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A NOVEL PLANAR ELECTROMAGNETIC TYPE BIO-SENSOR FOR NONCONTACT AND NONINVASIVE ESTIMATION OF FAT CONTENT IN PORK MEAT

S.C.Mukhopadhyay, *SMIEEE*, C. P. Gooneratne and S. Yamada, *MIEEE*

Abstract— **Planar electromagnetic sensors are able to detect the presence of cracks, discontinuities, mechanical fatigue and many other imperfections without material damage. Planar electromagnetic of interdigital configuration bio-sensor has been fabricated and developed for noncontact and noninvasive estimation of fat content of pork meat. The experimental results are reported.**

Index Terms— **Planar electromagnetic sensors, Meander, Mesh and Interdigital type, bio-sensor, Noninvasive estimation, fat content, pork meat.**

I. Introduction

A lot of researches on food inspection have been reported in technical literature [1 - 4]. The reported systems are quite expensive, needs a lot of calibration and many precautionary measures. There is still a need to develop a low cost and easy to use sensing system for the meat industry. The authors are involved with research works employing planar type sensors for last few years and are successful of developing a complete inspection system of the printed circuit board (pcb) of Pentium processor [5]. The exciting coil is of meander configuration whereas the sensing coil is either of mesh type or figure-of-eight type configurations. The planar type sensors have also been used for the inspection of material defects such as the existence of inner layer cracks and for the estimation of fatigue of metal products [6, 7]. A crack with alignment in parallel with the exciting meander coil is difficult to be detected by meander configuration. The alternative is to employ mesh type sensor. The response of both the meander and mesh type planar electromagnetic sensors to dielectric materials is moderate. In order to increase the sensitivity of the sensor system another type of sensor, the interdigital has been fabricated and developed and comparison of their relative performance have been carried out [8]. This paper has reported use of planar interdigital sensor as a bio-sensor for noncontact and noninvasive estimation of fat content in pork meat. A low cost novel sensing system based on microcontroller is proposed.

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II. Sensor and experimental procedure

In practice the bellies are cut into particular sizes and the possibility of testing them by doing experiments only once are preferred as shown in figure 1. Usually each belly is cut into an approximate size of 120 mm X 120 mm with a thickness of 20-30 mm and weighs around 1.1 kg to 1.3 kg. The interdigital sensors used for experimentation has one sided access to the meat under test (MUT). Electric field lines pass through the MUT, and the capacitance between the two electrodes, depend on the material dielectric properties as well as on the electrode and material geometry is measured. The proximity depth of electric field lines depend on the distance between two electrodes of opposite polarity. In order to have adequate penetration of electric field lines into the meat sample under test the distance between the electrodes must be more than the double of the thickness of the sample. Six pieces of bellies named as A1, B1, C1, A2, B2 and C2 with varying fat content are obtained from meat industry with known percentage of fat content. The meat samples are tested with reference to figure 2 and with the following arrangements.

Orientation 1 = [skin side up, label at front] – as shown above.
Orientation 2 = [skin side up, label at back] – Rotate 180°.
Orientation 3 = [skin side down, label at front but underneath] – Flip over.
Orientation 4 = [skin side down, label at back underneath] - Rotate 180^o.

Figure 1. The interdigital sensor and pork belly cuts

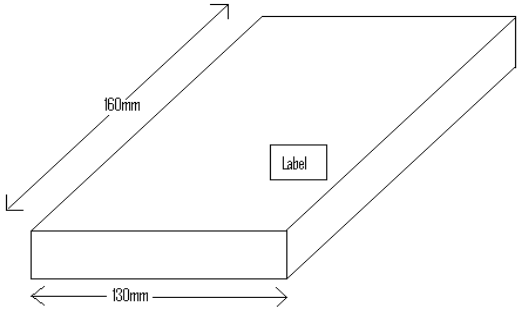

Figure 2. Pork belly sample dimensions

The interdigital sensors were driven by a 10V Sine wave. The measurements were made at frequencies in the range from 5 kHz to 1 MHz. The sensors were rested on a table with an insulating mat underneath, with the electrodes facing up. Each of the six pieces of pork was tested for all four orientations at the same frequency range mentioned above. The driving signal for the sensors were provided by the Agilent 33120A waveform generator and the Agilent 54622D mixed signal oscilloscope, analyzed the input voltage, output current and the phase. All efforts were done to make sure the pork pieces were all tested at similar temperatures, varying between 16-18°C.

III. Experimental results and analysis

Since different pork samples may have different effective permittivity, the imaginary component of impedance will be mainly affected. The figure 3 shows the variation of the reactive part of impedance as a function of frequency, for orientation 1, for all six samples. It is seen that there is a distinct difference in the magnitude of reactive impedance in the frequency range 5 kHz to 40 kHz. The difference in magnitude between samples decreases with increasing frequency. Even though the results are quite distinct for all six samples, the results obtained for orientation 1 and 2 differ from orientations 3 and 4. This is due to the fact that the response of the sensors depends on its penetration depth. If the thickness of the pork belly exceeds the penetration depth of the electric field lines, the sensors may not be able to respond to fat if the fat lies on the top surface of the meat sample. The impedance of the sensors provides an average indication of the fat, to the depth of penetration and the part of the meat within the electric field. The pitch and length of the sensor should be critically selected to derive optimum result.

In practice, measurement for one frequency or at only a few frequencies is required. The bar graph in figure 4 shows the reactive impedance values of different samples for orientation 1, at an operating frequency of 5 kHz. It can be seen that the impedance values are quite distinct from each other. Sample A1 has got the highest impedance and sample A2 has the lowest impedance.

The fat content is estimated by mathematical analysis and compareded to the results obtained by the chemical analysis. The magnitude and phase of the impedance of the sensor without meat samples (air) and with meat under test (MUT) are measured.

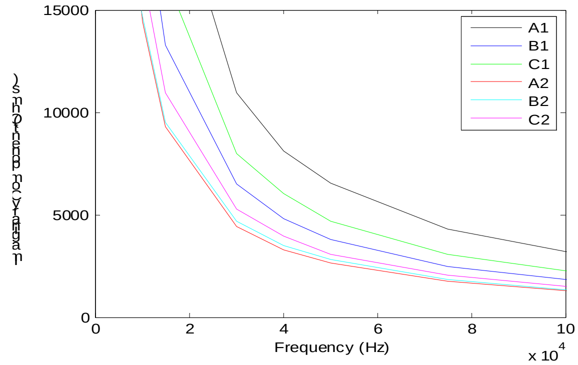

Figure 3. Sensor 1 characteristics for orientation 1

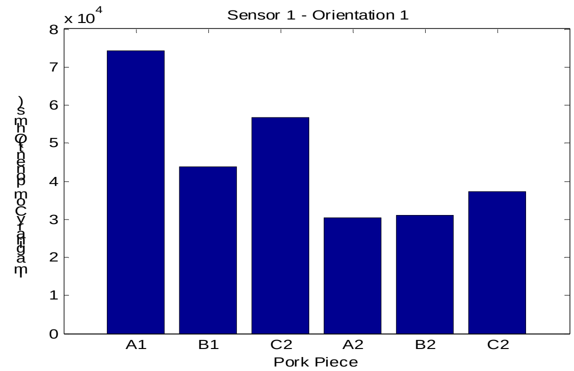

Figure 4. Sensor 1 characteristics at 5 kHz for orientation 1

The reactance impedances are calculated as follows

$$X_{air} = Z_{air} \times \sin(\phi_{air}) \qquad [1]$$

where Z_{air} and ϕ_{air} are the impedance magnitude and phase of the sensors without meat.

$$X_{MUT} = Z_{MUT} \times \sin(\phi_{MUT}) \qquad [2]$$

where Z_{MUT} and ϕ_{MUT} are the impedance magnitude and phase of the sensors with pork belly under test.

The effective permittivity of the sample is calculated as

$$\varepsilon_{eff} = \frac{X_{air}}{X_{MUT}}; \qquad [3]$$

The inverse of the effective permittivity is taken as the parameter of index, κ , and is used for the analysis to determine the fat and protein content. For the calculation of fat the following equation is used

$$\text{Fat}_{cal} = 48.1 \times (\kappa - 0.15) + 18.1 \qquad [4]$$

and for the calculation of protein the following equation is used

$$\text{Protein}_{cal} = 16.5 - 16.1 \times (\kappa - 0.15) \qquad [5]$$

Based on the above relationship the fat and protein content has been estimated and the results are shown in table 1. Figure 5 shows the comparison of the results obtained using the sensor with that obtained from chemical results. The maximum error is less than 4%. It shows a very good comparison as there is no statistical fit has been used to estimate the fat content. In practice some more results are required for calibration to obtain more accurate results.

Table 1: Calculated fat and protein content

Sample	Index parameter	Calculated Fat Content (%)	Calculated Protein content (%)
A1	0.3987	30.06	12.49
A2	0.1633	18.74	16.28
B1	0.2353	22.20	15.12
B2	0.1644	18.80	16.26
C1	0.3053	25.57	13.99
C2	0.2005	20.53	20.53

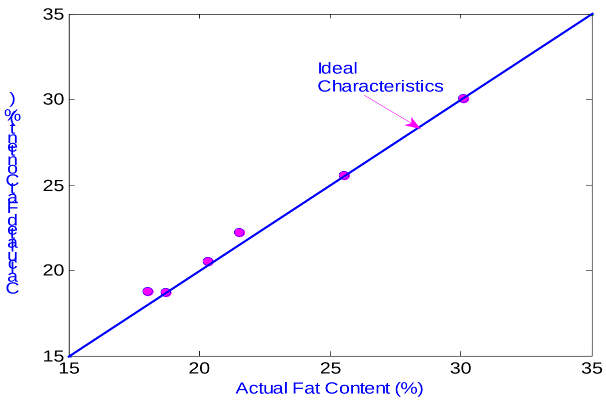

Figure 5: Comparison of actual and calculated results

IV. Effect of temperature

Temperature is an important factor to consider when experimenting with food materials. The impedance of a pork sample was measured for a range of temperatures as shown in figure 6. The experiment was run for nearly four hours, in which time the temperature of the pork sample changed from 2°C to around 12°C. It can be seen from figure that the impedance decreases with increasing temperature. All other samples were kept in a cooler and all samples that were experimented on were immediately put into the cooler after. However if experiments were conducted in a warm or hot environment the temperature will play a significant part in the results obtained. So it is advisable that the temperature must be maintained constant during experiment.

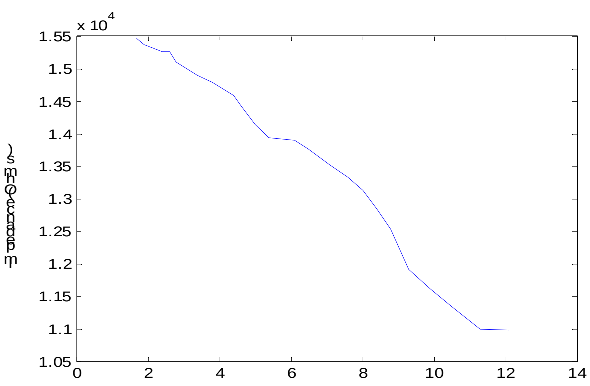

Figure 6: Effect of temperature on impedance of sensor

V. A low cost sensing system

Figure 7 shows the microcontroller based low cost sensing system under development. This will be very useful for a rough estimation of each and every sample of meat before they are send to market. The total time of estimation will take less than 1 minute. It is planned to have a wireless transmitter system to be included in the microcontroller to have communication with the central computer in the premises.

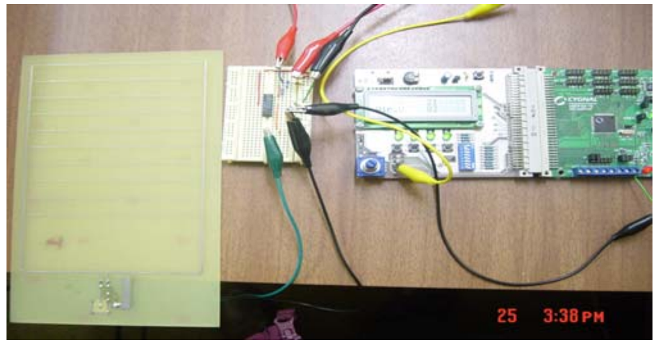

Figure 7: Microcontroller based low cost sensing system

VI. Conclusions

A planar electromagnetic type biosensor of planar interdigital configuration has been fabricated and developed for noncontact and noninvasive estimation of fat content of pork meat. The reported results show there is a possibility of developing a low cost sensing system for industry. The sensors can also find many other potential applications.

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