La compensación de temperatura en un sensor FDR de bajo costo

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Resumen

La reflectrometría del dominio de frecuencia (RDF) o más conocido en sus siglas en inglés, Frequency Domain Reflectometry (FDR) es una técnica bien establecida para la determinación de la humedad del suelo usando el cambio en la capacitancia eléctrica de sondas insertadas en el suelo debidas a la presencia de agua. Se emplearon dos técnicas FDR para medir la humedad del suelo, la primera pasando una frecuencia fija a través del suelo mediante sondas aisladas y posteriormente midiendo la amplitud de la señal reflejada. La segunda usa la capacitancia del suelo como el componente controlador en un oscilador de frecuencia variable. Sin embargo, la capacitancia medida se ve afectada también por la temperatura del suelo. Además, debido a la naturaleza sensible de la electrónica de monitorización, puede afectar a las medidas la temperatura de los componentes críticos de los circuitos. Los experimentos muestran que estos dos efectos son complementarios, la temperatura del suelo añadida a la capacitancia medida, mientras que la temperatura de los componentes electrónicos puede disminuir efectivamente la capacitancia medida. Estos parámetros, mientras ambos aumentan durante el día y caen por la noche, muestran una fase significativa de diferencia. Además, el peso de la compensación de temperatura requerida es el más alto en el rango medio de valores de humedad del suelo. Los efectos de la temperatura son menos significativos en las condiciones extremas muy secas o muy húmedas. Esta comunicación explora este fenómeno usando resultados a partir de un sensor recientemente desarrollado de cuatro sondas FDR de capacitancia de bajo coste.

Palabras clave: FDR, humedad del suelo, compensación de temperatura, bajo coste

Temperature compensation in a low cost FDR Soil Moisture Sensor

Abstract

Frequency Domain Reflectometry (FDR) is a well established technique in soil moisture determination, using the change in electrical capacitance of probes inserted into the soil caused by the presence of water. Here two different techniques are used, the first passing a fixed frequency through the soil via insulated probes, then measuring the amplitude of the reflected signal. The second uses the soil capacitance as the controlling component in a variable frequency oscillator. However, the measured capacitance is also affected by the temperature of the soil. Further, due to the sensitive nature of the monitoring electronics, the temperature of critical components in the circuits can also affect the measurements. Experiments show that these two effects are complementary, soil temperature adding to the measured capacitance, whilst electronics temperature can effectively decrease the measured capacitance. The profiles of the soil and electronics temperatures, whilst both rising during the day, and falling at night, show significant phase difference. Also the strength of temperature compensation required is highest in the mid-range moisture values, temperature effects being less significant at either extreme of very dry and very wet conditions. This paper explores these phenomena using results from a recently developed, four probe FDR capacitance based low cost sensors.

Keywords: FDR, Soil moisture, Temperature Compensation, Low Cost

Introduction

The FDR capacitance probe (Choi et al, 2015; Jaria and Madramootoo, 2013; Al-Asadi and Mouazen, 2014) 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), as can the temperature of the soil (Liu et al., 2015; Afa & Anaele, 2010).

Materials and Method

An insulated probe was 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 500mm^2. Using a CD4052B CMOS dual 4 into 1 analogue switch, 4 probes can be routed to the amplifiers for negligible cost, or alternatively 2 probes can be connected allowing their terminals to be crossed over should soil polarisation issues become a problem. This can provide data for neighbouring locations or at multiple depths into the soil. The 4 probe sensor system cost less than 12 Euros including IP56 rated box, FDR probes, DS18B20 temperature sensor, LM358 operational amplifier, electronic interfaces and microcontroller, powered by 4 AA batteries operating for in excess of 4 months. 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 125 kHz 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 SS readings. 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 (rSS), delivers a near linear response along with Tc and Td with the probe replaced by capacitors. The rSS values are here multiplied by 8000 to provide values in a comparable numerical range with those of Tc and Td.

Figure 1 shows rSS & Td readings over a 5 day trial with 2 irrigation events in the mornings of day 4 & 5. Both sets of data (rSS & Td) swing from low readings circa 40-50 indicating dry conditions, to wet conditions around with readings of 100-120 for the first irrigation at around reading 2280, rising again for the second irrigation starting around reading 3000. Soil temperatures can be seen to swing between 16´C & 45´C whilst box temperatures range from 20´C to 45´C. Although there are indications of a temperature effect on the rSS & Td readings, these are not particularly significant.

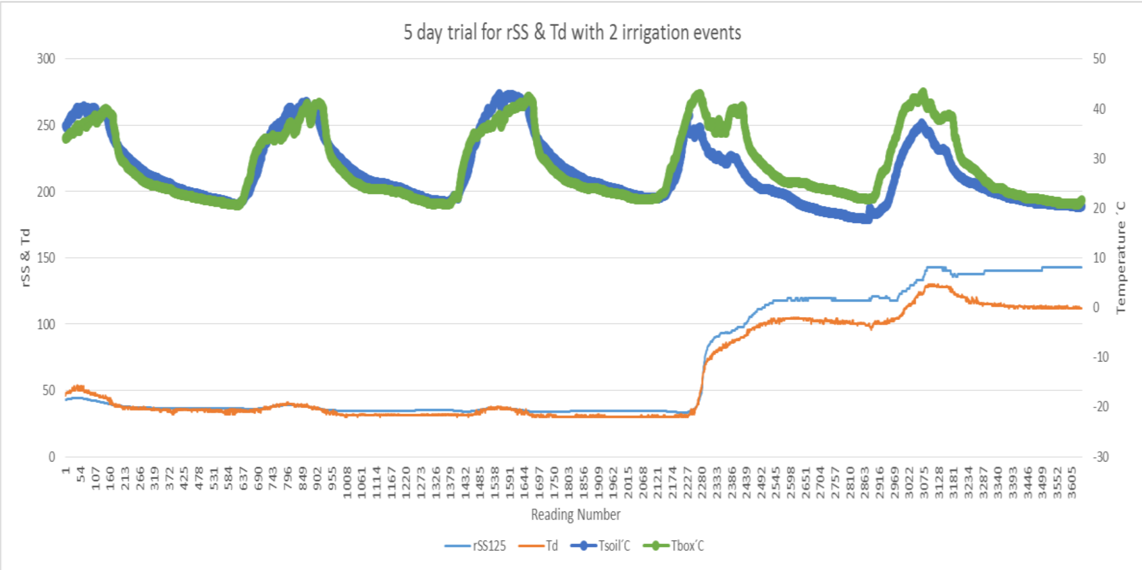

Figure 1 – Uncompensated Td and rSS readings with 2 irrigation events.

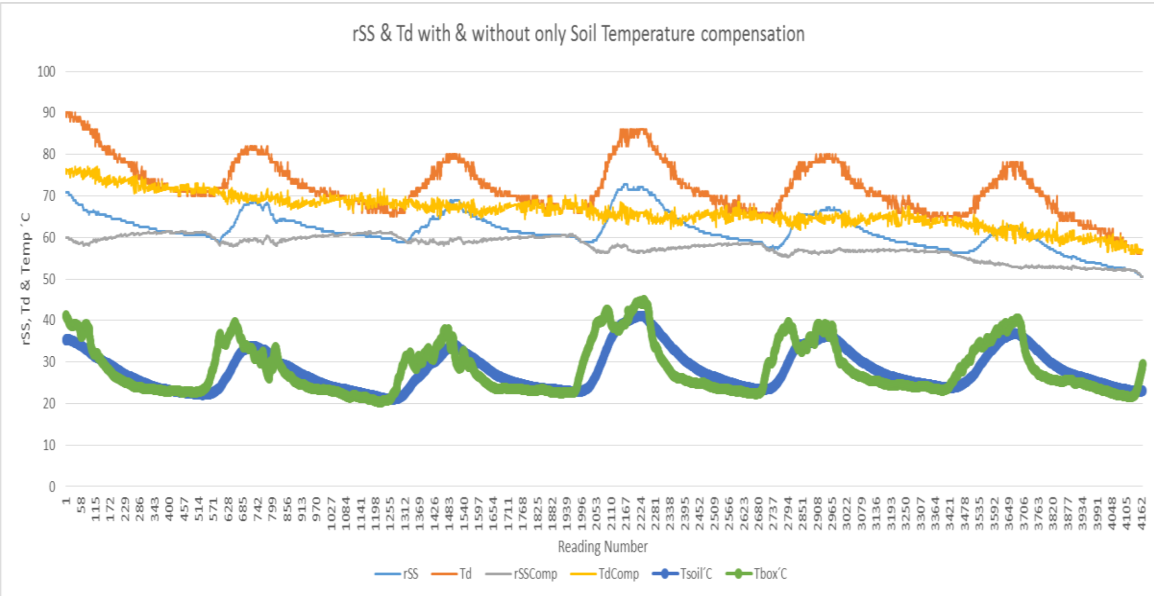

Figure 2 – Td and rSS readings with only soil temperature compensation

Figure 2 shows results from a 6 day trial during natural drying by evaporation. The uncompensated rSS and Td readings are now mid-range values (50-70 for rSS & 60 to 90 for Td), but show a significant variation with temperature. Compensating for only Soil Temperature (reducing the result by an amount proportional to the temperature) delivers significantly improved results, however it is clear that for rSS, the result still requires compensation for the temperature of the box electronics.

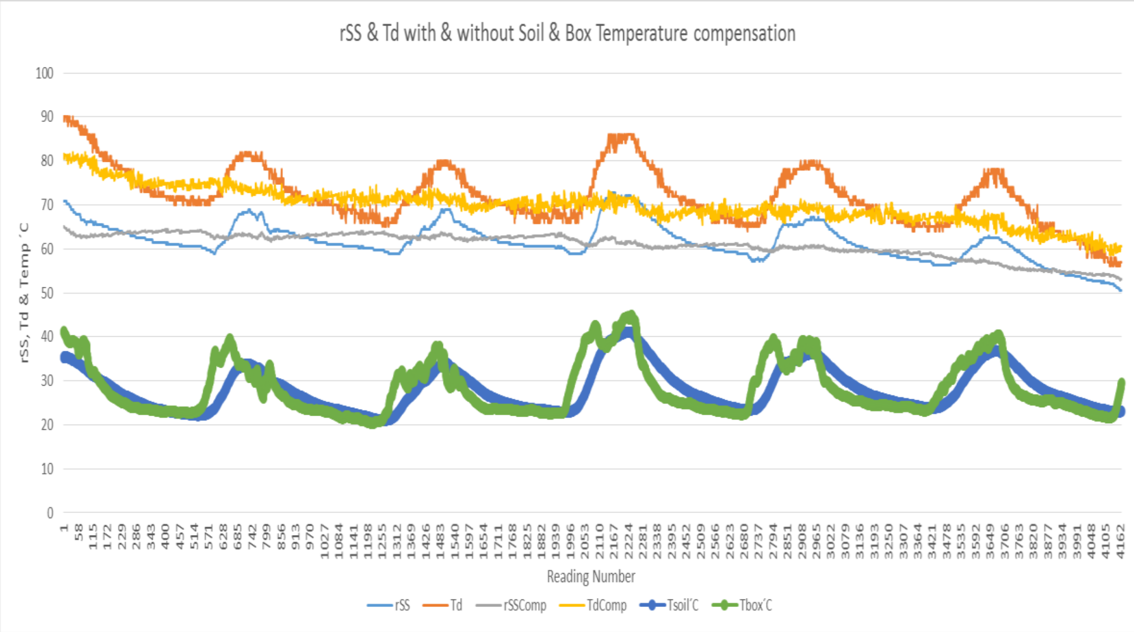

Figure 3 – Td and rSS readings with both soils and box temperature compensation

Figure 3 shows the results of the 6 day trial with both Soil and Box temperature compensation (where the result is increased by an amount proportional to the Box temperature). This shows a significant improvement for rSS over Figure 2.

Conclusions

This FDR sensor can clearly distinguish between wet and dry soil conditions, however between extremes, the sensor readings are subject to variation by temperature. High soil temperatures cause readings to appear wetter whilst electronics temperature causes readings to appear drier. Once perfected, the low cost of this sensor will make it highly suitable for large scale deployment where plants or trees need to be individually managed.

References

Afa, J.T., Anaele, C.M., 2010. Seasonal variation of soil resistivity and soil temperature in Bayelsa State. Am. J. Eng. Appl. Sci. 3 (4), 704–709.

Al-Asadi, R.A., Mouazen, A.M., 2014. Combining frequency domain reflectometry and visible and near infrared spectroscopy for assessment of soil bulk density.Soil Tillage Res. 135, 60–70.

Choi, E.Y., Yoon, Y.H., Choi, K.Y., Lee, Y.B. (2015). Environmentally sustainable production of tomato in a coir substrate hydroponic system using a frequency domain reflectometry sensor. Horticulture Environment and Biotechnology, 56 (2): 167-177.

Hanson, B.R., Peters, D.W., 2000. Soil types affects accuracy of dielectric moisture sensors. Calif. Agric. 54 (3), 43–47.

Jaria, F., Madramootoo, C.A., 2013. Thresholds for irrigation management of processing tomatoes using soil moisture sensors in Southwestern Ontario. Trans.ASABE 56 (1), 155–166.

Liu, B., Han, W.T., Weckler, P., Guo, W.C., Wang, Y., Song, K.X. (2015). Detection model for effect of soil salinity and temperature on FDR moisture content sensors. Applied Engineering in Agriculture, 30 (4): 573-582.

Tran, A.P., Bogaert, P., Wiaux, F., Vanclooster, M., Lambot, S. (2015). High-resolution space-time quantification of soil moisture along a hillslope using joint analysis of ground penetrating radar and frequency domain reflectometry data. Journal of Hydrology, 523: 252-261.