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Apple Vitality Detection by Impedance Measurement

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Abstract - Apple vitality was detected using impedance measurement. This system provides a nondestructive impedance measurement technique which can measure from 100 Ω to 10GΩ. This system is a microcontroller based, high precision and low power device and it also includes AD5933 chip. It is an Analog Device network analyzer which is a high precision impedance converter system. It combines an on-board frequency generator with a 12-bit analog-to-digital converter (ADC). Apple is excited with multiple frequencies, ranging from 0.01Hz to 100 KHz, ac excitation voltage signals with an appropriate dc bias.

Keywords- Apple, impedance, vitality, bruise, AD5933

I. INTRODUCTION

Impedance of a material is the opposition that the material offers to the flow of electrical charges through it. It can be defined as the frequency domain ratio of voltage to current. Impedance can also be expressed in terms of resistance and reactance. All materials both dissipate and store energy. Resistance (R) is a direct indicator of a material's propensity to dissipate energy while Reactance (Xc) is an indicator of energy storage. Cell membrane consists of a layer of non-conductive lipid material sandwiched between two layers of conductive protein molecules. Cell membrane structure makes them to behave as capacitors when exposed to alternating current. High reactance indicates better health and cell membrane integrity. Reactance (Xc) is offered by cell membranes only, resistance is offered by extracellular fluids. At high frequency current penetrate the cell membrane and passes through both intra and extra cellular fluids, but at low frequency current flows only through extracellular. Thus at high frequency resistance reduces than at low frequency. Cell structure of apple gets destroyed during decaying. As a result the resistance and reactance, that is the impedance value, gets reduced. Thus the classification of good and bad apples can be achieved by impedance measurement technique.

Electrical parameters of apple linearly depend on the mass due to the different amount of charge carriers in it [1]. Impedance was also related to the storage period. During storage time the impedance increases in unripe stage and decreases in eating-ripe and again increase in overripe stage [2]. Puchalski and Brusewitz measured resistance of apples before and after bruising at 1kHz. They used universal impedance bridge and sensor having two electrodes pushed into the fruit. There was a linear relationship between energy absorption and resistance of bruised tissue. Moisture content, soluble solid content, dielectric constant and loss factor remained relatively constant during storage period [3]. Jackson and Harker measured impedance of good and bruised apples. They used two Ag/AgCl electrodes impaled into the apple and a Hewlett Packard precision LCR meter. They found that the impedance of bruised one is lower than the good one and change in resistance at 50Hz was closely related to the bruise weight [4]. In order to eliminate the disadvantages of using the configuration having a single AD5933, a new configuration using two microsystems was proposed. It provides acceptable accuracy, less errors, small power consumption and increased frequency and impedance range [5,6].

Portable impedance analyzers are not commercially available for apple vitality detection. The realized analyzer is miniaturized by using AD5933, a high precision impedance converter system.

II. MATERIALS AND METHODS

Red delicious apple fruits were chose and stored in room temperature. At first the impedance of the apple was measured using LCR meter. The readings were taken for every 12 hours for two months. It was found that the impedance value diminishes as the storage period increases. The impedance value of the sample fruit during storage period was reduced from about 550kΩ to 230 kΩ at 1kHz frequency. Then the impedance of fresh apple was measured using AD5933 impedance analyzer chip circuit. Then the apple was bruised and again impedance was measured. Bruises were induced by dropping the apple from 50-cm height.

A. Impedance Measurements

At first Impedance measurement was done using the LCR meter. The readings are taken at 1 kHz measurement frequency. Electrical contact with the apple was made using Ag/AgCl electrodes. In order to increase the accuracy, high precision impedance converter system, AD5933 was used. A simple circuit using single AD5933 was used first. The advantages of the AD5933 chip are low power consumption and integration of most blocks required for impedance spectroscopy such as, sinusoidal signal generator, A/D converter and hardware DFT module. The on board frequency generator generates stimulus signal with known frequencies. Then the apple sample, which was connected between the input and output ports, was excited with various frequencies. The response current from the apple was converted into voltage by a trans-impedance amplifier. The output voltage of this amplifier was sampled and was processed by a DSP engine at each excitation frequency. Both the real and imaginary components were stored in two 16-bit registers. These registers must be read after each ADC conversion. The real and imaginary results from the DSP are read by the microcontroller using I2C and are further processed. But this circuit only allows to measure current signal flowing through the unknown impedance.

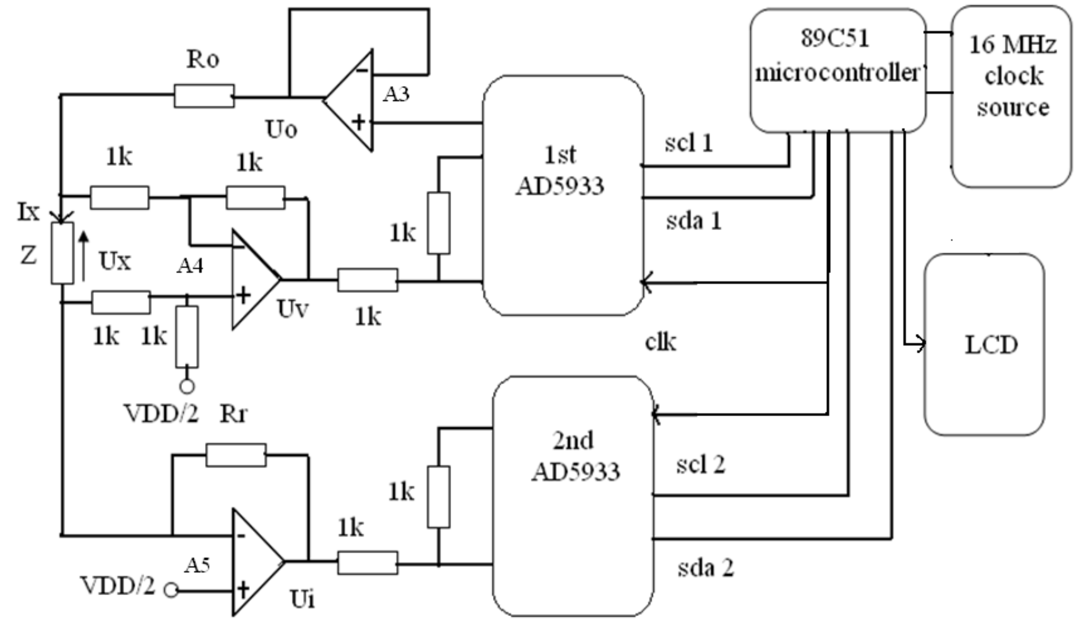


Fig.1 Schematic Diagram of the proposed system

In order to reduce the calibration cycle errors and to increase the measurement frequency range, the impedance measurement circuit is modified with two AD5933 ICs and AD8646 amplifiers. The voltage across the unknown impedance and the current was separately measured using two AD5933 impedance analyzer chip. For that the AD8646 amplifiers characterized by low input current are used in the configuration. A3 acts as a voltage follower. The amplified input current flows through the apple sample (Z) via electrodes. A4 was used as a differential amplifier circuit and its response is given to the first AD5933 IC. The first impedance analyzer chip generates the excitation frequency as well as it calculates the real and imaginary value proportional to the voltage across the unknown impedance sample. A5 is a current to voltage converter and its output was fed to the second analyzer chip, which measures the real and imaginary value proportional to the current signal. The synchronization of the two AD5933 impedance analyzer chips is maintained by providing an external clock source. Using I2C the real and imaginary values are read by the microcontroller from both chips. Then the modulus of impedance is measured using the formula

$$|Z| = \sqrt{\frac{(ReUv)^2 + (ImUv)^2}{(ReUi)^2 + (ImUi)^2}}\,Rr$$

$$Øz = \text{arctg}\,\frac{ImUv}{ReUv} - \text{arctg}\,\frac{ImUi}{ReUi}$$

and detect the vitality of the apple. Øz denotes the phase of the unknown impedance.

III. RESULTS

A good apple weighed 136gm was taken as a sample and measured its impedance. Then the sample was bruised by dropped it from a height of 50cm. After 15 minutes the impedance of the bruised apple was measured and it was found that the impedance was reduced by about 1KΩ. After 50 minutes again measurement was taken and was reduced by about 2KΩ. As a result of bruising both the reactance and resistance of the apple was reduced. This means that the volume of apple tissue accessible to current flow increases by bruising. The impedance characteristics of a fresh apple and a bad apple were measured using single AD5933 chip circuit. Table1 shows the experimental values at different frequencies for the good and bad apple. It was found that there was 400Ω difference between good and bad apple in both resistance and reactance.

The accuracy of the proposed impedance measurement device, having two AD5933 chips, was verified by using various ranges of resistors, for different Rr and Ro combinations at different frequencies ranging from 4khz to 100kHz. The accurate value of resistors was measured using Agilent 34401A digital multimeter. It was found that the error of the impedance magnitude is in the range from +1 to -2.

TABLE I: EXPERIMENTAL VALUES AT DIFFERENT FREQUENCY

FREQUENCY (Hz)	GOOD APPLE		BAD APPLE	
	R	I	R	I
100	5077	3712	4170	2799
500	5146	3805	4017	2658
1k	5120	3567	4086	2681
5k	4863	4213	3870	2966
10k	4700	4114	3912	3023
15k	4978	3642	4125	2713
20k	4936	3558	4150	2695
25k	4684	3962	3935	3019
30k	4981	3661	4158	2670
35k	4932	3547	4151	2687
40k	4982	3671	4112	2717
45k	4976	3637	4170	2711
50k	4980	3597	4190	2726
55k	4956	3580	4179	2722
60k	4988	3623	4201	2725
65k	4707	4070	3946	3092
70k	5016	3738	4156	2779
75k	5015	3685	4173	2777
80k	5038	3736	4160	2784
90k	5020	3681	4167	2781
100k	5034	3680	4161	2782

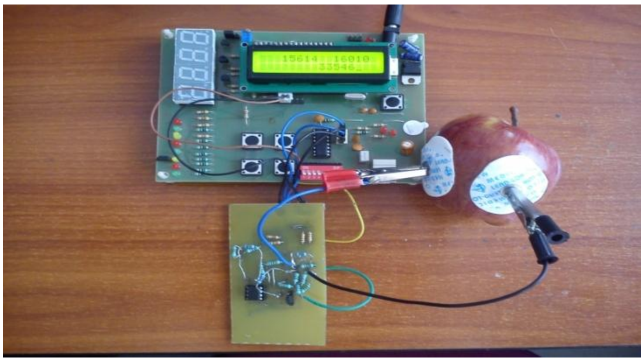


Fig.2 Experimental setup of the proposed system

TABLE II:RELATIVE ERROR OF THE IMPEDANCE

R(kΩ)	Error (%)
0.056	(-0.7,1.03)
0.330	(-1.7,-0.19)
0.6769	(-0.4,0.3)
1.49	(-0.6,0.26)
3.3	(-0.15,1)
4.688	(-1.03,-0.21)
5.599	(-1.1,-0.43)
7.53	(-1.16,-0.57)
9.766	(-1.61,-0.58)
15.095	(-1.9,-0.19)
21.9	(-1.38,0.19)
32.8	(-0.82,-0.64)
47.295	(-0.9,-0.14)
56.206	(-0.06,-0.78)
68.139	(-0.14,-0.72)
100.4	(-1.2,-2)

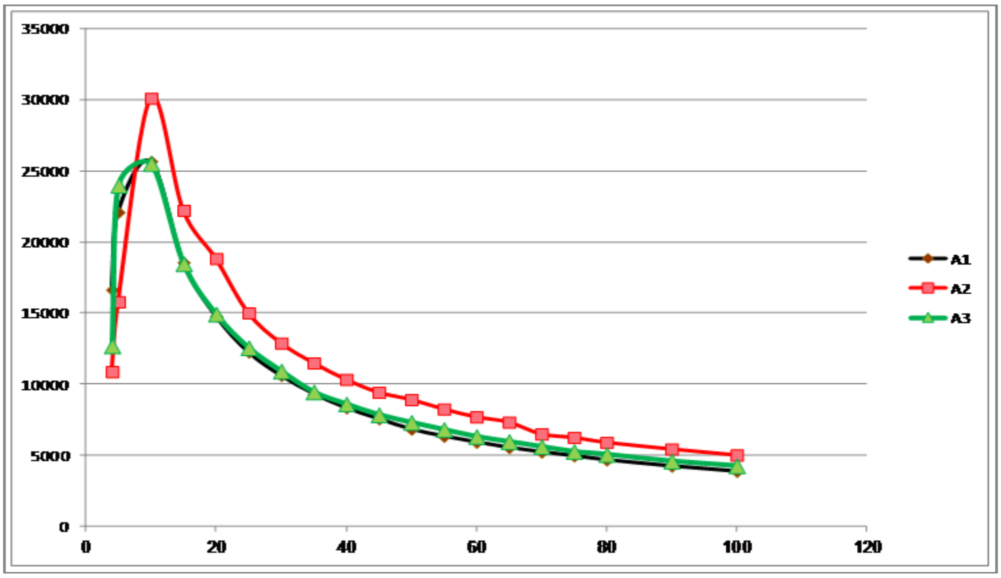


Fig.3 Plots of frequency against impedance of four different apples. A1 is bad, A2 is good and A3 is bruised apple.Fig4: Plots of frequency against impedance of four different apples. A1 is bad, A2 is good and A3 is bruised apple.

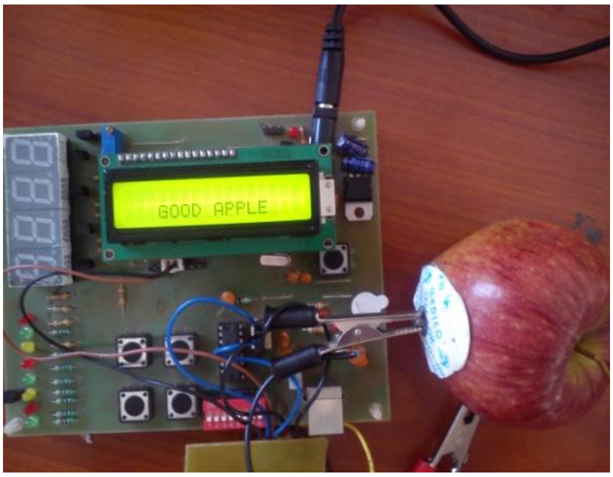
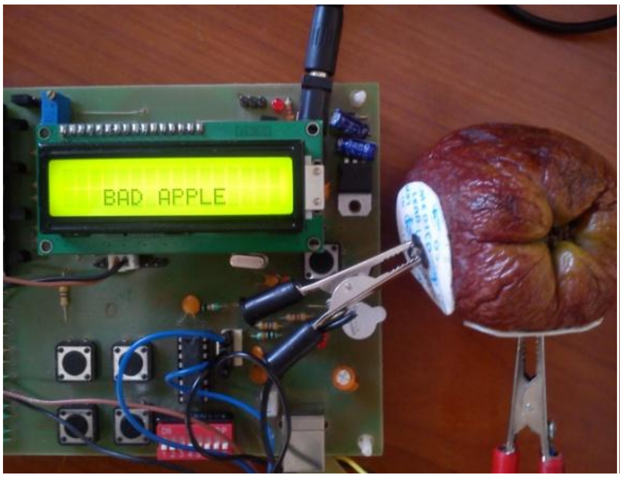


Fig.4 Good Apple Detection

Three Red delicious apple fruits, one good, one bad and a well bruised apple are chosen and the impedance of the apples was measured using the proposed impedance measurement device. It was found that the impedance of good apple is higher and for bad and bruised apples the impedance is low and they cannot reach the peak point of a good apple as it is shown in the graph. From the graph (Fig 3) it is apparent that the change was most at 10 kHz frequency. Thus the classification of good and bad apples was achieved using the proposed device.



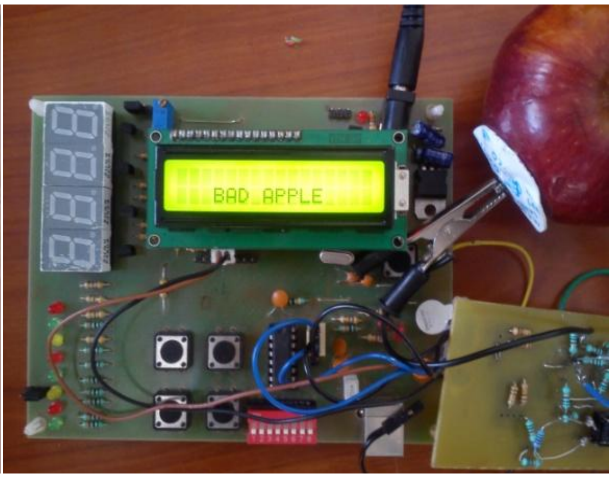


Fig.5 Bad Apple Detection

Fig.6 Bruised Apple Detection

IV. Conclusions

The proposed impedance measurement device is a powerful tool for the vitality detection of apple. The electrical impedance measurement was performed by Ag/AgCl electrodes without any physical damage to the fruit. This portable system is a high precision, low power, microcontroller based device. The AD5933 provides an accurate low cost solution to impedance measurement. It was found that the error ranges from +1 to -2 for the magnitude of impedance. The electrical impedance and weight of the apple decreased during storage time. The impedance reduced for bruised apple and high for good apple.

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