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A new bi-frequency soil smart sensing moisture and salinity for connected sustainable agriculture

J. Roux, C. Escriba, J.Y. Fourniols and G. Soto-Romero

Optimizing water consumption is a major challenge for a more sustainable agriculture with respect for the environment. By combining micro and nanotechnologies with the offered solutions of IoT connection (Sigfox and LoRa), new sensors allow the farmer to be connected to his agricultural production by mastering in real time the right contribution needed in water and fertilizer. The sensor designed in this research allows a double measurement of soil moisture and salinity. In order to minimize the destructuring of the ground to insert the sensor, we have designed a cylindrical sensor, easy to insert, with its electronics inside its body to propose a low power electronic architecture capable of measuring and communicating wireless with a LoRa or Sigfox network or even the farmer's cell phone. This new smart sensor is then compared to the current leaders in agriculture to validate its performance.

Introduction: In the context of agriculture modernization, the farmers need tools to develop the smart farming. For that, it is necessary to develop new sensors which can be deployed closest to the plants. To control the irrigation, the sensors measure the soil moisture near the crops. This new intelligent sensor combines non-contact moisture and salinity measurement, exploiting a capacitive reading between two spiral form factor electrodes on a cylindrical preform to optimize contact surfaces for minimal electrode volume. Thus, by reducing the cost of the measuring point, it is possible to deploy more sensors in the ground and thus obtain an observation in the field more in agreement with the variations of the behavior of the grounds. The two optimized parameters are, on the one hand soil moisture, which measured at different depths allows to know the mechanism of absorption of the crop plant; and on the other hand the salinity of the soil which gives information on the amount of soil nutrients necessary for the development of the plant.

In order to reduce the cost of manufacture and the constraints of placement in the ground, we did not retain the resistive measurement by contact [1] [2] [3] but privileged a capacitive measurement [4] [5]. The article presented will be oriented in three parts. The form factor of the electrodes will not be detailed in order to privilege on the one hand the electronic architecture of reading bi-frequency retained, then we will demonstrate by experimentation the usable frequency bands to observe respectively salinity and humidity. Finally, we will present the results of the assembled sensor and will position its measurement sensitivity with respect to Decagon™ and Sentek™ sensors used by the farmers.

Sensor's model: We chose the capacitive method to measure so the sensor is a capacity. But because of the integration, parasite capacities are created as shown in Fig. 1.

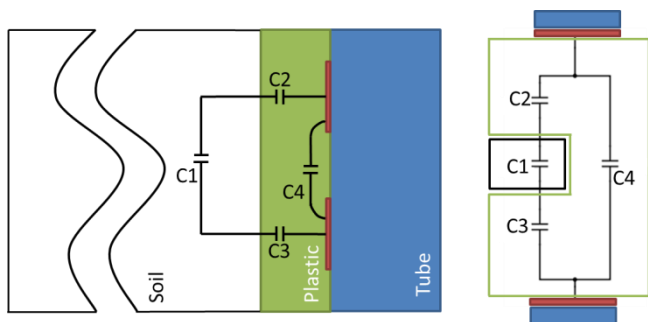


Fig. 1 Electric model of the sensor

In this model, we can see the variable capacity C_1 dependent to soil properties (humidity or salinity) and also fixed capacities created by the electrodes interferences C_4 and the plastic protection C_2 and C_3 . This model can be simplified by a single variable capacity in parallel with a single fixed capacity.

Measurement Architecture: The capacitive variation induced by the lining of soil properties in response to a variation of humidity and / or salinity is exploited by a Colpitts oscillator which generates a sinusoidal

signal of adjustable frequency to sweep the spectrum of measurements to search for the spectral band containing the information. In the Fig. 2, we can see the schematic of this Colpitts oscillator and its output frequency that is inversely proportional to the soil moisture.

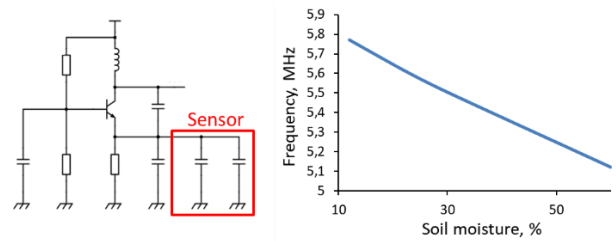


Fig. 2 Frequency response of the Colpitts oscillator by the soil moisture

The oscillation frequency can be read by an analog acquisition chain (Fig. 3) associating an integrated frequency / voltage converter and a voltage reading using a CAN built into a microcontroller. Therefore thinking microcontroller, forces us to compare this architecture with an all-digital solution (Fig. 4) with a dedicated embedded algorithm.

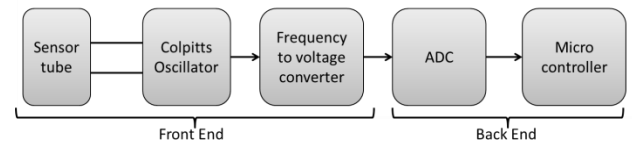


Fig. 3 Analog sensor architecture

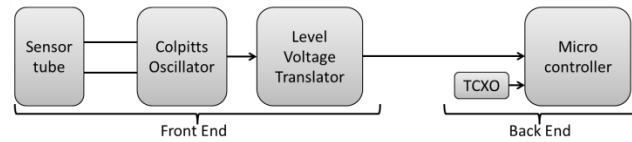


Fig. 4 Digital architecture of the sensor

Three levels of salinity have been defined; the frequency sweep performed by the Colpitts oscillator shows the variation of capacity on the interval 100kHz to 10MHz (Fig. 5).

Two areas of interest appear on this curve:

- An area where the capacitance variation of the electrodes is insensitive to the salinity: above 4MHz, the curves merge regardless of the salinity.
- An area where the capacity varies proportionally with salinity. Thus, the measurement of the salinity is defined at the frequency of 500kHz.

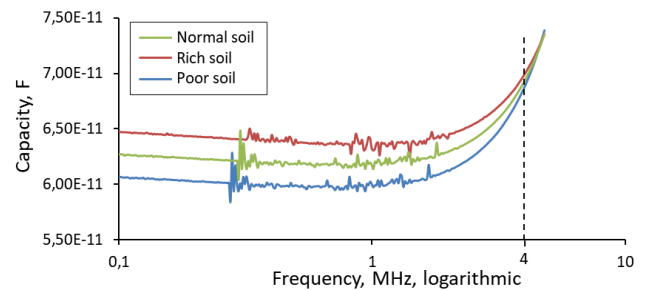


Fig. 5 Sensor's capacity by the soil salinity

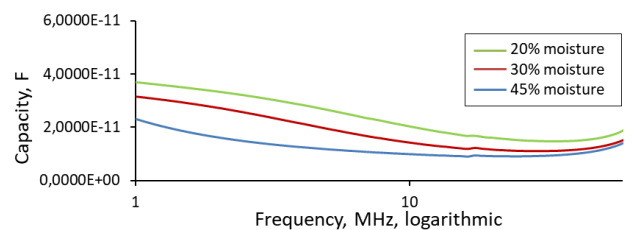


Fig. 6 Sensor's capacity by soil moisture

By observing (Fig. 6) the variation of capacity as a function of humidity, the reading frequency ranges are not superimposed with the exploitable

area of the 500kHz dedicated to the salinity measurement. We can therefore define 8MHz frequency for humidity measurement and thus obtain two operating ranges of our electrodes that will de-worm two totally uncorrelated salinity and soil moisture observations. To make the good choice between an analogue or all-digital architecture, it is necessary to compare the stabilization of the measurement with the variations of environment of which one of the principal parameters is the variation of temperature in the soil which varies between 5°C to 50°C (Fig. 7). While the time frequency converter has at a sensitivity of 0.3%.°C⁻¹ for the analog architecture; the TCXO choice allows the digital architecture to guarantee robustness to temperature variations. With this quartz cost constraint, all digital solution is chosen and can offer versatile corrections linked to soil characteristics variations (type of soil size of aggregates...).

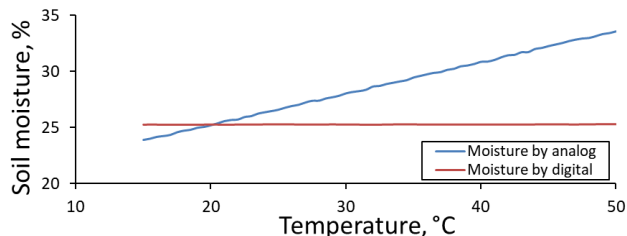


Fig. 7 Thermal response of both architectures

Sensor integration: To allow the insertion in the ground and to ensure the solidity, we decide to place the electronic card in the sensor tube even if the presence of components close to the electrodes will modify the electromagnetic behavior. The contact between the electrodes of the tube and the sensor is made using contact zones positioned on the top of the card. Connections with the outside (data + energy) are made on the top of the card and are solidified by cable holes. Complete integration is shown in Fig. 8 with its characteristics in Table 1.

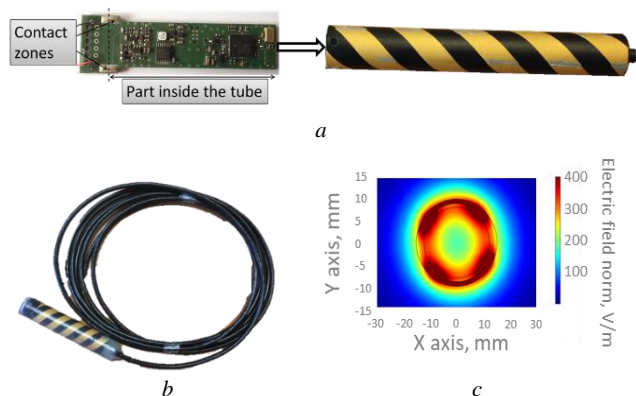


Fig. 8 Sensor integration

Table 1 Characteristics compared to industrial sensors

Sensor	Precision (% moisture)	Measuring time (ms)	Supply	Size (mm)
Our Sensor	±2%	15	3V – 5V @15mA	Ø24 x 150
Decagon™	±2%	20	2.5V-3.6V @10mA	20 x 50
Sentek™	±2%	50	12V @100mA	Ø40 x 500

To be available by the farmers, the sensor's data have to be online. For that, the sensor has to be connected. Several links exist but two of them stand out, Sigfox and LoRa. These protocols are low rate but long range and low energy. With these links, the sensor can transmit at more than 10km while remaining autonomous.

The sensor is buried on the soil so it cannot emit itself, he needs a part aboveground. This part concentrates the data of four sensors to measure at four depths. It will transmit the data to a server and a web application posts them to the farmers.

Sensor Measurements: Observe and compare the behavior of our sensor over long periods with industrialized sensors on an orchard and cornfield culture (Fig. 9 & Fig. 10). Look at the moisture response following the water supplies confirmed by the rain gauge. We can notice that we are more precise on the observation of the soil drying dynamics.

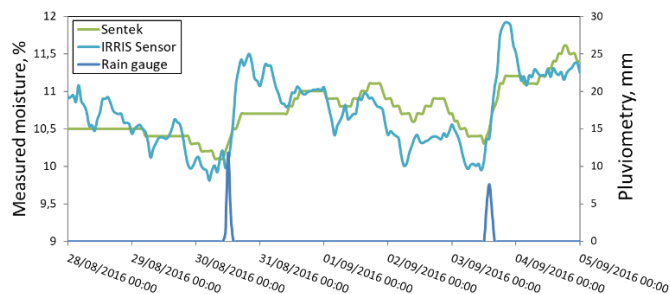


Fig. 9 Cornfield culture sensing

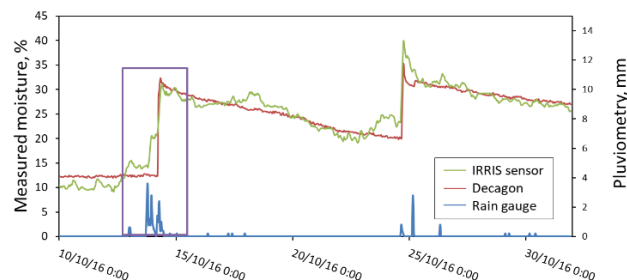


Fig. 10 Apple orchard sensing

We can observe on this graph the similarity of response between the Decagon™ and our sensor: response time to a water intake is immediate; drying dynamics are identical. In addition, note in the purple box area: our sensor detects a water intake not seen by the Decagon™ sensor, which, in this example, reflects a better sensitivity.

Conclusion: Using capacitive technology for our sensor, we develop a new smart sensor able to measure soil moisture and also soil salinity. For this purpose, double helix electrodes are formed to optimize the relationship between the sensor and the ground. Based on Colpitts oscillator we develop a dual-frequency electronics and a full digital signal processing to reduce cost. Regarding the humidity measurement, we obtain a sensor that has the same performance as the market leaders but for lower cost and a new functionality.

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