International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-9 Issue-8, June 2020

Quality Assessment of Fruits and Vegetables using Bio-impedance based Expert System

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Abstract: ***World Health Organization (WHO) recommends a daily intake of at least 400 grams of fruits and vegetables, to prevent diet related chronic diseases and micronutrient deficiencies. It is essential to ensure the quality of foods consumed by the population on a daily basis. Quality of fruits and vegetables is governed by nutritional level, appearance, flavor and climate. Quality assessment methods should be environment friendly and should also benefit both consumers and farmers by enhancing taste and increasing yield, respectively. Conventionally employed quality assessment methods like bio-chemical analysis, imaging etc. are destructive, inefficient and time consuming. Bio-tissues are made up of cells with selectively permeable cell membranes and this makes them equivalent to resistive-capacitive network. Such a network impedes an alternating current (AC) excitation signal applied to it. This bio-impedance (BI) is measured through LCR meters, impedance analysers and off-the shelf chip based boards. In this work we have developed an accurate, smart and non destructive bio-impedance based quality evaluation technique. BI is measured as magnitude and phase for 7 days for each variety of fruit and vegetable followed by exhaustive frequency (5 kHz-200 kHz), ripening and rot analysis. BI magnitude increases as number of days advance i.e. with ripening and the phase undergoes considerable decrease with rotting. The system is made smart by incorporating an expert system. 178 samples of bio-impedance data are used to train the expert system and supervised classification is done through Random Forest classifier. Any fruit or vegetable can be classified as 'Good' or 'Bad' immediately and accurately with a maximum accuracy of 98.57%.***

Keywords: Bio-impedance, Expert System, Impedance Analysers, LCR Meter, Quality Assessment , Random Forest.

I. INTRODUCTION

Quality of fruits and vegetables is defined by both intrinsic factors such as genotypic, amount of macro and micro nutrients and water content; extrinsic factors such as size, shape, color, smell, taste, texture; agro-environmental factors such as pests, climate, handling and post harvest decay. Consumer requirement of different grades of ripening of fruits and maturity of vegetables are also to be met. Quality evaluation techniques are essential estimates of yield and profit and ensure the delivery of fruits and vegetables which are at optimum grades and with high nutritional values.

Revised Manuscript Received on June 30, 2020.
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There is a need to have non destructive techniques which can assess both the external and internal quality of products prior to processing, sorting and marketing [1]. Existing methods of quality assessment are physical, optical, acoustic, imaging, semiconductor sensors and chemical analyses. These are suitable for only assessing specific contents (physical, acoustic) or are hazardous (X-ray) or have less penetration depth (optical) or are time consuming and destructive (chemical analyses). Repeated measurements are not possible in these methods since they are expensive techniques and also require laboratory facilities [2].

So, in order to evaluate the quality of fruits and vegetables it is necessary to employ a method which is non-destructive, cost-effective, fast, accurate, user friendly and considers all quality factors. Fruit and vegetable tissues comprise of cells which consists of extracellular, intracellular and membrane structures. Cell structure contributes to the quality of these. Whenever an electrical signal is passed through these tissues extracellular and intracellular structures act as resistors and the membrane which is selectively permeable acts as a capacitor. These offer hindrance to the flow of electric signal like a basic RC circuit.

The biochemical response of fruits and vegetables during ripeness, mechanical injury, and rot affect the electrical properties (impedance, conductance, and dielectric constant) of the tissue. Hence the typical response of the tissues to electrical stimulus changes with the changes in biochemical responses [3]. Electrical impedance measurements are non destructive, simple, cost effective, and less sensitive to external variables. A high frequency low amplitude current or voltage signal is applied to tissue with the help of electrodes. Response of the tissue to this is obtained as impedance [4]. This impedance depicts the characteristics of fruit and vegetable tissues and determines their quality. It can also indicate changes in cellular tissues of products during storage [5].

Frequency based electrical impedance measurement of biological tissue is done through LCR meters, impedance meters and off the shelf chip based devices by various researchers and are reported in the literature. Quality of apples is evaluated by measuring its impedance over frequency of 1 Hz-5 MHz using tetrapolar and bipolar electrode configurations with Solatron 1294 [6], Agilent 4395 [7], and IM3570 LCR meter [8]. Ripeness in mangoes is assessed over frequencies 1 kHz-6 kHz using terminal probes with LCR meters [9]. Strawberry grades are differentiated using impedance phase values over frequencies 1 Hz-1 MHz using bipolar AgCl electrodes with Solatron 1294 [10]. Off the shelf Analog Devices chip AD5933 evaluation board is used to measure impedance of avocado to assess the ripeness levels over 5 kHz-100 kHz using bipolar AgCl electrodes.

A machine learning approach is incorporated along with this to efficiently classify the new products into grades of ripeness [5]. Internal quality of lettuce is deduced from nitrogen content by correlating impedance value and nitrogen levels over 1 kHz-100 kHz using bipolar stainless steel needle electrodes with HiTester LCR meter [11].

Existing methods of quality assessment using BI, focus only on a single variety, i.e. observing the variation of BI values over a certain time period during growth, storage or ageing of the sample variety. It is required to develop a general method to assess quality based on many aspects (eg. frequency, ageing, physical damage etc.) for all the varieties of fruits and vegetables. The most effective solution for this is to use conventional LCR meters. They are readily available in labora-tories and offer exhaustive parametric studies. But LCR meters are frequency limited, bulky and involves manual judgements while interpreting measured values.

It is essential to club it with a smart system in order to eliminate these demerits. LCR meter enhanced by machine learning opens wide vistas for quality assessment. Expert systems (ES) employ faster processors to give immediate quality judgement, minimises number of measurements making it user friendly, nullifies frequency limitation through interpolation and makes accurate decision making through quick learning [12]. Impedance values i.e. phase and magnitude obtained from LCR meters along with variety and frequency, can be considered as features for the expert system.

In this work, 7 varieties of fruits and vegetables are subjected to frequency based, ageing based and rupture based BI measurement analyses over 7 days. Section 2 describes the experimental procedure followed to carry out the analyses. Section 3 presents and elaborates the experimental results obtained. This paper concludes by summarising the key points and also by suggesting insights on future exploration.

II. EXPERIMENTAL SETUP

In the proposed work, impedances of 7 varieties of fruits and vegetables such as apple, banana, brinjal, carrot, cucumber, lady's finger and tomato which are bought from local super-market, washed and dried. Bio-impedance values are observed over 7 days using Hameg HM8118 LCR meter from 5 kHz to 200 kHz. This frequency range is opted in accordance with the dispersion range (5 kHz to 200 kHz) of BI measurement and due to LCR maximum frequency restriction (200 kHz). As the tissue is capacitive in nature maximum information regarding the characteristics of intracellular, extracellular and membrane regions is obtained in this frequency range [13], [14]. Measurement of impedance is done at 24 hrs gap for each variety at 30°C temperature and for different frequencies. Impedance variation with respect to frequency, days and rupture intensity is studied in detail. The impedance values i.e. magnitude and phase, variety and frequency are used as features for the expert system. The expert system classifies the varieties as either 'Good' or 'Bad'. 4 methods of classification are compared based on their accuracies and the best method, Random Forest is used to predict the class of a new sample after training and testing.

A. Block Diagram and Measurement Device

Measurement of impedances of fruits and vegetables is carried out by using Hameg HM8118 LCR Bridge. This LCR meter produces a test voltage signal of 1 V_{pp} over a range of frequency 20 Hz-200 kHz in 69 steps. Range of resistors which can be measured is from 0.01 m to 100 m and capacitors from 0.01 pF to 100 mF . AC test signal can be set between 50 mV_{rms} and 1.5 V_{rms}. The meter expresses average of 100 measurements of impedances as real and imaginary forms as well as magnitude and phase forms in 70 ms [14]. Block diagram of experimental setup is as shown in Fig. 1. The electrode that applies voltage excitation created

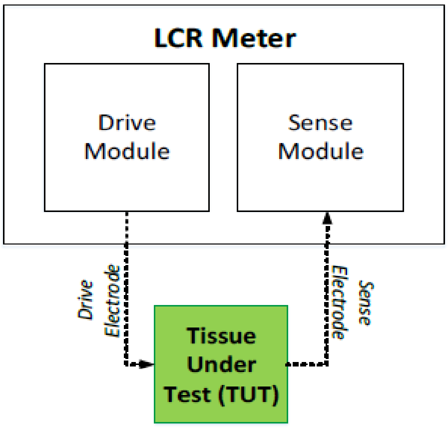


Fig. 1: Block diagram of proposed measurement

by drive module on the TUT is called the drive electrode and the electrode which detects the BI response is called the sense electrodes. Sense module measures BI and displays the magnitude and phase on the display of LCR meter.

B. Electrodes

The LCR meter uses two probes to measure the L, C, R and impedance values. For the present experiment, stainless steel needle electrodes of 4.5 cm are attached to crocodile clips during measurement. A driver electrode and sense electrode are inserted into each sample at a depth of 1 cm and a distance of 2.3 cm between them. This placement is same for all samples. Needles are placed static for accurate measurements and impedance values are measured by attaching crocodile clips to respective needle electrodes while measuring. Since a drive electrode is used for applying voltage excitation and a sense electrode is used to measure impedance response, the configuration is bipolar. Experimental setup to carry out impedance measurement of fruits and vegetables is as shown in Fig. 2.

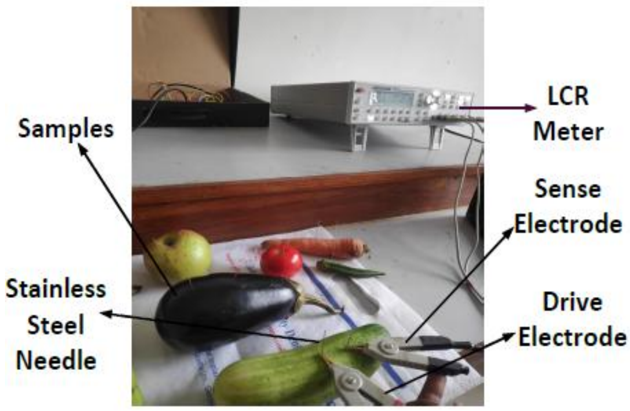


Fig. 2: Experimental setup

C. Measurement Procedure

Impedance measurement is performed for 7 days for the 7 varieties using the LCR meter at a gap of 24 hrs. Impedances in the form of magnitudes and phases at 4 different frequencies (5 kHz, 50 kHz, 100 kHz, 200 kHz) are measured by setting the corresponding frequency on the meter. Phase obtained is negative or lagging due to the capacitive nature of the equivalent circuit of biological tissue [4]. Change in impedance values with respect to number of days is also analysed. On the 7th day i.e. on the day of maximum deterioration, different magnitudes of ruptures are made on the fruit and vegetable surfaces. Impedance is measured for each rupture intensity and recorded. LCR meter measurements are combined with an expert system to efficiently identify whether a fruit or a vegetable is 'Good' or 'Bad'. The features considered for classifying the sample as 'Good' or 'Bad' is obtained from BI measurement. Bio-impedance magnitude, phase, variety and frequency are opted as features for learning. Concept of expert system employed is depicted in Fig. 3. Before incorporating

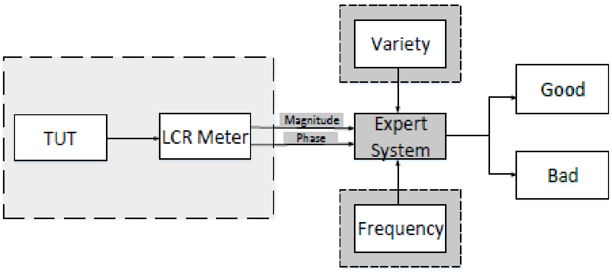


Fig. 3: Block diagram of proposed expert system

the expert system, the best method of classification is identified by comparing the accuracies of some major classifiers. Since the labels are known supervised learning is opted. k-Nearest Neighbour (kNN), Multi Layer Perceptron (MLP), Support Vector Machine (SVM), Decision Trees and Random Forests are the supervised classifiers compared here as they are most commonly used and meant for two class problems. Total number of BI samples used for classification in these methods is 178. Among which, 124 samples are used as the training set and 54 samples are used as the testing set for the 2 class (Good or Bad) classification. In the first trial, 4 features namely variety, frequency, BI magnitude and BI phase are used and in the second trial, 3 features discarding frequency are used. The observations are as follows in Table I. Accuracy

TABLE I: Classifiers and their accuracies

Classifier	Accuracy (%)	
	Classes=2	Classes=2
	Features=4	Features=3
kNN	53.7	57.4
MLP	59.25	61.11
SVM	57.4	61.11
Decision Tree	61.11	62.96
Random Forest	**72.2**	**64.8**

is the fraction of correct predictions by the classifier. It is one of the performance evaluator of classifiers. As it can be seen from the Table I Random Forest classifier has maximum accuracy of 72.2 % for 4 features and 64.8 % for 3 features. Random Forest offers maximum accuracy due to the presence of multiple decision trees. New sample is classified as 'Good' or 'Bad' by expert system based on this intelligent learning.

III. RESULTS AND DISCUSSIONS

Intention of this work is to classify the test sample as 'Good' or 'Bad'. This classification can be done by observing magnitude and phase of all the samples. In one experiment, we have considered three important factors which affect BI of sample namely testing, ageing, physical damage. Accordingly BI is plotted with respect to different testing frequencies (Fig. 4), number of days (Fig. 5) and rupture intensity (Fig. 6). Detailed explanation is as given below. Impedances in the form of magnitudes and phases are recorded at discrete frequencies of 5 kHz, 50 kHz, 100 kHz and 200 kHz using an LCR meter and stainless steel electrodes. Since the bio tissue is capacitive in nature, the phase is negative [13]. Variation of magnitude and phase with respect to frequency on Day 1 for each variety is as shown in Fig. 4.

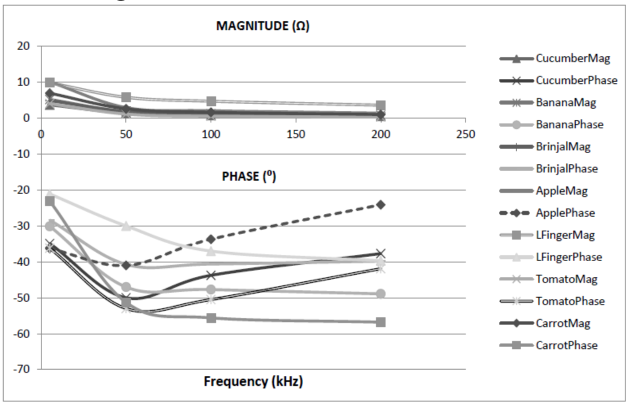


Fig. 4: Variation of magnitude and phase w.r.t. frequency on same day for each variety

It is seen from Fig. 4 that magnitude decreases with frequency and absolute value of phase increases till a frequency and then decreases. It is seen that for majority samples, maximum phase is obtained at 50 kHz. Exceptions are carrot and ladies finger for which the phase goes on increasing with frequency. Recordings are done for 7 days and variation of magnitude and phase with respect to number of days for each variety at 5 kHz as shown in Fig 5.

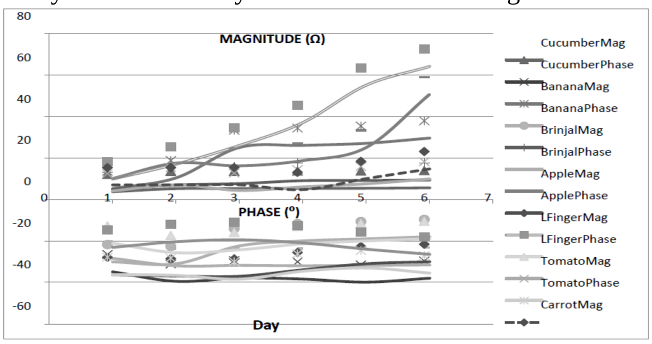
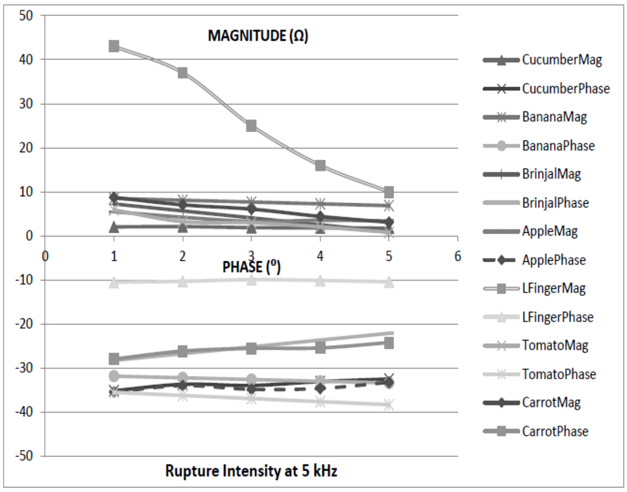
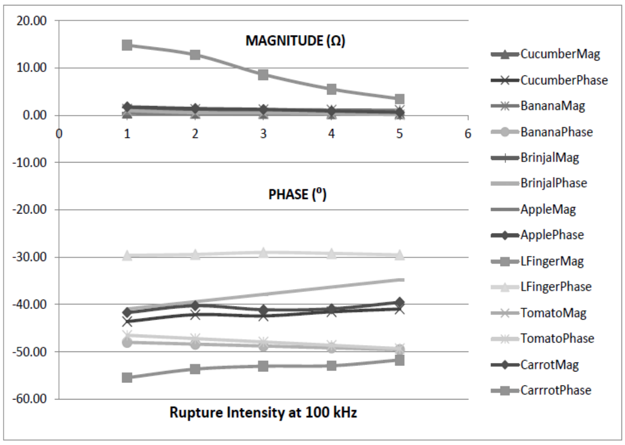


Fig. 5: Variation of magnitude and phase w. r. t. days for each variety at 5 kHz

It can be inferred that as deterioration occurs enzymatic, physical, chemical and biological changes cause more hindrance to the current flow and magnitude of impedance increases. Graph representing variation of magnitude and phase with respect to depth and width at same frequencies (5 kHz and 100 kHz) is shown in Fig. 6.



(a) Impedance versus rupture intensity at 5 kHz



(b) Impedance versus rupture intensity at 100 kHz

Fig. 6: Variation of magnitude and phase w.r.t. rupture intensity at (a) 5 kHz (b) 100 kHz

Rupturing is done manually by using needle stage by stage on Day 7 in addition to deterioration. Rupture intensity is defined as the horizontal deformation made using the needle in addition to the penetration of needle electrodes. Grades define intensity of rupturing i.e. as horizontal penetration increases grade increases. Magnitudes and absolute values of phases of impedances decrease as rupture increase and this behaviour is verified at 5 kHz (Fig.6a) and 100 kHz (Fig.6b), respectively. At 100 kHz the magnitudes of different varieties are almost similar as seen from graph, Fig. 6. Expert system here uses Random Forest classifier to classify a new sample as 'Good' or 'Bad' based on intelligent learning already done by training and testing on the available data. Four features namely, fruit variety, frequency, magnitude and phase are used by the expert system. 10 samples (5 Good and 5 Bad) of each variety are tested with the designed expert system and their quality is predicted. Based on the prediction 6 varieties are classified correctly into 'Good' and 'Bad' whereas 1 'Good' tomato is misclassified as 'Bad'. The accuracy for each variety is calculated as per Equation 1.

$$acc. = \frac{TP + TN}{TP + TN + FP + FN} \quad (1)$$

Where, acc. is the accuracy, FP is False Positive results, FN is False Negative results, TN is True Negative results and TP is the True Positive results. It is seen that accuracy is 100% for all varieties except tomatoes for which it is given as in Equation 2 obtained by substituting values in Equation 1.

$$acc._{tom} = \frac{4+5}{10} = 0{:}9 \quad (2)$$

Where, acc. $_{tom}$ is accuracy for tomato. The average accuracy for the proposed system is obtained as follows in Equation 3.

$$\begin{aligned} acc._{6var} &= 1 \\ acc._{tom} &= 0.9 \\ acc._{7var} &= \frac{6 * 1 + 1 * 0.9}{7 * 1} \\ &= 0.9857 \end{aligned} \quad (3)$$

where, the acc. $_{7var}$, accuracy for the proposed system is obtained as 0.9857 or 98.57 %. The accuracies for each variety and the average accuracy for the expert system is tabulated in Table II.

TABLE II: Accuracy of expert system

Accuracy (%)							
Apple	Banana	Brinjal	Carrot	Cucumber	Lady's Finger	Tomato	**Average**
100	100	100	100	100	100	90	**98.57**

Comparative analysis of existing techniques employing BI measurement is shown in Table III.

TABLE III: Comparative analysis of fruits' and vegetables' quality evaluation methods

Research Work	Device	Electrode Configuration	Frequency	Expert System	Accuracy	Study Purpose	Sample	Inference
Mango	LCR meter	Terminal probe	1 kHz-6 kHz	Nil	N. A.	Robotic arm fruit plucking	Mango	Riper-greater magnitude Rotten-less phase
Lettuce	HiTester LCR meter	Bipolar stainless steel	1 kHz-100 kHz	Nil	N. A.	Nitrogen content	Lettuce	Correlation of nitrogen content and BI
Strawberry	Solartron 1294	Bipolar Agcl	1 Hz-1 MHz	Nil	N. A.	Ripeness	Strawberry	Riper-less phase
Apple	Agilent 4395	10mm depth needle	200 Hz-1 MHz	Nil	N. A.	Storage	Apple	Parameter study
Apple	Solartron 1294	Tetrapolar, Brass	1 Hz-1 MHz	Nil	N. A.	Quality	Apple	Good-constant magnitude Rotten-less phase
Avacado	EVAL-AD5933	Bipolar AgCl	5 kHz-100 kHz	SVM	90 %	Ripeness	Avacado	Rotten-magnitude decreases
Apple	IM3570,Hioki	Bipolar stainless steel	100 Hz-5 MHz	Nil	N. A.	Ageing	Apple	Parameter study
Proposed Work-General	Haimeg LCR meter	Bipolar stainless steel	5 kHz-200 kHz	Random Forest	98.57 %	Quality	Apple, Banana, Brinjal, Carrot, Cucumber, Lady's Finger and Tomato	Ripening, Rotten-magnitude increases Rotten-Phase decreases

The comparative analysis shows that the present work is better in accuracy with respect to other works which has employed expert system. In the other works mentioned above only a single variety has been used for analysis whereas this work is focusing on multiple varieties.

Bio-impedance based quality assessment is intended to be applicable for any variety of fruit or vegetable. Because of this an average accuracy is calculated for all varieties. Both [5] and the present work match as magnitude decreases with deterioration (rupture intensity in this work) but in terms of accuracy the proposed work is superior.

It is a smart and intelligent method as it uses an expert system and also makes an accurate decision regarding quality. It also does a comprehensive study of variation of BI values with respect to variety, frequency, deterioration and number of days. Inference obtained from the study is accurate due to; use of needle electrodes, high frequency compatibility and exhaustive analysis.

IV. CONCLUSION

In this work, we have developed an environment friendly, accurate, smart and non destructive bio-impedance based quality assessment technique for fruits and vegetables which can benefit both consumers and farmers. 7 varieties of samples namely apple, banana, brinjal, carrot, cucumber, lady's finger and tomato are subjected to deterioration over 7 days. From Day 1 the BI of samples are measured using needle electrodes in bipolar configuration using an LCR meter (frequency range of 5 kHz-200 kHz). It is observed that the BI magnitude decreases with frequency and increases with ageing whereas the BI phase initially decreases and then increases with frequency.

On Day 7 study of variation of BI with respect to rupture intensity at 5 kHz and 100 kHz shows the magnitude and phase decreases with increase in rupture as the cell membrane of tissues are damaged.

A Random Forest based expert system intelligently predicts whether a new sample of fruit or vegetable is 'Good' or 'Bad' based on the learning done. The designed system has an accuracy of 98.57 %.

With the advancements in robotics the proposed system can be incorporated into robotic arms for sorting fruit and vegetable samples based on quality.

Environment friendly food control methods can be made possible by managing storage and rotting of samples. Moreover portable and mini BI measurement devices with expert systems can be utilised for plucking best quality samples directly from plantations. Presently, this work is being extended for more number of classes.

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