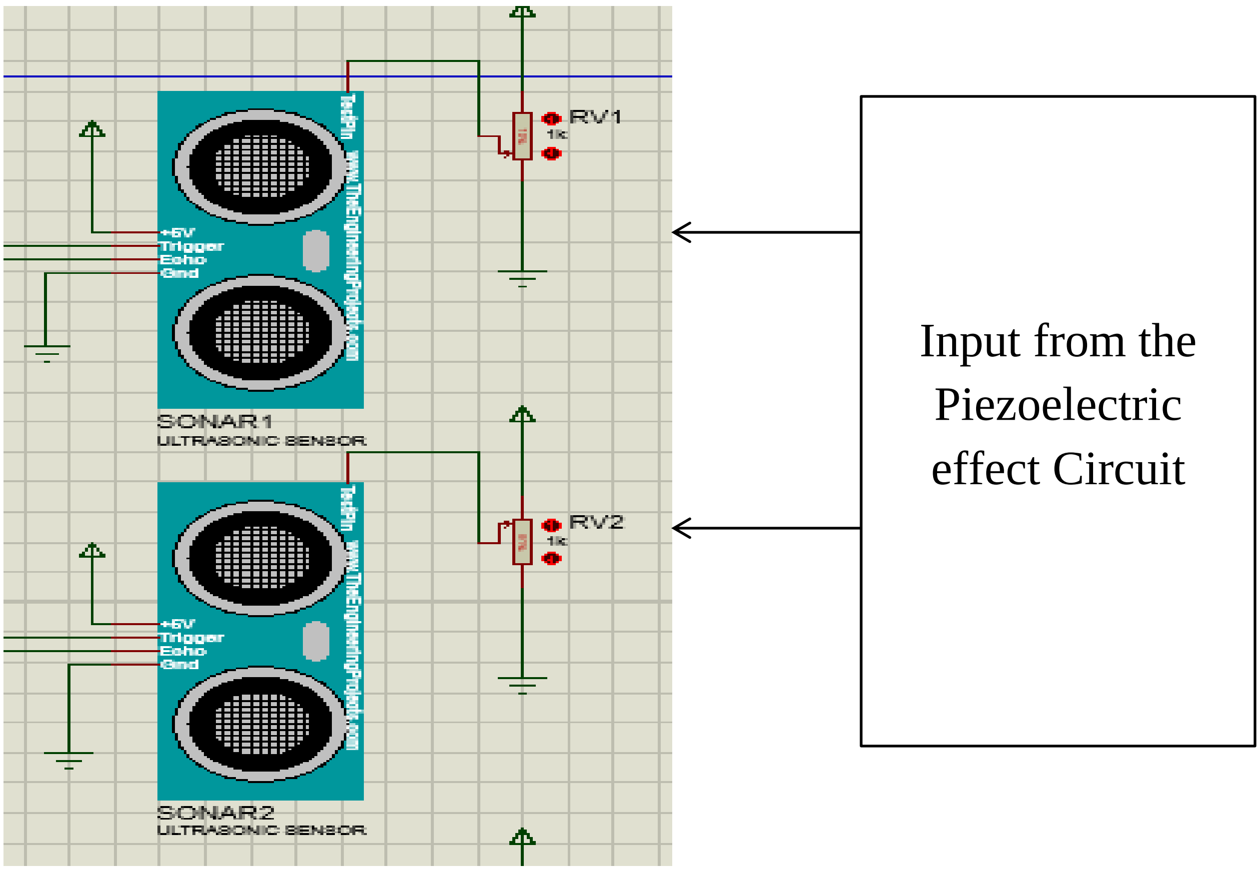

Figure 4.6. : Ultrasonic sensor simulation in Proteus

The band pass frequency filter allows to have from 40kHz – 20MHz. that is if the signal from the ultrasonic sensor is below 40kHz, the system will not detect it at all and if it is beyond 20MHz, since it is hazardous to the human body, it will not pass through.

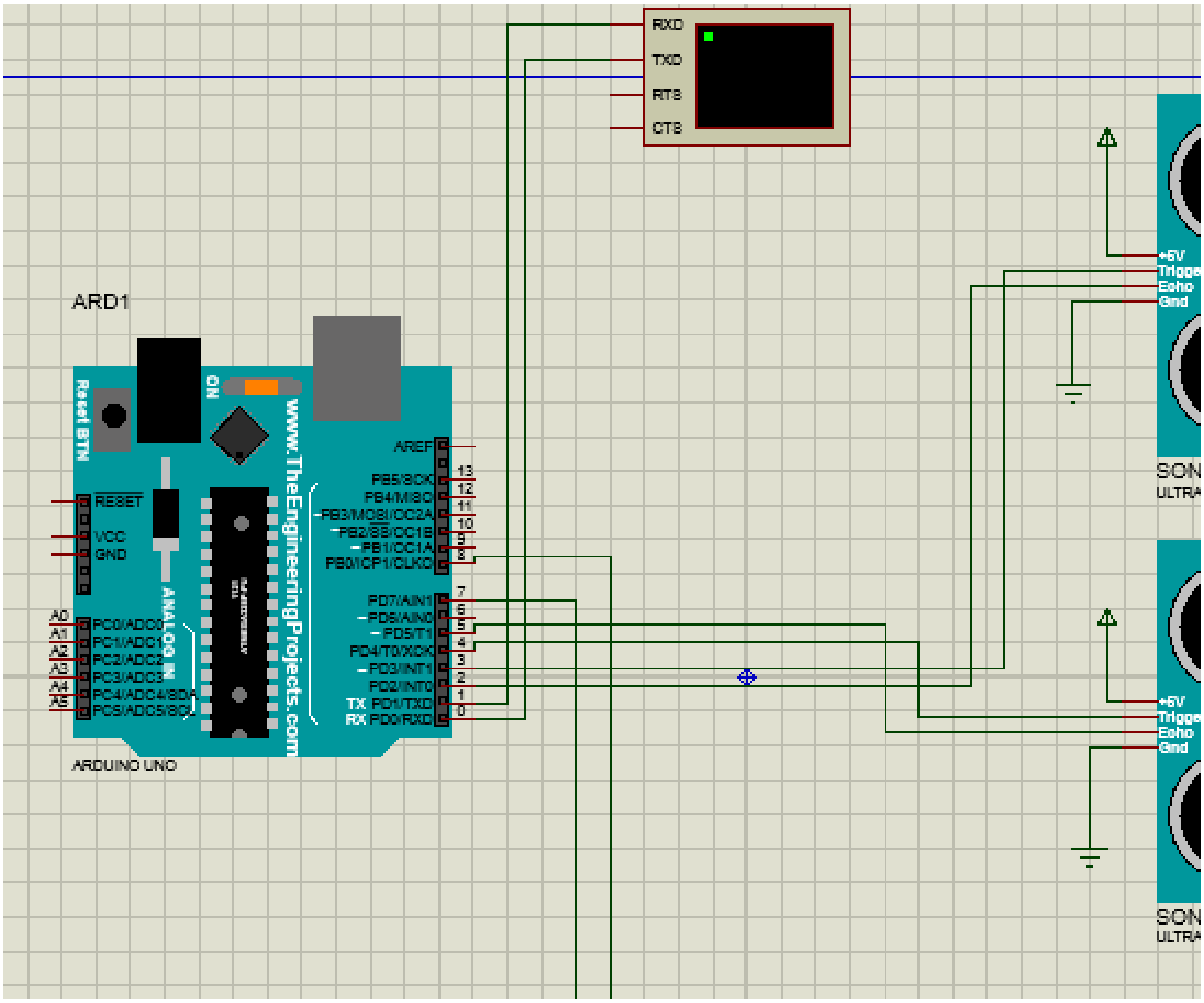

Figure 4.7.: The Arduino Microprocessor and the virtual port simulation in Proteus

Figure 4.7 above shows the connection to the Arduino microprocessor simulated in Proteus. Inside the processor, a length measurement algorithm is there to input the sonar signals and convert them into electrical signals. Afterwards, the program makes use of them and produces the output. These outputs are then displayed in the virtual port shown in figure 4.7 above as well.

The Arduino code used in this process firstly expects a trigger from the ultrasound. These triggers are done in the same way as for all of the ultrasound sensors. Conversely it does the same thing with the echo pin, which receives the signal bounced back from the surface.

Chapter 5

Results and Discussion

5.1. Sensing Environment

The sensing environment is represented in the simulation using the piezoelectric effect, much like the one in the widely known ultrasonographic probe used in hospital ultrasounds. Inside the probe, it contains crystals that have piezoelectric properties, called the piezoelectric crystals. What they do is that, whenever a mechanical or force-based motion is exerted, that mechanical energy is converted into an electrical one. The AC input shown in Figure 3.4. labeled “AC voltage source” is the raw electrical signal generated from the mechanical movement of the piezoelectric crystals. The electrical signal is then amplified through the pre-amplifier which has a regulated and conditioned voltage output that is then processed through the signal processor, in this case the Arduino microprocessor. The output signal is the one labeled “output” in the same figure mentioned (figure 3.4.).

The Ultrasonic sensor is placed between the filter and the variable resistor to get the input from the sensing environment and the give out an output to the frequency filter, which can then be processed in Arduino.

5.2. Frequency Filtering

Frequency filtering is a very important section of this thesis. This is due to the dangers of a high frequency in the human body. When a high frequency signal is subjected to skin, it causes it to vibrate and leaves a residue of energy within the body. That’s the reason for applying a water-based gel on the skin before trying to measure the target area in any medical ultrasonography. The gel is used on the skin in this case, so that the remainders of the energy generated from the ultrasound signal is attenuated to a safe amount, as it will not completely disappear. In doing so, the gel also prevents the irritation caused by the vibration propagating from the signal. As has been mentioned in the above sections, a band pass filter is used in this design, and the frequency response is shown in figure 5.1 below.

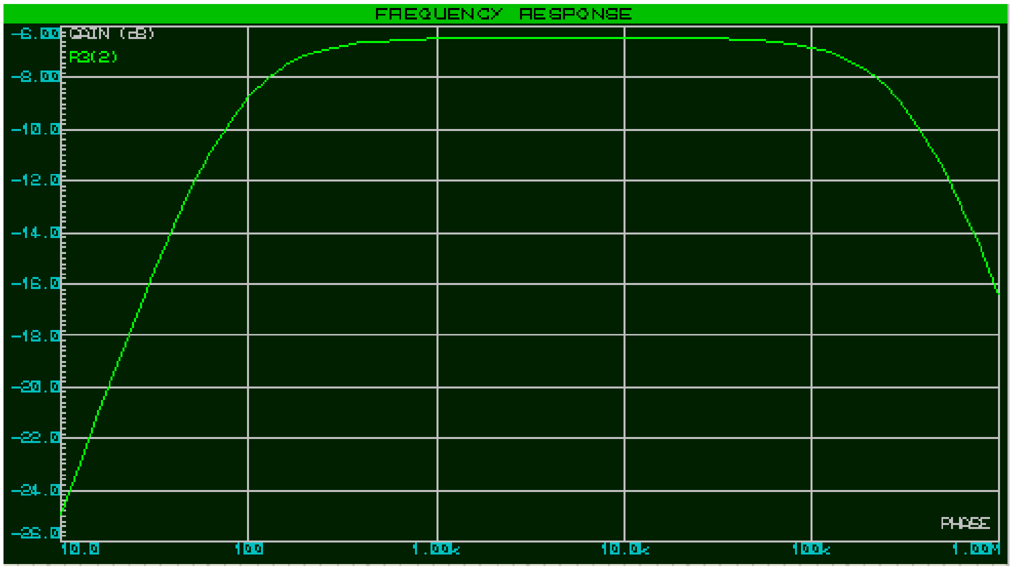

Fig 5.1. Frequency response of the Band pass filter in the Ultrasonic Sensor Probe

5.3. Length Measurement

After the signal generated from the US is passed through filter, it is then ready to be processed into the controller, which in this case is the Arduino microprocessor. Inside the processor, the algorithm is started and the output is shown in the virtual port connected to the system. As it has been mentioned, a virtual port is used instead of an actual display because the virtual port is suitable for real time simulation. And if any other display mechanism is used outside of the ones available in proteus, the use of other simulation platforms is a must. Therefore, instead of disconnecting all of the wirings and adding a virtual terminal, the virtual port is easily disengaged and can be replaced with the virtual terminal instead; or it can be used as a port itself. The output signal, which is the lengths of the bulge are shown in figure 5.2 below.

5.4. Output Display

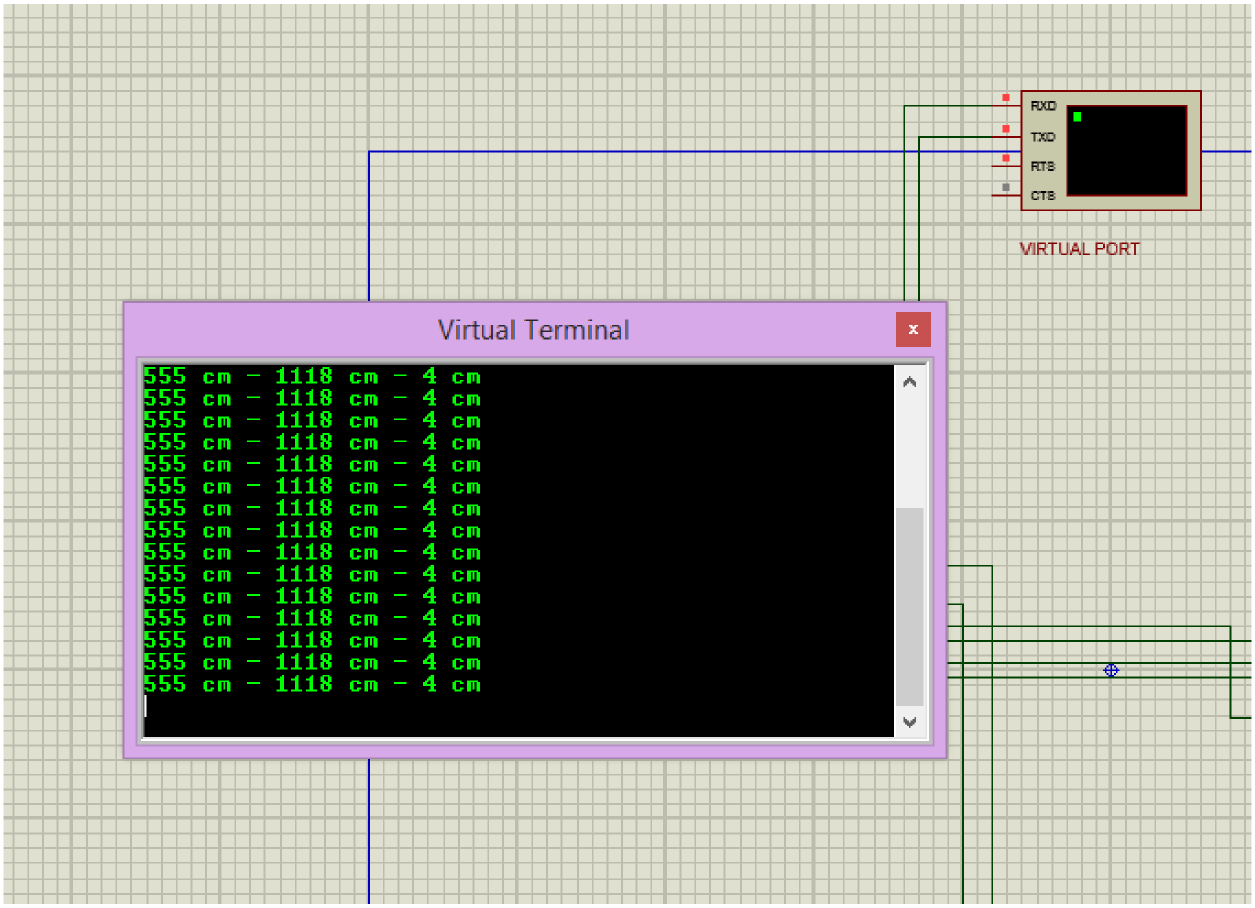

Fig 5.2. Virtual terminal output of the system in the Ultrasonic Sensor Probe

From the figure above, the first column shows the first measurement of the US output, the second column, the second sensor, and the third column the third one. When the value in the variable sensor is increased, the length measurement is also higher, which is, the resistor value and the length output are directly proportional. An increased value of the resistor indicates that the bulged disc matter is bigger. Conversely, a small value of the resistor indicates that the bulged disc matter is smaller.

The three sensors determine the severity of the protrusion. That is, if the first and second sensors log a significantly larger value than the third, then the disc is bulged but it is at a state of moderate danger (see figure 5.4). If only the first one shows a large value, then the disc is herniated slightly, hence the danger is also slight as well (see figure 5.3). If all three values are high, then the patient is in a severe stage of disc herniation (see figure 5.5).

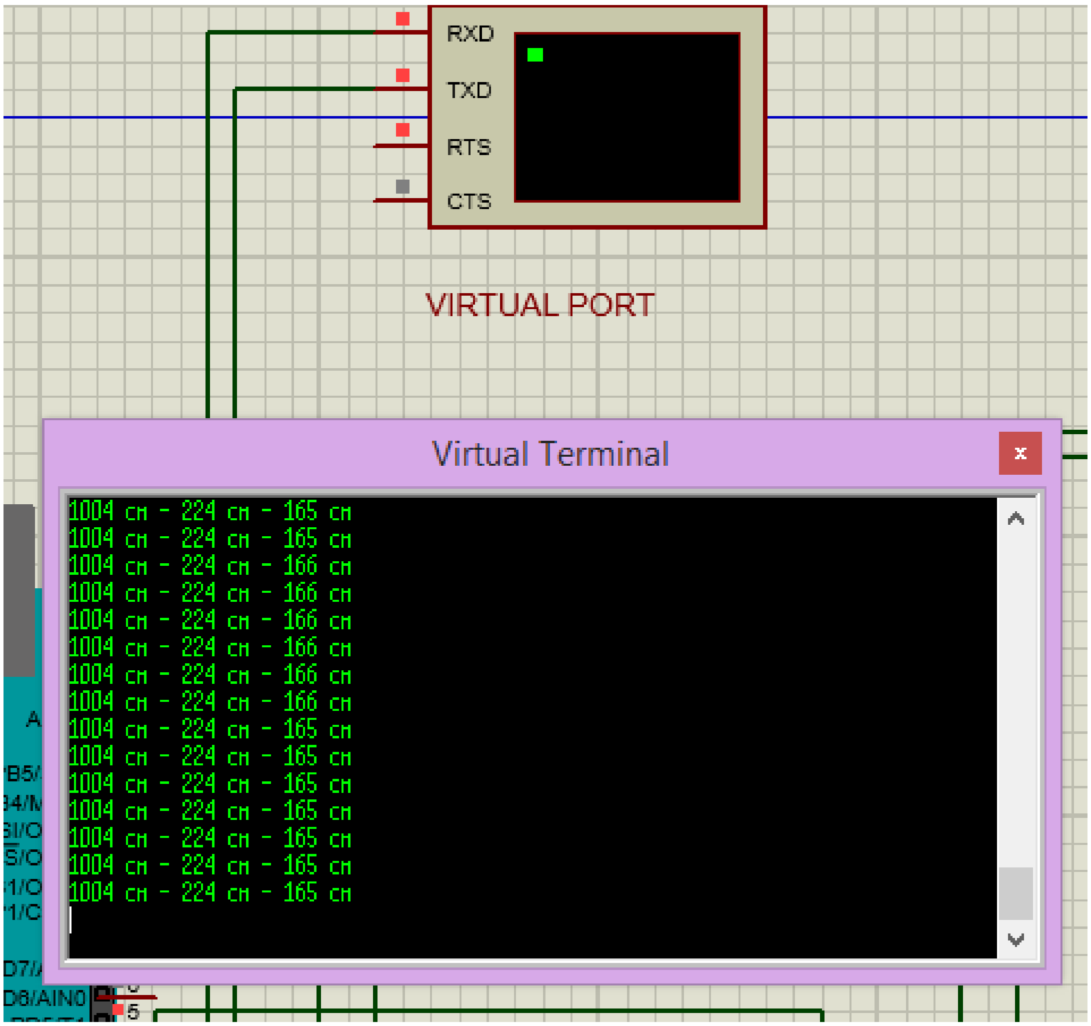

Figure 5.3.: The output of virtual terminal when only the first ultrasonic sensor is triggered

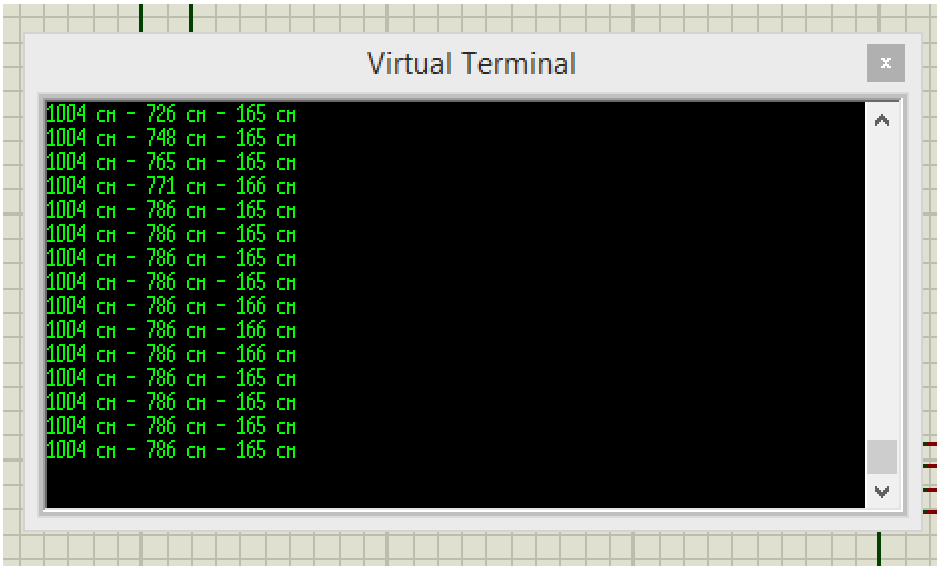

Figure 5.4.: The output of virtual terminal when the first and second ultrasonic sensors are triggered

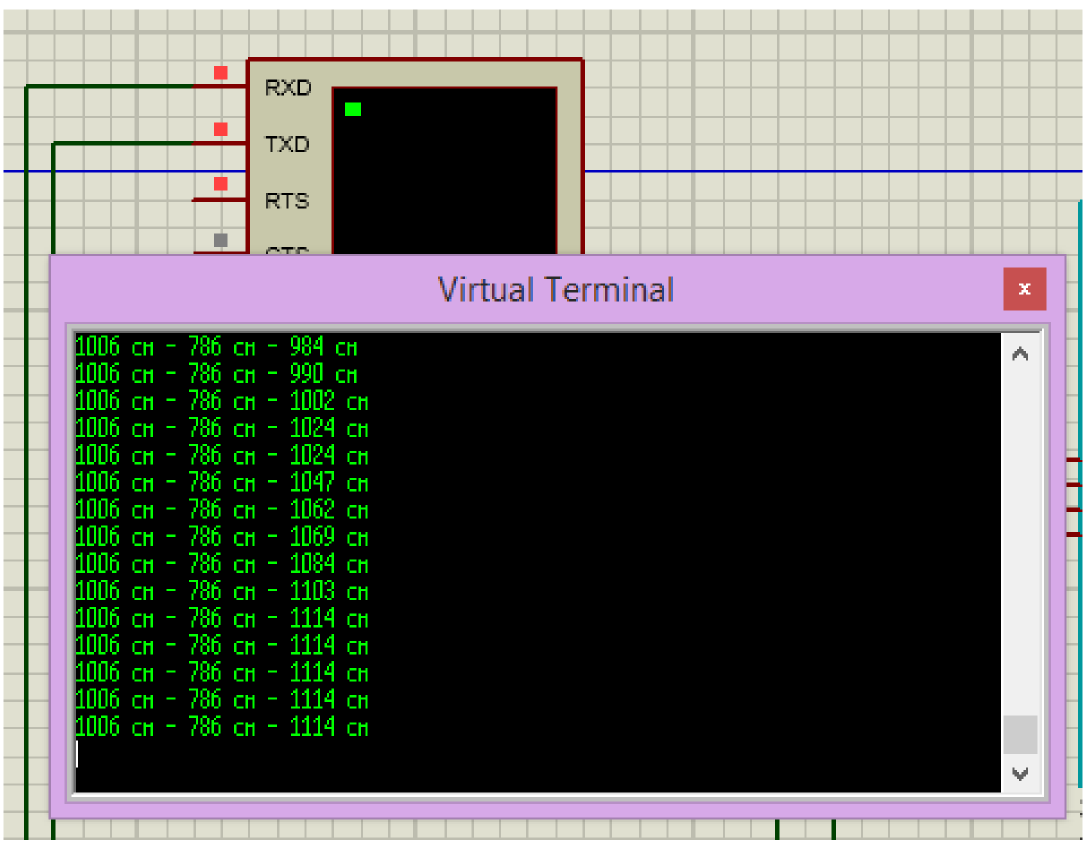

Figure 5.5.: The output of virtual terminal when all three ultrasonic sensors are triggered

Figure 5.2 show the maximum points of measurements. The extreme points of measurements are the points where the least, the highest and the middle grounds of the measurement range. The highest being when the variable resistor reaches 100 percent and the output reads 1118 cm. this number indicates the highest range of distance measurement the ultrasonic sensor could achieve. The lowest distance to be measured in this ultrasonic sensor is 4 cm, that is when the variable resistor reaches 0 percent. The closest an object could be placed for the distance to be measured is 4 cm. the average or the middle range of the ultrasonic sensor measurement is around 555 cm, that is when the variable resistor reaches the 50 percent mark.

Chapter 6

Conclusion

6.1. Conclusion

The designed system was able to model the relevant spinal cord imitation on a simulation platform. One of the objectives of this thesis was to mimic the sensing environment of the ultrasonic sensor probe to make it more realistic and this system has achieved that. This thesis was also able to get a length measurement out of the system setup where the setup simulates the spinal cord disc bulging and the environment in which the probe is designed. That is, the inside of the USP is fairly depicted in this thesis, in the proteus simulation.

It was able to successfully implement the length measuring algorithm written in Arduino platform, and actually get a usable result. Although in this research there are some shortcomings design wise, and in the implementation mechanisms, it opens up a pathway to future related work by initiating the underrated problems of lumbar disc herniation. It takes the first and important step in tackling this problem in a more friendly way so that the patients are not uncomfortable and are insecure about using this kit.

This research adds the element of flexibility in to the design as it uses easily replaceable components, so that whenever anyone interested is compelled to use a different approach in any of the design ideas, that person is able to swap out those components easily rather than disconnecting and rewiring other parts of the design. This is clearly depicted in the case of the virtual terminal. The virtual terminal could easily be replaced by actual real life display simulations without having to disconnect anything else. The virtual terminal also gives a real-time measurement values that are useful in determining and adjusting the probe accordingly if need be.

It achieved the goal of making the Ultrasonic probe portable, non-invasive, as it is completely external use only, affordable and easy to use. The simplicity gives the patients confidence in using the probe, that makes it all the more attractive and wider inclusive. As it is made out of non-expensive components, the manufacturing and material costs are low, therefore making it less expensive option out of all the options available in the market right now.

Since ultrasonic sensor is used instead of other radiation emitting sensors such as a laser sensor, it has little to no side effect during prolonged usage. In other words, it is as safe as using a medical ultrasonography probe.

6.2. Recommendations for Future work

One of the biggest limitations in this system is the modeling of the spinal cord. Since the human body has many variables to be considered when modelling it, it was very hard to incorporate all of them into the system. But, based on the scope and relevance of the thesis, representing just the sensing environment and the sensing mechanism is adequate. If there were also a better way to sense the spinal disc herniation aside from the Ultrasound Sensor, the accuracy of the system would have been improved immensely. This is due to the fact that an Ultrasound signal is easily absorbable inside a soft tissue. Although the addition of the simulation of the piezoelectric crystals in the system addresses the problem, it might not be a perfect answer.

The noise aspect of the sensor has not been addressed as well. That is, the effects the sensor has to handle during measurement like the external noise, or internal noise such as temperature variation, human error, placement of the probe on the target area etc, is not included in this thesis. As this system is good for identifying the general vicinity of the area where the spinal cord disc would appear, it does not give an accurate location of where the bulge is. It is designed to find areas that are skeletal and not the soft tissues, and find the bulge to measure it. However, it does not account for the abnormalities in the spine that might not necessarily be a disc herniation but rather something else that has protruded, like a tumor, or accumulated soft tissue within the spinal area, etc.

Design wise, this system needs more depth in the considerations of the variables, as to build a more robust and reliable system. It needs to include more complex subsystems within it so that the problems that have been mentioned above are taken into account.

The ultimate goal of this research is to provide a mechanism to alleviate the understated problem of Lumbar Disc Herniation in a way by introducing an accessible and affordable medical appliance. As this problem is unknown to many people, the researches done in having alternative option to the medical imaging, specifically in our country, is not vast.

The design of the Ultrasonic Sensor Probe mentioned throughout this thesis is indicative of the work that needs to be done in the area of Disc Herniation problems. With regards to this system, a sensing mechanism better than the Ultrasonic Sensor is essential in getting a more accurate reading from the probe. Accounting for the noises and external and internal hindrances is also a better way to make the system more reliable. The model of the sensing environment could be more detailed to include most of the obstacles the Ultrasonic Sensor goes through and before being analyzed. This helps in minimizing measurement errors and makes the system even more realistic. The more realistic a system is, the more it is likely to be applied in the real world.

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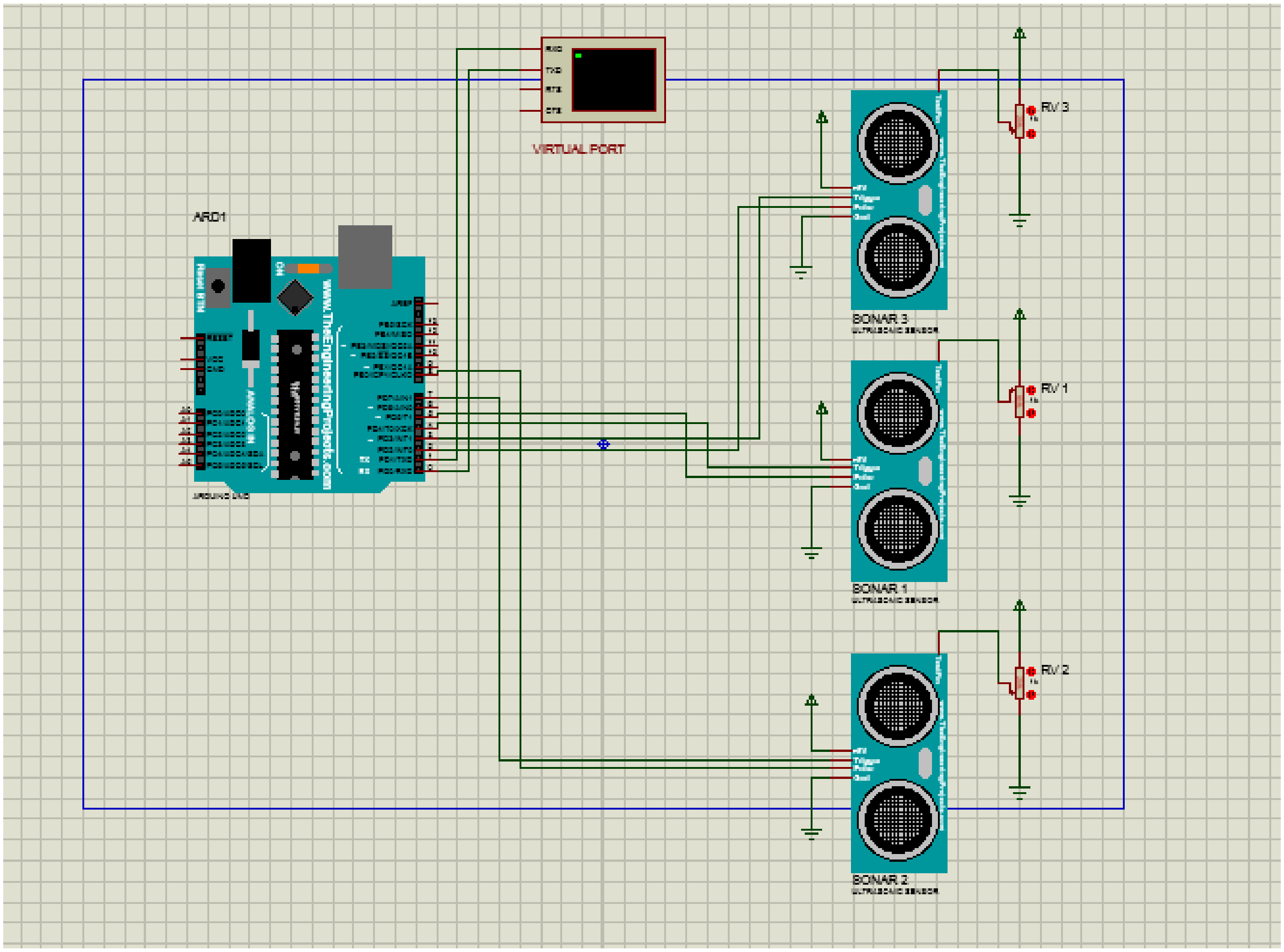
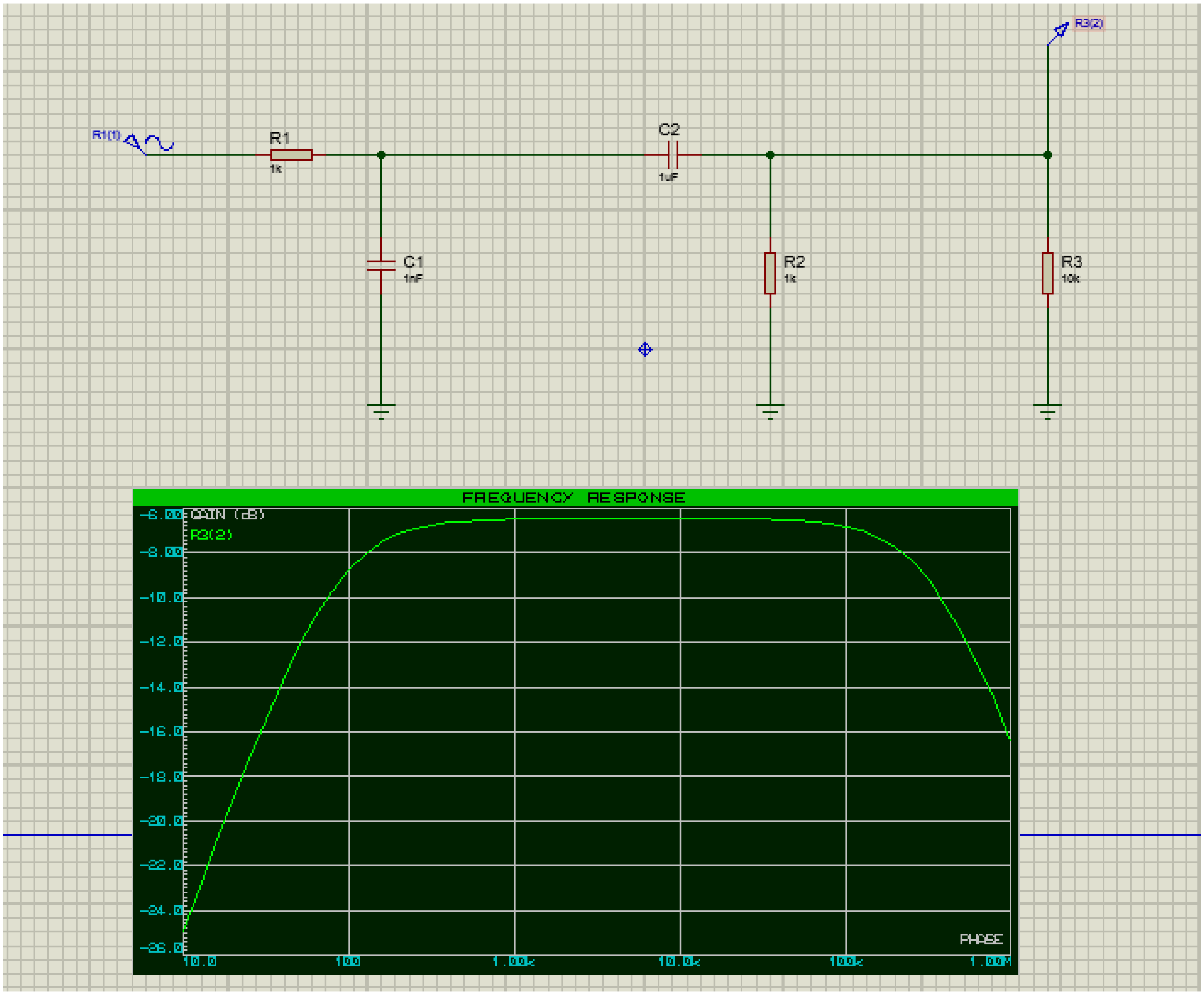
Appendix

```
#define trigPin1 3
#define echoPin1 2
#define trigPin2 4
#define echoPin2 5
#define trigPin3 7
#define echoPin3 8

long duration, distance, RightSensor,FrontSensor,LeftSensor;//BackSensor


void setup() {   // put your setup code here, to run once:

Serial.begin (9600);
pinMode(trigPin1, OUTPUT);
pinMode(echoPin1, INPUT);
pinMode(trigPin2, OUTPUT);
pinMode(echoPin2, INPUT);
pinMode(trigPin3, OUTPUT);
pinMode(echoPin3, INPUT);

}


void loop() {   // put your main code here, to run repeatedly:

SonarSensor(trigPin1, echoPin1);
RightSensor = distance;
SonarSensor(trigPin2, echoPin2);
LeftSensor = distance;
SonarSensor(trigPin3, echoPin3);
FrontSensor = distance;

Serial.print(LeftSensor);
Serial.print(" cm - ");
Serial.print(FrontSensor);
Serial.print(" cm - ");
Serial.println(RightSensor);
Serial.print(" - cm ");
}

void SonarSensor(int trigPin,int echoPin)
{
digitalWrite(trigPin, LOW);
delayMicroseconds(2);
digitalWrite(trigPin, HIGH);
delayMicroseconds(10);
digitalWrite(trigPin, LOW);
duration = pulseIn(echoPin, HIGH);
distance = (duration/2) / 29.1;
}
```

Appendix 1: Arduino code for the Ultrasonic Sensors



Appendix 2: Proteus Simulation diagram of the microprocessor and the Ultrasonic Sensors



Appendix 3: Proteus Simulation diagram of the frequency filter