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Automatic fault detection in a low cost frequency domain (capacitance based) soil moisture sensor

M.J. Oates[a,b,*], K. Ramadan[a,b], J.M. Molina-Martínez[c], A. Ruiz-Canales[a,b]

[a] Engineering Department, Miguel Hernández University of Elche, Orihuela, Spain
[b] Ctra, Orihuela-Beniel, km 3.2, Orihuela 03312, Spain
[c] Researching Group in Agromotic Engineering and the Sea, Technical University of Cartagena, Cartagena 30203, Spain

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ABSTRACT

Frequency Domain Analysis can be used to determine the moisture content of soils. At least two techniques can be used, the first using the soil capacitance as part of a low pass filter, measuring the attenuation of a fixed frequency signal, the second using the soil capacitance as the controlling component in a variable frequency oscillator. Whilst the two techniques demonstrate differing sensitivities to different conditions, they demonstrate an acceptably stable reciprocal relationship to each other over a wide range of soil moisture conditions. With insulated probes, it is possible under field conditions for these probes to be damaged or for moisture to creep into the electronics housing. Either of these conditions make the soil capacitor appear to 'leak' by providing a lower electrically resistive path in parallel with the soil capacitance. This resistance affects the measurements of the two techniques described above in different ways and thus readings from the sensors diverge from their normal relationships. These variations are measureable and thus the fault condition can be automatically detected. This can be used to flag potential problems in the soil moisture measurements raising an alarm condition, or stopping unnecessary irrigation based on erroneous results from a damaged sensor. This paper presents results demonstrating these phenomena using a Frequency Domain capacitance based sensor costing less than 10 Euros.

1. Introduction

In irrigation management, there are varied techniques for determining the water requirements of a crop. These measuring techniques include the determination of water requirements by obtaining the volume of water based on a water balance. In general, these techniques can be divided into direct measurement or indirect measurement of the water requirements of a crop. An example of the first technique is lysimetry (Schaetzl and Rothstein, 2016). In this case, there is a direct measuring of a parameter (weight, volume, pressure, among others) that is varying over time. The indirect techniques are based on indirect measurement of the parameters of the water balance. The indirect determining of soil water balance in a crop can be obtained by several techniques: remote sensing (Maes et al., 2016); use of plant sensors (Torres et al., 2016); use of meteorological sensors (Gao et al., 2016) among others and a combination of the previous cited. Another technique for determining the water balance based in indirect measurements is the measuring of soil moisture. The use of soil-based water measurements is used in a various devices (Ojha et al., 2015; Jaguey et al., 2015; Navarro-Hellin et al., 2015; Tarange et al., 2015). The ultimate objective of these techniques is to provide farmers with information about the most appropriate volumes of irrigation to apply in each phenological period of the crop, depending on the desired yield levels and other parameters. For determining soil moisture, a great range of sensors are used (Vienken et al., 2013).

There is a wide range of electrically based soil moisture measurement techniques well established in the fields of geophysical surveying (Linck and Fassbinder, 2014; Lehmann et al., 2014) and agronomy (Fatas et al., 2014; Baghdadi et al., 2014), These include resistivity based methods such as the Wenner (Jiao-Jun et al., 2014) and Schlumberger Arrays (Mosuro et al., 2012); capacitance based methods such as Frequency Domain Reflectometry (FDR) (Al-Asadi and Mouazen, 2014; Jaria and Madramootoo, 2013); Time Domain Reflectometry (TDR) (Janik et al., 2014); as well as Radiation based techniques such as the Neutron Probe (Kodikara et al., 2014). Whilst low cost implementations of resistive based sensors have been suggested in the past (Austin and Rhoades 1979; Igboama and Ugwu,

* Corresponding author.
E-mail address: moates@btinternet.com (M.J. Oates).

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2011), commercial implementations of these units (for example the Landviser® Landmapper®, that include interpretation software for vertical electrical properties of the soil) are expensive (typically $500–$1600), lack integrated data-logging capabilities, or are simply unavailable.

Frequency Domain Reflectometry (FDR) or the frequency domain capacitance probe, is used to determine the moisture content of soils. The principle of operation of the Frequency Domain capacitance probe relies on the fact that the dielectric constant between water and air differs by a factor of 80. Thus the presence of water in the soil between the probe plates produces a highly significant change in its capacitance, the higher the water concentration, the higher the capacitance. This capacitance can then be measured by electrical means. As the probe is electrically insulated, there is no direct current flow within the soil, and thus the conductive effect of ion based salts in the soil is minimized. However different soil types can be expected to display different properties (Hanson and Peters, 2000).

These capacitance based probes are critically dependent on the insulation provided between their plates. Should this become damaged, the sensor would give erroneous results, which could however still appear to be in normal operational range. This would lead to erroneous irrigation decisions.

This paper investigates how this damage can be automatically detected despite the individual readings appearing to be within normal ranges. For this purpose, a low cost Frequency Domain sensor system was designed and implemented in an experimental plot. The manuscript includes, firstly, the description of the two electrical methods that are used to determine the effective capacitance of the probe for the designed sensor system. Moreover, the description of five experiments to illustrate the fault detection in the designed sensor system will be developed. Subsequently, the obtained results in the five cited experiments are discussed. Finally, some conclusions about the experiments and the possibilities of the employment of this device for irrigation management are added.

2. Material and methods

A low cost Frequency Domain sensor system for measuring the soil moisture was designed and implemented and this is described in detail in Vázquez de León et al., 2015. For the experiments in soil (Experiments 2, 4 and 5 that are explained below), an insulated probe was used inserted vertically with its top buried 3 cm into a hi-silica, clay based soil in an experimental plot without crops. The location of the cited soil of the experimental plot is latitude: 37° 57′ 29.60″N and longitude: 0° 48′ 4.55″W. The average altitude is 130 m a.s.l. This is located in San Miguel de Salinas (Alicante), in the South Eastern Spain. The main part of the designed soil moisture sensor system is the probe. The probe consisted of a 20 mm × 60 mm printed circuit board (PCB) with two double sided, parallel 7 mm wide tapered prongs insulated by two coats of varnish, with the PCB, but not the plating of the prongs, joined together at the top. The two prongs are separated by an air gap of 6 mm. The effective plate area is 500 mm^2. This was connected to the sensor electronics via a 30 cm multi-strand 0.75 mm^2 mains cable soldered to the probe. This was surrounded by hot glue to eliminate sharp edges before the varnish was applied.

To summarise, two electrical methods are used here to determine the effective capacitance of the probe. The first involves using the probe as the capacitive component of a low pass filter. An Arduino microcontroller outputs a fixed frequency square-wave of 250 kHz on pin D3 (and later 125 kHz, 83.3 kHz and 62.5 kHz). These frequencies were selected to be as high as practical, given the limited Gain Bandwidth Product of the LM358 low cost Operational Amplifier, and also to be aligned with the corner frequency of the resulting low pass filter. The signal is then passed into a 47 K ohm resistor which then connects to one terminal of the FDR capacitive probe. The other end of the probe is connected to the electrical ground. The junction of the probe and the 47 K resistor is also connected to the +ve input of one of the operational amplifiers. This amplifier is configured as a near unity gain buffer with a 330R feedback resistor from the output to the −ve input. The output is then connected via a 1N4001 diode to a ‘peak detector’ circuit consisting of a 1.8 M resistor and 100 nF capacitor connected in parallel

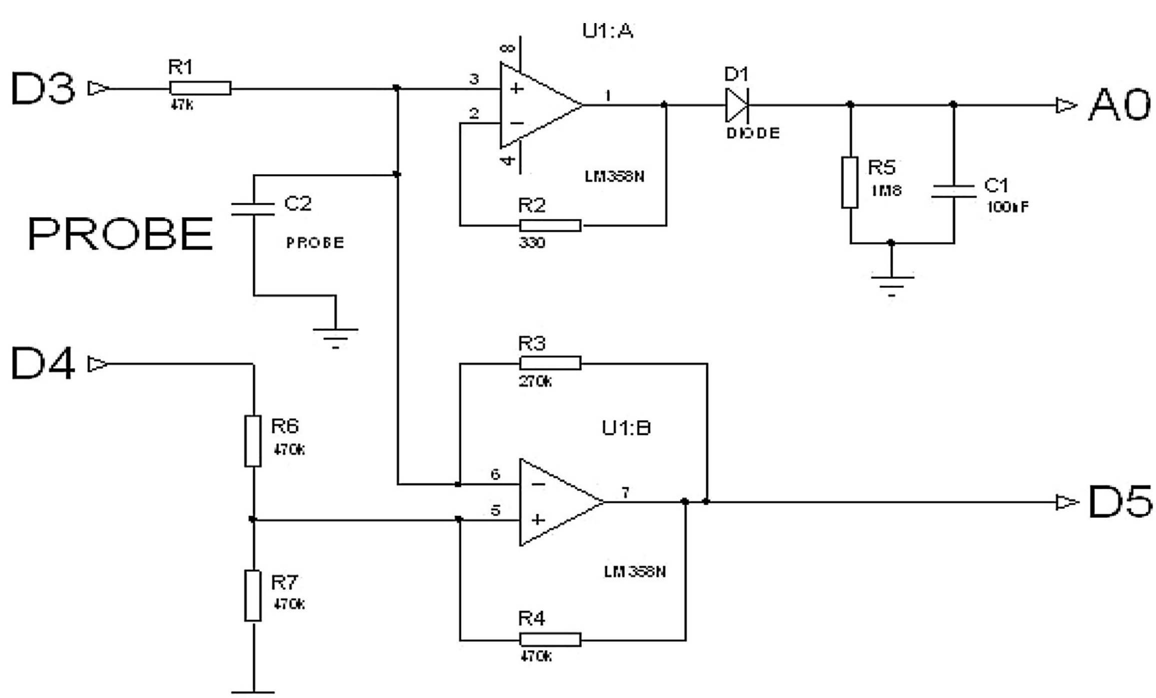

Fig. 1. Circuit diagram of a single probe sensor.