

Detección automática de fallos en un sensor FDR de humedad del suelo de bajo coste

M.J. Oates¹, M. G. González¹, A. Ruiz-Canales¹, J.M. Molina-Martínez², A.L. Vázquez de León¹.

¹ Departamento de Ingeniería, Escuela Politécnica Superior de Orihuela (EPSO-UMH), Crtra. de Beniel, km 3,2 03312, Orihuela (Alicante), moates@btinternet.com

² Grupo de Investigación de Ingeniería Agromótica y del Mar (UPCT), Paseo Alfonso XIII, 48. 30203 Cartagena (Murcia), josemiguel.molina.martinez@gmail.com

Resumen

La reflectometría del dominio de frecuencia (RDF, o más conocido como FDR en sus siglas en inglés) se emplea para determinar el contenido de humedad de los suelos. Esta metodología puede basarse al menos en dos técnicas. La primera usa la capacitancia del suelo como parte de un filtro de paso bajo, midiendo la atenuación de una señal de frecuencia fija. La segunda usa la capacitancia del suelo como el componente controlador en un oscilador de frecuencia variable. Aunque las dos técnicas muestran diferentes sensibilidades a diversas condiciones, las dos muestran una relación recíproca aceptablemente estable y cada una sobre un amplio rango de condiciones de humedad del suelo. Con sondas aisladas y en condiciones de campo es posible que éstas sean dañadas o que la humedad alcance la caja donde va alojada la electrónica del dispositivo. Cualquiera de esas circunstancias hace aparecer en el condensador del suelo pérdidas por suministrar una trayectoria de baja resistencia eléctrica en paralelo a la capacitancia del suelo. Esta resistencia afecta de diferentes maneras a la medida de las dos técnicas descritas previamente aunque los resultados diverjan a partir de sus condiciones iniciales. Estas variaciones se miden y permiten detectar los fallos causados. Esto se puede usar para detectar problemas potenciales en las medidas de humedad del suelo aumentando la señal de alarma o parando el riego innecesario según los resultados erróneos que genera el sensor dañado. Esta comunicación presenta resultados que demuestran estos fenómenos usando un sensor FDR capacitivo que cuesta menos de 10 euros.

Palabras clave: capacitancia, detección de error, riego.

Automatic fault detection in a low cost FDR based Soil Moisture Sensor

Abstract

Frequency Domain Reflectometry (FDR) is 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 uses 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 results diverge from their normal relationships. These variations are measured and fault conditions 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 an FDR capacitance based sensor costing less than 10 Euros.

Keywords: Capacitance, Error Detection, Irrigation.

INTRODUCTION

The FDR capacitance probe (Choi et al, 2015; Al-Asadi and Mouazen, 2014; Jaria and Madramootoo, 2013) 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 (Tran et al., 2015; Hanson & Peters, 2000).

MATERIALS AND METHODS

For experiments in soil (2 and 4), an insulated probe was used buried horizontally 3cm into a hi-silica, clay based soil, typical of the Vega Baja region of South Eastern Spain. The probe consisted of a 20mm * 60mm PCB with two double sided, parallel 7mm wide tapered prongs insulated by two coats of marine 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 6mm. The effective plate area is 500mm². Experiments 1 & 3 used ceramic disc capacitors (33pF to 470pF) and metal film resistors in place of the probe. Temperature measurements were made using a DS18B20 waterproof digital temperature probe, 3cm into the soil sample. The unit was powered by 4 AA batteries operating for in excess of 4 months, providing a stand-alone, RF based sensor system for less than 10 Euros.

In Summary, two electrical methods were used to determine the effective capacitance of the probe. The first involved using the probe as the capacitive component of a low pass filter. An Arduino microcontroller running at 5v and 16MHz was used to output a fixed frequency square-wave of 250kHz (and later 125kHz, 83.3kHz and 62.5kHz) into the filter, followed by a unity gain amplifier and peak detector. The resulting voltage was sampled after a stabilization period of 20ms. The values were sampled by a 10 bit ADC but then linearly rescaled to make best use of 256 values (8 bits) for efficient storage and transmission. These are referred to as SS250, SS125, SS83 and SS62 respectively.

The second method uses the probe as the capacitive element in an oscillator circuit, repeatedly charging and discharging the capacitor as the voltage passes between two thresholds. The time taken for the voltage to rise and fall between these thresholds is measured over four, half-wave oscillations providing an indication of the capacitance. These are referred to as Time to Charge (Tc) and Time to Discharge (Td) respectively.

RESULTS AND DISCUSSION

The SS readings show a large change per unit change in capacitance at lower capacitance values and a much smaller change per unit value at higher capacitance values. This gives a higher resolution in measurement units at lower capacitance values, but when turned into its reciprocal value (rSSxxx), delivers a near linear response along with Tc and Td in Experiment 1 with the probe replaced by capacitors. The rSSxxx values are multiplied by 8000 to provide values in a comparable numerical range with those of Tc and Td.

A plot of reciprocal of Signal Strength at 125kHz (rSS125) vs. capacitance gives a straight line, the rSS250 slope decreasing slightly with increased capacitance, whilst the rSS62 slope increases with capacitance. As the rSS125 readings and Time to Charge (Tc) and Discharge (Td) all appear linear with Capacitance, so the Tc & Td readings appear linear with respect to rSS125. The slope of the Tc line with respect to rSS125 is 0.890 whilst for Td is 0.445. There is also a linear relationship between Td and Tc. Regression analysis shows that with an offset of 12.2, Tc is approximately 1.75 times the value of Td.

Figure 1 shows the relationship between Td & Tc with respect to rSS125 for Experiment 2 with the capacitors replaced by the two pronged insulated probes in a soil sample at different levels of moisture. With the exception of the 6th reading (Tc=224, Td=128, rSS125=135.6), the readings follow straight lines with the Tc slope for the first few readings now being 1.868 and Td slope being 1.072. The overall slopes being 1.244 and 0.622 respectively. The anomaly is possibly caused by temperature differences (Liu et al., 2015; Afa & Anaele, 2010) as these readings are also known to be affected by both the temperature of the soil and the monitoring electronics. Despite this one anomaly, both the Td and Tc slopes start considerably greater in this soil experiment than in the Capacitor experiment, but this slope reduces significantly at higher moisture levels clearly indicating that the soil does not always behave like a simple capacitor. At higher moisture levels the fixed frequency technique becomes more sensitive than the variable frequency technique. The Tc to Td regression analysis delivers a Tc offset of 21.5 which gives a slope of 1.99. As the Tc to Td slopes for both Capacitors and Soil are similar, a metric was devised using a offset of 17 (average of 12.2 and 21.5. This now gives a metric for both experiments giving a value of between 1.75 and 2.05 regardless of soil moisture level and temperature.

For Experiment 3, each capacitor value was bridged in parallel with a resistor ranging from 680k to 4M7 Ohm. This simulated damage to the insulation of either the probe surface or its wiring or moisture intrusion into the box of the monitoring electronics. In all cases, the 680k resistor caused oscillation to stop and so an error is detected. In all cases the smaller the resistor value, the larger the returned rSS value, and this effect increased with higher frequency signals. This is because the resistor changes the 'corner frequency' of the filter. Td values were seen to fall with lower resistor value, whilst Tc values increased, as the resistor allows charge to leak from the capacitor thus taking longer to charge, but speeding up discharge. In the case of all 8 capacitor values tried, whilst the 'no resistor' value for the (Tc+17)/Td metric was in the 'valid' range between 1.75 and 2.05, even the 4M7 Ohm resistor pushed this metric above 2.15. Even lower values of resistor push this value even higher. This allows the sensor to detect a breach in the electrical insulation even when Td, Tc and rSS values all appear to be within valid ranges.

With the 4M7 Ohm resistor, the Tc vs rSS125 slope is 0.880 and the Td vs rSS125 slope is 0.414, little changed from the 0.890 & 0.445 seen for the capacitors without parallel resistors. It is worth noting that the soil experiments return greater slope values

for both Tc and Td with respect to rSS125. This suggests that some factor is slowing both charge and discharge of the soil capacitance for the variable frequency technique to a greater degree than the for the fixed frequency technique. It is possible that this represents some series resistive or inductive effect or possibly a more complex electro-chemical effect within the soil. This seems worthy of further investigation.

Figure 2 shows the results from a 6 day field trial of the system in which data was collected every 2 minutes. For the first 4 days (readings 1 thru 3200) the soil is allowed to dry naturally by evaporation. The daily temperature cycles of the soil and the inside of the box of monitoring electronics are shown at the top of the plot ranging from 20°C to 45°C. The next plot shows the $(T_c+17)/T_d$ metric multiplied by 100 to give plotted values comparable with the Td & rSS125 readings. This value can be seen to range between 175 and 205 (1.75 and 2.05) regardless of soil or box temperature and remains within these limits after both irrigation events (at around readings 3260 & 3960). Both the rSS125 and Td readings can clearly be seen to fall over the first 4 days, being affected slightly by temperature, and this effect is explored in another communication. However both techniques are seen to strongly respond to the irrigation events on the mornings of day 5 and 6. The $(T_c+17)/T_d$ metric however, remains within the acceptable 1.75 to 2.05 range.

CONCLUSIONS

By utilising two different capacitive measurement techniques on the same probe, one based on a fixed frequency principle the other on a variable frequency, distinction of experimental conditions can be determined. This also demonstrates that the soil does not behave as a perfect capacitor especially under wet soil conditions. The fixed frequency SS technique gives higher resolution at lower capacitance values (typical of dry soil conditions) however in its reciprocal form, the fixed frequency rSS technique delivers more sensitivity to wet soil conditions than the variable frequency Tc/Td technique.

Looking at the ratio of Time to Charge vs Time to Discharge, it can be determined if the probe or sensor electronics have been affected by damage or condensation regardless of soil or box temperature or the soil moisture level. This is true even though the readings themselves appear to be within normal ranges. This is essential to avoid incorrect or inappropriate irrigation and allows the sensor to transmit a 'detected error' condition.

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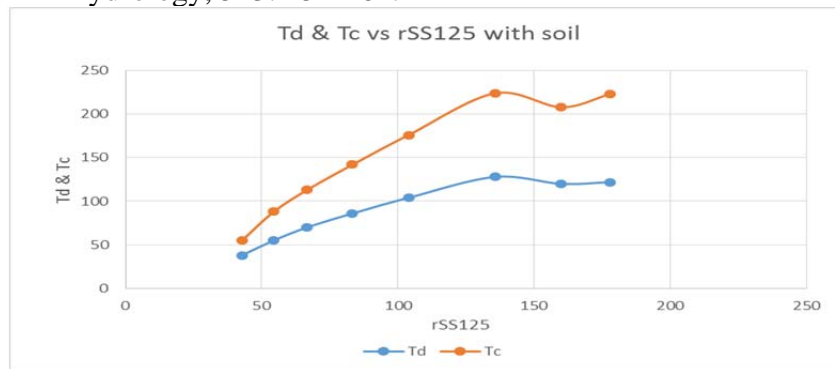


Fig. 1. Td & Tc vs rSS125 in soil.

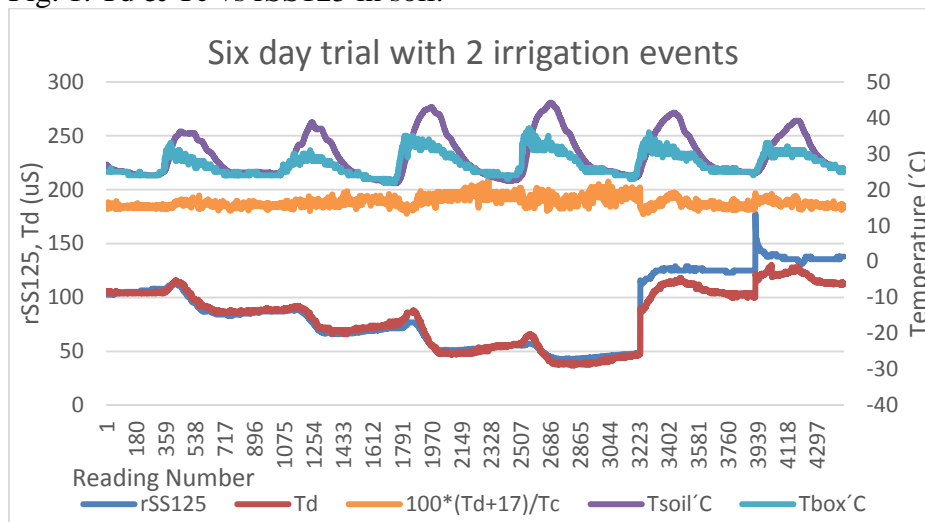


Fig. 2. Results from 6 day field trial in soil with 2 irrigation events.