



Laporan Akhir Projek Penyelidikan Jangka Pendek

**Characterization of Raw Ripe Fruits using
Electrical, Optical, Thermal and Ultrasonic
Techniques**

By

**Dr. Mahfoozur Rehman
Dr. Mohd Rizal Arshad**

2010



FINAL REPORT
FUNDAMENTAL RESEARCH GRANT SCHEME (FRGS)
Laporan Akhir Skim Geran Penyelidikan Asas (FRGS) IPT
Pindaan 1/2009

A RESEARCH TITLE :Characterization of Raw Ripe fruits using Electrical,Optical,Thermal and Ultrasonic Techniques
Tajuk Penyelidikan

PROJECT LEADER : Dr. Mahfoozur Rehman
Ketua Projek

PROJECT MEMBERS : 1. Dr. Mohd Rizal Arshad
 (including GRA) 2.
Ahli Projek



PROJECT ACHIEVEMENT (Prestasi Projek)

B ACHIEVEMENT PERCENTAGE			
Project progress according to milestones achieved up to this period	0 - 50%	51 - 75%	76 - 100%
Percentage			x
RESEARCH FINDINGS			
Number of articles/ manuscripts/ books	Indexed Journal	Non-Indexed Journal	
	TWO		
Paper presentations	International	National	
	TWO		
Others (Please specify)	Two papers are under review		
HUMAN CAPITAL DEVELOPMENT			
Human Capital	Number		Others (Please specify): PhD Viva passed with minor corrections(31st March2010)
	On-going	Graduated	
PhD Student	one		
Masters Student			
Undergraduate Students		one	
Temporary Research Officer			
Temporary Research Assistant		one	
Total	TWO only		

EXPENDITURE (Perbelanjaan)

C	Budget Approved (Peruntukan diluluskan)	: RM 90,000.00
	Amount Spent (Jumlah Perbelanjaan)	: <u>RM 90828.84</u>
	Balance (Baki)	: <u>RM -828.84</u>
	Percentage of Amount Spent (Peratusan Belanja)	: -0.92 %

ADDITIONAL RESEARCH ACTIVITIES THAT CONTRIBUTE TOWARDS DEVELOPING SOFT AND HARD SKILLS
 (Aktiviti Penyelidikan Sampingan yang menyumbang kepada pembangunan kemahiran insaniah)
D

International		
Activity	Date (Month, Year)	Organizer
(e.g : Course/ Seminar/ Symposium/ Conference/ Workshop/ Site Visit)	1.MTECS-2008,8and 9th March2008	1.Deprtment of Electronics Engineering Z.H.College of Eng.& Tech.,Aligarh Muslim University,Aligarh. INDIA
	2.Agriculture Congress2009, 27-29 Oct.2009	2.University Putra Malaysia,KL,Malaysia,Palace of Golden Horses,Seri Kembangan,Selangor,Malaysia
	3. International Conference on Robotics,Vision,Signal Processing andPowerApplications,Dec., 19-20,2009 Awana Porto Malai,Langkawi,Malaysia	3. School of Electric and Electronic Engineering,USM
National		
Activity	Date (Month, Year)	Organizer
(e.g : Course/ Seminar/ Symposium/ Conference/ Workshop/ Site Visit)		

PROBLEMS / CONSTRAINTS IF ANY (Masalah/ Kekangan sekiranya ada)

- E**
1. Funds were not sufficient to have more than one research assistant. Hence only one student worked on the project who did major work on Impedance spectrometry and developed it for the assessment of quality of fruits successfully.
 2. For ultrasonic and optical techniques we could not get good equipments and results with the low cost components and equipments are not satisfactory.
 3. Thermal techniques were used to differentiate between raw and ripe mangos. However with the proto type model non-destructive testing could not give repititve results. Hence finally this technique was also been dropped from assessing the quality of fruit.
 4. It was difficult to get students in this field because it is a multi-disciplinary project. When projects were floated for post graduate and under graduate students very few students showed their interest in their implementation.

RECOMMENDATION (Cadangan Penambahbaikan)

- F
1. Equipment based on impedance spectrometry may be used for the assessment of quality of fruit satisfactorily. Our analysis is based on experimentations done at 1 kHz frequency. It may be tried at other lower frequencies also.
 2. It may help in the quality assessment of those mangos whose colour does not change whether ripe or unripe.
 3. Fruits can be stored only when these are plucked at a particular stage. If plucked before that stage, fruits will never ripe and will get spoiled. Right time of plucking can be ascertained by impedance spectrometry at low cost and in a very simple manner. Other fruits should also be tested by our technique.
 4. It is a non-destructive technique and may be used with robots to pluck fruits at right state.

RESEARCH ABSTRACT – Not More Than 200 Words (Abstrak Penyelidikan – Tidak Melebihi 200 patah perkataan)

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In this project it was proposed to use Electrical, thermal, Optical and ultrasonic techniques to assess the quality of the fruits non-destructively. However, due to limited funds we started working on Electrical and thermal techniques. Electrical impedance spectrometry proved to be very powerful technique in the characterization of raw and ripe fruits. We developed our own probes to conduct non-destructive techniques to characterize the quality of the fruits. Initially we developed a probe to measure the surface impedance of the fruit. However, surface impedance was not very effective and bulk impedance proved to be a better choice. Hence another probe for the measurement of bulk impedance was designed and fabricated. The photograph and the cross sectional view of the Probe are shown in Fig. 1 & 2. The characteristics of the fruits were determined in the frequency range of 1 kHz to 200 kHz. However sensitivities were higher in the lower frequencies and we concentrated measurements at 1 kHz and could nicely characterize the raw, ripe and over ripe fruits in terms of effective capacitances and resistances of the fruit under test. Jist of the information obtained from the characteristics is shown in Fig. 3 It shows the variation of impedance of the fruit in eight days while fruit goes through the stages of raw, ripe and over ripe. This information has not been given in any research paper so far. A microcontroller based system is designed fabricated and tested to assess the quality of the fruit at remote places. This technique measures the resistive part of the impedance of the fruit. Results are quite satisfactory and may help in the assessment of the quality of fruit successfully.

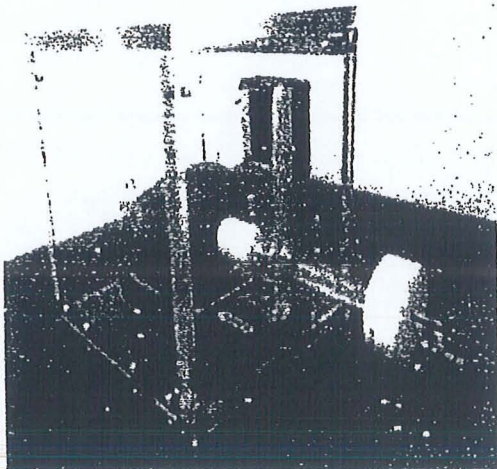


Fig.1 Photograph of the probe

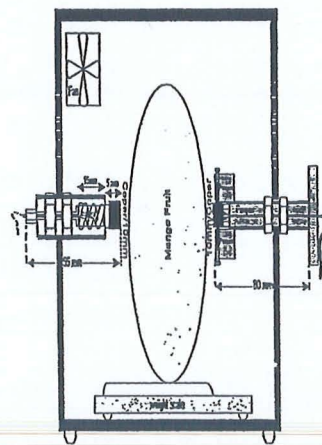


Fig.2 Cross sectional view of the probe

Study of the variations in the value of effective resistance and capacitance of Mango sample with in seven days

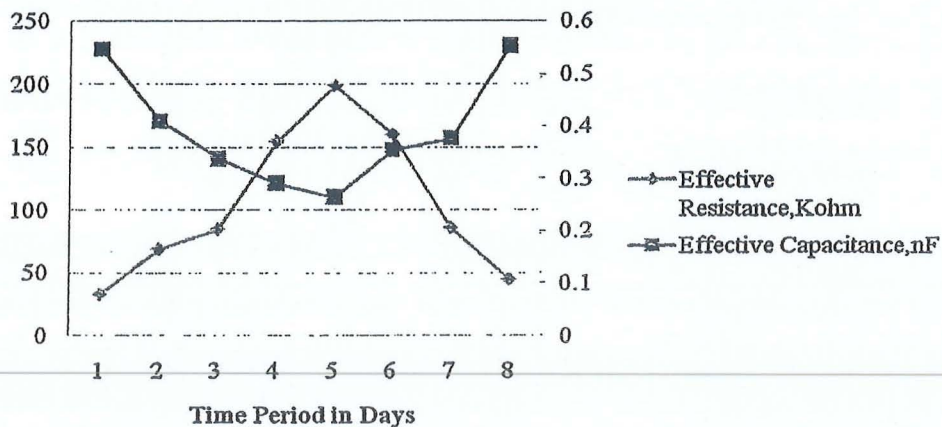


Fig.5 Variations in the values of effective resistance and capacitance of fruit with time

Thermal technique is tried in two ways. Initially it was tried to develop a novel technique for the measurement of thermal resistivity. The work is reported in a Journal and result is awaited. Second part dealt with non-destructive testing of fruits. In this case cooling of a hot body when placed on different types of fruits is studied. Decrease in temperature was studied in raw, ripe and over ripe mangoes. Results are not so encouraging in comparison of impedance spectrometry. Fruit will get affected by hot body employed for testing purposes.

Date : 12.04.2010
 Tarikh

Project Leader's Signature:
 Tandatangan Ketua Projek

COMMENTS, IF ANY/ ENDORSEMENT BY RESEARCH MANAGEMENT CENTER (RMC)
(Komen, sekiranya ada/ Pengesahan oleh Pusat Pengurusan Penyelidikan)

H

Name:
Nama:

Signature:
Tandatangan:

Date:
Tarikh:

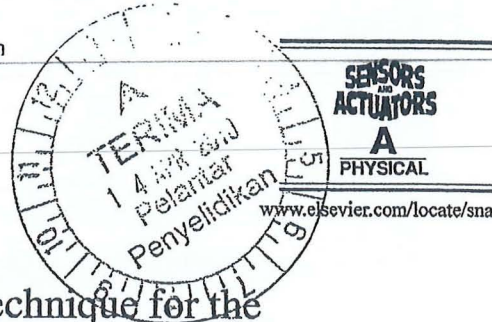
**DEVELOPMENT OF NOVEL, INTELLIGENT AND REMOTE MONITORING
TECHNIQUES USING ELECTRICAL IMPEDANCE SPECTROSCOPY
AND FIBER OPTICS**

By

BASEM ABDEL JALIL ALI ABU IZNEAD

**Thesis submitted in fulfillment of the requirements
for the degree of
Doctor of philosophy**

November 2009



Development of an electro-optic technique for the measurement of temperature rise of hot bodies

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Abstract

This research paper deals with the theory, design, fabrication and test results of a new system which can be used for the remote measurement of temperature rise of hot bodies. Due to the isolation provided by optical fiber, it can also be used in the measurement of temperature of high-potential bodies. The proposed circuit has the capability of providing linear and precise measurement of temperature rise by suitable design of different components. Its main application will be in the remote measurement of temperature rise under hazardous conditions. Experimentally, it has been verified that the relationship between output signal and temperature rise is appreciably linear.
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Keywords: Remote measurement; Optical fiber; Temperature measurement; Platinum resistance thermometer; Optical technique

1. Introduction

The measurement and/or regulation of temperature is an important everyday application of transducers. Its measurement and control play important role in a wide variety of consumer products. The industrial and medical applications cover a wide range of temperatures of interest. Its importance further increases when it has to be made under injurious conditions where the conventional methods fail. One of the burning topics is the measurement of temperature of high-potential parts of the transmission system like high-voltage transmission conductors, power transformers; switch gears which play important role in the stable operation of supply system [1–3]. Sometimes, increase in temperature, beyond safe limit, is due to over loading, friction and sparking inside the machine or chip. Under such situation, devices may be damaged. To avoid this damage, proper sensors should be employed to warn timely. The system, to be used for the purpose must be capable of operating under extreme conditions, without affecting the real temperature, as well as must have the added feature of remote sensing with continuous monitoring, at low cost. In this paper, we have

presented a low cost, simple and robust technique which can be used in extreme conditions. However, it has equally important applications in accurate measurement of temperature of important items like ovens, rooms, and industrial processes. It has mainly two parts, i.e., transmitter and receiver. The transmitter (which may be designed into very small size) is installed over the hot body during observation, while receiver is kept at a remote place for safe study and recording of temperatures.

2. Theory and design

The circuit of the proposed technique is shown in Fig. 1. The platinum resistance sensor (Pt100 size, 2 mm × 5 mm) is used to measure temperature rise, in the device. The sensor is connected in the feed back loop of an inverter. The output of the inverter is connected in the circuit of a summing amplifier together with the supply voltage (V_S). Output of the inverting amplifier may be given by following expression:

$$V_0 = -\frac{R_T}{R_1} V_S \quad (1)$$

Output of the summing amplifier maybe obtained through following standard procedure. Considering only the output

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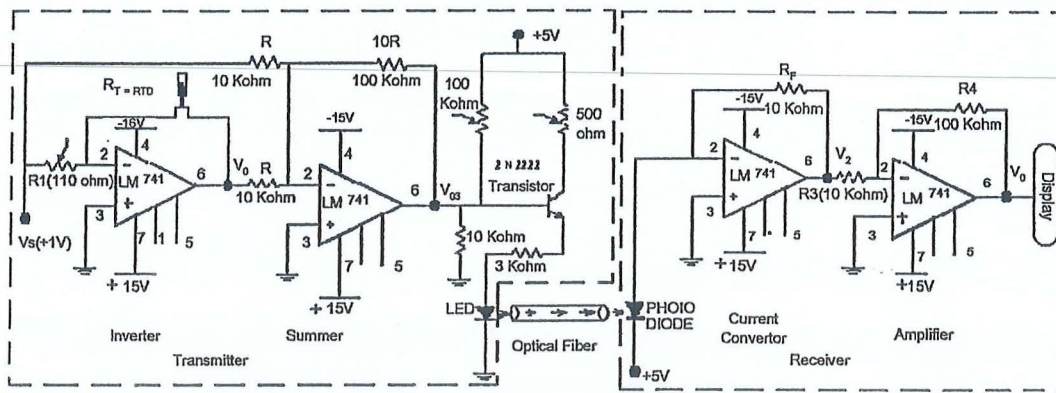


Fig. 1. Circuit diagram of the proposed temperature rise measuring system.

developed, at the output of the summer, by the output of the inverter,

$$V_{01} = -\frac{10R}{R} V_0 = -10 \left(-\frac{R_T}{R_1} \right) V_S = \frac{10R_T}{R_1} V_S \quad (2)$$

The output developed, when supply voltage, V_S , is connected through a resistance (R) in the summer circuit:

$$V_{02} = -\frac{10R}{R} V_S = -10V_S \quad (3)$$

Total output, V_{03} will be the sum of voltages given in Eqs. (2) and (3).

$$\begin{aligned} V_{03} &= V_{01} + V_{02} = \frac{10R_T}{R_1} V_S - 10V_S = 10V_S \left(\frac{R_T}{R_1} - 1 \right) \\ &= \frac{10V_S}{R_1} (R_T - R_1) = K_1 \Delta R \end{aligned} \quad (4)$$

However, increase in resistance is due to rise in temperature and relationship between temperature rise and increase in resistance may be developed as follows.

Suppose initial temperature is T_1 and final temperature is T_2 , and R_1 and R_2 are resistances at these temperatures, respectively. For metallic resistances, relationships between temperature and resistances may be written as follows [4]:

$$R_1 = R_0(1 + \alpha T_1) \quad (5)$$

and

$$R_2 = R_0(1 + \alpha T_2) \quad (6)$$

where R_0 , R_1 , R_2 are resistances of the detector at 0, T_1 and T_2 °C, respectively. α is the temperature coefficient of resistance of platinum.

Subtracting Eq. (5) from Eq. (6), we get

$$R_2 - R_1 = \Delta R = \alpha R_0(T_2 - T_1) = \alpha R_0 \Delta T \quad (7)$$

Replacing ΔR by ΔT in Eq. (4), we get

$$V_{03} = K_1 \alpha R_0 \Delta T = K \Delta T \quad (8)$$

where $K = \alpha R_0 K_1$

Eq. (8) shows that the output voltage of the summer is directly proportional to the temperature rise of the hot body. It is a very important outcome and may be used to display the temperature rise using a seven-segment display system. To convert it into optical signal, a transistor and an LED is used as shown in Fig. 1. Output of the summer is connected to the base of the transistor [5]. The transistor current may be given by following expression:

$$I_T = \frac{V_B - V_F}{R_E} \quad (9)$$

where I_T is the current which will pass through the LED and optical power developed will be directly proportional to it if it is assumed that LED is operating in the linear region. V_B is the voltage applied at the base of the transistor and may be taken equal to V_{03} . V_F is the forward voltage of the LED and R_E is the total resistance of the emitter circuit.

Now substituting $V_B = V_{03} = K \Delta T$, we get

$$I_T = \frac{K \Delta T - V_F}{R_E} \quad (10)$$

To make I_T directly proportional to ΔT , it is necessary to bias the transistor through collector voltage, as shown in Fig. 1. The resistance of the biasing circuit will be so adjusted that the LED just starts conducting when summer voltage increases above zero value. Under this condition, expression for I_T may be written as follows:

$$I_T = \frac{K \Delta T}{R_E} \quad (11)$$

Current given by Eq. (11) will pass through the LED and will produce optical power which may be given by following expression [6]

$$P_0 = K_0 I_T \quad (12)$$

This power will be launched into the multimode optical fiber. The signal, representing temperature rise, will travel through the optical fiber and will produce current in the photo diode which will be converted into voltage with the help of current to voltage converter. Expression for output voltage may

be developed as follows [7,8]:

$$I_D = \mathfrak{R}P_0 = \mathfrak{R}K_0I_T = \mathfrak{R}K_0 \frac{K\Delta T}{R_E} = \mathfrak{R}K'_T\Delta T \tag{13}$$

where I_D is the photo diode current, \mathfrak{R} the responsivity of the photo diode and $K'_T = K_0K/R_E$. \mathfrak{R} is given by following expression:

$$\mathfrak{R} = \frac{\eta e}{hf} \tag{14}$$

where η is the quantum efficiency of the photo-diode, e the charge on the electron, h the Plank's constant, and f is the frequency of the incident light.

Eq. (13) shows that photo-diode current is directly proportional to incident optical power at constant quantum efficiency. Under this condition, photo-diode current is directly proportional to temperature rise which is the basic requirement of the experimental work. Photo diode is interfaced with the current to voltage converter which has a feedback resistance of R_F . The output voltage of current to voltage converter will be

$$V_C = -I_D R_F \tag{15}$$

If it is further amplified with the help of an inverting amplifier the final output voltage will be

$$V'_0 = -\frac{R_4}{R_3} V_C \tag{16}$$

Substituting the value of V_C , we get

$$V'_0 = \frac{R_4}{R_3} I_D R_F \tag{17}$$

Substituting the value of I_D from Eq. (13), we get

$$V'_0 = \frac{R_4}{R_3} R_F \mathfrak{R} K'_T \Delta T \tag{18}$$

At constant responsivity of photo diode, Eq. (18) may be written as follows

$$V'_0 = K_T \Delta T \tag{19}$$

where $K_T = K'_T R_F \mathfrak{R} R_4 / R_3$ is constant for constant responsivity of the photo diode. Eq. (19) shows that output voltage of the receiver is directly proportional to increase in temperature of the device which is under monitoring. It is a very important result and can be used in the remote measurement of temperature with good order of accuracy and linearity.

3. Experimental methods and results

Initially, experiments were conducted to study the self-heating effect of the platinum resistance detector (type Pt100 size, 2 mm × 5 mm, 110 Ω) when current is passed through it. For best results, the current passing through detector should be less than the current which causes the rise in temperature. The graph representing the self-heating of the platinum detector is shown in Fig. 2. It is observed from the graph that temperature does not change up to a current of 10 mA. The temperature

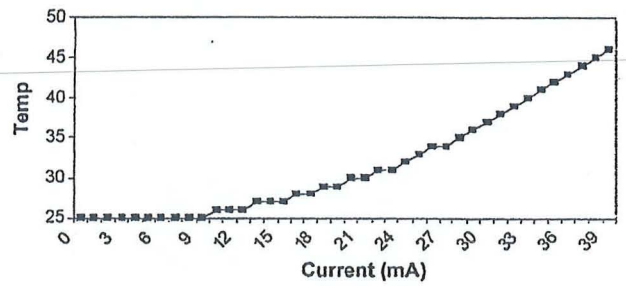


Fig. 2. Self-heating curve of platinum resistance detector.

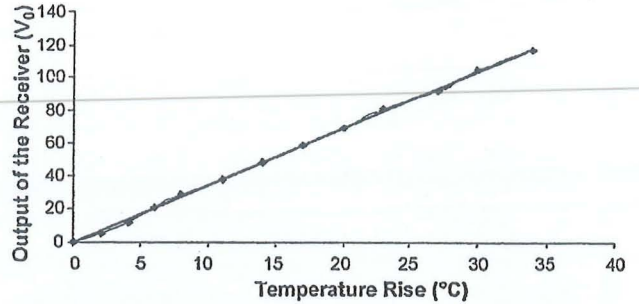


Fig. 3. Relationship between temperature rise of hot body and output of the optical receiver.

measuring circuit should be designed in such a way that current passing through sensor should not be more than 10 mA. Platinum resistance detector, used in this paper has a resistance of 110 Ω only. To limit the current, through it, to be less than 10 mA, a supply voltage of 1.0 V is used. The controlled heating system is made of a carbon resistance of square cross section and platinum detector is pasted on its one side. It is heated by passing dc current and temperature is measured with the help of a digital thermometer as well as by the proposed sensor. A multi-turn variable resistance is used in place of forward resistance of the inverter and it is so adjusted that output of the summing amplifier is zero volt precisely when heating is not started. After setting this condition, remaining circuit, consisting of transistor and LED is completed. With the help of biasing of the transistor, output power of the LED is brought to zero level. Under this condition, output of the photo detector should also be zero. Now, current, through the carbon resistance, is increased slowly and a set of readings between output voltage of the receiver and temperature of hot body are taken. Results are repeated many times and average value is plotted in Fig. 3. It is appreciably linear. It is very much in conformity with the theory developed in Eq. (19).

4. Conclusions

A low-cost system is developed for the remote measurement of temperature rise of hot bodies. In this application, platinum resistance sensor is used to sense the temperature rise with high degree of accuracy and LED is used to convert the electrical signal into optical signal linearly and it also provides optical isolation between input and output circuits. It can be devel-

oped in very small size which can be properly pasted on hot surface under measurement which may be the cable of an electrical installation whose safety we are planning or it may be the surface of the conductor of over head transmission line whose temperature is being monitored from a safe distance. Optical fiber is made of insulating material and ground display system may safely monitor the temperature. Similarly the temperatures of generators, switch gears, etc. may be safely monitored. It can be installed on the cables of rooms containing highly important documents to save them from internal short circuits. Signals in the form of sound signals may be generated when temperature rise is beyond pre-specified value. It can also be developed in the form of MEMS with further development work.

Acknowledgments

The authors would like to thank the School of Electric and Electronic Engineering for supplying the necessary facilities to design, fabricate and test the proposed scheme. This work is partly supported by the Fundamental Research grant Scheme sanctioned by University Science Malaysia.

References

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Biographies

Mahfoozur Rehman received B.Sc. Engg. (Electrical) and M.Sc. Engg. (Instrumentation and Control) from Z.H. College of Engineering and Technology, Aligarh Muslim university, Aligarh, India in 1966 and 1972, respectively and Ph.D. (Electrical) from Indian Institute of Technology, Madras, Chennai, India in 1981. He has been working in the field of Sensor Technology and has published nearly 70 papers in International Journals, Conferences, National journals and refereed National Conferences. He took voluntary retirement from the post of professor in Electronics Engg. Dept. in 2004 and joined School of Electric and Electronics Engg., USM, Pinang, Malaysia.

Basem Abdeljalel received Bachelor and Master degrees in Biotechnical and Medical Equipment and system from National Aerospace University, KHAI, Ukraine in 2000 and 2001, respectively. At present, he is working for PhD degree in the School of Electric and Electronics Engineering, USM, Pulau Penang, Malaysia. He is working in the field of remote measurement of electrical and non-electrical quantities.

Mohd Rizal Arshad received his B.Eng. from the University of Liverpool in 1994 in Medical Electronics and Instrumentation, followed by M.Sc. graduate course in the area of Electronic Control Engineering at the University of Sal ford in 1996. He worked on tele-operated robot using graphical interfaces project for his M.Sc. He then pursued his Ph.D. qualification in the area of 3D vision system in University of Liverpool, and graduated in February 1999. Since March 1999, he has been working with the School of Electric and Electronics Engineering, Universiti Sains Malaysia (USM) as a lecturer, and currently as the acting dean for the School. He has published a number of papers in International Journals and conferences in the field of Mechtronics.



Remote Measurement of Electric Current Using Magneto-Optic Technique

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Abstract: The paper deals with the development of an interesting technique which can help in the remote measurement of electrical current, using magnetic and optical devices. Major advantage of the presented technique is the isolation provided by Hall sensor as well as by the optical devices of measuring system from the actual power circuit. It will help in the repair of measuring system without closing the main circuit which is a crucial requirement of supply system. Output of the optical receiver is interfaced with the microcontroller to display the current as well as to instill intelligence to the system. It has been successfully used for the measurement of currents up to 60 A and relationship between current under measurement and output of the system is appreciably linear. *Copyright © 2008 IFSA.*

Keywords: Hall effect sensor, Fiber optic sensor, Remote measurement, Measurement of current, Microcontroller based measurement

1. Introduction

The measurement of Electrical quantities, without making contact with the circuit under test, is a very important requirement and it will avoid the closure of the main circuit during testing or making any modifications in the measuring systems. For the measurement of current and voltages, without electrical contact, current and potential transformers are used on AC circuits but they also can not fulfill the basic requirements because open circuiting of secondary winding of current transformer may create problems, and is not advised under standard practices [1]. This paper adopts Hall Effect sensor to isolate the main

circuit from the measurement circuit as well as it reduces the amplitude of the signal to low value. As a second step, low level signal is converted into an optical signal with the help of LED by choosing the most linear part of the LED characteristic. Resulting optical signal is transmitted with the help of optical fiber and is finally converted into a voltage signal with the help of optical detector. Output of the optical detector is further amplified then interfaced with the microcontroller to display the current as well as intelligent steps to incorporate special warnings at the receiving end. Main circuit and measuring circuits do not have any undesirable reflections to cause any sort of damage of chips. It has been used for the measurement of currents up to 60 A successfully. With, higher rating Hall sensors/proper shunts still higher ranges may be covered. For long distance transmission, LED optical source may be replaced by Laser and multimode Optical Fiber may be replaced by single mode fiber. Currents at high voltages may be measured with out any danger to equipment and personals due to high order of isolation between power circuit and measuring system.

2. Basic Principles

In the proposed scheme, initially high values of currents are converted into low values of voltages with the help of Hall sensor [2]. The output voltage of the Hall sensor is used to forward bias the LED to produce light which is transmitted to remote place with the help of Optical Fiber. At the destination, optical signal is converted into electrical signal with the help of optical receiver circuit. Output of the optical receiver is interfaced with the microcontroller to provide intelligence as well as to display the current, under measurement, with high degree of isolation. The theoretical aspects of different devices, used in the scheme, are given below.

2.1. Magnetic Field and Current Sensing Integrated Circuits Based upon Hall Effect

The Hall Effect was discovered in 1879 by Edwin Hall. It arises from the Lorentz force experienced by a charged particle moving in a magnetic field .If the carriers are flowing in a slab of metal or semiconductor; they are deflected preferentially to one side of the slab, producing a voltage as shown in Fig. 1. Referring to Fig.1, the Hall voltage is given by, [2]

$$V_H = \frac{R_H I_X B_Z}{T}, \quad (1)$$

where R_H =Hall coeff. (m^3/C), I_X =Current through the sensor (Amp), B_Z =Flux density in sensor (Tesla), T =Plate thickness (m).

The Eq.(1) is valid for $L \gg W \gg T$, approximately, L is not much greater than W and $W \gg T$ for cases where the equation is valid, and nonlinearity in Hall coefficient can be neglected, the Hall voltage is directly proportional to the current and the magnetic flux density and inversely proportional to the thickness of the plate. The R_H is between four and five orders of magnitude larger for semiconductors than for most metals due to the fact that the carrier density is much smaller in semiconductors. This translates directly into increased sensitivity. Hall Effect devices are easy to fabricate and can be made as an intrinsic part of nearly any bipolar or MOS process. A great deal of thought has been given to realize high quality Hall devices from available active circuit processes. Allegro Micro Systems have developed a chip for the measurement of current linearly and have incorporated Different signal conditioning blocks to get linear output without the effect of noise and temperature [3]. Its block diagram is shown in Fig. 2. It has five terminals and out put is available on 3rd terminal. The relationship between output voltage is input current is appreciably linear in different temperature ranges. It has low output impedance

and can be easily connected without loading problems. It will play important role in the development of remote measurement presented here.

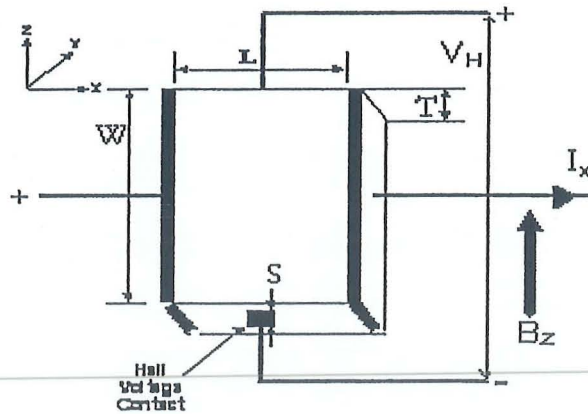


Fig. 1. Basic Hall Sensor.

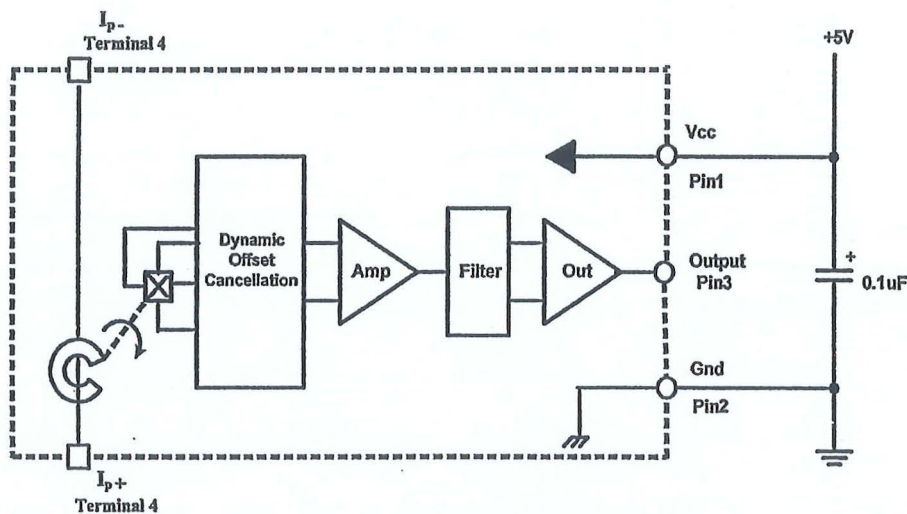


Fig. 2. Hall Sensor (Allegro Micro System).

2.2. Use of Light Emitters to Convert Electrical Signal into Optical Signal

Light Emitters convert Electrical signal into a corresponding Optical signal that can be transmitted with the help of optical fiber. A light Emitting diode is a semiconductor p-n junction that is optimized to release light of approximately the band gap energy under forward bias when electrons fall from the conduction band to the valence band. LED can work at low current densities but the emitted photons have random phases and the device is an incoherent optical source. LED is preferred over Lasers due its distinct advantages like simpler fabrication, low cost, reliability, less temperature dependence, simpler drive circuitry and linearity. These advantages combined with the development of high radiance, relatively high bandwidth devices have ensured that the LED remains an extensively used source of optical power. The power internally generated in an LED is given by following expression [4]:

$$P_{\text{int}} = \eta_{\text{int}} \frac{hcI_L}{e\lambda}, \quad (2)$$

where, η_{int} = LED Internal quantum efficiency, λ = Wavelength, h = Planck constant, I_L = drive current through LED, e = charge of an electron, c = velocity of light.

However, emitted light of the LED is of main significance because it will reach the photo detector to produce current. The emitted light will be different from the internally generated light due to the effect of materials used in the fabrication of LED. Following equation gives the expression for the emitted optical power.

$$P_e = \frac{P_{\text{int}} F n^2}{4n_x^2}, \quad (3)$$

where P_e is the emitted optical power, P_{int} is the internally generated power, F is the transmission factor of the semiconductor-external interface, n is the refractive index of the optical fiber, n_x is the refractive index of material of LED.

Substituting the value of internally generated power in (3) we get

$$P_e = \frac{\eta_{\text{int}} hc I_L F n^2}{4e\lambda n_x^2} = K_e \cdot I_L. \quad (4)$$

For a particular construction, K_e is constant and emitted light may be taken proportional to load current. The drive current I_L depends upon the output voltage of the Hall sensor as discussed in previous section. If the output voltage of Hall sensor is V_H at a particular Primary current of I Amp then resulting current through the LED is

$$I_L = \frac{V_H - V_{fv}}{R_T}, \quad (5)$$

where, V_{fv} is the forward voltage of the LED.

Current given by Eq.(5) will pass through LED and will produce Optical power which may be given by following expression [4]

$$P_e = K_e I_L \quad (6)$$

This power will be launched into the multimode optical fiber by polishing the optical fiber nicely. Now the signal representing the current under measurement will travel through the Optical Fiber and in the receiver side this light will fall upon the Photo Diode and produce a current, I_D . Expression for detector current may be given by following expression:

$$I_D = \mathfrak{R} \cdot P_e = \mathfrak{R} K_e I_L, \quad (7)$$

where I_D is the photo diode current and \mathfrak{R} is the responsivity of the diode and may be given by following expression:

$$\mathfrak{R} = \frac{\eta e}{hf}, \quad (8)$$

where η is the quantum efficiency of the diode, e is the charge on the electron, h is the Plank constant, f is the frequency of the incident light.

Substituting the value of I_L in (7) we get

$$I_D = \mathfrak{R}K_e \cdot \frac{V_H - V_{fv}}{R_T}. \quad (9)$$

Substituting the value of V_H in (9) we get

$$I_D = \mathfrak{R} \cdot K_e \frac{1}{R_T} \left[\frac{R_H \cdot I_X \cdot B_Z}{T} - V_{fv} \right]. \quad (10)$$

For a particular chip we can make some assumptions and final expression may be written as follows:

$$I_D = K_1 I_X - K_2. \quad (11)$$

Eq. (11) shows that the relationship between I_D and I_X , may be represented by a straight line. I_D can be converted into voltage using the current to voltage converter and may be further amplified using an inverter. A summing amplifier at the end may be used to develop linear relationship between I_D and I_X as shown in Fig. 3. The output voltage of the current to voltage converter may be given by following expression:

$$V_0 = -I_D \cdot R_F \quad (12)$$

The output of the inverter, with a gain of $-k_3$, will be

$$V_{01} = I_D K_3 \cdot R_F \quad (13)$$

Substituting the value of I_D we get

$$V_{02} = K_3 \cdot R_F (K_1 I_X - K_2) \quad (14)$$

A summer amplifier is so designed that it will subtract a voltage equal to $K_3 \times R_F \times K_2$ from the voltage V_{02} . The final expression will be:

$$V_{03} = K_3 \cdot R_F \cdot K_1 I_X = K_4 I_X \quad (15)$$

Eq. (15) shows that output voltage, V_{03} of the summer will be proportional to primary current in the input circuit and relationship between V_{03} and I_x will be linear.

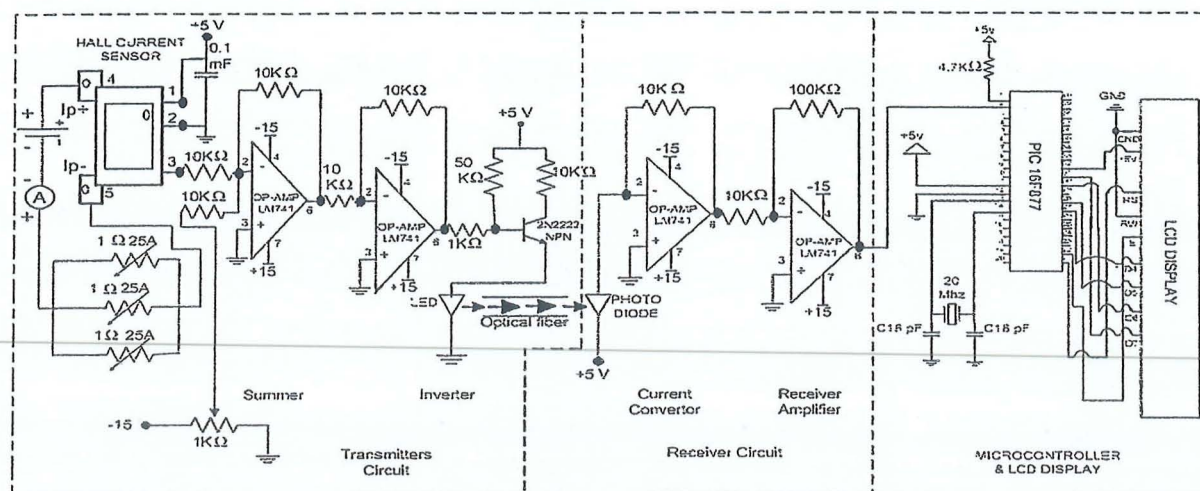


Fig. 3. Circuit diagram of the proposed technique.

3. Experimental Results

Initially, the characteristics of the Hall Sensor, Optical transmitter and optical receiver were determined and verified in the laboratory and it was found that the devices gave quite repetitive characteristics. To verify the scheme, connections were made as shown in Fig. 3. It was tested for Direct Currents due to some limitations of the equipment. To get better sensitivity, ends of the optical fiber were polished with great care and then they were fixed inside the transmitter and receiver carefully. The connections in the primary circuit were checked to avoid loose connections which may give rise to terminal heating. Constant voltage supply of 5 volts was given to the photo diode and LED to avoid noise. Current was increased in steps of 5 A and resulting output of the photo detector circuit was recorded with the help of a multimeter. Observations were repeated a number of times and at different ambient temperatures. It was observed, for the temperature variations in an air-conditioned Laboratory, there was no variation in the results.

The results are shown in Fig. 4. Same observations were repeated after interfacing the optical receiver with the microcontroller followed by the LCD display system. The results obtained are shown in Fig. 5. According to the theoretical derivations developed in Eq. (15), relationship between the current under measurement and output voltage is appreciably linear.

4. Conclusions

A novel scheme is presented for the measurement of large values of currents without making direct contact with the main power circuit. It employs the famous Hall devices for current sensing and optical sources and detectors for transmitting the signals to remote places for safe measurement. Any changes may be made in the measurement circuit, beyond the output of the of the Hall sensor, without affecting the main power circuit and hence without being affected by the high voltage of the primary circuit, due to perfect isolation. Linearity, accuracy and reliability of the measurement mainly depend upon the Hall

Sensor, transmitter and receiver. The maximum non-linearity of the Hall sensor (ACS750xCA-075) used is 5% while maximum error is 1% only [3]. Accuracies of transmitter and receiver may be much better than this. Repeatability of the circuit has been tested through rigorous experimentation. With further development work, accuracy, reliability and repeatability of circuit may be improved. Complete circuit is compact, robust and can be prepared at low cost. It may be further extended for the measurement of a.c. current, and voltages and power.

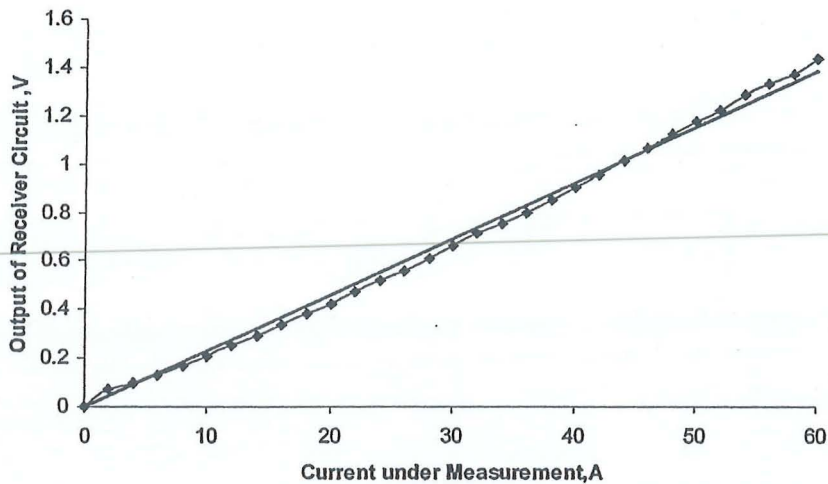


Fig. 4. Relationship between current under measurement and Output Voltage of the receiver.

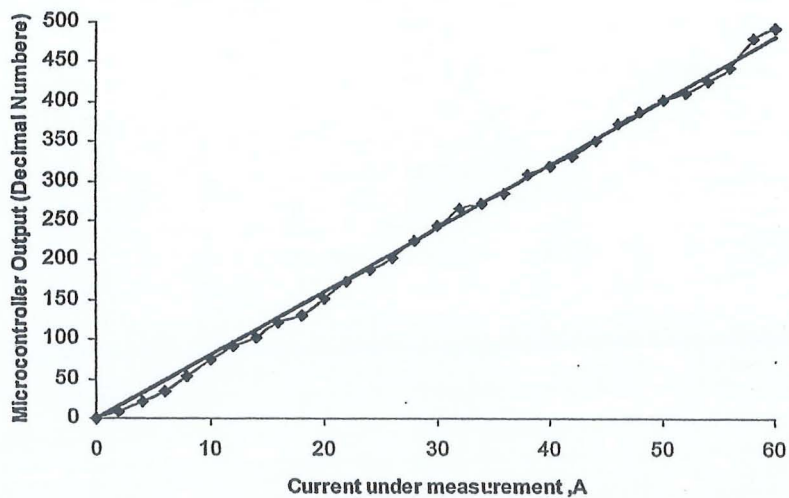


Fig. 5. Relation ship between current under measurement and microcontroller output.

Acknowledgments

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CHARACTERIZATION OF RAW, RIPE AND OVER RIPE TOMATOES USING IMPEDANCE SPECTROMETRY

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INTRODUCTION

This paper deals with the development of a non-destructive Impedance spectroscopic technique which may assess the conditions of the fruits to pluck them with the help of robotic arms. The characterization of fruits has been an important issue in the automatic sorting of fruits from the harvest site as well as from the cool storage. The quality of the fruits, at the time of consumption, also depends on the maturity stage reached at the time of harvest. Characterization techniques may be divided into two groups i.e., non-destructive and destructive techniques. For automatic sorting of fruits, with the help of robotic arms, generally, non-destructive techniques are preferred. Impedance spectrometry has been successfully used in the characterization of fruits (Harker and Dunlop, 1994; Harker and Maindonald, 1994; Inaba et al., 1995; Bauchot et al., 2000). However, their aim was to analyze the fruits with the help of impedance spectroscopy and they used both destructive and non-destructive techniques for this purpose. They did not plan to develop any technique for the characterization of fruits for commercial purposes (Bauchot et al.2000). Non-destructive techniques based on Ultrasonic, optical, microwave and semiconductor sensor have been used successfully for the testing of fruits, for commercial purposes.. A tomato maturity predictive sensor was developed to be used at packing houses for detecting unripe tomatoes that will never turn red by making spectral and colour measurements of green-mature tomatoes just after harvest. Colour was measured daily and used as an index for classifying harvest day spectral data into ripe or unripe (Hahn, 2002). Preliminary investigations are made with the help of two terminal probes and an accurate LCR meter. The bulk impedance of tomatoes have been measured to characterize raw and ripe fruits.

METHODOLOGY

A fruit can be represented by an electrical equivalent circuit which is composed of resistances and capacitances connected, in a specific manner, according to the structure of the fruit. When bulk impedance is measured between two points, effective impedance may be composed of capacitances and resistances. If the effective impedance (Z_{ef}) is measured with the help of a bridge, either series or parallel mode may be used. However, in the present investigations, parallel combination of effective capacitance (C_{ef}) and effective resistance (R_{ef}) are measured. It may be given by following expression:

$$1/Z_{ef} = 1/R_{ef} + j C_{ef} \quad (1)$$

The values of these capacitances and resistances will depend upon the structure of the fruit. These will be different when measured for raw, ripe and over ripe vegetables/fruits of nearly same size because impedances offered by skin, pulp and seed of the fruit/vegetable will be different. In this case, raw and ripe fruits /vegetables may be characterized in terms of their effective resistances and effective capacitances, measured at low frequencies. Suitable frequency, at which maximum difference occurs between impedances may be determined by determining their effective resistance versus frequency and effective capacitance versus frequency characteristics in the frequency range of 1 kHz to 200 kHz.

RESULTS AND DISCUSSION

The Change in Effective Resistance, with time, at 1kHz for the case of Tomatoes

In the case of tomatoes of selected size, the effective bulk resistance varies from 84.2k Ω (unripe, green), at 1 kHz to 616.1 k Ω (ripe, red) at 1kHz, for a selected size of the probe, as shown in Table-1. The results show that resistance increases by a factor of 7.3 from unripe to ripe and this factor reduces to 4.3 on fifth day. Appreciable difference exists between the resistance of the raw and ripe fruits and hence this technique may be successfully used to differentiate between raw and ripe tomatoes.

The change in Effective Capacitance, with time, at 1kHz, for the case of tomatoes

In the case of tomatoes of selected size, the effective bulk capacitance varies from 0.882nF (unripe, green), at 1 kHz to 0.421nF (ripe, red) at 1kHz, for a selected size of the probe, as shown in Table-1. On comparison it is observed that the effective capacitance decreases by a factor of 2.1 from raw to ripe state and on fifth day it rises to 0.722nF. It can be easily analyzed that effective capacitance increases when tomato enters the over ripe condition. However, change in capacitance is not so high as change in resistance when tomato passes from the phase of raw to ripe condition.

Day	Resistance Average (Kohm)	Capacitance Average (nf)
1	84.2	0.882
2	207.5	0.661
3	335.4	0.512
4	616.1	0.421
5	363.8	0.722

CONCLUSION

In the light of experimental data, it can be concluded that impedance spectrometry may be successfully used to differentiate between the ripe and raw tomatoes. Color of the fruit together with its test has been used to differentiate between the raw and ripe fruits. For automatic operation resistance to voltage converting circuits together with the microcontrollers may be used to create suitable signals to pluck the tomato from the bush.

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Paper, submitted to the Journal of
Computer and Electronics in Agriculture

*Cover Letter

From

Dr. Mahfoozur Rehman

Associate Professor

School of Electric and Electronics Engineering, Engineering Campus ,USM

Nibong Tebal-14300, Pinang, Malaysia

To

Editors-in-Chief

N.H. Hancock

R.E. Plant

K.C. Ting

G. van Straten

Dear Sirs,

I hereby declare that my paper entitled "Non-destructive evaluation of Fruits using Electrical Impedance Spectroscopy" is the outcome of my original research and the same has neither been submitted nor under consideration for publication elsewhere. Please consider my paper for publication in your journal of **Computers and Electronics in Agriculture**.

Thanking you



Dr. Mahfoozur Rehman

18th February 2010

1 Non-destructive evaluation of Fruits using Electrical Impedance Spectroscopy

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15

Abstract

16 This paper deals with the development of a non-destructive Impedance spectroscopic technique

17 which may assess the conditions of the fruits to pluck them with the help of robotic arms.

18 Preliminary investigations are made with the help of three-terminal probe and an accurate LCR

19 meter. The bulk impedance of mango has been measured to characterize raw and ripe fruits.

20 Effective resistance and effective capacitance versus frequency characteristics have been

21 determined. The bulk effective resistances, of the ripe fruits, are found to be more than those of

22 the raw fruits, in the frequency range of 1-6kHz. In the same frequency range, effective

23 capacitances of the raw fruits are found more than those of the ripe fruits. In the light of the data

24 obtained, it can be said that the effective resistance may be used to differentiate between raw and
25 ripe fruits in the frequency range of 1-6 kHz.

26 **Key words:** Electrical Impedance spectroscopy; Quality assessment of fruits, Impedance
27 Measurement, Non-Destructive Testing of fruits, Post harvest Assessment.

28 1. Introduction

29 The characterization of fruits has been an important issue in the automatic sorting of fruits from
30 the harvest site as well as from the cool storage. The quality of the fruits, at the time of
31 consumption, also depends on the maturity stage reached at the time of harvest. Characterization
32 techniques may be divided into two groups i.e., non-destructive and destructive techniques. For
33 automatic sorting of fruits, with the help of robotic arms, generally, non-destructive techniques
34 are preferred. Impedance spectrometry has been successfully used in the characterization of
35 fruits in a very high frequency range (Harker and Dunlop, 1994; Harker and Maindonald, 1994;
36 Inaba et al., 1995; Bauchot et al., 2000). However, their aim was to analyze the fruits with the
37 help of impedance spectroscopy and they used both destructive and non-destructive techniques
38 for this purpose. They did not plan to develop any technique for the characterization of fruits for
39 commercial purposes. Non-destructive techniques based on Ultrasonic, optical, microwave ,
40 Image Categorization and semiconductor sensors have been used successfully for the testing of
41 fruits, for commercial purposes (Krairiksh et al., 2004, Mizrach, 2000, Rocha et al 2010; Xiao-bo
42 et al, 2010 and Alonso et al 2003). Non-destructive ultrasonic tests have been used to elucidate
43 the influences of storage temperature and time on the softening process of avocado fruit. This
44 method is based on the measurement of acoustic wave attenuation in the fruit tissue, by means of
45 ultrasonic probes in contact with the fruit peel (Mizrach, 2000). An automated firmness

46 monitoring system, for apples, was developed based on non-destructive acoustic impulse
47 response technique to estimate the firmness during storage and determine the time when cool
48 stores should be opened (Belie et al., 2000). An application of high frequency electromagnetic
49 waves was developed to test the mango by measuring its dielectric property at 12.4 GHz
50 (Krairiksh et al., 2004). A tomato maturity predictive sensor was developed to be used at packing
51 houses for detecting unripe tomatoes that will never turn red by making spectral and colour
52 measurements of green-mature tomatoes just after harvest. Colour was measured daily and used
53 as an index for classifying harvest day spectral data into ripe or unripe tomato (Hahn, 2002). An
54 application of ISFET sensors (semiconductor sensors) to analyse calcium, potassium and nitrates
55 in several apple varieties, both in juice and in situ fruit has been developed. Results show that the
56 analysis of potassium, calcium and nitrate permits to distinguish among apple varieties and can
57 also be used to determine correctly the concentrations of these ions (Alonso et al., 2003).

58 Impedance spectrometry is a low cost and simple technique and has a lot of potential to be used
59 to characterize fruits non-destructively in vivo and at the site of harvest and storage. It has been
60 recently used for the analysis of eggplant pulp (Wu et al., 2008). Effects of drying, freezing and
61 thawing treatments on its impedance characteristics have been determined. An integrated
62 approach to electrochemical impedance spectroscopy has been presented by Orazem et al., 2008.

63 Impedance microbiology has been successfully used for the quantification of bacterial content in
64 milk by means of capacitance growth curves (Felice et al., 1998). In another research work
65 impedance spectroscopy has been used in the study of apple juices and apple pasteurized pulp
66 (Ryszard et al., 2005). In the present study, an attempt has been made to develop a low cost
67 technique for the characterization of raw and ripe fruits, through non-destructive impedance
68 spectroscopy, for commercial applications. In practice, impedance is measured as either bulk

69 impedance or surface impedance. Both techniques have their advantages and limitations. In this
70 study, bulk impedance (assuming parallel combination of resistance and capacitance) is used for
71 the assessment of the ripeness of the mango fruit. For this purpose, effective capacitance versus
72 frequency and effective resistance versus frequency characteristics have been determined for the
73 cases of mangoes.

74 2.0 Materials and Methods

75 2.1 Fruit characterization by Electrical properties

76 The equivalent circuit of a fruit may be represented by the electrical equivalent circuit shown in
77 Fig.1. If effective impedance (Z_{ef}) is measured, with the help of a bridge, either series or parallel
78 mode may be used. However, in the present investigations, parallel combination of effective
79 capacitance (C_{ef}) and effective resistance (R_{ef}) is selected. It may be given by the following
80 expression:

$$81 \quad 1/Z_{ef} = 1/R_{ef} + j\omega C_{ef} \quad (1)$$

82 The values of the effective capacitance and effective resistance will depend upon the structure
83 of the fruit. Effective values are taken because it will not be pure resistance or pure capacitance
84 but combination of resistances and capacitances due to the complex nature of the equivalent
85 circuit (Hague and Foord 1971]. These will be different when measured for raw, ripe and over
86 ripe fruits of nearly same size because impedances offered by skin, pulp and seed of the fruit will
87 be different in above conditions. Hence raw and ripe fruits may be characterized in terms of their
88 effective resistances and effective capacitances. Optimum frequency, at which maximum
89 difference among impedances of raw, ripe and over ripe fruits may be achieved, may be assessed

90 by determining their effective resistance versus frequency and effective capacitance versus
91 frequency characteristics in the frequency range of 1 kHz to 200 kHz.

92 The effective impedance of a fruit, as measured by a probe and LCR meter may depend upon a
93 number of factors. The effect of some factors may be assessed systematically while others which
94 affect randomly may be determined statistically. Hence impedance of a fruit may be represented
95 by following expression:

$$96 \quad Z_{ef} = f(x_1, x_2, x_3, \dots, x_n) \quad (2)$$

97 where $x_1, x_2, x_3, \dots, x_n$ are the variables which affect the value of Z_{ef} in two ways. Either it
98 will be a systematic effect or random effect. The corresponding changes due to systematic effect
99 in Z_{ef} may be obtained by careful experimentation. Similarly the effect of the factors which
100 affect randomly may be assessed by taking large number of readings and determine the effect
101 statistically. Some of the factors are discussed below:

102 X_1 is attributed to the condition of the fruit which is the function of time i.e. it may be unripe,
103 ripe or over ripe. This should represent the major systematic change in Z_{ef} with time. Our aim is
104 to use this change to characterize the fruit. It may be obtained by measuring the effective
105 impedance at suitable time intervals.

106 X_2 factor may be related to the shape of the fruit. If fruit is symmetrical, impedance may remain
107 approximately constant when measured across a certain periphery having nearly same diameter,
108 like apple, tomato etc. In the case of unsymmetrical shape, bulk impedance will have different
109 values i.e., mango. However, in the case of mango, two nearly parallel surfaces may be used to
110 define the bulk impedance for analysis purposes.

111 X_3 factor may depend upon the size/weight of the fruit. Size will decide the distance between the
112 electrodes as well as the parallel paths in the fruit. It may be assessed by measuring impedances
113 of the fruits of different weights to develop a relationship between capacitance/resistance verses
114 mass.

115 X_4 factor will decide the value of impedance depending upon the contact area of the electrodes of
116 the probe. It will decide the value of the impedance which will be measured by the LCR Bridge.

117 For small area, value of impedance will be large while large areas will offer small impedance
118 only. However, for constant area probe there will be no variation in impedance.

119 X_5 factor may be the temperature of the fruit. It will affect the impedance directly and can be
120 assessed by measuring the impedance at different temperatures.

121 X_6 is a factor which will change the impedance of the fruit at constant controlled temperature
122 due to random variation of temperature around the controlled temperature as well as due to the
123 random variation of contact resistance. Effect may be assessed by measuring the impedance
124 several times with in a very short interval of time. Its effect may be assessed in terms of standard
125 deviation.

126 X_7 is a factor which affects the impedance of the fruit by changing the position of the probe
127 slightly around one point only. The change may be due to the variation in the impedance offered
128 by the fruit at different positions in a symmetrical surface.

129 X_1 to X_7 factors will affect the measured value of the impedance of the fruit. Main aim of this
130 study is to categorize unripe, ripe and over ripe fruits which are available at a place or on a tree,
131 with the help of measurement of impedance of the fruit. However, at a particular instant, fruit
132 will have one condition i.e. it will be ripe, unripe or overripe. With the help of impedance

133 measurement, it is to be proved that the variations in the value of Z_{ef} , due to variables other than
134 time, are negligible or very small in comparison of variations due to time. This variation is our
135 requirement and will be measured with good order of accuracy. However, the variations in the
136 value of Z_{ef} , due to random effects will be ascertained in terms of standard deviations using
137 Excel software. The effects of other variables which affect the measurement systematically will
138 be minimized by making the measurements under controlled conditions. Condition of the fruit is
139 assessed on sensory basis only due to non-availability of facilities for chemical analysis etc. The
140 variety of mango which is available on the trees of University area is used for testing purposes. It
141 changes colour from dark green to bright yellow colour on ripening. The change in impedance
142 and change in colour follow one another and yellow fruit is appreciably sweet when tested by a
143 number of staff and students. If raw and ripe fruits have distinctly different impedances at a
144 particular frequency, a signal proportional to the impedance of the ripe fruit may be generated to
145 actuate a robot to pluck a ripe fruit (Edan, 1995).

146 2.2 The bulk impedance measuring system

147 The bulk impedance measuring system is shown in Fig. 2(a) and its full cross sectional view is
148 shown in Fig. 2(b). Lower potential electrode is spring loaded and can be moved in vertical
149 direction only. It can be fixed in its position at the time of experimentation. Higher potential
150 electrode can be moved in vertical direction as well as in the horizontal direction (towards or
151 opposite to the position of lower potential electrode). The order of impedance offered by the fruit
152 will be governed by the cross sectional area of the electrodes. Bigger cross section will provide
153 low resistance and higher capacitance and will not be able to make good contact with the fruits
154 which mostly have curved surfaces. Smaller cross section of the electrode will provide higher
155 resistance as well as low capacitance and will be able to make good contact with the surface of

156 the fruit. Different cross sections were tried and finally electrodes of 5mm diameter were
157 selected. Fruits of maximum width 7.2 cm and maximum height 8.5cm may be tested for their
158 bulk impedances by the designed setup. The pressure applied on the fruits will be governed by
159 the high potential electrode because lower potential electrode is stationary as well as spring
160 loaded. The mass of the fruit is measured with the help of a Digital mass measuring system
161 installed in the bottom of the device while temperature is measured with the help of temperature
162 sensor AD590. To provide uniform temperature inside the container exhaust fan and holes are
163 provided.

164 **2.3 Post Harvest Experiments**

165 **2.3.1 Determination of effective resistance versus frequency and effective capacitance** 166 **versus frequency characteristics of Mango**

167 For the preliminary investigations, the bulk effective impedances (Hague and Foord, 1971) of the
168 fruits have been measured, with the help of an LCR meter [LCR-800, Gw Instek] and two
169 terminal probe, developed for this project, as shown in Fig.2(a) & (b), to characterize the
170 conditions of the fruits. The bulk effective Impedance is measured in terms of the parallel
171 combination of effective capacitance and effective resistance in the frequency range of 1 kHz to
172 200 kHz. LCR meter have digitally controlled Frequency & voltage variations. It can measure
173 impedance in series or parallel mode which can be easily selected from the front panel. Sample
174 are selected of uniform size and weight and are properly cleaned and their dimensions, weight
175 and temperature is correctly recorded. Proper contacts are made between the electrodes of the
176 probe and the fruit skin. Arrangements are available to measure the mass and width of the fruit in
177 the system. Effective resistances and effective capacitances of the samples are measured at one

178 volt, in the frequency range of 1 kHz to 200 kHz and results are shown in Fig.3&4. Higher
179 voltage and very high frequencies are not used to avoid self heating. Fig.3 shows the variations
180 of the effective resistance of a mango fruit when subjected to frequencies from 1 kHz to 200 kHz
181 for seven days. Similarly Fig.4 shows the variations of effective capacitance with frequency for
182 seven days. In this duration, unripe mango becomes ripe/ overripe depending upon the condition
183 of the fruit in the beginning. It is concluded, after the analysis of the characteristics shown in
184 Fig.3&4, that fruits have highest effective resistance and capacitance at 1 kHz (in the frequency
185 range of 1 kHz to 200 kHz). Hence it is decided to ascertain the variations, in the values of
186 impedance of the fruit, at 1 kHz.

187 **2.3.2 Study of variation in the values of effective resistance and capacitance due to random** 188 **variations of contact resistance and temperature**

189 The effect of the random variations of contact resistance (due to random changes in contact
190 pressure) and random variation of temperature, on the measured values of the effective
191 impedances of the fruit, are ascertained by measuring the impedances of the fruit, at 1kHz, in a
192 batch of ten readings where each reading is the average of three readings. These measurements
193 were made at a controlled temperature of 25⁰ C. The data with standard deviation is given in
194 Table-1

195 **2.3.3 Study of the effect of the weight of the mango on the impedance when measured at** 196 **1kHz.**

197 To study the variation of impedances with weight, four samples of different weights are selected
198 from the same branch of the tree. The impedance is measured at 1 kHz ten times under controlled
199 conditions and average value of the effective resistances and capacitances of the samples are

200 measured with the help of designed probes and precision grade LCR meter. The data obtained is
201 tabulated in Table No.2 for analysis purposes.

202 3. Results and Discussion

203 3.1 Effective Resistance versus Frequency Characteristic of mango

204 The effective resistance versus frequency characteristic is shown in Fig.3. In the case of raw
205 mango of selected size, the effective bulk resistance varies from (28.8 ± 0.8) k Ω at 1 kHz to
206 (8.3 ± 0.8) k Ω at 200 kHz when measured with the help of the designed probe system, including
207 the random effects. However, the same mango on the sixth day, when it is nearly ripe (when
208 color changed from dark green to yellow), offers an effective resistance which varies from
209 (271.5 ± 0.8) k Ω at 1 kHz to (36.6 ± 0.8) k Ω at 200 kHz .The results show that appreciable ratio
210 (9.42) exists between the effective resistances of ripe and raw fruits at 1 kHz. On the other hand
211 the ratio reduces to 4.41 at 200 kHz. The variation in effective resistance of the fruit (Mango) at
212 1 kHz, which is shown in Fig.5, is enough to characterize raw and ripe fruits in terms of their
213 effective resistances only. The variation due to random effect is nearly negligible under
214 controlled conditions. However, changes in effective resistance from raw to ripe mango is so
215 large that small variations due to changes in size, temperature and contact resistances will not
216 affect the final assessment of the fruit. Hence, an electronic circuit which may develop signals
217 proportional to effective resistance and effective capacitance separately may be used in the
218 development of a low cost fruit characterization instrument (Rehman& Hasan 1998). The
219 referenced circuit could be effectively used to characterize fruits in terms of the ranges of
220 resistances. The bars to represent random errors in effective resistance versus frequency are not.
221 used as errors are nearly negligible in comparison of resistances shown by the LCR meter.

222 3.2 Effective Capacitance versus Frequency Characteristic of mango

223 Effective capacitance versus frequency characteristic is shown in Fig.4. The effective
224 capacitance varies from (0.65 ± 0.021) nF at 1 kHz to (0.13 ± 0.021) nF at 200 kHz in the case of
225 raw mango (first day, dark green). The same mango, on the sixth day, has effective capacitance,
226 which varies from (0.12 ± 0.021) nF at 1 kHz to (0.028 ± 0.021) nF at 200 kHz. It can be easily
227 concluded that the ratio between the effective capacitances of raw and ripe fruit at 1 kHz is 5.42
228 which is quite low in comparison of the ratio between the effective resistances of ripe and raw
229 fruits (9.42).

230 3.3 Effective resistance and effective Capacitance versus time Characteristic at 1 kHz

231 To study the variations in the values of impedances offered by the fruit, under test, at 1 kHz, data
232 is extracted from the characteristics shown in Fig.3 &4. It is redrawn in Fig.5. It clearly shows
233 that effective resistance of the fruit under test increases with time and reaches a peak and starts
234 decreasing with the passage of time. Initially when fruit was clearly raw and had green color,
235 effective resistance was lowest and effective capacitance was highest. When fruit started
236 changing colour effective resistance started increasing and effective capacitance started
237 decreasing and reached a highest value and lowest value respectively on the same day as shown
238 in Fig.5. With further delay, effective resistance started decreasing and reached a new lowest
239 value on eighth day. It is the most important characteristic which may be utilized to establish
240 relation ship between condition of fruit and effective resistance and effective capacitance as
241 measured by the bridge. The duration is so selected that it covers all the conditions of fruit from
242 raw to over ripe. The frequency selected is 1 kHz which is suitable with respect to its effect on
243 the fruit due to self heating caused by different type of losses. Resistance characteristic is nearly

244 the inverse characteristic of resistance. It shows that the ratio of effective resistance of ripe to
245 raw fruit is 9.42 while ratio of effective capacitance of ripe to raw fruit is 1/5.42. This fact
246 shows the effectiveness of the resistance measurement over capacitance measurement, to
247 characterize the raw and ripe fruits.

248 4. Conclusion

249 The impedance spectrometric technique has been developed and applied successfully in the
250 characterization of raw and ripe mangos in the frequency range (1kHz to 200kHz). It has been
251 observed that the effective capacitances as well as effective resistances of the samples decrease
252 sharply with increase in frequency (1 kHz to 6 kHz) and finally varies very slowly after 30 kHz.
253 By measuring the effective resistances and effective capacitances of the fruits, at a particular
254 frequency, raw and ripe conditions may be established. The characterization, through impedance
255 spectrometry, will be simpler and low cost at lower frequencies. The effect of random variation
256 of temperature and pressure is also determined and found negligible in comparison of change in
257 effective capacitance and resistance due to ripening process. The ratio between the effective
258 resistances of ripe and raw mango, measured at 1 kHz, is 9.42 while ratio between effective
259 capacitances of ripe and raw mangos is 1/5.42. Hence the effective resistances and effective
260 capacitances of mango fruits may be used to differentiate between raw and ripe mangos.
261 However, the ratio of effective resistances of raw and ripe mangos is more than the ratio of
262 effective capacitances of raw and ripe mangos. Hence effective resistance measurement may be
263 used to differentiate between raw and ripe fruits in the presence of all sources of error for
264 commercial purposes.

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330 **Fig. Captions**

331 Fig. 1 Electrical Equivalent circuit of mango

332 Fig. 2 Photograph of the Experimental set-up

333 Fig.3 Effective Resistance versus Frequency characteristics of Mango

334 Fig. 4 Effective Capacitance versus frequency characteristics for mango

335 Fig.5 Effective resistance and capacitance variations for a mango, with time

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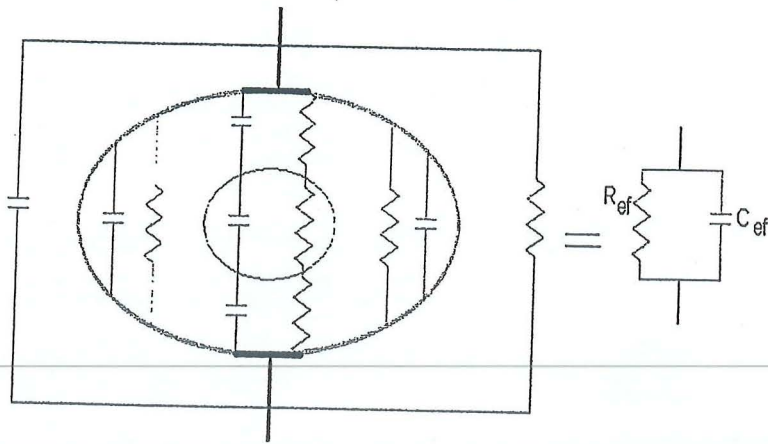
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349 Fig. 1. Electrical Equivalent circuit of mango

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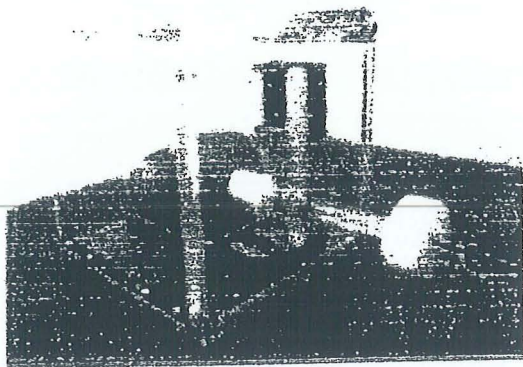
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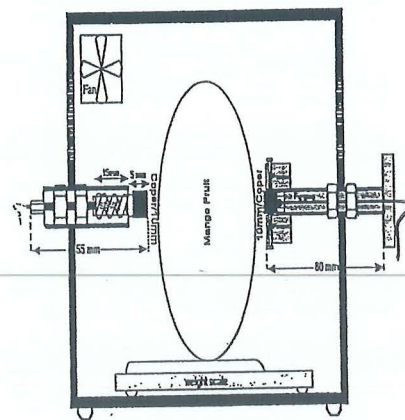


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365 Fig. 2 (a). Photograph of the Experimental set-up



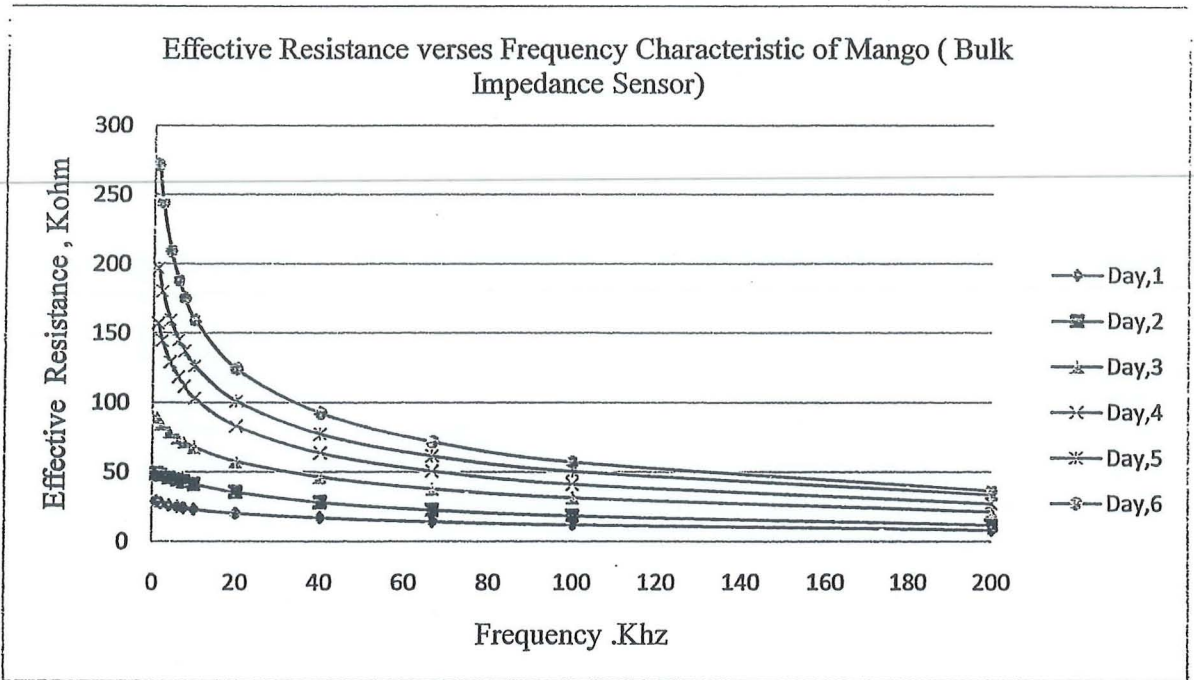
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Fig.2(b) Cross sectional view

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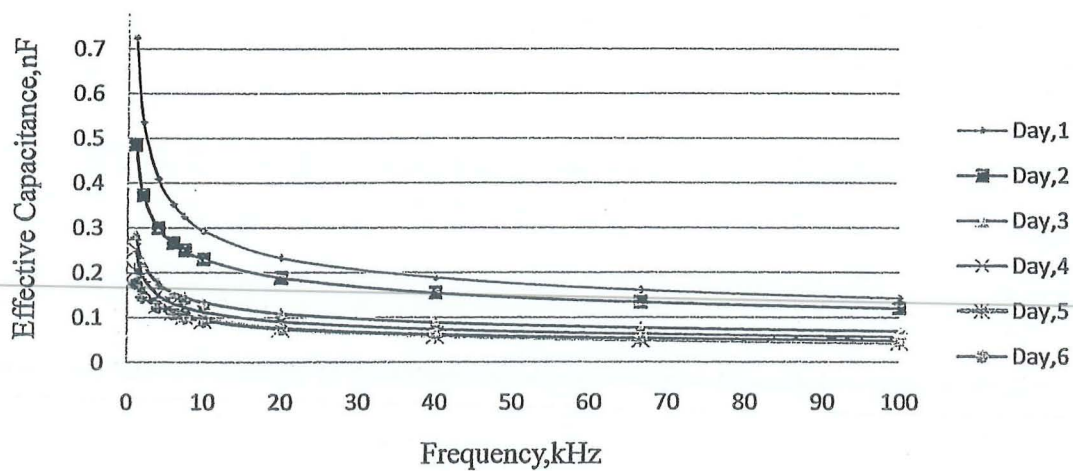
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370 Fig. 3. Effective Resistance versus Frequency characteristics of Mango by Non-Destructive
371 Technique

Effective Capacitance versus Frequency Characteristic of Apple (Bulk Impedance Sensor)



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373 Fig. 4. Effective Capacitance versus frequency characrestics for mango By Non-destructive
374 technique

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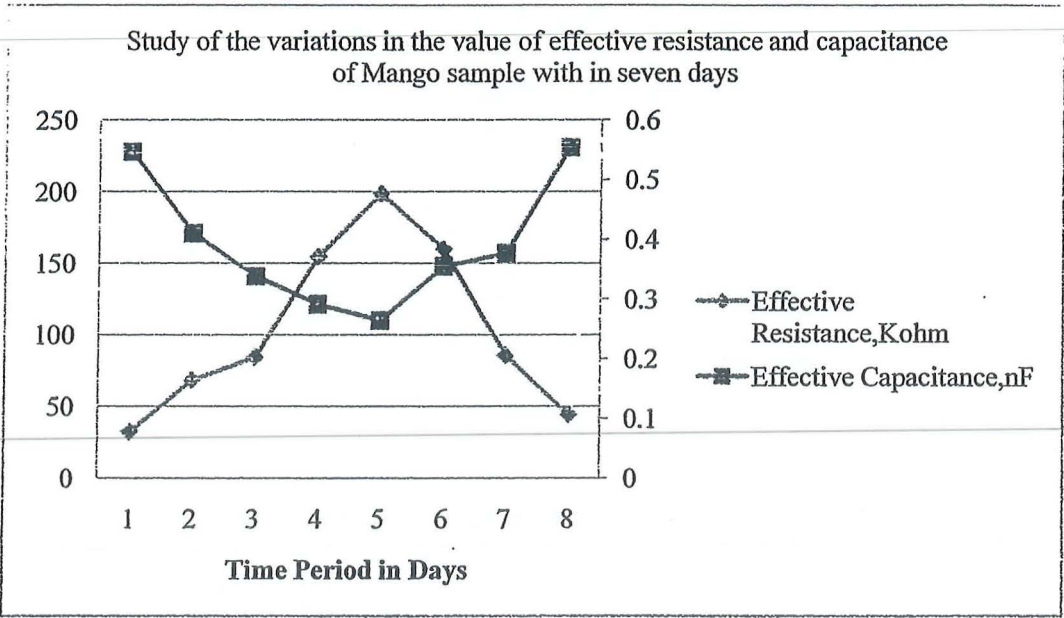
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385 Fig.5 Effective resistance and capacitance variation with time

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396 Table-1 Study of the random variation of the effective resistance and capacitance of a mango sample with
397 respect to contact area of the electrodes and temperature. (Readings are taken at the same point). Applied
398 Frequency 1kHz

Repetition No	Fruit Resistance , K ohm	Fruit Capacitance, nf
1	23.86	0.591
2	25.25	0.583
3	26.31	0.615
4	24.91	0.602
5	25.37	0.622
6	25.83	0.645
7	26.53	0.583
8	25.37	0.591
9	24.91	0.596
10	26.18	0.628
Average Value	25.45	0.605
Standard deviation σ	0.799	0.021

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408 Table 2 Variation of the resistance and capacitance of the mango samples with weight.

	Weight, gm	Resistance, Kohm	Capacitance, nF
SAM 4	247.7 gm	32.54	0.547
SAM3	255 gm	30.24	0.694
SAM 1	263 gm	28.83	0.725
SAM 2	282 gm	29.66	0.677

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Frequency(Khz)	Mango Sample	
Temperature °C	Resistance,Kohm	Capacitance,nF
11	11.86	1.64
11.2	11.77	1.65
11.3	11.73	1.66
11.4	11.72	1.66
11.7	11.65	1.68
11.9	11.64	1.68
12	11.62	1.69
12.2	11.6	1.69
12.3	11.59	1.69
12.5	11.57	1.7
12.8	11.56	1.7
13	11.54	1.71
13.2	11.5	1.71
13.5	11.48	1.72
13.8	11.46	1.72
13.9	11.45	1.72

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