Advances in Robotics
& Mechanical Engineering

DOI: 10.32474/ARME.2022.03.000171

ISSN: 2643-6736

Review Article

Automatic Leaf Moisture Measurement Using Capacitance

Salvador Valle[1], **Federico Hahn**[1]*.

[1]*IAUIA Universidad Autonoma Chapingo, Texcoco México.*

***Corresponding author:** Federico Hahn, IAUIA Universidad Autonoma Chapingo, Texcoco México

Received: 📅 July 28, 2022 **Published:** 📅 **August 8, 2022**

Abstract

Leaf water content is an important physiological parameter that limits plant growth. It limits photosynthesis efficiency and biomass productivity. Also, it encourages plant diseases and weed growth leading to more of 33% of crop losses in agricultural fields. Tree and crop canopies have to be monitored in order to take important production decisions. Orchard and crops are considering remote sensing techniques for precision agriculture. Moisture sensors can be classified as leaf wetness sensors (LWS) and capacitance sensors. LWS predict fungal crop and tree diseases that appear in the leaves. Capacitance sensors were developed and tested in mango leaves and on ornamental plants variety *Codiaeum variegatum sp*. grown in the house to measure leaf moisture in situ. The correlation between capacitance leaf moisture and leaf moisture obtained from a laboratory oven was 0.96. Mango leaves were classified in 2 stages the ones in the tree and those that fell to the floor.

Keywords: Capacitive Monitoring; Capacitive Reading Circuit; ESP32; Leaf Moisture; *Codiaeum Variegatum Sp*

Introduction

Tree canopy is exposed to light, external environment becoming the main place for photosynthesis and respiration [1]. Sensors are being built for precision agriculture of intensive orchards. These sensors installed in robots or UAV are important for decision-making on orchard pruning [2] and flowering management [3]. With global water shortage and climatic changes, applying deficit irrigation can overcome the demand from fruit trees. Slight water stress can maintain fruit quality and yield [4]. Remote sensing platforms collect sensor data from planes, satellites or drones [5,6]. Thermal sensor and optical sensors can detect water status and diseases [7,8]. RGB and hyperspectral find new application every day [9,10]. Water droplets due to rain, sprinklers, etc., act as free water on plant leaves. This free water under proper environmental conditions (temperature and humidity) allows fungal germination, becoming some days later in the focal point of disease [11]. Millions of hectares are attacked globally by different pests that require of leaf moisture to survive. Producers rely on disease-warning systems that require of leaf wetness duration data (LWD) to operate [12]. LWS (leaf wetness sensors) are attached with a clip to the leaf and measure electrical impedance changes of a wire grid. These sensors are commonly referred as artificial leaves. Oval capacitive artificial leaves were printed on a 1.6 mm thick fiberglass plate (PCB substrate). The principle of measurement of these capacitive static LWS depends on the relative dielectric constant; water dielectric is $\varepsilon r \approx 80$, meanwhile fiberglass has a εr between 3 and 6 [13]. On the other hand, electronic LWS offers more stability and reliability, but it is much more expensive, and famers do not acquire them [14]. Lightweight built LWS embraces the interdigitated electrodes (IDEs) on the polyimide flexible substrate. The response time once water contacts it, is of 10 seconds and sensor capacitance varies by 6% over a temperature range from 20°C to 65°C [15].

Water content in leaves can be determined in laboratories by the weight change between fresh and dried leaves but is certainly destructive and time-consuming. The electrical conductivity (EC) is a physical variable related to how electricity flows within a substance [16]. It is measured by the complex permittivity of water but requires of a sinusoidal voltage supply. Manual sensors use capacitance to measure the dielectric changes, but the sensing material should be inserted within the plates. Capacitance soil sensors 5TE (Decagon Devices, Inc., Pullman, USA) measured bulk electrical conductivity in field conditions [17]. The moisture of tea leaves was also measured with capacitance by means of electrical impedance [18]. A parallel plate capacitor was designed and tested to estimate water content and biomass in spinach grown within a greenhouse [19]. Ceap and precise Capacitance probes use their complex relative permittivity for soil moisture IoT sensing [20,21]. Remote plant water stress caused by drought in the field, can be detected with vegetation indices using red and NIR [22]. The spectral band of 956 nm of wavelength correspond to the 2nd overtone of free O-H, meanwhile the spectra at wavelengths of 1,320, 1,420, and 1,458 nm are associated with the 1st overtone of free O-H [23]. It would be practical to measure leaf moisture without removing the leaf from the tree. Therefore, in this paper a small capacitor is built and an analysis of different capacitance reading systems are considered so that the embedded microcontroller can acquire its value, transmit via Bluetooth to a smartphone that will show the moisture value in the screen.

Flat Capacitor design

Capacitance (C) in an ideal flat capacitor is obtained from equation 1, being the permittivity of vacuum $\varepsilon_0 = 8.854 \times 10^{-12}$ Fm^{-1}. Ɛr represents the dielectric constant of the material between the sheets of the capacitor having a space d given in meters. The area (A) is given in square meters.

$$\frac{1}{C} = \frac{1}{\varepsilon_{r1}\varepsilon_0 A/d_1} + \frac{1}{\varepsilon_{r2}\varepsilon_0 A/d_2} \qquad (1)$$

Different plate capacitor designs have been reported [24-27] varying in size. For example, the capacitor developed by Afzal et al., 2010, [25] has two oval-circular plates of 4 and 3 cm, and a gap of 1.3 mm. The parallel plate capacitor used to measure moisture in paddy grains had dimensions of 10.8 x 15.8 x 5 cm [27].

Leaf capacitance measurement

Several solutions are available for the measurement of the value of the capacitive sensor. Oscillation circuits are simple for capacitance measurement, being those based on the relaxation-based technique [28] and the VCO (voltage-controlled technique) [29]. Wheatstone bridge circuits can provide stable and accurate measurements [30]. Measurement errors are high, unless directly implemented on chip [31,32]. The proceeding of the leaf moisture sensing in shown in Figure 1. All starts when the capacitor with a clip structure is fixed to the leaf. Capacitor weight is 6 grams and the clip weights another 2 grams. A box fixed to the closest branch has the embedded circuit together with a pair of circuits that will be discussed in Figures 2, 3. All the circuits selected worked with a lithium battery. In order to transmit wirelessly the capacitor values, the Bluetooth of the cell phone had to be initialized. The system is ready, and a reset will cause the capacitor to read the leaf moisture and the values will be acquired by a microcontroller (TTGO LoRa32 OLED V2.1.6., Lily go, China).

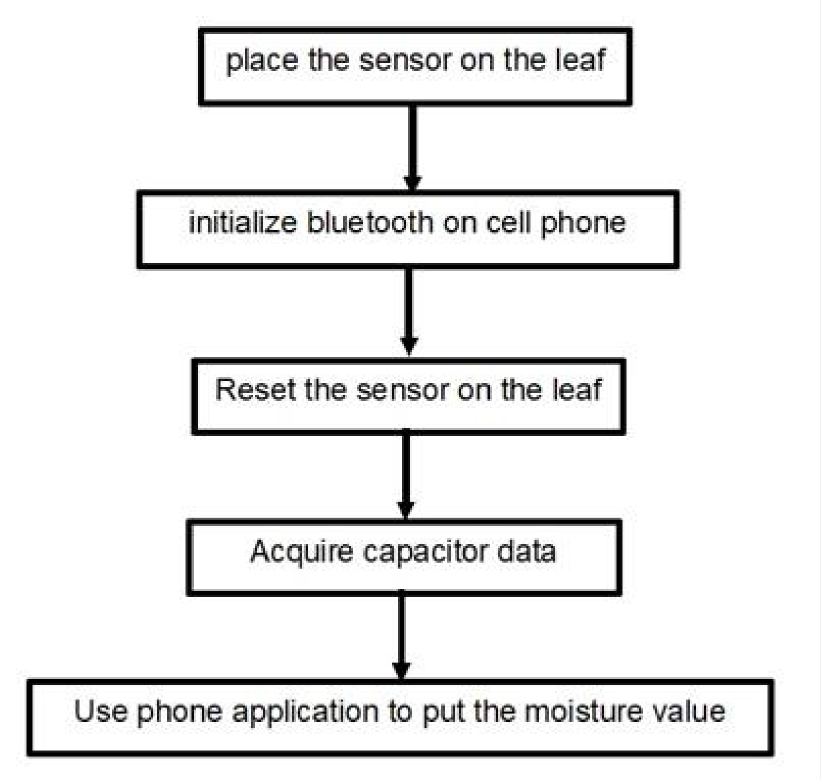

Figure 1: Procedure for leaf moisture sensing.

Citation: Salvador Valle, Federico Hahn*. Automatic Leaf Moisture Measurement Using Capacitance. Adv in Rob & Mech Engin 3(5)- 2022. ARME.MS.ID.000171. DOI: 10.32474/ARME.2022.03.000171

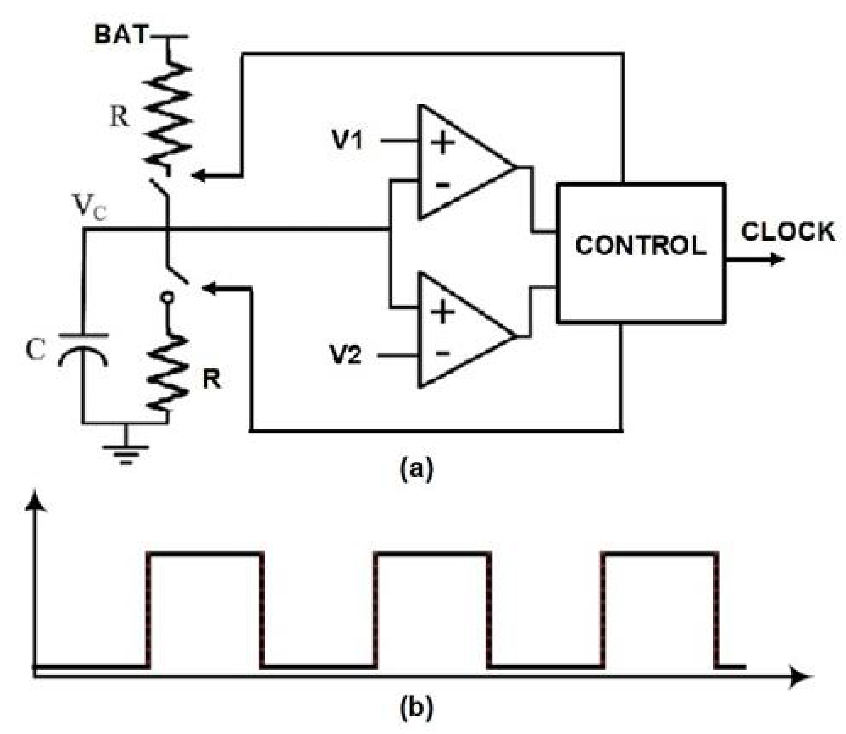

Figure 2: Block diagram (a) of the circuit (b) that generates a square wave depending on the value of the capacitor.

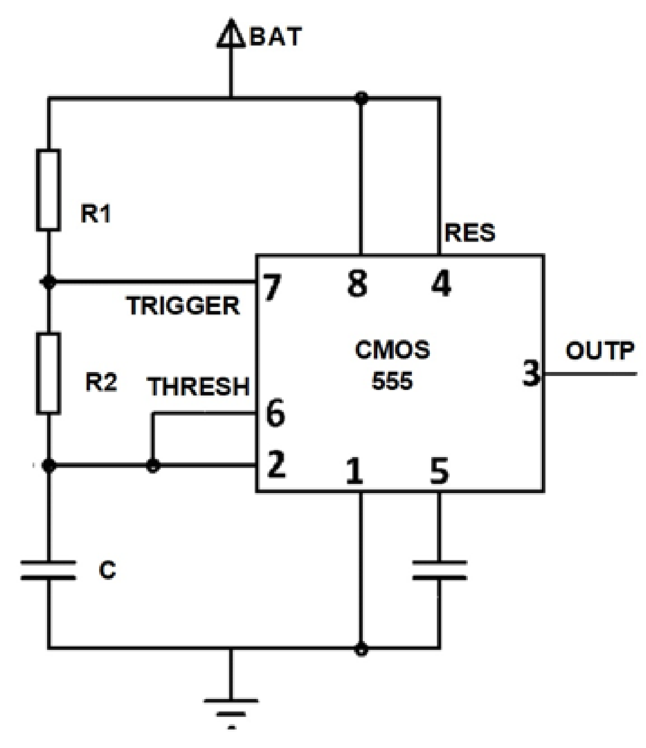

Figure 3: A stable multivibrator using the CMOS 555 circuit.

Once the smartphone application is initialized it will show the moisture value in % of weight basis (Figure 1).

Two different circuits were implemented to acquire the leaf moisture capacitance (Figure 2,3). The circuit (Figure 2) works by charging and discharging the flat plate capacitor, C. The two resis-

Citation: Salvador Valle, Federico Hahn*. Automatic Leaf Moisture Measurement Using Capacitance. Adv in Rob & Mech Engin 3(5)- 2022. ARME.MS.ID.000171. DOI: 10.32474/ARME.2022.03.000171

tances should have the same impedance to generate a 50% duty cycle square wave (Figure 2b). The capacitor starts charging when the multiplexer (switch) connects the resistance to the power supply (BAT).

The charging capacitor voltage enters two comparators with high input impedance providing output signals for the control circuit. The control circuit will provide the clock output and will activate the multiplexers, according to the low and high voltages introduced to the comparators (V_1 & V_2). The equation for charging a capacitor is given by equation 2. The capacitor voltage v(t) at a given time (t) starts from the capacitor initial voltage until reaching the final voltage V.

$$v(t) = V\left(1 - e^{t/RC}\right) \tag{2}$$

The time taken (t) to charge the capacitor to a given voltage v(t) depends on the capacitor and resistance values, and is given by equation 3:

$$t = RC\ln\left(V|(V - v(t))\right) \tag{3}$$

$$C = \frac{t}{R\ln\left(V/_{(V-v(t))}\right)} \tag{4}$$

Equation 4 will provide the capacitor value, proportional to the leaf moisture measurement. The logarithm value is a constant where V is the battery voltage and v(t) will correspond to the maximum voltage V1 fixed at the comparator in Figure 2. When the comparator reaches this value its output changes of state and the capacitor will start its discharge state. The second circuit uses a CMOS 555 timer (Figure 3) being fed by a 3.3 lithium rechargeable battery. Another researcher [20] used a low pass filter at the output to obtain an average voltage that could be connected to the microcontroller ADC. A regulator is connected between the battery to avoid changes in the CMOS 555 output. The circuit first charges the capacitor through R1+R2 and then discharges the capacitor through R2 to generate the output. After turning on the circuit, the output of the 555 goes high until the charging capacitor C reaches 2/3 of the supply voltage. After reaching it, the 555 output switches to zero and capacitor begins to discharge through resistor R2 (Figure 3). When the voltage on capacitor C1 reaches 1/3 of the supply, it starts charging again, and so on as long as the supply is maintained. The capacitor in pin 5 avoids that noise enters the system. Equation 5 gives the capacitor charging period, and from equation 6, the capacitor value can be calculated.

$$t_{on} = 0.69(R_1 + R_2)C \tag{5}$$

$$C = \frac{t_{on}}{0.69(R_1+R_2)} \tag{6}$$

Embedded system operation

The microcontroller has a Bluetooth unit, ADC and input/output digital ports. Its operation depends on the circuit used. With the first circuit (Figure 2) the embedded ESP32 microcontroller waits until the first compactor turns on (changes from 0 to 1). The battery is disconnected from the capacitor and the microcontroller generates a 10μs delay turning on the multiplexer and discharge the capacitor. The ESP32 counts periods of 100 ms, until the other comparator provides a 0 to 1 transition. The number of 100 ms periods represent the value of t, and once this value is introduced in equation 4, the capacitance can be calculated. A regression algorithm provides the leaf moisture value. Ten measurements are automatically taken and averaged to obtain the final value. In the case of the second circuit, it will only read the CMOS 555 output and count this period.

Results

The capacitor was fixed to leaves (Figure 4) of ornamental plants variety Codiaeum variegatum sp. that were held under different watering conditions in order to obtain diverse leaf water content. Capacitance varied from 11.2 to 14 in the ornamental leaves, being the latter value obtained for moist leaves (Figure 5). Capacitance was also measured in mango leaves, Figure 6. Leaves had 3 stages: fresh, mature and recollected from the soil. Leaves picked from the soil were still green and fall during strong winds during storms. Light green colored tender leaves presented the highest moisture and capacitance was over 14.2 pF. Dry leaves presented a capacitor average value of 10.3 pF. The effect of V1 and V2 in the circuit of Figure 2 was studied for mature mango leaves. For V1 and V2 values of 0 and 3.3 V (battery voltage), the average capacitance obtained was of 14.03 with a standard deviation of 0.452. If V1 was changed to 0.7 VBAT and V2 to 0.3 VBAT, average and standard deviation decreased to 13.95 and 0.278, respectively. The CMOS 555 was simpler and worked precisely.

Figure 4: Ornamental plant with capacitor sensor.

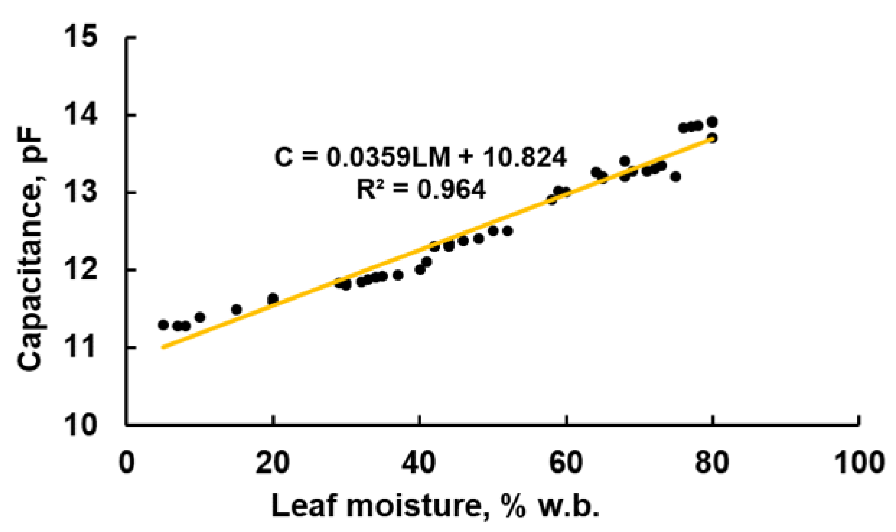

Figure 5: Capacitance measured under different mango leaf moisture.

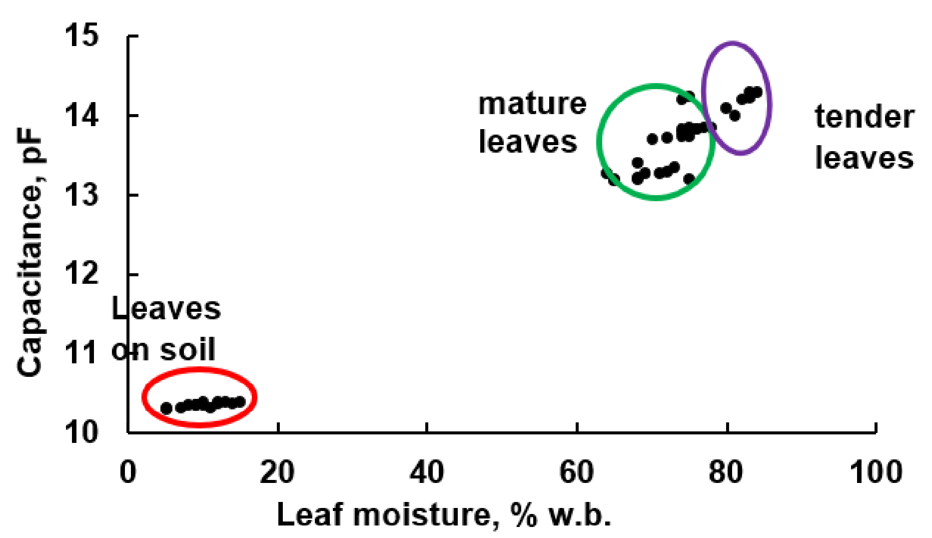

Figure 6: Capacitance measured in mango leaf, being tender leaves circled in violet, green mature leaves in circled in green and red circled leaves collected from the floor.

Conclusion

This work shows an automatic system for measuring the moisture of leaves based on a parallel plate capacitor. The capacitor is light and can be easily fixed to the leaf plant. Two circuits to measure capacitance were tested being the CMOS 555 simpler and cheaper. In mango trees it was difficult to obtain leaves with different moisture levels as the soil is humid, so measurements were classified as dry or humid. In the case of the ornamental *Codiaeum variegatum sp.* held under different watering conditions a correlation of 0.964 was found between leaf moisture and capacitance.

Acknowledgements

I would like to acknowledge all the technical staff of the University that helped to build the prototype.

References

1. Sun G, Wang X, Yang H, Zhang X (2020) A Canopy Information Measurement Method for Modern Standardized Apple Orchards Based on UAV Multimodal Information. Sensors 20(10): 2985.
2. Johansen K, Raharjo T, McCabe, M (2018) Using multi-spectral UAV imagery to extract tree crop structural properties and assess pruning effects. Remote Sensing 10: 854.
3. Wang Z, Underwood J, Walsh K (2018) Machine vision assessment of mango orchard flowering. Comput Electron Agric 151: 501-511.
4. Zhang C, Valente J, Kooistra L, Guo L, Wang W (2021) Orchard management with small unmanned aerial vehicles: a survey of sensing and analysis approaches. Precision Agric 22: 2007-2052.

Citation: Salvador Valle, Federico Hahn*. Automatic Leaf Moisture Measurement Using Capacitance. Adv in Rob & Mech Engin 3(5)- 2022. ARME.MS.ID.000171. DOI: 10.32474/ARME.2022.03.000171

5. Salgadoe A, Robson A, Lamb D, Dann E, Searle C (2018) Quantifying the severity of phytophthora root rot disease in avocado trees using image analysis. Remote Sensing. 10(2): 226.

6. Usha K, & Singh B (2013) Potential applications of remote sensing in horticulture-A review. Scientia Horticulture 153: 71-83.

7. Zarco Tejada P, Gonzalez Dugo V, Berni J (2012) Fluorescence, temperature and narrow-band indices acquired from a UAV platform for water stress detection using a micro-hyperspectral imager and a thermal camera. Remote Sensing of Environment 117: 322-337.

8. Park S, Ryu D, Fuentes S, Chung H, Hernandez Montes E O Connell M (2017) Adaptive estimation of crop water stress in nectarine and peach orchards using high-resolution imagery from an unmanned aerial vehicle (UAV). Remote Sensing 9(8): 828.

9. Xue J, Fan Y, Su, B, Fuentes S (2019) Assessment of canopy vigor information from kiwifruit plants based on a digital surface model from unmanned aerial vehicle imagery. International Journal of Agricultural and Biological Engineering, 12(1): 165-171.

10. Mu Y, Fujii Y, Takata D, Zheng B Y, Noshita K, et al. (2018) Characterization of peach tree crown by using high-resolution images from an unmanned aerial vehicle. Horticulture Research 5: 74.

11. Huber L, Gillespie T (1992) Modeling leaf wetness in relation to plant disease epidemiology. Annual Review of Phytopathology 30 (1): 553-577.

12. Rowlandson T, Gleason M, Sentelhas P, Gillespie T, Thomas C, et al. (2015) Reconsidering Leaf Wetness Duration Determination for Plant Disease Management. Plant Disease 99: 310-319.

13. Hornero G, Gaitán Pitre J, Serrano Finetti E, Casas O, Pallas Areny, R (2017) A novel low-cost smart leaf wetness sensor. Computers and Electronics in Agriculture 143: 286-292.

14. Haickel H (1980) New developments of an electrical method for direct measurement of the wetness-duration on plants Agric. Meteorol 22: 113-119.

15. Patle K, Saini R, Kumar A, Surya S, Palaparthy V, Salama K (2021) IoT Enabled, Leaf Wetness Sensor on the Flexible Substrates for In-situ Plant Disease Management. IEEE Sensors Journal 1-1.

16. Behzadi G, Fekri L (2013) Electrical Parameter and Permittivity Measurement of Water Samples Using the Capacitive Sensor. International Journal of Water Resources and Environmental Sciences 2(3): 66-75.

17. Aljoumani B, Sànchez-Espigares J, Cañameras N, Josa R (2015) An advanced process for evaluating a linear dielectric constant-bulk electrical conductivity model using a capacitance sensor in field conditions. Hydrological Sciences Journal 60(10): 1828-1839.

18. Mizukami Y, Sawai Y, Yamaguchi Y (2006) Moisture Content Measurement of Tea Leaves by Electrical Impedance and Capacitance. Biosystems Engineering 93(3): 293-299.

19. Jones C, Stone M, Maness N, Solie J, Brusewitz, G (2006) Plant Biomass Estimation Using Dielectric Properties. 2006 Annual International Meeting Portland, Oregon July 9 - 12 Paper Number: 063092.

20. Placidi P, Gasperini L, Grassi A, Cecconi M, Scorzoni A (2020) Characterization of Low-Cost Capacitive Soil Moisture Sensors for IoT Networks. Sensors 20(12): 3585.

21. Roux J, Fourniols J, Soto Romero G, Escriba C (2018) A connected soil humidity and salinity sensor for precision agriculture. 5th Annual Conference on Computational Science & Computational Intelligence (CSCI'18), Dec 2018, Las Vegas, United States.

22. Galieni A, D Ascenzo N, Stagnari F, Pagnani G, Xie Q, et al. (2021) Past and Future of Plant Stress Detection: An Overview from Remote Sensing to Positron Emission Tomography. Front Plant Sci 11: 609155.

23. Jin X, Shi C, Yu CY, Yamada T and Sacks EJ (2017) Determination of Leaf Water Content by Visible and Near-Infrared Spectrometry and Multivariate Calibration in Miscanthus. Front Plant Sci 8: 721.

24. Shay I, Zahn M (2002) Cylindrical Geometry Electro-quasi-static Di electrometry Sensors. In: Electrical Insulation and Dielectric Phenomena. Proceedings of IEEE Conf 20-24 October 2002 Cancun Quintana Roo Mexico pp: 126-129.

25. Afzal A, Mousavi S, Khademi M (2010) Estimation of Leaf Moisture Content by Measuring the Capacitance. J Agr Sci Tech 12: 339-346.

26. Scaife B (1998) Principles of Dielectrics. Oxford Science Publications, Oxford, UK.

27. Nathk D, Ramanathan P (2019) Novel Technique to Measure Moisture Content of Paddy and the Error Correction. Gazi University Journal of Science 32(3): 914-926.

28. Liu Y, Chen S, Nakayama M, Watanabe K (2000) Limitations of a relaxation oscillator in capacitance measurements. IEEE Trans. Instrumentation Meas. 49: 980-983.

29. Martin K. (1981) Voltage-controlled switched-capacitor relaxation oscillator. IEEE J Solid State Circuits 16: 412-414.

30. Tarikul I (2017) Advanced Interfacing Techniques for the Capacitive Sensors. In: Advanced Interfacing Techniques for Sensors. Chapter 3: 73-109. Springler International

31. Van der Goes F, Meijer G (1996) A novel low-cost capacitive-sensor interface. IEEE Trans Instrum Meas 45: 536-540.

32. Yoo Y, Choi B (2021) Readout Circuits for Capacitive Sensors. Micromachines 12: 960.

DOI: 10.32474/ARME.2022.03.000171

Citation: Salvador Valle, Federico Hahn*. Automatic Leaf Moisture Measurement Using Capacitance. Adv in Rob & Mech Engin 3(5)- 2022. ARME.MS.ID.000171. DOI: 10.32474/ARME.2022.03.000171