Development of a Capacitive Sensing Device for Prediction of Water Content in Sugarcanes Stalks

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Abstract

Practically, all properties of agricultural crops depend on moisture content. A new parallel plate capacitance sensor was built to relate the moisture content and dielectric properties of sugarcane stalks. The results revealed a relatively strong quadratic relationship between the moisture content on green weight basis of sugarcane material put through the plates of sensor and the measured voltage (mV) by capacitance sensor circuit output. The coefficient of determination (R^2) was 0.91. Some other samples were used to test the results and there was a high correlation between calibrating and testing samples for the device and the coefficient of determination (R^2) was found to be 0.95. More research is suggested for improving the electronic circuit and investigation about the sensor type is suggested.

Keywords: *Dielectric Constant, Agricultural Crops, Moisture Content, Capacitance Sensor, Sugarcane*

1. Introduction

Extreme conditions of either drought or excess of moisture often occur during the life-time of a crop. Farming practice shows that both of these conditions can be helpful to optimum development of a crop. It is the task of management to create conditions under which the plant can absorb moisture at optimum efficiency. The level of the water utilization efficiency factor, which could be regarded as the amount of water consumed to produce one tone of cane over a period of time, is a useful indicator of managerial efficiency.

Sugarcane (*Saccharum officinarm L.*) is an important raw material for the sugar industries [4]. A high positive correlation between the effective moisture supplied by rainfall and cane elongation can be observed in the field. A practical way of monitoring the uptake of moisture as related to cane growth is to determine the moisture content, on a green weight basis. When this moisture index (*MI*) is well above 74% of green weight, it indicates that the availability of soil moisture is sufficient to ensure satisfactory growth of cane. As the moisture level decreases, either during the dry season or as a result of a managed drying off regime, sugar and other dry matter is accumulated in the cane stalk.

Various methods were generated for determining the moisture content of agricultural crops. A typical method is the oven drying technique, which is a destructive and time-consuming method. Microwave spectroscopy is an appropriate technique for estimating the moisture content of the agricultural materials [5, 8]. The moisture content can be also determined by using neutron moisture gauges, which exploit the dependency of neutron parameters on the average hydrogen concentration [9].

Infrared and laser light absorption spectroscopy are used for measuring the surface moisture content in various materials [3], but these techniques need expensive instrumentation. However, using capacitive sensing method is a simple, express and economical technique that can be used to estimate the moisture content of agricultural materials. Because of these benefits, capacitive sensor techniques are applied in precision agriculture. For example, Jarimopas *et al*., (2005) [6] designed and developed an electronic device with a cylindrical capacitive sensor to measure the volume of selected fruits and vegetables. Afzal *et al*., (2010) [1] estimated leaf moisture content by measuring the dielectric constant of leaves in five different types of crops. Soltani *et al*., (2011) [11] designed and developed an electronic device with a capacitive sensor for evaluating banana ripening status. Júnior (2008) [7] designed a capacitive moisture meter for combines. Trabelsi *et al*. (2009) [14] measured the dielectric properties of shelled peanuts to estimate the moisture content. Weidong (2007) [15] designed and developed an on-line monitoring system to measure the moisture content of grain during the drying process. Rai *et al*. (2005) [10] designed and developed a capacitive moisture meter for grain (wheat, paddy, sunflower, mustard and soybean). Soltani and Alimardani (2011) [12] designed and developed an electronic device for determining corn and lentil moisture content.

Gradinarsky *et al* (2006) [5] found that the measured complex dielectric constant of the material will be affected by a number of additional factors, some of which are as follows: the varying density of the material seen by the sensor and the varying temperature of the material.

The possibility of the moisture content determination could be useful for the aim of management in sugarcane fields. On the basis of these findings, the main aim of this research was to establish a non-destructive and rapid measuring method using a capacitive sensor for predicting sugarcane stalks moisture content.

This work was conducted in order to find out whether a relationship exists between the moisture content of material put through the capacitance sensor plates and its output signal.

2. Material and Methods

2.1. Sample Preparation

Sugarcane stalks harvested on October, 2011 from a field in Debel Khazaie, Ahvaz, Iran were transported to the Physical Properties of Materials Laboratory, Department of Agricultural Machinery Engineering, Faculty of Engineering and Technology, University of Tehran, Karaj, Iran. The stockpile sugarcane was stored (1 months) indoors until the time of the experiments in the laboratory having air conditions of about 25 °C and relative humidity of about 55%. Samples of sugarcane stalks of approximate length of 25 cm were cut using a bandsaw with fine blade.

In order to approach the higher moisture levels and to prohibit geminating, the sugarcane stalks must be placed near the vapor of water; so the samples were put in saturated air in an isolated box at 30˚C for 24 hours. To achieve the lower moisture content levels, the oven method was used at 103˚C for providing 5 levels of moisture contents with time duration of 2 hours for each level. After providing each level, the voltage of each sample was measured with an electronic device and finally the samples were kept in an oven at 103˚C for 72 hours to determining the absolute moisture content of samples at each level.

2.2. Instrumentation

In order to predict the various moisture contents of sugarcane stalks, an electronic device was designed and developed. The device for moisture content measurement has four components: a rectangular parallel plate capacitor, electronic circuitry, microcontroller, and display (**Error! Reference source not found.**). Measuring the voltage is presented after the sugarcane billet is placed on the capacitive sensor plates.

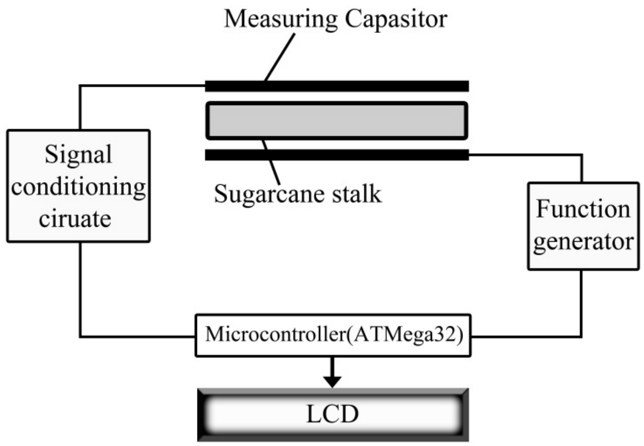

Figure 1. Block Diagram of Instrument for Predicting the Moisture Content of Sugarcane Billet

2.3. Experiments

Dielectric measurement of sugarcane stalks was carried out at 5 levels of moisture content. After providing each level, they were kept at room temperature (25 ℃) to revoke the effect of temperature in the measured voltage. After electrical experiments, the moisture content of each sample was measured using the oven method. Moisture content (M.C) was computed on dry basis by Eq.1. Measurements were accomplished in the laboratory with an average room temperature of 25 ˚C.

$$M.C\% = \frac{w_w}{w_d} \times 100 = \frac{w_i - w_d}{w_d} \times 100 \qquad \text{Eq. (1)}$$

where w_i is the initial weight of sample, w_w is the weight of sample water and w_d is the weight of dry sample.

Microsoft Excel 2010 was used to analyze data and determine the regression models between the studied attributes. Also, SPSS (2007) version 16.0 [13] was used for preparing T-test for analyzing the test results.

3. Results and Discussion

3.1. Investigation of Relationship between Moisture Content and Voltage

3.1.1. Each Sample between Levels: Table 1 shows five selected samples of sugarcanes billets at five different levels of moisture content and measured voltage (mV) for each level. Also the coefficient value (R^2)for linear regression between different levels for showing correlation between moisture content and measured voltage of each sample are presented. According to R^2 values, a high correlation was observed between M.C. and measured voltage at each sample.

Table 1. Relationship between Five Sample of Sugarcane Stalks Measured Voltages (mV) for Five Level and Moisture Content (M.C.) of Samples (w.b. %)

		Level 1	Level 2	Level 3	Level 4	Level 5	R^2
Sample 1	M.C.	73.28%	70.77%	69.41%	68.34%	65.97%	0.95
	Voltage	193	182	175	172	168	
Sample 2	M.C.	68.95%	66.86%	64.98%	64.06%	62.27%	0.95
	Voltage	217	205	193	190	187	
Sample 3	M.C.	69.95%	68.99%	68.17%	66.99%	65.06%	0.94
	Voltage	195	190	185	182	178	
Sample 4	M.C.	72.33%	71.50%	68.39%	66.25%	63.30%	0.97
	Voltage	163	161	153	151	147	
Sample 5	M.C.	70.98%	70.36%	68.98%	67.31%	63.84%	0.94
	Voltage	163	161	158	156	153	

The relation between measured voltage and moisture content (M.C.) of sugarcane stalk samples are presented in Figure 2. A high correlation was observed between measured voltage and moisture content for each sample. When the moisture content of the samples was increased, an increase in measured voltage was observed. This increase was vivid in each sample and was independent from the shape of the samples and their physical properties and it can be indicated that there was a high correlation between the moisture content and measured voltage for each sample. In each curve, level five is located at the top of the curve and level one is located at the bottom of the curve. This upheld the reduction of voltage with decreasing the moisture content of the samples; also in each sample, the curves are not crossover and this may be caused by the difference between samples' physical properties.

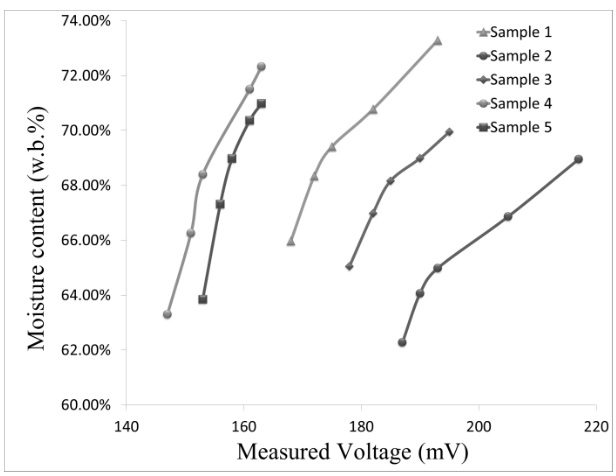

Figure 2. The Relation between Measured Voltage and Moisture Content (M.C.)

The best equation that fitted to data was found as a quadratic function. The results of the regression analysis (R^2) are presented in Table 2. The lowest value of the coefficients of determination was found in sample two (R^2 = 0.9721) which is an acceptable value. It means that the quadratic function can be fitted to relate the voltage-moisture content as well.

Table 2. The R^2 Values for Quadratic Function between Moisture Content and Measured Voltages for each Sample

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
R^2 values	0.9817	0.9721	0.9918	0.9937	0.9992

3.1.2. Whole Samples: Figure 3 shows the relation between moisture content (M.C.) and measured voltage of sugarcane stalks. According to R^2 = 0.2184 presented in Figure 3, there was no reliable correlation between the measured voltage and the moisture content of the sugarcanes stalks. This is justified by different reasons, for example: shape of samples, amount of rudes in the surface of samples, different physical properties for each sample such as mass, dimensional parameters and their volumes.

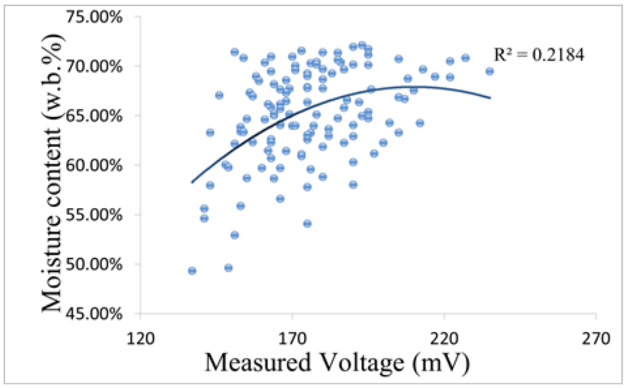

Figure 3. Relation between Moisture Content (M.C.) and Measured Voltage (mV)

3.1.3. All Samples with Respect to the Size

The mass of samples was used as an index for physical properties of sugarcanes stalks; Figure 4 presented the correlation between the measured voltage in per mass unit (M.V.M) (mV/gr) and moisture content of samples in per mass unit (M.C.M) (w.b%/gr). With an increase in M.C.M, the M.V.M values were also increased; and at higher M.C.M, the curve is smoother. A high correlation (R^2=0.9136) was observed between M.V.M and M.C.M for sugarcane stalks (Table 3).

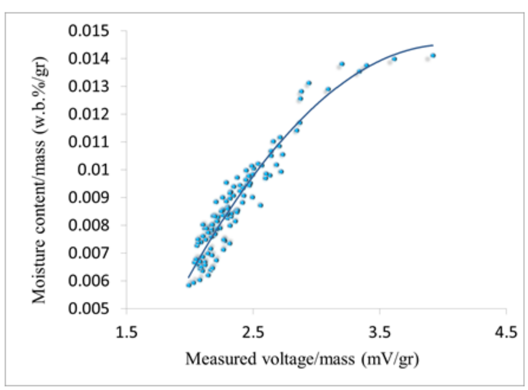

Figure 4. Relationship between Moisture Content per Mass Unit (w.b%/gr) and Measured Volume per Mass Unit (mV/gr)

Table 3 presents some of the statistical analyses of these results and also presents the equation between the two parameters. The R^2 values can be explained as the proportion of the variance in the voltage that the system is shown attributable to the variance in the actual mass measurements. The best equation that fitted to data was found as a quadratic function.

Table 3. The Summarized Relation between M.C.M and M.V.M and its Equation

	Min	Max	Mean	Std	Equation	R^2
M.C.M (w.b.%/gr)	0.0058	0.0141	0.0088	0.0019	$M.C.M = -0.002M.V.M^2 + 0.0161M.V.M - 0.018$	0.9136
M.V.M (mV/gr)	1.9895	3.9188	2.3709	0.3292		

3.2. Test Results

After calibrating the electronic device, fifty eight other samples of sugarcane stalks were tested for verifying the result of the calibration. The minimum, maximum, average values and standard deviation of sugarcane stalks moisture content in per mass unit (w.b%/gr) measured with oven method and predicted with capacitive sensor method are presented in Table 4.

Table 4. Relationship between Measured and Predicted M.C.M

	Min	Max	Mean	Std	R^2
Measured M.C.M (w.b.%/gr)	0.0058	0.0175	0.0097	0.0027	0.9537
Predicted M.V.M (mV/gr)	0.0067	0.0142	0.0093	0.0020	

The results of correlation between predicted and measured moisture content of sugarcane stalks per mass unit is shown in Figure 5. The R^2 value was calculated as 0.9537; this high R^2 value presented a vivid correlation between the capacitive sensor method results and the oven method results. The suggested capacitive sensor method provided more than 95% accuracy in estimating the value of sugarcane stalks moisture content.

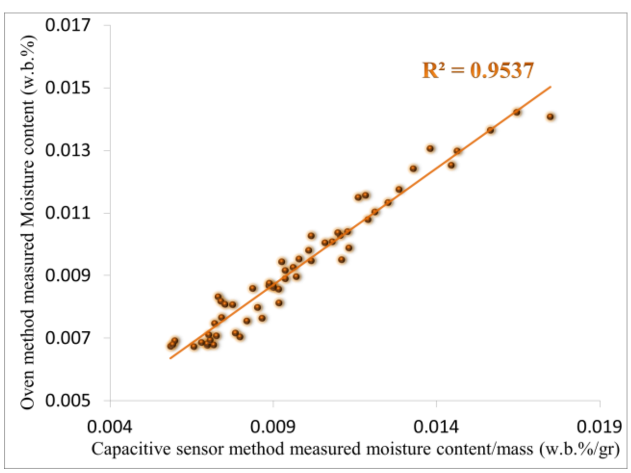

Figure 5. Relation between Predicted and Measured Moisture Content of Sugarcane Stalks per Mass Unit

The paired T-test comparison was performed for investigating the relationship between actual and predicted results. The mean moisture content in per mass unit difference between capacitive sensor method and oven method and the Standard Deviation (S.D) of the M.C.M differences are presented in Table 5. The obtained P-value was 0.000. Consequently, the paired T-test results confirm the moisture content estimated by electronic device and oven method was not significantly difference at the 5% level ($P > 0.05$). The corresponding standard deviation (S.D) for the difference between the two groups was 8.21*10-4 (Table 5).

Table 5. Paired t -Test Analysis between the Two Measurement Methods

Groups	Mean	S.D (cm^3)	Mean difference (cm^3)	95% Confidence Interval of the Difference		t	Sig. (2-tailed)
				Lower	Upper		
Predictad and actual M.C.M	$4.83*10^{-4}$	$8.21*10^{-4}$	$1.08*10^{-4}$	-4.08	7.43	4.482	0.000

The average difference, reported in Table 5 was 1.08*10-4. From these results, it can be seen that sugarcane stalks' sizes and mass had a direct effect on the determined moisture content ($P > 0.05$).

4. Conclusion

To examine change in dielectric constant of sugarcane stalks as a function of moisture content, an electronic device was designed and developed. A high correlation was found between dielectric constant and moisture content for each sample was found and quadratic trend line was fitted to data. Calibrating of device for moisture content of sugarcane stalks was not significantly reliable, calibrating for the moisture content in wet basis as moisture content in per mass unit (M.C.M) presented a reliable relation between M.C.M and measured voltage in wet basis as voltage in per mass unit (M.V.M). The results achieved showed that a development of the electronic circuit connection and additional study of the sensor can be suggested.

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