KAUNAS UNIVERSITY OF TECHNOLOGY

ELECTRICAL AND ELECTRONICS ENGINEERING FACULTY

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EDEMA DETECTION USING NON-INVASIVE METHOD

Master's Degree Final Project

Supervisor

prof. dr. Vytautas Markevičius

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Final Degree Project, PR00M118

"Edema Detection Using Non-Invasive Method"

DECLARATION OF ACADEMIC INTEGRITY

10 June 2016

Kaunas

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SUMMARY

The master thesis work involves the study of a medical condition called edema, commonly known as swelling. Edema occurs when excess fluid gets trapped in body cells and tissues. An overview of causes of edema, severity of edema, methods used by doctors presently for detection are covered in the report. At present, there is no standard procedure for detecting edema. Purpose of this study is to develop a simple non-invasive model which can possibly detect the condition.

The non-invasive technique used in this work is optical method. An Infrared light emitting diode and a phototransistor pair is used as the sensor. This reflective optical sensor pair is used to acquire data from normal body and swollen body members. The optical sensor pair, TLC556 timer and a digital oscilloscope is used to acquire the signals. Pig meat is used as normal body and swollen body members for performing experiment, with the former being the reference signal and the latter being sample signal. Difference between the reference and sample signals is used as a possibility to detect edema.

Sripriya Suseela. Edemos detekcija panaudojant neinvazinį metodą: *Magistro baigiamasis projektas* / vadovas prof. dr. Vytautas Markevičius; Elektros ir Elektronikos Inžinerijos fakultetas, Kauno Technologijos Universitetas.

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SANTRAUKA

Magistro tezės apima medicininės būklės vadinamos edema arba dar dažnai vadinamos patinimu studijas. Edema susidaro, kai pertekliniai skysčiai įstringa žmogaus ląstelėse ir audiniuose. Apžvalgoje aptariamos edemos priežastys, sunkumas ir gydytojų naudojami šiuolaikiniai detekcijos metodai. Iki šiol nėra standartizuotos procedūros edemos detekcijai. Šio tyrimo tikslas sukurti paprastą, neinvazinį modelį, kuris galėtų detektuoti šią būklę.

Šiame tyrime buvo panaudotas neinvazinis optinis metodas. Infraraudoną šviesą skleidžiantis diodo ir fototranzistoriaus pora panaudoti kaip jutiklis. Atspindžio principu veikianti optinių jutiklių pora buvo panaudota registruoti duomenims normalių audinių ir patinimo atveju. Optinių jutiklių pora, TLC556 laikmatis ir skaitmeninis osciloskopas panaudotas signalams registruoti. Kiauliena naudota modeliuojant normalų ir patinusį audinį eksperimentų metu. Skirtumai tarp abiem atvejais užregistruotų signalų buvo panaudojami galimai edemos dekcijai.

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List of abbreviations

RBC - Red Blood Cells

WBC - White Blood Cells

ECG - Electrocardiogram

BIZ - Bio-Impedance measurements

NIR - Near-Infrared

EM - Electromagnetic

LED - Light Emitting Diode

ECW - extracellular water

ICW - intracellular water

TBW – Total Body Water

FFM - fat-free-mass

Introduction

Edema is the medical term for swelling. Swelling is a response of the body to injury or inflammation. When the small blood vessels become leaky, they release fluid into the nearby tissues and the extra accumulation of the fluid causes the tissues to swell resulting in Edema [1, 2].

Edema could be an indication of some serious internal health disorder [2]. Some of the severe cases of edema could be an indication of:
Heart diseases - in heart failure, an increase in venous pressure caused by ventricular systolic or diastolic dysfunction increases capillary hydrostatic pressure resulting inability of the lymphatic system to return this fluid to the vascular space. This results in edema. With left ventricular failure, this manifests as pulmonary edema; whereas with right ventricular failure, this leads to peripheral edema.

Liver and diseases - end-stage liver disease results in profound salt and water retention. Peripheral edema may become prominent in later stages. A kidney condition called nephrotic syndrome can result in severe leg edema, and sometimes whole-body edema.

Cerebral edema - is extracellular fluid accumulation in the brain. It can occur in toxic or abnormal metabolic states and conditions such as systemic lupus or reduced oxygen at high altitudes. It causes drowsiness or loss of consciousness.

Macular edema - is swelling or thickening of the eye's macula, the part of eye responsible for detailed, central vision. Edema surrounding the eyes is called periorbital edema or eye puffiness. The periorbital tissues are most noticeably swollen immediately after waking, as a result of the gravitational redistribution of fluid in the horizontal position.

Pulmonary edema - is a condition caused by excess fluid in the lungs. This fluid collects in the numerous air sacs in the lungs, making it difficult to breathe. Pulmonary edema occurs when the pressure in blood vessels in the lung is raised because of obstruction to the removal of blood via the pulmonary veins. This is usually due to failure of the left ventricle of the heart. It can also occur in altitude sickness or by inhaling of toxic chemicals. Pulmonary edema produces shortness of breath.

Lymphedema - results from impaired lymphatic transport leading to the pathologic accumulation of protein-rich lymphatic fluid in the interstitium. Abnormal removal of interstitial fluid is caused by failure of the lymphatic system. It is most commonly due to a failure of the pumping action of muscles due to immobility.

Symptoms of edema depends upon the amount of edema and the body part affected. Edema in a small area from an infection may cause no symptoms at all. On the other hand, a large local allergic reaction may cause edema affecting the entire arm. Here, tense skin, pain, and limited movement can be symptoms of edema. Leg edema of any cause can cause the legs to feel heavy and interfere with walking. If the leg edema is due to a heart disease, the legs may easily weigh an extra 5 or 10 pounds each. Severe leg edema can interfere with blood flow, leading to ulcers on the skin. Pulmonary edema causes shortness of breath, which can be accompanied by low oxygen levels in the blood. Symptoms of macular edema may include blurred or wavy central vision and/or colors appear "washed out" or changed. Swelling or puffiness of the tissue directly under the skin, stretched or shiny skin, skin that retains a dimple after being pressed for several seconds, increased abdominal size are some of the symptoms.

A medical procedure is strictly defined as non-invasive when no break in the skin is created and there is no contact with the mucosa, or skin break, or internal body cavity beyond a natural or artificial body orifice. There are many non-invasive procedures, ranging from simple observation, to specialized forms of surgery. Some of the diagnosis performed for edema by non-invasive methods are: Chest X-ray, Pulse oximetry, ECG, Echocardiogram, Pulmonary artery catheterization, Cardiac catheterization. Some of these tests helps in identifying pulmonary edema.

1. Literature Survey

Body fluids of human body can be divided into fluid compartments. The two main fluid compartments are the intracellular and extracellular compartments [3, 2]. Total body water is divided between the intracellular and extracellular spaces. The intracellular compartment is the space within the organism's cells; it is separated from the extracellular compartment by cell membranes. About two thirds of the total body water of humans is held in the cells, mostly in the cytosol, and the remaining is found in the extracellular compartment.

The extracellular fluids may be divided into three types:

- interstitial fluid in the "interstitial compartment" (surrounding tissue cells and bathing them in a solution of nutrients and other chemicals)

- blood plasma and lymph in the "intravascular compartment" (inside the blood vessels and lymphatic vessels)
- transcellular fluid such as ocular and cerebrospinalfluids in the "transcellular compartment"

The extracellular space, which comprises about one third of total body water, is composed of the intravascular plasma volume (25%) and the extravascular interstitial space (75%) [2].

Capillaries are the smallest blood vessels in the body and they are very delicate. They are responsible for the exchange of material (nutrients and oxygen) between bloodstream and the tissues [4] . Interstitial fluid is important as it surrounds the cells and it determines the transportation of nutrients from blood to cells and returns the waste.

Capillaries have RBC, WBC, platelets and plasma. Interstitial fluid consists of water, oxygen, hormones, fatty acids, sugar, salt, carbon di oxide. Cells consume oxygen. Oxygen is supplied from RBC to plasma to interstitial fluid and finally to the cells and tissues. Cells consume oxygen and accumulates carbon-di-oxide. This accumulated carbon-di-oxide is sent from the cells to interstitial fluid back to plasma and the RBC and flushed out of the body.

The hydrostatic pressure and osmotic pressure influences the amount of fluid exchange between the capillaries and interstitial spaces - fig 1 indicates the capillary forces. Fenestrations are the pores present in the capillaries which favours the exchange of material. Capillary damage can occur during accidents and this leads to larger fenestrations and causes imbalance in the flow of fluid resulting in edema. When capillary breaks it leaks fluid to surrounding tissue causing edema.

Interstitial fluid consists of water, oxygen, hormones, fatty acids, sugar, salt, carbon di oxide. Out of which the water is the major constituent in interstitial fluids. When capillary break occurs, excess fluid is accumulated in the interstitial spaces that causes swelling.

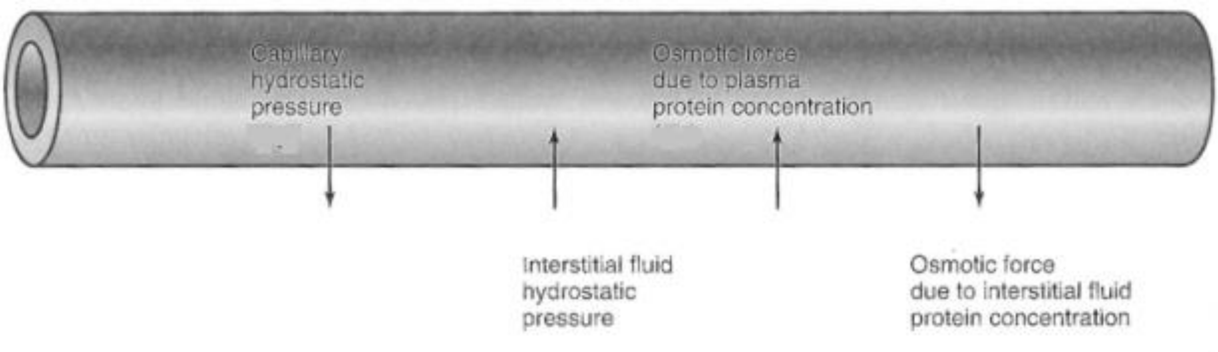

fig 1: Diagram indicating capillary forces

Because the tissues constituting the interstitium easily accommodate several liters of fluid, a patient's weight may increase nearly 10% before pitting edema is evident. The source of this expansion of interstitial fluid is the blood plasma. Because normal blood plasma is only about 3 litres, the diffusion of large amounts of water and electrolytes into the interstitial space necessitates the renal retention of sodium and water to maintain hemodynamic stability. Hence, blood volume and normal osmolality are maintained despite movement of large amounts of fluid into the extravascular space [2].

1.1 Changes in skin properties due to edema

- Skin is anisotropic and viscoelastic system.
- Edema reduces the elasticity of skin. If the edematous region is pressed, it would cause pit in the respective area. The pit disappears slowly indicating that the skin has become stiffer and shows resistance to come back to the original position [5].
- Skin properties depends on skin thickness, skin temperature and skin barrier perturbation.

1.2 Existing methods to detect edema

Edema detection at present is done only by few techniques which are not very reliable. Measurements to quantify edema have lagged behind other quantitative medical assessments. Below are some of the methods used presently.

1.2.1 Assessment by measuring "Pitting"

The main types of classification of edema is shown in table 1 [6]. Peripheral edema results from the build up of interstitial fluid that reduces the elasticity of the tissue and increases its resistance to applied pressure. When pressure is applied to edematous tissue, it remains depressed for several seconds before returning to its original state, a phenomenon known as "pitting" [7]. Clinicians currently assess edema by observing the pitting response after depression with a fingertip, rating edema severity using a scale from 1 (least severe) to 4 (most severe). These evaluations are subjective and often inconsistent with assessments made by other specialists, reducing the accuracy of diagnosis and making the measurements difficult to communicate to other clinicians. Currently, no medical devices are in the market to facilitate the assessment of edema, and clinicians are unaware of any other commonly used medical devices that have been successfully adapted to measure properties of edematous tissue [5]. Below are some of the grading methods and decisions used in deciding the severity of pitting edema. Picture of assessment of pitting edema is shown in fig 2 and table 2 shows the grade and descriptions used in grading method 1. table 3 and table 4 Shows the grade and descriptions used in grading method 2 and grading method 3 respectively.

Edema Types	Description
Cutaneous edema	It occurs when a small area gets pressurized and the indentation continues even after the pressure is removed.
Peripheral pitting edema	It is a common type which comes about when there is water retention and can be caused by various conditions like heart failure, pregnancy or diseases.
Non-pitting edema	It is where indentation is not persistent and is associated with conditions like myxedema, lipedema ad lymphedema.

table 1: Classification of Edema *[6]*

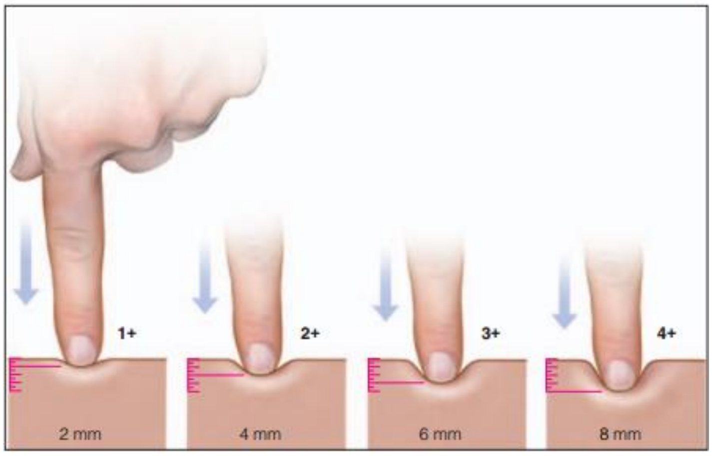

fig 2:Assessment of pitting edema *[6]*

Grade	Definition
1+ (+)	2mm or less: slight pitting, no visible distortion, disappears rapidly.
2+ (++)	2-4mm indent: somewhat deeper pit, no readably detectable distortion, disappears in 10-25 seconds.
3+ (+++)	4-6mm: pit is noticeably deep. May last more than a minute. Dependent extremity looks swollen and fuller.
4+ (++++)	6-8mm: pit is very deep. Lasts for 2-5 minutes. Dependent extremity is grossly distorted.

table 2: Grading method 1 – Dent depth and duration *[6]*

Grade	Definition
1+	There is a barely detectable 2mm depression. Immediate rebound.
2+	There is a 4mm deep pit. A few seconds to rebound.
3+	There is a 6mm deep pit. 10-12 seconds to rebound.
4+	There is an 8mm deep pit (very deep). >20 seconds to rebound.

table 3: Grading method 2 - Dent depth and rebound *[6]*

Grade	Definition
Absent	There is no edema
1+	Mild: Both ankles/feet
2+	Moderate: Both feet, hands, lower arms and lower legs
3+	Severe: Generalized bilateral pitting edema, which includes both legs, arms, feet and face.

table 4: Grading method 3 - Overall severity of edema *[6]*

There are few types of edema where pitting does not occur. It is known as non-pitting edema. If a patient has non-pitting type of edema, the indendation due to the pressure on the affected area doesnot persist. In myxedema, for example, the tissues are gradually filled with water-loving molecules such as hyaluronan, a carbohydrate-like molecule. These molecules are responsible for attracting fluid to the tissues. They absorb water and swell up to cause edema. The osmotic pressure generated by this action is most likely to be the reason why this type of edema presents as non-pitting edema . The osmotic pressure would make the affected area appear taut and feel turgid. Non-pitting edema usually affects the legs or arms [8].

The diagnosis of pitting and non-pitting edema is determined by their symptoms. The doctor will examine the skin over the swollen area to check whether it is stretched or shiny. He may also apply pressure on the swollen area to see if it leaves an indentation. Additional medical examinations such as a blood test, urine test, a chest X-ray, and ECG may also be performed to verify the cause of the edema.

Treatment of pitting and non-pitting edema depends on the causes of edema and whether it is temporary or permanent. The initial treatment usually focuses on eliminating the condition that causes it. Treatment may also involve positioning the affected body parts to improve drainage.

For example, swelling in feet or ankles may be reduced by having the person lie down in bed or sit with the feet propped up on cushions. Intermittent pneumatic compression can be used to pressurize tissue in a limb, forcing fluids to flow out of the pressurized area [8].

1.3 Methods presented by researchers

Below are some of the methods presented by researchers for quantitiative examination of edema:

1.3.1 Bio-impedance measurements

The measurement of body fluid volumes, extracellular water (ECW), intracellular one (ICW) and their sum, total body water (TBW) is important in many pathologies. TBW is strongly related to fat-free-mass (FFM) which contains, in healthy individuals, an average of 73.2% of water [9]. Bioimpedance techniques have been used for monitoring cardiovascular functions, assessing total body water, detecting blood flow through limb segments, etc. These techniques measure the overall bulk resistance of the thorax, body or limbs, using either two or four electrodes and cannot, therefore, provide information on conductivity changes originating from a specific region of the medium. Recently, multiple impedance measurements from arrays of 16 or 32 electrodes have been used to reconstruct the conductivity distribution of a body region by Electrical Impedance Tomography, Conductivity changes associated with cardiac, respiratory or digestive activity have been imaged in this way. The approach used can be compared to designing a matched filter that is especially sensitive to conductivity changes occurring in the subcutaneous layer of the forearm. Reconstruction is based on linear approximation to the relationship between boundary voltage changes and perturbations in a region of the medium [10] [11].

1.3.2 Measurement of volume

Inserting the inflamed paw in a tube of fluid elevates the fluid level, and test and control levels can be compared. a cylinder of fluid cylinder is placed on a sensitive digital balance and the forces necessary to insert the paw into the fluid column, before and after induction of edema, are compared [12].

1.3.3 Diffuse reflectance spectra

Water absorption is very low in the visible spectral range – that is why visible spectral range can be used for different medical applications, and it is often called “medical window”. Water absorption increases in the near-infrared spectral range with the first relatively noticeable absorption peak being at ~980 nm. As non-expensive silicon detectors have some (although little) spectral sensitivity also at ~980 nm, the first idea would be to try to use spectral bands of 980 nm and, for example, 650 nm for determination of water content in a sample (or skin). A much more noticeable water absorption peak in the near-infrared range, comparing to 980 nm peak, is at 1450 nm, so that could be used for this study. Water is a diffuse medium, hence some part of the incident light wll be captured by the detector. Absorbance is calculated using beer-lambert‘s law. Spectral sensitivities are plotted [13].

1.4 Aim of work

- Study about edema, its severity, causes and symptoms
- Study the existing methods used to detect edema and hence understand the purpose of the work i.e., there is presently no proper quantitative method to assess edema
- Identify a suitable non-invasive method which can possibly detect edema
- Design a circuit for data acquisition
- Model edematous and non-edematous tissues to perform experiments
- Conduct experiments to identify the differences in the suggested model
- Plot the graphs in Matlab to view the differences

2. Research Methodology

The research methodology used here is Optical Method to Detect Edema. A possible solution to the problem is tried by using Infrared LED and phototransistor pairs as sensors to identify the problem. Near-infrared light has the ability to pass through biological tissue such as skin, bone and muscle, and with less scattering than shorter wavelengths of light. Like other optical measures, light is exposed to the region of interest and undergoes scattering and absorption before being detected by a photosensor. Near-Infrared spectroscopy can be used to investigate more superficial tissues (e.g., the cutaneous circulation) by simply investigating tissue reflectance rather than absorbency [14].

Optical method to determine Edema is used for my project based on a paper which used near-infrared (NIR) spectroscopy as a non-invasive method for detecting cutaneous edema. It is stated in the paper that water has stronger light absorption property in the NIR spectral region than in the visible spectral region, the NIR reflectance of skin tissue should be more sensitive to the change in tissue water content than the visible reflectance. This characteristic could be used for detecting small changes in tissue water content with associated edema. Since the NIR absorption by water would be too strong beyond 1300 nm, only the spectral region between 980 nm and 1300 nm was selected for detecting edema in skin tissue [13].

The main element to be detected is excess water in edematous regions. The sensor used for the purpose is reflective optical sensors. A schematic of the reflective optical sensors is shown in fig 3.

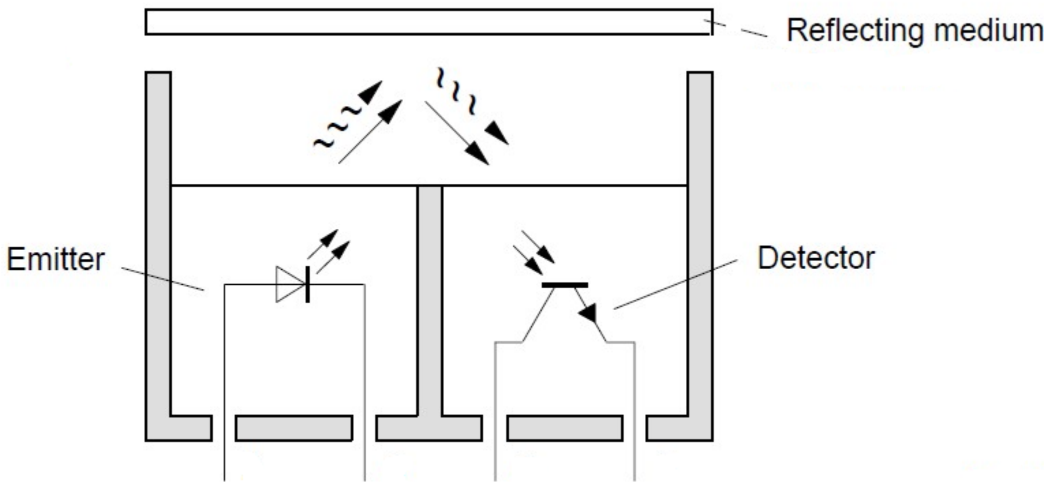

fig 3: Schematic of Reflective Optical Sensors

An optical sensor is a device that converts light rays into electronic signals. Similar to a photo resistor, it measures the physical quantity of light and translates it into a form read by the instrument. One of the features of an optical sensor is its ability to measure the changes from one or more light beams. This change is most often based around alterations to the intensity of the light. Optical sensors can work either on the single point method or through a distribution of points.

2.1 Infrared radiation

Electromagnetic spectrum is the range of all possible frequencies of the Electromagnetic (EM) radiation. The details of wavelength and frequency are given in table 5. The EM spectrum constitutes of Gamma Rays, X-rays, Ultraviolet, Visible light, Infrared (IR), Microwave and Radiowave. The IR region of the Spectrum is classified into 3 areas: Near Infrared – 750nm to 2.5µm, Mid IR – 2µm to 5µm, Far IR – 5µm to 15µm. Infrared (IR) is invisible radiant energy, electromagnetic radiation with longer wavelengths than those of visible light, extending from the nominal red edge of the visible spectrum at 700 nanometers (frequency 430 THz) to 1 mm (300 GHz) . Most of the thermal radiation emitted by objects near room temperature is infrared. Infrared spectroscopy examines absorption and transmission of photons in the infrared energy range [15].

Name	Wavelength	Frequency (Hz)
Gamma ray	less than 0.01 nm	more than 30 EHz
X-ray	0.01 nm – 10 nm	30 EHz – 30 PHz
Ultraviolet	10 nm – 400 nm	30 PHz – 790 THz
Visible	400 nm– 700 nm	790 THz – 430 THz
Infrared	700 nm – 1 mm	430 THz – 300 GHz
Microwave	1 mm – 1 meter	300 GHz – 300 MHz
Radio	1 mm – 100,000 km	300 GHz – 3 Hz

table 5: wavelength and frequency of electromagnetic radiation

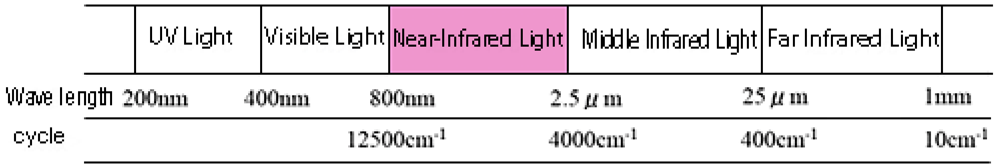

fig 4: NIR light region *[16]*

However, near-infrared light absorption is much weaker in intensity as compared with mid-infrared light absorption. Various methods of near-infrared absorption measurement are known, such as the transmittance and diffuse reflectance methods.

Water absorbs a wide range of electromagnetic radiation with rotational transitions and intermolecular vibrations responsible for absorption in the microwave (~1 mm - 10 cm wavelength) and far-infrared (~10 μ - 1 mm), intramolecular vibrational transitions in the infrared (~1 μ- 10 μ) and electronic transitions occurring in the ultraviolet region (< 200 nm). Infrared Source is the best optical source suited for skin. Due to the property of the NIR reflections in water, a wavelength of 950 nm was chosen for the IR emitter and a corresponding phototransistor was chosen as the reflective optical sensors [16] [17].

A relation between wavelength and frequency is shown is equation (1).

$$\lambda \cdot f = c \tag{1}$$

where λ- wavelength, f- frequency, c- speed of electromagnetic radiation-3×10^8 m/s.

Absorption - ratio of absorbed radiation by an object to incoming radiation.
Emissivity- emitted radiation of an object compared to the radiation from a black body source.
Reflection - ratio of radiation reflected by the object and incoming radiation.
Transmissivity - gases and solid states have different transmissivities. Transmissivity describes the level of infrared radiation, which permeates the object.

A grey body is an object, which has the same emissivity at all wavelengths and emits less infrared radiation than a black radiator (ε < 1). Bodies with emissivities, which depend on the temperature as well as on the wavelength, are called non grey or selective bodies (e.g. metals). Only few bodies meet the ideal of the black body. Many bodies emit far less radiation at the same temperature. The emissivity ε defines the relation of the radiation value in real and of the black body. The infrared sensor receives the emitted radiation from the object surface, but also reflected radiation from the surroundings and perhaps penetrated infrared radiation from the measuring object, as shown in equation 2:

$$\varepsilon + \rho + \tau = 1 \tag{2}$$

where,

ε - Emissivity

ρ - Reflection

τ – Transmittivity

Most bodies do not show transmissivity in infrared, therefore for infrared, equation 3 is applicable.

$$\varepsilon + \rho = 1 \tag{3}$$

This fact is very helpful as it is much easier to measure the reflection than to measure the emissivity. A black body is a radiator, which absorbs all incoming radiation. It shows neither reflection nor transmissivity i.e., $\alpha = \varepsilon = 1$ (α absorption, ε emissivity). A black body radiates the maximum energy possible at each wavelength. The concentration of the radiation does not depend on angles [17].

2.2 Project Schematic

fig 5 shows the overall block diagram of the project. The reference signal and sample signal is obtained by directing IR radiation on the subject of study. This is clearly shown in fig 6. The reference signal is obtained from the healthy region of the body and it is used as the reference for measurement. The Sample signal is obtained from the affected area. Difference between these two sample and reference signal can be recorded from the oscilloscope or viewed on oscilloscope and stored in PC. Conclusions are made using the visible differences in the amplitude of the signal be made. If the region is affected, the severity can be measured by the amplitude of the sample signal indicating the extent to which the cells and tissues are inflated.

fig 5: Overall block diagram of the project

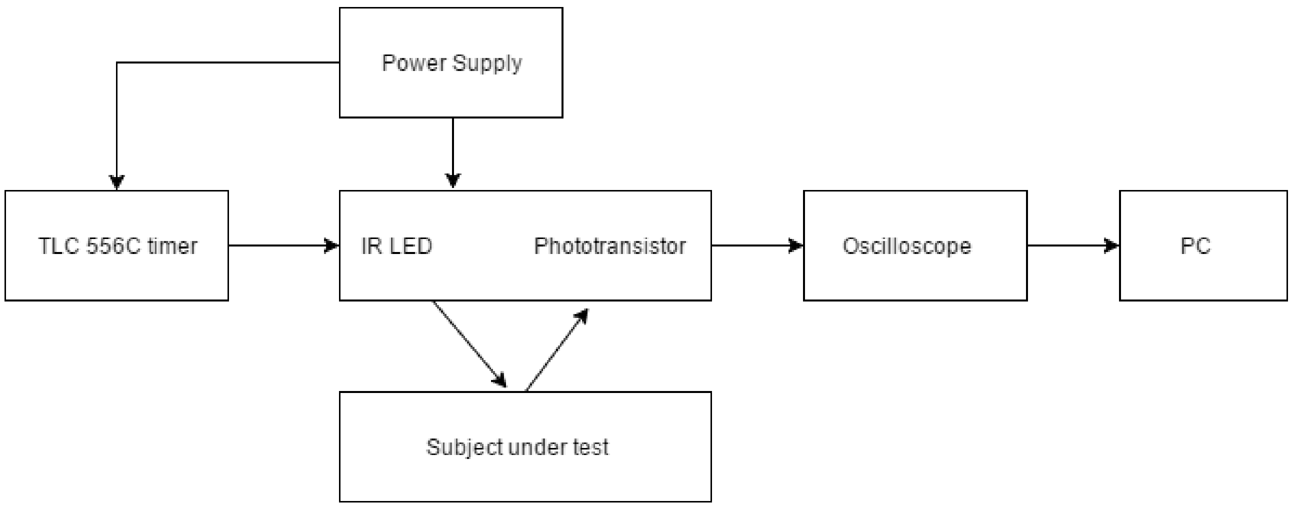

fig 6: Data acquisition of reference and sample beam

2.2.1 Scheme to connect sensors

The sensors cannot be connected to the power supply directly. Hence a protection scheme for sensors is designed. fig 7 shows the scheme designed to connect the sensors.

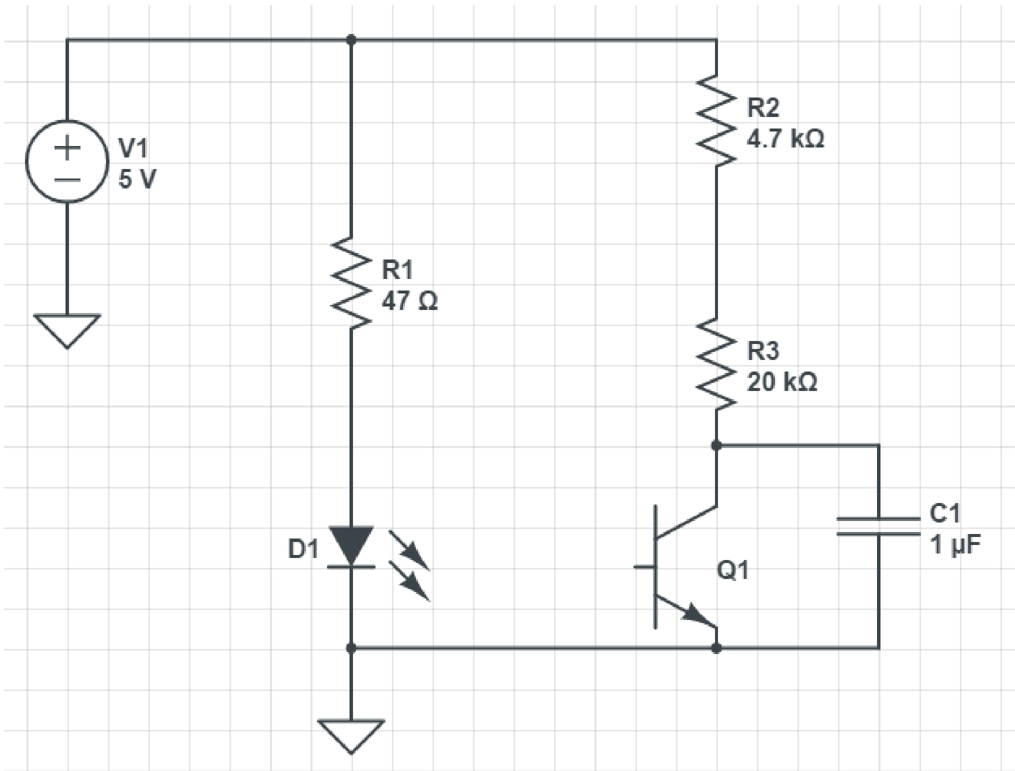

fig 7: Initial scheme to connect the sensors

The resistor values for the scheme was decided as follows:

If a supply voltage of 5V is provided, the voltage required for the LED is 1.5V.

V= 5-1.5 = 3.5V

Using the datasheet, the current limit is 80mA. Hence by using Ohm's law:

R = V/I = 3.5/0.08 = 47Ω

Similarly at the phototransistor end, 4.7 ohms was chosen. When the circuit was connected and tested lot of noise was present along with the required signal, capacitor was connected across the output terminal to get better output.

Due to the high sensitivity of the sensor, switching the LED light was required. Hence a timer was implemented as shown in the fig 8 . The timer is designed to be in astable mode. Astable mode can be used to make an LED flash on and off. in astable mode, the 555 timer produces an accurate pulse frequency that can be adjusted depending on the values of two resistors and one capacitor in an external circuit. The Output pin of timer cannot be connected directly to the LED. Hence based on the current limit specifications and the input voltage, sufficient amount of resistance should be given and a transistor is used in the circuit as it will help the LED to switch.

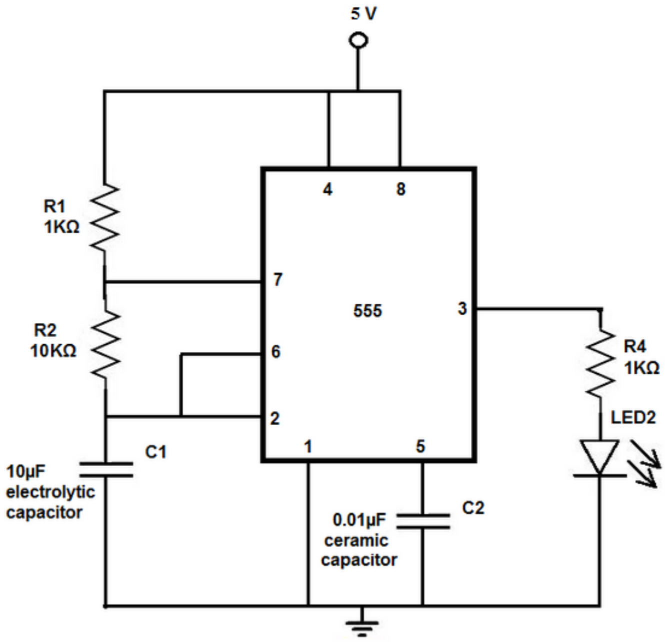

fig 8: Circuit of a 555 timer

Pin numbers indicate:

1 – ground

2 – trigger

3 – Out

4 – Reset‘

5 – control

6 – threshold

7 – discharge

8 – Vcc

Timer circuit

For 50% duty cycle,

R_1= 1 kΩ; R_2=10 kΩ; C_1 = 10 µF; C_2 = 0.01 µF; R_4 = 1 kΩ

$T = 0.7 (R_1 + 2 R_2) * C_1 = 0.147s$

$T_{high} = 0.7 * (R_1 + R_2) * C_1 = 0.077s$

$T_{low} = 0.7 * R_2 * C_1 = 0.07s$

Duty cycle, D = T/P *100 = 52%

f = 1/T = 6.8 Hz

where T_{high} is the length of the ‚on‘ output pulse in seconds, and T_{low} is the length of the ‚off‘ output pulse in seconds. R_1 and R_2 are the resistance values in Ohms of resistors 1 and 2 respectively, and C_1 is the capacitance in Farads of capacitor 1. Overall circuit diagram of the project is as shown in fig 9.

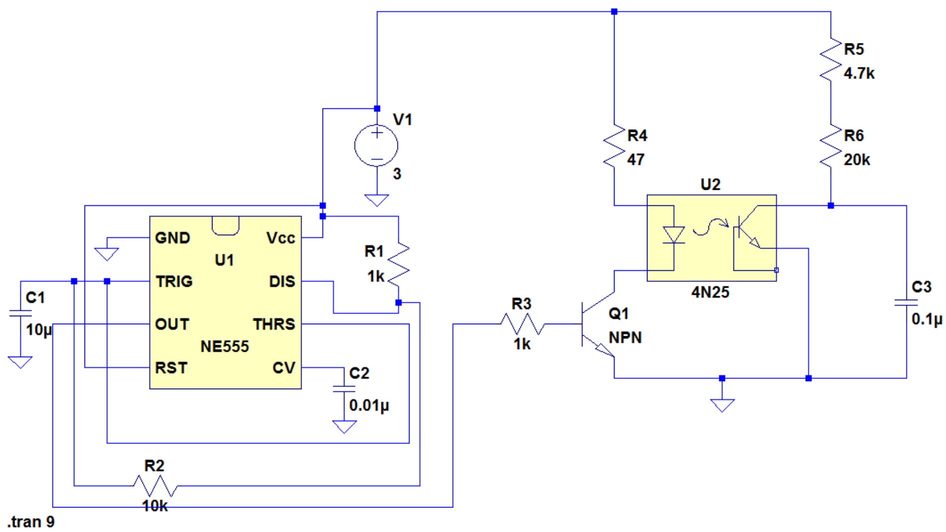

fig 9: Overall circuit diagram

2.2.1.1 Components used

Below are the list of components used for construction of circuit:

a) TSUS4300 – IR Emitting diode

- TSUS4300 is an infrared emitting diode in standard GaAs on GaAs technology. Its lens provides a high radiant intensity without external optics.
- Peak wavelength λp = 950 nm

- Angle of half intensity $\phi = \pm 16°$
- Forward current, I_F =100 mA

b) SFH320 – Silicon NPN Phototransistor

- Specially suitable for applications from 380nm to 1150nm and of 880nm
- High linearity
- Wavelength of maximum sensitivity, 980nm

c) TLC556C timer

556 is a 14 pin dual timer but has the same working as a 555 timer.

- trigger level approximately one-third of the supply voltage and a threshold level approximately two-thirds of the supply voltage.

d) SDS1000 digital oscilloscope

2.2.2 Structure designed to place the sensors

A structure was designed to place the sensors in such as way so as to get the measurements easily from the body. It was designed on solidworks and the structure was printed using makerbot 3-D printer. fig 10, fig 11 and fig 12 shows the top view, side view and the final design of the structure. All the dimensions are indicated in mm.

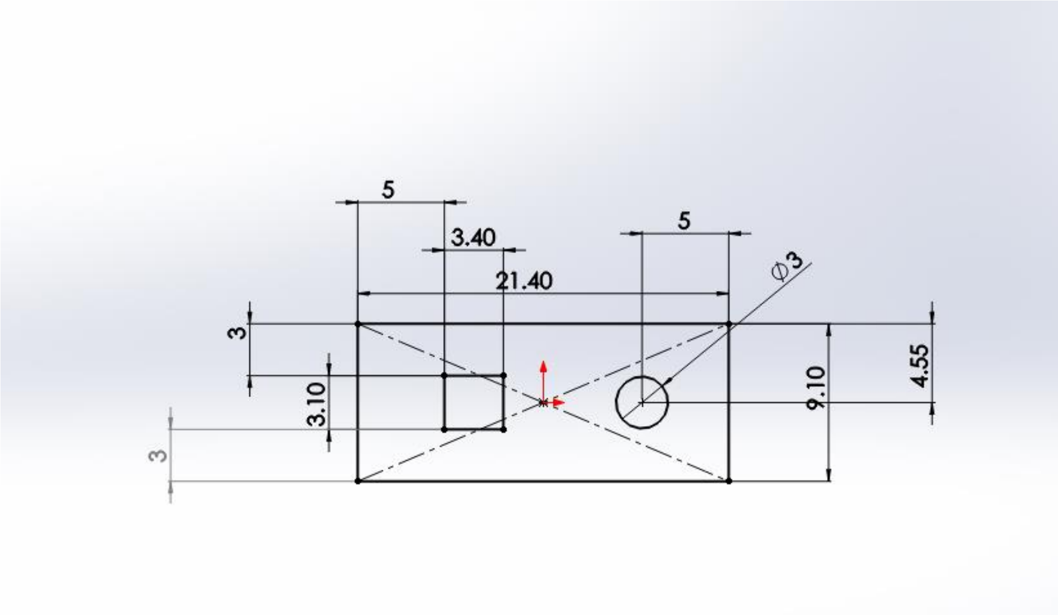

fig 10: Top view of solidworks scheme

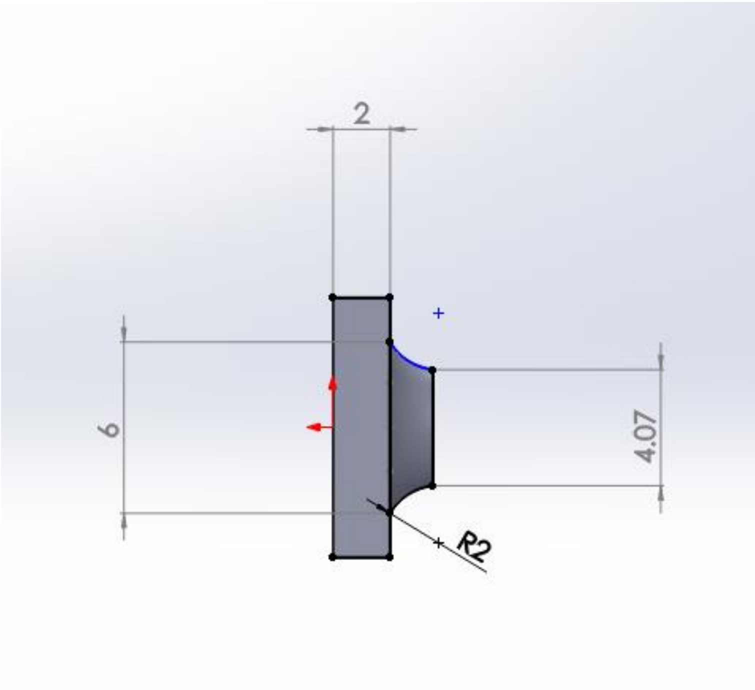

fig 11: Side view of solidworks scheme

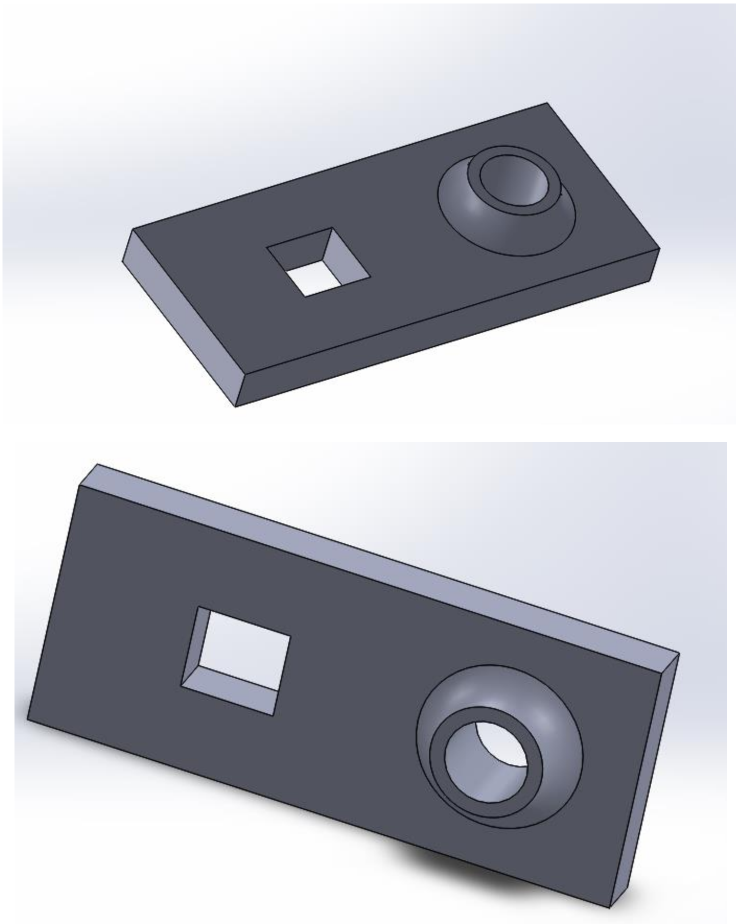

fig 12: Final design of structure on solidworks

The structure shown in was used to place the sensors in such a way that it can be placed on the body. A final snapshot of the structure is shown in fig 13. This sensor package along with the protection circuit as shown in the circuit diagram, is used for data acquisition.

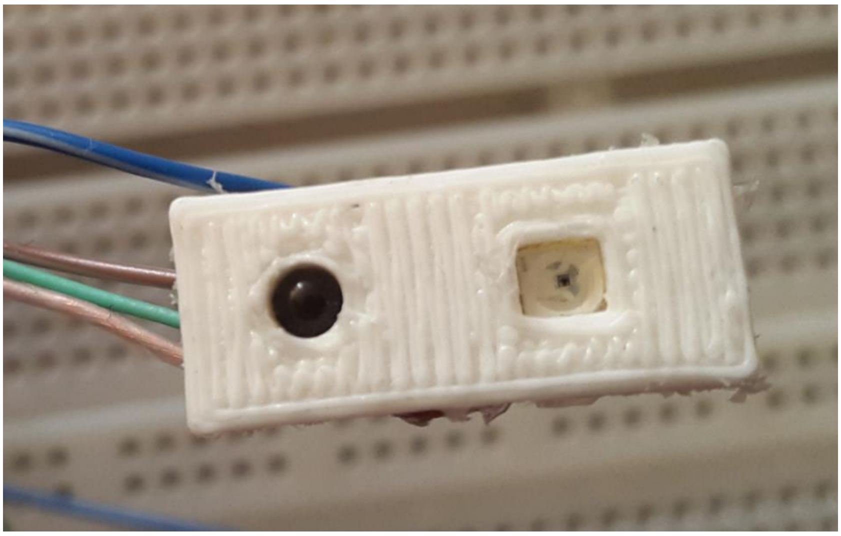

fig 13: Snapshot of Structure designed to place the sensors

2.3 Edema model

The model to represent edema is done using pig meat. Pig meat was chosen as the pig skin properties are closest to human skin properties. The porcine skin has striking similarities to the human skin in terms of general structure, thickness, hair follicle content, pigmentation, collagen and lipid composition. This has been the basis for numerous studies using the pig as a model [18]. Pig skin is composed of three major layers with different structures- epidermis (blood free layer), dermis (vascularized layer with dense irregular connective tissue with collagenous fibers) and hypodermis (adipose tissue composed of two sub-layers separated by thin connective tissue) [19, 20]. fig 14 shows the figure of different layers of skin.

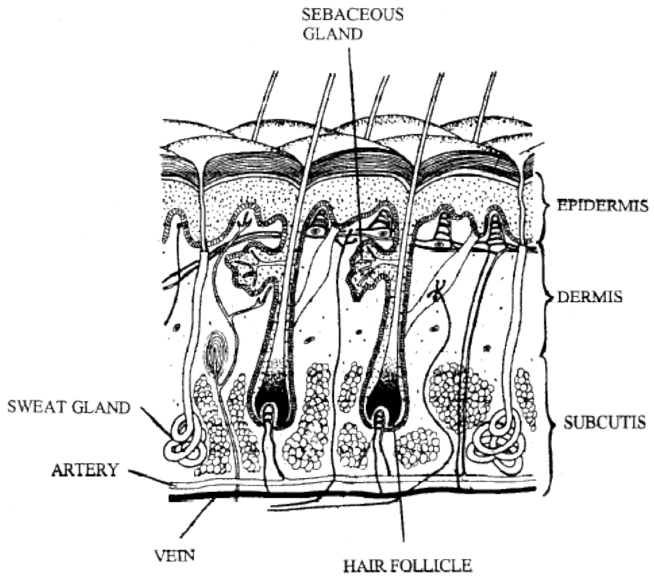

fig 14: different layers of skin

NIR radiation can penetrate into tissues offering a potential spectral window without the hazards of ionizing radiation. Light has to travel through the skin (epidermis and dermis) before reaching the target layer (subcutaneous adipose tissue), which influences the reflectance measurements. The absorption and scattering properties of the different tissue layers affect the light penetration through the pig skin.

Near infrared water detection instrument generally has two measurement methods[17-19]: transmission method and reflection method. Reflection method, namely, determine the water content of samples by detecting the reflected light intensity from the sample surface. In the band from 900nm to 680nm, the absorption of water is less and the curve of absorption tends to flat [21]. The model of the tissue being swollen is done by injecting fluids into the meat piece. Wate was injected in the meat piece as a representation of edema. Oil was injected in the meat piece to ensure that the reflections in the previous model indicates water.

Several trials of the pork meat with water, without water and with oil were tested and the results were recorded. fig 15 and fig 16 and are some of the snapshots captured while experimenting.

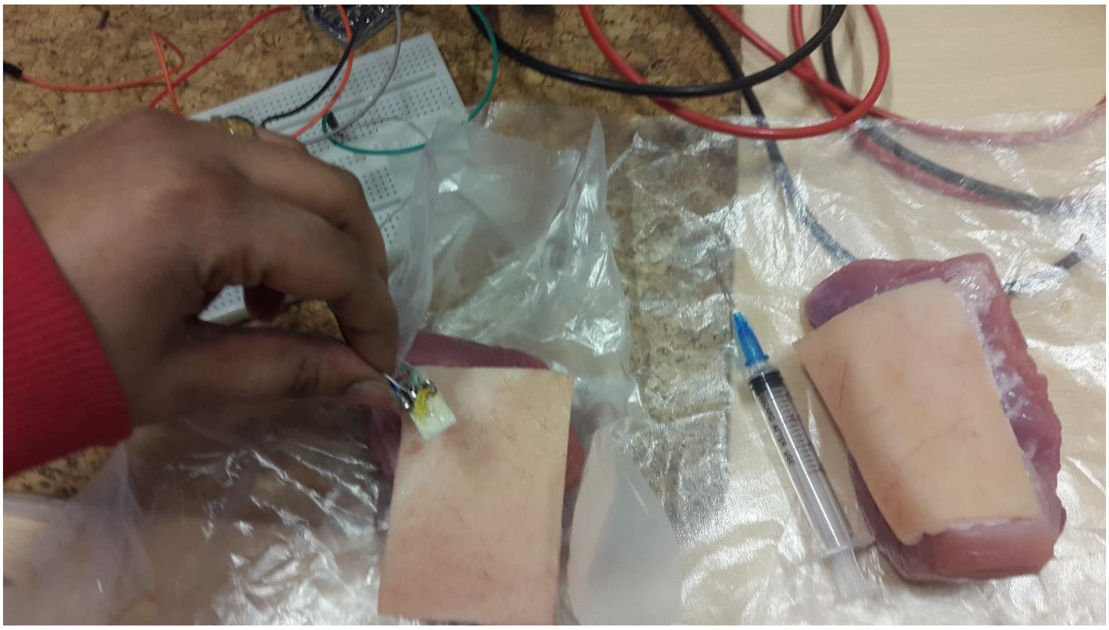

fig 15: Snapshot of conducting experiment

fig 16: Snapshot of injecting water into pork meat

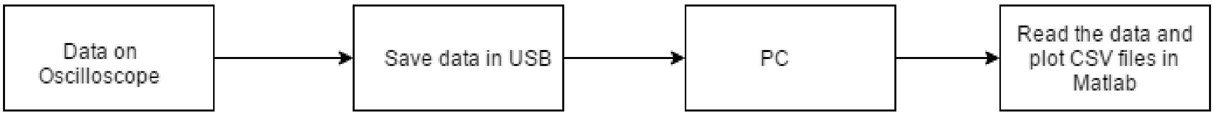

fig 17: Procedure to save and plot data

fig 17 shows the procedure to store and access data. The data collected from the sensor is seen on the oscilloscope and it is saved on the USB device. Data of 9 seconds is collected. The data is exported as a csv file and a screenshot of the signal is saved and transferred to the PC. The saved data is accessed using Matlab. A program is written on matlab to read the csv data files and to plot them as a function of time. Various trials were performed with water, without water and with oil and recorded using the procedure mentioned above. The readings are plotted on matlab and plot of reference signal, sample signals, comparison of reference and sample signals and a mean plot of all the readings are plotted to view the differences.

3. Results and Observations

Initial tests were done to check the working of the sensor and to observe the response to a surface with and without water and below are the observations. Sensor was working successfully and below are the observations noted in the oscilloscope:

- Sensor showed outputs of the reflection when kept on skin.
- Surrounding light (noise) is an important factor and it is mixing up with the refection signals from the skin.
- The difference in reflections on dry skin and wet skin was tested. There were amplitude differences in the signal when kept on dry surfaces and wet surfaces.

The signals viewed on the oscilloscope was unclear and not understandable as it was very noisy. The sensor was highly sensitive to the surrounding light and even minor motions around the sensor. The sensor was reflecting and responding to all the movements happening around it. With such high sensitivity it is very difficult to obtain only the useful signal.

To get the useful signal and in order to eliminate the noise, switching of the IR LED is done. By switching the IR LED, the useful signal acts as AC and the surrounding light and external noise which is constant, behaves like DC thus it helps in achieving noise reduction. Switching the IR LED is performed using a timer. The timer used in this experiment is IC TLC556. The timer circuit was designed to achieve 50% duty cycle with a frequency of 6.8 Hz. Due to the presence of timer in the circuit, the follwing changes were observed:

- The sensor stopped being sensitive to minor movements
- Even though noisy, the output was more understandable

The designed sensor was used in data acquisition. Several trials were performed on pork meat as pig skin property is closet to human skin. 3 types of data are collected:

Reference model: Data from pork meat
Sample model 1: Data from pork meat injected with water
Sample model 2: Data from pork meat injected with oil

Pig skin is injected with water as a representation of edema. Normal pork meat indicates a normal case. In the third type of model, the meat is injected with oil. The output signal for the the case of normal signal and signal obtained due to water injection are as shown in fig 18, fig 19. Reflective optical sensor refelects everything. From sample model no.1, there is no assurance that the acquired data indicates reflections from water. Hence a third model was used where the meat was injected with a medium which has a different density compared to water.

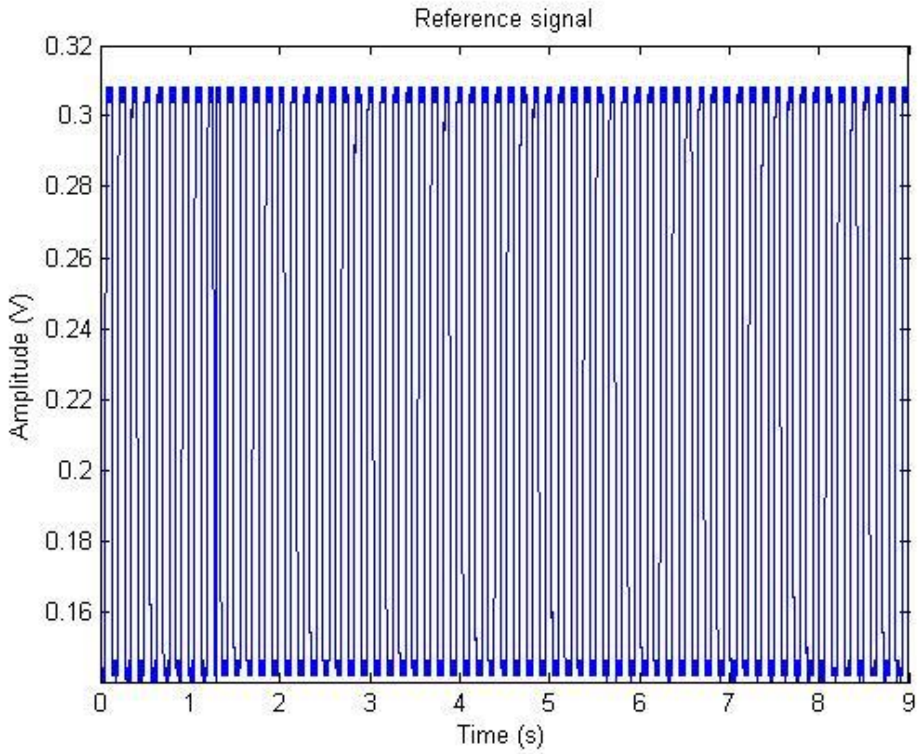

fig 18: Reference signal - without water

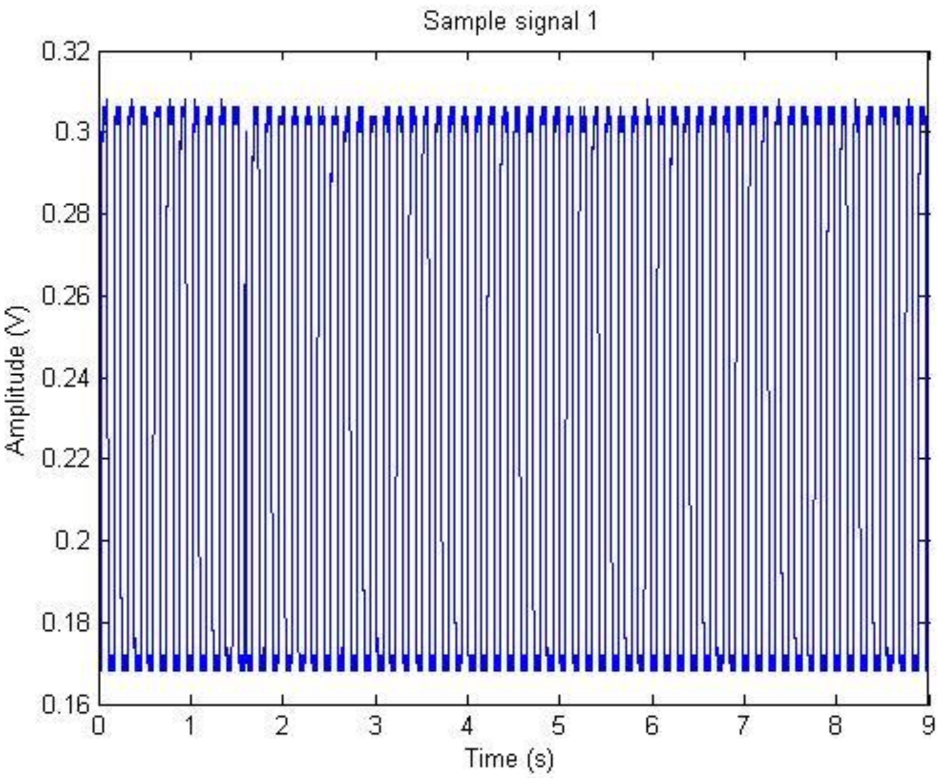

fig 19: Sample signal 1 - with water

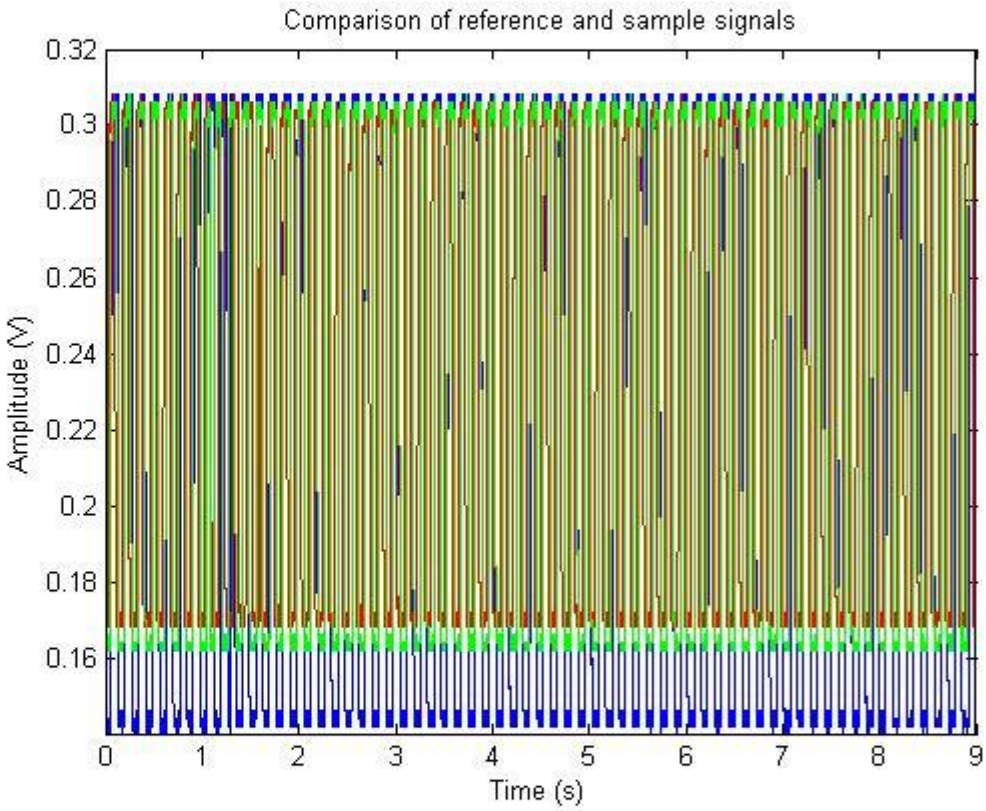

fig 20: Comparison of reference and sample signals

From the above graph, fig 20 we can observe the amplitude differences in the 3 cases. Comparing the normal pork meat (signals indicated in blue) with the pork meat injected with water (signals indicated in red), the amplitude of the signal is lesser when the pork meat is injected with water. The amplitude of the pork meat injected with oil (signals indicated in green) falls in between the normal meat and meat injected with water.

There is a difference of 20mV for signal with and without water. Several trials were conducted for capturing the real signals. By taking the average value of the collected data, the below plot fig 21 is obtained. Signals indicated in blue depicts the amplitude values of the sample with water and the signals indicated in red depicts the amplitude values of the sample without water.

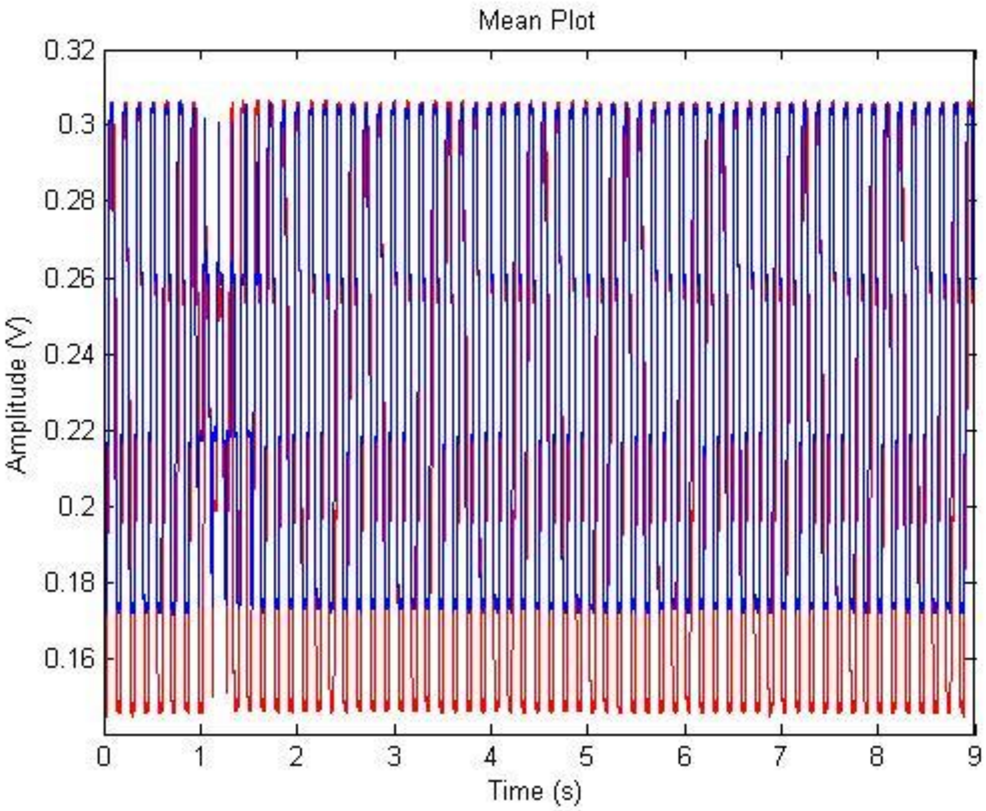

fig 21: Mean plot of values with and without water

From the average plot it can be clearly observed that there is a consistent difference of 20mV in all the trials. A comparison graph showing the values for meat piece with and without water is shown in fig 23. **Error! Reference source not found.** shows the average readings of all the trials and an average of 20mV difference is seen.

The above plotted signals are quite noisy. To reduce the noise, the following method is employed. The frequency of the TLC556 timer is approximately 7Hz due to the circuitry shown in fig 8. So the IR signals corresponding to this frequency, is the signal of interest and the other frequencies can be eliminated. Hence a lowpass filter was implemented with the cut-off frequency as 10Hz so that only the lower frequencies are allowed and the higher frequencies are eliminated. The filtered signal is as shown in fig 22.

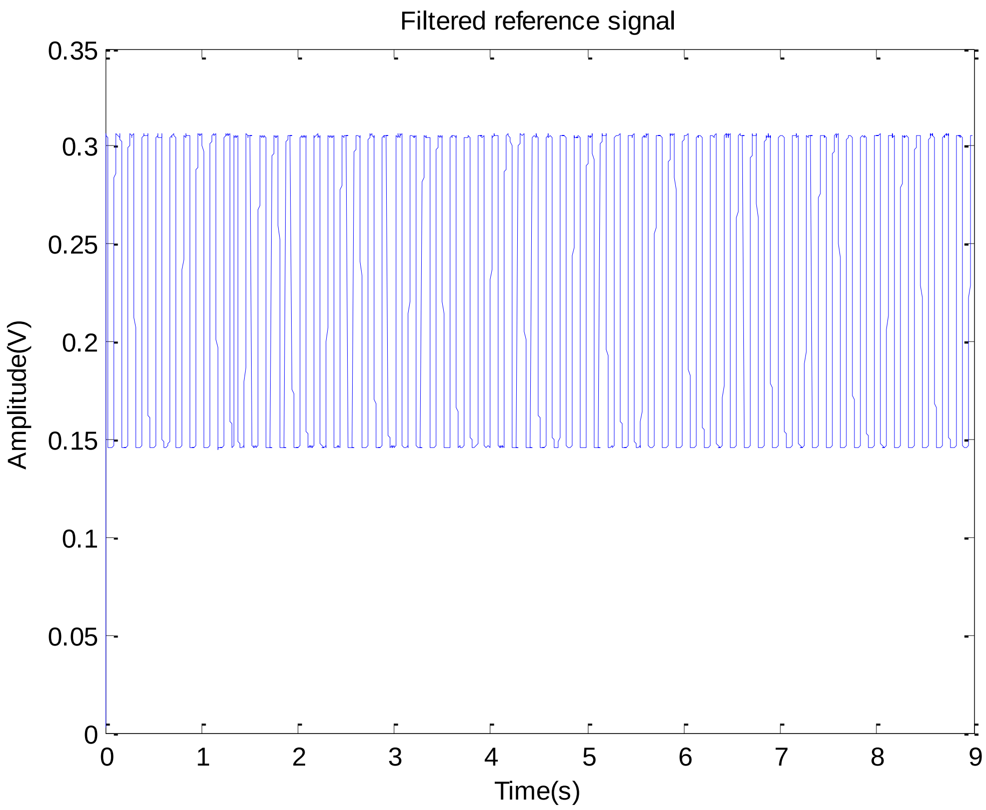

fig 22: Filtered signal using a lowpass filter

Title	without water (V)	with water (V)	difference (mV)	
Trial 1	0.16	0.157	3	(less water)
Trial 2	0.158	0.136	22	
Trial 3	0.146	0.134	12	
Trial 4	0.16	0.136	24	
Trial 5	0.158	0.142	16	
Trial 6	0.166	0.122	44	(more water)
Average	**0.158**	**0.137**	**21**	

table 6: Average values of readings of trials conducted on day 1

Title	without water (V)	with water (V)	difference (mV)	
Trial 1	0.144	0.142	2	(less water)
Trial 2	0.136	0.132	4	
Trial 3	0.148	0.132	16	
Trial 4	0.138	0.122	16	
Trial 5	0.164	0.144	20	
Trial 6	0.13	0.086	44	(more water)
Average	**0.1433**	**0.1263**	**17**	

table 7: Average values of readings of trials conducted on day 2

An input voltage of 3V is given to the sensor and readings were obtained from the oscilloscope. The amplitude of the signal in each of the trials with water and without water obtained from the oscilloscope is mentioned in the table. The difference between the voltage readings with and without water is shown in the last column.

difference (mV) = (without water – with water)*1000

the average value of each of the readings is obtained as follows:

average = (Trial 1+Trial 2+Trial 3+Trial 4+Trial 5+Trial 6)/6

Totally 30 trials were conducted on different days to test whether the values are repeatable. In all the 30 trials conducted for with water, without water and with oil in the sample, there were clear amplitude differences and the values were repeatable. The trials conducted on two different days are shown in *table 6* and table 7. By comparing the values in both the tables, it is clear that the experiments are repeatable.

Also, trials were performed to observe the changes in output with respect to the quantity of water. If the water level is lesser, the amplitude of the signal was increasing to an extent almost close to the normal signal. A 2ml syringe is used to inject water into the meat piece. fig 24 shows the amplitude change with respect to water content.

In the first trial shown in table 6 and table 7, we can observe that the difference in readings in the first trial is very less, as there is no much water injected into the model. Minimum of 4ml of water is injected for all the readings except for trial 1 with 2ml and trial trial 6 with 8ml. As the water quantity is increased, the difference between the readings have also increased.

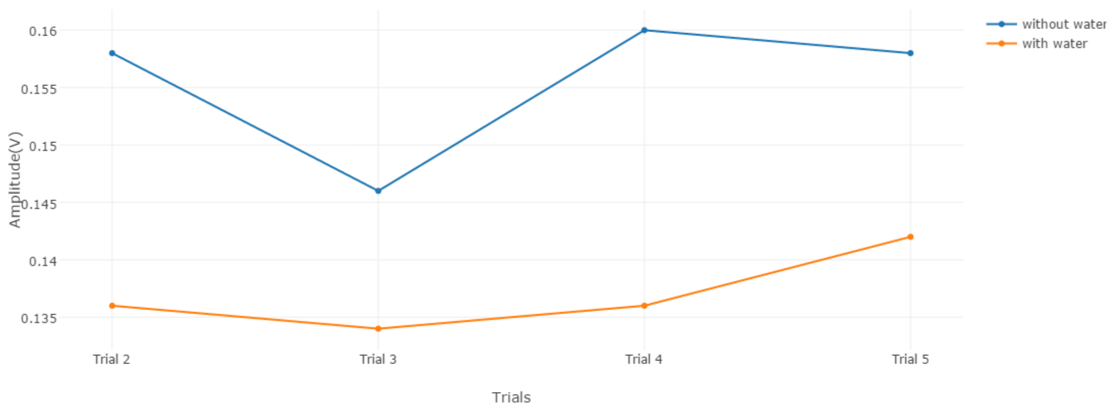

fig 23: comparison of average amplitude value across 4 trials

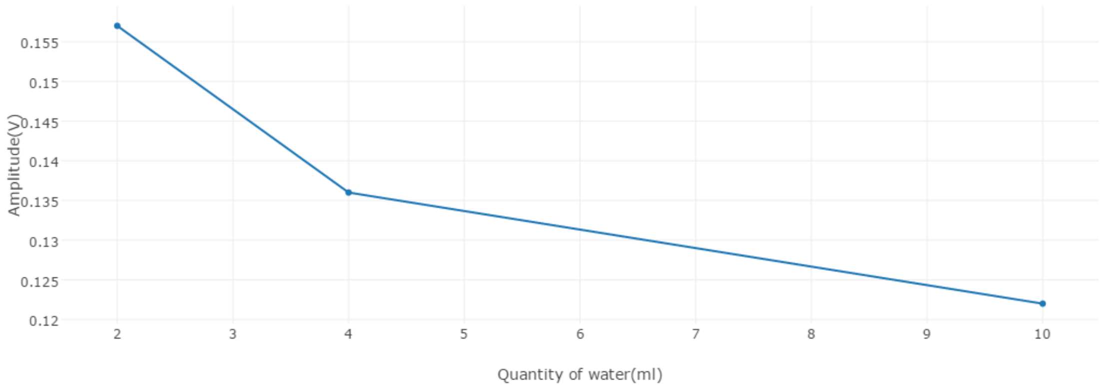

fig 24: amplitude values with respect to change in water content

The circuity used in this work can be compared to that of a TV remote control circuitry. The remote uses an IR LED to convey information. Typically a 940nm IR LED is used, which is similar to that of the wavelength used in this work. And the IR recievers used for such appliances have limited operating angle. To avoid external disturbances and to gain some immunity against ambient light, the IR sensor triggers only when a 32kHz -60kHz modulated IR signal is sent. The device can operate at this required frequency due a 555 timer working in astable mode. At the recieving end, a band pass filtering is given to accept only the range which is same as that of the handset (32 to 60kHz) and the signal is demodulated and the required information is taken [22, 23].

Such a device uses modulation and bandpass filtering to obtain accurate signals containing information. Using this concept as a basis, if the TLC556 timer is oscillated at a particular high frequency, which is quite distinct from the surrounding noise or any ambient light signals, a more accurate signal could be obatined for this experiment. The output signal obtained from the phototransistor can be filtered with respect to the frequency of interest and only the useful signal can be retained. This will help in getting much more accurate readings and gives us a better understanding of the edematous and non-edematous signals.

3.1 Advantages

- Results are more reliable
- Cost efficient compared to X-rays or other scanning techniques
- Harmless for human body when compared to X-rays or other scanning techniques
- Results can be recorded and a patients‘ history can be saved which helps in future diagnosis

3.2 Disadvantages

If practically implemented for testing on human bodies,

- Results may not have repeatability as noise factors may tamper with the actual readings
- Ensuring a good reference value for comparison with the affected area is quite challenging

4. Conclusion and future work

A study on Edema detection by electronic means is done. Present methods of detecting edema and various methods proposed by researchers in detecting edema is explained in the report. Non-invasive methods are studied as it is more preferrable than invasive method. Presently no quantitative and reliable means of measuring is present. Doctor analyses the patient by depressing their finger over the affected area which is not very reliable. Moreover, this procedure can be applied only if the type of edema is pitting. For non-pitting edema or if the patient is suffering from pulmonary edema or any such internal problems which is not visible, pitting procedure has no relevance. For non-pitting edema, diagnosis is done using X-ray, MRI or other methods of scanning which is quite expensive.

A reflective optical type of sensor for detection of edema is the methodology used in this work. IR LED of wavelength 950nm and a phototransistor pair is used as the sensor. The particular wavelength of IR radiation is used as the absorbance of radiation in water at that paticular wavelength is minimum and majority of the light thats incident will be reflected by the surface.

A protection circuit for the sensor is designed and its working is tested and the sensor works sucessfully. But due to the external noise (movement, visible light) the sensor was very sensitive. To avoid these external disturbances, timer was introduced. Signal was more understandable in this case. Edema was modelled using pig skin a) injected with water b)injected with oil. Oil which has a different density than that of water was used just to ensure the reflections are different for different materials. The amplitude of the signal for oil was different compared to that of water. Changes in readings with water content was also observed. Readings of pig meat (normal), pig meat injected with water are compared and a 20mV difference between the output signals is observed. If less quantity of water is injected, the amplitude of the signal would have very less difference compared to the normal meat piece. If the water injected is more, the amplitude differences are more. This clearly indicates that the severity of edema has been modelled and proved from the conducted experiment. Several trials were conducted on different days with different pieces of meat and the readings were noted. The readings were repeatable.

Hence instead of using “pitting“ and its grading scales as the reference to test on patients, optical methods of testing can be implemented. This type of a testing is more reliable as well as lesser in cost.

It was found that a remote control handset uses a similar ciruitry for communicating. IR remote control uses modulated signals to avoid ambient noise. A high frequency carrier wave generated by the timer in the remote control circuitry is modulated with the useful information and sent across to the receiver. Reciever filters the required band of frequencies and demodulates the useful information and performs its action. Such an idea can be possibly applied to this work to get more understanding about the skin tissues.

Future work includes extracting real signals from the human body and studying the signal behaviour. To diagnose a patient, a reference reading is required. The reference indicating the normal value of human skin tissue. If there is a database made by recording data from numerous people, this database can serve as a reference to diagnose the patients. Another possibility is to use the patients‘ body itself as a reference for ones own readings. Assuming that the skin property of an individual would be same throughtout the body, the affected areas can be detected and the severity can be identified by comparing with the normal body area.

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Appendix

Matlab code to read the data and for plotting the signals:

```
clc; clear all; close all;
%%
%Filenames of excel data

filename1='no water skin 1.csv';
filename2='no water skin 3.csv';
filename3='no water skin 4.csv';
% filename4='no water skin 5.csv';
filename5='with water skin 1.csv';
filename6='with water skin 3.csv';
filename7='with water skin 4.csv';
% filename8='with water skin 5.csv';

%%
% Call function to read the signals

[a1,b1] = readdata(filename1);
[a2,b2] = readdata(filename2);
[a3,b3] = readdata(filename3);
% [a4,b4] = readdata(filename4);
[a5,b5] = readdata(filename5);
[a6,b6] = readdata(filename6);
[a7,b7] = readdata(filename7);
% [a8,b8] = readdata(filename8);

%%
% Calculate mean value of signals
Fs=5000;
Fn = Fs/2;
fc = 10;

Wn =[fc/Fn];
B = fir1(20,Wn);
% fil1 = filter(B,1,b1);
fil2 = filter(B,1,b2);
% fil3 = filter(B,1,b3);

s1 = [b1 b2 b3];                %store data in array
```

```
s2 = [b5 b6 b7];

m1 = mean(s1,2); %mean of signals without water
m2 = mean(s2,2);    % mean of signals with water

%%
% Plot signals

testing_signals={'Signal Without Water';'Signal With Water';'Comparison of Signals with and without water';'Mean Plot'};
sigplot(a1,m1,m2,testing_signals{4,1});

function [a,b] = readdata(filename)
%UNTITLED Summary of this function goes here
%   Detailed explanation goes here

sig= xlsread(filename);
a=sig(:,1); b = sig(:,2);

end

function sigplot( a,m,n,test_signal )
%UNTITLED2 Summary of this function goes here
%   Detailed explanation goes here

plot(a,m,'r',a,n,'b');
title(test_signal);
xlabel('Time (s)');
ylabel('Amplitude (V)');

end
```