DOI 10.5162/SMSI2023/P32

Homogeneous Soil Moisture Sensor with High Repeatability for Different Soil Depths.

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Summary:

This paper presents a solution in measuring the moisture content of soil more reliably and more reproducibly. The sensor can detect moisture levels in different depths of the soil probed and in a more homogeneous way than comparable sensors that are commonly used. The repeatability of the measurement is also increased intrinsically because a larger soil volume is being sampled.

Keywords: Soil moisture sensor, FDR, Plate capacitor

Introduction

A lot of data generated by existing sensor systems has the problem of being very dependent on the installation process. Due to miniaturization of sensors and the heterogeneity of the soil volume probed, the latter is also often not contributing homogeneously to the measured values. A result is that many sensors that are currently used professionally have problems with repeatability and need to be calibrated. A thorough comparison of existing soil moisture sensor systems with different measurement principles is given in [1].

When examining the analyzed sensors in that paper, two things become clear. First, they only measure the soil moisture in a relatively small volume of around 600 ml. And second, they are all either using very punctual measurement probes or a highly non-homogeneous electrical field for their Frequency Domain Reflectometry (FDR) measurements. But soil itself can be very heterogeneous as presented in [2], which makes it unclear how well the sensed moisture values reflect the actual soil moisture content.

In order to avoid this, a solution is presented with improved performance and quantified sensor repeatability.

Approach

When using FDR probes with two rods as measuring electrodes, the non-linear behaviour of the electric field is causing problems. This is due to the fact that the electrodes generate an electric field similar to that of an infinite long line of charge, which can be described as follows [3]:

$$\vec{\mathbf{E}}_{\mathrm{line}}(\rho) = \frac{\lambda}{2\pi\epsilon_0\rho}\vec{\mathbf{e}}_\rho \qquad (1)$$

$\vec{\mathbf{E}}_{\mathrm{line}}(\rho)$: Electric field of line charge density at radius ρ
λ: Line charge density
ϵ_0: Dielectric constant
$\vec{\mathbf{e}}_\rho$: Unit vector in ρ direction

The electric field is inversely proportional to the distance from the electrodes and therefore strongest when close to the rods. If the rods are placed in the soil loosely or directly next to a big irregularity in the soil (e.g. stones or air pockets), the measured values differ very much. Water that accumulates directly on the sensor rod surfaces then also has a higher impact on the measured value. This effect was exploited in [4] for a specific measurement purpose but is generally not desired.

A solution for this problem is to use differently shaped electrodes. Instead of rods placed in the soil, two plates can be used. These imitate the electric field of a surface charge density with infinite surface as follows:

$$\vec{\mathbf{E}}_{\mathrm{surf}}(\mathrm{d}) = \frac{\sigma}{2\epsilon_0}\vec{\mathbf{e}}_{\mathrm{d}} \qquad (2)$$

$\vec{\mathbf{E}}_{\mathrm{surf}}(\mathrm{d})$: Electric field of surface charge density at distance d
σ: Surface charge density
$\vec{\mathbf{e}}_{\mathrm{d}}$: Unit vector in d direction

Equation (2) shows that the electric field strength between two plates is independent of the distance d from the plates. Therefore, this design is further evaluated.

Experimental Setup

In order to measure in different soil depths, 3 pairs of electrodes were realized on a printed circuit board (PCB). The capacitance between the electrodes was measured using the FDC2214 measurement chip [5]. The traces were shielded with ground potential with the 4-layer PCB structure to minimize external noise. The final sensor design can be seen in fig. 1.

Fig. 1. Sensor setup.

Installing the sensor in the soil can be accomplished by pre-punching the necessary slits in the soil with a hammer and a dummy sensor. This makes it possible to probe the soil almost in its original condition.

Results

First, the designed sensor was inserted into soil multiple times. The offset of the measured capacity was subtracted and normalized over the whole dynamic range. A histogram of the repetitions can be seen in fig. 2 for different heights.

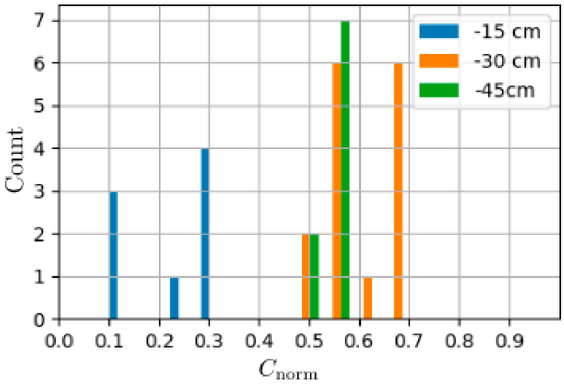

Fig. 2. Installation histogram with number of occurrence against normalized capacity.

For multiple insertions, the measured and normalized capacity is within 15 % of the total dynamic range, which is comparable to the sensors in [1]. The top sensor has a lower capacity because the soil is dryer on the surface.

In the next step, two latex balloons were filled with approximately 1.5 liters of air and water. These balloons were slightly squeezed between the different measurement levels. The measured capacities are shown in table 1. The volumetric sensitivity is calculated by subtracting the offset value of the air balloon from the water balloon and the completely submerged sensor value. The ratio between the water balloon between the sensor legs and the completely submerged sensor quantifies the contribution of water directly at the measurement point compared to the maximum possible value when the sensor is submerged. For two demo sensors the values lie within 50 % - 65 %.

Tab. 1: Volumetric sensitivity of two demo sensors

	$C_{\mathrm{b,a}}$	$C_{\mathrm{b,w}}$	C_{sub}	δ_{sen}
-10 cm	415 pF	457 pF	476 pF	68.8 %
	398 pF	428 pF	446 pF	62.5 %
-30 cm	350 pF	388 pF	413 pF	60.3 %
	334 pF	359 pF	387 pF	47.9 %
-45 cm	273 pF	311 pF	332 pF	64.4 %
	269 pF	297 pF	318 pF	57.1 %

$C_{\mathrm{b,a}}$: Capacity with air filled balloon
$C_{\mathrm{b,w}}$: Capacity with water filled balloon
C_{sub}: Capacity when submerged in water
δ_{sen}: Volumetric sensitivity

Conclusion and further work

The sensor design presented has a quantified installation sensitivity of around 15 % and volume sensitivity value of 50 % - 65 % in 1.5 liters of probe volume. It is therefore able to give a rough estimate of the soil moisture without calibration needs and a homogeneous measurement principle.

During the work it was noticed that the measured value is temperature sensitive and the thick sensing legs require heavy tools for the insertion. In future work the temperature sensitivity can be eliminated by implementing a differential measurement principle and the installation uncertainty can be improved by a thinner leg design because it is less invasive to the soil.

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