QUALITY INSPECTION OF LEATHER USING NOVEL PLANAR SENSOR

A Thesis Submitted in Fulfilment of the Requirements
for the Degree of Master of Engineering (Research)

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"This dissertation is dedicated to my Family"

ABSTRACT

Value of leather produced from sheep is determined by its quality and looseness is one of the quality attributes that determines the value of the leather. As of now, looseness in sheep skin can be determined only after the tanning process is done and it is a long and expensive process to treat the looseness in skins after the tanning process. An interdigital sensor based sensing system has been developed which works on the principle of sensing technique based on interaction of electric field with the materials under test. Finite element software has been used for analysis and design of sensors. It has been reported that a good correlation was found between the actual looseness values and calculated looseness values.

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PUBLICATIONS

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Conference Publications

1. V. Kasturi, S.C. Mukhopadhyay, G. Sengupta, "Embedded Microcontroller Aided Planar Interdigital Sensor Based property Estimation of Sheep Skin", 14th Electronics New Zealand Conference (ENZCon 2007), Victoria University of Wellington, Wellington, New Zealand, 12 – 13 November, 2007.

2. V. Kasturi, S.C. Mukhopadhyay, G. Sengupta, "Interdigital Sensors: A Review of their Applications", 2nd International Conference on Sensing Technology (ICST) Massey University, Palmerston North, New Zealand, November 26-28, 2007.

3. V. Kasturi, S.C. Mukhopadhyay, Y. M. Huang, "A Novel Bio-sensor for Non-invasive Sensing of Sheep Skin", 4th Asia Pacific Conference on Transducers and Micro/Nano Technologies (APCOT 2008), National Cheng-Kung University, Tainan, Taiwan, pp. 251 – 254, 22 – 25 June, 2008.

4. A. R. Mohd Syaifudin, S.C.Mukhopadhyay and V. Kasturi, "Smart Sensing System for Health and Environmental", Digital Signal Processing Creative Design Contest (DSP 2008), Southern Taiwan University, 29 November, 2008.

5. V. Kasturi, S.C. Mukhopadhyay, "Planar Interdigital Sensors Based Looseness Estimation of Leather ", 3rd International conference on sensing technology, National Cheng-Kung University, Tainan, Taiwan, pp. 462 – 466, Dec 1 – Dec 3, 2008.

Journal Publications

1. V. Kasturi, S.C. Mukhopadhyay, T. Allsop, S. Deb Choudhury, G. E. Norris, "Assessment of pelt quality in leather making using a novel non-invasive sensing approach", Journal of Biochemical and Biophysical methods, Volume 70, issue 6, pages 809 – 815, 24 April, 2008.

Textbook Publications

Work is published in the Sensors book by Springer.

1. S. C. Mukhopadhyay, Y. M. Huang, "Estimation of Property of Sheep skin to Modify the Tanning Process", Sensors: Advancements in Modeling, Design Issues, Fabrication and Practical Applications - Springer, pp. 91 – 112, July 2008.

Presentations

1. Participated in IEEE pacific zone seminar, December 2007.
2. Presented my research work at IEEE Postgraduate student presentation day, August 2008.

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CHAPTER 1

INTRODUCTION

1.1. Introduction

In this research, interdigital sensors were used to identify the looseness characteristics of sheep skins in a non-destructive or non-invasive way. Non-Destructive Testing (NDT) is important as it would not alter the chemical or physical properties of the material under test. Non-Destructive Testing is used in various fields which are explained in detail in the nest section.

1.2 Non-Destructive Evaluation

NDT is applied at almost any stage in the production or the lifecycle of components. In this report, we developed an interdigital sensor based sensing system that could measure the looseness in sheepskin in a non-destructive and non-invasive method. Materials and manufactured products are usually tested before delivery to ensure their performance, safety, durability and quality. In some scenarios, the materials and products need to be tested, not only at the production stage but also at specified intervals during their performance stage like examination of critical regions in structures and components used in aircraft that could be affected by fatigue, components used in chemical processing etc. It is essential that any test made on the product should not alter its properties or performance. Any technique which meets the above requirements can be referred to as Non-Destructive Evaluation (NDE) or also called as Non-Destructive Testing (NDT). NDE is the assessment procedure which doesn't alter the material under test physically or chemically. NDT testing has gained importance due to great change in technology where risks are high and strict precautions are required [1]. Previously, tests were limited to audible or visible inspections. Audible inspection involved striking a casting or forging with an iron bar to produce a sound to determine if a vessel or a structure got a crack or not. Requirement of fast performance and

durable materials resulted in development of new materials and redesign the structures to reduce their weight and increase strength. All the above requirements have led to widespread applications of non-destructive testing in various fields to ensure that safety limits are not exceeded [1].

Some of the reasons for conducting NDT techniques can be stated as:

- To avoid defects in the materials likely to cause failure,
- To ensure the dimensions of a component or structure,
- To determine the structural and physical properties of a material,
- To meet the health and hygiene standards,
- To avoid physical or chemical alteration of material or component under test.

NDT can be performed on metals as well as non-metals and the method of testing usually depends on factors such as the type of the material, its dimensions, position of interest within the material under test, interior or exterior defects. Some of the NDT methods are:

- Visual and Optical Testing [2,3]: Visual examination, computer controlled camera image recognition.
- Radiography testing [4]: X-rays, gamma rays and neutron beams.
- Magnetic particle testing [5]: Inducing magnetic field in a ferromagnetic material.
- Ultrasonic testing [6]: transmission and detection of ultrasonic sounds.
- Penetrant testing [7]: Coating objects with fluorescent dyes or visible dye.
- Leak testing [8]: Gauge measurement, liquid and gas penetration, soap bubble tests and electronic listening devices.
- Acoustic emission testing [9]: detection of acoustic emissions
- Electromagnetic testing [10]: eddy current inspection, remote field testing, flux leakage and barkhausen noise inspection.

For complete inspection of an object, combination of two or more above methods is generally required [1]. The most commonly used methods are ultrasonic testing, X-radiography, eddy current testing, magnetic particle inspection and dye penetrating. The international standards organizations usually give more attention to the above inspecting methods.

Some of the NDT applications in various industries include:

- Power Stations [11]: NDT can be used for inspecting generator turbine for existence of any crack, fatigue etc.
- Metal Industry [12]: for the inspection of cracks, defects and any other flaws and their characterization, wall thickness, quality assurance, fatigue estimation, determination of hardness and coating thickness testing etc in steel production and steam and pressure vessel construction.
- Petrochemical Industry [13]: used to detect surface breaking defects through paint and other coatings of various thicknesses, and then accurately size them in terms of length and depth.
- Transportation [12]: for measuring the life of the tracks in railways.
- Food Industry [14]: estimating dielectric properties of various types of meat.
- Medical Sciences [15]: To measure the thickness of coating on the tablets
- Civil Engineering [16]: Inspection of concrete structures, bridges, cracks or decrease in strength due to aging problems.
- Aviation Industry: detecting corrosion and disbonds in large areas of lap joints in aircrafts [17]. For fatigue estimation in parts of aircraft [1].
- Pipe Inspection: For inspection of pipes carrying gases [18], milk, water, oils etc.

It is evident that NDT techniques are being applied successfully in various fields. Even, picking up the fruit at regular supermarket could also be regarded as non-destructive testing which involves visual inspection. Most of the sensors can be employed in non-destructive evaluation of the materials. In the case of interdigital sensors (discussed in detail in chapter.3) the material to be tested is placed over it or arranged between its parallel plates to investigate its characteristics. In this report, non-destructive testing was extended to

inspection of properties of sheep skin during different stages (discussed in chapter.2) of converting raw pelts into finished leather using novel interdigital sensor which is explained in detail in chapter. 3.

1.3 Sensors

A Sensor is a device that measures a physical quantity and coverts it into a signal that could be read by an instrument or an observer. A sensor is capable of detecting a change in physical conditions like temperature or thermal conductivity or change in chemical concentration and they should be able to convert the detected change into a measurable unit. Sensors are an important part of any measurement or an automation application. A good sensor should be sensitive to the measured property and should not influence the measurements of material under test or its properties. Sensors are used in everyday objects such as infrared automated door openers, touch-sensitive elevator buttons and lamps which dim or brighten by touching the base. There are also innumerable applications for sensors of which most people are never aware.

When selecting a sensor following things should be considered:

- Accuracy: It should provide accurate readings
- Cost: The cost of sensor should be economical
- Range: The minimum and maximum range of the output value of sensor
- Resistance to factors affecting the sensor: The factors that influence the reading of the sensors
- Repeatability: Able to repeat the same experimental values
- Precision: Should be able to detect the smallest change in the measurement.
- Life expectancy: Sensor should have a good durability.
- Quick response: real time monitoring
- Low operation and maintenance costs
- Meets safety standards
- Continuous operation
- Ease of calibration
- Easy Interfacing: Should be adaptable to various interfacing devices

Sensors are an integral part of everyday life. Sensors may be broadly classified as thermal, electromagnetic, mechanical, chemical, optical, ionizing or acoustic types, depending upon their fabrication and the physical quantity that they measure. For example, chemical sensors respond to the change in the concentration of a chemical or recognition of a chemical [19]. Biosensors respond to the micro-organisms that either stick to it or grow on the surface of the sensors [20]. In the process of detecting or responding to certain factors, the sensors produce either a current or voltage signal. These signals often need to be conditioned before processing. The processing can be efficiently done using a digital data acquisition system.

Sensors are classified into passive and active sensors [21]. Passive sensors can only be used to detect parameters when the naturally occurring energy is available. For all reflected energy, this can only take place during the time when the sun is illuminating the Earth. Energy that is naturally emitted for example, thermal infrared can be detected day or night, as long as the amount of energy is large enough to be recorded.

Active sensors provide their own energy source for illumination. The sensor emits radiation which is directed towards the target to be investigated. The reflected radiation from the target is detected and measured by the sensor. Advantage of active sensor is that, it could obtain the measurements anytime regardless of day or season. Active sensors are capable of examining wavelengths that are not sufficiently provided by the sun, such as microwaves. However, active systems need a large amount of energy to adequately illuminate the target.

Sensors are calibrated for certain conditions and are capable of reporting changes at certain speeds. Sensors will be more useful when they are amplified [22]. Sensors could be either read directly (e.g. mercury thermometer) or should be interfaced with an indicator (e.g. an analog to digital converter, a computer to display the value, or a display setup or even a microcontroller for a digital display of values) that would make it easier to read the values. In general, sensors are mostly either analog or digital sensors. Analog sensors produce an output signal that is continuous in both time and magnitude. Physical variables that are continuous in nature such as air flow, temperature and speed can be measured by analog sensors. Disadvantages of analog sensors are electric system noise, cross talk and as well as

performance reductions over transmitting the analog signal over large distances. Examples of analog sensors include potentiometers, resistance temperature devices (RTD), microphones and strain gauges.

Digital sensors generate what is called a 'Discrete Signal'. This means that there is a range of values that the sensor can output, but the value must increase in steps. There is a known relationship between any value and the values preceding and following it. 'Discrete Signals' typically have a stair step appearance when they are graphed on chart. The output of the digital sensor must be compatible with the digital receiver. Examples of digital sensors include switches, infrared detectors and position encoders.

Sensors usually output one of two types of signal, an analog signal or a discrete signal. Microcontrollers usually deal with discrete or digital signals. An analog to digital converter allows the output of an analog device to be used by a Microcontroller. Many Microcontrollers have A/D converters built in.

Interfacing will depend on what type of output a sensor provides and care should be taken to not to create a path that allows too much current to flow. Current limiting resistors are important in interfacing Microcontrollers to sensors. Sensors are critical to today's society since they provide the connection between the real world and the world of process controllers and computers. The over all accuracy and reliability of the control system would depend on the sensors accuracy. Sensors have played a major role in improving energy efficiency, service, product quality and reducing emissions [23]. Sensors are integral when it comes to controllability, reliability and profitability of a process [22, 23].

Sensors technology follows a pattern of continuous development and many prototypes will be introduced depending on the requirement in various fields. While manufacturing a sensor, the factors that manufacturers would consider are cost reduction, reliability, system compatibility, safety in hazardous/hostile environments and noninvasive/nonintrusive design.

Many of the sensor technologies that are in use today apply complex mixtures of several different materials, where the principles of functionality of each component is not known or well understood [24]. Furthermore, aging of the sensors could also result in inaccuracy. So, for the successful implementation of novel sensor technologies, it is important to have a good understanding of sensing mechanisms and their degradation behaviour which would aid in the development of advanced, affordable, reliable, and novel technologies that would have a major impact on the society. A firm understanding of the material characteristics is also important in selecting the appropriate combination of sensing elements to achieve selectivity in complex array structures [24].

There is a high demand for novel sensors that are able to withstand and perform in extreme hostile/hazardous environments [25]. Novel technologies which are reliable in extreme environments are continuously being researched and developed, however the sensing requirements are becoming much more demanding. It is important to understand the sensing mechanisms and how they operate in each case. The miniaturization and faster processing of signals of such devices and systems seems to be the next step in sensor technology and with the aid of nanotechnology, MEMS it does not seem a distant dream.

Dielectric Analysis (DEA) techniques could be used for testing materials that have poor electrical conductivity [26-31]. DEA is based on the principles of electrostatics. DEA techniques are non-destructive and can be used to relate molecular motions observed in an electric field, to a variety of polymeric properties. In electroquasistatic applications, capacitive sensing dielectrometry is used to provide information of materials with poor conductivity [28]. Depending on the measurements of materials electrical properties such as dielectric constant, conductivity, loss tangent or complex permittivity, characteristics of the materials such as layer thickness, thermal conductivity, presence of defects , porosity can cure state can be determined.

1.4. Objective of the research

Farmers, companies and researchers all around the world are looking for better methods to improve the quality of leather. There is always a demand for good quality leather and the companies there by farmers are paid according to the quality of leather they supply. According to Wikipedia, tanning is the process of of converting putrescible skin into non-putrescible leather and once the tanning process is finished you cannot reverse it. Tanning process is explained in detail in chapter, 2.

Value of the leather is determined by its quality and looseness is one of the quality attributes that determines its value [32]. A sheep skin is made up of collagen fibre which enables the skin to be flexible. The collagen fibres needs sufficient space around it so that they can move in relation to other collagen fibre for free movement, however an extra space which is more than required between them results in looseness. In figure 1.4.1, cross section of leather with more visible spaces represented in white color is shown. In figure 1.4.2, cross section of leather with little or less space is shown. Here, more looseness in leather means inferior quality and a good quality leather should be stronger or mire tight. In comparison to both the figures 1.4.1 and 1.4.2, 1.4.1 is inferior quality and 1.4.2 is good quality leather.

Figure 1.4.1: Cross section of loose leather with extra spaces between the fibres (LASRA)

Figure 1.4.2: Cross Section of tight leather with less space between the fibres (LASRA)

Looseness can be treated by altering the leather making process which would depend on the amount of looseness present in the skins. New Zealand lamb skins have a reputation for looseness, a condition arising from the open fibre weave of the skin which can lead to the formation of coarse and unattractive creases in the leather [32]. Aggressive processing of the skin in the early stages of leather making can exacerbate the condition by removing too much of the leather making substance. Under processing of sheep skins may not result in desired quality leather. In either ways it is harmful for the reputation of the parties involved in the production and also reduces the value of the leather. So, for the production of better quality leather you need to know the proper leather making process required for that particular sheep skin lot.

It is difficult to identify the looseness in skins at an early processing stage in order to take corrective action, as the extent of the problem is really evident after tanning the skins. So, some means of identifying looseness in skins at the pickling stage would allow the processes to be modified to reduce the damage. The aim of the research was to develop a noninvasive and non-destructive interdigital sensor based sensing system to measure the looseness in skins during early stages that could be used as a production control tool for monitoring product quality which is economical and easy to use at the same time.

1.5. Research on Skin Property Estimation

Some ideas were developed to measure the looseness in hides. The Shoe and Allied Trades Research Association (SATRA) in the UK developed a "break" scale [33]. This involves bending the hide around a pre-shaped mandrel and observing the creasing on the inward-folded grain surface which was compared with a scale and graded. However, this scale cannot be applied to ovine skins due to the differing character of ovine leather.

There had been some unsuccessful attempts to determine the looseness in sheep skins earlier. There were attempts to develop a non-destructive device for measuring looseness at an intermediate stage of production of leather from lamb pelts. Successful attempts at non-destructive testing of cattle hides was extended to sheep skins. The tests on cattle hides were carried out on one side only by applying concentric twisting forces, but when applied to relatively thin sheep skins the forces caused the whole thickness of the skin to move, creating ridges and folds which does not have any relationship to the physical characteristics of the grain surface [34]. There was a limited success with destructive techniques for measurement of looseness in ovine skins [35]. Leather and Shoe Research Association (LASRA) conducted a study to compare the objective and subjective methods for assessing the looseness in sheep skins [36].

- Subjective assessment:

  An experienced leather technologist graded sixty pelts of varying skin character and sorted them into four different grades of equivalent looseness. Each grade was assigned a number from one (least looseness) to four (extreme looseness) as a subjective assessment.

- Objective assessment:

  Objective assessment was based on the break scale developed by SATRA which was redeveloped to suit the ovine skins. Under this method, an area was chosen which was 100 mm apart from midline of the skin and 100 mm from the belly edge off which eight sites were picked for looseness assessment. At each assessment site, the skin was folded perpendicular to the backbone to produce crease. The appearance of the crease was then compared with the LASRA

looseness scale and was graded from 1 (no looseness) to 8 (extreme looseness). This procedure was repeated for all eight sampling sites and mean value of grades at all sample sites was considered as the looseness grade of that particular skin.

There was 95% confidence interval of objective looseness for each subjective looseness grade. Objective ranking and Subjective ranking had a correlation between the rankings of 0.830.

Acoustic emission was tested to check the disruption of adhesions in calfskin and mature cattle hides. Tensile strength of the bovine leather was examined and determined that acoustic emission can be used to detect failure processes in leather before it actually tears or is substantially weakened [37]. Later, acoustic emission sensors were used to measure the softness in leather. A rotational acoustic sensor was rolled across the leather samples to collect their AE quantities such as waveforms, frequency hits, counts and energy. Sound waves produced by the fibrils, fibres and fibre bundles due to deformation of leather (squeezed, pressed, torn or stretched) caused by an external force are detected by an acoustic sensor and converted into electric signals. The higher AE energy was an indication of stiffer leather and stiffer leather is prone to bad grain break. It was reported that stiffer leather samples produce more counts than softer samples and softness, grain break and tensile strength of the leather could be measured non-destructively using the setup [38].

1.6. Organization of the Thesis

This thesis is organized into six chapters. In chapter 1, theory of Non-destructive evaluation, an introduction to sensors and objective of the work is presented. Chapter 2 describes the evaluation of quality of leather, looseness and leather making process. In chapter 3, introduction to Interdigital sensors, their working procedure, modelling the sensors using FEMLAB and comparison of sensors is shown. Chapter 4 describes the experimental set-up and the interfacing of sensor signal to a data acquisition system. Chapter 5 includes experimental observation and results. Finally, the work has been concluded in chapter 7.

CHAPTER 2

LEATHER: EVALUATION OF QUALITY

2.1. Introduction

Looseness is a major problem in the leather industry. It is apparent as coarse wrinkles in the finished leather and traces can be found in early processing or pickled stages. There are a variety of possible causes of looseness in skins such as putrefaction of the raw material, overliming, excessive swelling during liming, excessive mechanical action, inadequate penetration of fat liquor but the effects are not apparent until the leather is tanned. The effects of looseness can be ameliorated by modifications to the tanning process but these are expensive. New Zealand pelts have a reputation for being loose and the price of the pelt is discounted with increase in looseness. If the processor can keep track of looseness in the pelts at the pickled stage or during the early stages, he can alter the tanning process to correct the problem and produce leather of desired quality depending on its end use. So, we designed a non-destructive and non-invasive method of measuring the looseness values in sheep skins using interdigital sensor based sensing system. In this chapter, sheep skin structure, looseness and factors affecting looseness, tanning process, and different types of leathers are discussed in detail. All the information regarding skins and skin samples were supplied by LASRA (Leather and Shoe Research Association New Zealand).

2.2. Structure of Sheep skin

When an animal is alive its skin has the natural properties of flexibility, toughness and being waterproof, but, when animal dies the skin looses these properties. After death of the animal, if the skin is wet it is susceptible to bacterial attack and when dry the skin become inflexible making them useless. Animal skin that has been processed to retain its flexibility, toughness and waterproof nature is known as leather. Tanning is the process which involves converting raw skin to leather. Tanning converts putrescible biological material into a stable material which is resistant to microbial attack and has enhanced resistance to wetness and heat [39]. Tanning permanently alters the structure of skin so that it can not ever return to rawhide.

The cross section of sheep skin is shown in figure 2.2.1. In order to understand the technology involved in skin processing, knowledge of sheepskin structure and composition is important. The skin is complex topic because of the functions it has to perform for the animal. The major component of the skin is the fibrous protein collagen which accounts for around 77% of the fat-free dry weight of the skin and is the source of the tensile strength of the skin. Unlike keratin, the protein of hair and wool, collagen has few natural permanent cross-links which can give it thermal stability. As a consequence the skin structure is irreversibly disrupted by increasing the temperature to around 66^{o}C. One of the main purposes of tanning is the stabilisation of the collagen structure by the formation of strong, permanent cross-links between the protein chains and during tanning process processed leather will able to withstand temperatures to about 100^{o}C. The type and thermal stability of the cross-link depends on the process involved in tanning.

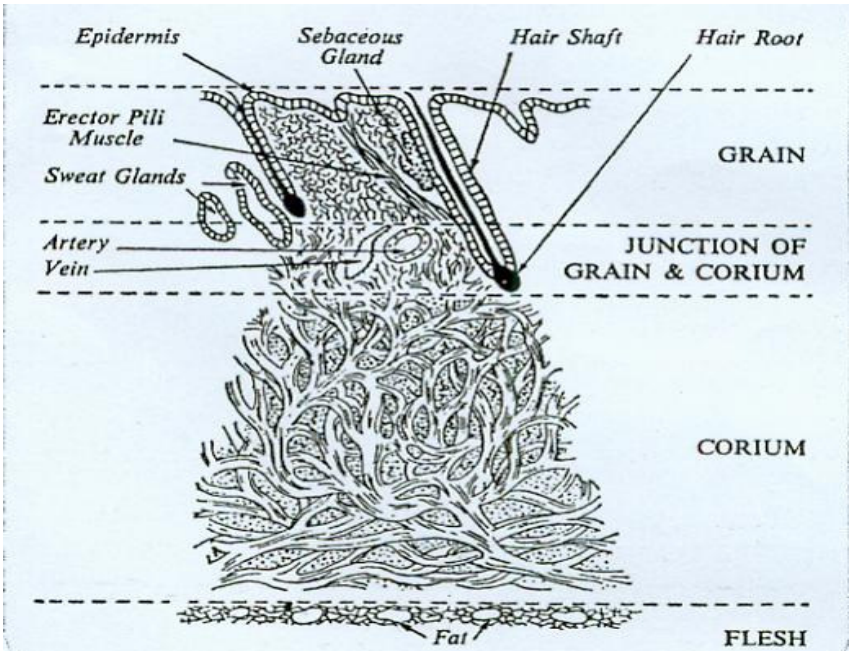


Figure 2.2.1: Cross section of sheep skin (LASRA)

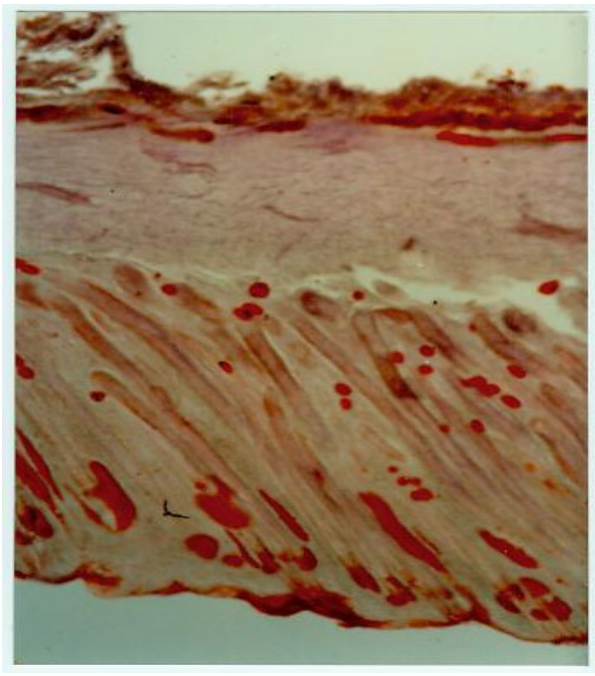
A sheep skin is composed of three major identifiable parts – the epidermis, the grain layer and the corium. The disruption of the collagen network causes the grain layer to be weak and despite accounting for half the thickness of the skin it cannot contribute much to skin strength. Collagen fibres are thin and tightly woven together in the grain layer whereas

in the corium the collagen fibres are coarser, stronger and tightly woven together. The grain and corium layers structures are affected differently while processing because of the differentiating rates of penetration of different reagents because of their varying respective structures. Between the grain layer and the corium and there is frequently a layer of cell that contains fat which becomes distinctive with age. The presence of this fat can discolour the finished leather as well as produce unpleasant odours, so it is important to get rid of the fat while processing the sheep skin [40].

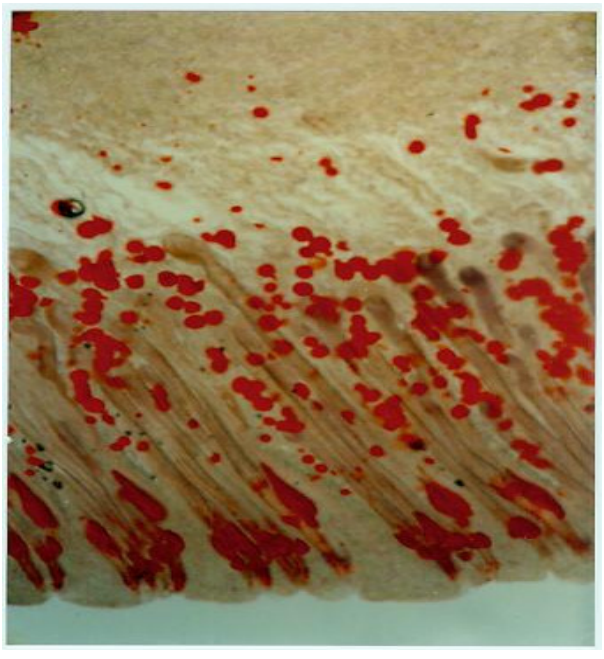
As discussed in chapter 1, looseness can be termed as extra space between the collagen fibres. Looseness can also be referred to a condition of incompact fibre weave and affects the skin thickness as a whole rather than just corium or grain or the grain corium junction. Looseness can also be detected in skins in the pickled stages or early processing stages. Most skin fat could be found at the grain/corium junction and the zone of weakness or looseness of the leather could not be related to the presence of fat in those skins [41]. There are other factors such as breed, age, bacterial damage etc which result in looseness. The above factors are discussed later in this chapter.

In figure 2.2.2, images four different leather samples are shown. Each sample showed in figures 2.2.2 (a), (b), (c) and (d), have different concentrations of fat present in them. All the images show the fat coloured in red as they have been stained with Sudan III. The looseness can be observed as white space in these images. Image 2.2.2(a) has less fat which would affect the colour and odour of the finished leather and less looseness which makes it good quality leather. Image 2.2.2(d) got lots of fat as well as more looseness which makes it inferior quality leather.

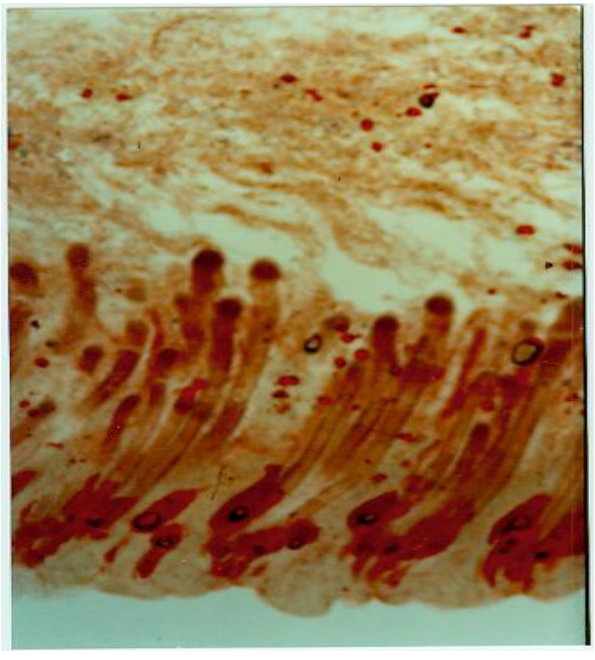
2.2.2(a)



2.2.2(b)



2.2.2(c)



2.2.2(d)

Figure 2.2.2: Leather samples with fat cells and looseness shown (LASRA)

2.3. Looseness

Leather is usually graded depending on its end use. Looseness results in the appearance of unpleasant creasing, especially when the leather is folded or flexed. The greater the looseness the coarser the creases are on the leather. Looseness deteriorates the quality as well as the value of the leather. Looseness is not restricted or confined to just one area or specific site of the leather, but is a function of leather as a whole [36]. Looseness in leather is measured by holding it and manually pulling it in opposite direction. Depending on the creases appearing on the skin it is compared with a scale (LASRA) as shown in figure 5 and graded from 1 to 6, where 1 being least loose and 6 being more loose [42]. Leather with looseness values in between 1 to 3 are regarded as good quality leather and quality as well as value degrades from 4 towards 6.

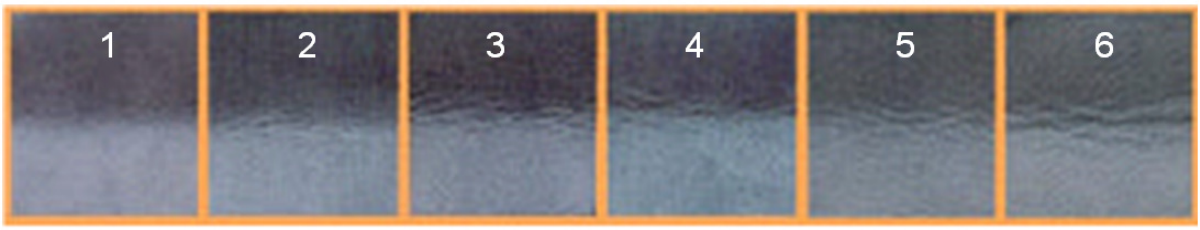


Figure 2.2.3: Looseness scale determined by LASRA

New Zealand pickles lamb pelts are characterised by two key features that reflect strongly on their ease of processing by overseas industries and their value in the international garment leather trade. These features are the high level of natural fat in the pickled pelt or skin at early processing stage and the property known as looseness. The key focus of lamb pelt processing is the production of flat pelts for garment use and the avoidance of looseness. Looseness in leather is a major problem in the industry. Looseness eventuates from the natural structural nature of the skins derives from wool breeds and is influenced by the fat and protein removal that occurs in processing. Controls can be exercised over looseness but there is no means of measuring this key feature in production to be able to confirm its extent of presence or absence. Looseness is commonly determined after it had been processed into leather. A production that attracts a reputation for looseness suffers in the market as a consequence.

2.4 Factors affecting Looseness

There were concerns over the degree of looseness in pelts produced in New Zealand which is often blamed on bating however there are a variety of factors that affect looseness. In sheepskins looseness can also arise if the skins are particularly fatty at the junction of the grain and corium. Removal of the fat during degreasing leaves a void between the two layers, which is exacerbated by subsequent mechanical action. Looseness can lead to floating grain and the presence of floating grain.

Floating grain: It is a result of a failure in adhesion between the grain and the corium. This occurs due to the sharp change in structure between the grain and the corium layers accentuated by localised deposition of fat at the grain/corium junction, which lead to a zone of weakness.

Looseness: It is a condition of in-compact fibre weave and substance loss.

Looseness pertains to the whole structure of the skin whereas floating grain is a function of a specific site on the skin.

There are many different causes for looseness, there is no simple formula or single process to provide a solution. If the problem suddenly occurs in the production, then any change in processing such as change in chemicals or treating times etc have to be rechecked. Raw skins need to be checked for any traces of bacteria. Equipments also need to be checked for example, incorrect operation of the timer on the processing drum, or breaking down of water thermostat. It is advised not to overcome the problem by adding more chemicals, but to address the cause, ‘leather should not be loose, there must be something causing it’ [32]. An ability to objectively measure looseness at the pickled stage would further increase the producers ability to maintain the market appeal for the product and if required manipulate processing steps in response to the changing nature of the raw material and changing nature of the end requirement.

A basic guide for producing good quality leather with low looseness values would be [32]:

- Use good quality raw hides and skins
- Minimise swelling during liming
- Avoiding prolonged running times of drums as well as excessively fast speed drums
- Proper conditioning prior to staking or dry drumming
- Adequate fatliquoring
- Ensure the desired action of chemicals

With consideration to all the above factors, there are other factors that influence looseness, they are:

- **Rawstock Effects**
- **Processing Effects**
- **Storage Effects**

- **<u>Rawstock Effects</u>:** Several factors such as breed and animal health can be placed under Rawstock effects.

  - **Breed**

    The breed of the sheep could be a factor that affects the looseness of the pelts. Research work shows that amongst three breeds Cheviot, Drysdale and Romney, Cheviot produced tighter leather compared to Drysdale and Romney with respect to looseness [43]. The predominant sheep breed in New Zealand is the Romney-cross which is quiet prone to loose skin.

  - **Animal Condition**

    Usually an animal in poor condition is anticipated to have a looser pelt, however, it was found that level of feed did not have an effect on the looseness of the lamb pelts [43].

- **Age**

  The age of the stock at slaughter also has a significant effect on the looseness of the leather. It was found that increasing age at slaughter decreased looseness of lamb pelts [44].

- **Bacterial Damage**

  Looseness in pelts is also affected by the bacterial effects on the skin. The effect appears similar to over bating and is caused by bacterial and skin enzymes breaking down the skin structure. This damage will occur if the skins are not adequately preserved from the time they are removed from the carcase to the commencement of processing the fellmongery. Skins must be promptly chilled after slaying and kept cold both until and during transport to the processing stations.

- **Processing Effects:** A variety of factors that involve processing can affect looseness. Looseness caused by the processing is the major contributor to the problem.

  - **Painting**

    Two factors may affect looseness in painting process

    - Paint concentration
    - Time held in painted condition

Paint concentration affects the degree of swelling in the collagen matrix. The higher the concentration of sulphide, greater the alkalinity in liming stage which results in extra swelling. This swelling can lead to disruption of the grain/corium junction and floating grain.

The time held in the painted condition is also an important factor as the pelt substance is being dissolved and opens up with time. The longer a pelt is held in the painted condition the looser is the pelt.

Swelling aids in the splitting up of collagen fibres, allowing the removal of cementing substances within the skin. Removal of these cementing substances enhances the properties of finished leather like softness, flexibility, strength and also aids dyeing. Excessive swellings, however, increases the effects of drum/processor damage, as well as leading to increased mottle, double hiding and looseness. The rate of swelling is also a factor, if swelling occurs gradually over a long period of time the skin structure can potentially adjust to the change in swelling gradually. However, if swelling occurs rapidly distortions between grain and corium may become apparent leading to floating grain. Addition of sodium sulphate or sodium carbonate significantly reduces swelling during depilation and lower application rates of more concentrated depilation will significantly reduce swelling. Swelling factors do significantly impact the properties of pelts in terms of flatness and looseness.

- **Liming**

  Sulphide concentration and liming time are important factors that would affect looseness. Float length exerts a strong influence on degree of swelling. At a certain pH level, the degree of swelling increases along with the water quantity. Too much mechanical action of the processing drum during liming will also promote looseness. Generally liming drums are only run for short periods (5minutes every hour) and at low speeds (12 rpm).

- **Bating**

  Overbating affects the looseness of pelts and it is not always easy to detect overbating. Bating process is also dependent on the previous processes carried out. Required bating would depend on how the skin was painted and limed because of the amount of inter-fibrilar matter remaining and degree of flatness to be produced in the end product. Increasing the degree of bating increases the strength of leather to a maximum value and further bating would decrease the strength.

- **Storage Effects:** Work by Leather and Shoe Research Association (LASRA) has shown that storage of pickled pelts affects the soluble protein substance of the pelts. Acid hydrolysis from the pickle acid in a pelt causes break down of the collagen and there by reduces the quality of the product. Looseness in pelts increases with storage time [45].

2.5. Processing of Sheep skin

When an animal is alive, its skin is soft, flexible, very tough and hard wearing: it has the ability to allow water vapour to pass out, but it will not allow water in. When the skin dies it loses these characteristics: if it is kept wet it rots, and if it is dried it goes hard and brittle. The process of tanning is to retain the skin's natural properties as stated above, to chemically process it and at the same time stabilise its structure so that it will no longer be subject to putrification. . Thus leather is animal skin that has been processed to retain its natural properties. Skin is made up of many bundles of interwoven protein fibres called collagens that are able to move in relation to one another when the skin is alive. When the skin dies, these fibres tend to shrivel and stick together. Essentially, the purpose of tanning process is to permanently fix the fibres apart by chemical treatment, and to lubricate them so they can move in relation to one another. Well tanned leather, therefore, retains the properties of flexibility, toughness and wear. It also continues to 'breathe', allowing water vapour to pass through but remaining reasonably water-proof. It is this characteristic which accounts for the comfort of genuine leather shoes and clothing [46].

The process of converting a raw skin into imputrescible, removing the unwanted matter from the structure and stabilise and preserve it, whilst retaining the useful properties is the ideology behind tanning. Modern tanning process is usually done in 8 steps that involve unhairing, liming, deliming and bateing, pickling, tanning, neutralizing, dyeing and fatliquoring, drying and finishing. The whole process is a long time consuming process which could take from 1 day up to 6 or 7 days.

2.6. TANNING IN ANCIENT HISTORY

Tanning has come a long way. Many years ago there was a saying “Every animal has just enough brains to preserve its own hide”. It was due to the methodology followed by the ancients, which involved animal brains in the tanning. In ancient history leather was used for water bags, harnesses, boats, armour, quivers, scabbards, boots and sandals. Skins were first soaked in water to clean and soften them and then they would pound and scour the skin to remove any remaining flesh and fat. Then, the hair was removed by either soaking the skin in urine, painting it with an alkaline lime mixture, or simply letting the skin putrefy for several months then dipping it in a salt solution The hair was scrapped off with knife after the hair fibres were loosened. Once the hair was removed the skin was bated by pounding dung into the skin or soaking the skin in a solution of animal brains. Sometimes the dung was mixed with water in large vat and the prepared skins were kneaded in the dung water until they became supple, but not too soft and the kneading could last two or three hours. Cedar oil, Alum or tannin was applied to the skin as a tanning agent in variation to the regular process [47]. There were no means to measure the looseness or control the looseness in the leather produced.

2.7. MODERN METHODS OF TANNING

Using modern technology animal skins are converted to leather in an eight step process as follows [46, 48]:

Step 1 – Unhairing: The animal skins are steeped in an alkali solution that breaks down the structure of the hair at its weakest point (the root) and so removes the hair. The hides are placed in vats containing aqueous solution of unhairing chemicals and agitated to loosen and remove the hair [49, 50]. The rate of unhairing depends on the temperature of the mixture of chemicals, chemical concentration and amount of agitation. These parameters would depend on the end use of hair such as being used as an

end product or treated as waste. The unhairing process does not remove or loosen all of the hair on the hide.

Step 2 – Liming: The hairless skin is immersed in a solution of alkali and sulphide to complete the removal of the hair and to alter the properties of the skin protein (collagen) [50]. The collagen becomes chemically modified and swells, leaving a more open structure. During unhairing, hide absorbs enough moisture to increase its thickness about two-fold, referred as alkaline swelling and this may not occur uniformly throughout the hide. During liming process, further swelling of fibrous structure takes place and enables the separation of the fibres and fibrils from one another and opens up the whole structure [51]. In liming, skins are immersed in the solution for whatever time is necessary to produce the desired effects. The process of unhairing finishes during the liming process and collagen is modified considerably. Too much mechanical action of the processing drum during liming can result in looseness [45].

Step 3 – Deliming and Bating: The skin structure is then opened further by treatment with enzymes, and further unwanted material is removed. Deliming removes residual alkaline chemicals used in the previous process and swelling is reduced. Bating separates the collagen protein fibres within the hide and destroys remaining hair roots and unwanted pigments [51]. Cleaner appearance and softer texture of pelts is achieved during this process. Increasing the degree of bating increases the strength of leather to a maximum value and further bating would decrease the strength [45]. The bating process may alone take from 1 to 4 hours however, the reaction time for the dual process, bating and liming may range from a few hours to overnight. After bating, the hides are washed to remove all unwanted substances that has been loosened or dissolved. In the past deliming and bating were separate processes, but currently these are performed simultaneously using bates consisting of deliming chemicals.

Step 4 – Pickling: Pickling preserves the leather and allow the hides to be stored for longer periods of time [52]. Pickling is the most acidification process as skins are agitated in a solution of salt and sulphuric acid [53]. Skins are subjected to controlled swelling using acid and complete penetration of the acid requires few hours. Excessive swelling can result in the looseness.

Step 5 – Tanning: This is the most chemically complex step. Tanning is the process whereby the hides are made into product that resists decay or putrification [54, 55]. During tanning, the skin structure is stabilised in its open form, by replacing some of the collagen with complex ions of chromium [49, 56]. Depending on the compounds used the colour and texture of the leather changes. When leather has been tanned it is able to 'breathe' and to withstand 100^{o}C boiling water, more flexible than an untreated dead skin and builds up resistance to chemicals and abrasion [47].

Step 6 – Neutralising, Dyeing and Fat Liquoring: After tanning leather is neutralised to remove unwanted acids to prevent deterioration during the drying process, and prepared for next processes: dyeing and fat liquoring [56]. Typical dyes used for dyeing are aniline-based. Variations in hide pigmentation and depth of colour penetration are factors that affect colouring of the hides. Once the leather is dyed, fat liquoring is the process in which 'tanned' fibres are treated with reactive oils, which attach themselves to the fibrous structure, and lubricate them so that they can move readily in relation to one another, producing a soft, supple leather. The quantity and quality of oils used determine the firmness, flexibility and strength of the final product.

Step 7 – Drying: The leather is subjected to a drying process to remove excess moisture. As water is removed from the leather, its chemical condition is stabilised and the final properties of leather are determined [48].

Step 8 – Finishing: Finishing involves applying a surface coating which would enhance the natural qualities of the skin and covers defects such as scars, horn damage, seed scars etc [51]. In case of suede leather it is buffed to give it an even texture. The main requirements of finishing process are evenness and the reproducibility of colour and adequate wear and feel properties.

Animal skins that are processed in New Zealand go on to be made into a variety of leather goods, or are exported in an unfinished condition to be further treated overseas [47].

There are various tanning processes [57], some of them are,

- **Vegetable-tanned leather -** is tanned using tannin and other ingredients found in vegetable matter, tree bark, and other such sources.

- **Chrome-tanned leather –** is tanned using chromium sulfate and other salts of chromium.

- **Aldehyde-tanned leather -** is tanned using glutaraldehyde or oxazolidine compounds.

- **Synthetic-tanned leather -** is tanned using aromatic polymers such as the Novolac or Neradol types.

- **Alum-tanned leather -** is tanned using aluminium salts mixed with a variety of binders and protein sources, such as flour, egg yolk, etc.

- **Rawhide** is made by scraping the skin thin, soaking it in lime, and then stretching it while it dries.

2.9. TYPES OF LEATHER

Leather in general is sold in three forms, Full grain, Corrected grain and the Split leather [57].

- **Full-Grain** leather or **Top-Grain** refers to the upper section of a hide that contains the epidermis or skin layer. The hides that have not been sanded, buffed or snuffed(otherwise known as Corrected) in order to remove imperfections on the surface of the hide. Only the hair has been removed from the epidermis. The grain remains in its natural state which will allow the best fiber strength, resulting in greater durability. The natural grain also has natural breathability, resulting in greater comfort for clothing. The natural full-grain surface will wear better than other leather. Rather than wearing out, it will develop a natural "Patina" and grow more beautiful over time. The finest leather furniture and footwear are made from Full-Grain leather. For these reasons only the best raw hide are used in order to create full-grain or top-grain leather. Full grain leathers can mainly be bought as two finish types: aniline and semi-aniline.

- **Corrected-Grain** leather is any top-grain leather that has had its surfaces sanded, buffed or snuffed in order to remove any imperfection on the surface due to insect bites, healed scars or brands. Top-grain leather is often wrongly referred to as corrected-grain. Although corrected-grain leather is made from top-grain as soon as the surface is corrected in any way the leather is no longer referred to as top-grain leather. The hides used to create corrected leather are hides of inferior quality that do not meet the high standards for use in creating aniline or semi-aniline leather. The imperfections are corrected and an artificial grain applied. Most correct leather is used to make Pigmented leather as the solid pigment helps hide the corrections or imperfections. Corrected grain leathers can mainly be bought as two finish types: semi-aniline and pigmented.

- **Split leather** is leather that is created from the fibrous part of the hide left once the top-grain of the raw hide has been separated from the hide. During the splitting operation the grain and drop split are separated. The drop split can be further split (thickness allowing) into a middle split and a flesh split. In very thick hides the middle split can be separated into multiple layers until the thickness prevents further splitting. Split leather then has an artificial layer applied to the surface of the split and is embossed with a leather grain. Splits can are also used to create suede. The strongest suedes are usually made from grain splits (that have the grain completely removed) or from the flesh split that has been shaved to the correct thickness. Suede is "fuzzy" on both sides. Suede is less durable than top-grain. Suede is cheaper because many pieces of suede can be split from a single thickness of hide, whereas only one piece of top-grain can be made.

CHAPTER 3

INTERDIGITAL SENSORS

3.1. Introduction

The operating principle of interdigital sensors is explained in detail along with different sensing possibilities and their applications in various fields. We have utilized four types of Interdigital sensors. These sensors are of the planar type and have a very simple structure. The interaction of these sensors on dielectric material will be discussed. The operating principle behind this sensor is based on the interaction of electric field generated by the sensor with respect to the material under test (MUT). The sensor has been fabricated using simple printed circuit board (PCB) fabrication technology. The sensing properties of the four sensors are compared for different materials to select the best sensor to conduct experiments with the sheep skins. Planar interdigital sensors were chosen for the estimation of looseness in sheep skin as the skin could be placed over the sensor and the experimental procedure would not alter the properties of the skin. So the property estimation using the interdigital sensors is considered as Non-Destructive and Non-Invasive testing.

3.2. Operating principle of Interdigital sensors

The operating principle of Interdigital sensor is same as in a parallel plate capacitor [26-28, 30, 31]. The relationship between the sensor and the capacitor can be seen in figure 3.2.1, how the transition takes place from a capacitor to the sensor [58]. There is an electric field generated between the positive and negative electrodes (instantaneous polarity) which are shown in figure 3.2.1 (a) and (b) respectively. When a material is placed on the sensor, the electric field passes through the material under test which can be observed in figure 3.2.1 (c). The dielectric properties of the material as well as the geometry of the material under test affect the capacitance and conductance between the two electrodes. The variance in the

electric field can be used to determine the properties of the material depending upon the application.

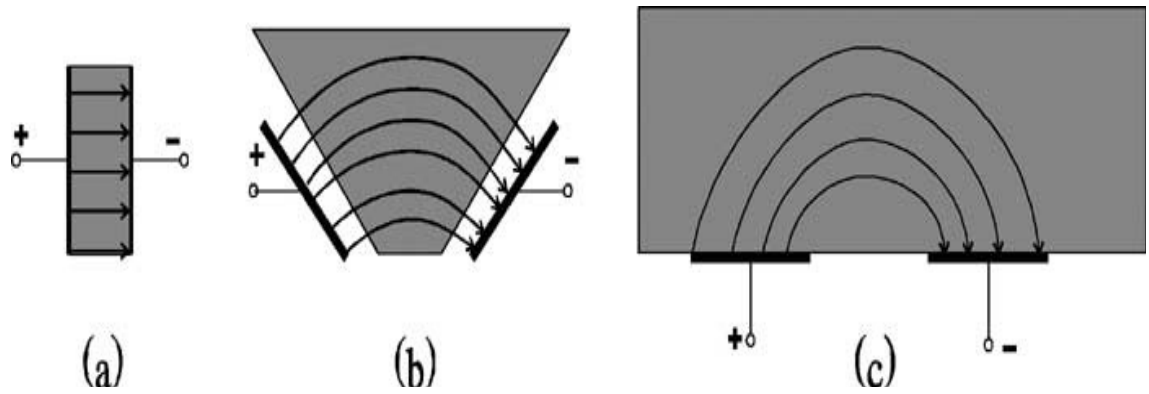


Figure 3.2.1: Operating principle of an Interdigital sensor [28]

Historically, the first and still the most common reason for making an interdigital electrode structure was to increase the effective length, and, therefore, the capacitance between the electrodes [28]. Possibly the earliest design of interdigital electrode structure could be found in the patent of N. Tesla, issued in 1891 [59]. In this example, each "finger" was a rectangular plate, immersed in an insulating liquid. The total capacitance of the "electrical condenser" proposed by Tesla increases approximately linearly with the number of plates.

One set of electrodes are connected to an AC voltage source and act as an excitation/driving electrodes. The remaining electrodes are connected to ground. When there is a material between the electrodes, the electric fields from the driving electrodes penetrate through most of the material under testing, and then terminate on the sensing electrodes. The proximity depth of electric field lines of the sensor depend on the distance between two electrodes of opposite polarity. The electric field lines are affected by the dielectric properties of the material under test [26, 28 and 31,]. Potential difference between positive and negative electrodes are maintained constant, however, the capacitive current drawn from the source is a function of dielectric properties of the materials under test. The main advantage of using the interdigital sensor is that the electric field is only produced on the testing surface; this controls interference of field lines from outside of the testing zone, concentrating it to the material under testing [28].

In figure 3.2.2, the structure of typical interdigital sensor is shown. Here, one end of electrodes are connected to AC voltage source (‘+’ terminal) also called as excitation source and other end of electrodes are connected to ground (‘-‘ terminal). In our experiments, AC voltage source was provided by a frequency generator and the current through the sensor was captured across the resistor which is connected in series with the sensor. Due to the arrangement of electrodes in this structure, it is also sometimes called comb structure and referred to as finger like pattern [28].

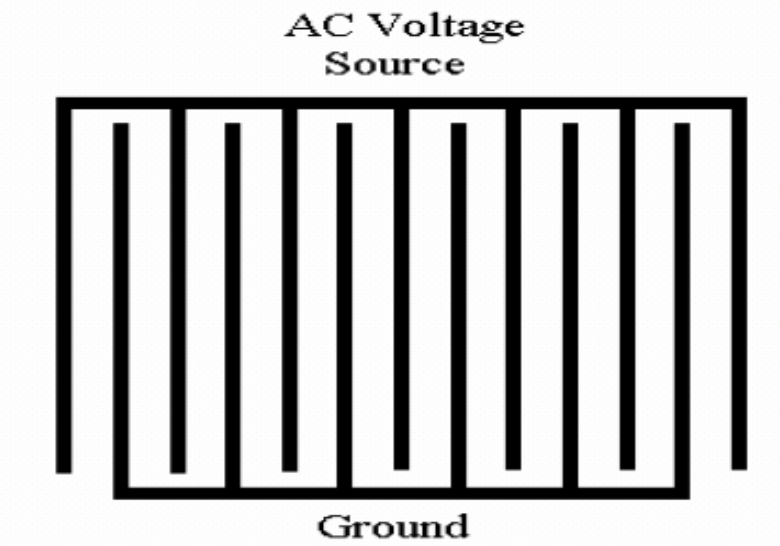


Figure 3.2.2: Interdigital sensor structure

The extent of an electric field can be varied by changing the distance between opposing electrodes. The flow of electric field lines between electrodes for varying lengths, in between electrodes are shown in figure 3.2.3. The electric field lines corresponding to minimum separation distance between the positive and negative electrodes is ‘l_1’ where the alternating electrodes are of opposite polarities (+,-,+,-,+,-) and to that for the maximum separation distance is ‘l_3’ where the electrode structure is still the same but with a greater distance between them. The blue, red and green correspond to the low, medium and high pitch length respectively. So, depending upon the requirement the desired extent of electric field can be achieved by varying the length between the electrodes and the strength of the signal can be controlled by controlling the electrode pattern.

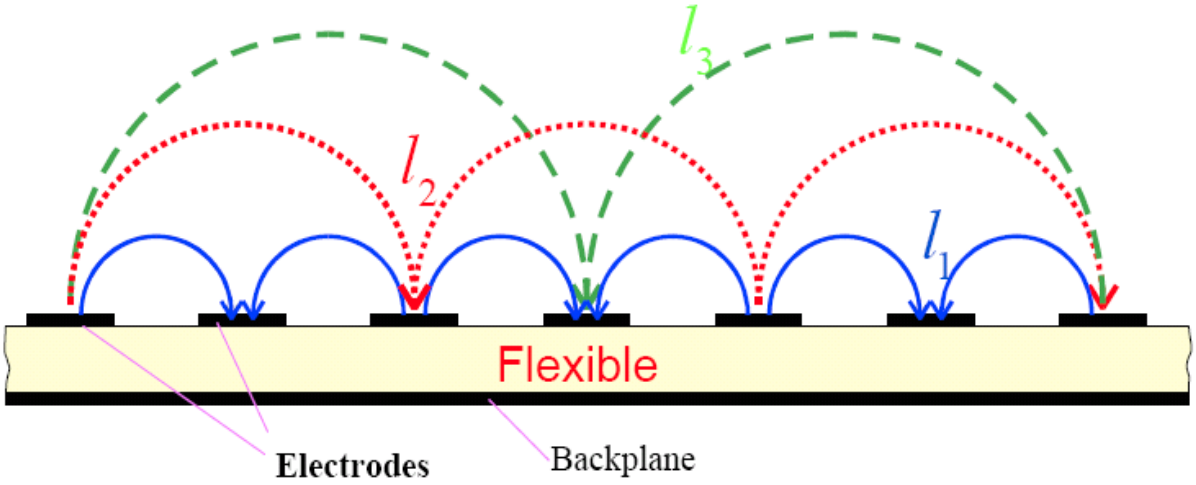


Figure 3.2.3: Electric field formed between two electrodes for different pitch

The length between the two adjacent electrodes of same type is referred to as spatial wavelength (λ) and ideally the penetration depth is one fourth of the spatial wavelength [28]. For the spatial wavelength of 1mm as shown in figure 3.2.4, penetration depth is as little. The spatial wavelength increases along with an increase in penetration depth linearly. D is driving electrode or the AC voltage source electrode and S is sensing electrode or the ground electrode. So varying penetration depths can be achieved by adjusting the spatial wavelength between the electrodes.

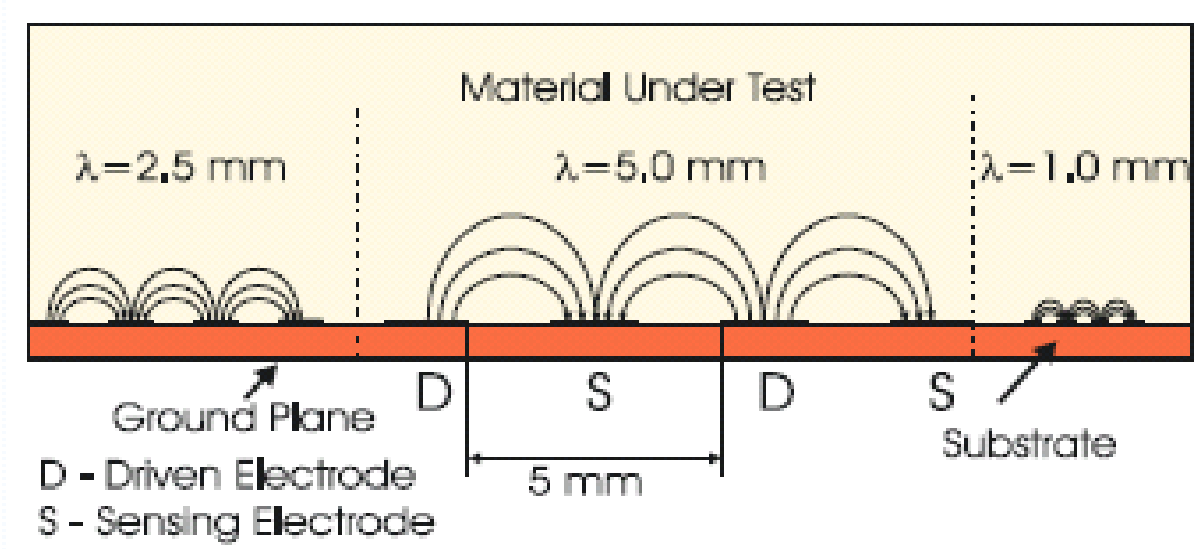


Figure 3.2.4: Penetration depths for varying spatial lengths between the electrodes

Interdigital sensors can be employed in various applications depending upon the requirements. They could be used to measure the density of the material as shown in figure 3.2.5 (a), the distance between the material under test and sensor could be measured with the help of varying excitation fields as in figure 3.2.5 (b). It is also possible to identify the non-uniform or unevenly shaped materials using the interdigital sensors as shown in figure 3.2.5 (c) and they are also very good moisture sensors, as shown in figure 3.2.5 (d). Thus an interdigital sensor can not only measure the dielectric properties of a material but also the density, shape of the material.

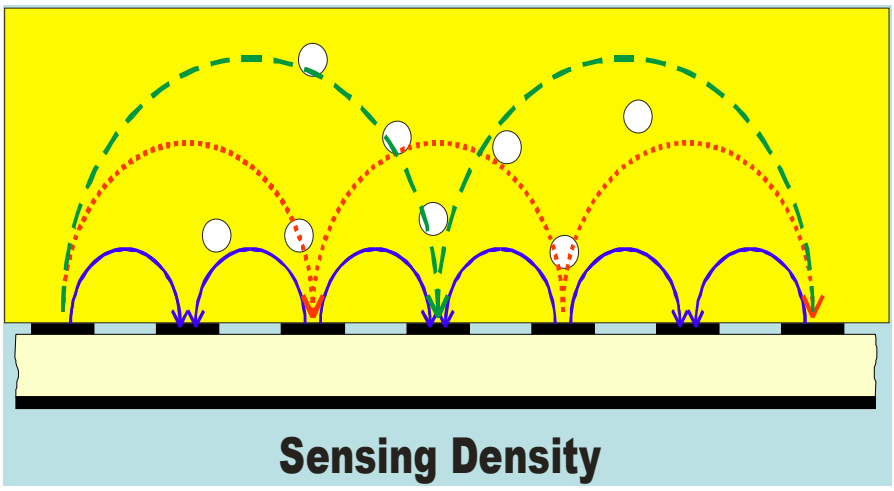


Figure 3.2.5(a): Sensing the material density [60]

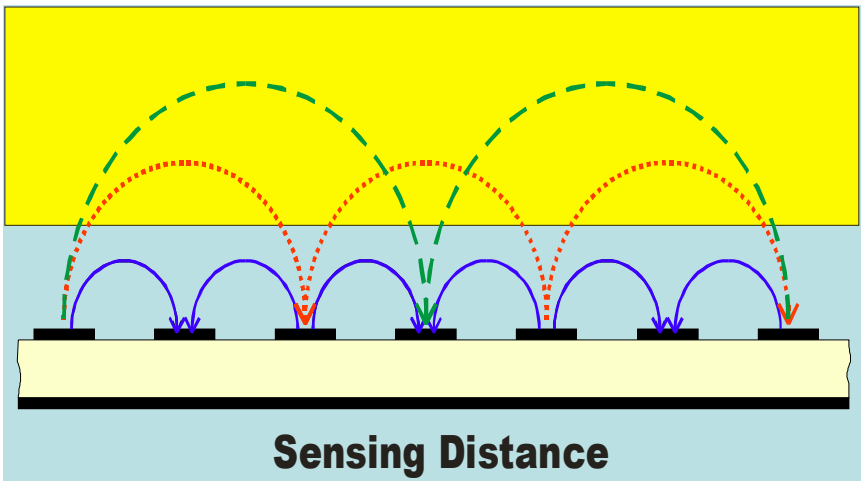


Figure 3.2.5(b): Measure the distance between sensor and the material [60]

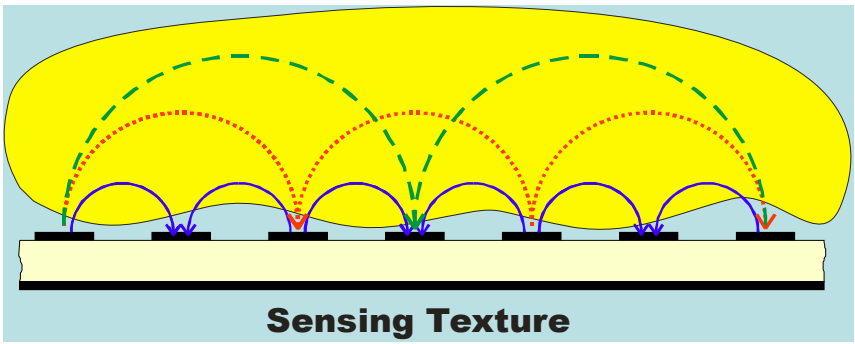


Figure 3.2.5(c): Track the structure of the material under test [60]

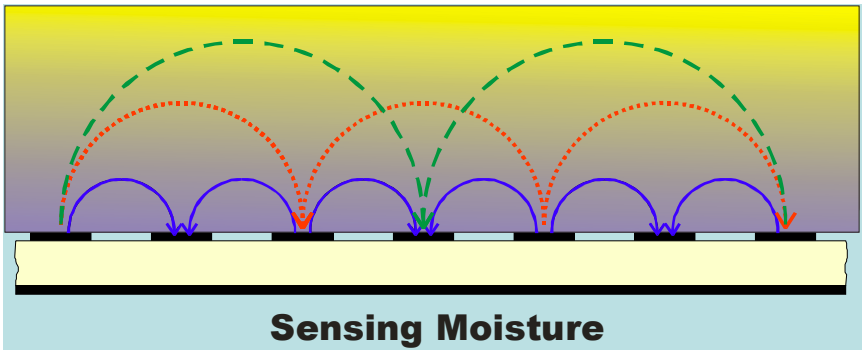


Figure 3.2.5(d): Sensing the moisture [60]

Extensive use of interdigital electrodes for sensing applications started in the 1960s [61] along with other forms of coplanar electrode structures [62]. Later, independent dielectrometry studies with single [63], and multiple penetration depths using interdigital electrodes have continued in several countries [64, 65]. Interdigital sensors are really popular for their one side access and their ability for non-destructive testing (NDT). Nondestructive testing or NDT is defined as the use of noninvasive techniques to determine the integrity of a material, component or structure or quantitatively measure some characteristics of an object. So in short NDT can be used to measure or read the properties of a material without physically altering it. NDT is applied in various industries during production, quality maintenance and also to check the durability of the product while in use. The use of NDT is more helpful in the severe hazardous environments.

3.3 Applications of Interdigital Sensors

The sensitivity of interdigital sensor changes with a change in geometric parameters [66], even the variations within the production tolerances of a manufacturer changes the response of sensors greatly. Interdigital sensors are used to study and monitor the dielectric properties of the insulating materials as the dielectric property starts to cease with age and absorption of water [67]. The moisture content in pulp can be measured up to 96% using Interdigital electrodes whereas it is limited to only 90% using other methods [31], Interdigital electrodes offers single-sided measurements and high sensitivity unlike other methods and can be used in normal working conditions as well. The Interdigital sensors are used in Bio-medical field to monitor the change in impedance caused by the growth of immobilized bacteria [68], when the sensor is immersed into a liquid the bacteria present in the solution gets hooked to the electrode there by causing a change in impedance. A Micro Sensor based on interdigital electrodes is used to measure the water content in the human body as the water content in the skin could be used as an index to confirm the health of human skin [69]. The Micro Sensor measurements are compared with standard skin moisture measuring instrument and their results matches at a specific frequency which is encouraging. Infrared Spectrometers are used to measure the fat to protein content of milk which is an important factor for processing of milk by dairy companies. Infrared Spectrometry is an expensive and a heavy system which cannot be carried around with ease [70], this can be substituted with an Interdigital sensor. The Sensor responds well to the fat concentration, the impedance decreases with the increase in fat content. The fat content in other dairy products such as butter, cheese, curd and yoghurt can also be determined using these sensors. As in the estimation of fat content of milk products, the Interdigital sensors can also be used for the estimation of fat content in pork meat [71]. For this, three sensors were designed and tests were done with different samples of pork meat at different orientations. Quadratic and Cubic expressions were calculated to determine the fat and protein content in each sample, and the experimental results came close to the values predicted using chemical analysis. The Interdigital sensors are used to inspect the quality of Saxophone reeds [72] the measured impedance of the sensor is used to predict the properties of each reed. The reeds involved in experiments were earlier used for playing saxophone for qualitative analysis to avoid bias

while doing experiments. There is a good correlation factor between both the results. The dielectric properties of freshly slaughtered meat differ from the properties of the meat that is bought from a supermarket [73], the dielectric properties change further with freezing and cooking of meat. So, the dielectric properties can be used to determine the storage and cooking history of the meat. The capacitive sensors can be interfaced with microcontrollers for effective signal processing, temperature, humidity and pressure output data of the sensor [74]. An interface chip handles the communication between the sensors and the microcontroller. A wireless micro-instrumentation system is designed for environment monitoring which uses capacitive sensors for recording acceleration, pressure and humidity [75], this system includes an embedded microcontroller, sensors for monitoring environmental parameters, interfacing electronics for communication between MCU (Microcontroller unit) and sensors and a PM (Power Management) chip to control power consumption and maximize the life of battery powered microsystem. A low power generic interface circuit is designed for microsystems and capable of interfacing with a large variety of capacitive sensors [76]. The chip can interface with up to 6 capacitive sensors, is highly programmable and supports communication with a standard bus sensor with the help of microcontroller. To detect gases, chemicals and organic impurities, electrodes could be coated with a thin layer that is sensitive to chemicals which are to be detected and the electrodes are deposited on an insulating substrate [28]. Detection of carbon dioxide has become very important due to the global warming and a low cost sensor has been designed for this using thick film technology. Experiments are being done to develop a multi-sensor array system with meander, mesh and interdigital sensors for the detection of unexploded plastic landmines as meander, mesh sensors respond well to conducting, magnetic materials and interdigital sensors respond well to dielectric materials [77]. A porous silicon based sensor with interdigital structure has been developed for the detection of humidity [78]. The heating is provided by an integrated heating element placed over the porous material. With proper selection of geometry and operation conditions the performance of the sensor could be improved. The accuracy of interdigital dielectrometry measurements can be improved by immersing the sensor and the solid material into a dielectric liquid. The liquid fill the gap between the sensor and the material under test [79], difference between the dielectric constants of the liquid and air helps us to reduce the effect of the measurement perturbations on estimated values of properties for materials of interest. Nano-scaled interdigital sensors

are developed for detection of affinity binding of molecular structures [80]. Genetic diseases and viral infections can be detected by presence of DNA sequences, certain antigens or antibodies which bind to selective probes. This Nano-scaled sensor is more advantageous when compared with other electrochemical biosensors. Interdigital gold electrode arrays can be used to fight agro-terrorism which could disrupt the safety of nation's food supply [81]. The sensor detects the change in impedance caused by the sitting bacteria that settles on the electrodes. The biosensor is immersed into the liquid to check the presence of bacteria and as most of the bacteria attaches to the sensor surface in about five minutes makes it quick equipment which could be used by military personnel, border security agents, food inspectors and first response teams in the event of terror attacks. The interdigital electrodes can be used for studying the dielectric properties of the materials. The dielectric properties of food materials such as wheat, other grains and crop seeds are important as they play a major role in estimating the behaviour of the materials when they are subjected to microwave fields for purpose of heating or drying [82]. Thick film technology is applied to design low-cost humidity Interdigital structured capacitive sensors [83]. This shows great sensitivity to the water vapour present in surrounding atmosphere by monitoring the changes in capacitance of the device. Even, in the automotive industry, thick-film interdigital capacitive elements are used as a displacement sensor in car suspension systems. In various industrial and medical processes it is essential to detect the content of specific gas molecules in a mix of various gas molecules to control the process. Capacitive sensors are used for detection of gas as the capacitance can be amplified easily which would enable sensitive detection at low cost [84]. For hydrocarbon sensing, zeolite was selected as the dielectric layer as the hydrocarbon adsorption influences the dielectric constant of zeolite [85]. Planar interdigital capacitors consisting of a thin film of H or Pt ion-exchanged Y type zeolite were studied for hydrocarbons such as butane. The response time was dependent on thickness of the zeolite layer and the operating temperature. An automated aroma sensing system is required for wine fermentation to detect and minimise the undesired flavours which causes major losses to the wine industry. An interdigital capacitive sensor is being developed for the on-line and real time monitoring of wine fermentation process [86]. A square spiral inductor and an interdigital capacitor on a printed circuit board coated with a protective electrically insulating Sio2 layer followed by a gas sensing layer made of multiwall carbon nanotube (MWNT) - silicon dioxide (Sio2) is used as a sensor for the detection of carbon dioxide [87]. The

permittivity and/or conductivity changes in MWNT- Sio2 change the resonant frequency of the sensor which is remotely monitored by a loop antenna. As the MWNTs are used in combination with a passive, remote query sensor platform there is no requirement for internal batteries or wire terminals to power the sensor. This makes the gas sensor usable for long-term wireless monitoring applications such as measuring the CO2 levels in food or medicine packages to check for product spoilage. Interdigital capacitive sensors are widely used as chemical sensors due to their simple technology. The capacitance changes are linearly dependent on the analyte concentration. Sensors coated with some chemicals shows higher sensitivity to organic molecules with higher dipole moment such as alcohols, acetone and chloroform and less sensitivity to organic molecules with small or zero dipole moment such as carbon tetra chloride, n-hexane and n-octane. Some other chemicals exhibit opposite properties which can be utilised to design the sensors as needed [88].

CHAPTER 4

EXPERIMENTAL SETUP AND ANALYSIS OF SENSORS

4.1. Introduction

Experimental setup and the procedure followed to measure the signal from the sensor across various positions of skin are explained in this chapter. Various structures and analysis of interdigital sensors have been discussed. The performance of four types of interdigital sensors is compared for cheese, butter, and air. Depending on the analysis, the best sensor was selected to conduct experiments with sheep skin.

4.2. Design of Interdigital Sensors

Four designs of interdigital sensors were considered for this project. In design configuration (i) of figure 4.2.1, the pattern of electrodes is + - + - + - +, which is an arrangement of alternative positive and negative electrodes separated by a distance of 30 mm. It consists of total 6 electrodes of 118mm length and 0.5 mm width, 3 connected to exciting/driving electrodes and 3 are connected to ground.

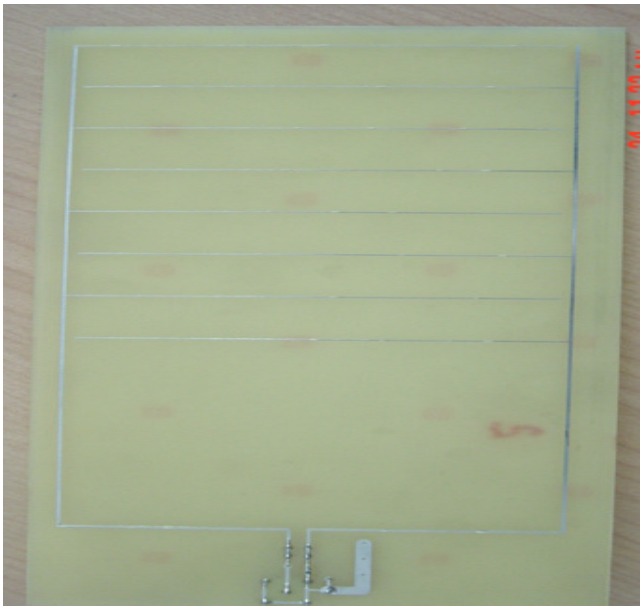


Figure 4.2.1: Image of sensor 1

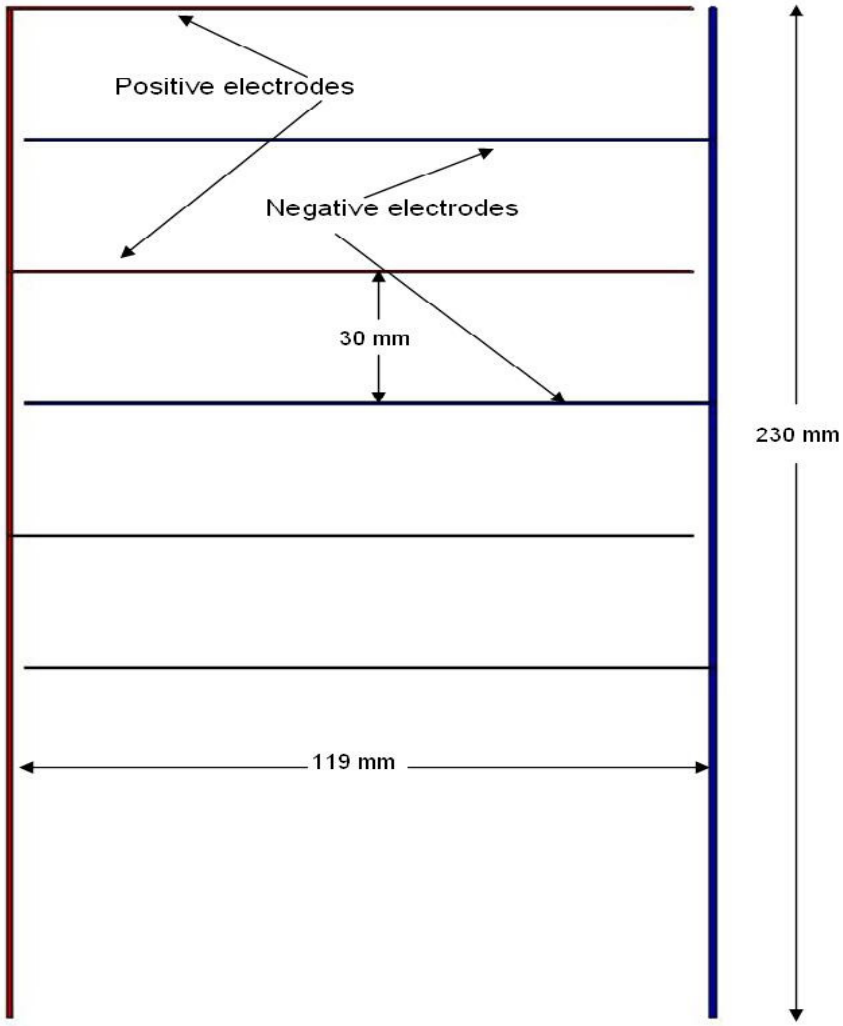


Figure 4.2.2: Design configuration of sensor 1

The pattern of electrodes in design configuration (ii) in figure 4.2.3 is again + - + - + - + - + with driving and ground electrodes arranged alternatively. This configuration has 10 electrodes of 118 mm length and 0.5 mm width separated by a distance of 15 mm, 5 of them are connected to exciting/driving electrodes and 5 are connected to ground.

Figure 4.2.3: Image of sensor 2

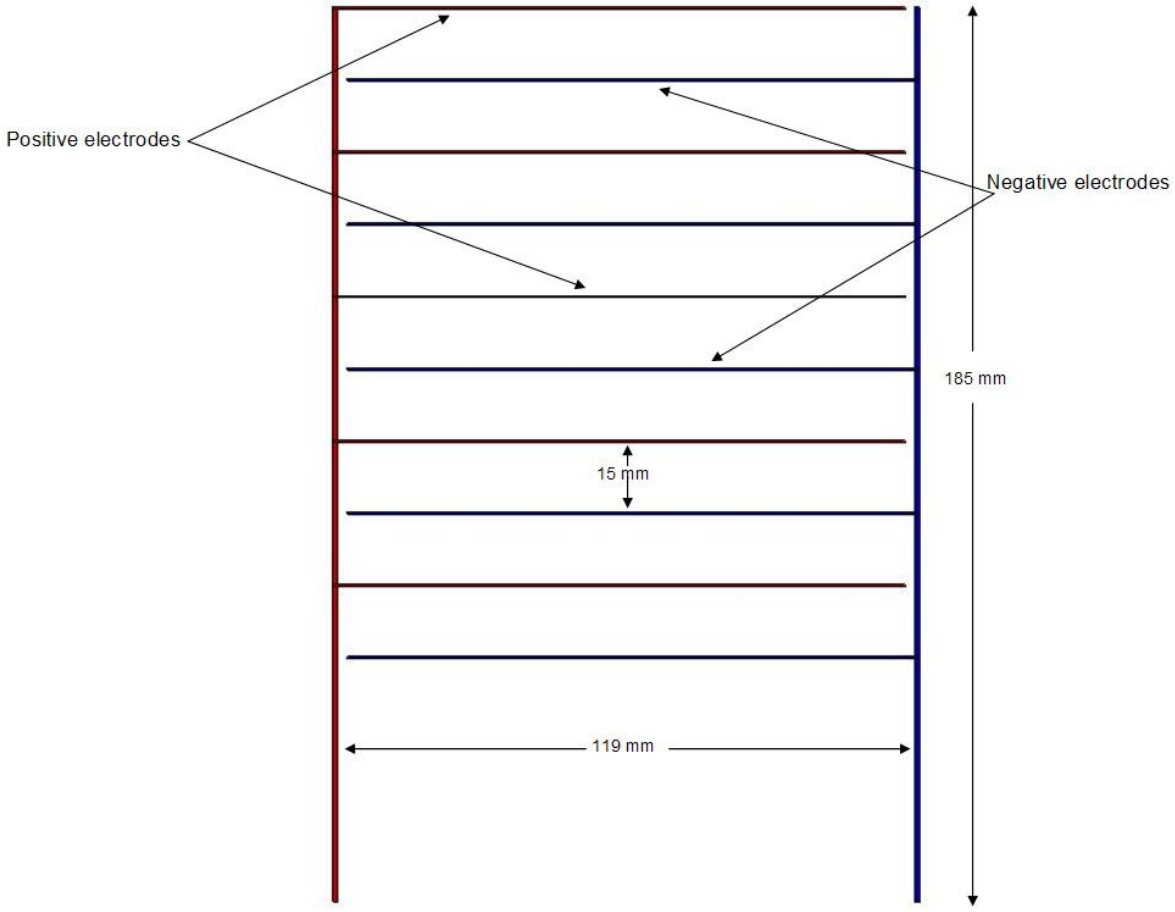


Figure 4.2.4: Design configuration of sensor 2

In design configuration (iii) of figure 4.2.5, electrodes are arranged as + - - - - - - , which consists of 1 driving electrode and a series of 10 ground electrodes. Ground electrodes are placed 40.5 mm away from driving electrode to enable bigger penetration depths. Ground electrodes are placed 5 mm away from each other. The driving electrode is of 3 mm width and 118 mm in length, ground electrodes are of 0.5 mm width and 118 mm in length as well.

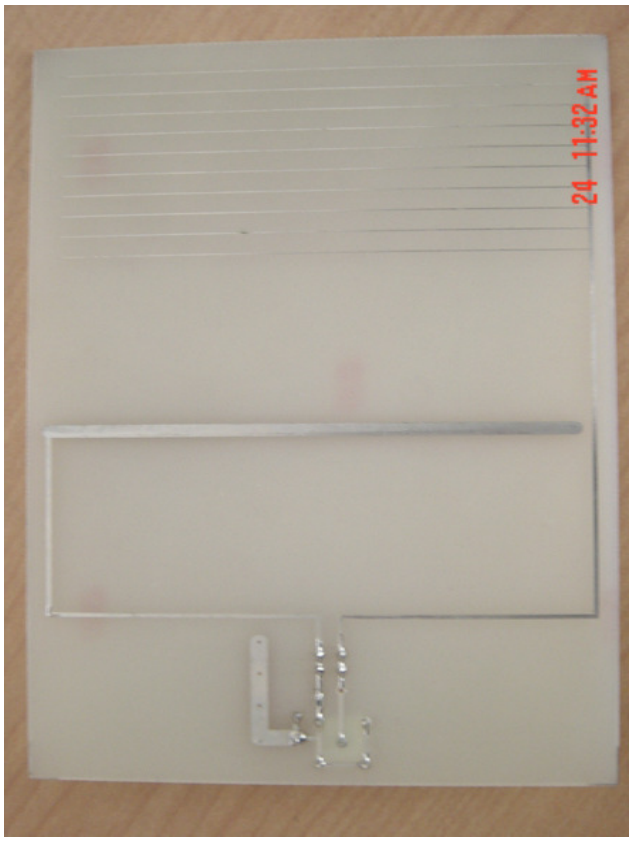


Figure 4.2.5: Image of sensor 3

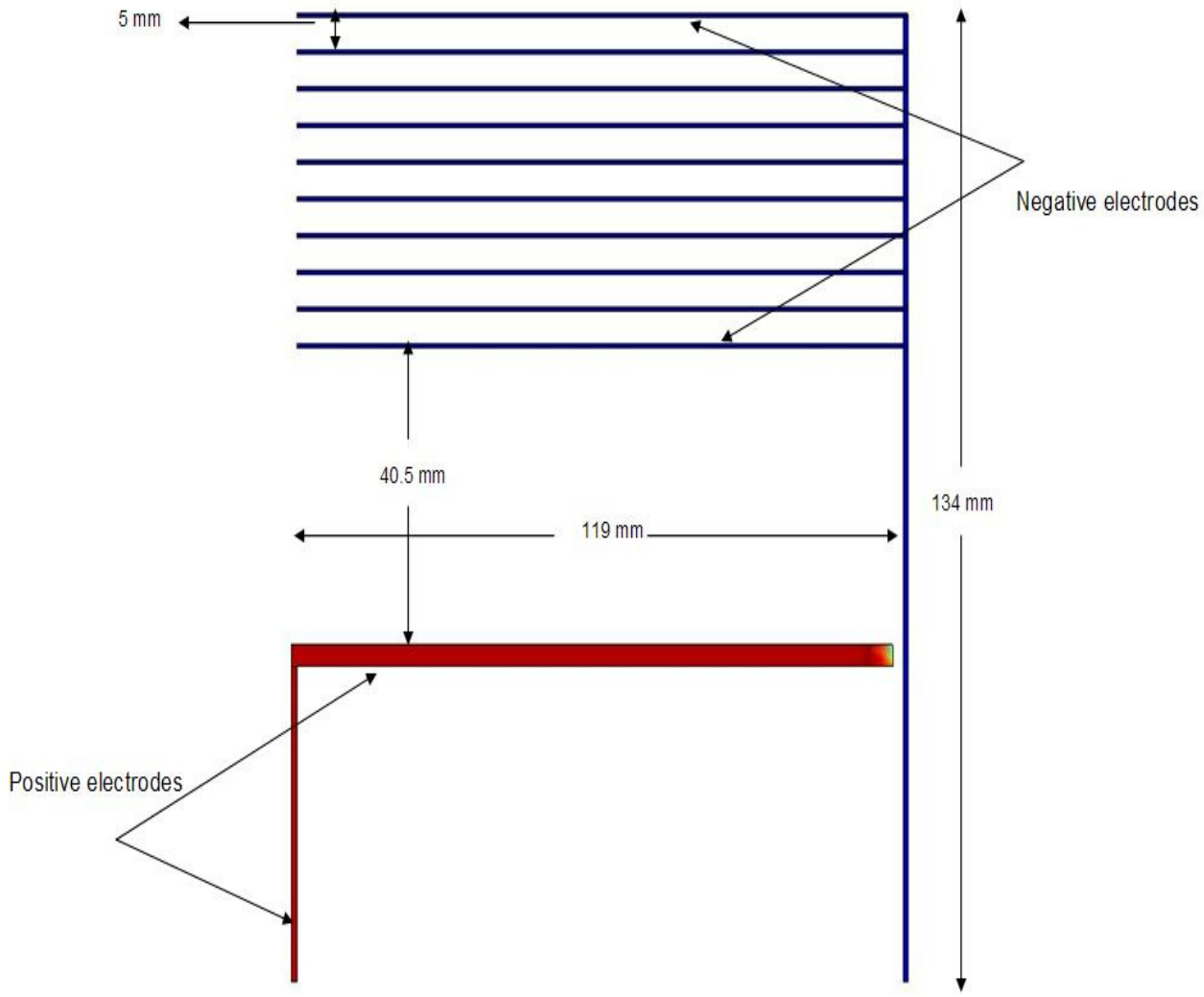


Figure 4.2.6: Design configuration of sensor 3

In design configuration (iv) of figure 4.2.7, electrodes are arranged in the pattern of + - - - - - - - + - - - - - - - + etc, a driving electrode followed by a series of 7 ground electrodes. The above pattern was repeated with a driving electrode again. More number of negative electrodes enables a better or strong current signal off the sensor. Each electrode is separated by a distance of 4 mm; each electrode is of 136 mm in length and 1 mm in width.

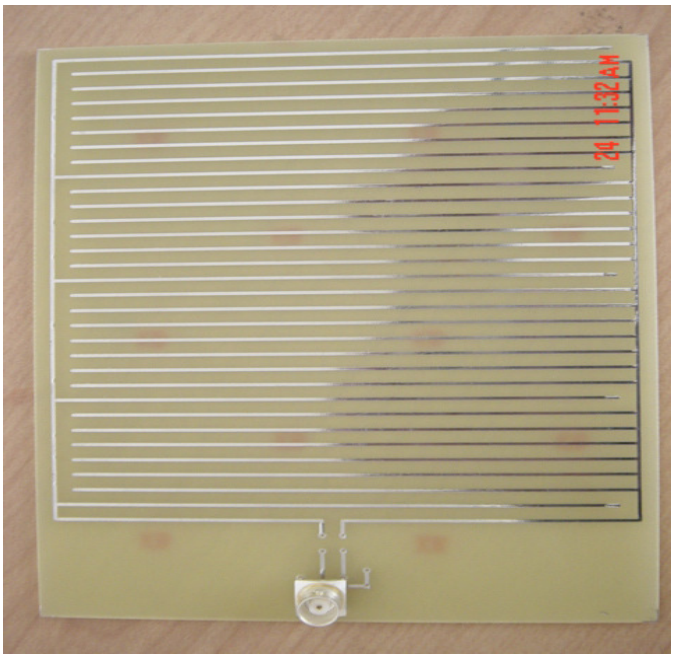


Figure 4.2.5: Image of sensor 4

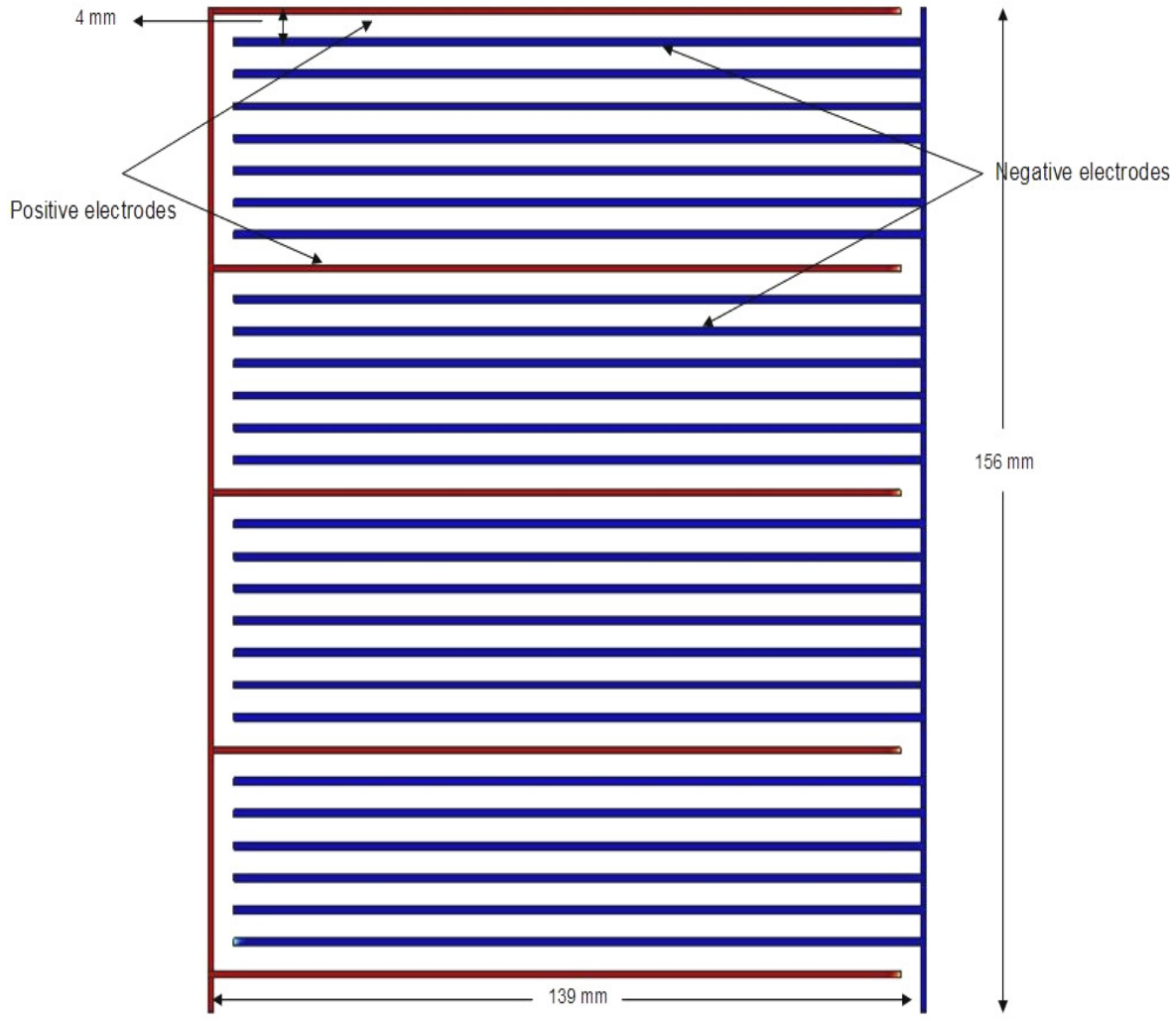


Figure 4.2.8: Design configuration of Sensor 4

Four interdigital sensors are shown in figures 4.2.1, 4.2.2, 4.2.3 and 4.2.4 with varying structures and pitch lengths. Pitch length is the distance between the electrodes and by varying the distance between the electrodes, we can achieve various penetration depths depending on the requirement.

The electric field generated in between driving and ground electrodes is altered by the dielectric properties of the material placed in between them. The modified field is measured and is used for the estimation of system properties in an indirect way. Four different designs of Interdigital sensors designed above could be used for the estimation of material properties in a non-invasive and non-destructive way. Each sensor has a resistor placed in series as shown in figure 4.2.9, where, the modified signal is captured across this resistor and sent to interfacing circuit for estimation of system properties.

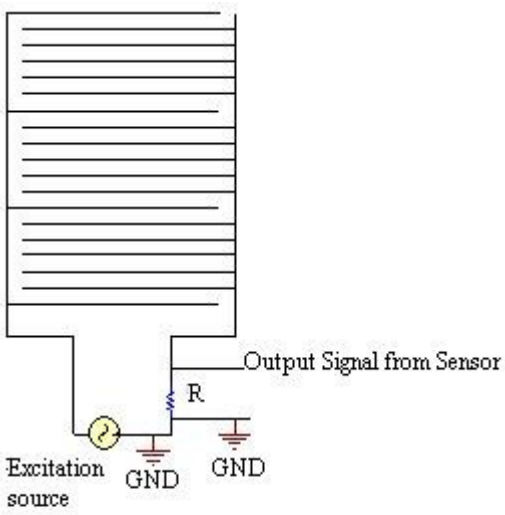


Figure 4.2.9: The sensor, excitation and output signal

The current through the sensor is measured by measuring the voltage across the resistance, R, which is connected in series with the sensor.

So we have,

$V_R = I \times R$; where, V_R is the voltage across R

R is the series resistance

I is the current drawn by the sensor

Now,

$I = \frac{V}{\mathbf{Z}}$; where, $\mathbf{Z}$ is the impedance of the sensor along with R

$\mathbf{Z} = \sqrt{(X^2 + R^2)} \approx X$ as $X >> R$; X is the reactance of the sensor

$V_R = R \times \frac{V}{X}$; as, $I = \frac{V}{X}$

$|V_R| = RV\omega C$; as, $X = \frac{1}{\omega C}$, C is the capacitance of the sensor

As, for a traditional parallel plate capacitor, $C = \frac{\varepsilon_o \varepsilon_r A}{d}$ and $\omega = 2\pi f$

$|V_R| = RV 2\pi f \frac{\varepsilon_o \varepsilon_r A}{d}$; A is the area of the plate

d is the distance between the plates

ε_o is the permittivity of free space

ε_r is the relative permittivity of the material

$= K(\varepsilon_r f)$; where, $K = RV 2\pi \varepsilon_O \frac{A}{d}$; K is constant for a fabricated sensor.

So, $V_R \alpha f$, $V_R \alpha \varepsilon_r$. The voltage across resistor V_R is proportional to both frequency and effective relative permittivity of the material. For the experiments conducted, frequency was kept constant from which we can say voltage across resistor V_R is proportional to the effective relative permittivity of the material under test. The measured effective relative permittivity is used to determine the properties of the system.

4.3. Finite Element Modeling of Interdigital sensors

For Interdigital sensor the electric field distribution is the most important thing so the performance and analysis of the sensors have been carried out using finite element modeling. Before experimentation the finite element software FEMLAB by COMSOL [89] was used to model and analyze the distribution of electric field. Femlab solves all kinds of scientific and engineering problems based on partial differential equations (PDEs). For analysis of interdigital sensors electromagnetic module in 3-D mode is selected and then Electrostatic mode is chosen as shown in figure 4.3.1.

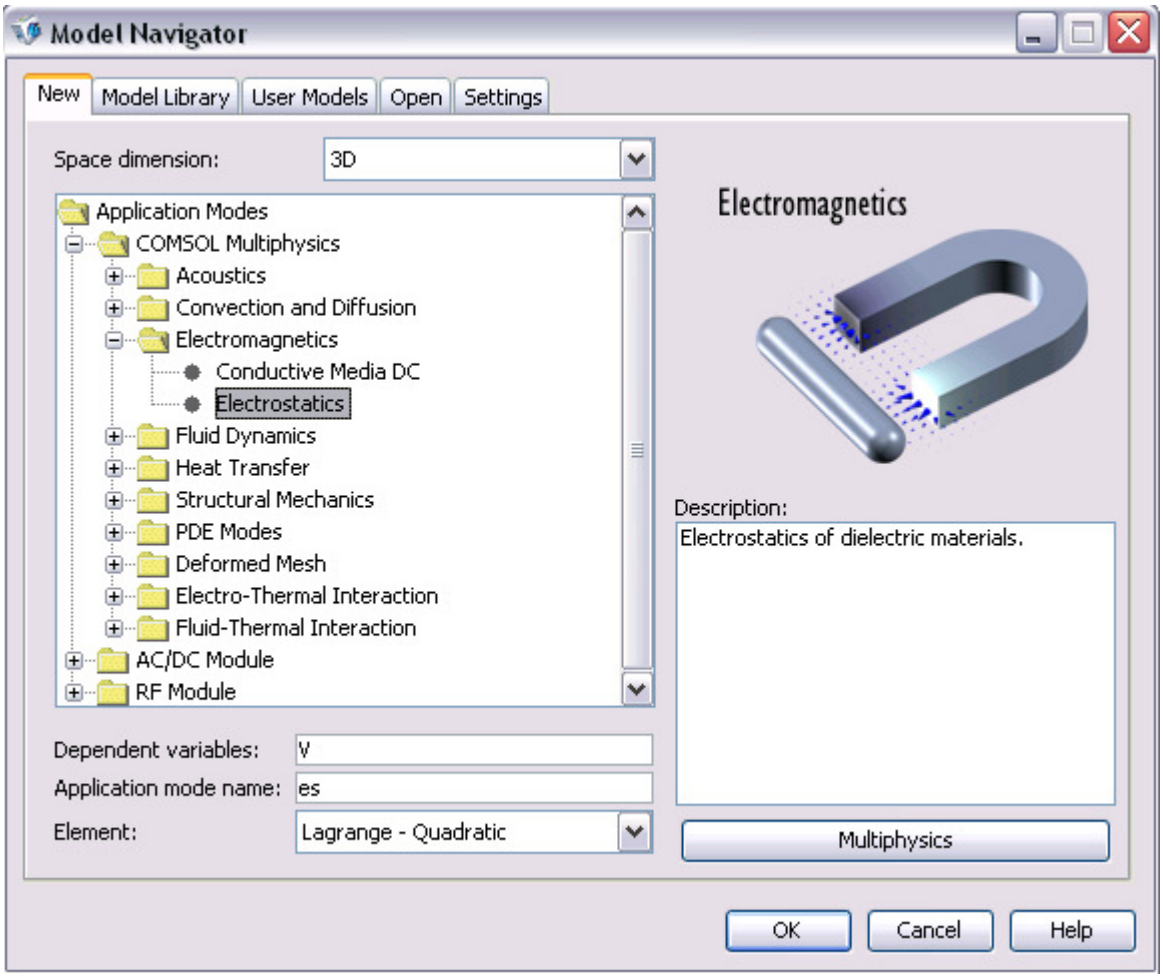


Figure 4.3.1: FEMLAB model navigator

STEPS TO DESIGN AN INTERDIGITAL SENSOR

As discussed that the Interdigital sensor has one set of electrodes connected to a driving or excitation source and the other set of electrodes connected to ground, this forms the basis of a parallel plate capacitor [28], the sensing and excitation electrodes can be viewed with a better clarity in figure 4.7. The Interdigital sensor is modeled as shown in figure 4.3.2. The large rectangular block that surrounds the sensor acts as the environment the sensor is exposed to. Modeling of only sensor 4 has been shown in this section. The electrodes and the rectangular block are created using block tab under draw menu.

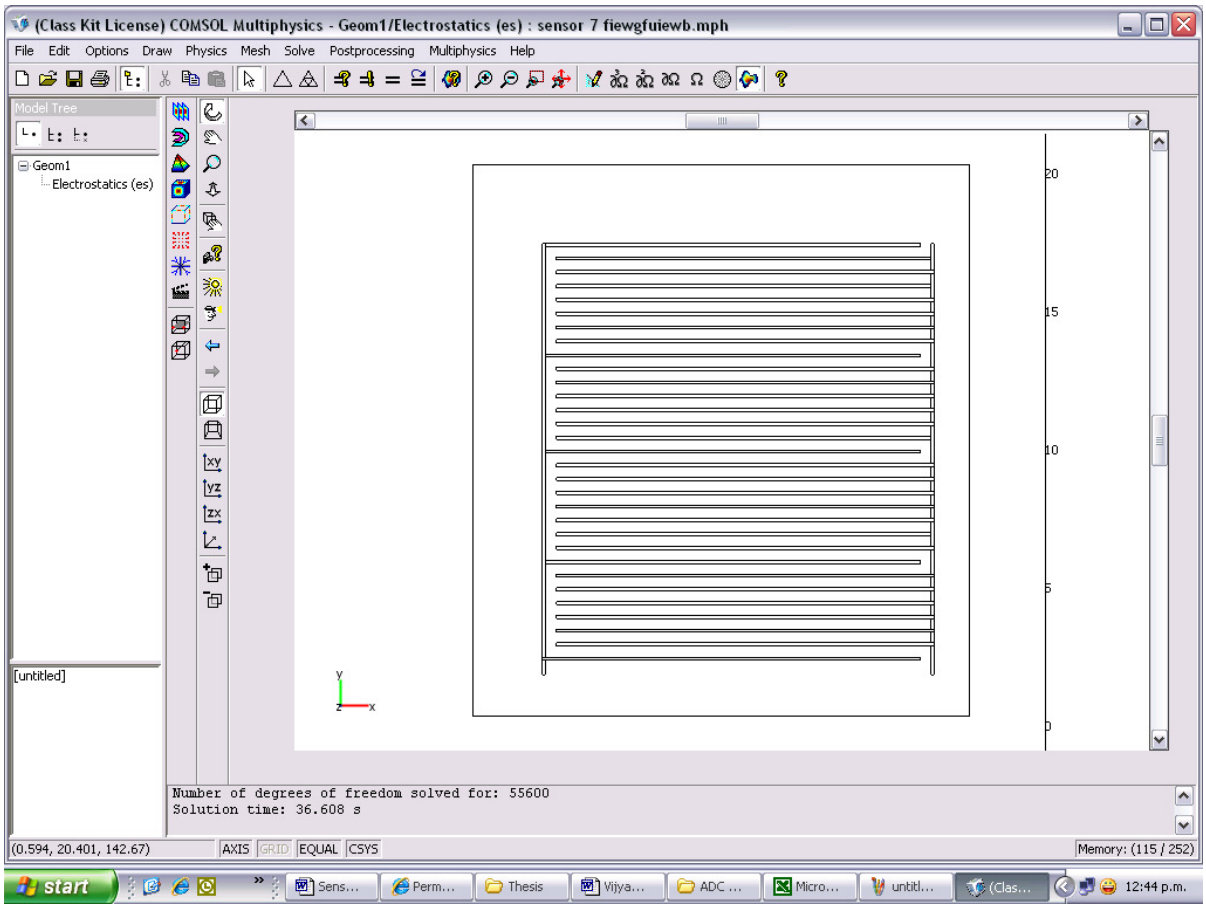


Figure 4.3.2: Model of Interdigital Sensor

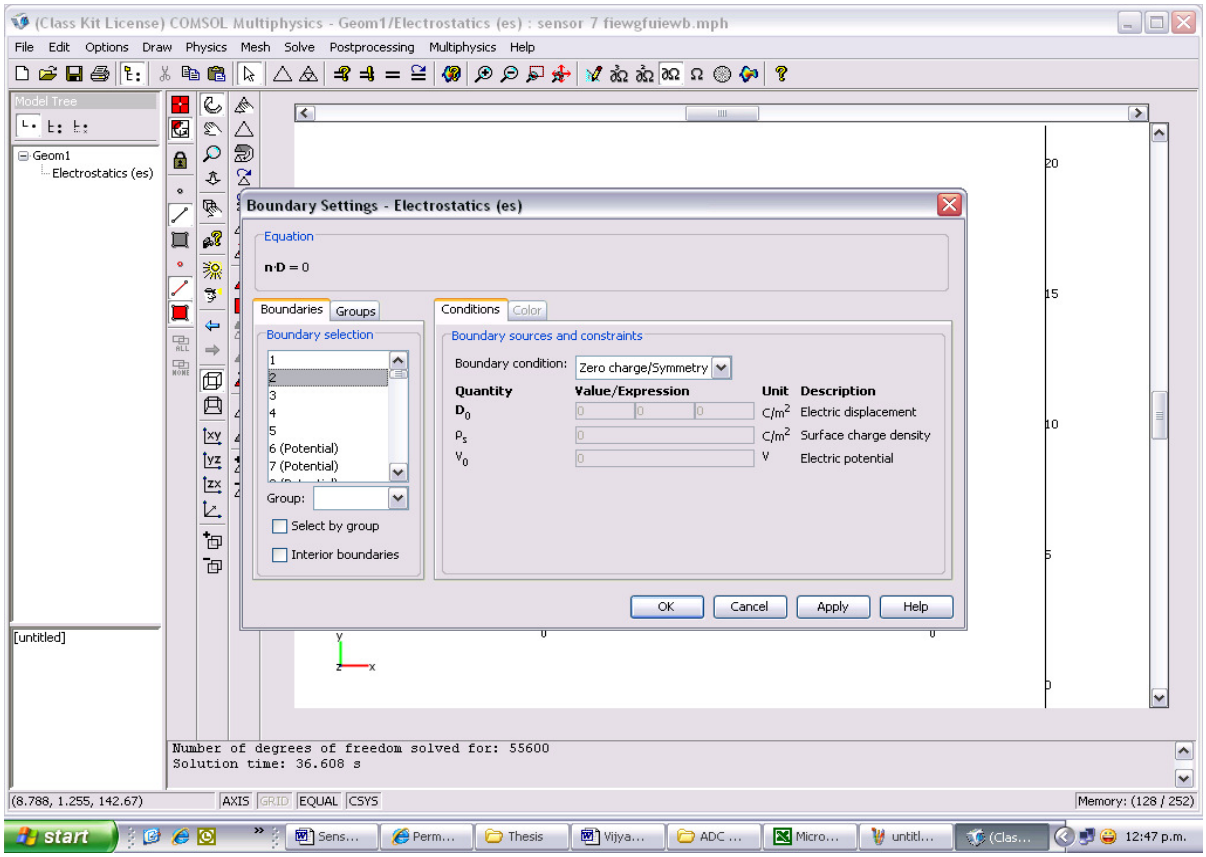


Figure 4.3.3: Window for boundary setting of rectangular block

In the "Boundary Settings" menu each sensor boundary is defined according to the required condition. All boundaries of the rectangular block (block exposed to the environment) are set to "Zero charge/symmetry". The block is set to "Zero charge/symmetry" so that it does not have any effect on the electric field generated between the electrodes. The window for setting the boundary conditions is shown in figure 4.3.3. Boundary setting options window can be opened by pressing F7 on the keyboard or under physics menu. Depending upon the sensor design the positive electrodes of the sensor are set electric potential of 1V and negative electrodes are set to ground potential. As shown in figure 4.3.4 below, excitation electrodes are set to a voltage of 1V and the sensing electrodes are set to ground. An electric field is thus formed between the driving and the ground electrodes.

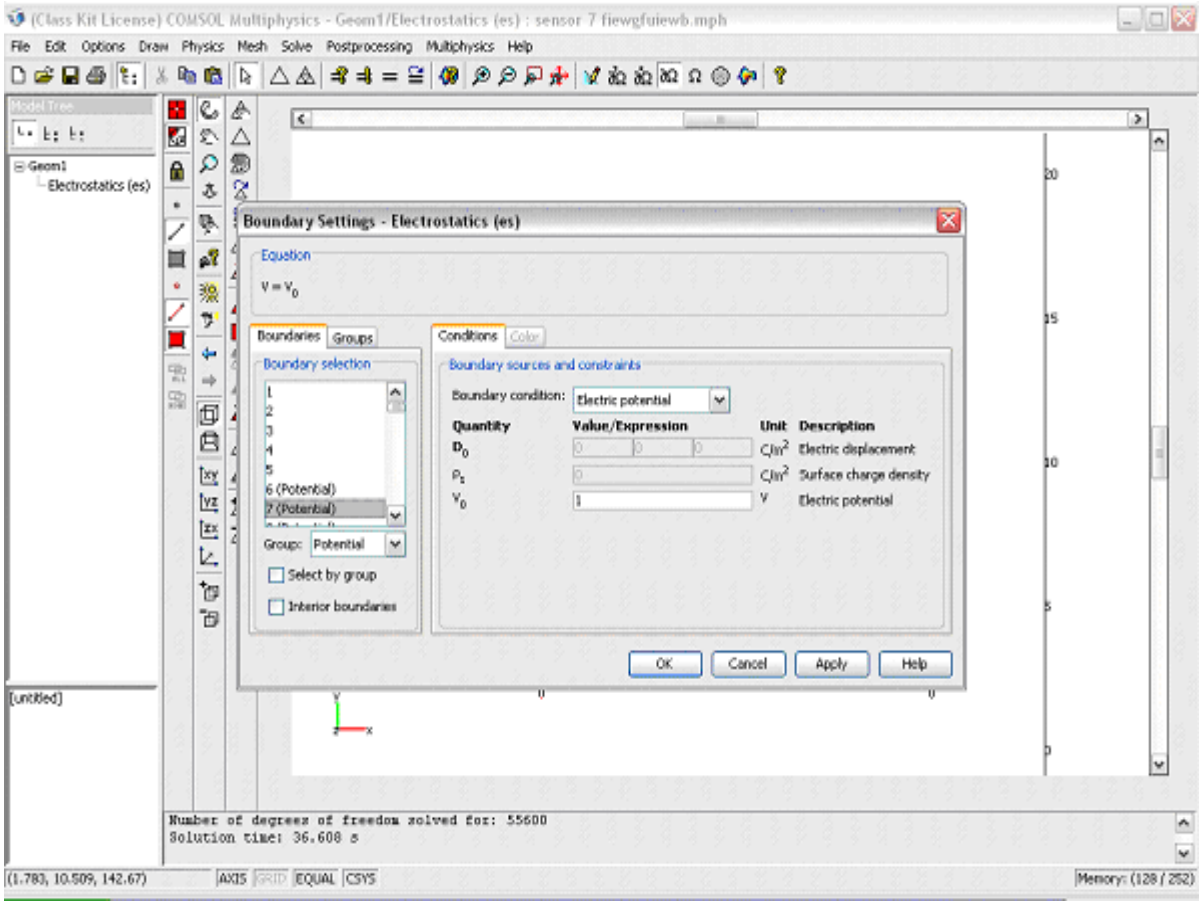


Figure 4.3.4: Window for boundary setting of sensor

The sensing electrodes are shown red in color and the ground electrodes are shown in blue color as in figure 4.3.5. The permittivity is set in the “Subdomain Settings” menu, it can be found under physics menu or by pressing F8. The window for setting the subdomain is shown in figure 4.3.7. The relative permittivity is set to 1 for the whole rectangular block that covers the sensor to represent air as the relative permittivity of the air is 1.

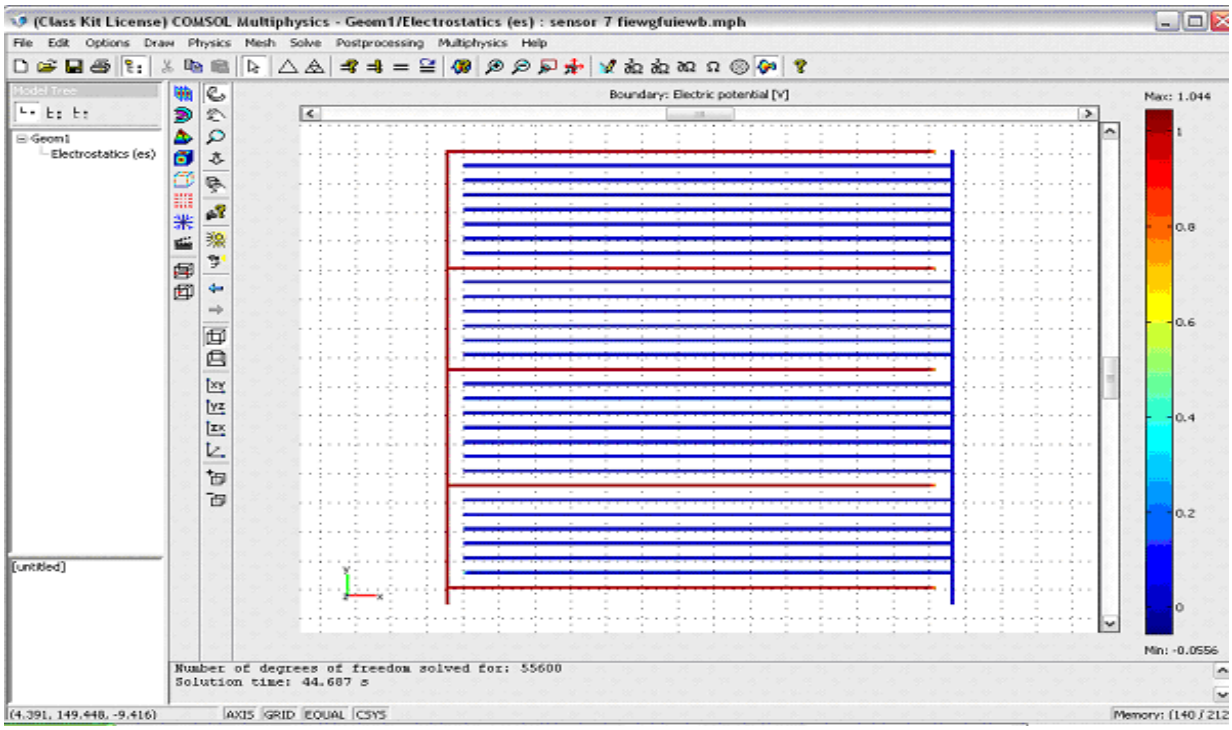


Figure 4.3.5: Window showing excitation and ground electrodes distinctively

As the driving electrodes have electric potential and sensing electrodes are set to ground, they need to be excluded from the rectangular box set to Zero charge symmetry to be able to see the flow of field. To do this, all the driving electrodes are considered as one block and the ground electrodes are considered as other block and they are deleted from the rectangle which is considered as another block as shown in figure 4.3.6. Here, rectangle is represented as BLK1, driving electrodes as CO2 and ground electrodes are represented as CO1. This window can be found under draw menu by clicking create composite object.

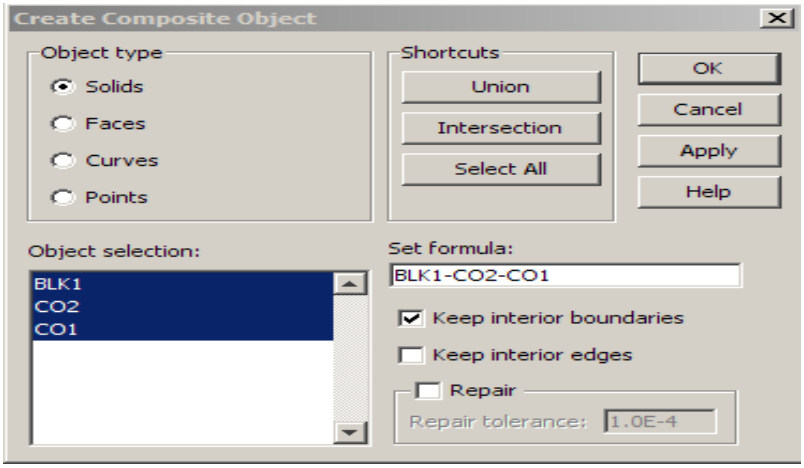


Figure 4.3.6: Window for create composite object

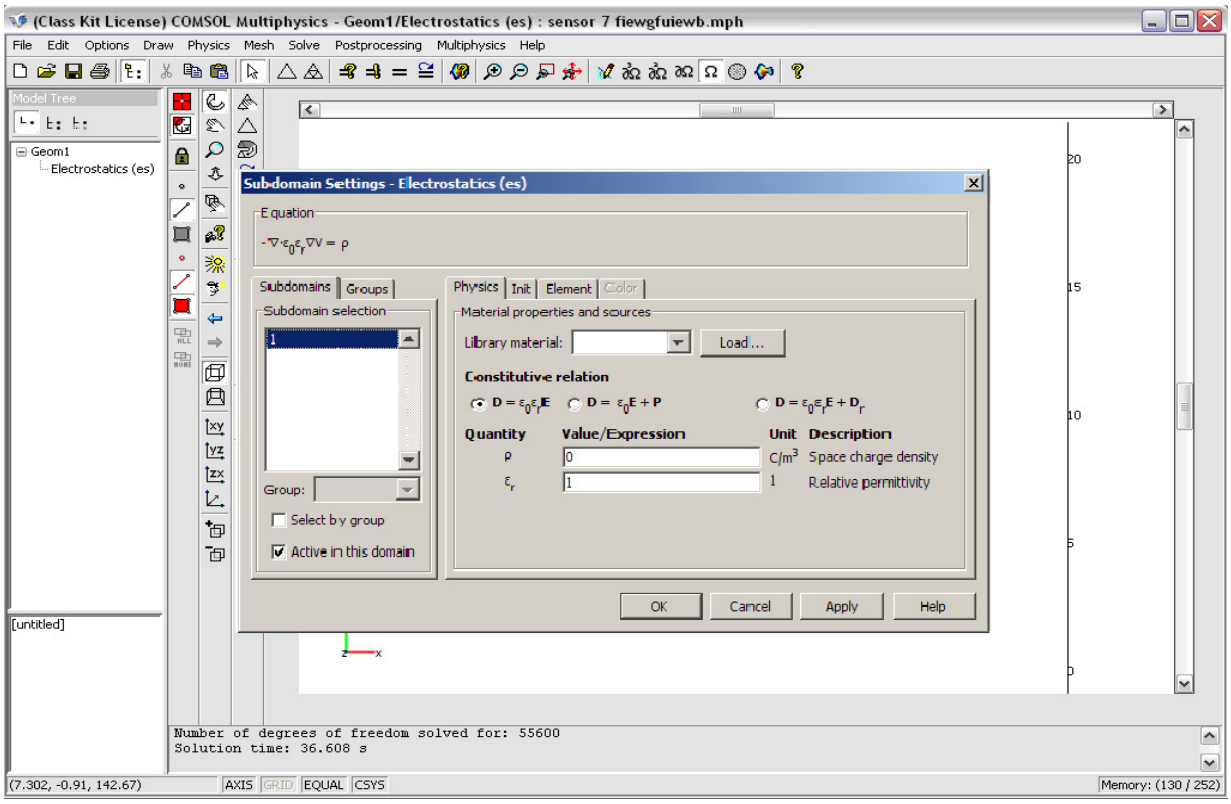


Figure 4.3.7: shows the window for setting the Subdomain.

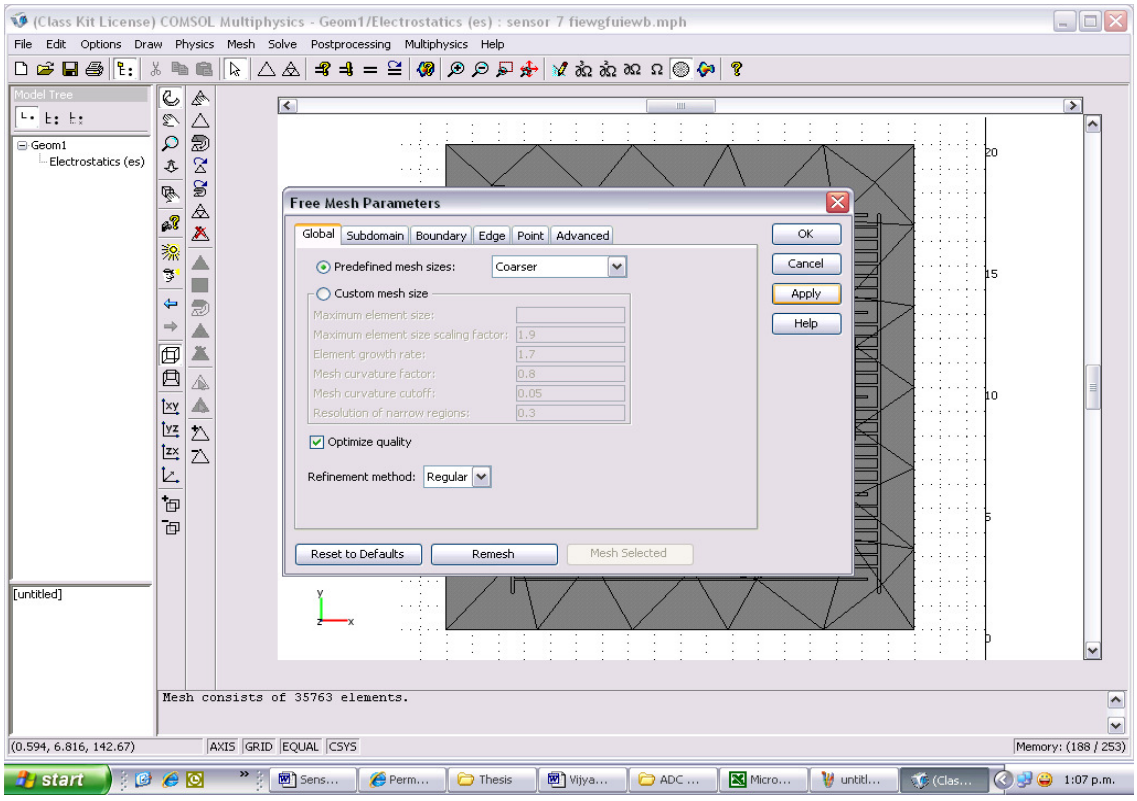


Figure 4.3.8: Mesh of the model

Coarser mode is selected under the mesh mode. Figure 4.3.8, shows the required settings for mesh menu. Figure 4.3.9, shows the required setting for solving the problem.

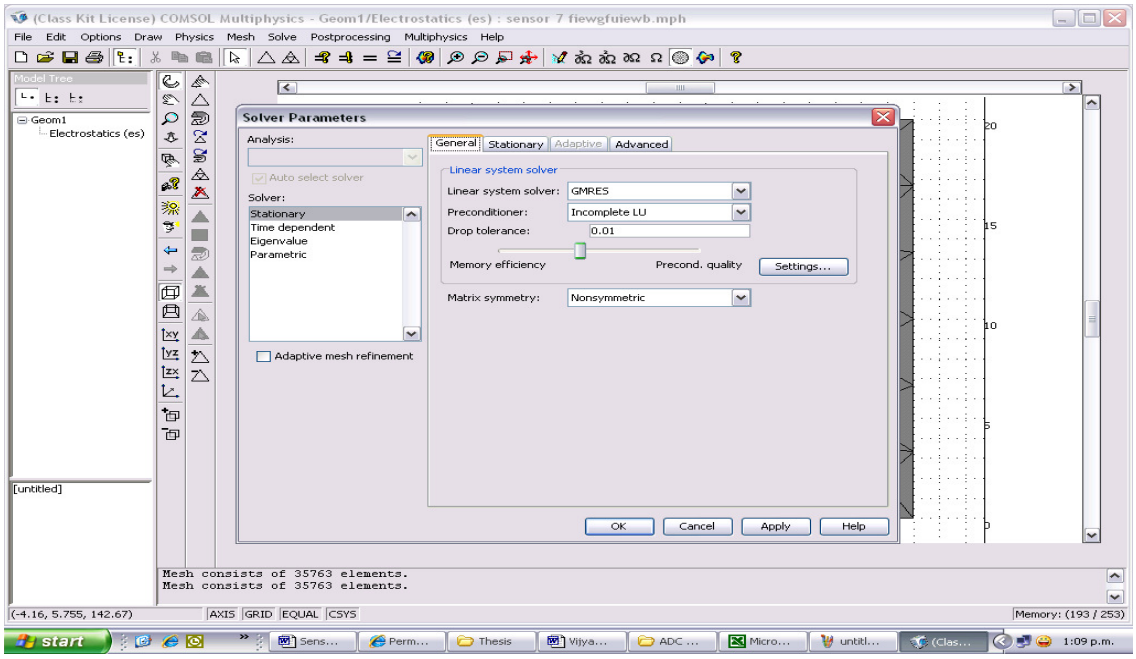


Figure 4.3.9: Solve menu

After the mesh, the model has to be solved. The solve parameters could be found under solve menu and the parameters are set as shown in figure 4.3.10. After setting the parameters the model is to be solved by pressing the solve button.

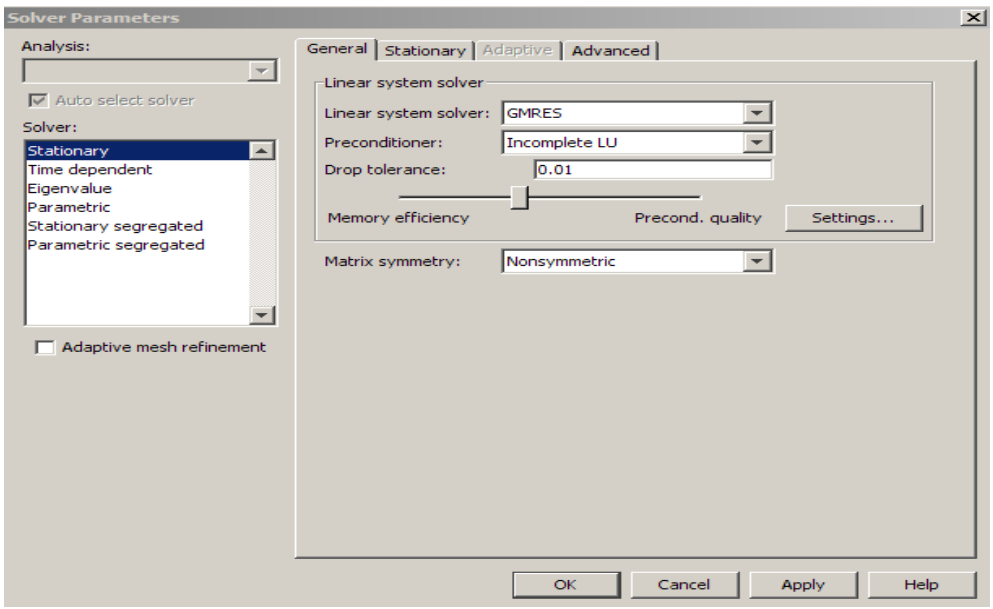


Figure 4.3.10: Menu to set solve parameters

On clicking 'Solve', a progress window opens to show how the solution is converging, and if the settings are well defined Femlab modeling can be progressed to 'Postprocessing' mode, which shows the graphical solution. Many are obvious visualization options: variable(s) to be plotted; graph types such as surface, streamline, and contour; and animations for time-dependent solutions. Electric field distribution for different sensors can be observed by selecting electric field for streamline plotting and selecting electric field, norm on clicking on tube radius button. Electric field distribution for sensors is shown in figures 4.3.11, 4.3.12, 4.3.13 and 4.3.14.

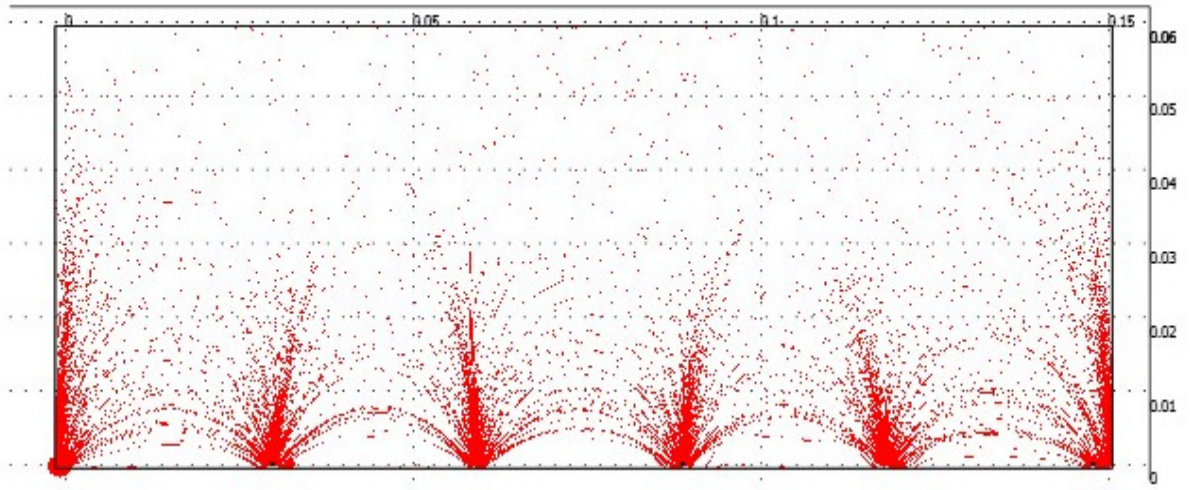


Figure 4.3.11: Electric field intensity for sensor 1

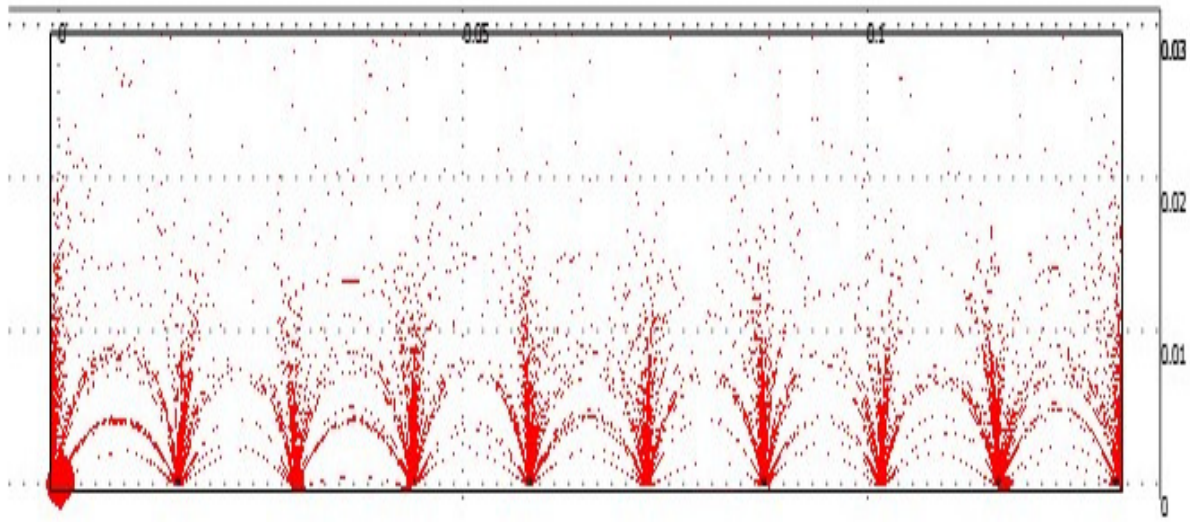


Figure 4.3.12: Electric field intensity for sensor 2

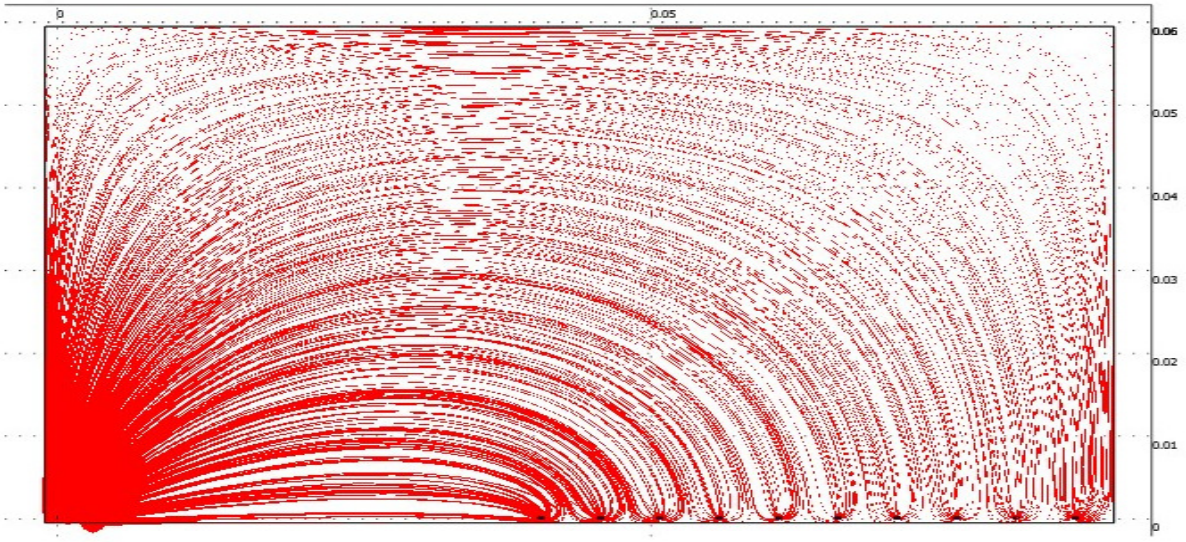


Figure 4.3.13: Electric field intensity for sensor 3

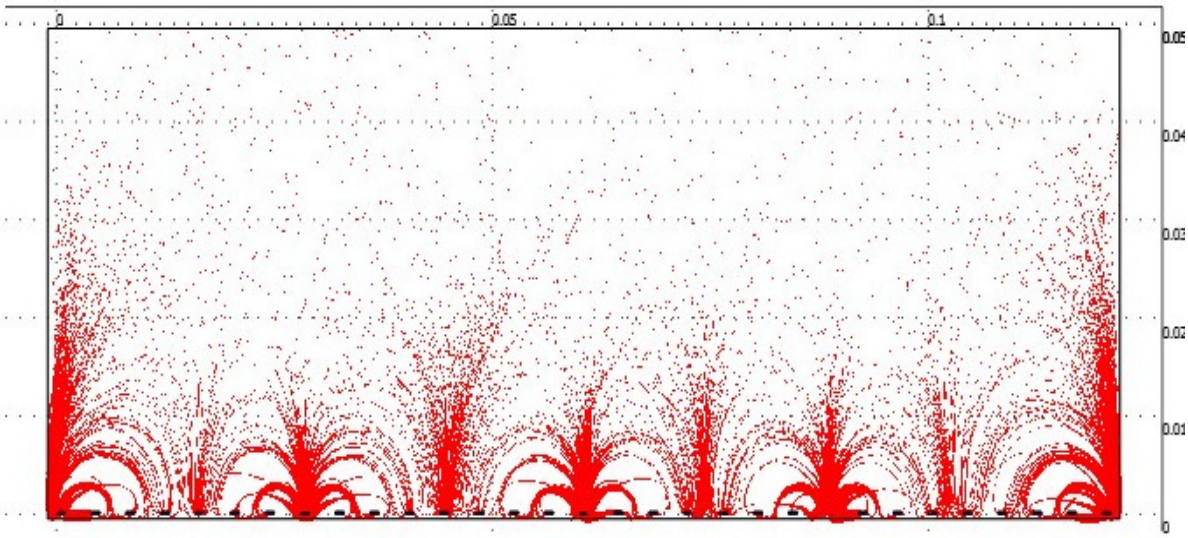


Figure 4.3.14: Electric field intensity for sensor 4

The capacitance of the sensor electrodes can be calculated by,

$$C = \frac{2W_e}{V_0^2}$$

Where, W_e is the stored electrical energy and V_0 is the applied voltage.

The calculated capacitances for the sensors from the COMSOL are shown in the table below. All the values shown in the table are in the units of pF.

Table 4.3.1: Capacitance values of four sensors

Sensor	Capacitance value
Sensor 1	1.3802766
Sensor 2	2.789662
Sensor 3	0.4635122
Sensor 4	7.514484

From the figures 4.3.11, 4.3.12, 4.3.13 and 4.3.14, it is observed that electric field distribution decreases with increase in height. The scale 0.01 equals 1 cm or 0.01 m. From the above figures we can see that sensor 4 has most field distribution below 5 mm or 0.005 cm, this is important as thickness of sheep skin for the most of samples that we considered is around 1.5 mm or 0.0015 cm as per scale. Sensor 3 has better field distribution that could be helpful for analyzing the materials that have thickness of around 0.05 cm.

4.4 Preliminary Experiments

Sensitivity for the sensors was verified by comparing sensor output voltage across the resistor for air, cheese, and butter. For these experiments cheese, butter and air were considered. First the sensor output voltage for air was measured without any material on its top and then voltage for each material was measured and the data is presented in the tables below.

Table 4.4.1: Sensor output voltage values for sensor 1

Sensor 1				
		Air	Cheese	Butter
Frequency	Vs (V)	Vair	Vr (V)	Vr (V)
1 Khz	20	0.029	0.039	0.046
2 Khz	20	0.0547	0.078	0.078
3 Khz	20	0.081	0.114	0.109
4 Khz	20	0.109	0.159	0.143
5 Khz	20	0.134	0.193	0.173
6 Khz	20	0.159	0.231	0.212
7 Khz	20	0.187	0.268	0.243
8 Khz	20	0.212	0.306	0.278
9 Khz	20	0.237	0.35	0.309
10 Khz	20	0.262	0.387	0.34

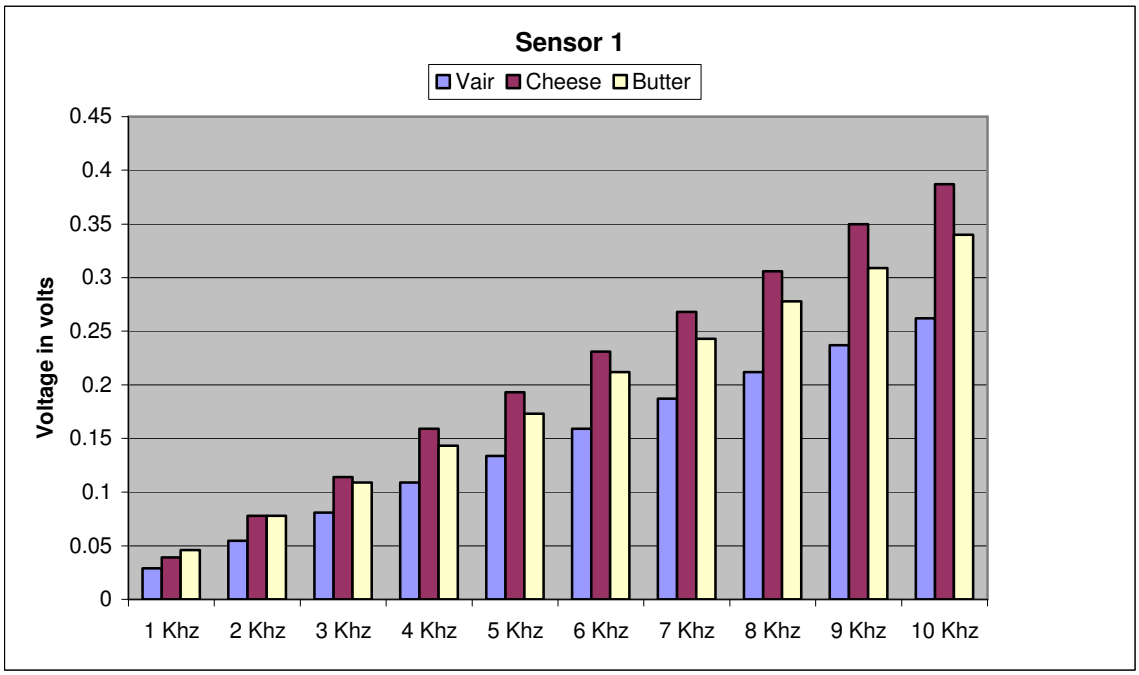


Figure 4.4.1: Graphical representation of sensor output voltage values for sensor 1

From the graph in figure 4.4.1, it is observed that sensor 1 is distinctive for the materials considered and the sensor output voltage increases with increase in frequency.

Table 4.4.2: Sensor output voltage values for sensor 2

Sensor 2				
			Cheese	Butter
Frequency	Vs (V)	Vair	Vr (V)	Vr (V)
1 Khz	20	0.053	0.065	0.09
2 Khz	20	0.104	0.131	0.156
3 Khz	20	0.162	0.212	0.225
4 Khz	20	0.212	0.284	0.293
5 Khz	20	0.268	0.356	0.356
6 Khz	20	0.315	0.475	0.431
7 Khz	20	0.375	0.562	0.493
8 Khz	20	0.425	0.637	0.568
9 Khz	20	0.475	0.718	0.618
10 Khz	20	0.531	0.768	0.687

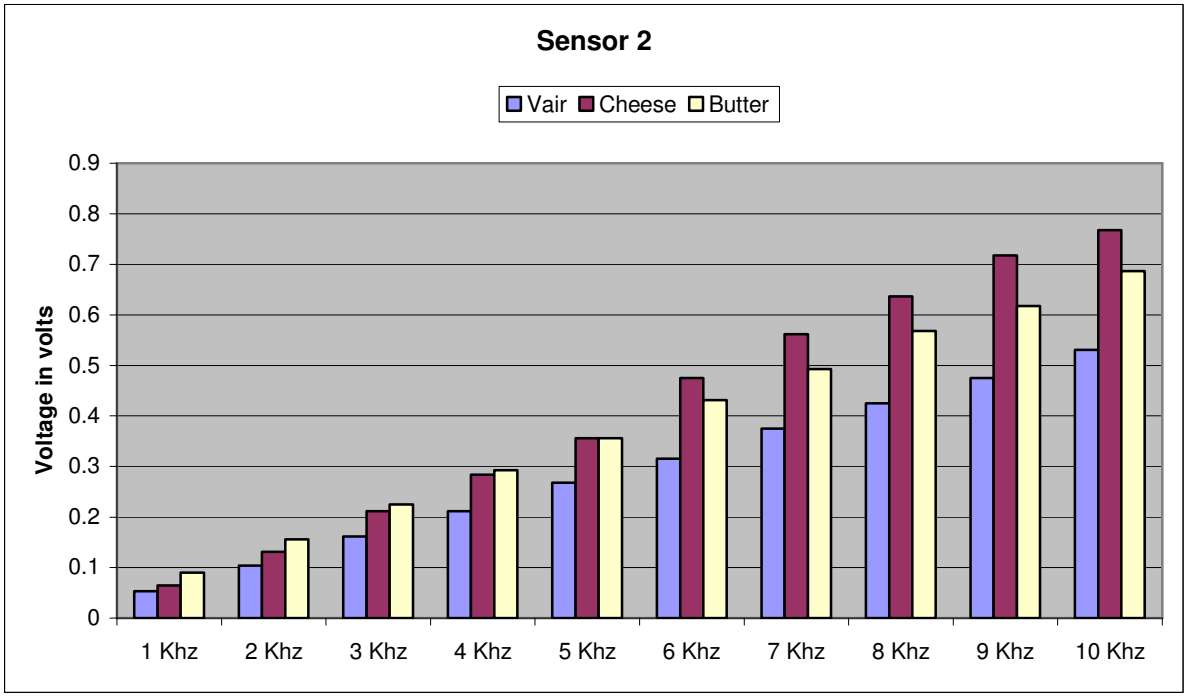


Figure 4.4.2: Graphical representation of sensor output voltage values for sensor 2

The sensor output values of sensor 2 for different materials are shown in figures 4.4.2. From the figure 4.4.2, it is observed that sensor 2 is distinctive for different materials as well and the sensor output voltage increases with increase in frequency. The signal strength is almost twice compared to the sensor 1 and this could be due to the increase in the number of electrodes as sensor 1 has 3 driving and sensing electrodes each and sensor 2 has 5 driving and sensing electrodes each.

Table 4.4.3: Sensor output voltage values for sensor 3

Sensor 3				
			Cheese	Butter
Frequency	Vs (V)	Vair	Vr (V)	Vr (V)
1 Khz	20	0.014	0.026	0.018
2 Khz	20	0.031	0.054	0.034
3 Khz	20	0.045	0.078	0.05
4 Khz	20	0.059	0.103	0.069
5 Khz	20	0.073	0.126	0.086
6 Khz	20	0.087	0.153	0.101
7 Khz	20	0.1	0.185	0.117
8 Khz	20	0.112	0.212	0.134
9 Khz	20	0.126	0.237	0.15
10 Khz	20	0.143	0.268	0.167

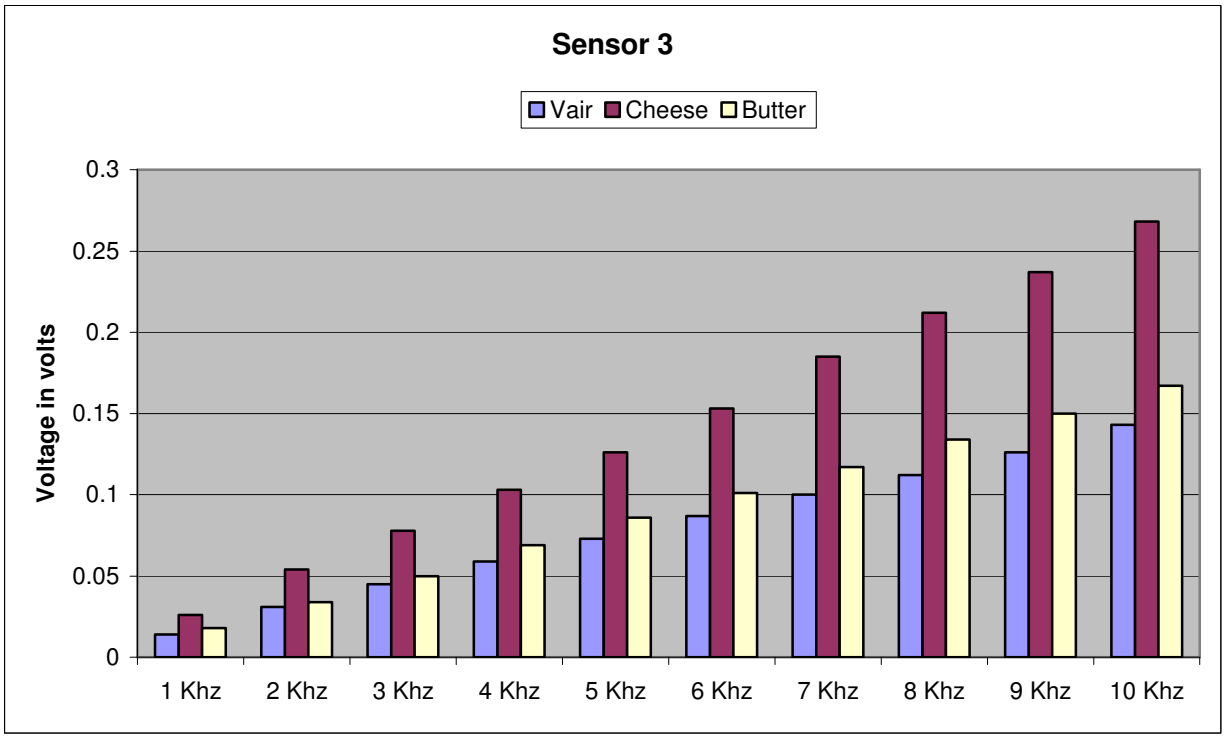


Figure 4.4.3: Graphical representation of sensor output voltage values for sensor 3

The sensor output values for sensor 3 is shown in figures 4.4.3. Sensor 3 is also distinctive for the materials considered. It has lowest signal strength compared to the first and second sensor this could be due to the unique arrangement of electrodes as shown in figure 4.2.3. For this sensor the field distribution is greater but the signal strength is low.

Figure 4.4.4: Sensor output voltage values for sensor 4

Sensor 4				
			Cheese	Butter
Frequency	Vs (V)	Vair	Vr (V)	Vr (V)
1 Khz	20	0.156	0.168	0.212
2 Khz	20	0.312	0.35	0.4
3 Khz	20	0.456	0.506	0.587
4 Khz	20	0.625	0.688	0.797
5 Khz	20	0.781	0.844	0.953
6 Khz	20	0.938	1.031	1.125
7 Khz	20	1.063	1.172	1.281
8 Khz	20	1.203	1.344	1.469
9 Khz	20	1.344	1.5	1.641
10 Khz	20	1.484	1.672	1.813

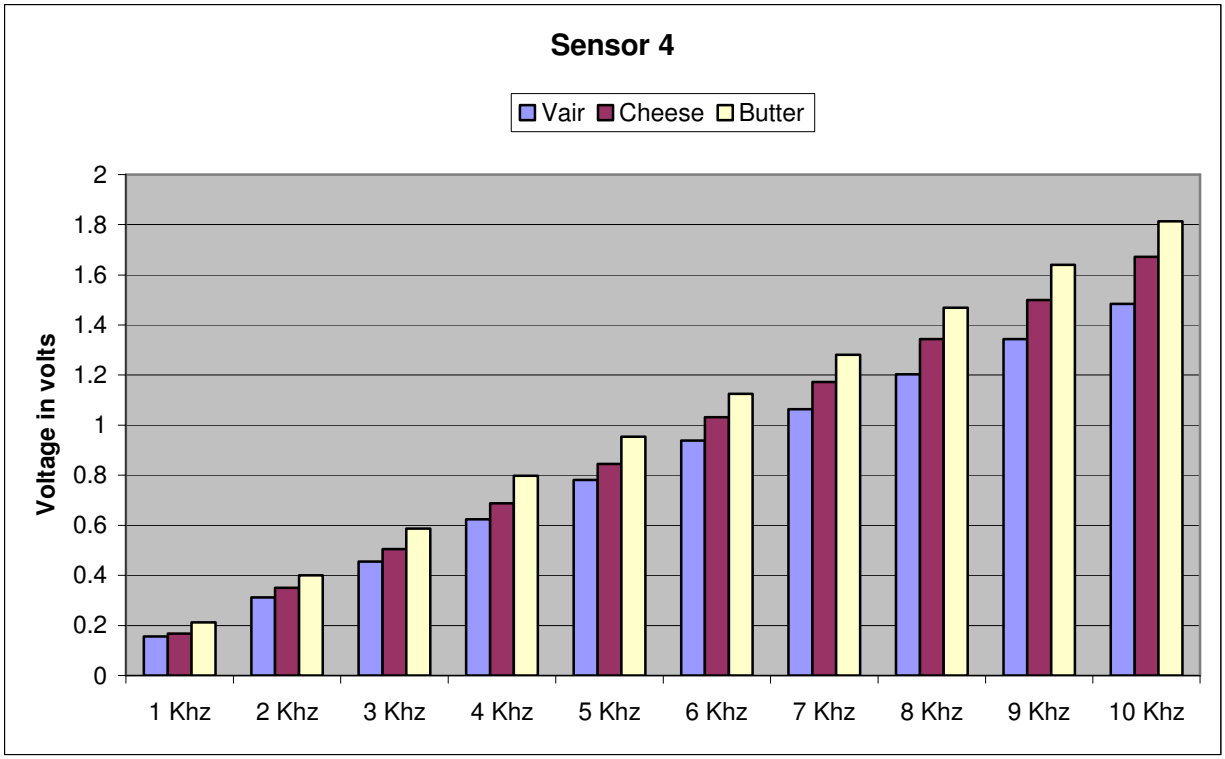
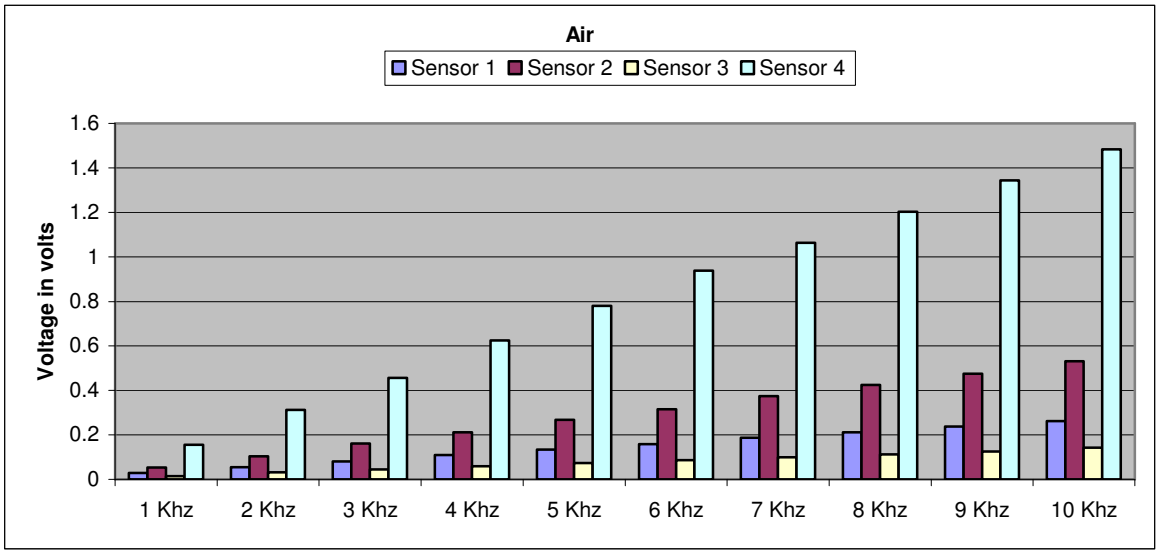
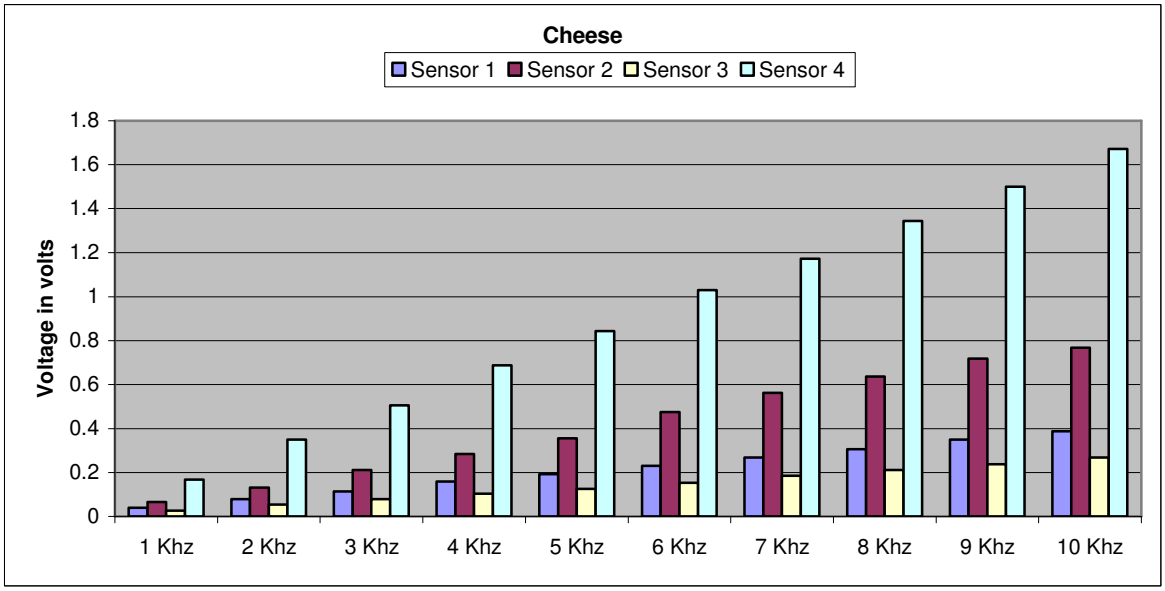


Figure 4.4.4: Graphical representation of sensor output voltage values for sensor 4

Sensor output values for sensor 4 are shown in figure 4.4.4. Sensor output values increases with increase in frequency and sensor is distinctive for the materials considered. Sensor 4 also has better signal strength when compared to sensors 1, 2 and 3.





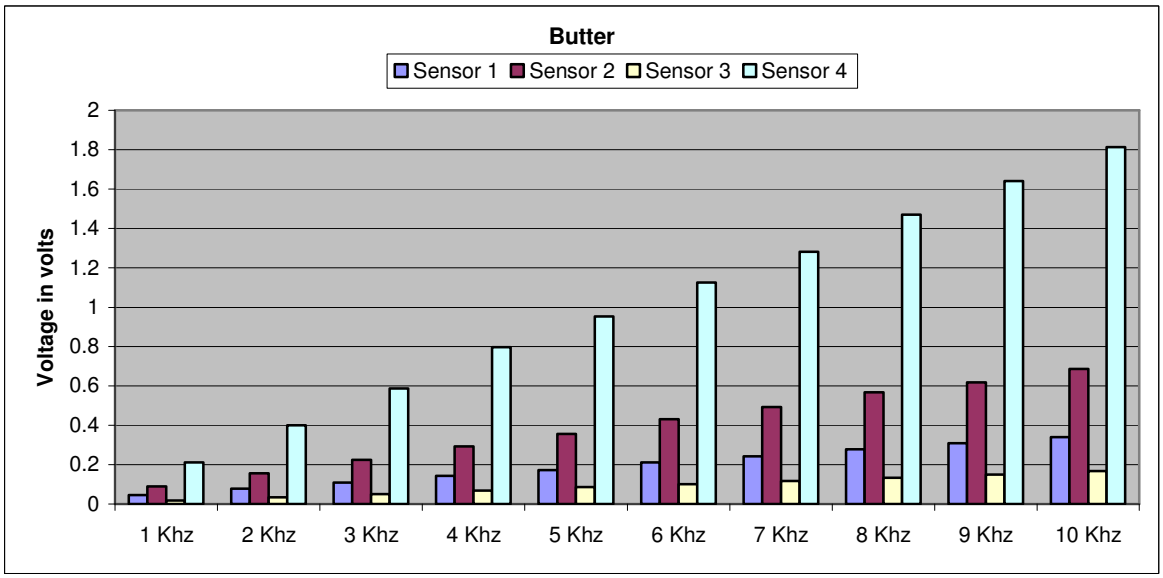


Figure 4.4.5: Sensor values for each material individually

In figure 4.4.5, sensor values for each material has been plotted to compare the sensors signal strength. For all the materials considered sensor 4 has better signal strength. Sensor 4 has better signal strength at 10 kHz for a 10 V peak to peak sinusoidal supply signal and as the objective is to design a low cost sensing system the frequency was restricted to an interval of 1 kHz to 10 kHz. As the sensor 7 has better signal strength and the field distribution is better at 5 mm, sensor 7 was chosen to study the looseness in sheep skins.

4.5. Experimental Setup

The experimental results for different interdigital structures showed good responses as shown in the previous section. This is encouraging as it would help us in building a low cost sensing system and it would benefit the local leather industry. The block diagram of the experimental setup is shown in figure 4.5.1.

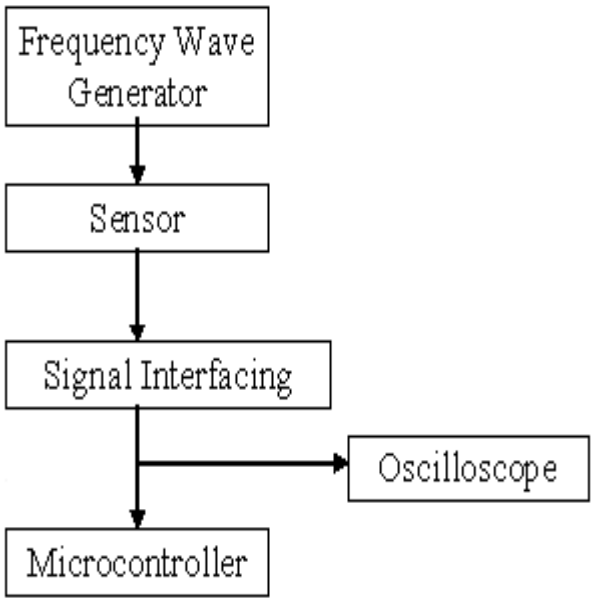


Figure 4.5.1: Block diagram of experimental setup

The sensor is supplied a 10 V peak to peak sinusoidal signal with varying frequency initially in the range of 1 to 10 kHz as the objective of the research was to develop a low cost based sensing system. The current through the sensor was captured across the resistor placed in series with the sensor and sent to full wave rectifier circuit to get an output of DC signal which could be easily read by a microcontroller for a digital display. Interfacing the output signal with the microcontroller is explained in detail in chapter 6. The output signal from interfacing circuit is monitored using an oscilloscope as well. The experimental setup is shown in figure 4.5.2.

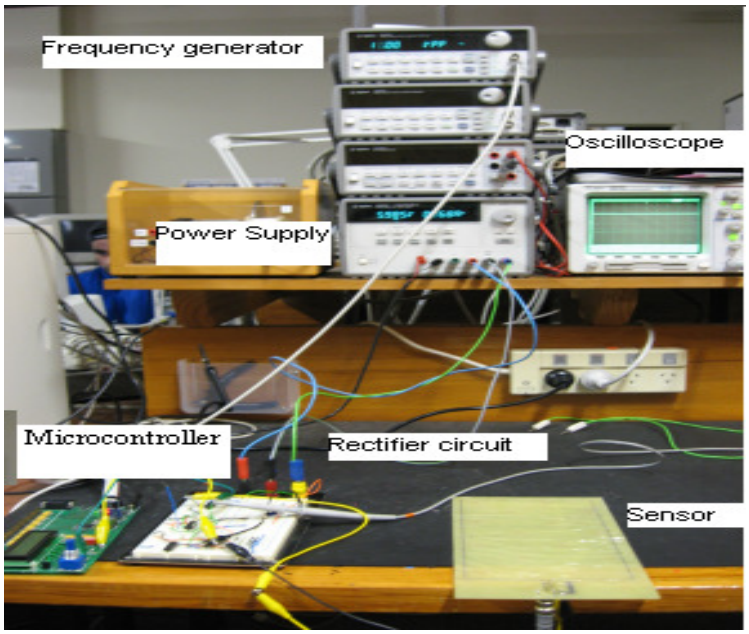


Figure 4.5.2: Experimental setup

The interfacing circuit requires a positive as well as negative 9 V supply which is supplied by an external power supply. A full-wave precision rectifier circuit, which does not use any diodes was designed and built using operational amplifiers. The rectifier circuit is shown in figure 4.5.3.

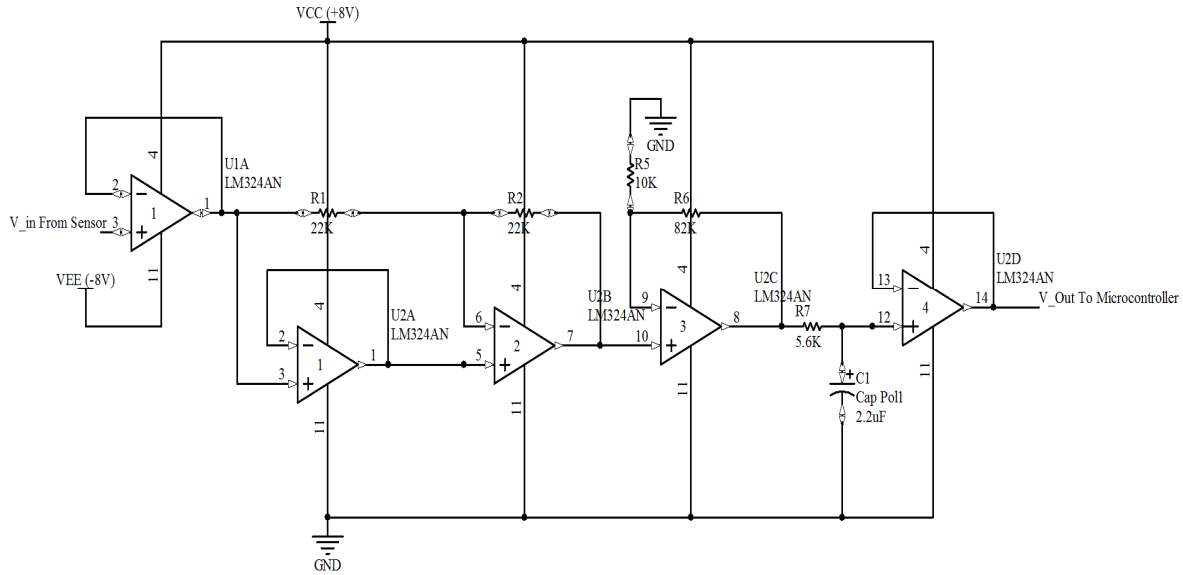


Figure 4.5.3: Full-wave rectifier circuit

IC1 is operated with a ±9V bipolar supply to ensure that both the positive and the negative halves of the sinusoidal input voltage signal are restored. The output signal from the sensor is passed through the IC1 buffer to also avoid loading problems and is then passed on to the precision full-wave rectifier circuit. The rectifier circuit functions as follows: when the

sensor output voltage Vs > 0, then IC2 output is half of the circuit input voltage (i.e. Vs / 2), and IC3 operates as a subtracter, whose output equals the input voltage (i.e. Vs). The waveforms at different stages of the precision rectifier circuit are shown in figure 4.5.4. The rectified signal is then passed on to IC4 which implements a gain of about 8. A little change in the sensor output voltage will result in greater change in output values of the rectification circuit. The output of IC4 is passed through an RC circuit. The DC signal across the capacitor is passed through a buffer to avoid loading problems. It is then fed to a differential amplifier to get the minimal output voltage and then on to the C8051F020 microcontroller for ADC conversion.

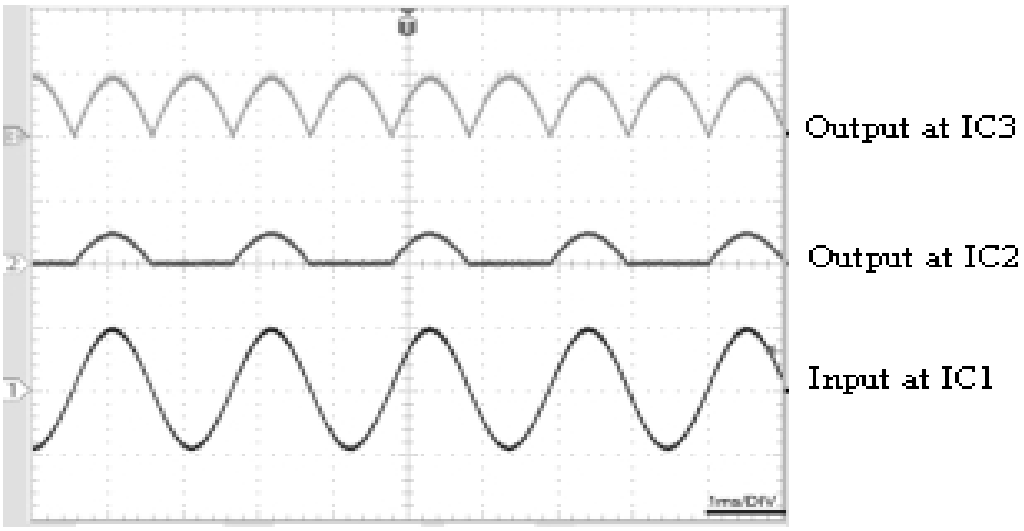


Figure 4.5.4: Voltage waveforms at different stages in the precision rectification circuit [90].

4.6. Conclusion

In this chapter, design of four sensors is shown and modeling of an interdigital sensor using FEMLAB by COMSOL is discussed. The response of the sensors for materials like cheese, butter and air is measured and sensor 4 has better signal strength. Capacitance for sensor 4 is also the highest compared to others, so, sensor 4 was chosen to measure the looseness property in the sheep skins. Experimental set-up and interfacing circuit has also been discussed.

CHAPTER 5

EXPERIMENTAL PROCEDURE AND RESULTS

5.1. Experimental procedure

A total of 18 skin samples were considered for this research. Skins were divided into three groups depending on their treatment or change in their tanning procedure from the normal procedure. Each group of skins were treated uniquely,

Group 1 – Standard process
Group 2 – Treated with 5 times concentration than the regular enzyme in processing
Group 3 – Left in alkali for 48 hours rather than normal 12 hours

To differentiate each skin from the other and to identify the group they belong to, holes were punched near the tail area of each skin as shown in figure 5.1.1. Number of holes punched on left represent the group number and the holes on right side of the tail area represent the sample number.

Figure 5.1.1: Image of sheep skin

For better understanding of the properties of materials using an interdigital sensor, skin is placed over the sensor so that it covers most part of the sensing area of the sensor but at the same time the skin should not touch the electrodes as that would affect the outcome of the sensors. The electrodes referred above are shown within a red circle in figure 5.1.2.

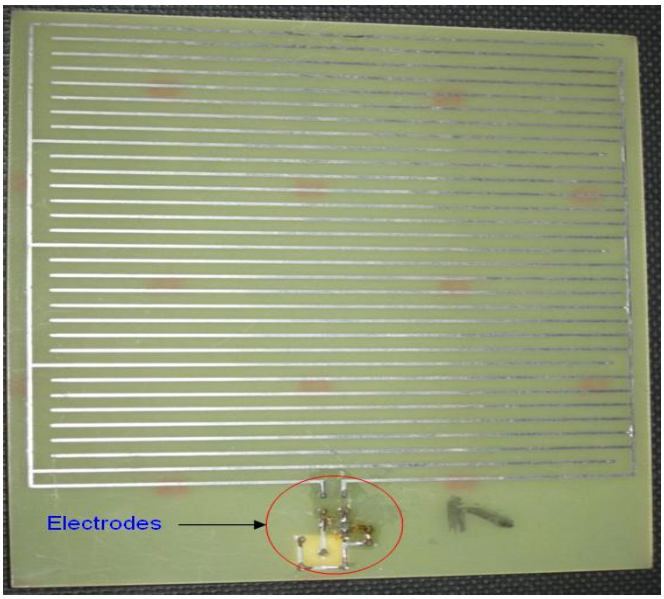


Figure 5.1.2: Pins of the sensor

Looseness is not confined to one particular area or a specific site of a skin, but is spread throughout the skin [36]. So, most part of the skin area was supposed to be considered

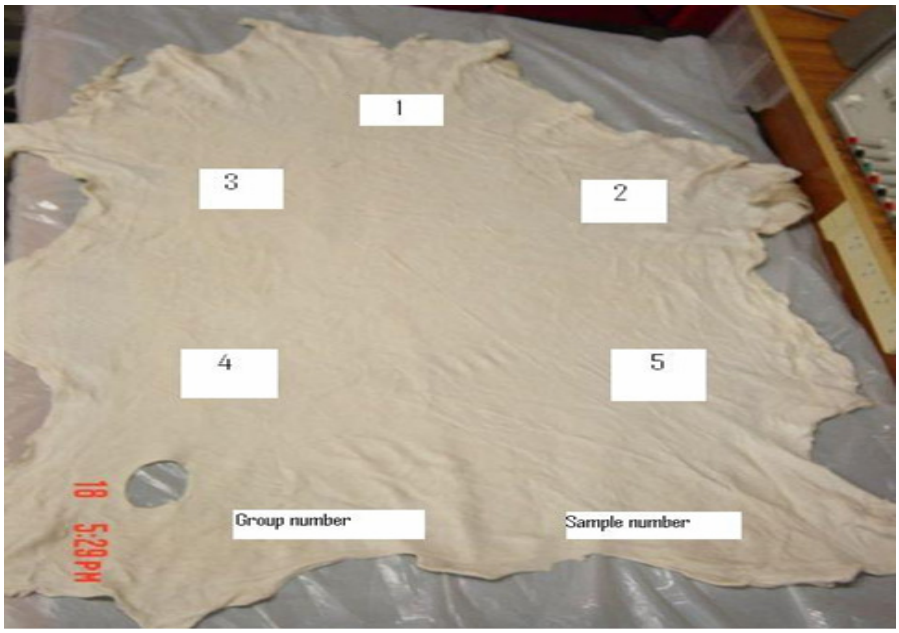


Figure 5.1.3: Sheep skin labelled into five zones

for estimating the looseness within it. Each skin was labelled in to five zones for measuring the sensor signal across it. As shown in figure 5.1.2, area near the top was labelled as position 1, area near the middle part of skin was considered as position 2 and position 3, and the area at the bottom of the skin as position 4 and position 5. These areas were chosen as most part of the skin could cover the effective sensing area without touching the electrodes.

While measuring the sensor voltage across skin, sensor was kept stationary but skin was moved around to accommodate each of the labelled zones. Sensor was glad wrapped to avoid direct contact between the sensor and the skin as this would aid in meeting the hygiene requirements. Sensor voltages at every zone of each of the skins are recorded. The experimental set-up is shown in figure 5.1.4.

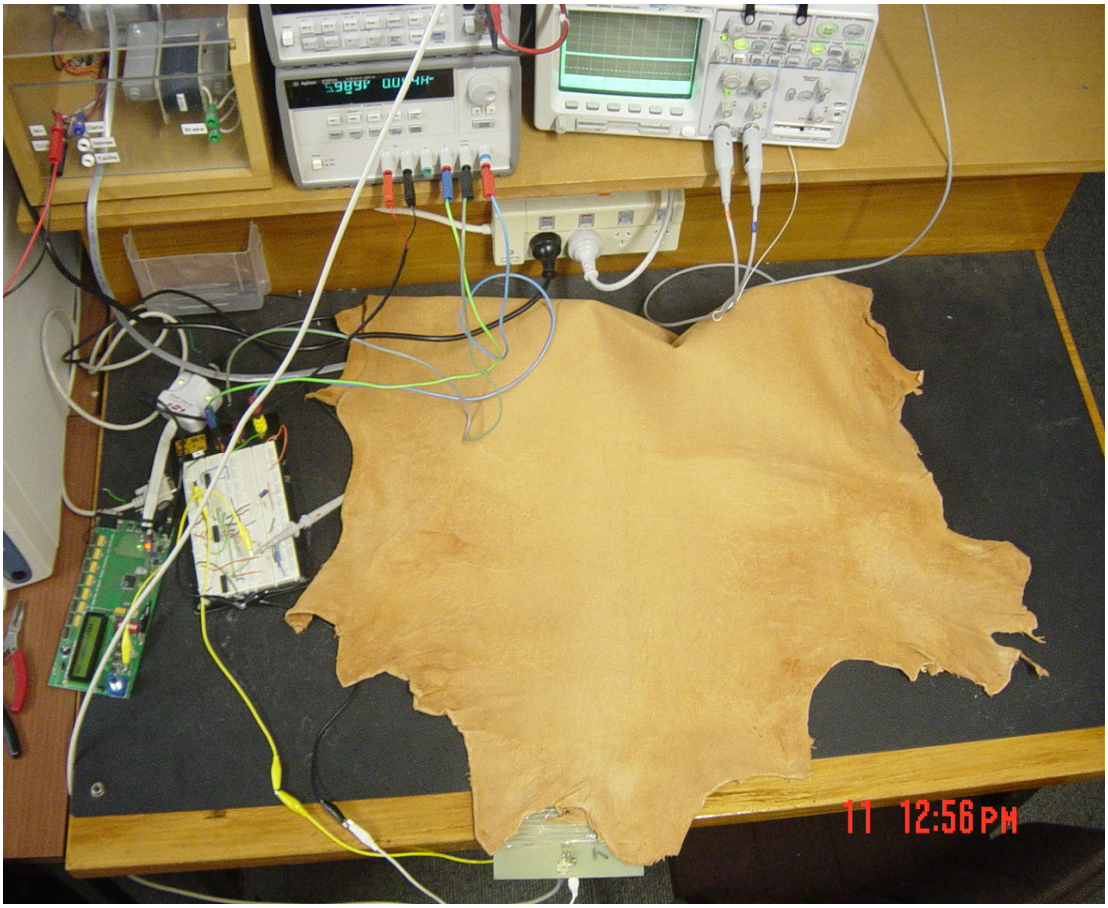


Figure 5.1.4: Sensor with skin placed over it

Sensor output voltage was to be measured across the zones of each sample or skin, as the objective of research was to find the looseness in skins before the tanning process is finished. Then, the skins were sent back to LASRA (Leather and Shoe Research Association) for tanning. After the skins were converted to leather, experiments were repeated to measure the sensor output voltage and compare with looseness to check the repeatability of output signal. Sensor output voltage of skins before tanning could not be compared with looseness values immediately as looseness could be determined only after tanning.

5.2. Observations for sheep skins before tanning process

Before the tanning process the sheep skins were spread on a table as shown in figure 5.2.1 to dry them or get rid of excess moisture in them. The skins were wiped with paper towels and turned upside down periodically for ensuring the same treatment for whole of skin. Care was taken so that samples were not dried up completely as this would introduce air gap between the surfaces of sensor and skin respectively. Drying of sample will also change the properties of unprocessed skin as skin starts to become less flexible and rigid. At this stage, collagen fibres shrivel and tend to stick together which would harm the flexibility property of the skin.

Figure 5.2.1: Skin spread on table to get rid of excess moisture

Depending on the change in tanning process, skins were divided into 3 groups, each group had 6 samples. Sensor output voltages for each of five zones for every skin are shown below. All the readings are in volts. The results obtained at 10 kHz are shown in table 5.1.1. From the figure 5.2.2, it can be observed that the sensor responds well to the different positions on the skin. Each position on the skin gives a different reading which makes it unique from the rest of the skin. Values at each of the position could be influenced by left over fat, thickness or and the relative permittivity of the material. For the group 1,

- The readings for sample 1 are between 5.9 and 5.6, except position 3 (this could be a result of lift off or an air gap). The readings come pretty close for each position for sample 1.
- The readings for Sample 2 also come pretty close to each other which are between 5.5 and 5.4, except position 2 (this may be due to the presence of fat at that spot).
- The readings for Sample 3 vary through out the skin they vary from 5.88 to 5.47.
- The readings for sample 4 are in a range between 5.65 and 5.4 however there is a variance at position 2 which gives a value of 5.
- The readings for Sample 5 vary from 5.7 to 5.1 and three of the positions that is positions 1, 3 and 4 vary by only a factor of 0.4 from each other.
- The readings for sample 6 are between 5.5 and 5.3, this is the sample in the group which does not exhibit large variations for different positions on the skin.

Table 5.1.1: Sensor results for various samples

	Group 1					
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Position 1	5.84	5.46	5.81	5.4	5.5	5.5
Position 2	5.75	5.75	5.56	5	5.7	5.4
Position 3	5.15	5.43	5.46	5.4	5.1	5.3
Position 4	5.87	5.4	5.87	5.65	5.3	5.43
Position 5	5.65	5.43	5.6	5.4	5.4	5.43

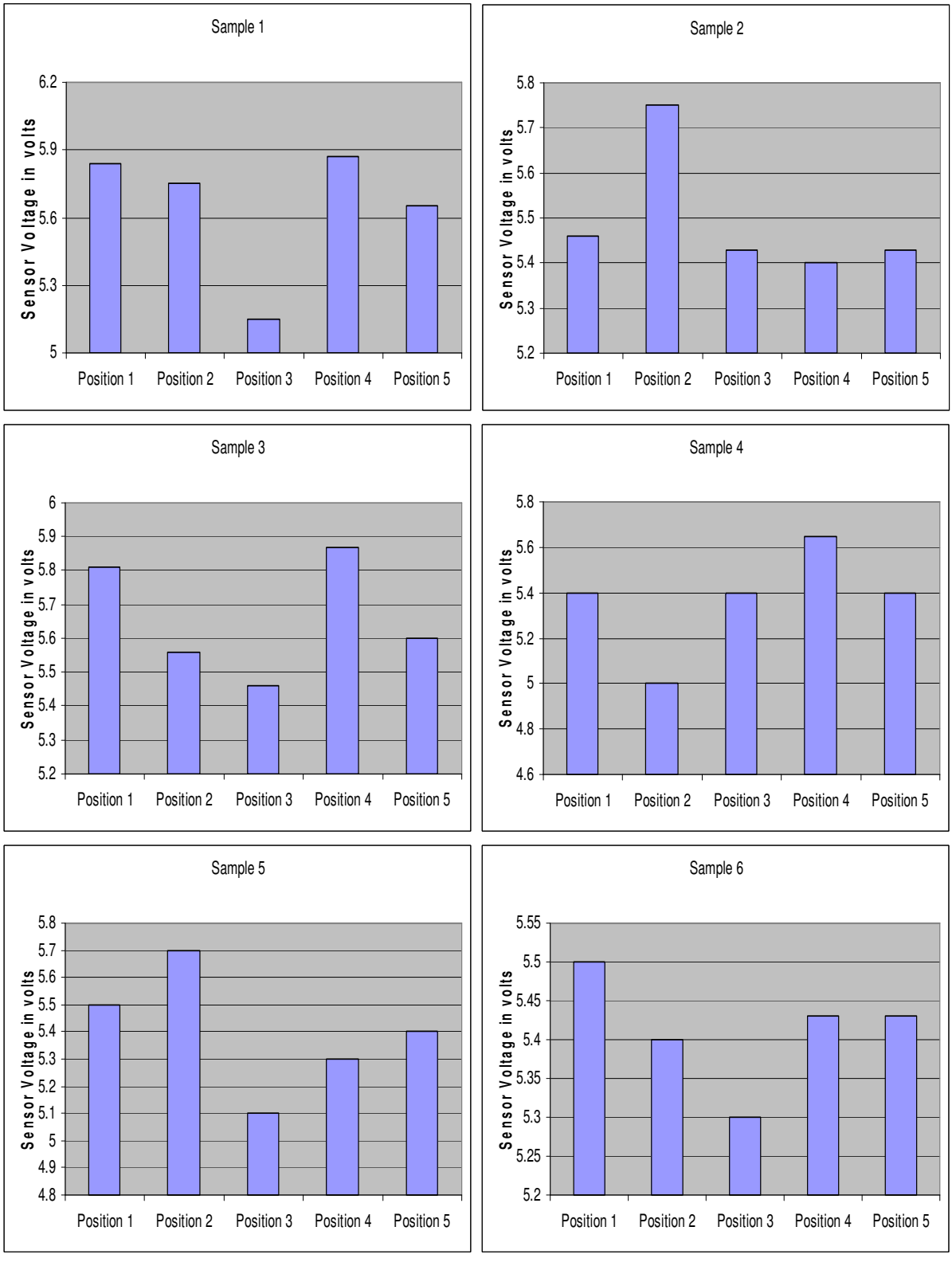


Figure 5.2.2: Sensor output voltages at each position of various samples for Group 1

Results for group 2 are graphically represented in figure 5.2.3. The readings for different samples of group 2 are discussed below,

- The readings for Sample 1 vary from 5.62 to 5.18. Positions 2, 3 and 4 have values closer to each other.
- The readings for Sample 2 are between 5.39 and 4.62. Positions 1 and 5 display the same readings and positions 2 and 3 are close to each other.
- The readings for Sample 3 are between 5.2 and 4.1 and the measurements at different positions are close enough.
- The readings for Sample 4 vary from 5.6 to 5.18. Positions 2, 3 and positions 4, 5 show close proximity to each other respectively.
- The readings for Sample 5 are close enough. The values range from 5.5 to 5.2, each of them vary from the other within the range of only 0.1 volt.
- The readings for Sample 6 are between 5.6 and 5.13. The positions 1, 5 and positions 3, 4 come close enough to each other respectively.

The results for group 2 are tabulated in table, 5.2.2.

Table 5.2.2: Results for group 2

	Group 2					
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Position 1	5.62	5.37	5.18	5.6	5.5	5.37
Position 2	5.4	5.06	4.18	5.25	5.4	5.12
Position 3	5.43	5.18	5.2	5.18	5.2	5.3
Position 4	5.5	4.68	5	5.4	5.3	5.3
Position 5	5.18	5.37	4.31	5.45	5.43	5.4

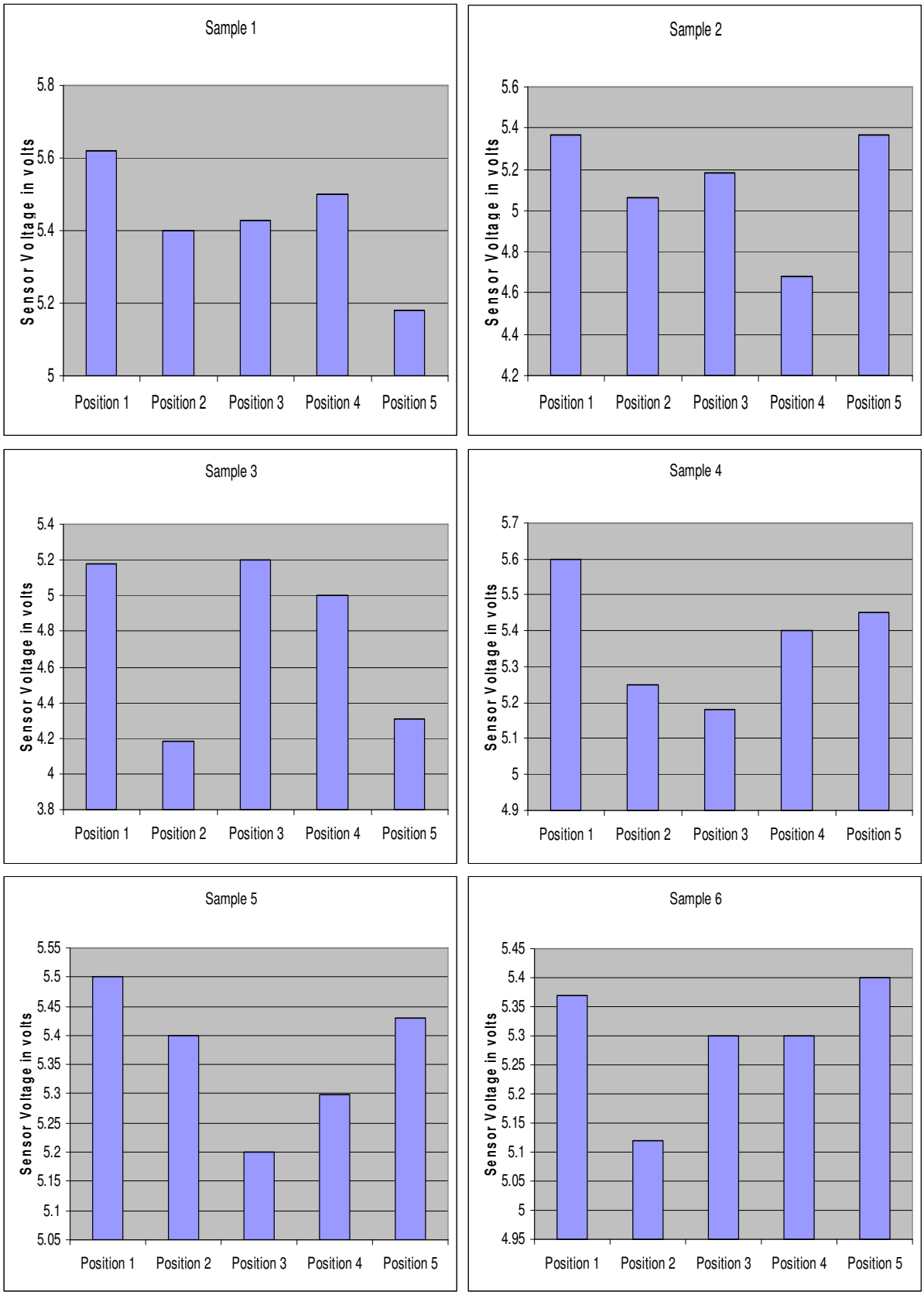


Figure 5.2.3: Sensor output voltages at each position of various samples for Group 2

Results for group 3 are presented in graphs in figure 5.2.4. In this group, different positions of each individual sample exhibit nearby values to eachother.

- The readings for Sample 1 vary from 5.62 to 5.37. The values at different positions do not have much variance.
- The readings for Sample 2 vary from 5.68 to 5.31. Values at positions 1, 5 and positions 2, 4 are almost equal to each other respectively.
- The readings for Sample 3 vary from 5.9 to 5.4. Positions 1, 2 and positions 4, 5 have a variance of 0.3 volts between each other.
- The readings of Sample 4 are in between 5.6 and 5.4. The values at position 1 and 4 are equal for this sample and the variance between most of the positions on an average is 0.5
- The readings for Sample 5 vary from 5.71 to 5.21. For this sample, the readings at positions 2, 3 and 4 do not have much variance.
- The readings for sample 6 vary from 5.71 to 5.4. Position 1 exhibit highest signal, position 2 and 4 vary by 0.5 and position 2 and position 5 vary by 0.5 volts

The results for group 3 are tabulated in table, 5.2.3.

Table 5.2.3: Results for group 3

	Group 3					
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Position 1	5.5	5.68	5.5	5.56	5.53	5.71
Position 2	5.43	5.56	5.46	5.5	5.23	5.56
Position 3	5.56	5.31	5.59	5.6	5.21	5.4
Position 4	5.37	5.56	5.43	5.56	5.25	5.5
Position 5	5.62	5.65	5.4	5.4	5.71	5.6

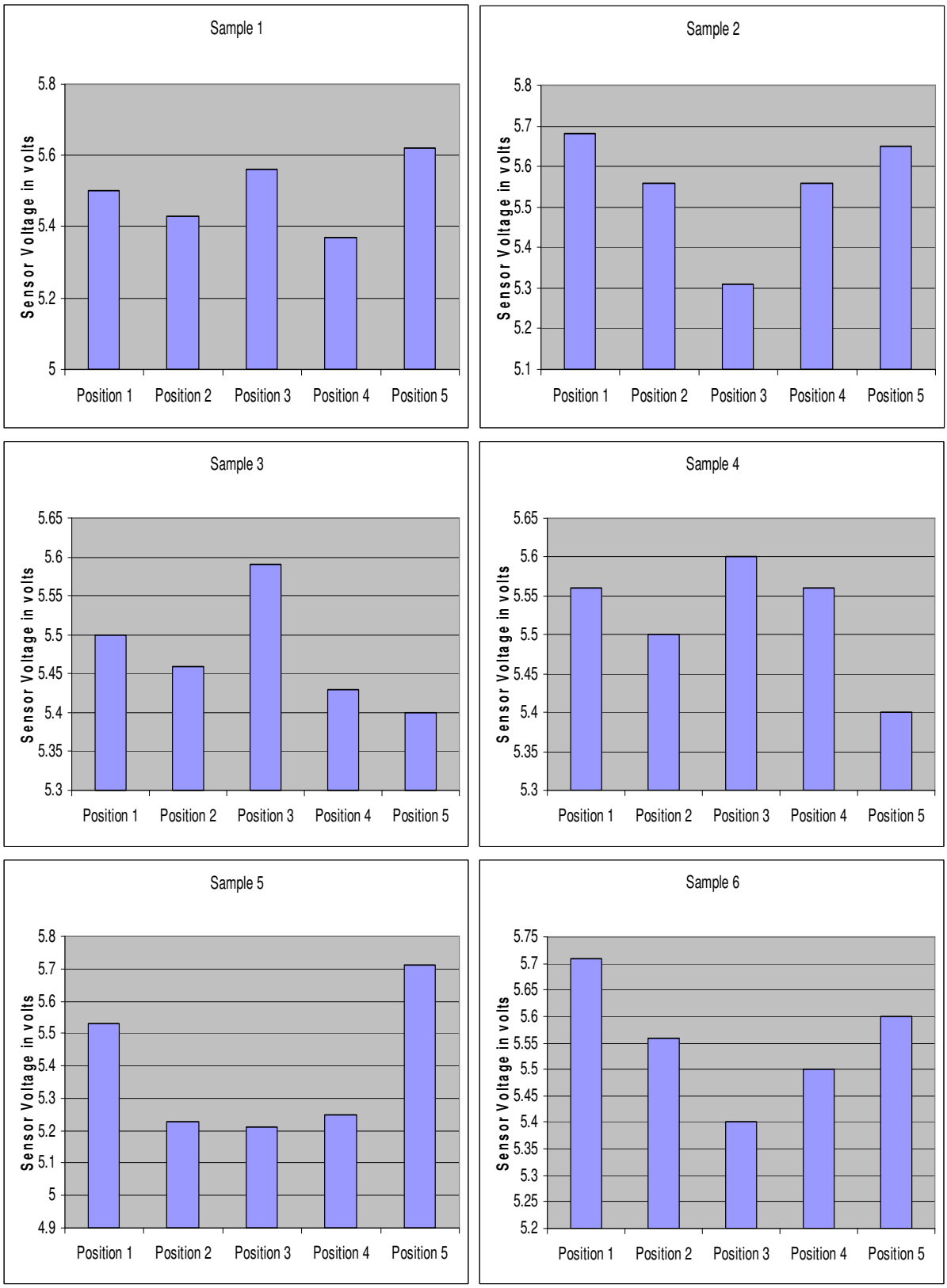


Figure 5.2.4: Sensor output voltages at each position of various samples for Group 3

5.3. Looseness values for Sheep skins

The objective of research was to determine looseness in the sheep skins, so, sensor output voltage was to be compared with the looseness values determined by the experts. Looseness in sheep skins were determined by two experts from LASRA on a scale of 1 to 6 as shown in the figure 2.2.3 in chapter 2 [42]. Skins are held and manually pulled in opposite direction and depending on the appearance of creases or wrinkles they are graded a certain value of looseness. Skins with looseness graded as 1, 2 and 3 are considered good quality leather with minimum looseness, 1 having least looseness values. Skins with looseness values as 4, 5 and 6 are considered as inferior quality leather and the skins with looseness value 6 are considered low quality and more loose. Looseness values for three different groups as determined by two experts are shown in the figure 5.2.5 (i), (ii) and (iii).

It can be observed from the figure 5.2.5 that each skin could be distinctive from the other irrespective of their same chemical treatment. Each of the individuals mostly had a different looseness value for the same skin as it depends on personal expertise. Also, looseness scale is expressed in integer values which could be a limitation by itself. These looseness values were compared with the sensor output voltages to find a correlation between looseness and sensor output voltage. Expert 2 was more experienced and the looseness values provided by him were taken as a measure for comparison with sensor output voltage values.

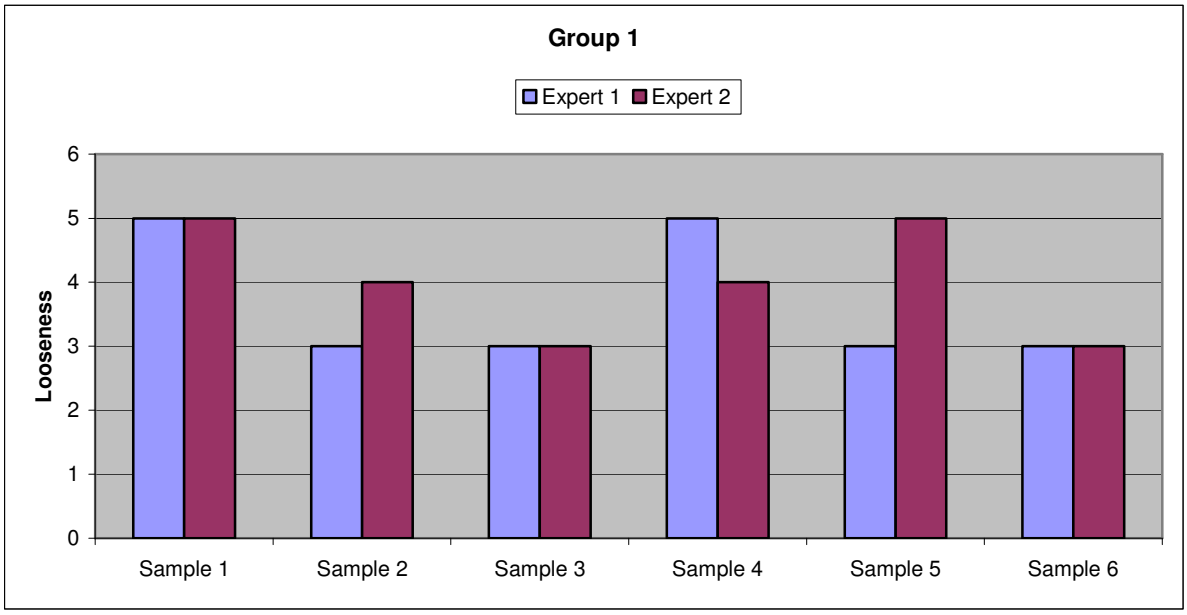


Figure 5.2.5 (i): Looseness values for group 1 determined by two experts from LASRA

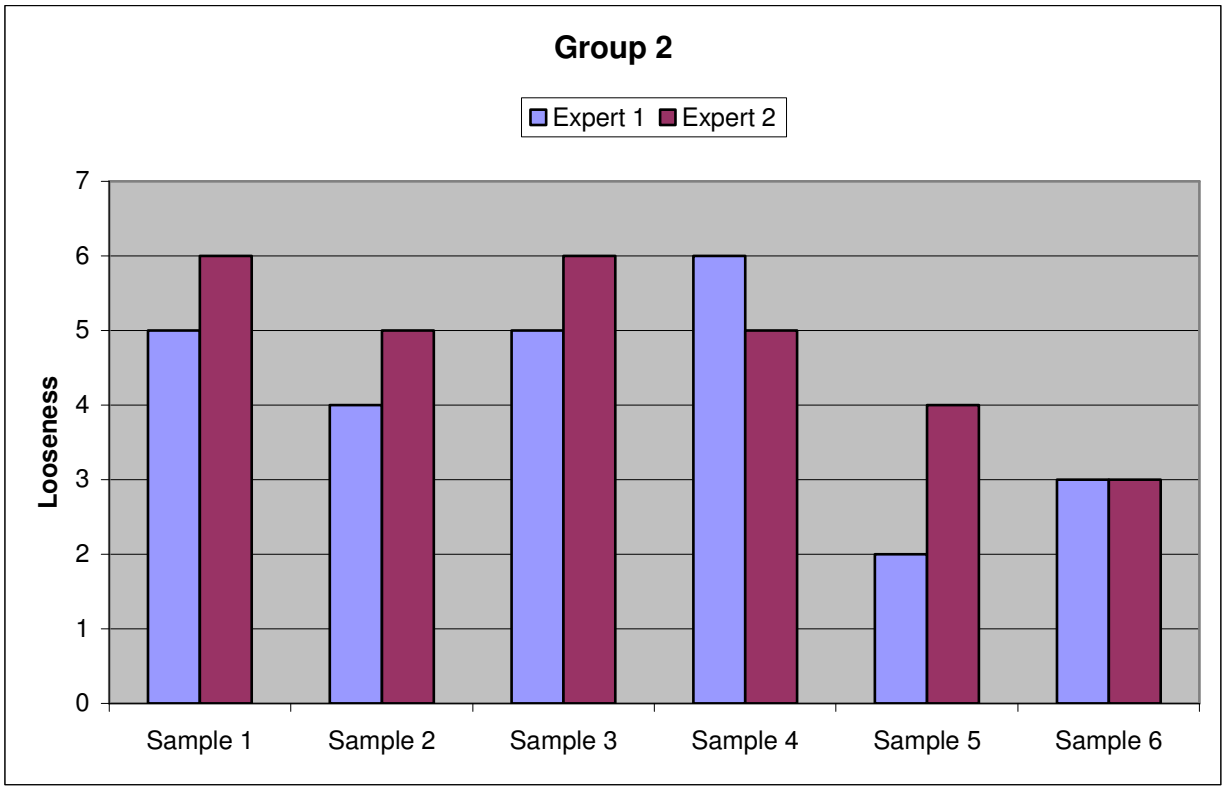


Figure 5.2.5 (ii): Looseness values for group 2 determined by two experts from LASRA

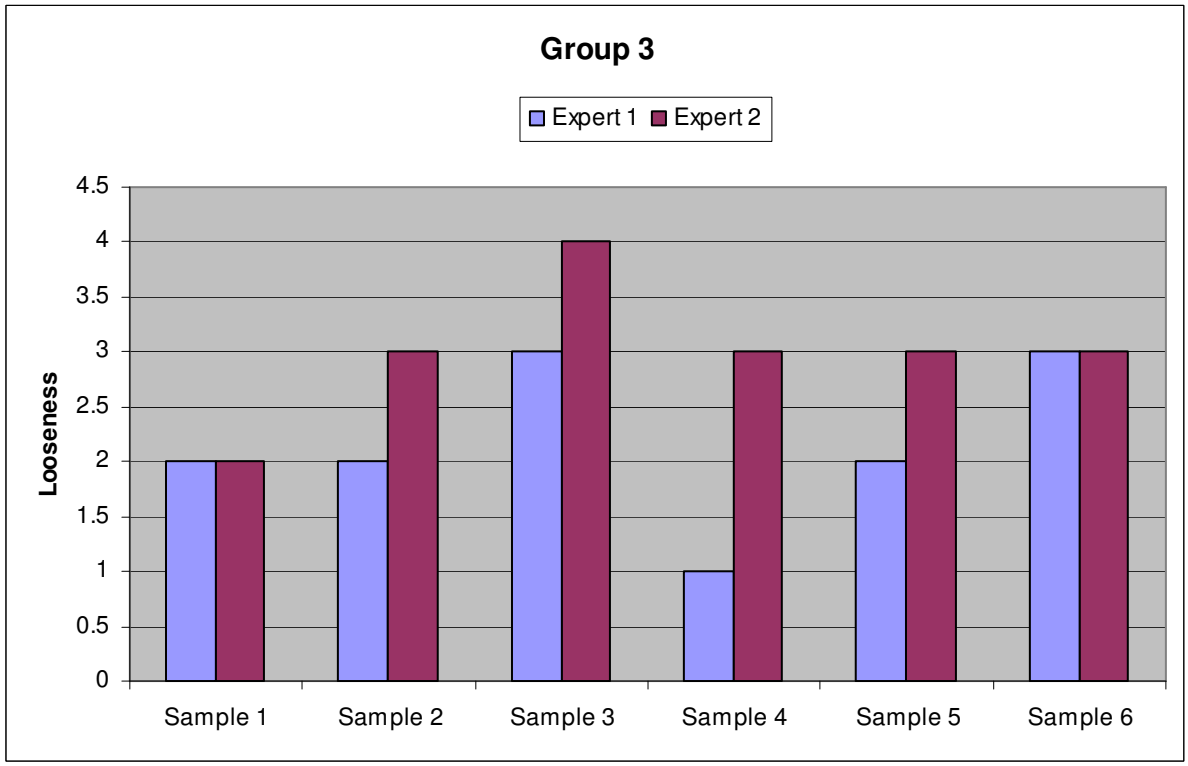


Figure 5.2.5 (iii): Looseness values for group 3 determined by two experts from LASRA

First the sensor output voltages across the position 4 and 5 of each skin were compared with looseness values provided by expert 2. First sensor output voltage for the samples of group 1 was compared with looseness values provided by expert 2. A good correlation could be observed between the sensor output voltages and looseness values except for the sample 3 and sample 5 as shown in figure 5.2.6. It can be observed that sensor output voltage values drop and rise along with looseness values. This can be observed by removing samples 3 and 5, as shown in figure 5.2.7. The discrepancy in values of sample 3 and sample 5 could be due to the presence of fat on the sample as the skins were not processed when sensor voltage was measured and or could also be due to other factors like variation of thickness.

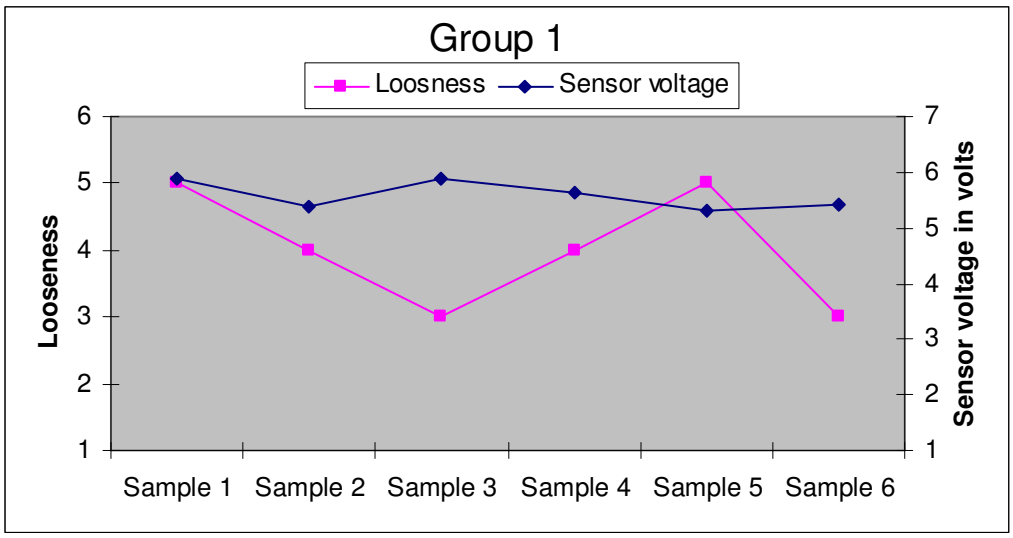


Figure 5.2.6: Comparison of sensor output voltage with looseness values for position 4 of group 1

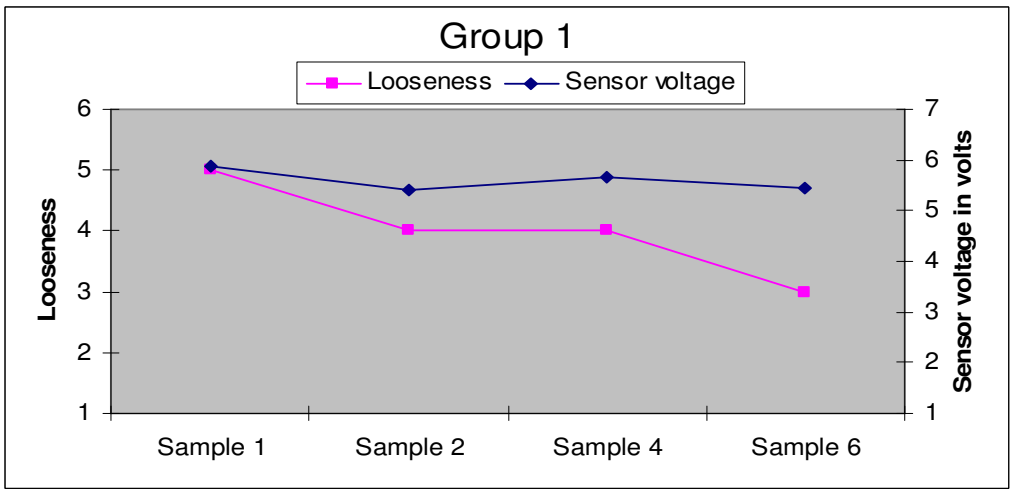


Figure 5.2.7: Comparison of sensor output voltage with looseness values for position 4 of group 1

Then the sensor output voltage values for position 5 were compared with looseness values provided by expert as shown in figure 5.2.8. In the figure 5.2.8, a correlation can be observed for samples 1, 2, 4 and 6 but samples 3 and 5 have different values and they do not correlate with looseness values trend which could be again due to presence of fat or variance in thickness. So, by ignoring samples 3 and 5 a better correlation can be observed as shown in figure 5.2.9.

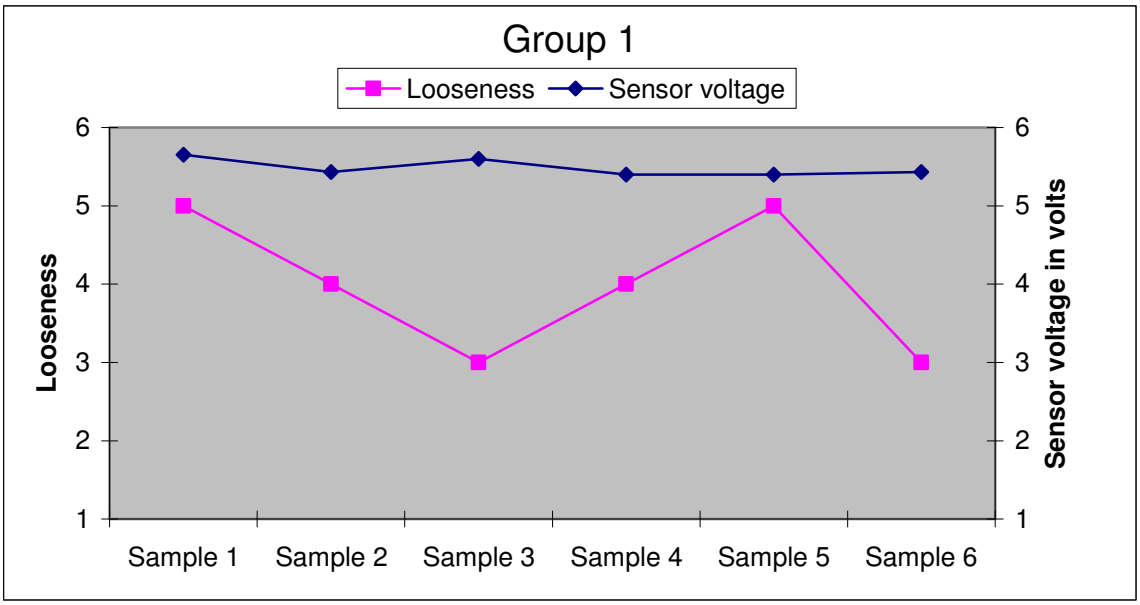


Figure 5.2.8: Comparison of sensor output voltage with looseness values for position 5 of group 1

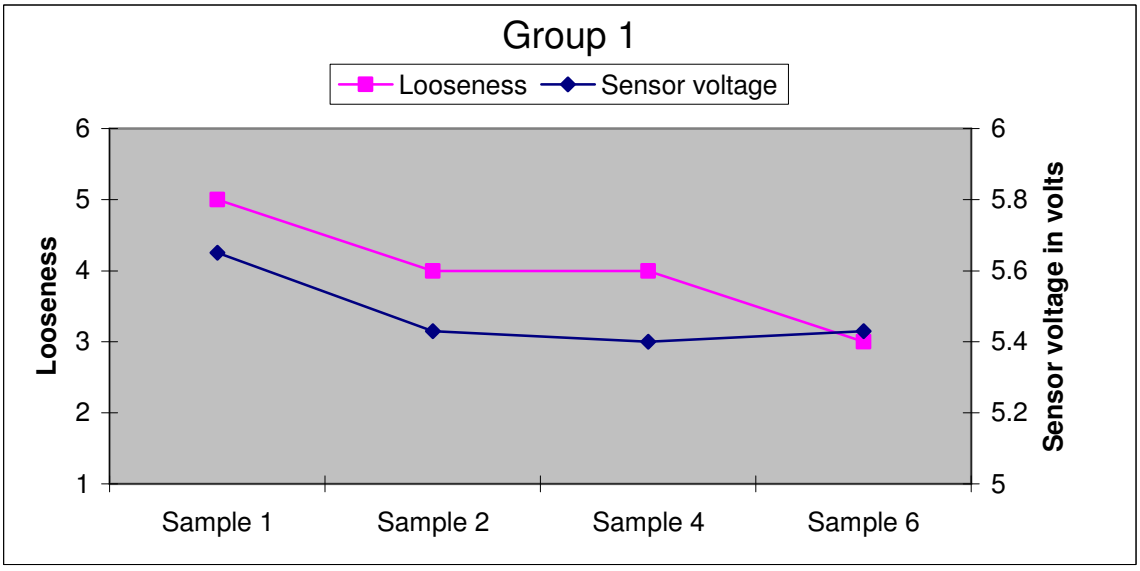


Figure 5.2.9: Comparison of sensor output voltage with looseness values for position 5 of group 1

Looseness in a sheep skin is determined by manually pulling the skin near the positions 4 or 5 according to LASRA, an average of voltages of the positions 4 and 5 was compared with looseness values provided by expert 2 as shown in figure 5.2.10. It can be observed from the figure 5.2.10 that sensor output voltage drops and rises along with looseness values apart for the samples 3 and 5 which has the similar trend observed in the figure 5.2.6. By ignoring the samples 3 and 5, a better correlation can be observed in figure 5.2.11.

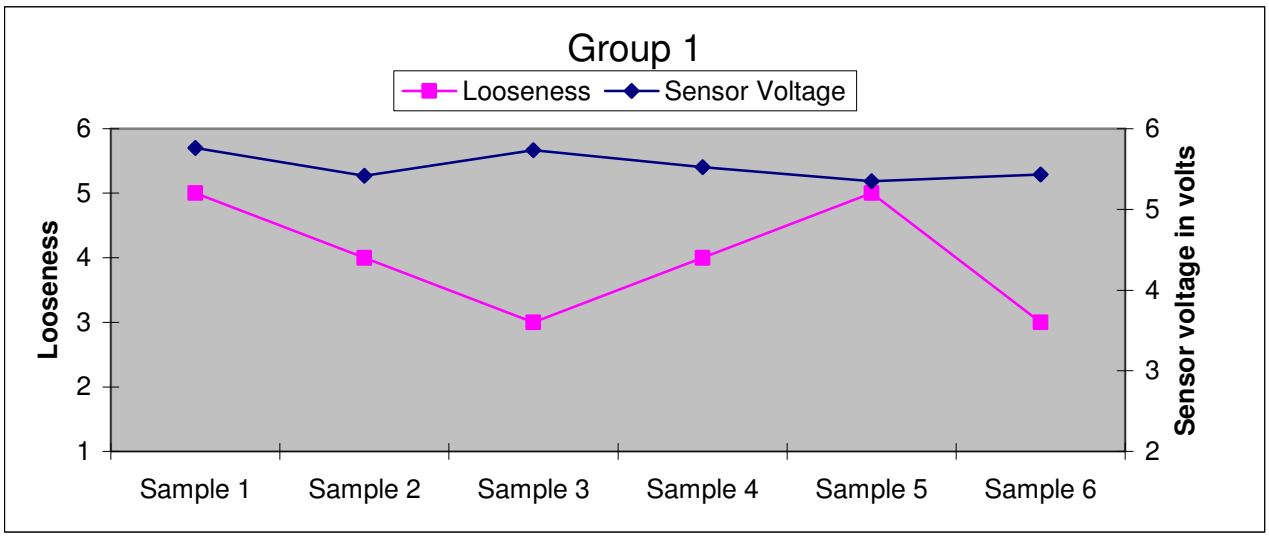


Figure 5.2.10: Comparison of sensor output voltage with looseness values for average of positions 4 and 5 of group 1

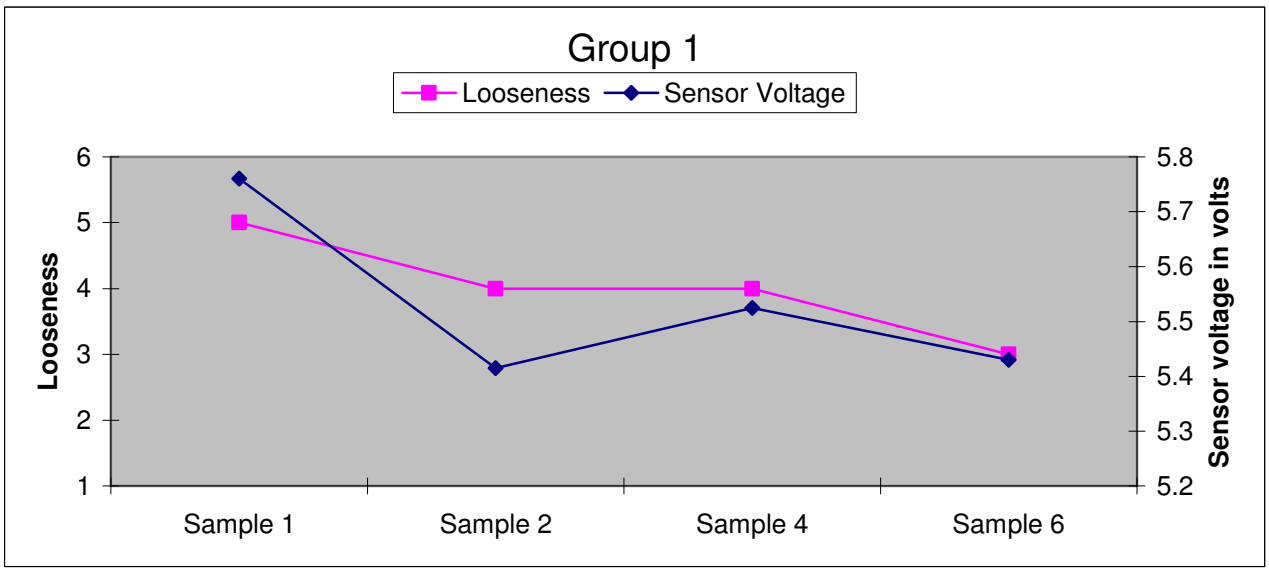


Figure 5.2.11: Comparison of sensor output voltage with looseness values for average of positions 4 and 5 of group 1

Looseness is spread throughout the skin; averages of voltages of all positions of skins of group 1 are compared with looseness values provided by expert 2 in figure 5.2.12. From figure 5.2.12, similar trend of voltages dropping and rising along with looseness values can be observed for samples 1, 2, 5 and 6. Sample 3 and sample 4 values do not fit the correlation trend which has similar scenario observed for the comparison of position 5 values with the looseness values. By ignoring the values of sample 3 and sample 4 a better correlation was observed between both the values as shown in figure 5.2.13. Even though samples 2 and 4 had same looseness values a change in voltage values was observed.

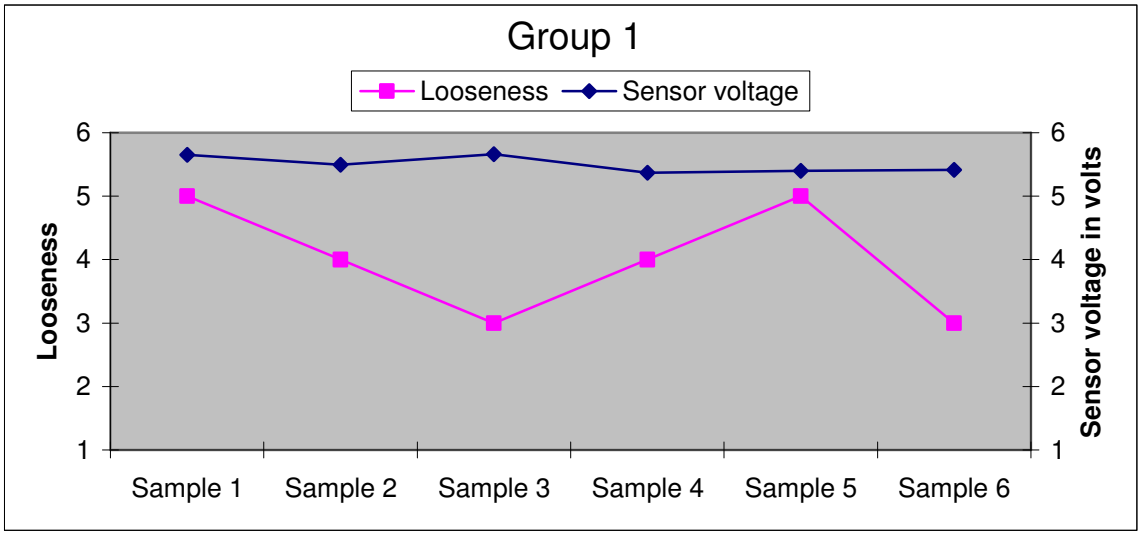


Figure 5.2.12: Comparison of sensor output voltage with looseness values for average of all positions of group 1

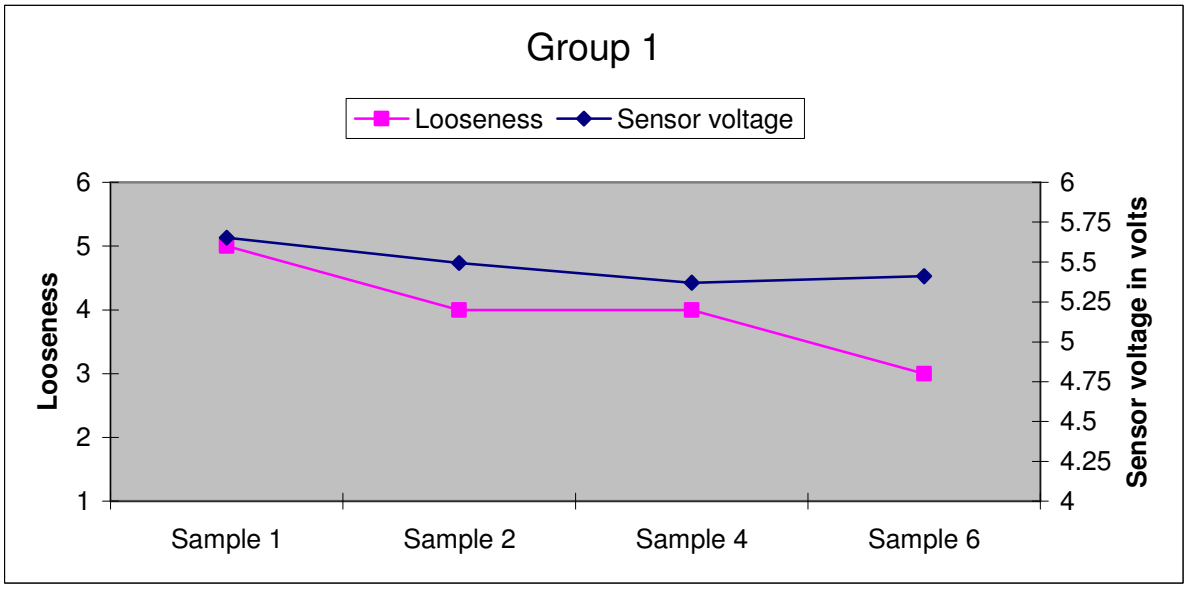


Figure 5.2.13: Comparison of sensor output voltage with looseness values for average of all positions of group 1

The voltages across the positions 4 and 5 for each skin in group 2 were compared with looseness values provided by expert 2. First sensor output voltage for the samples of group 2 was compared with looseness values provided by expert 2 in figure 5.2.14. A correlation between the sensor output voltages and looseness values for the samples 1, 2, 3, 4 and 5 could be observed. It can be observed that sensor output voltage values drop and rise along with looseness values. At sample 4, there is a huge increase in the voltage when compared to sample 2 even though they had same looseness values and this could be due to the presence of fat on the sample as the skins were not processed when sensor voltage was measured and or could also be due to other factors such as thickness. So, by removing samples 5 and 6, a better correlation between the looseness values and sensor output voltages could be observed as shown in figure 5.2.15.

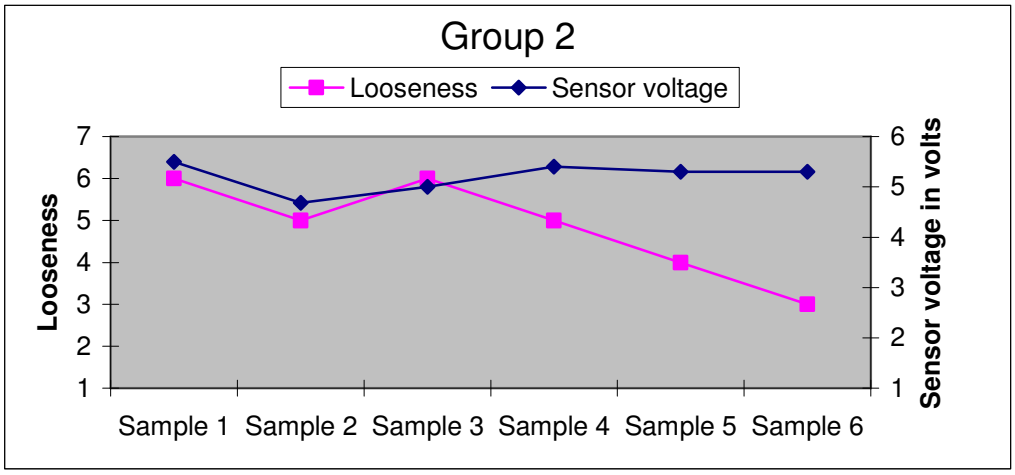


Figure 5.2.14: Comparison of sensor output voltage with looseness values for position 4 of group 2

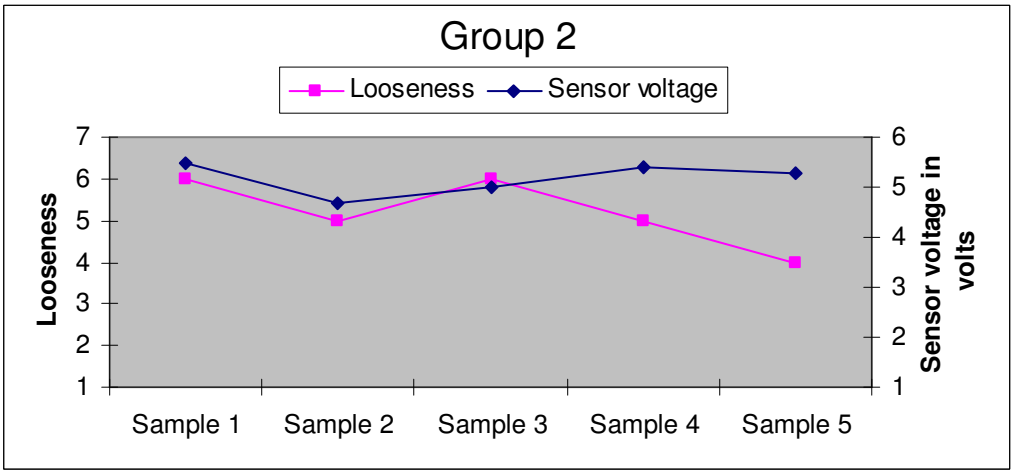


Figure 5.2.15: Comparison of sensor output voltage with looseness values for average of position 4 of group 2

Then the sensor output voltage values for position 5 of each sample of group 2 were compared with looseness values provided by expert as shown in figure 5.2.16. A correlation between the sensor output voltages and looseness values for the samples 1, 4, 5 and 6 could be observed. It can be observed that sensor output voltage drops along with looseness values. The discrepancy in values of samples 2 and 3 could be due to the introduction of air gap or also could be due to measurement error when sensor voltage was measured and or could also be due to other factors such as thickness. Figure 5.2.17 show a better correlation without considering samples 2 and 3.

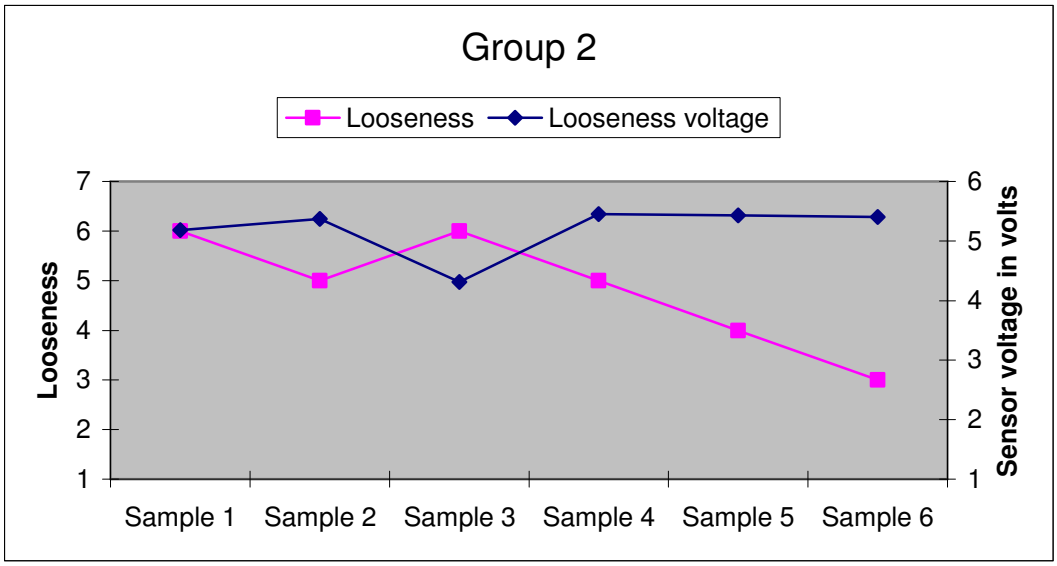


Figure 5.2.16: Comparison of sensor output voltage with looseness values for position 5 of group 2

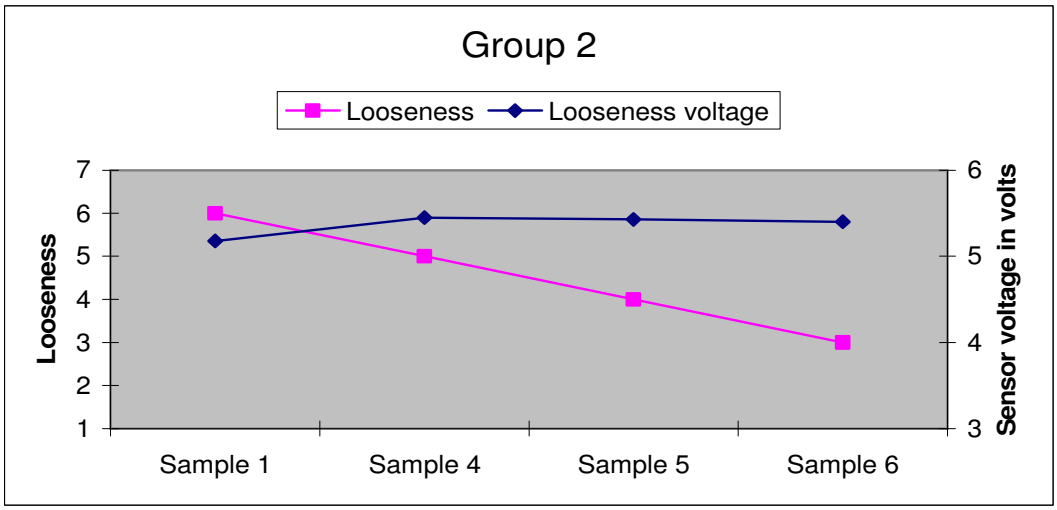


Figure 5.2.17: Comparison of sensor output voltage with looseness values for position 5 of group 2

An average of voltages of the positions 4 and 5 was compared with looseness values provided by expert 2 as shown in figure 5.2.18. It can be observed from the figure 5.2.18 that sensor output voltage drops along with looseness values for the samples 2, 5and 6 but there is a sudden increase in voltage for sample 4 which was the similar trend observed in the figure 5.2.14. This correlation could be observed better in figure 5.2.19 by removing the values for sample 3. It can be observed that sensor voltage increases for the sample 4, even though there is a decrease in looseness but after that decreases along with looseness values for samples 5 and 6.

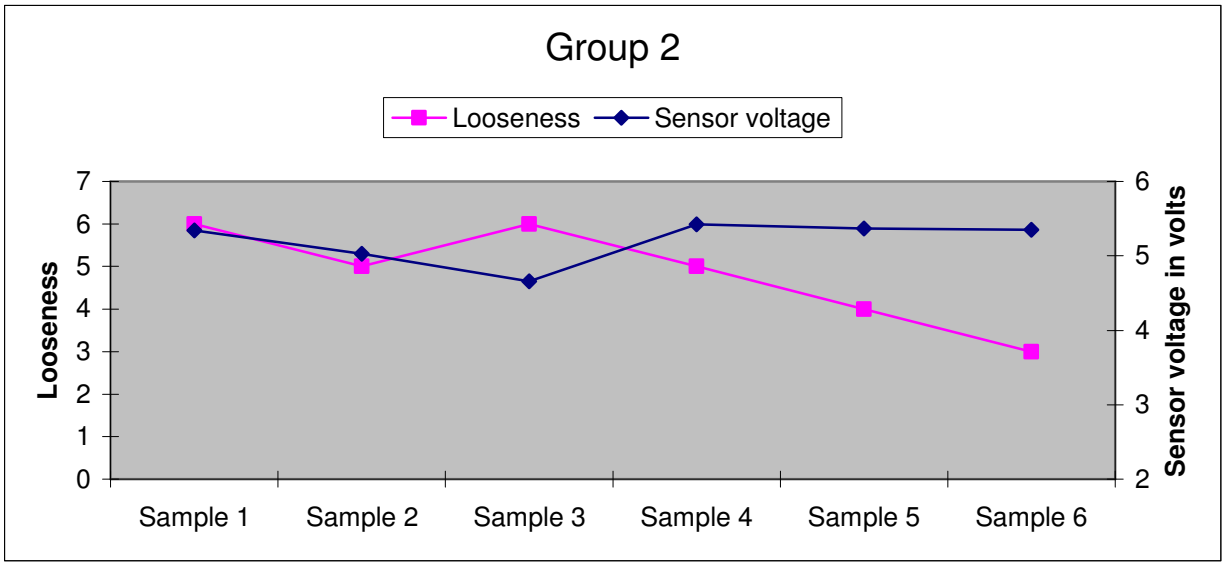


Figure 5.2.18: Comparison of sensor output voltage with looseness values for average of positions 4 and 5 of group 2

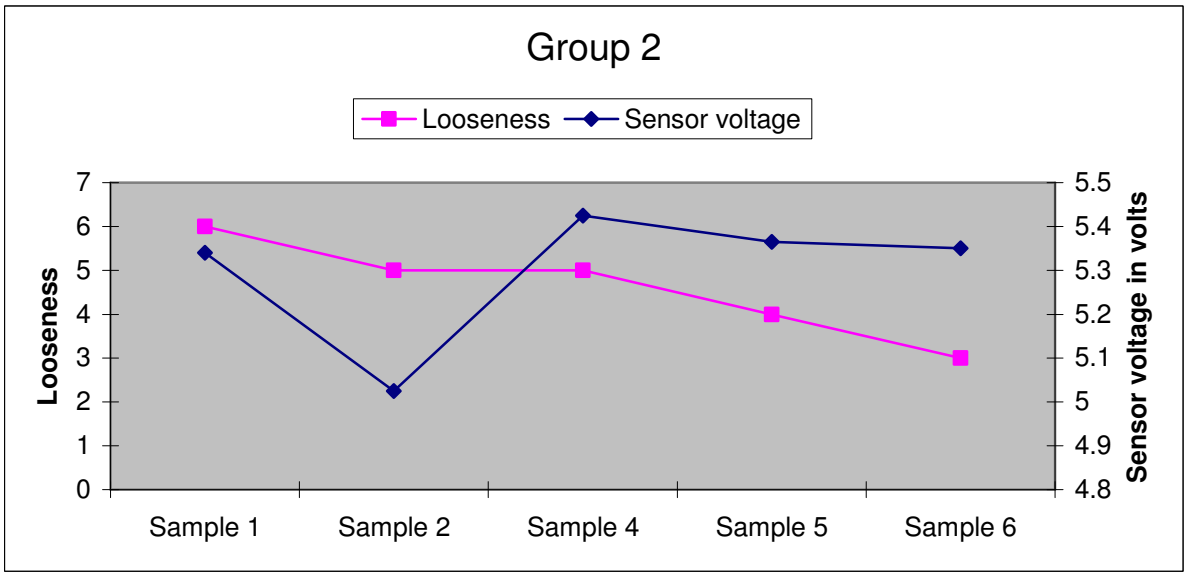


Figure 5.2.19: Comparison of sensor output voltage with looseness values for average of positions 4 and 5 of group 2

As the looseness is spread throughout the skin, averages of voltages of all positions of skins of group 2 are compared with looseness values provided by expert 2 in figure 5.2.20. From figure 5.2.20, it could be observed that sensor voltages drops along looseness for sample 2 but there is an increase in voltage for sample 4 and after that voltage drops along with looseness values for samples 5 and 6. This trend can be observed much clearly by removing the value of sample 3 in figure 5.2.21.

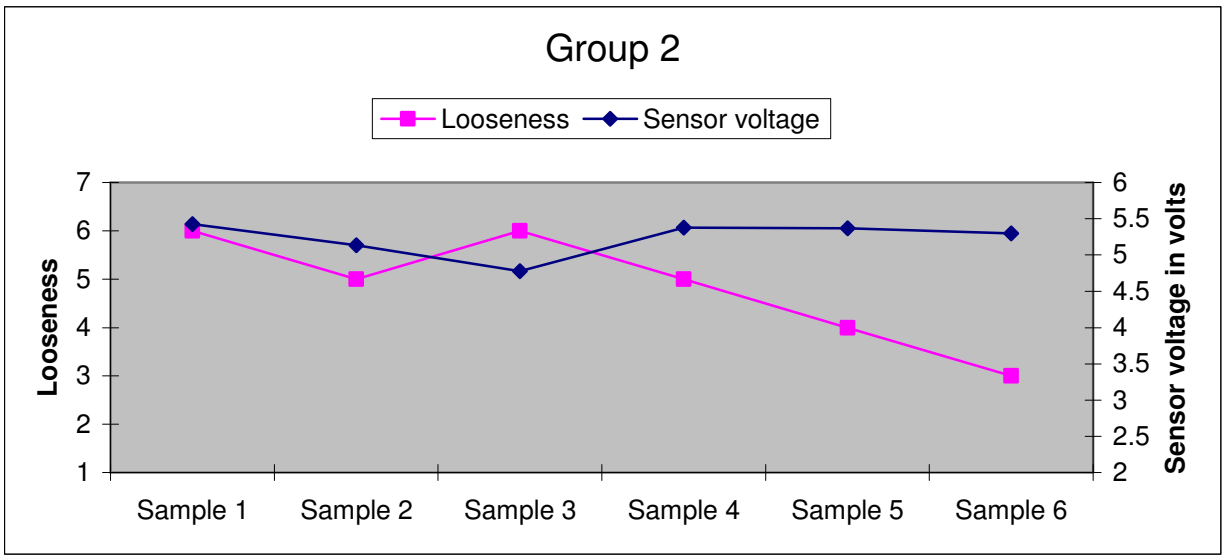


Figure 5.2.20: Comparison of sensor output voltage with looseness values for average of all positions of group 2

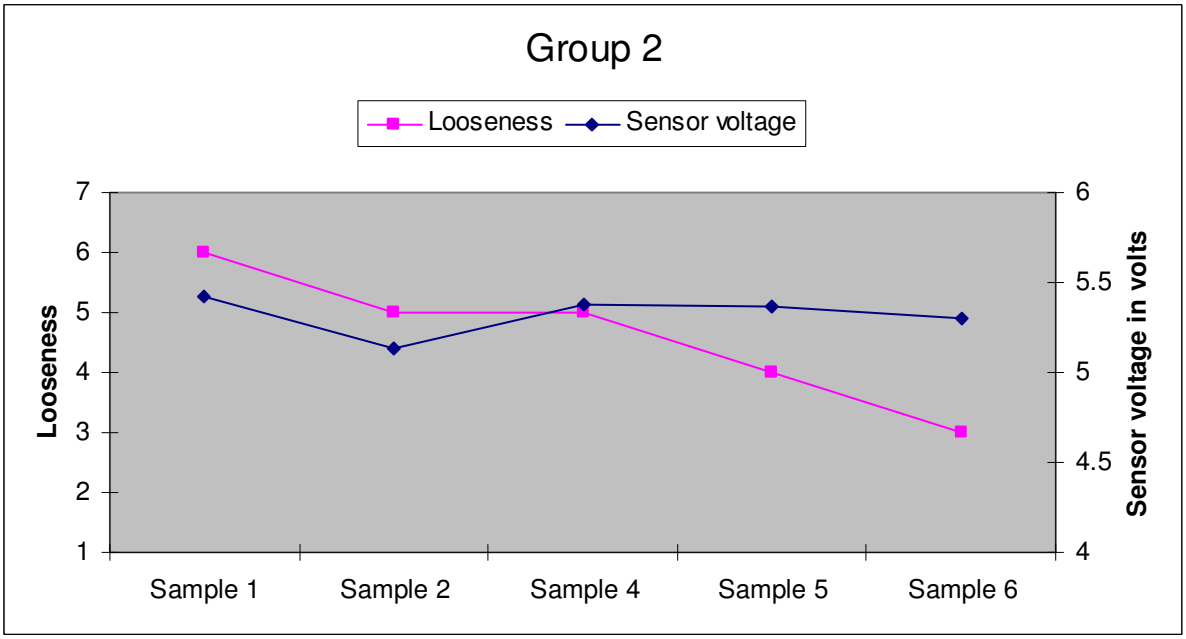


Figure 5.2.21: Comparison of sensor output voltage with looseness values for average of all positions of group 2

Voltages across the positions of 4 and 5 of each skin were compared with looseness values provided by expert 2. First sensor output voltage for the samples of group 3 was compared with looseness values provided by expert 2 in figure 5.2.22. A good correlation could be observed between the sensor output voltages and looseness values except for the sample 3 and sample 5. It can be observed that sensor output voltage increases along with looseness value for sample 2 and then reasonably stays in correlation with looseness values. This correlation could be observed better by removing samples 3 and 5, as shown in figure 5.2.23. The discrepancy in values of sample 3 and sample 5 could be due to the presence of fat on the sample as the skins were not processed when sensor voltage was measured and or could also be due to other factors like thickness.

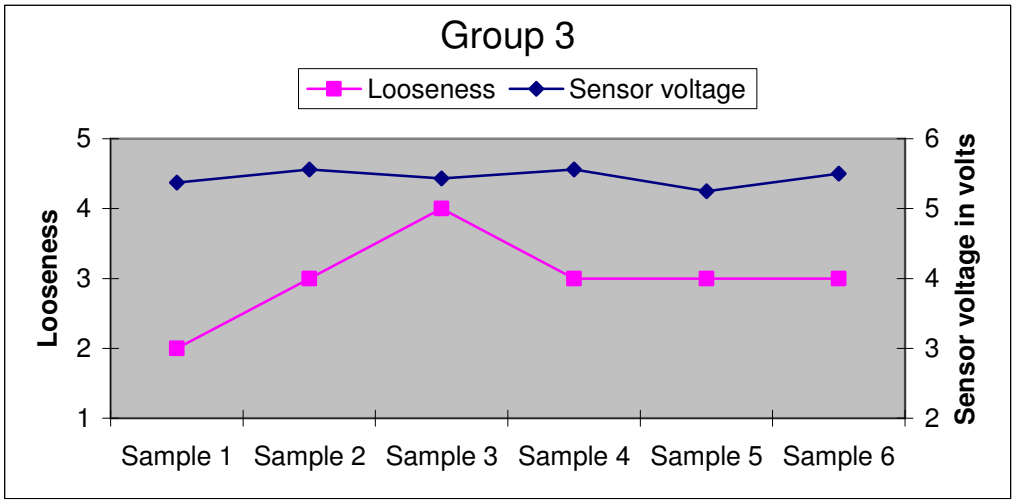


Figure 5.2.22: Comparison of sensor output voltage with looseness values for position 4 of group 3.

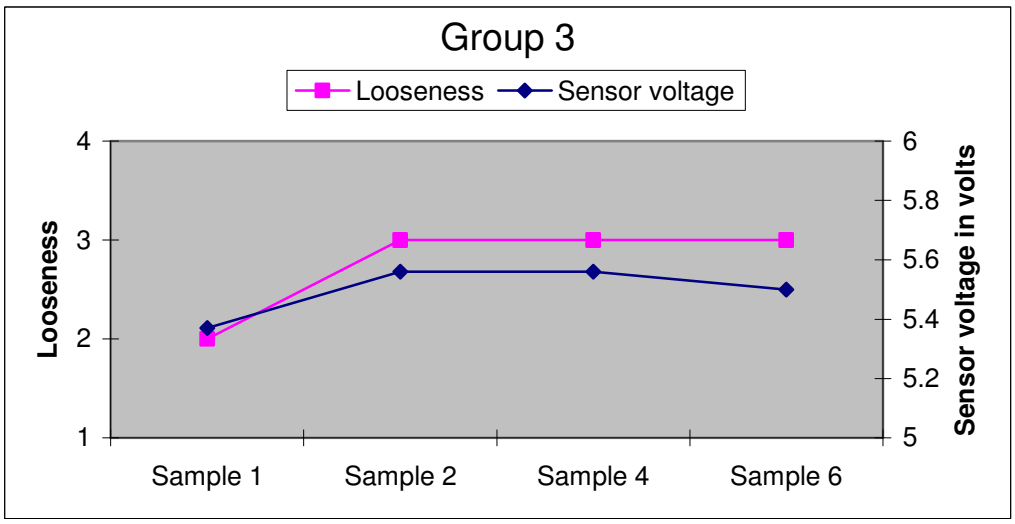


Figure 5.2.23: Comparison of sensor output voltage with looseness values for position 4 of group 3.

Then the sensor output voltage values for position 5 were compared with looseness values provided by expert as shown in figure 5.2.24. In the figure 5.2.24, voltage value increases slightly along with increase in looseness value and then varies slightly for samples 2, 5 and 6 even though all of them have same looseness values this could be due to the left over fat before processing at those places or change in their thickness. So, by ignoring samples 3 and 5 a better correlation can be observed as shown in figure 5.2.25.

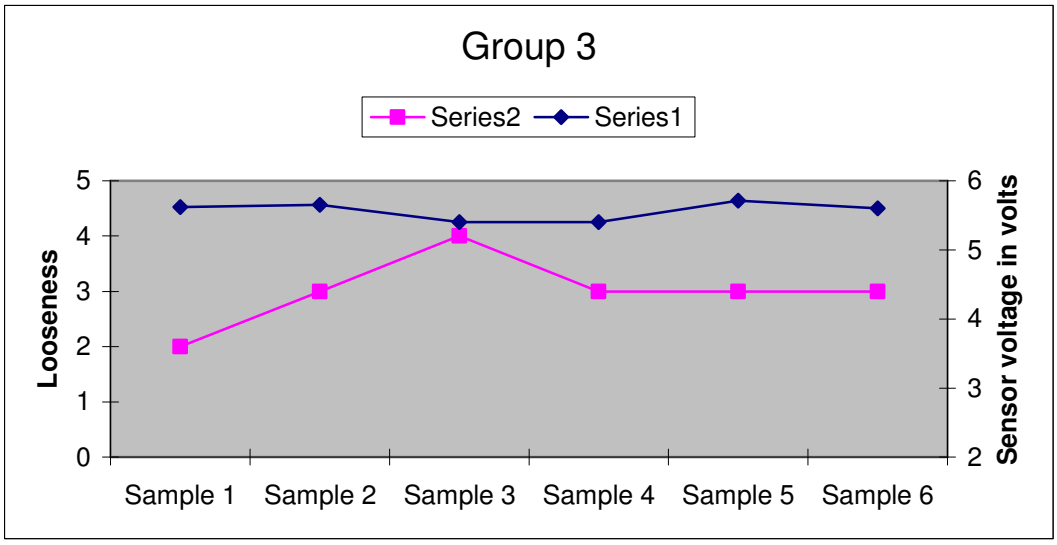


Figure 5.2.24: Comparison of sensor output voltage with looseness values for position 5 of group 3.

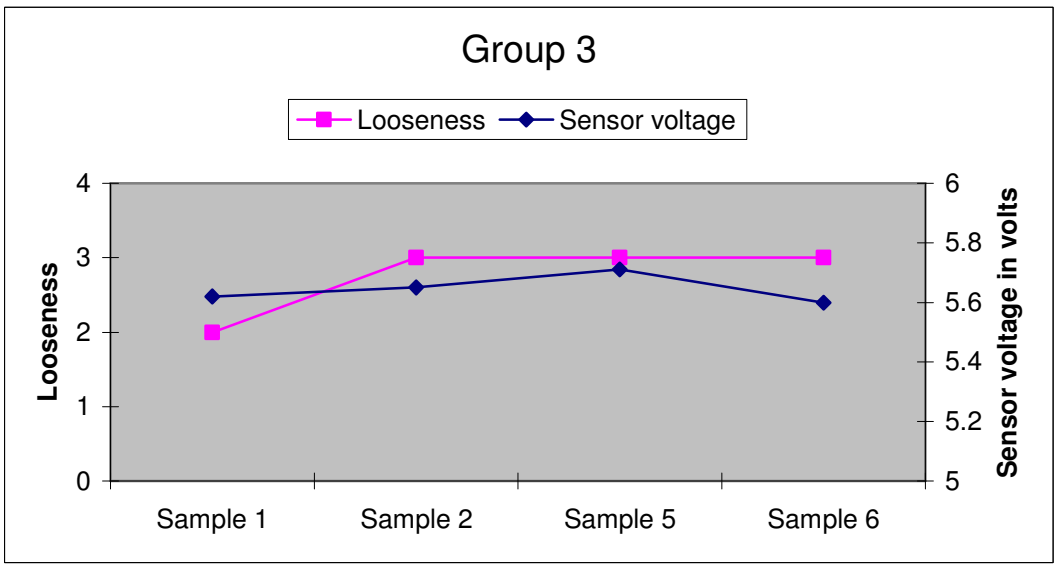


Figure 5.2.25: Comparison of sensor output voltage with looseness values for position 4 of group 3.

Looseness in a sheep skin is determined by manually pulling the skin near the positions 4 or 5 according to LASRA, an average of voltages of the positions 4 and 5 was compared with looseness values provided by expert 2 as shown in figure 5.2.26. It can be observed from the figure 5.2.26 that sensor output voltage increases along with looseness value for sample 2 but for sample 4 it decreases even though it has same looseness value. For sample 4 and 5 we have same voltage values for same looseness which is encouraging and then an increase for sample 6 for same looseness value this change could be influenced by thickness of the material or other factors such as presence of fat on the skin. This trend can be better observed in figure 5.2.27.

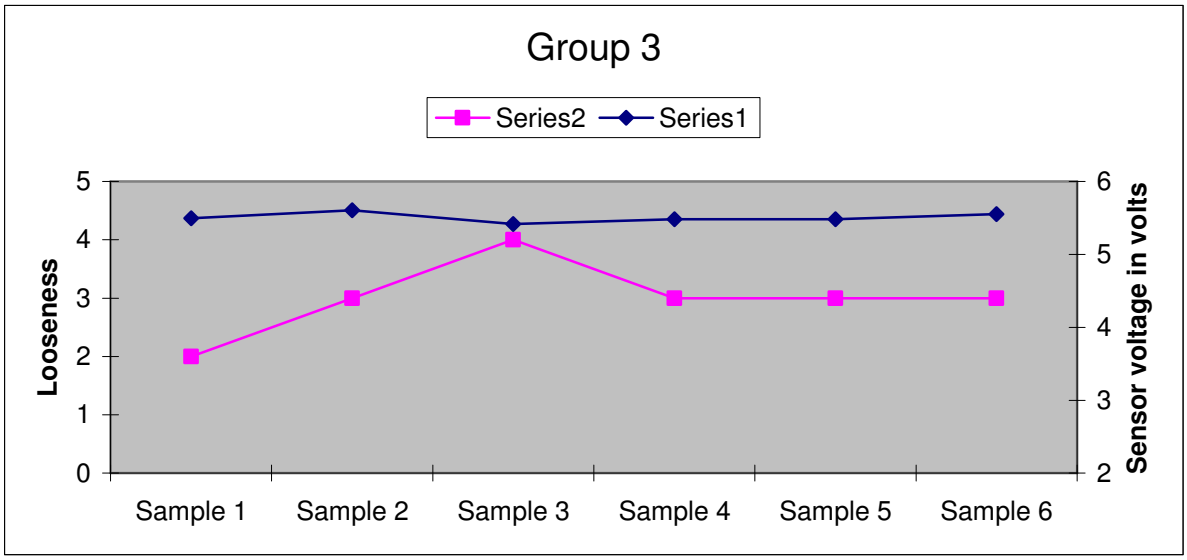


Figure 5.2.26: Comparison of sensor output voltage with looseness values for average of positions 4 and 5 of group 3.

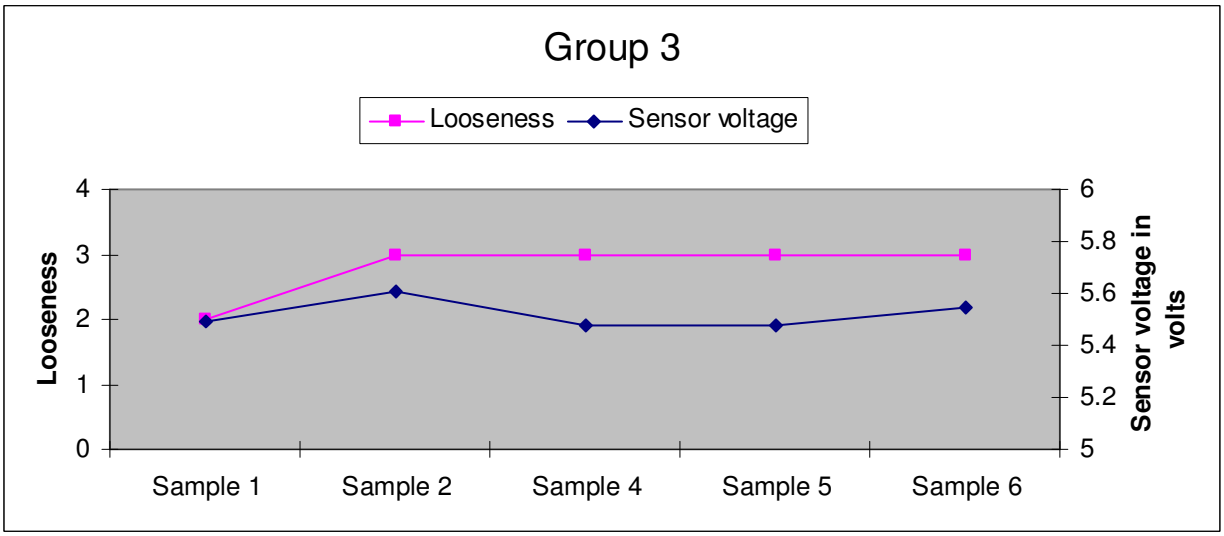


Figure 5.2.27: Comparison of sensor output voltage with looseness values for average of positions 4 and 5 of group 3.

Looseness is spread throughout the skin; averages of voltages of all positions of skins of group 3 are compared with looseness values provided by expert 2 in figure 5.2.12. From figure 5.2.28, it could be observed that sensor voltage increases along with looseness values for sample 2, and in correlation with looseness values 4 and 6 with little. By ignoring the values of sample 3 and sample 4 a better correlation was observed between both the values as shown in figure 5.2.29. Even though samples 2, 4 and 6 had same looseness values a change in voltage values was observed with little variance.

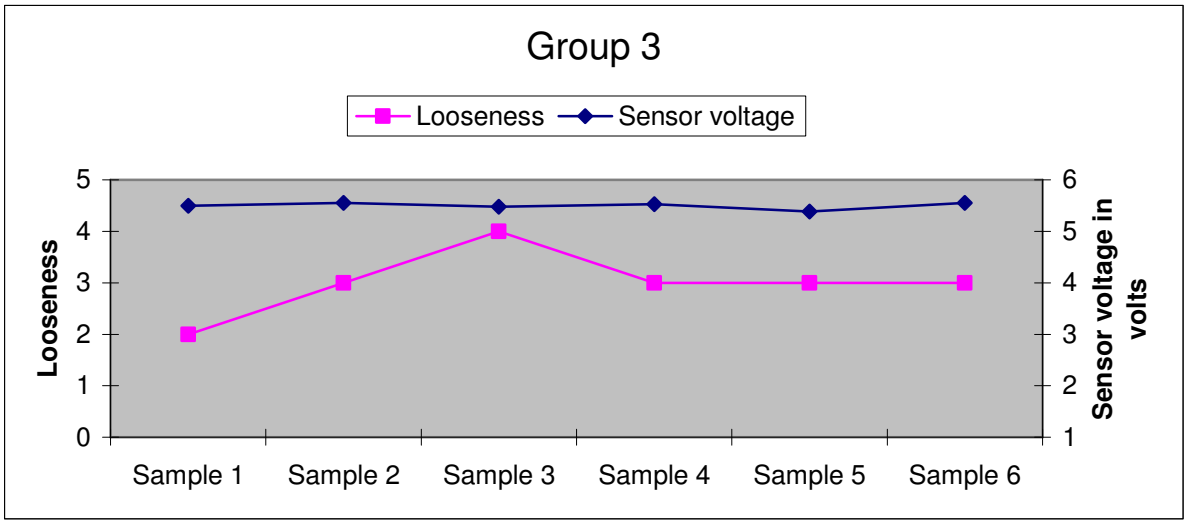


Figure 5.2.28: Comparison of sensor output voltage with looseness values for average of all positions of group 3.

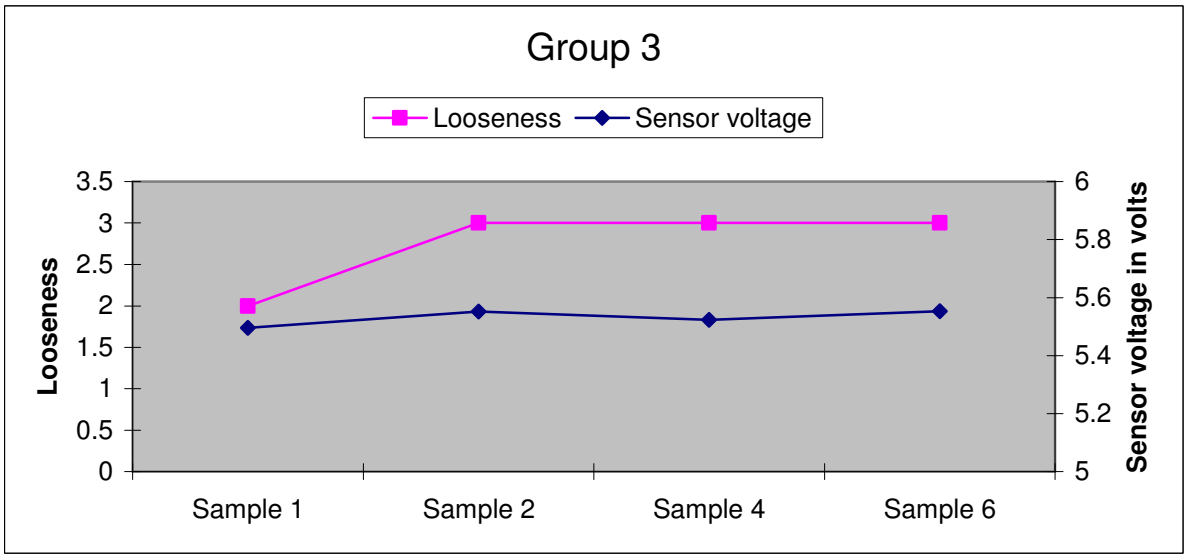


Figure 5.2.29: Comparison of sensor output voltage with looseness values for average of positions 4 and 5 of group 3.

From the figures above it was observed that some of the samples had voltages rising and dropping along with looseness values and some of the samples did not correlate with looseness trend and this was accounted for thickness and fat left on the skin before tanning process. Care is to be taken so that no fat is to be left on the skins while skinning the sheep and the effect of thickness is studied in the next section.

5.4. Effect of thickness of sheepskin on the sensor voltage

Thickness of sheep skin varies throughout its body, so in this section effect of thickness of sheep skin on sensor voltage is analyzed. Thickness of each skin is measured by taking an average of thicknesses of 5 positions of the skin. Image of skin after tanning is shown in the figure 5.3.1, which could be called leather as it had been processed. 5 positions were marked as shown in figure 5.3.1 and then were cut in to pieces. 5 holes were made in each of the positions of skin as shown in figure 2 and an average of thickness of those 5 holes was taken as average of that particular position. The holes that were made were of a size less than 10 cents New Zealand coin as shown in figure 5.3.3, and the measurements were made using a LCD digital caliper.

Figure 5.3.1: Leather with marked positions

Figure 5.3.2: Skin area of one of the positions with 5 holes in it.

Figure 5.3.3: Comparison of size of the hole with 10 cents coin.

The sensor output voltage at positions of the skin is plotted against the average thickness values. First the average thickness of all positions is plotted against sensor voltage

values for those positions and the comparison is shown in figure 5.3.4. For this plot, only 17 samples were considered as 1 sample was not cut to be used for future demonstrations. So the figure below was plotted for 85 samples, 5 positions each of 17 sheep skins. Considering 63 samples as shown in figure 5.3.5, it could be observed that sensor voltage increases along with thickness.

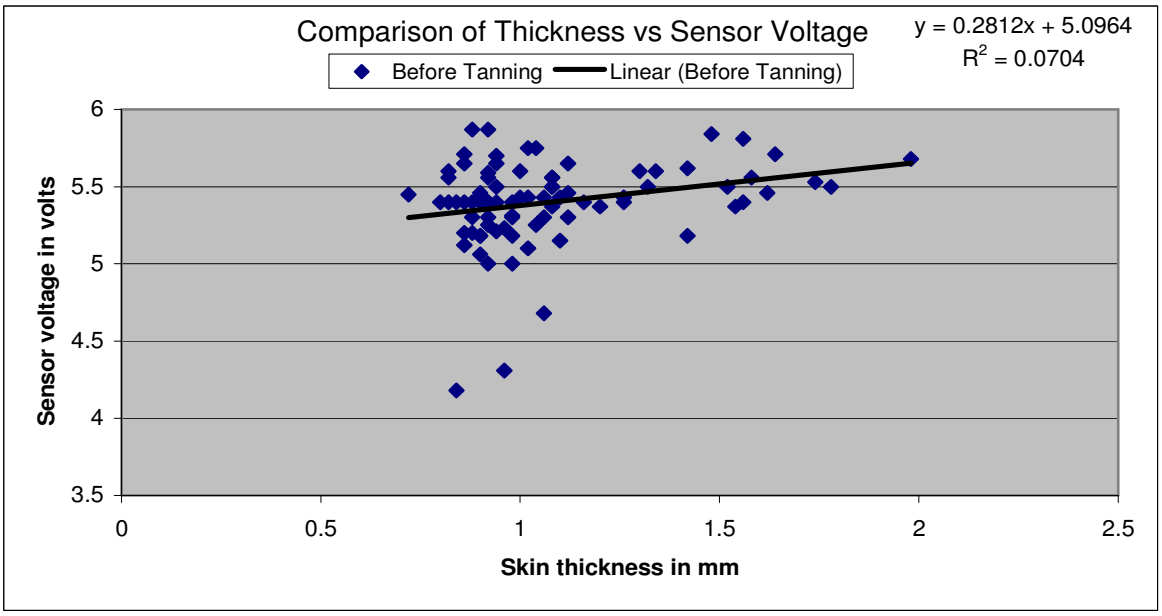


Figure 5.3.4: Comparison of thickness with sensor voltage before tanning.

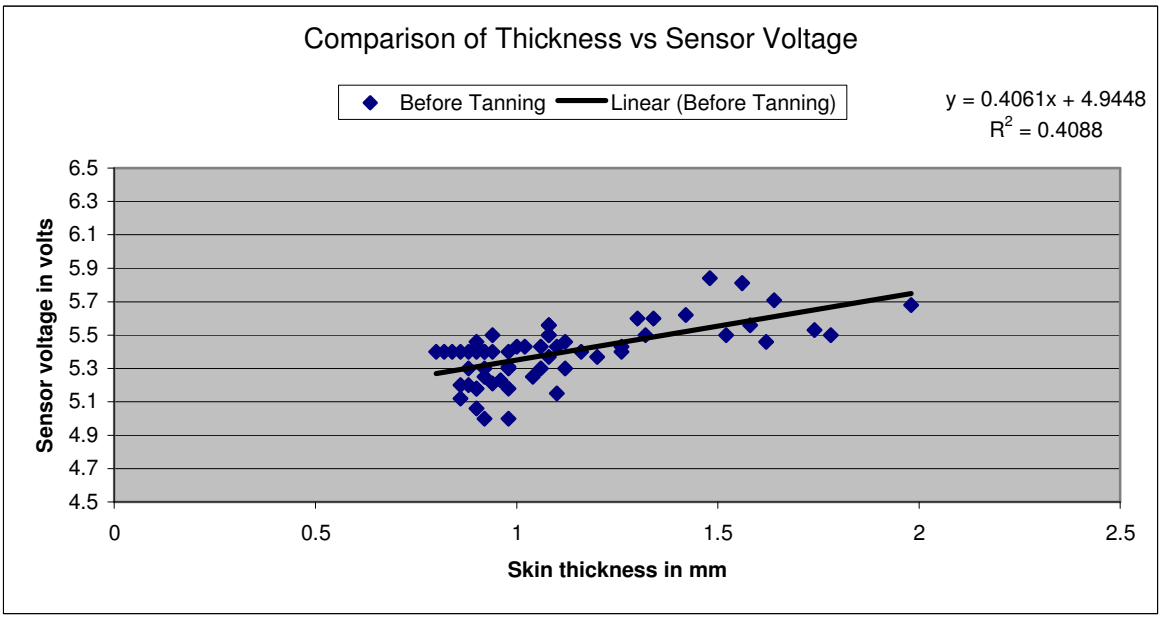


Figure 5.3.4: Comparison of thickness with sensor voltage before tanning.

Average thickness of each skin was measured by adding the average values of 5 positions. Figure 5.3.5 shows the skins arranged in the increased order of thickness.

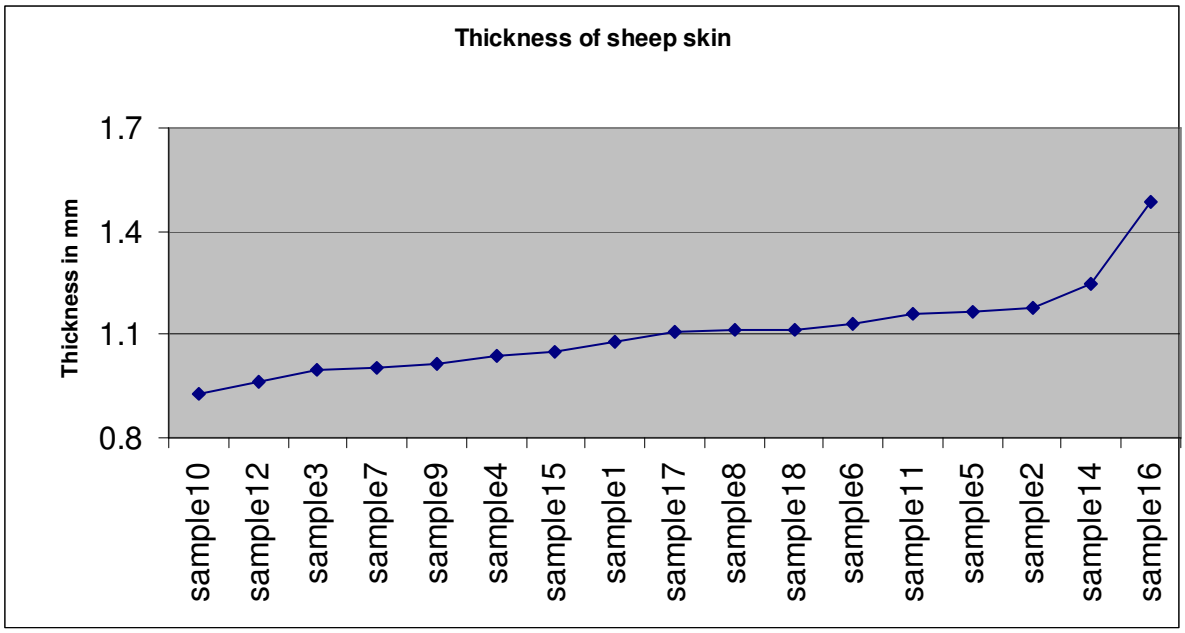


Figure 5.3.4: Comparison of thickness with sensor voltage before tanning.

Sensor voltage values for all the samples are compared with looseness values and the samples are arranged in the increasing order of thickness as shown in figure 5.3.5. There is a good correlation between the looseness values and sensor output voltage where voltage drops and increases along with looseness values. From sample 10 to sample 7, looseness drops and increases along with looseness values, then the voltage decreases for sample 4 along with looseness value however for sample 15 an increase in voltage can be observed even though both the samples 4 and 15 have same looseness value this could be due to the increase in thickness. After sample 15, sensor voltage follows the trend of looseness values. Samples 17 and 6 have same looseness values but there is slight increase in the voltage value for sample 6. This trend could be observed better in the figure 5.3.6. From figure 5.3.6, it can be observed that samples 4, 15 and 2 have same looseness value but the voltage increases along with increase in thickness, it can also be observed that samples 12, 17, 6, 14 and 16 have same looseness value 3 but there is a steady increase in the sensor output voltage which is shown in figure 5.3.7.

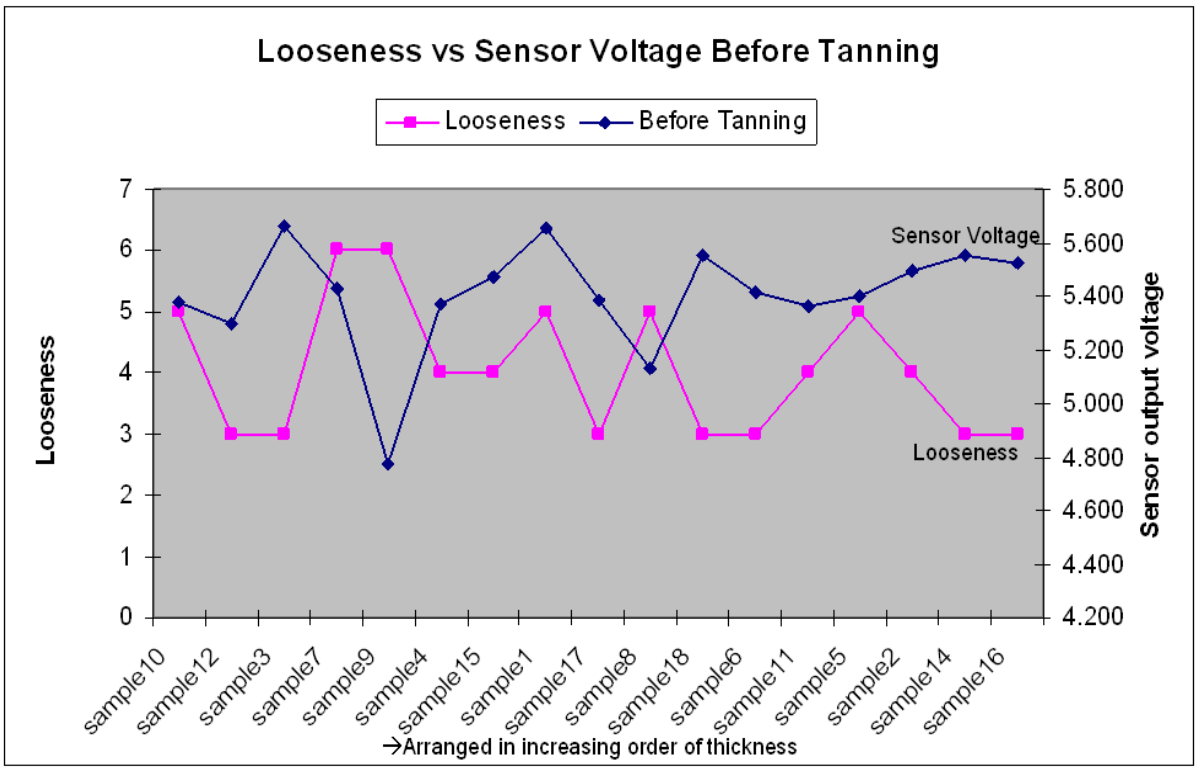


Figure 5.3.5: Comparison of looseness with sensor voltage before tanning with skins arranged in the increasing order of thickness.

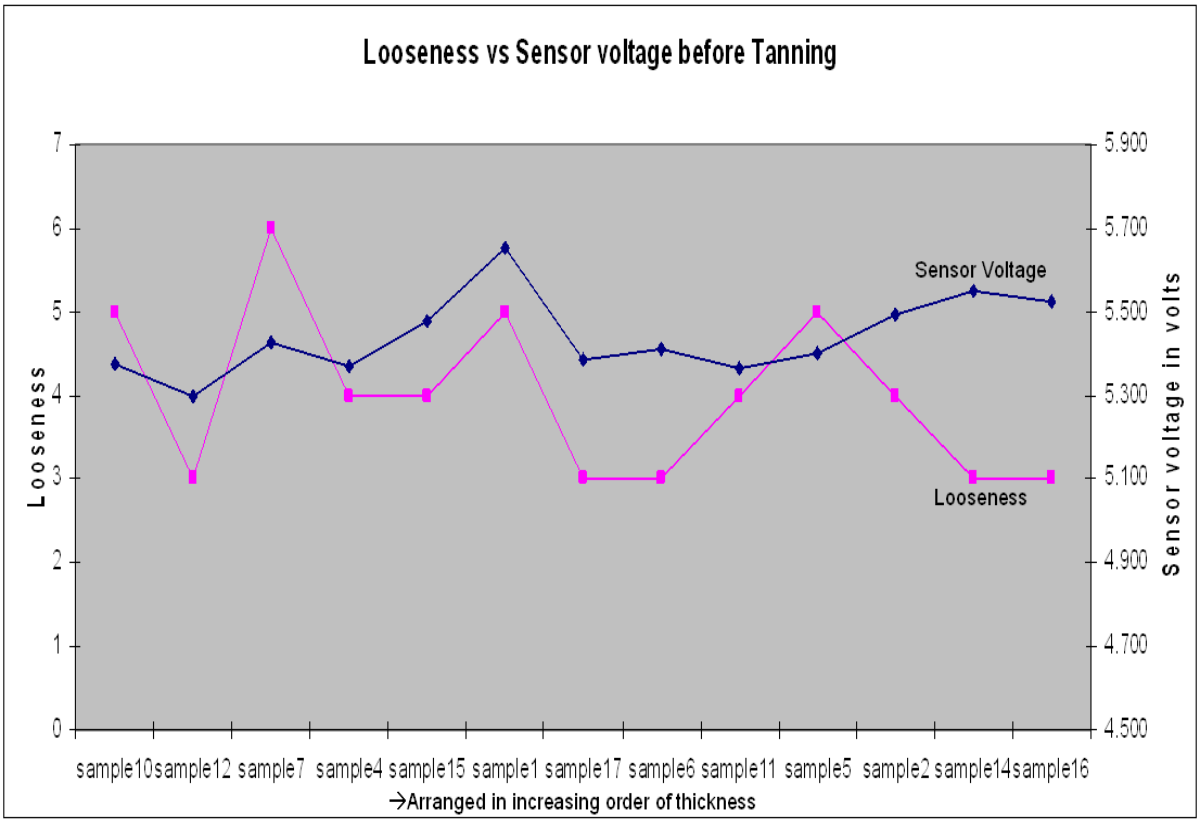


Figure 5.3.5: Comparison of looseness with sensor voltage before tanning with skins arranged in the increasing order of thickness without considering few samples.

By considering the samples which had same looseness but different voltages a graph was plotted as shown in figure 5.3.6. It can be observed that sensor voltage steadily increases from sample 12 to sample 16 along with the thickness as the samples were also arranged in the increasing order of thickness. There is a little variance in voltage values for samples having same looseness such as samples 17, 6 and sample 14, 16 as it has to be understood that the voltage values are real numbers whereas the looseness values are integers.

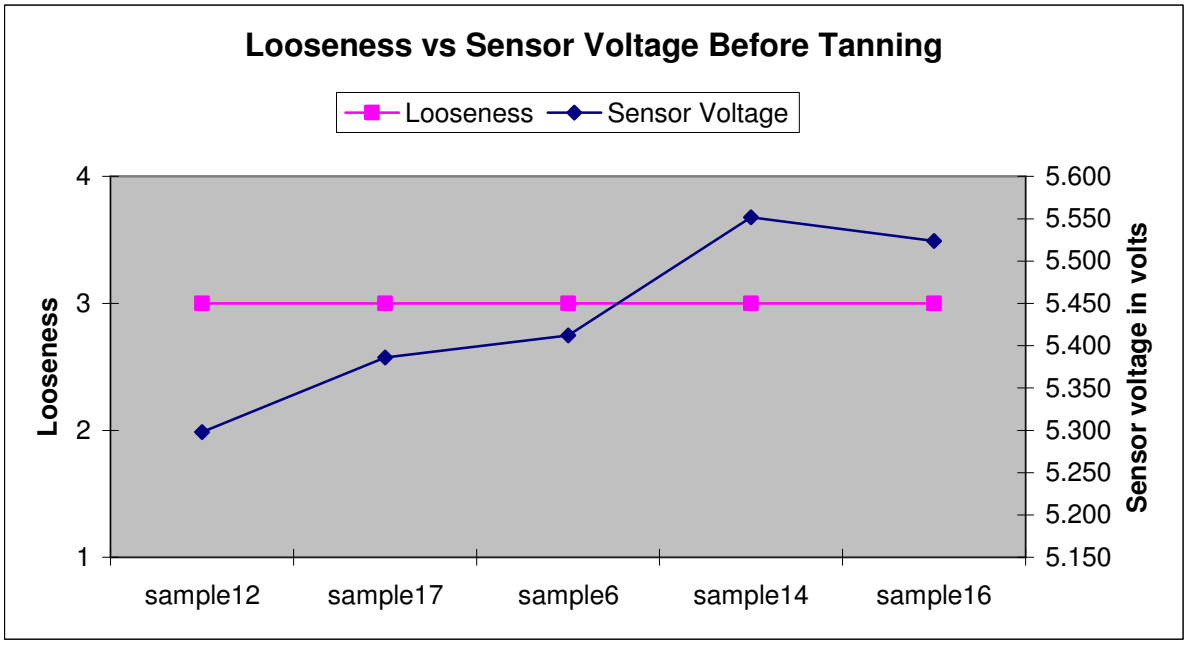


Figure 5.3.6: Comparison of looseness with sensor voltage for the samples having same looseness arranged in increasing order of thickness.

5.5. Observations for sheep skins after tanning process

First the voltages across the position 4 and 5 of each skin were compared with looseness values provided by expert 2. The sensor output voltage for the samples of group 1 were compared with looseness values provided by expert 2. A good correlation could be observed between the sensor output voltages and looseness values except for the samples 1 and sample 5 as shown in figure 5.4.1. It can be observed that sensor output voltage values drop and rise along with looseness values. This trend can be observed better by removing samples 1 and 5, as shown in figure 5.4.2. The discrepancy in values of sample 3 and sample 5 could be due to the presence of fat on the sample as the skins were not processed when sensor voltage was measured and or could also be due to other factors like thickness.

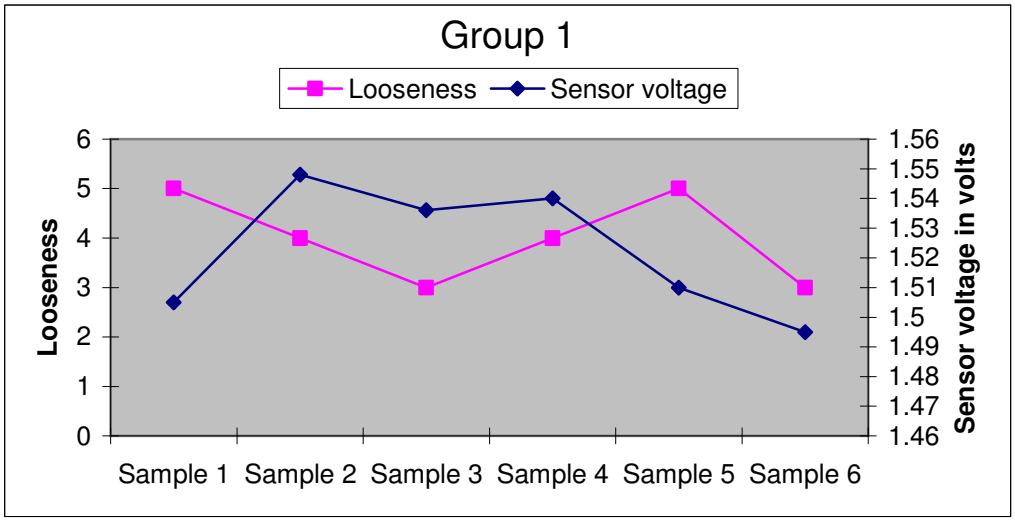


Figure 5.4.1: Comparison of sensor output voltage with looseness values for position 4 of group 1

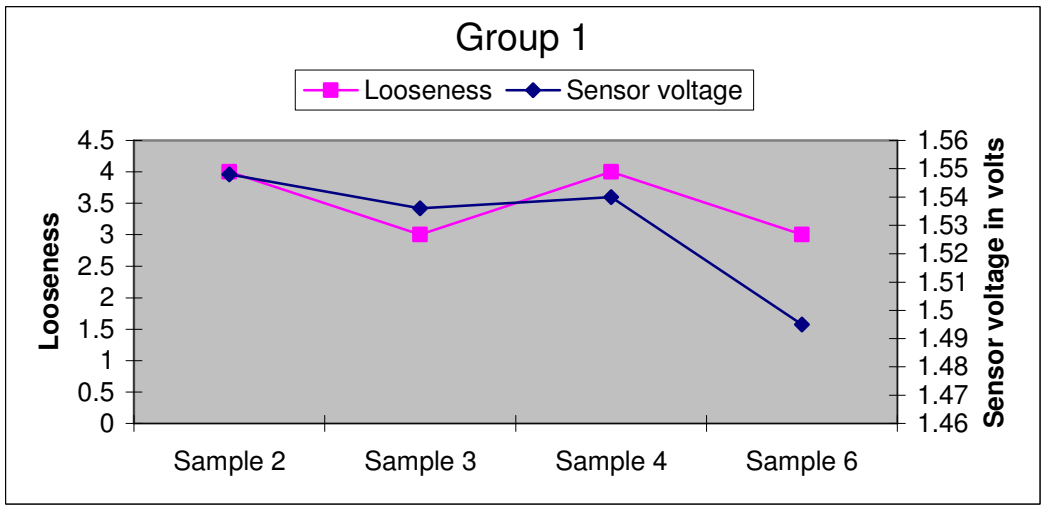


Figure 5.4.2: Comparison of sensor output voltage with looseness values for position 4 of group 1

Then the sensor output voltage values for position 5 were compared with looseness values provided by expert as shown in figure 5.4.3. In the figure 5.4.3, a correlation can be observed for samples 2, 3, 4 and 6 but samples 1 and 5 have differing values and they do not correlate with looseness values trend which could be again due to presence of fat or variance in thickness. So, by ignoring samples 1 and 5 a better correlation can be observed as shown in figure 5.4.4.

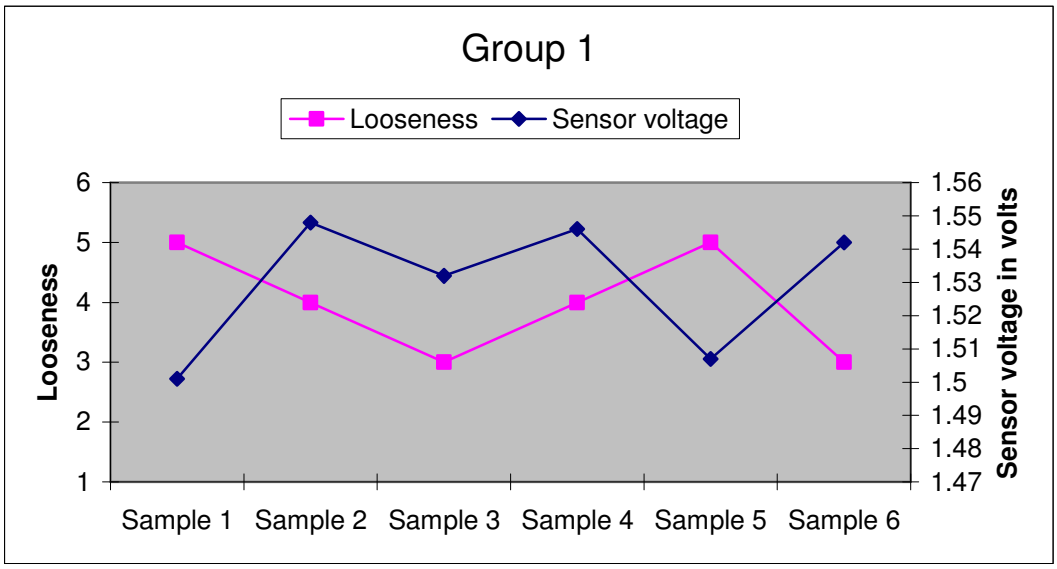


Figure 5.4.3: Comparison of sensor output voltage with looseness values for position 5 of group 1

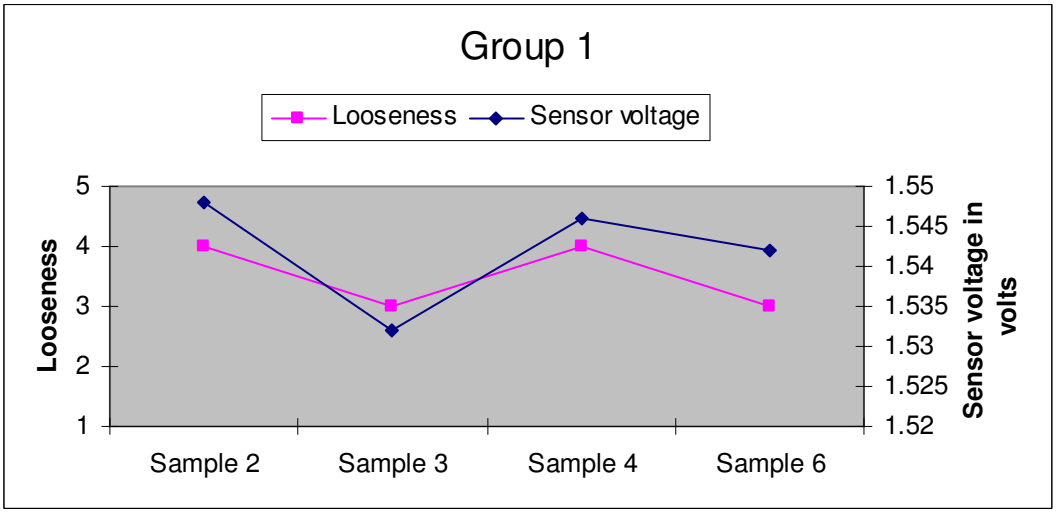


Figure 5.4.4: Comparison of sensor output voltage with looseness values for position 5 of group 1

The looseness in a sheep skin is determined by manually pulling the skin near the positions 4 or 5 according to LASRA, an average of voltages of the positions 4 and 5 was compared with looseness values provided by expert 2 as shown in figure 5.4.5. It can be observed from the figure 5.4.5 that sensor output voltage drops and rises along with looseness values apart for the samples 1 and 5 which was the similar trend observed in the figure 5.4.2 and 5.4.4. By ignoring the samples 1 and 5, a better correlation can be observed in figure 5.4.6.

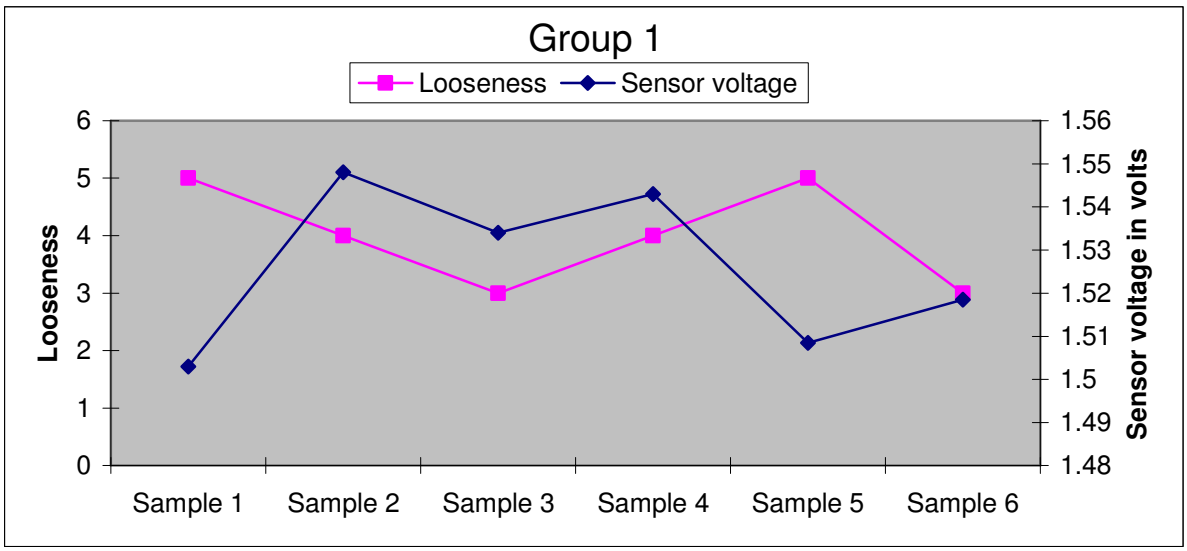


Figure 5.4.5: Comparison of sensor output voltage with looseness values for average of positions 4 and 5 of group 1

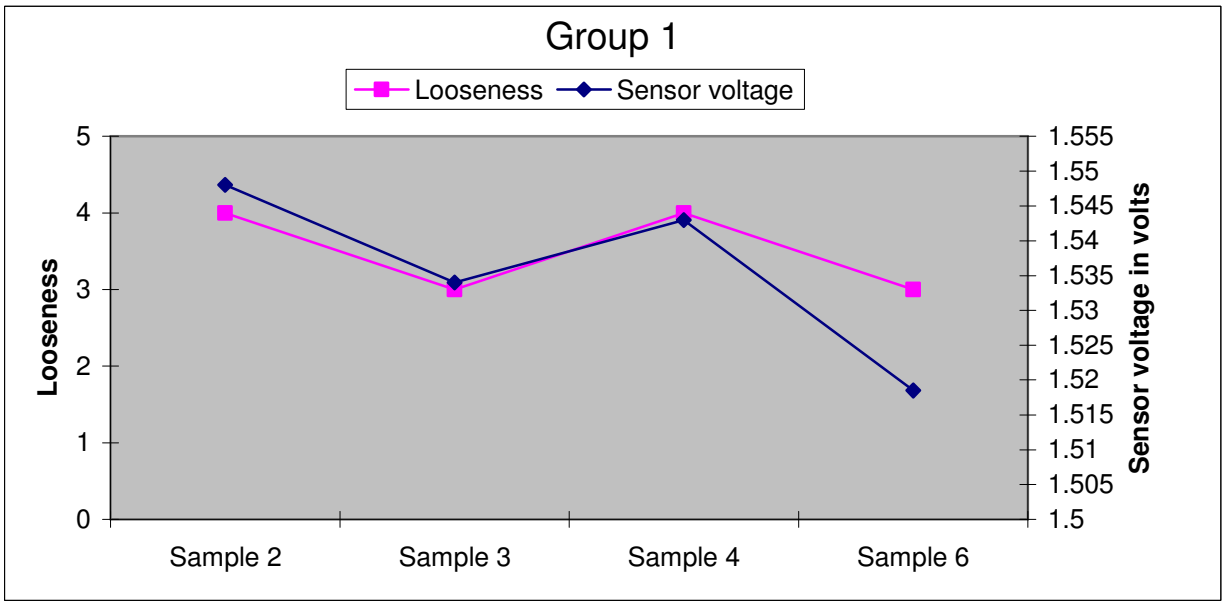


Figure 5.4.6: Comparison of sensor output voltage with looseness values for average of positions 4 and 5 of group 1

Looseness is spread throughout the skin; averages of voltages of all positions of skins of group 1 are compared with looseness values provided by expert 2 in figure 5.4.7. From figure 5.4.7, similar trend of voltages dropping and rising along with looseness values can be observed for samples 1, 4, and 6, whereas voltage tends to vary only little for sample 3 even though looseness drops by a unit. Sample 2 and sample 3 values do not fit the correlation trend of looseness values. By ignoring the values of sample 2 and sample 2 a better correlation was observed between both the values as shown in figure 5.4.8.

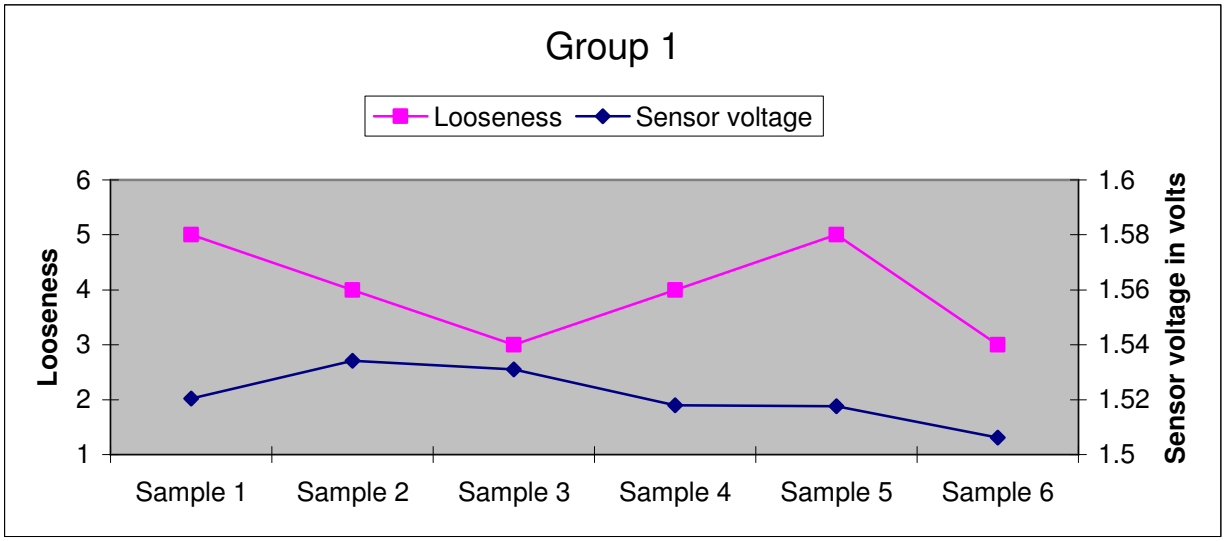


Figure 5.4.7: Comparison of sensor output voltage with looseness values for average of all positions of group 1

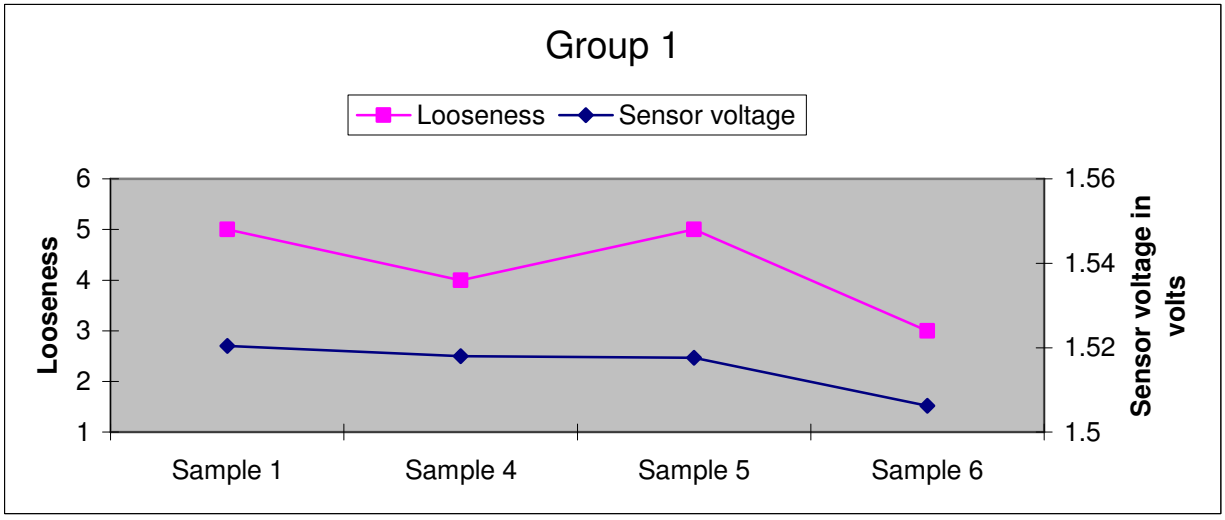


Figure 5.4.8: Comparison of sensor output voltage with looseness values for average of all positions of group 1

The voltages across the positions 4 and 5 for each skin in group 2 were compared with looseness values provided by expert 2. First sensor output voltage at position 4 for the samples of group 2 was compared with looseness values provided by expert 2 in figure 5.4.9. Samples 2 and 4 got same looseness but the sensor voltage drops a little for sample 4 when compared to sensor 2 but voltage is same for sample 3 even though looseness is increases by a unit of 1 when compared to sample 2 and this could be due to the presence of fat on the sample as the skins were not processed when sensor voltage was measured and or could also be due to other factors such as thickness and also the looseness is measured as an integer whereas sensor voltage is a real number. So, by removing samples 5 and 6, a better correlation between the looseness values and sensor output voltages could be observed as shown in figure 5.4.10. For samples 5 and 6, there is an increase in sensor voltage though looseness drops.

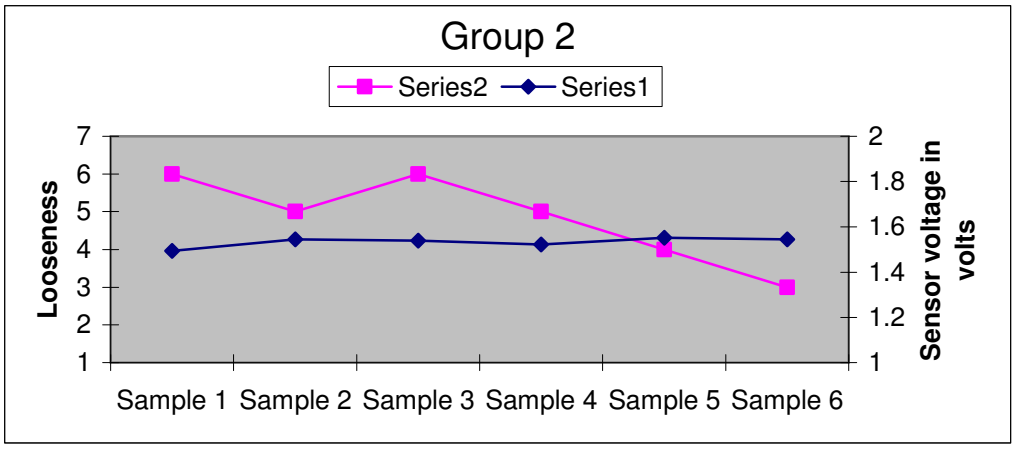


Figure 5.4.9: Comparison of sensor output voltage with looseness values for position 4 of group 2

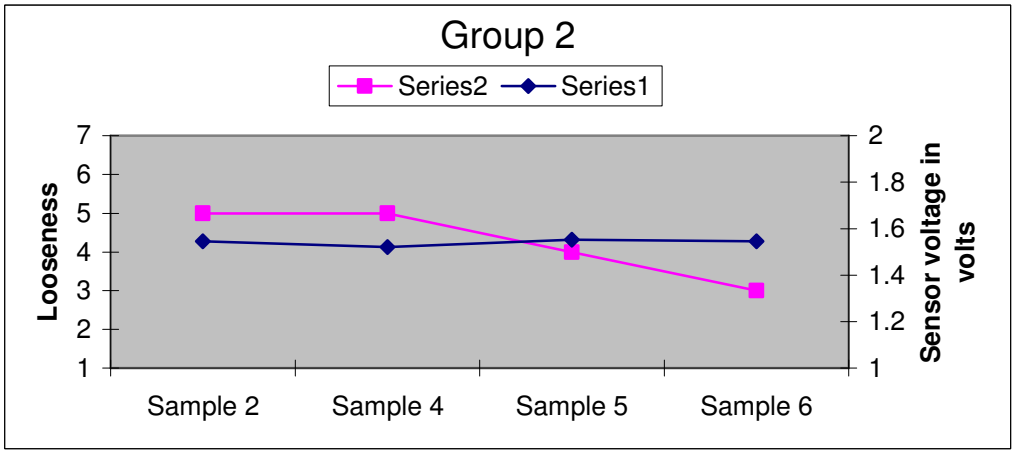


Figure 5.4.10: Comparison of sensor output voltage with looseness values for average of position 4 of group 2

Then the sensor output voltage values for position 5 of each sample of group 2 were compared with looseness values provided by expert as shown in figure 5.4.11. A correlation between the sensor output voltages and looseness values for the samples 2, 3, 4, 5 and 6 could be observed. It can be observed that sensor output voltage increases and drops along with looseness value for samples 3 and 4. For sample 5 voltage increases even though looseness drops by a unit which was same trend that was observed for values for position 4 of the same skin. This trend can be observed better in figure 5.4.12.

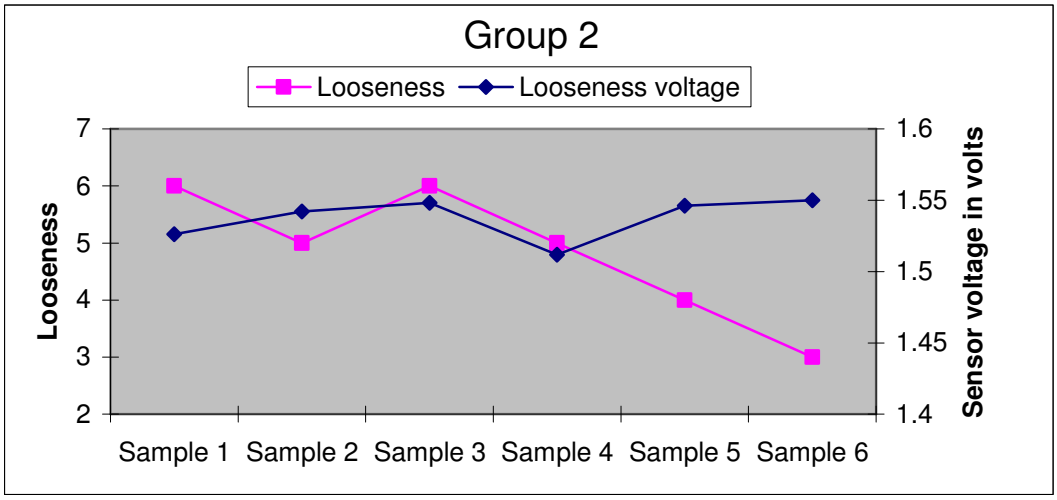


Figure 5.4.11: Comparison of sensor output voltage with looseness values for position 5 of group 2

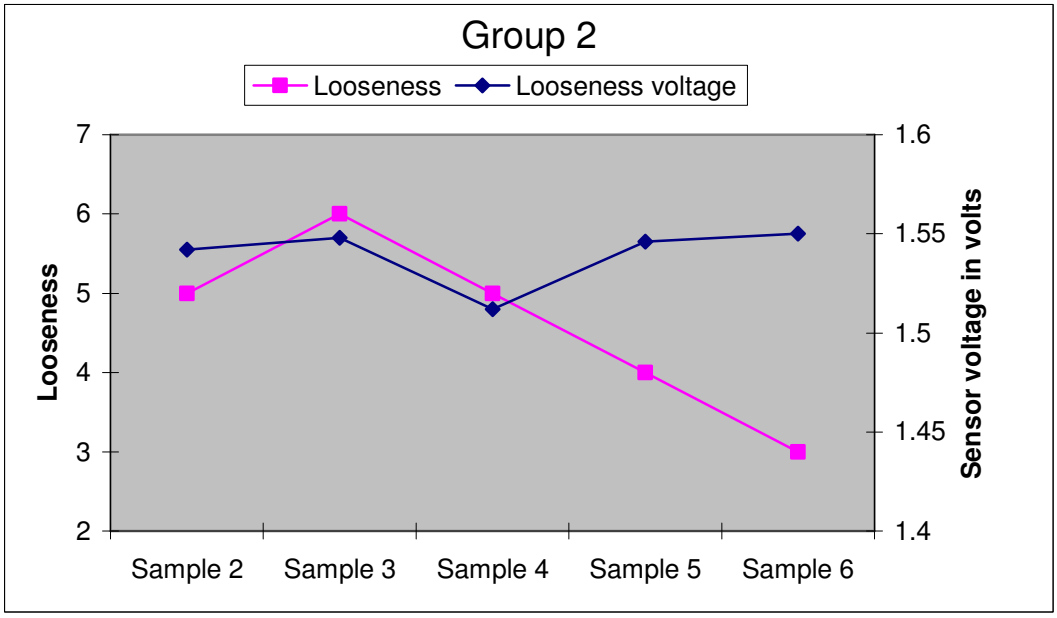


Figure 5.4.12: Comparison of sensor output voltage with looseness values for position 5 of group 2

An average of voltages of the positions 4 and 5 was compared with looseness values provided by expert 2 as shown in figure 5.4.13. It can be observed from the figure 5.4.13 that sensor output voltage drops along with looseness value for the sample 4 but there is a sudden increase in voltage for sample 5 which was the similar trend observed in the previous observations. This correlation could be observed better in figure 5.4.14. It can be observed that sensor voltage is constant for samples 2 and 3 and 5 and 6 respectively even though there is change in looseness.

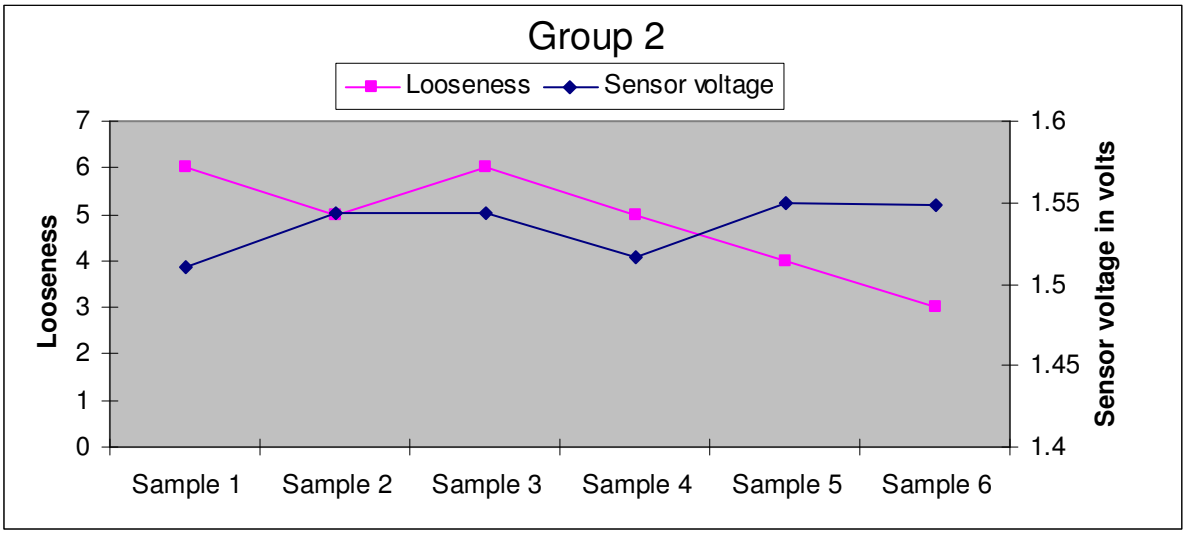


Figure 5.4.13: Comparison of sensor output voltage with looseness values for average of positions 4 and 5 of group 2

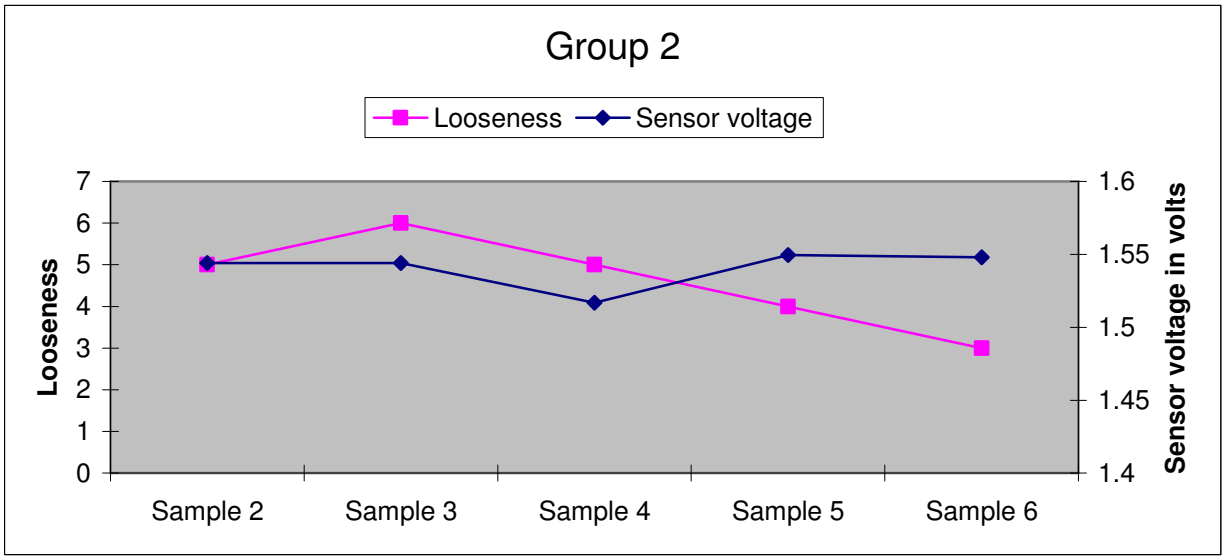


Figure 5.4.14: Comparison of sensor output voltage with looseness values for average of positions 4 and 5 of group 2

Looseness is spread throughout the skin; averages of voltages of all positions of skins of group 2 are compared with looseness values provided by expert 2 in figure 5.4.15. From figure 5.4.15, it could be observed that sensor voltages increases and drops along with looseness for samples 3 and 4 but there is an increase in voltage for sample 5 and after that voltage drops along with looseness values for sample 6. This trend can be observed much clearly in figure 5.4.16.

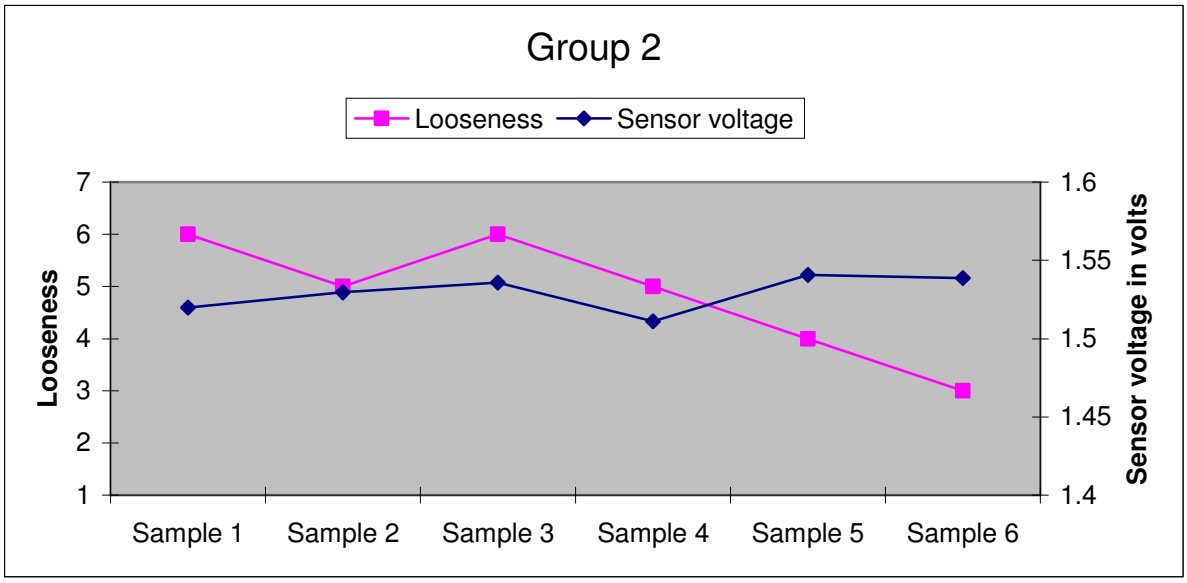


Figure 5.4.15: Comparison of sensor output voltage with looseness values for average of all positions of group 2

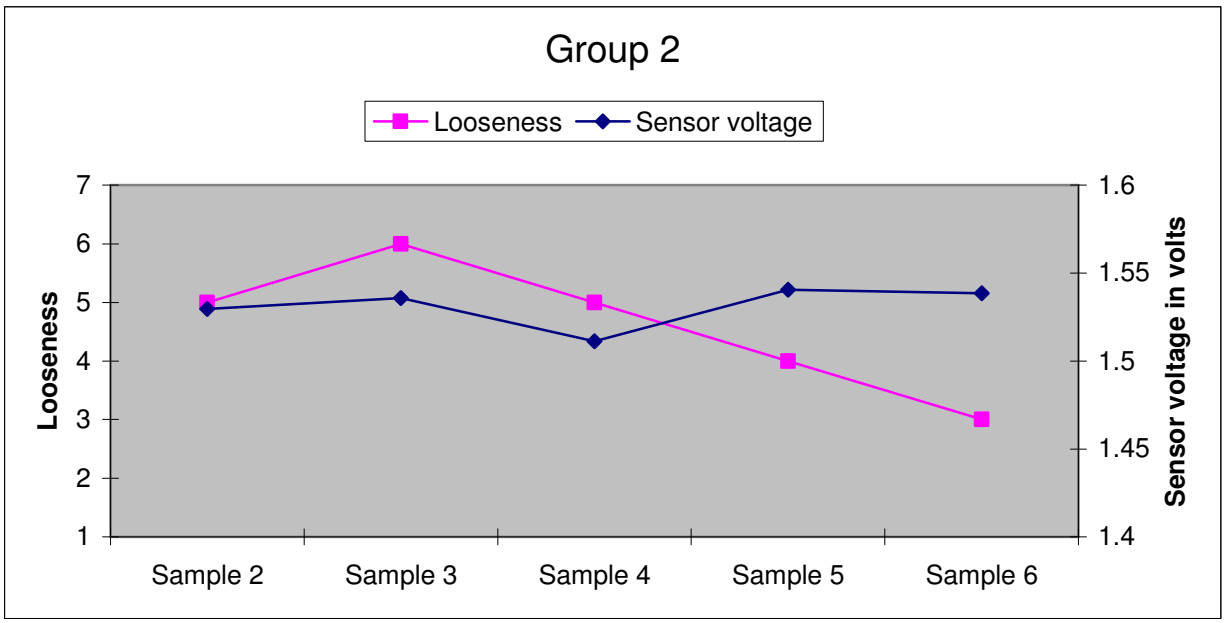


Figure 5.4.16: Comparison of sensor output voltage with looseness values for average of all positions of group 2

Voltages across the positions of 4 and 5 of each skin were compared with looseness values provided by expert 2. First sensor output voltage for the samples of group 3 was compared with looseness values provided by expert 2 in figure 5.2.22. For this group only 5 samples were considered for analysis. Samples 2, 4, 5 and 6 have same looseness values but the voltage values vary for every sample, this could be due to presence of left over fat or change in thickness. Also the looseness values are integers whereas sensor voltage values are real numbers.

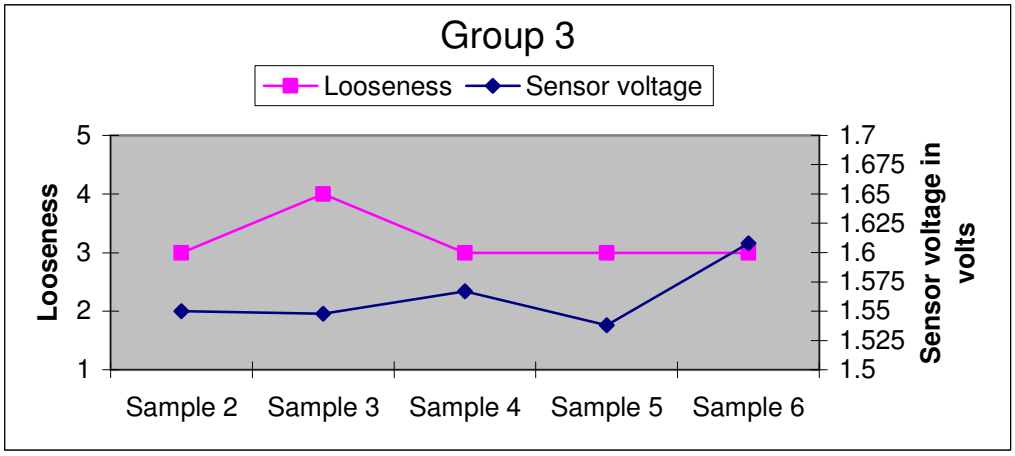


Figure 5.4.17: Comparison of sensor output voltage with looseness values for position 4 of group 3.

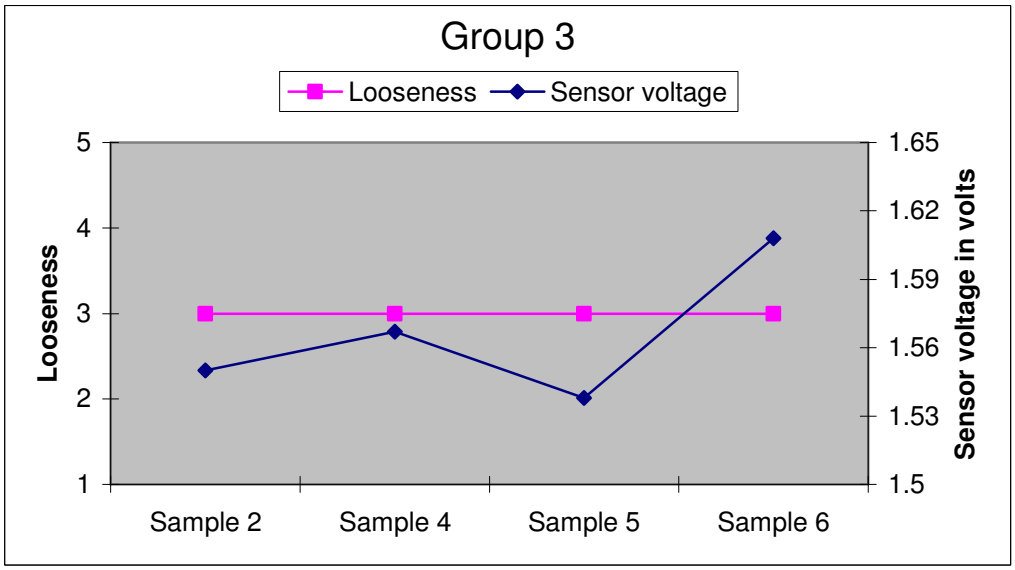


Figure 5.4.18: Comparison of sensor output voltage with looseness values for position 4 of group 3.

Then the sensor output voltage values for position 5 were compared with looseness values provided by expert as shown in figure 5.2.24. At position 5, voltage value varies slightly even though looseness is same for samples 2, 4, 5 and 6 this trend can be observed more clearly in figure 5.4.20. There is a very slight increase in voltage for sample 4 but there is a drop in voltage for sample 5 followed by an increase in voltage for sample 6.

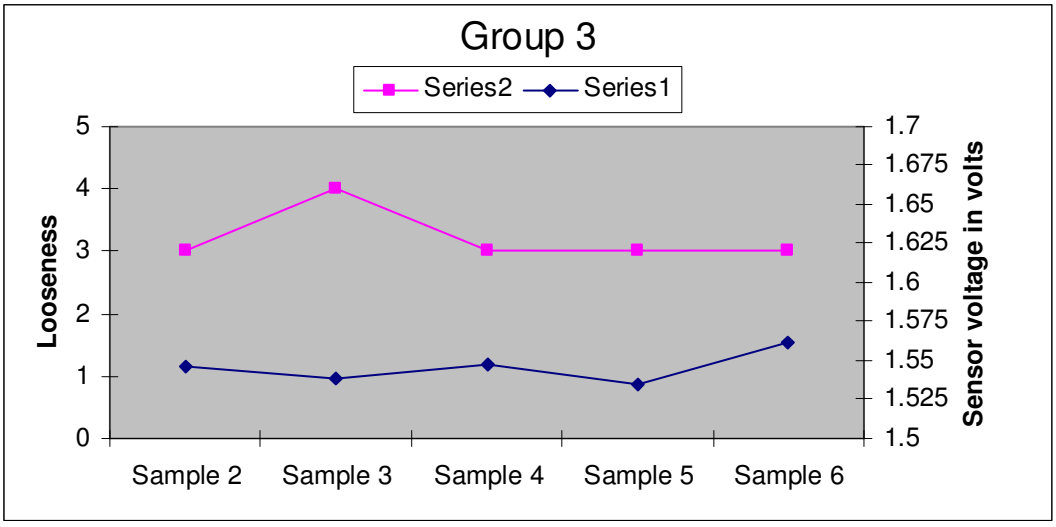


Figure 5.4.19: Comparison of sensor output voltage with looseness values for position 5 of group 3.

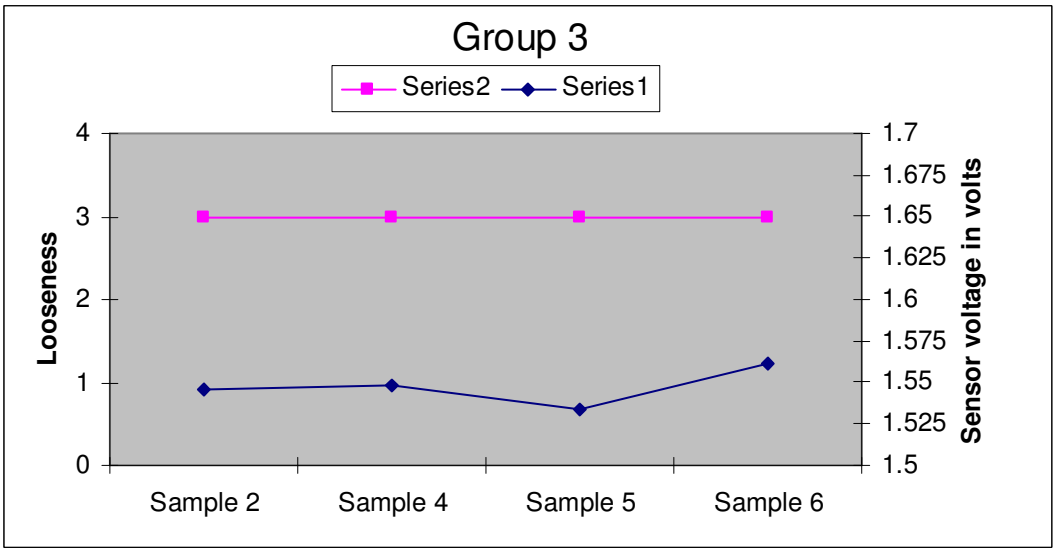


Figure 5.4.20: Comparison of sensor output voltage with looseness values for position 4 of group 3.

Looseness in a sheep skin is determined by manually pulling the skin near the positions 4 or 5 according to LASRA, an average of voltages of the positions 4 and 5 was compared with looseness values provided by expert 2 as shown in figure 5.4.22. It can be observed that sensor output voltage varies for the samples 2, 4, 5 and 6 even though they have same looseness values. This was the same trend which was observed for positions 4 and 5 individually.

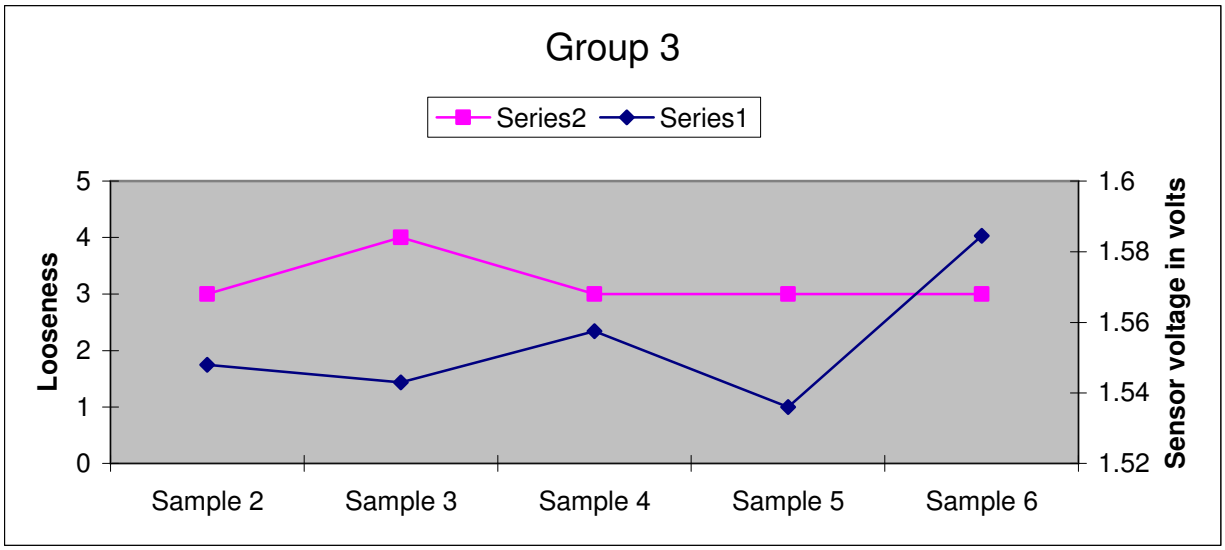


Figure 5.4.21: Comparison of sensor output voltage with looseness values for average of positions 4 and 5 of group 3.

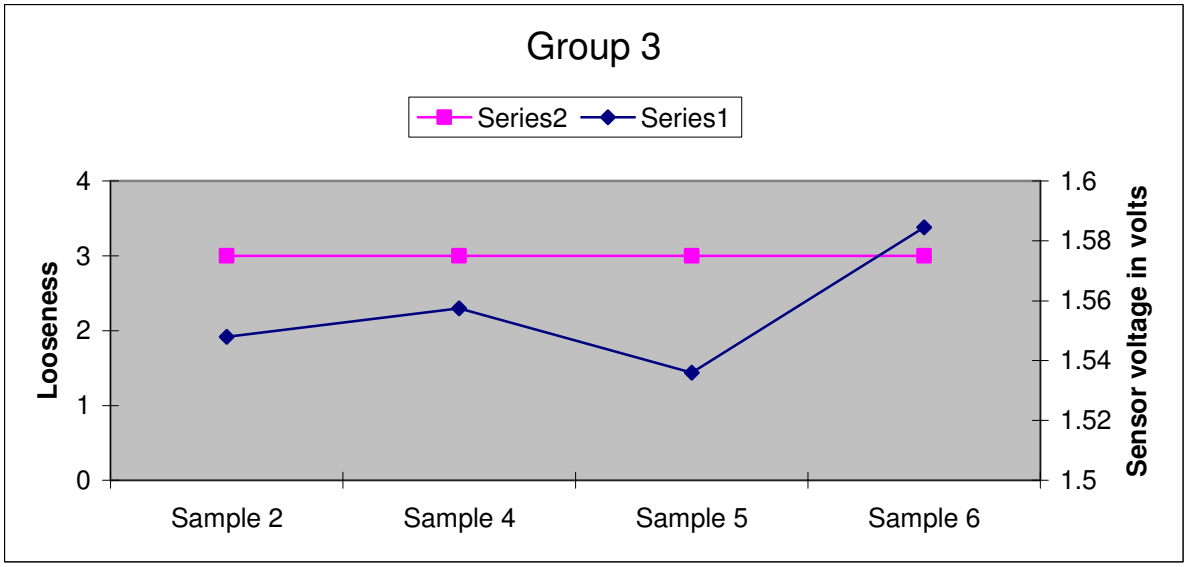


Figure 5.4.22: Comparison of sensor output voltage with looseness values for average of positions 4 and 5 of group 3.

Looseness is spread throughout the skin, averages of voltages of all positions of skins of group 3 are compared with looseness values provided by expert 2 in figure 5.4.22. It could be observed that sensor voltage varies for samples 2, 4, 5 and 6, even though they have same looseness values. For sample 5 there is a drop in voltage but apart from that voltage varies only little for samples 2, 4 and 6. This could be due to the integer type values of looseness whereas the sensor voltages are real numbers.

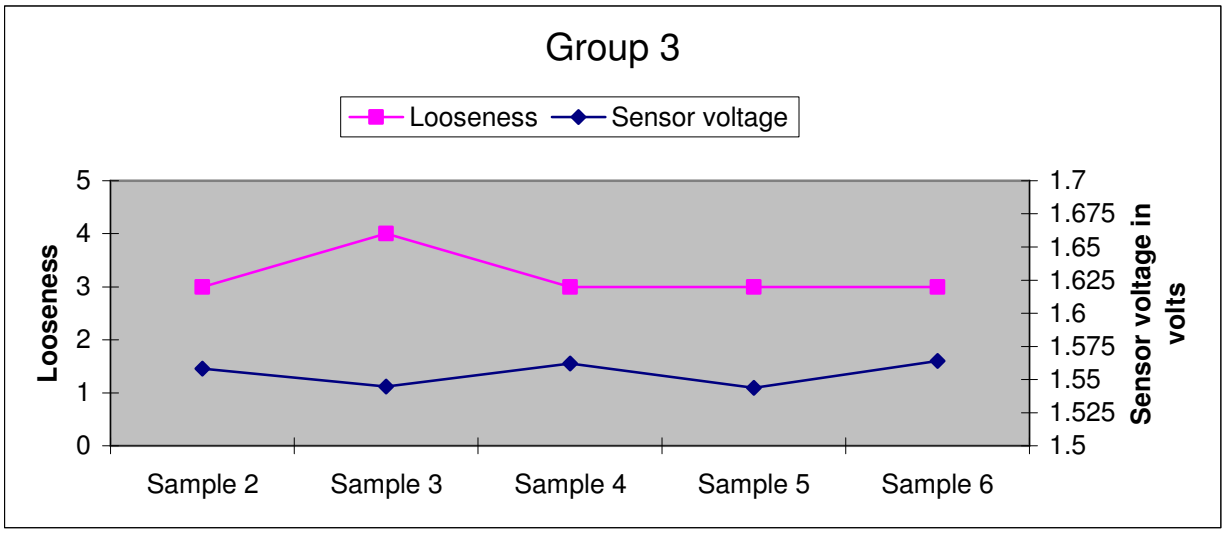


Figure 5.4.23: Comparison of sensor output voltage with looseness values for average of all positions of group 3.

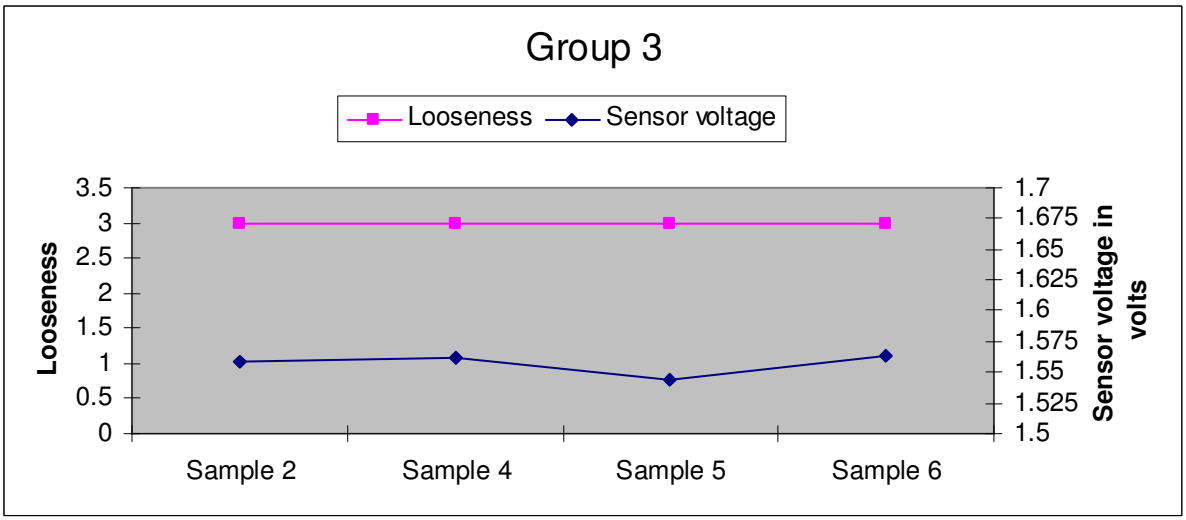


Figure 5.4.24: Comparison of sensor output voltage with looseness values for average of all positions of group 3.

When the samples are arranged in the increasing order of thickness as shown in figure 5.4.25, relationship between the looseness and sensor voltages can be observed. It can be observed that voltage drops and increases along with looseness values for most of the samples and this trend could be observed better in figure 5.4.26. Voltage tends to increase from sample 2. For samples 12, 3, 6, 14 and 16, looseness values are same but the sensor voltage tends to vary.

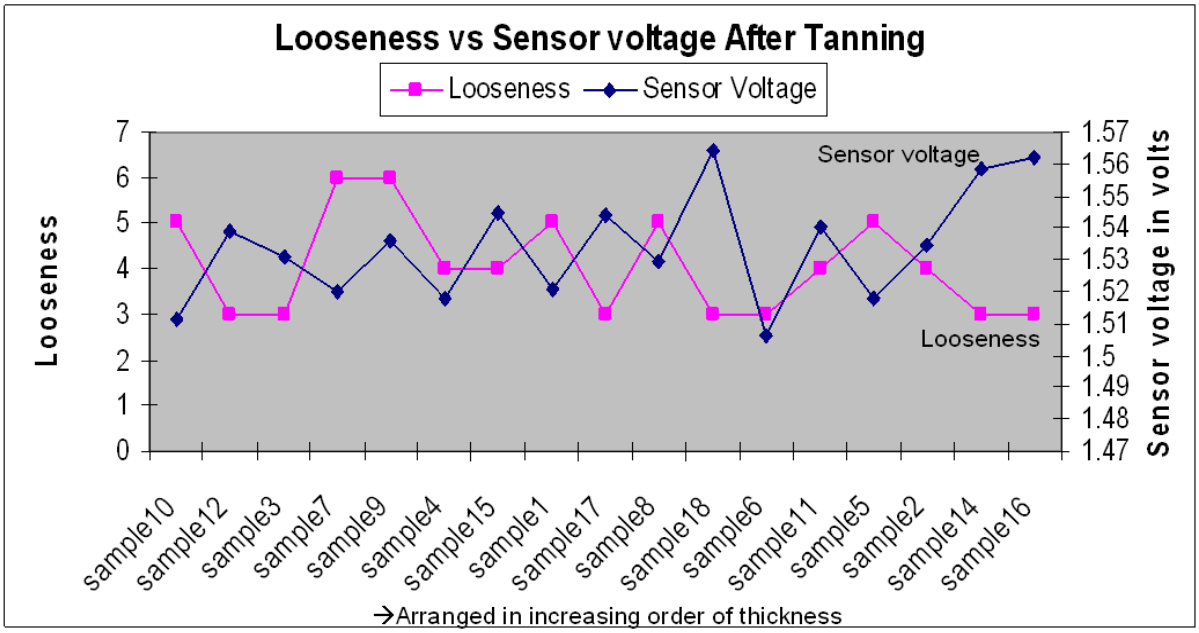


Figure 5.4.25: Comparison of looseness with sensor voltage after tanning with skins arranged in the increasing order of thickness.

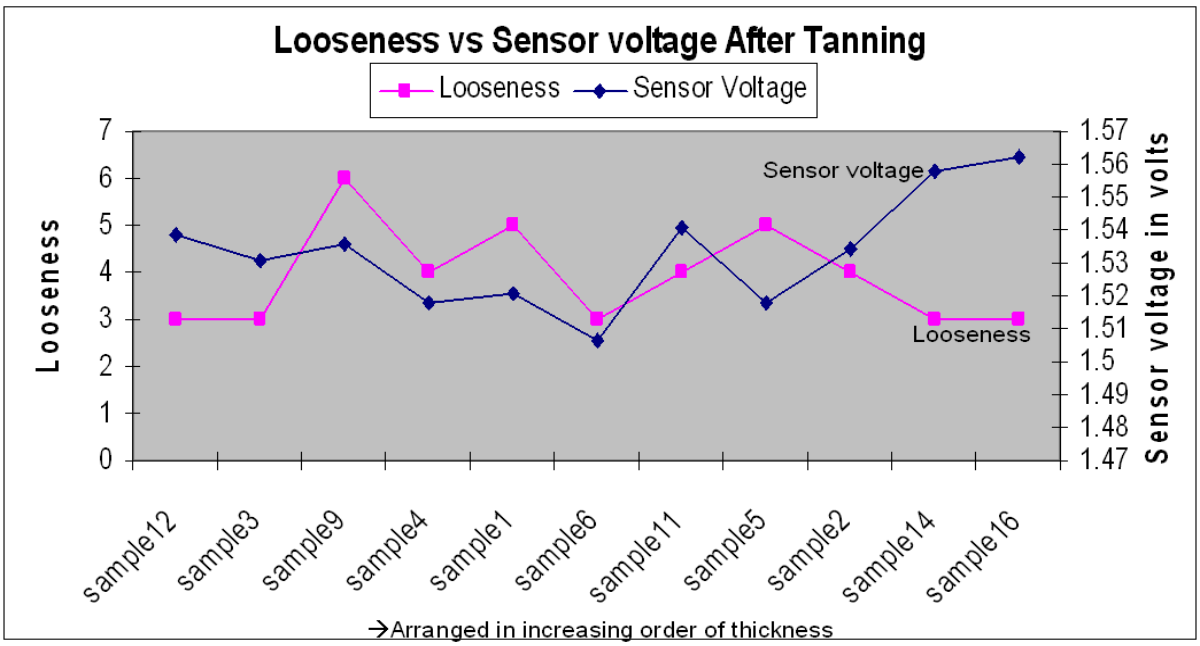


Figure 5.4.26: Comparison of looseness with sensor voltage after tanning with skins arranged in the increasing order of thickness.

For some of the samples which have same looseness, voltage increases steadily along with increase in thickness as shown in figure 5.4.27. In this figure samples are arranged in increasing order of thickness.

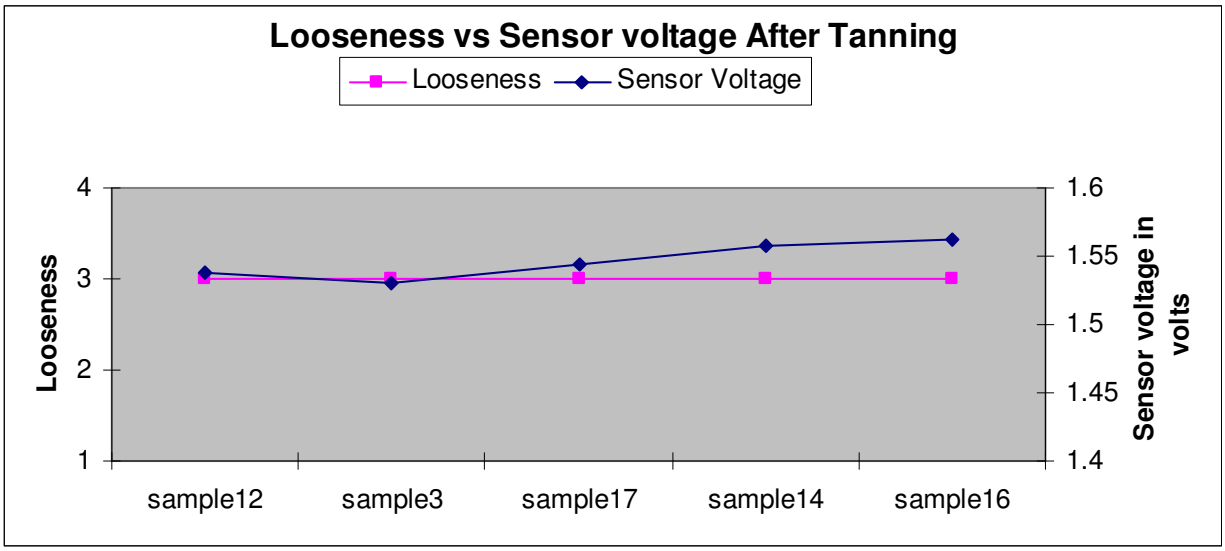


Figure 5.4.276: Comparison of looseness with sensor voltage after tanning with skins arranged in the increasing order of thickness.

5.6. Calculation of looseness in Sheep skin

Looseness could be calculated for each skin by calculating the scaling factor for each individual skin by using the formula below. Each skin will have a different scaling factor depending on its voltage.

$$Scaling = \frac{V_{actual} - V_{\min}}{V_{\max} - V_{\min}} \quad \text{---------- (1)}$$

where, V_{actual} = actual average voltage of each individual skin (average of all positions)

V_{min} = Minimum average voltage of skin (average of all positions)

V_{max} = Maximum average voltage of skin (average of all positions)

$$Looseness_{Calculated} = looseness_{\max} - scaling \times (looseness_{\max} - looseness_{\min}) \quad \text{------(2)}$$

Where, $Looseness_{max}$ = Maximum looseness found in a skin which is usually 6.

$Looseness_{min}$ = Minimum looseness found in a skin which is usually 3.

Scaling = Scaling is the scaling value calculated for that particular skin.

Looseness was calculated for skins before they were tanned and compared with actual looseness values provided by the expert from LASRA and then looseness was calculated from the voltage values obtained after tanning process and compared again with actual looseness values.

Actual looseness values as provided by one of the experts are compared with calculated looseness values as shown in figure 5.5.1. The scaling factor and calculated looseness is tabulated in the table 5.5.1. It could be observed that as calculated looseness values are real numbers they are few decimal values either less or more than actual looseness values for their respective samples. Difference in the values is represented by the bars as shown in figure 5.5.1. By eliminating samples that have a high variance between the calculated and actual looseness values a better correlation can be observed in figure 5.5.2.

Table 5.5.1: Scaling factor and calculated looseness values for skins before tanning

Sample number	Actual Looseness	Scaling factor	Calculated Looseness
sample10	5	0.679	3.96
sample12	3	0.591	4.23
sample3	3	1.000	3.00
sample7	6	0.736	3.79
sample9	6	0.000	6.00
sample4	4	0.673	3.98
sample15	4	0.792	3.62
sample1	5	0.991	3.03
sample17	3	0.691	3.93
sample8	5	0.404	4.79
sample18	3	0.880	3.36
sample6	3	0.720	3.84
sample11	4	0.668	4.00
sample5	5	0.707	3.88
sample2	4	0.813	3.56
sample14	3	0.878	3.37
sample16	3	0.847	3.46

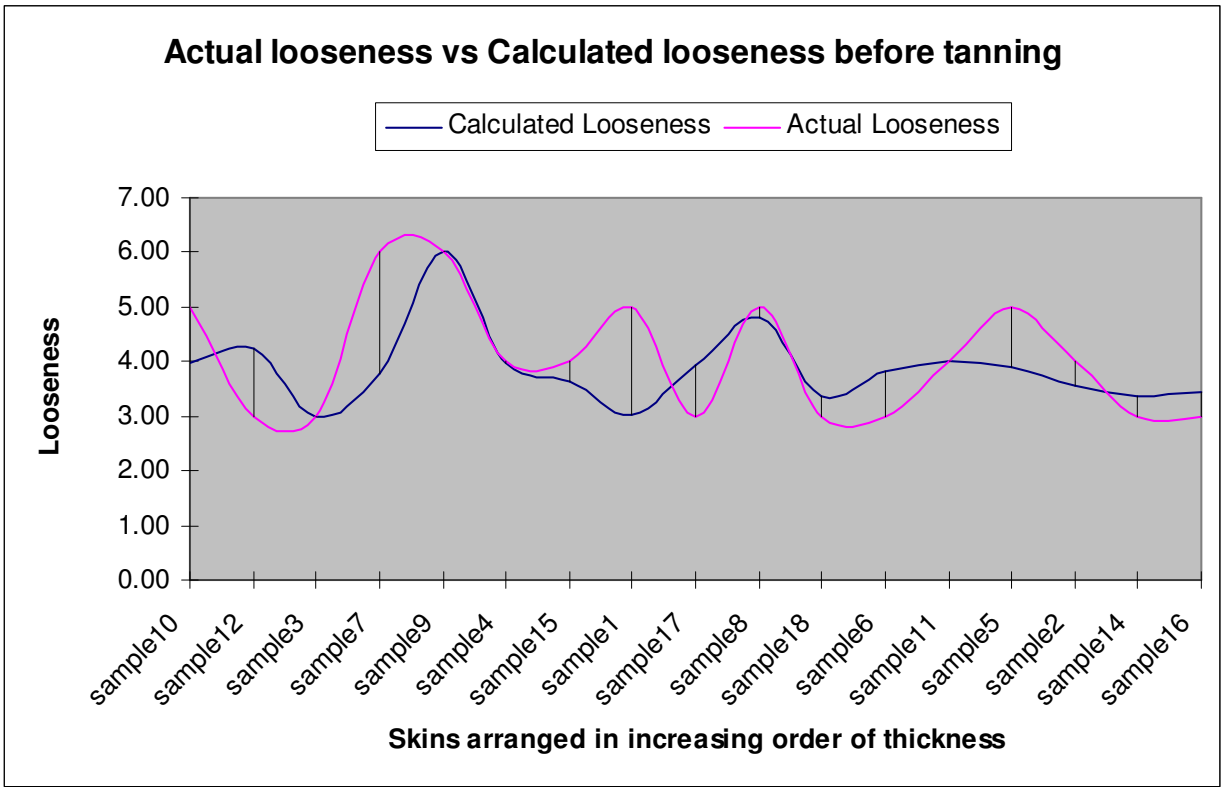


Figure 5.5.1: Comparison of actual looseness with calculated looseness with skin samples arranged in increasing order of thickness.

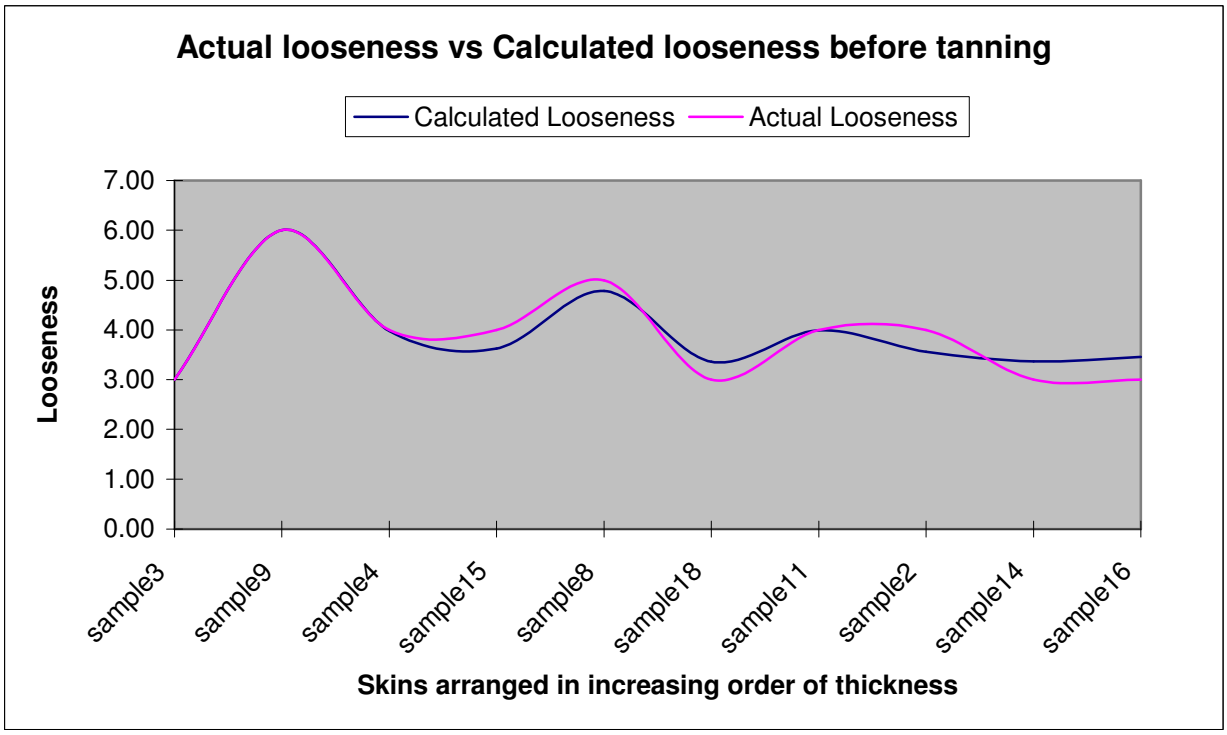


Figure 5.5.2: Comparison of actual looseness with calculated looseness with skin samples arranged in increasing order of thickness.

Looseness was calculated for samples using scaling factor calculated from the voltages recorded on samples after tanning process. Table 5.5.2 has the calculated looseness and scaling factor values for skins after tanning process. The difference between the actual looseness and calculated looseness is shown in the figure 5.5.3 and this could be due to the real number type values of calculated looseness. Some of the readings could also be influenced by air gaps introduced. By eliminating the samples that have a high variance between the calculated and actual looseness values a better correlation can be observed in the figure 5.5.4.

Table 5.5.2: Scaling factor and calculated looseness values for skins after tanning

Sample number	Actual Looseness	Scaling factor	calculated looseness
sample10	5	0.086505	5.740484
sample12	3	0.560554	4.318339
sample3	3	0.429066	4.712803
sample7	6	0.238754	5.283737
sample9	6	0.512111	4.463668
sample4	4	0.204152	5.387543
sample15	4	0.66782	3.99654
sample1	5	0.245675	5.262976
sample17	3	0.650519	4.048443
sample8	5	0.404844	4.785467
sample18	3	1	3
sample6	3	0	6
sample11	4	0.595156	4.214533
sample5	5	0.197232	5.408304
sample2	4	0.484429	4.546713
sample14	3	0.899654	3.301038
sample16	3	0.968858	3.093426

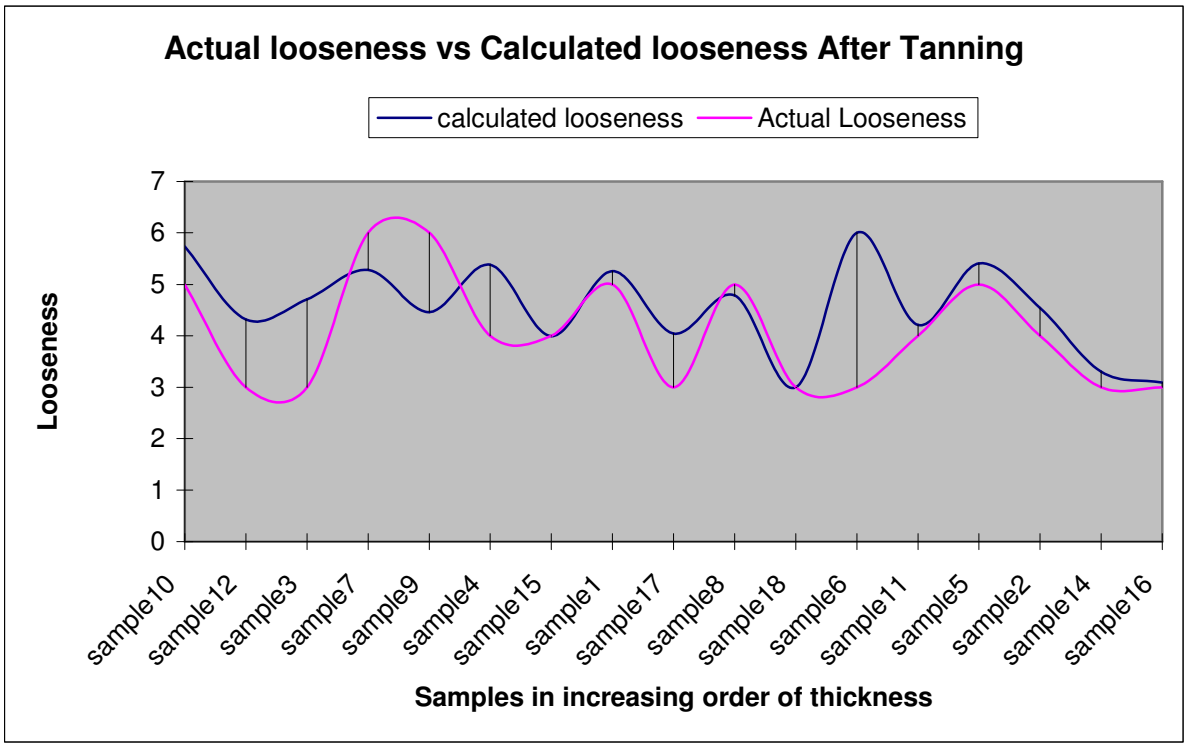


Figure 5.5.3: Comparison of actual looseness with calculated looseness with skin samples arranged in increasing order of thickness.

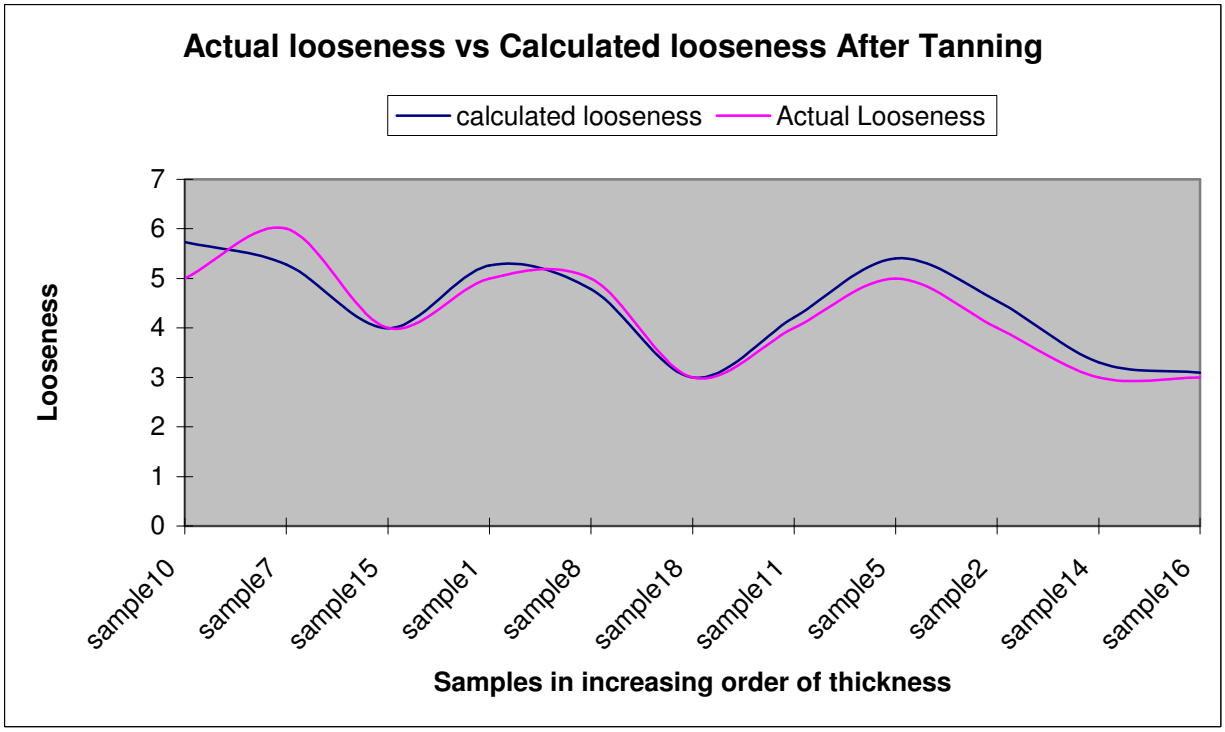


Figure 5.5.4: Comparison of actual looseness with calculated looseness with skin samples arranged in increasing order of thickness.

5.7. Conclusion

Voltages for samples before and after tanning process was measured and compared with looseness values provided by the expert from LASRA. It was observed at many instances that sensor voltage values followed the same trend as looseness values for various samples. Looseness was compared with sensor voltages values specifically for positions 4 and 5 individually and also average of both the positions as the looseness is determined usually by examining at these positions. A good correlation was observed between the voltage values and looseness in figures 5.2.7, 5.2.9, 5.2.11, 5.2.13 etc.

Then, the average voltage values of all positions of a skin was considered and compared with looseness values as looseness feature is spread throughout the skin. It could be observed from the figures 5.3.5 and 5.4.26 that the sensor voltage values follow the trend of looseness values. The effect of thickness of skin on voltage was studied where it was observed that voltage values increases along with increase in thickness. This helps us to understand the increase in voltage values for samples 14 and 16 when compared to sample 12 even though they had same looseness value.

As the objective of research was to identify the looseness in sheep skin, formula for calculating looseness in sheep skin has been developed. Calculated looseness values were compared with actual looseness values and they were quite proximate as shown in figures 5.5.1 and 5.5.2.

Based on the findings as stated above, we can calculate the looseness present in a sheep skin approximately before the tanning process. This set-up would be quite helpful as the looseness can be found only after tanning process as of now.

CHAPTER 6

DATA ACQUISITION SYSTEM

6.1 Introduction

For the experiments in this report the sensor voltage values were measured using an oscilloscope. It would be impractical to carry an oscilloscope to the farm yards or industries to measure the sensor voltage values. A C8051F020 microcontroller could be used to convert the voltage values into a digital display and in this section the performance of microcontroller is verified.

6.2 Data acquisition system

For the collection of voltage and current signals, an efficient data acquisition system is very important. The analog data is captured using an analog-to-digital converter. A Silicon Lab microcontroller C8051F020 was used as shown in figure 7.1. The microcontroller has two ADC's operating at 100 kHz and 500 kHz respectively. The microcontroller's ADC has a 12-bit resolution. The converted digital data is displayed on the LCD display of the expansion board.

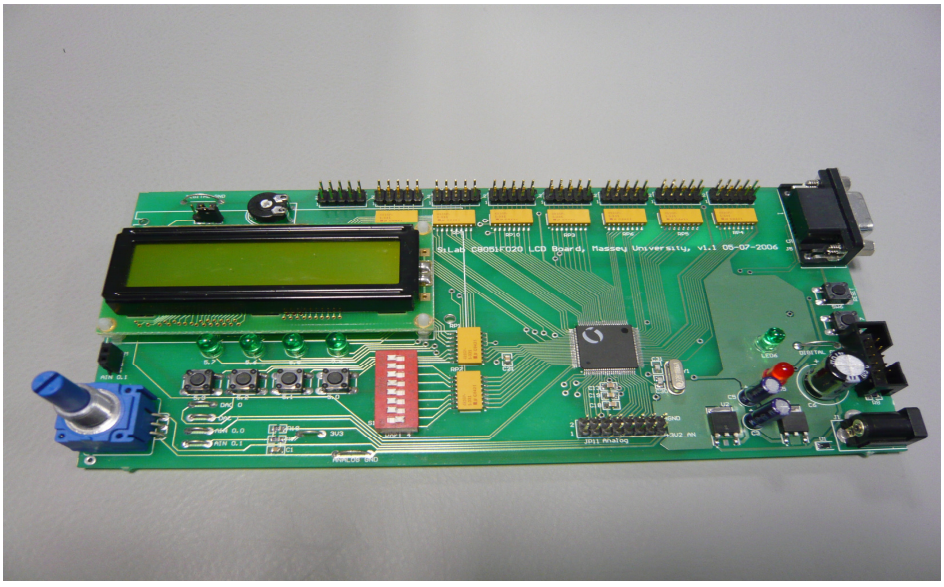


Figure 7.1: Microcontroller

The sheep skin is placed on top of the sensor and the sensor is glad wrapped to avoid the direct contact between the sensor and skin. The sensor output voltage which is a sinusoidal signal is sent to the signal rectification circuit as shown in figure 7.2 to convert it into a dc signal and then supplied to the microcontroller for ADC conversion to get a digital display.

The microcontroller potentiometer needs to be calibrated prior to the experiments so that the display values correspond to the change in voltages. If the potentiometer voltage is greater than supply voltage from rectifier circuit, changes in voltages for various samples will not be shown.

6.3 Experimental Results

17 samples of sheep skins were tested at 10 kHz and the ADC values were recorded for each skin. ADC values were then compared with looseness values and it was established that we could define an interval of ADC values for each looseness value as shown in table 6.1. For looseness value 6 ADC values are below 1700, skins having looseness value 5 have ADC values in between 1700 to 2200. For looseness value 4, ADC values are in between the range of 2800 to 2900. It was observed that skins having ADC values in the range of 2800 to 2900 had looseness values of both 3 and 4 and this could be due to the integer number type values of looseness. Samples that have looseness values 3 mostly had ADC values greater than 2900. Samples that have ADC values more than 3200 would have a looseness value of 2.

Table 6.1: Relationship between ADC values and Looseness values

ADC Values	Loosenss Value
< 1700	6
1700 - 2200	5
2200 - 2800	4
2800 - 2900	4 or 3
> 2900	3
> 3200	2

6.4 Conclusion

Data acquisition system is included into the testing system which helps the user to take note of the readings easily. An effective interval has been defined for each looseness value which helps us to determine the looseness of the skins depending on the ADC value displayed by each of the skin. Inclusion of SiLab C8051F020 microcontroller helps to reduce the cost of over all system to a great extent as well.

CHAPTER 7

CONCLUSIONS AND FUTURE WORK

7.1 Conclusions

Looseness in leather could be determined before tanning using planar interdigital sensor sensing system. The non-destructive testing techniques are applied in many fields and in this report this technique has been extended for measuring the looseness in sheep skin which is one of the key factors in determining the quality of finished leather. Applications of non-destructive testing in various fields have been discussed. Sensors, classification of sensors depending upon their fabrication, their end use and the factors that should be considered while selecting a sensor were explained in the chapter 1. Objective of the research and previous attempts to design the systems to determine the looseness in sheep skins are also discussed in chapter 1.

In chapter 2, structure of sheep skin and the difference between the ancient and current tanning methods has been explained. It was found that the looseness could be caused by various factors such as age, bacterial damage, storage or/and processing effects also looseness is predominant in some of the breeds as discussed in chapter 2. Each of the processing steps in early stages of modern or current tanning procedures can also result in looseness, so, a system that would help us to determine the looseness in sheep skins would be an advantage. So, the skins were brought to the lab for experiments before tanning process then returned to get converted in to finished leather. Various types of leather have also been explained in chapter 2.

Planar interdigital sensors were chosen to measure the looseness properties of sheep skin as they have been and are being employed in various fields as explained in the section 3.3 of chapter 3. The electric field generated by interdigital sensors interact with dielectric

properties of sheep skin to give a measure of looseness in the sheep skins. Interdigital sensors were chosen as they have been successfully employed in various fields and also they have only one side access and they could be designed as per the required use. Operating principle of interdigital sensors and sensing capabilities are explained in detail in chapter 3.

Four designs of interdigital sensors were designed and fabricated for this research experiments. Capacitance for each sensor was also calculated. It is also discussed in chapter 4 that sensor output voltage is dependent on the relative permittivity of the material. As the objective was to design a low cost sensing system the excitation signal was set at 10 kHz with amplitude of 10 V peak to peak sinusoidal wave signal. Four sensors responses were observed for different type of materials. The materials were cheese, butter and air. Response of the sensors was measured at frequencies in the range of 1 kHz to 10 kHz. It was observed that sensor 4 had a stronger signal compared to the other three sensors and also it had better electric field intensity, hence sensor 4 was selected to measure the looseness property in the skins.

Each skin was labelled into five zones and sensor voltage was distinctive for each zone of same skin. But as the looseness feature is spread all through the skin, an average of voltages of all positions of skin was compared with looseness. A good correlation was observed between the looseness values and sensor voltage values. Sensor voltage dropped and increased along with looseness values. It was also observed that some skins had same looseness values but different voltage values which was accounted for thickness, presence of fat or also human error.

Effect of thickness on sensor voltage was studied by measuring the average thickness of holes made in each of 5 zones of a skin. It was observed that sensor voltage increases along with increase in thickness of skin. Then the sensor voltage was plotted with looseness values for the samples that had same looseness values and a trend of increasing voltage was observed as the samples were also arranged in the increasing order of thickness. After the skins were converted in to finished leather experiments were repeated to verify the

repeatability of the sensors. Sensor voltages were measured at the same zones after the skins were tanned and the voltage values followed the same trend as voltage values before tanning process. Hence, the repeatability of sensors was confirmed. Formula for calculation of looseness was developed which was dependent on the scaling factor of skins. Calculated looseness values were compared with actual looseness values and both the values were quite proximate.

9.2. Recommendations and Future Work

More sensor designs have to be explored. Determination of looseness for specific zone by experts instead of whole skin will be helpful in designing a more accurate system. As of now thickness has to be determined by measuring the thickness manually, a system that could measure the thickness of skins in real time would be helpful. As the interdigital sensors were previously employed in determining fat content in other materials, skins could be tested for fat using different interdigital sensor structure. Human error could be avoided by marking the zones with permanent marker that would not be washed off while tanning procedure as it is required to measure the voltage at same position to check the repeatability of sensors.

Experiments were done in a controlled lab environment, from a commercial point of view care need to be taken as the moisture and temperature could have an effect on the sensor's measured voltage. Calibration of the sensor according to the moisture and temperature or defining the sensor characteristics for different combinations of moisture and temperature will also help in accurate readings.

In this research looseness in skins was determined before tanning process, the study of looseness characteristics at each step of tanning process will provide a further insight of the change in looseness or which processing step results in looseness the most and measures could be taken to alternate the process.

CHAPTER 8

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