Design and Development of a Portable Banana Ripeness Inspection System

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Abstract: Automatic control of environmental conditions is an important problem of banana ripening treatment. In this study, a capacitive sensing system was designed and developed. In this method banana fruit is placed in the capacitive sensor as a dielectric material and then the capacitance of sensor is measured. Experiments were carried out with 10 kHz to 10 MHz sinusoidal frequencies. A consistent decrease of ε_b had occurred at 100 kHz and 1 MHz frequencies when banana had been ripened. A high correlation was observed between ε_b and ripening period (R^2 = 0.96) at 100 kHz frequency. This system has the following characteristics: rapid response, simple operation, non-destructive measurement, and low cost.

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1. Introduction

Recently, capacitive sensors have been used for property determination of agricultural products. The earliest use of capacitive sensor in agriculture as a function of a sensor refers to 80 years ago. The earlier application of this type of sensor was in sensing grain moisture content. The next application of capacitive sensor is qualification of agricultural products. Kato (1997) investigated the relationship between density and internal quality of watermelon. He developed a new electrical method for density sorting of spherical fruits, which measured the volume of fruit by electric capacity and mass by electronic balance. Jarimopas et al. (2005) designed and developed an electronic device with a cylindrical capacitive sensor to measure the volume of selected fruits and vegetables. They reported the electronic device volume measurements of a calibration set of 30 samples correlated very well with those produced by the water displacement method. The R^2 values for watermelons, large cucumbers, wax gourds and guavas were 0.999, 0.957, 0.999, and 0.99, respectively. Rai et al. (2005) designed and developed an electronic device with a parallel plate capacitor to measure the moisture content of selected grain. They reported that the developed instrument was working satisfactorily for all practical purposes in the range of 5-25 % of grain moisture with an accuracy of ± 1%. Ragni et al. (2006) used a sine wave radio frequency oscillator with parallel plate capacitor sample probe to predict the quality of egg during storage period. They noted the suggested models enabled to classify samples of shell eggs, while they were not useful to assess with accuracy a single egg. Kumhάla et al. (2009) tested a capacitive throughput sensor for potatoes and sugar beets. The principle of the sensor was based on the fact that the dielectric constant of an air/material mixture between two parallel plates increases with material volume concentration. They developed theoretical model for a capacitive throughput sensor. Soltani and Alimardani (2011) investigated correlation between moisture content and dielectric constant of pea and black-eyed pea. They obtained best results at 1 MHz frequency for pea and black-eyed pea with R^2 of 0.994 and 0.999, respectively.

To control the condition of banana ripening treatment and having a good ripened banana fruit, an expert person is needed for determining the level of banana ripeness. Sometimes, banana fruits do not reach to full-ripe step and so the green spots remain on the peel of banana. This problem is because of manual controlling of ripening treatment. To achieve a good ripening, an online controlling system is essential. This work aims to design and develop a device to monitor the ripeness level of banana fruit during ripening treatment and control ripening conditions such as temperature, air moisture content and ethylene concentration.

2. Materials and methods

Sample preparation

The Cavendish variety of banana fruits transported from the Ecuador was used. The banana fruits have been stored at 14ºC temperature when they were transferred. Forty three fingers of banana were randomly selected from banana boxes in a ripening room of Damirchiloo warehouse located in Karaj city, Alborz state, Iran. The experiment was carried out at the airtight ground-warehouse with storage humidity level of 85% - 88% for five days, the time needed for completing the ripening treatment of fruits. At this site, ripeness is currently assessed visually by comparing the peel color of banana with standardized color charts that describe various stages of ripeness. In trade market, seven ripening stages of bananas are usually discerned (Figure 1). Color stage is judged visually by using a chart scale provided to categorize banana based on its level of ripeness. On the first day, banana fruits were at stage one (0% ripened) and on the fifth day, they were at stage six (100% ripened). Ethylene gas with 1000 ppm concentration was treated about 24 hours on first day. It is very important to control temperature, humidity and ethylene gas concentration in the ripening room. In order to give a good artificial climacteric rise of banana fruits during the ripening, electrical measurements were performed in the ripening room. The experiments were conducted in controlled temperature room at 15.5 °C. To measure capacitive properties of banana, a rectangular parallel plate capacitor with 25 cm in length and 10 cm in width was constructed as a standard hardware instrument. The conductive plates were selected from aluminum materials because of its consistency that would not be easily ionized, as a factor that will ruin the results of experiments.

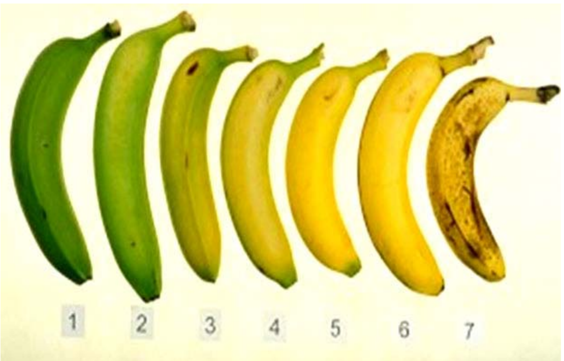

Figure 1. Color chart of banana fruit to recognize the stage of ripeness [1].

Electrical measurements

To study the feasibility of this method, an experimental electronic measuring system was developed. The system is composed of a function generator, data acquisition card and a personal computer. To extract the dielectric constant (ε_r) of the material in the sensor, an AC current was needed, because the DC current is not able to pass through the capacitive sensor. A sinusoidal function generator (Model: AM-1300, Korea) was used to generate sweep sine wave from 10 kHz to 10 MHz. To measure the output voltage of sensor, a data acquisition card (Model: APC-40, Korea) with 100MS/s data sampling rate was used. Figure 2 shows the block diagram of ε_r measuring system. To avoid any conduction of fruit because of the banana being in contact with capacitor plates, samples were suspended between the sensor's plates.

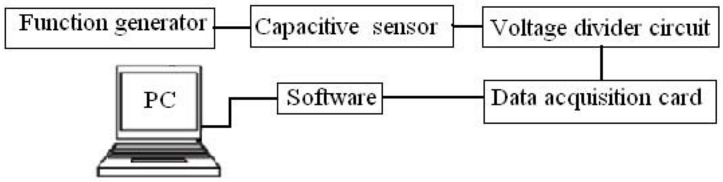

Figure 2. The block diagram of experimental measurement system.

Estimation of banana fruit dielectric constant

When a banana sample is suspended through the sensor, an air gap is introduced between banana fruit and plates, therefore the dielectric material through the capacitive sensor is a mixture of air/banana fruit, and in fact, a series-parallel capacitor is formed. To estimate the banana fruit dielectric constant (ε_b), a model was proposed by Soltani et al. (2011). In their proposed model, the projected area and thickness of banana fruit is needed. Soltani et al. (2010) developed a new method to predict the projected area of banana as functions of fruit dimensions.

Design of capacitive sensing unit

In order to predict the ripeness percent of banana fruit in warehouses, an electronic unit was designed and developed. The electronic device for ripeness measurement has four components: two rectangular parallel plate capacitor, electronic circuitry, microcontroller, and display (Figure 3). Measuring of ε_b initiates after the banana is placed through capacitive sensor on two small brackets. All voltage measurements, calculations and analysis operations are done by microcontroller and then results of ripeness estimation are shown on the display.

The circuit diagram for predicting the ripeness stage of banana fruit is shown in Figure 3. The ATmega 32 microcontroller is the principal part of the system. The ATmega 32 converts analog voltage to digital voltage, estimates ε_b and hence of banana ripeness level. The main components of sinusoidal signal generator circuit are IC-XR2206, resistors R1 and R3. R1 at pin 7 provides the desired frequency tuning and R3 at pin 3 adjusts the amplitude of signal. The output voltage from sensor is converted to DC current by a diode bridge, and then the A/D unit of ATmega 32 measures the output voltage. The system had been calibrated by standard capacitors previously and relation between measured voltage and capacitance was extracted. The dimensions of banana fruit are entered to microcontroller by a 4×4 keypad, finally the results of banana ripeness prediction is displayed on a 16×2 characters LCD (Figure 4). Figure 5 shows the flow diagram of banana ripeness sensing program.

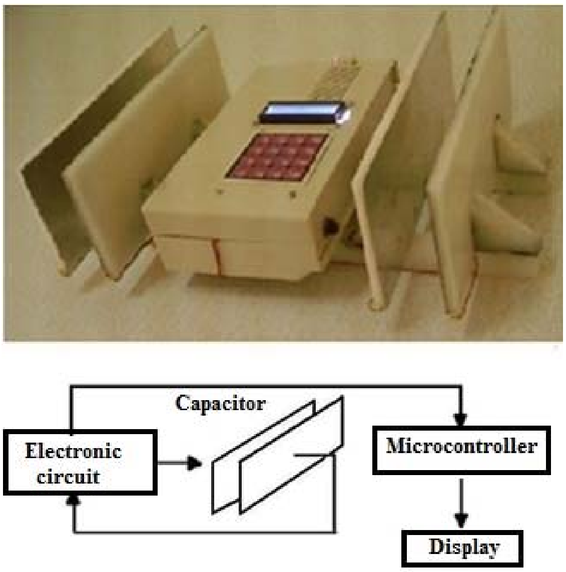

Figure 3. Schematic diagram and designed system for ripeness level prediction.

3. Results and discussion

Relation between percent of ripeness and ε_b was investigated at 10 kHz, 100 kHz, 1 MHz and 10 MHz frequencies. Results of linear regression are presented in Table 1. The highest value of R^2 (~0.96) was obtained at 100 kHz. Therefore, the 100 kHz sine wave was selected for production of AC current and calibration of designed system. Relation between percent of ripeness and ε_b at 100 kHz is shown in Figure 6.

Table 1. Linear regression between ripeness percent and ε_b.

Frequency	R^2	Linear regression
10 kHz	0.811	$P_r = -75.45\ \varepsilon_b + 350.3$
100 kHz	0.96	$P_r = -178.5\ \varepsilon_b + 804.47$
1 MHz	0.937	$P_r = -304.8\ \varepsilon_b + 1374$
10 MHz	0.6	$P_r = -198.6\ \varepsilon_b + 998$

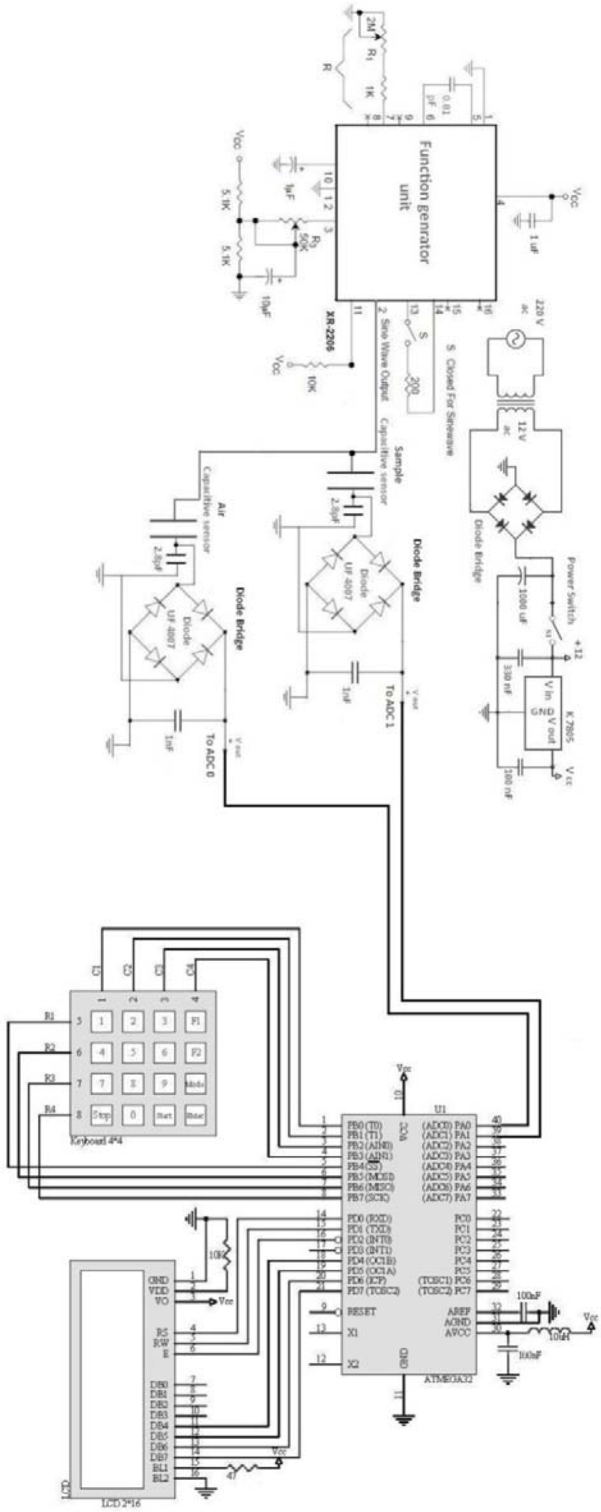

Figure 4. Electronic circuit diagram of the device for banana ripeness measurement.

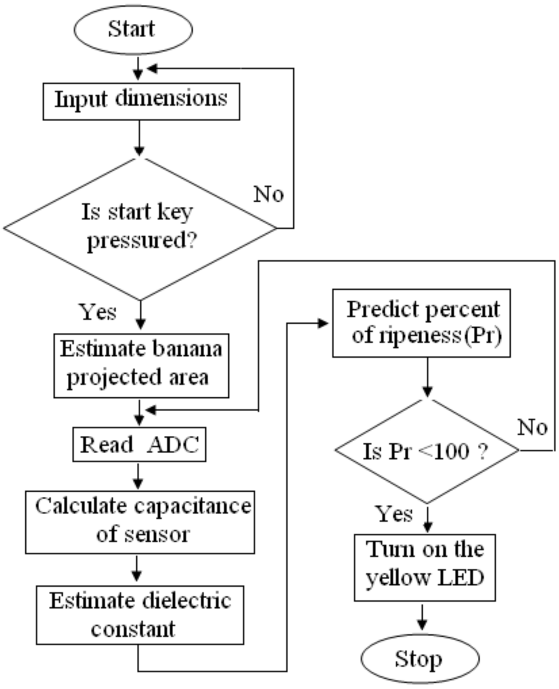

Figure 5. Flow chart of banana ripeness predicting program.

The slope of line was found by means of regression analysis. Since the initial values of dielectric constant differed among samples, to obtain calibration equation for each sample, the first day's dielectric constant, ε_{b0}, was used as the abscissa. The level of ripeness is computed by Eq. (1):

$$P_r = -178.5(\varepsilon_b - \varepsilon_{bo}) \tag{1}$$

Where P_r is the percent of ripeness, ε_b is dielectric constant of banana, and ε_{b0} is the dielectric constant of banana in first measuring and -178.5 is the coefficient of calibration.

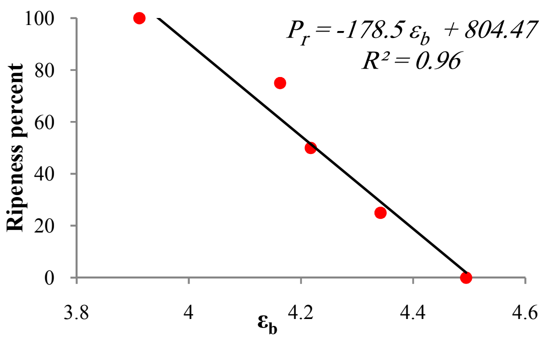

Figure 6. Correlation between percent of ripeness and ε_b.

4. Conclusion

A low cost device for predicting the ripeness level of banana fruit was designed and built. This unit estimates the ripeness level of banana by its dielectric constant. The designed system can predict the ripeness level of banana fruit reliably. By this unit, the condition of ripening room such as temperature can be controlled automatically. Dimensions of sample had a direct effect on ε_r. The proposed model aiming to eliminate the effects of banana mass and air gap needs to dimensions measurement operation, so the operator need to measure dimensions of banana and inter into the system.

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