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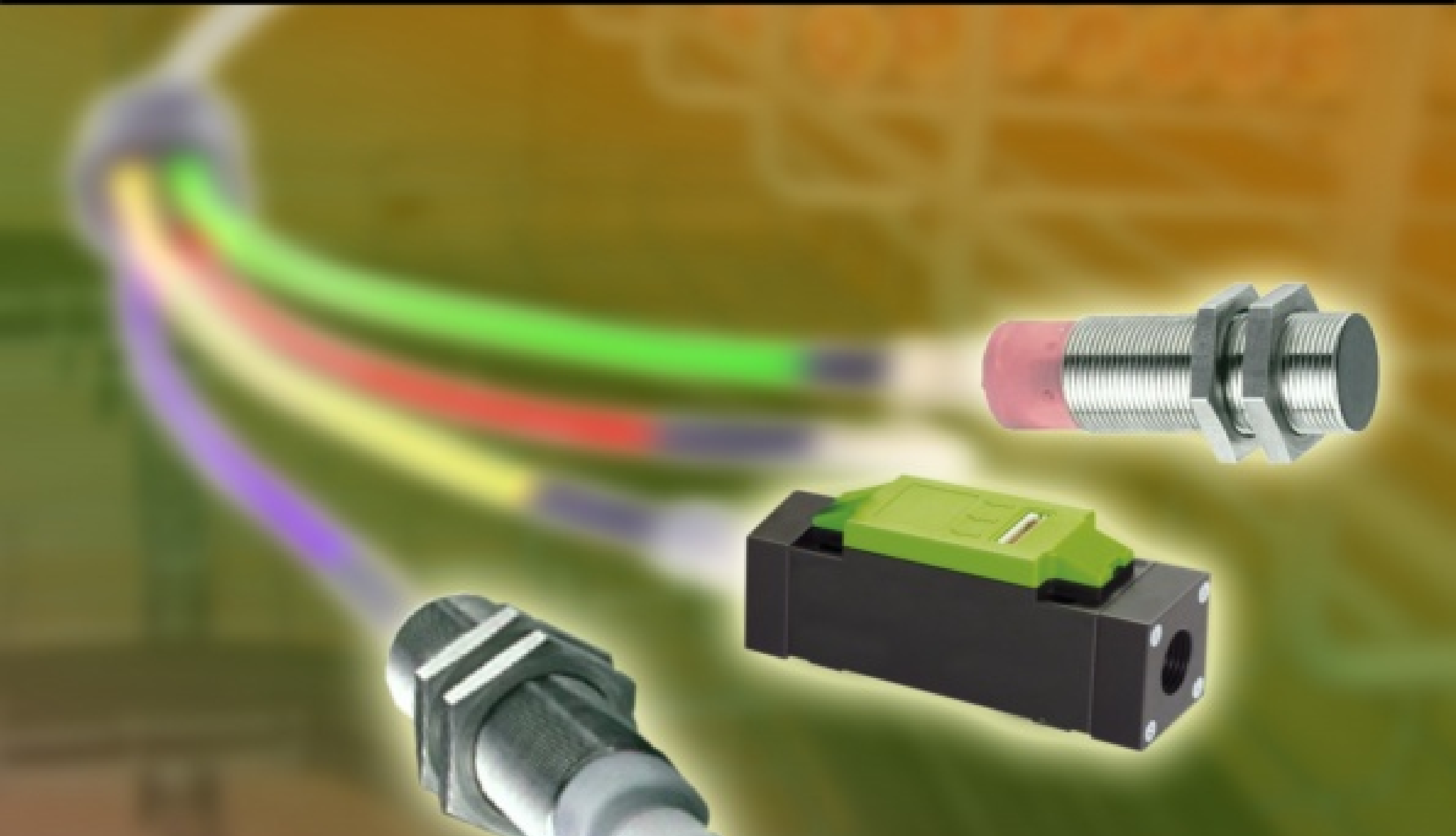

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A Novel Noninvasive Sensing Approach of Assessment of Pelt Quality

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Abstract: The separation of the upper dermal of the skin (the papillary layer or grain) from the lower dermis (corium) is regarded as a defect in leather making. It is difficult to detect pelts at an early processing stage and it only becomes really apparent once the skin is made into leather. There would be great advantages in detecting the problem at the pickled pelt stage (skins treated with sodium sulphide and lime, bated with enzymes, and then preserved in NaCl and sulphuric acid) so that adjustments to the processing could be made to mitigate the effect. A novel bio-sensor for inspection of leather in a non-invasive way has been fabricated and developed. The sensor has the planar Interdigital structure and the consecutive fingers are connected to positive and negative electrodes respectively. The experimental results show that the sensor has a great potential to estimate the leather quality in a non-invasive and non-destructive way. *Copyright © 2007 IFSA.*

Keywords: Pelt quality, Biosensor, Interdigital sensor

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1. Introduction

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. 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. The problem is usually most evident in the belly area but may extend over much of the skin. However, it is difficult to identify looseness at the early wet process stages in order to take corrective action as the extent of the problem is only really evident after tanning the skins. Therefore 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 method of identification of looseness in pickled pelts that can be used as a production control tool; for monitoring product quality where excessive structural material is being removed during processing. Lamb skins exhibit very significant degrees of biological variability according to breed, animal age, variations throughout the season and regional climatic conditions. An effective, non-destructive assessment test that could measure looseness in production would bring objective control into an area that, to date, has no means of efficiently controlling this key property.

There has been one reported previous attempt to develop a test for looseness in lamb pelts [1] in which a piece of pelt was clamped between two plates one of which was vibrated by an oscillator. The extent of the transmission of the vibration to the other plate was then taken as a measure of the continuity of the skin structure between them. That is, a loose skin would not transfer as much of the vibrational energy to the other plate as a tight skin. However, very poor correlations were recorded between the measurements of this apparatus on pickled pelt and the looseness eventually assessed in the crust leathers made from the pelts so the apparatus was discarded.

The approach described in this paper was to process New Zealand lamb skins under a variety of conditions that are known to generate looseness and to test them as pickled pelts and then to tan them to the crust leather stage to assess the degree of looseness. The values for looseness for individual skins were then correlated with the impedance measurements determined on the pickled pelts.

Inspection of leather (skin) before processing is very important in leather industry. The technique used so far is expensive and needs a lot of calibration. So there is an urgent imperative for a low cost and easy to use sensing system useful in the leather industry. In order to overcome this problem a planar Interdigital sensor has been used and compared for the relative performance. This paper describes the use of planar Interdigital sensor as a bio-sensor for non-contact and non-invasive way in determining the quality of leather. Three configurations of sensor have been used and the results obtained from each configuration were compared with the results from the chemical method. It was noticed that configurations #1 and #2 show an error, when compared with the result obtained from chemical method. However, the result obtained from configuration #3 was convincing and comparable with chemically obtained results. Furthermore configuration #3 was proposed as a microcontroller based low cost novel sensing system.

2. Skin Processing Methods

Two dozen fresh lamb skins from the same line of stock were collected at a meat plant. They were then fleshed and randomly divided into four groups of six skins each. Each group was then processed by a different process; comprising a standard process with three variants designed to increase the propensity to looseness in the pelts. In brief, the processes were:

1) Standard process

Skins were coated on the inner (flesh) surface with an alkaline solution of sodium sulphide which was allowed to penetrate and react with the skin for two hours after which time the wool could be readily pulled from the outer (grain) surface. The dewooled skins were then processed by agitation in a large vessel under alkaline conditions for 16 hours. This process is referred to as ‘liming’. The alkali was then washed out and the pH of the immersion solution was raised to eight for treatment with a pancreatic trypsin enzyme (0.05% Tanzyme, Tryptec Biochemicals Ltd.) for 75 minutes at 35°C. This process is known as ‘bating’. The enzyme was then washed out and the skins pickled in 20% (w/v) sodium chloride and 2% (w/v) sulphuric acid. All the percentage treatment rates were based on the weight of the skins when they were transferred to the processing vessels after removal of the wool.

2) Excess trypsin enzyme treatment (‘overbating’)
The process as above except that the application rate of trypsin enzyme was 0.2% rather than 0.05%. All other treatments were as for the standard process.

3) Prolonged holding after depilation
The process as for (1) except that the depilated skins were held for an additional 18 hours before being put in to alkaline processing. All other treatments were as for the standard process.

4) Excessive alkaline processing time (‘overliming’)
The depilated skins were processed under strongly alkaline conditions for 42 hours rather than the standard 16 hours. All other treatments were as for the standard process.

At the pickle stage all the skins were examined for evidence of looseness and a sample was cut from the hind area of the pelt adjacent to the backbone. The main part of the skin was then chrome tanned to ‘wet blue’ at which stage they were again examined for signs of looseness. Finally the skins were tanned to crust leather by a standard process using a retannage with a minimum of filling effect so that any propensity to looseness in the leathers would not be disguised. The tanned skins were mechanically softened (staked) using a Cartigliano through-feed staker to ensure that all areas of each skin were subjected to the same amount of mechanical action.

3. Planar Interdigital Sensors for Assessment of Pelt Quality

Interdigital sensor operates on the same principle in which a parallel plate capacitor operates [2-4]. The relationship between the parallel plate capacitor and an Interdigital sensor is shown in Figure 1. The flow of field lines is between the positive and negative electrodes. Depending on the location of consecutive positive and negative electrodes, the field lines can be as shown in Figure 1 for three different situations. The blue, red and green correspond to the low, medium and high pitch length respectively. The geometry affect the capacitance and the conductance between the two electrodes.The electrodes of an Interdigital sensor are coplanar[4]. Hence, the measured capacitance will have a very low signal-to-noise ratio. The intensity of the field lines can be increased by increasing the distance between the electrodes, number of electrodes and the size of the sensor. This increasing of electrodes has lead to the structure known as interdigital structure. The term “Interdigital” refers to a digit-like or finger-like periodic pattern of parallel in-plane electrodes, used to build up the capacitance associated with the electric fields that penetrate into a material sample.

(a) (b)

Fig. 1. An Interdigital sensor behaving as a parallel plate capacitor.

It can be seen in Figure 2 that one set of electrodes is made positive by connecting an AC voltage source while the other set of electrodes is made negative by connecting it to the ground. An electric field is formed between the positive and the ground electrodes.

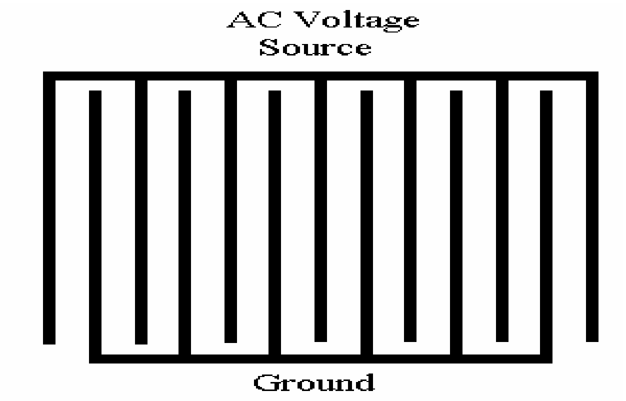

Fig. 2. Interdigital sensor structure, where one set of electrodes is made positive and other set of electrodes is made negative.

These planar Interdigital sensor has many applications in determining components in aqueous solutions [5], estimation of fat content in meat, estimation of fibre, moisture and titanium dioxide in paper pulp [6], complex permittivity characterization of materials [7] and gas detection [8].

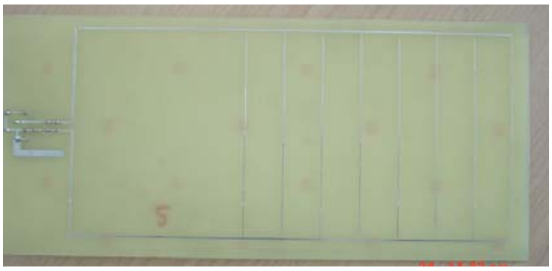

Fig. 3. Fabricated planar Interdigital sensor, configuration #1.

A total of six pieces of skin were subjected to various treatments and for each piece five samples were tested for non-invasive inspection of leather quality. The leather to be tested was placed on the sensor as shown in Figure 4 and the measurements were taken.

Fig. 4. Non-invasive inspection of leather (skin).

The experimental set-up used in the experiment is shown in Figure 5. The interdigital sensor was driven by a 10V sine wave using Agilent 33120A waveform generator. The Agilent 54622D mixed signal oscilloscope analyzed the input voltage, output current and the phase. The measurements were made at low frequency of 5 KHz.

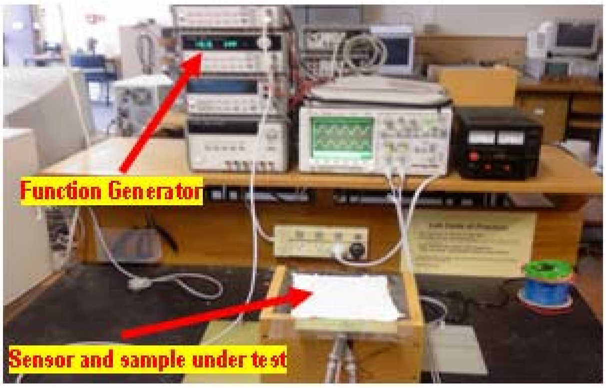

Fig. 5. The experimental set-up.

The results obtained using the planar interdigital sensor are shown in Figure 6 and Figure 7. When the results were compared with that obtained from chemical analysis, it was observed that the level of error was large. The reason of large error was considered to be the lack of penetration of electric field lines into the leather as well as the presence of field lines throughout the leather samples.

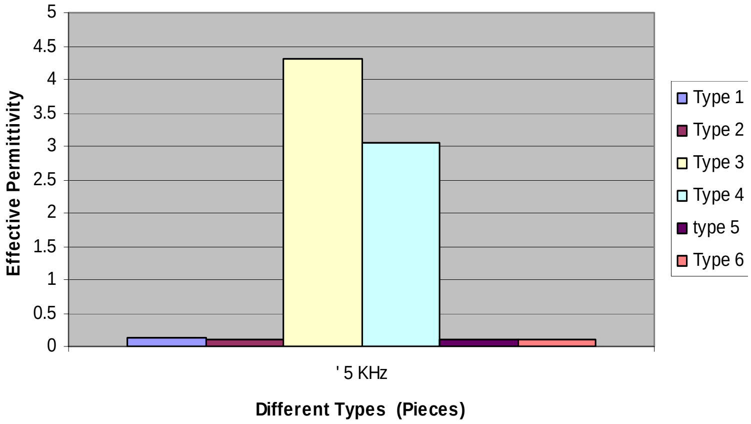

Fig. 6. The effective permittivity of different type (pieces) at 5 kHz.

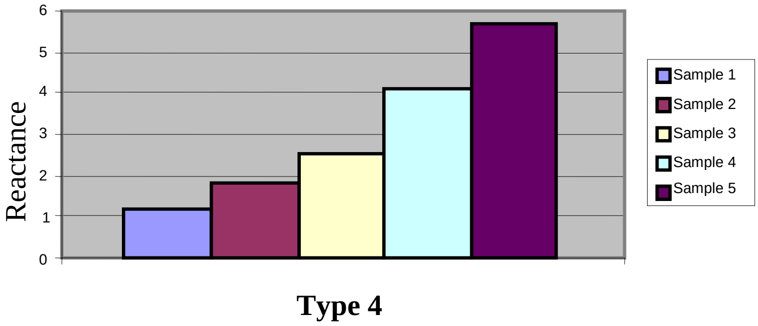

Fig. 7. The result on similar leather samples.

It was observed that sensor in Figure 3 does not penetrate well through the sample, so to have more volumetric penetration a new design of the sensor was used. Figure 8 shows the flow of field lines of sensor configuration #1, it was observed that the flow of intensity of field lines was more at the neighbouring electrodes. Therefore the field lines will not be able to penetrate well if the skin sample is thick and the result obtained are not accurate.

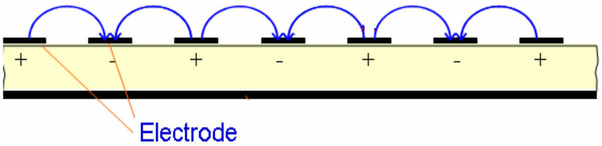

Fig. 8. Electric field distribution of sensor configuration #1.

The pitch of the sensor should be dependent on the thickness of the leather (skin) sample. The accuracy of the result using sensor in Figure 3 can be improved slightly by taking the measurements in different orientations. This could be very laborious. This led to the use of a new sensor structure. Figure 9 shows the second configuration of planar interdigital sensor. In this structure there is only one positive electrode at one side and a few negative electrodes at different distances. The varying depth of field lines helps to penetrate into the leather (skin).

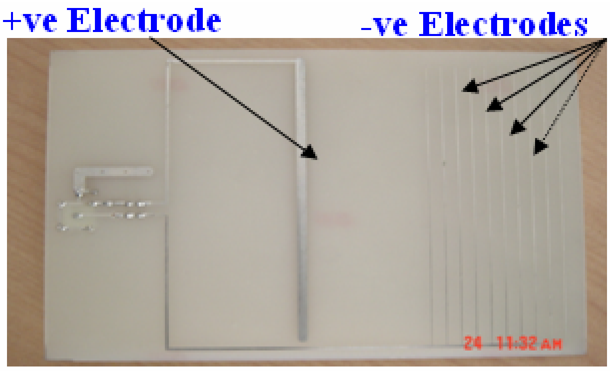

Fig. 9. Fabricated planar Interdigital sensor, configuration #2.

The result obtained corresponding to the second configuration of the planar Interdigital sensor is shown in Figures 10 and Figure 11. This sensor provides slightly improved results compared to configuration#1 but still the error is large compared to chemical testing.

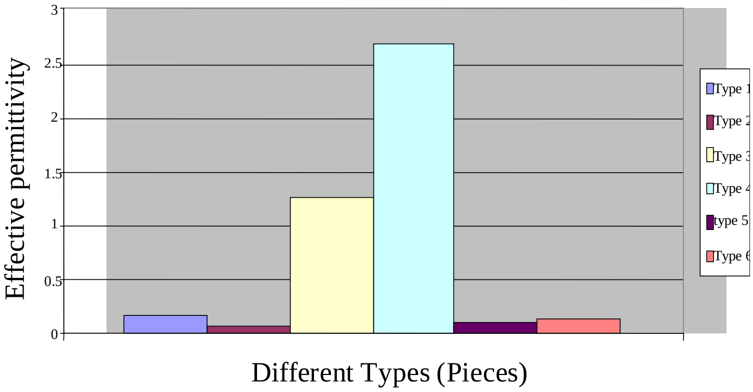

Fig. 10. The effective permittivity of different type (pieces) at 5 kHz.

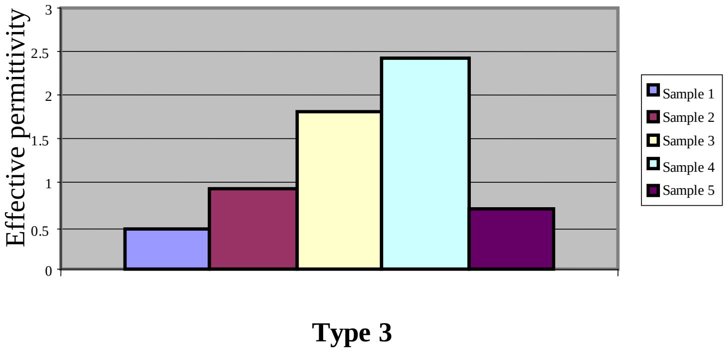

Fig. 11. The result on similar leather samples.

The flow of field lines for the sensor configuration #2 is shown in Figure 12. It is noted that the field lines penetrate well through the thick skin but the field lines do not cover through out the leather (skin) sample. This is due to more depth of the field lines as the pitch length increases the intensity of field lines gets weaken close to the negative electrodes. The ideal representation of the flow of field lines is shown more clearly in Figure 12.

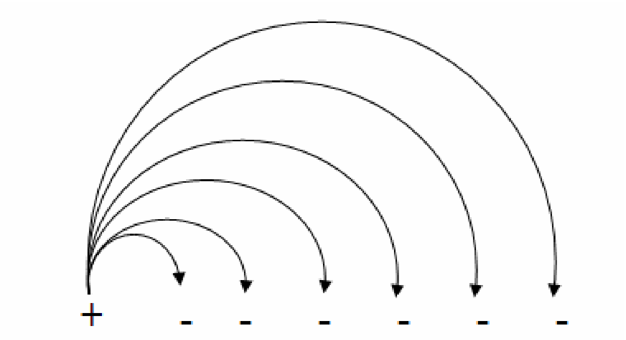

Fig. 12. Electric field distribution of the sensor configuration #2.

Figure 13 shows the novel configuration of planar interdigital sensor in which the positive electrodes exist intermittently and a few (six in this fabricated system) negative electrodes between two positive electrodes. This provides complete penetration of the leather (skin) sample under test and it also provides more uniform field distribution throughout the sample under test.

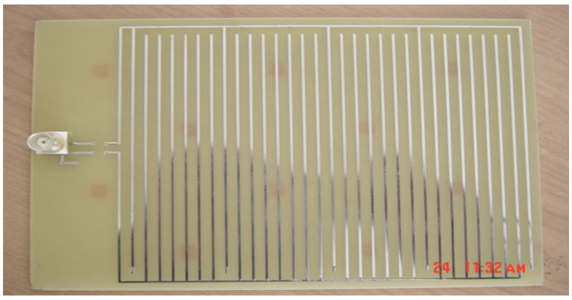

Fig. 13. Fabricated planar Interdigital sensor configuration #3.

The flow of field lines for the sensor configuration #3 is shown in Figure 14. It is noted that the field lines penetrate completely through the sample and the intensity of field lines is strong compared to other two configurations throughout the sensor.

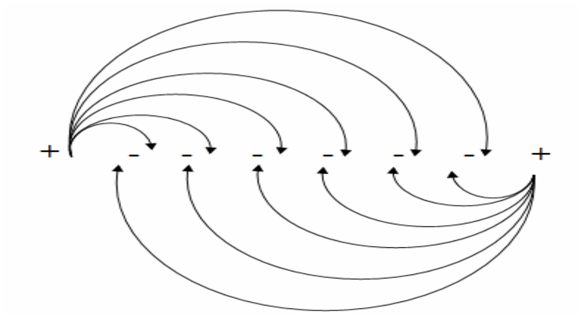

Fig. 14. Electric field distribution of the sensor configuration #3.

The result obtained using the planar interdigital sensor configuration #3 is shown in Figure 15 and Figure 16. It can be seen from Figure 15 that the effective permittivity of different samples at 5 KHz is quite distinctive from each other. Figure 16 shows the comparison of results of five similar samples of same type (piece) to check the consistency of results showing that the novel sensor configuration #3 gives very consistent results. These results show that the sensor is able to detect differences in skin subjected to different treatments, allowing the leather technician to make an informed decision about adjustment to optimize the process for achieving better quality perfection.

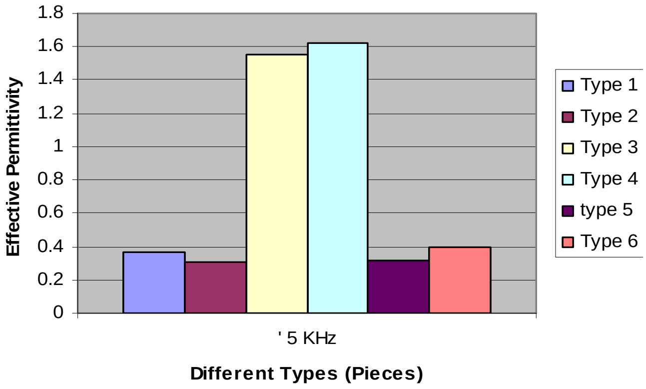

Fig. 15. The effective permittivity of different type (pieces) at 5 kHz.

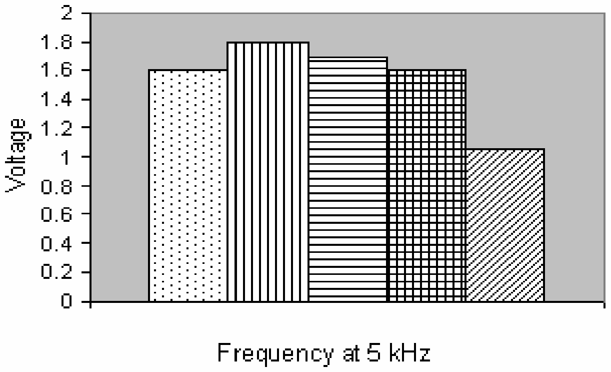

Fig. 16. The result on similar leather samples.

The Figure 17 shows the dimension details of the fabricated sensor. The aim was to develop a microcontroller based low cost sensing system as shown in Figure 18.

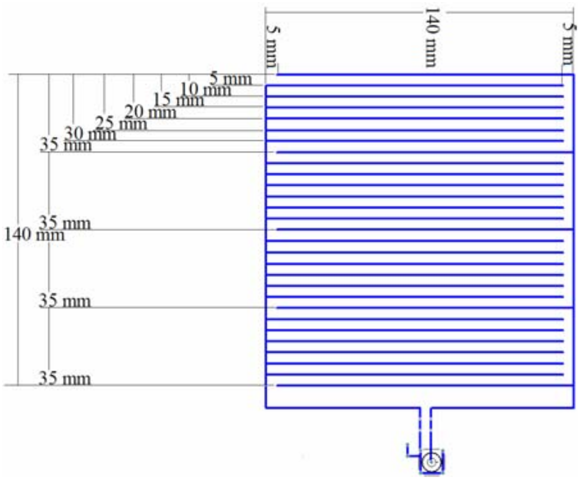

Fig. 17. Dimension details of configuration #3.

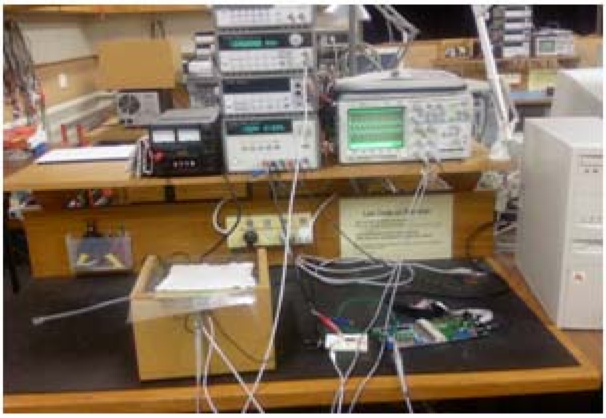

Fig. 18. Sensing and instrumentation system for a low cost sensing system.

The SiLab C8051F020 has two ADCs operating at 100 kHz and 500 kHz respectively. So an operating frequency of 5 KHz can be very well used with this system. The sensor output is fed into the non-inverting input through a capacitor and the voltage divider is used to offset the signal. The sensor output needs to have an offset since the 12-Bit Analog to Digital Converter (ADC) cannot process values less than zero. A LM324 Low Power Quad Operational Amplifier is used in the circuit. The sensor signal is amplified by a gain of around 4.3. VCC is set to 5V, and the Zener diode makes sure the signal into the ADC input in the microcontroller doesn’t exceed 3.3Volts. The analog signal from the sensor output is connected to the ADC pin in the microcontroller. The program stores the highest and the lowest peak of the signal, hence calculating the peak value. The value is outputted as a digital value. So as the response of the sensor changes with the type of material under test, the output digital value will change accordingly. The type of communication between the sensor and the computer can be wireless or wired but depending upon the factors such as factory environment, avoiding manual testing time and to establish sensor array a wireless communication was chosen. The wireless communication was established using nRF24E1-EVBOARD with an operating frequency of 2.4 GHz, using 10 bit ADC, the sampling rate of 100kSps and the bit rate of 1Mbps.

While experiments are conducted it is recommended that the temperature and humidity should be maintained constant. The sensor is responsive to these two environmental conditions and proper care should be taken to minimize these effects.

4. Modeling Using Finite Element Analysis

Modeling of all three types of Interdigital sensor was done using finite element analysis. The analysis was done to see the electric field distribution, variation of electric field strength with depth and with width of the sample and the sensitivity. Figures 19, 20 and 21 show the electric field distribution of three different configurations of sensors. From the field distribution the variation of electric field strength with permittivity values as well as depth of the sample under test has been calculated.

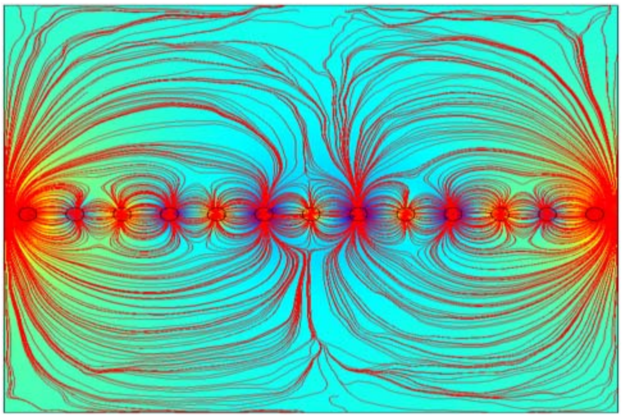

Fig. 19: The electric field distribution of the sensor configuration #1 (+ - + - + - + - + - + - +).

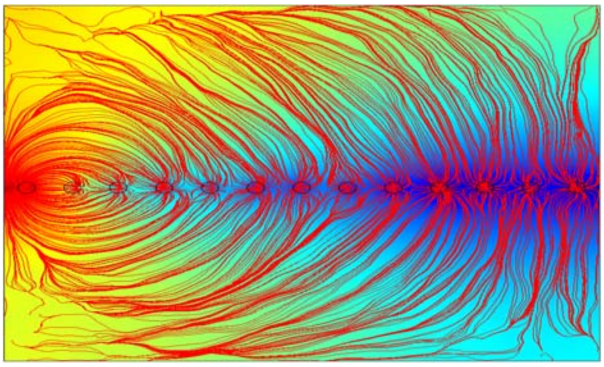

Fig. 20. The electric field distribution of the sensor configuration #2 (+ - - - - - - - - - - - -).

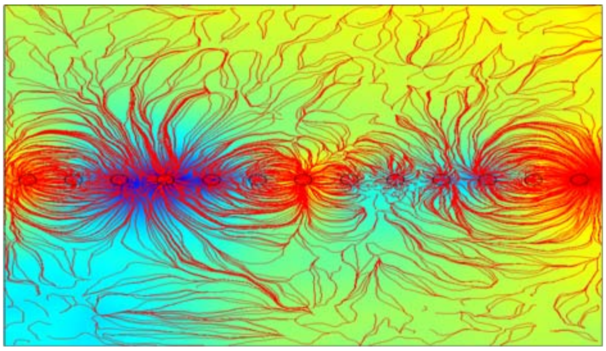

Fig. 21. The electric field distribution of the sensor configuration #3 (+ - - - - - + - - - - - +).

Figure 22 shows the variation of electric field along the length of the sensor for a depth of half of the pitch length. It is seen that the magnitude of the electric field intensity is maximum for the sensor configuration #3. Figure 23 shows variation of electric field intensity along the length of the sensor for a depth of 5 times of the pitch length. It is seen that if the material under test is thick, maintaining the uniformity of field intensity is required which is achieved by the sensor configuration #3.

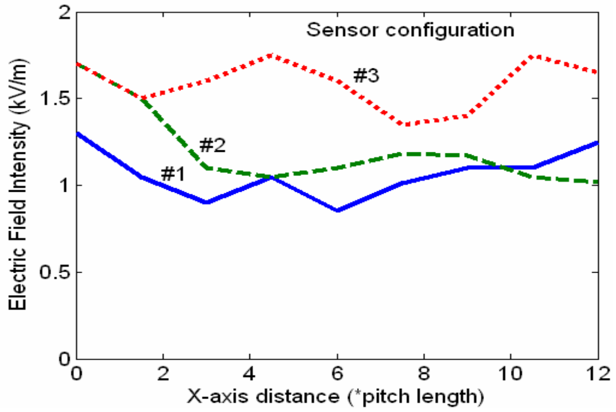

Fig. 22. Variation of electric field intensity with respect to the depth of half of the pitch length.

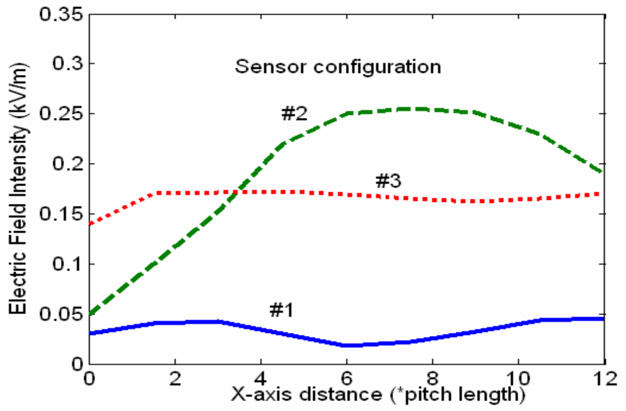

Fig. 23. Variation of electric field intensity with respect to the depth of 5 times of the pitch length.

Figures 24 and 25 show the variation of electric field intensity as a function of depth of the sensor and dielectric permittivity of the material under test, it is seen that the sensor configuration #3 provides the best result.

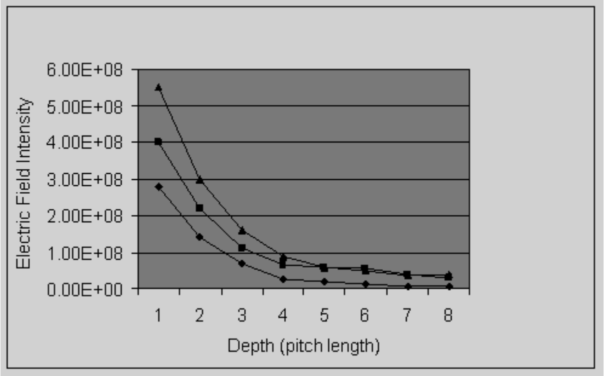

Fig. 24. Variation of electric field intensity with respect to the depth of the sensor.

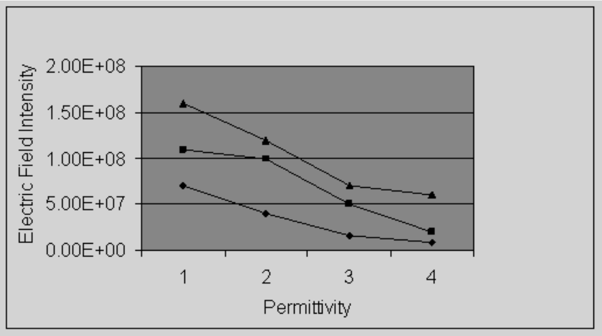

Fig. 25. Variation of electric field intensity with respect to dielectric permittivity.

5. Results and Analysis

Six pieces of skin were tested for non-invasive inspection of leather quality. All six pieces were treated with different chemicals but later on these pieces were washed in brine to remove some of the acid and then neutralised to some extent with sodium formate before being exhaustively washed with water. They were all processed together at this stage so any differences should not be due to the post-pickle treatments. The impedance of the sensor was measured with and without skin samples. The resistive part on impedance did not show much variation but the capacitive reactance proved to be very sensitive towards the various treated pelt samples. The effective permittivity of leather under test is calculated in the following way:

$$X_{air} = Z_{air} \times \sin(\phi_{air}), \tag{1}$$

where Z_{air} and ϕ_{air} are the impedance magnitude and phase of the sensors in air.

$$X_{skin} = Z_{skin} \times \sin(\phi_{skin}), \tag{2}$$

where Z_{skin} and ϕ_{skin} are the impedance magnitude and phase of the sensors with skin under test.
The effective permittivity of the sample is calculated as

$$\varepsilon_{eff} = \frac{X_{air}}{X_{skin}}. \tag{3}$$

Figure 26 shows that for these sensors reactive impedance decreases with frequency and this provides an opportunity to develop a low cost sensing system at low frequency of operation. All results are shown corresponding to one frequency of operation of 5 KHz. To obtain better results the other two sensors configurations have been used. In comparison the chemical results are assumed to be 100% accurate which is derived by destructive method. The accurate results of chemical test are achieved at the cost of time and money. During experiments, it was observed that the temperature had a strong effect on the results. This is related to the moisture content in the sample. Therefore the temperature should be maintained constant during the experiment for obtaining accurate results.

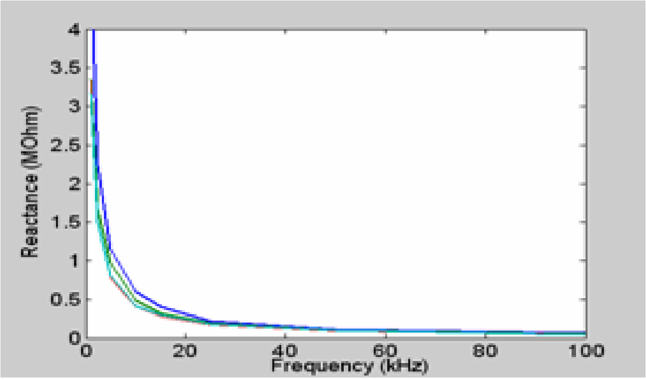

Fig. 26. Variation of Reactive Impedance with frequency.

6. Assessments of Looseness

Evaluation of looseness of the skins at the pickled pelt and wet blue stages involved a subjective evaluation of the fineness of the creases caused by manually pulling and folding the skins.

Evaluation of looseness in the crust leather entailed comparing the appearance of the creases in the upper (grain) layer resulting from bending the leather upwards to an angle of about 45° with the creases in a series of eight standard leathers of increasing looseness. Skins with little or no creasing were graded 1 while those that gave large, coarse creases in the grain layer were designated a grade of 8. Each leather was evaluated at five different locations and the mean value for each skin determined.

Statistical comparisons were made using Student's t-test.

6.1. Effect of Processing Treatments on Looseness of Leather

Figure 27 shows the mean and standard deviation of the looseness scores for the six pelts in each group after they had been tanned to crust leather by a standard process. By comparison with the control group the over bated and extended liming groups were not significantly looser but holding as slats caused significantly ($p<0.05$) increased looseness.

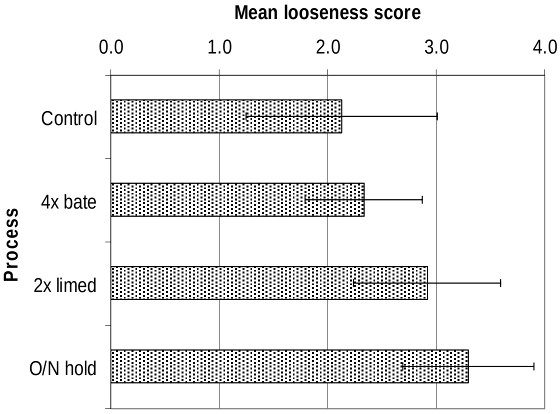

Fig. 27. Mean (± SD) looseness scores of leathers from different processes.

6.2. Effect of Processing Treatments on Impedance Measurements on Pickled Pelts

Figure 28 illustrates the effect of the different processing treatments on the impedance measurements made on four of the pickled pelts from each group of six skins. There was no significant difference between the impedance in the control skins and those given additional bating but highly significant differences ($p < 0.05$ and $p < 0.01$ respectively) between the control and the skins after over liming and protracted holding as slats.

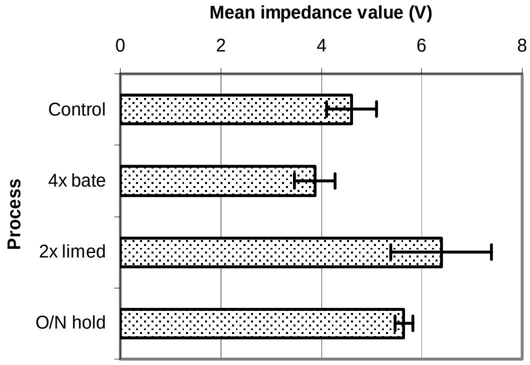

Fig. 28. Mean (±SD) impedance values for pickled pelts from various processes.

6.3. Relationship Between Impedance and Looseness Measurements

Figure 29 shows then relationship between the impedance measured on a pickled skin sample and the mean looseness score of the leather derived from that pickle. There is a significant correlation between these two sets of values ($R^2 = 0.486$, $p > 0.01$ for 14 d.f.).

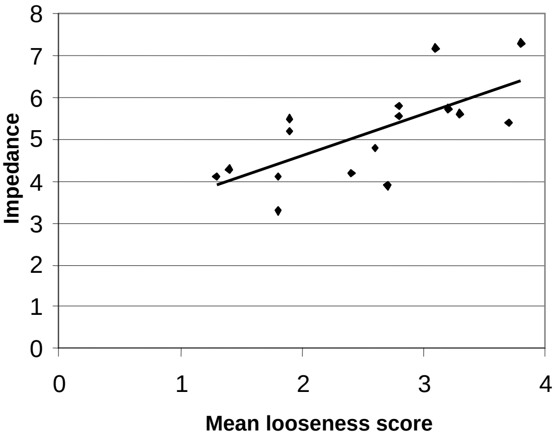

Fig. 29. Correlation between skin impedance and leather looseness for individual skins.

7. Conclusions

On the basis of these results impedance measurements on pickled pelts would have some predictive capability for the occurrence of and severity of looseness in the final leather. Planar Interdigital type electromagnetic sensor is used for the inspection of leather quality in a non – contact and non–invasive way. The sensor responds quite well to different types (pieces) of leather (skin) as well as different samples of the same type, though the error was quite large when using sensor configuration #1 but slightly the error was improved when sensor configuration #2 was used. A new sensor, configuration

#3 was able to give more accurate results compared to those obtained from configuration #1 and #2. The planar electromagnetic type sensor has the potential to be used as a biosensor for inspection of dielectric materials. The reported results show that there is a possibility of developing a low cost sensing system for industry. This planar sensor has big advantage and that it does not need any power to operate.

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Guide for Contributors

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- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
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- Nanosensors;
- Microsystems;
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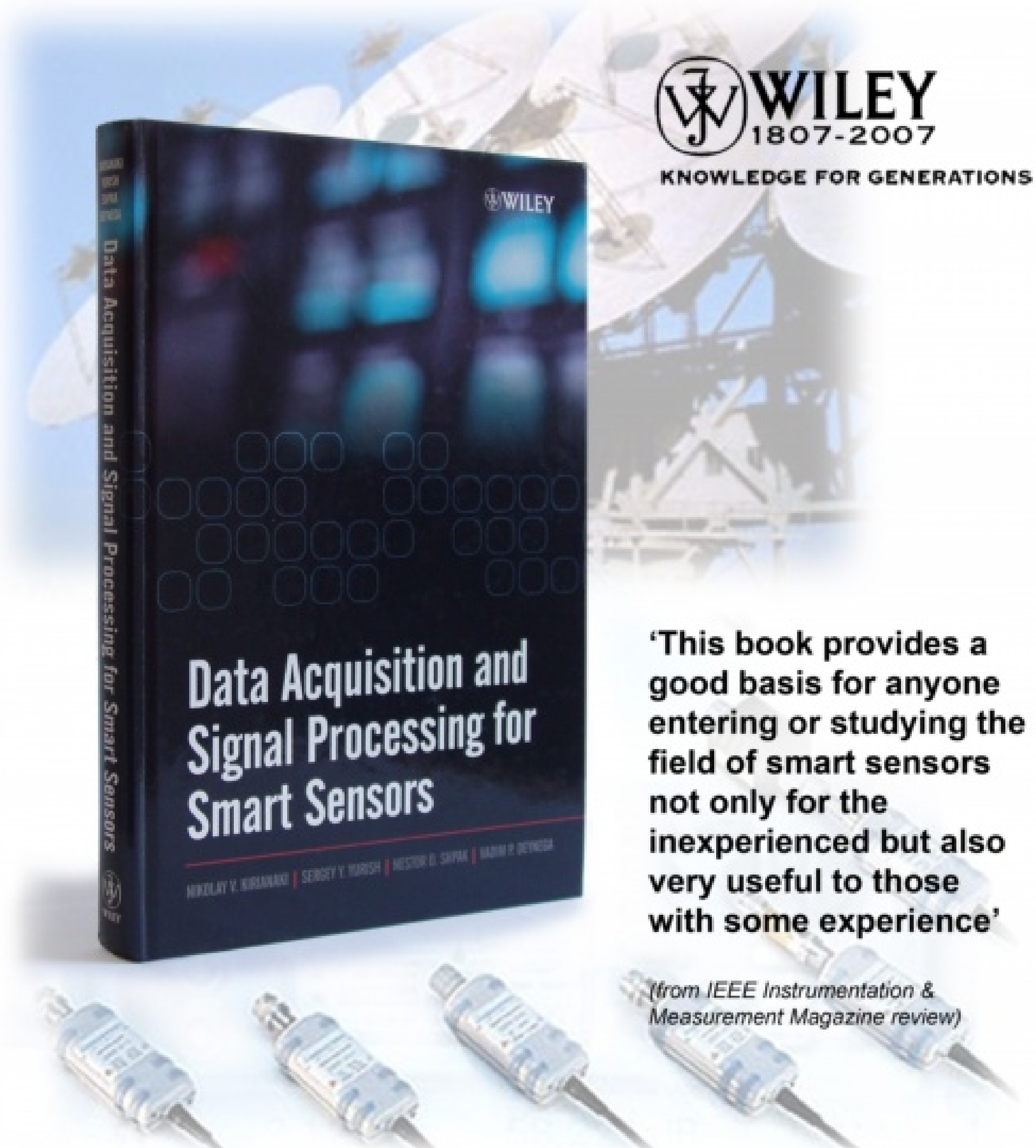
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