Developing Affordable Sensors in Agriculture Based on Results Obtained at Embrapa Instrumentation

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Embrapa 50 ANOS

MINISTÉRIO DA AGRICULTURA E PECUÁRIA

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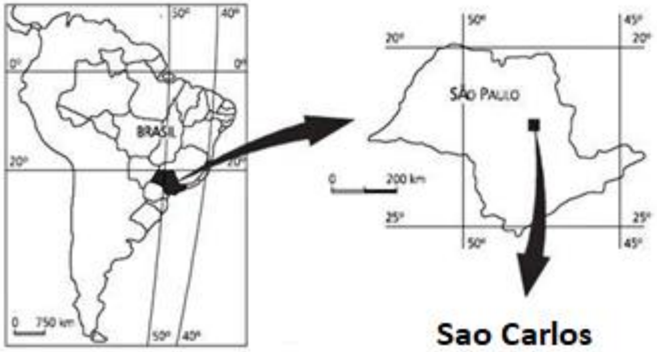
Summary

- INTRODUCTION;
- RECENT DEVELOPMENT OF AFFORDABLE SENSORS AT EMBRAPA INSTRUMENTATION;
- CONCLUSIONS;
- FUTURE WORK.

Embrapa Instrumentation

Sao Carlos (SP) – BRAZIL

One of 46 Embrapa units spread out in Brazil.



Motivation

- Fully printed sensors will reach $7.6bn revenues by 2027[(1)]
- The global agricultural sensors market size was valued at USD 4.74 billion in 2021. It is expected to reach USD 16.83 billion by 2030, growing at a Compound annual growth rate (CAGR) of 15.12% during the forecast period (2022–2030) [(2)] ;
- The ultimate success of chemical, biosensors and sensors resides in designing inexpensive, single use and reusable, reliable and sensitive[(3)].

(1) Chansin, G. Pinted and Flexible Sensors 2017-2027: Technologies, Players, Forecasts, https://www.idtechex.com/research/reports/printed-and-flexible-sensors-2017-2027-technologies-players-forecasts-000504.asp

(2) Agricultural Sensors Market Growth, Share, Forecast to 2030. https://straitsresearch.com/report/agricutural-sensors-market#:~:text=Market%20Snapshot&text=The%20global%20agricultural%20sensors%20market,period%20(2022%E2%80%932030). 2021 ,

(3) H. H. Weetall□ “Chemical Sensors and Biosensors, Update, What, Where, When and How”. Vol.14, pp.237–242, 1999;

Selected Sensor Characteristics

Static
- Accuracy
- Distortion
- Hysteresis
- Minimum detectable signal
- Nonlinearity
- Selectivity/Specificity
- Sensitivity
- Threshold

Dynamic
- Dynamic error response
- Hysteresis
- Instability and drift
- Noise
- Operating range
- Repeatability
- Step response

National Research Council. 1995. *Expanding the Vision of Sensor Materials*. Washington, DC: The National Academies Press. https://doi.org/10.17226/4782.

Low Cost Sensor Technology

- is defined as sensor technology originally developed *for consumer applications and/or research*. Competitive and low cost because of economies of scale, these sensor technologies enable new applications or allow more cost-effective utilization of sensing in production and environments.

Kückelhaus et al., 2013

RECENT DEVELOPMENT OF AFFORDABLE SENSORS AT EMBRAPA INSTRUMENTATION.

II. SENSOR FOR SOIL MOISTURE MEASUREMENT, USING MICROWAVE TECHNIQUES

Waveguide Technique

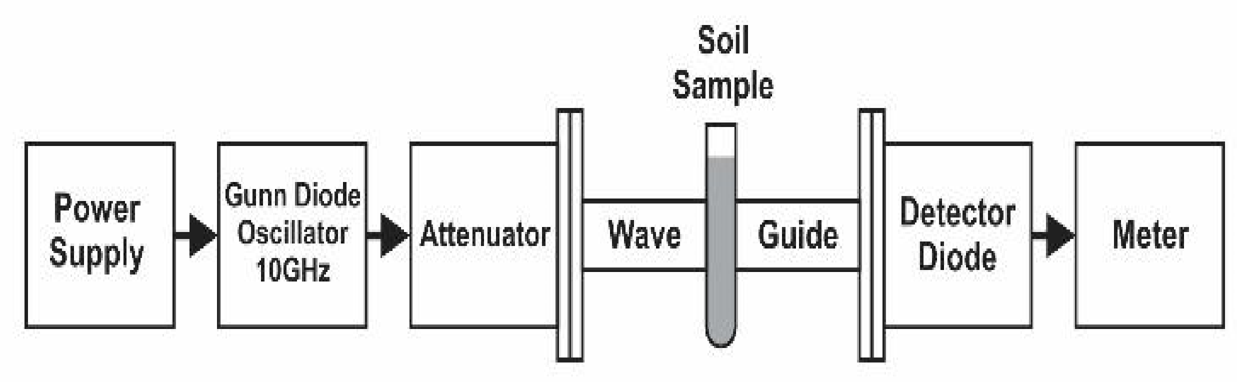
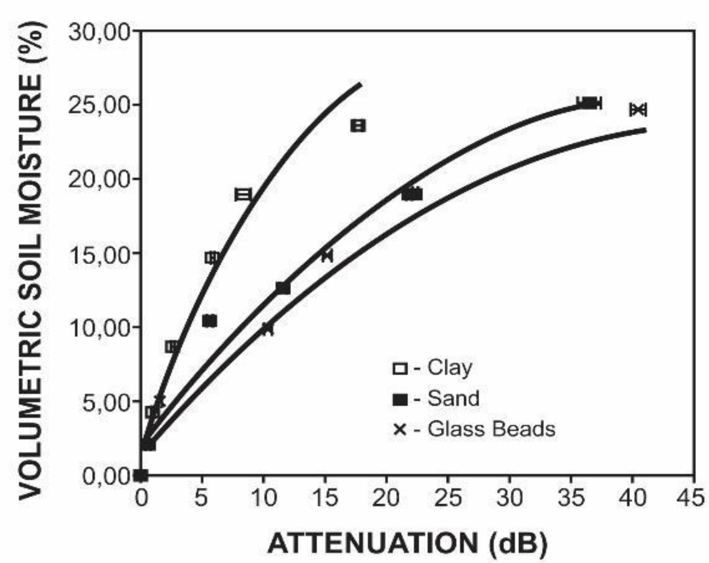
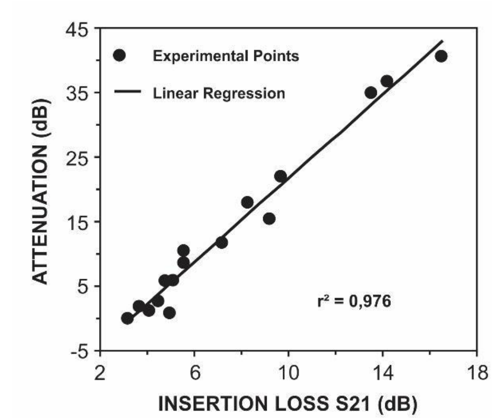


Figure 1. Presents a system for measuring soil moisture content that uses microwave signal transmission and reception through the waveguide technique





Free Space Technique

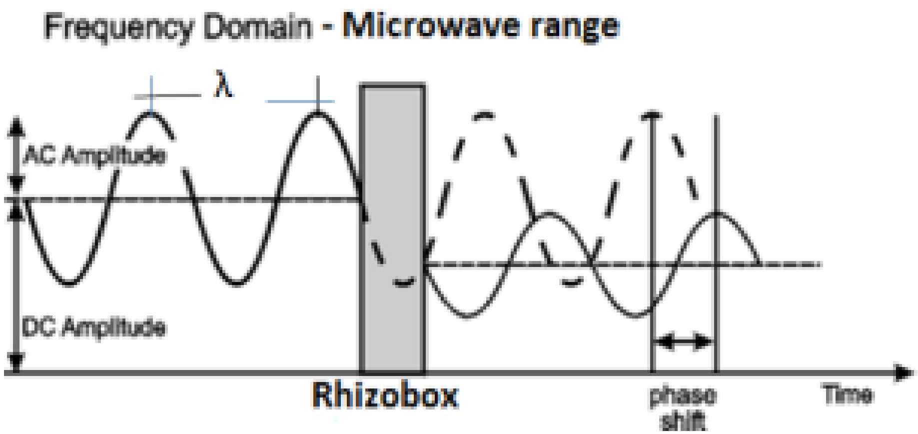
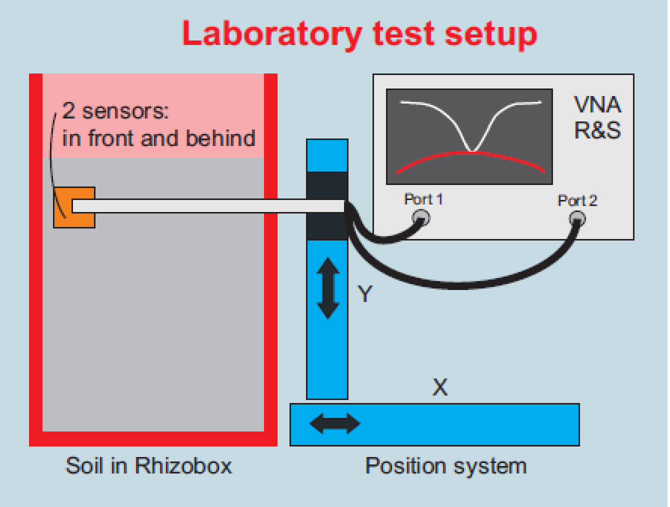


Diagram with basic principle of the system developed.



The draw of the system developed to measure S21 (dB) of the soil moisture in the rhizobox, using Vector Network Analyzer, in the microwave range (4.6 GHz to 5.0 GHz).

$dB_m = 10 * \log (P/1mW)$

Φ (°) = Phase shift

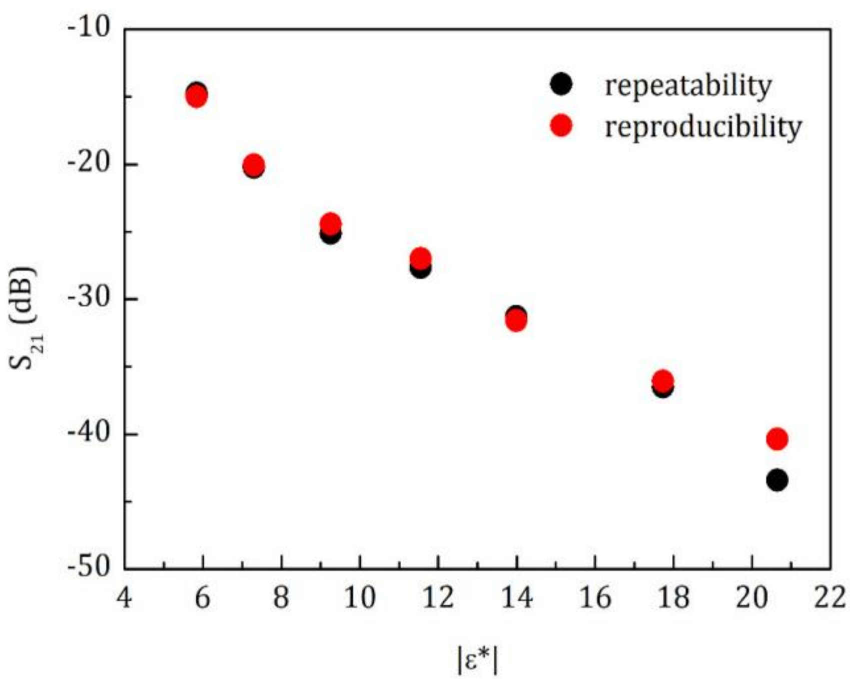
Vector Network Analyzer (ZNB 8, Rohde & Schwarz)

- Range of the Frequency: 4,55 GHz – 5,05GHz;
 (up to 140 dB)
- Temperature stability of typ. 0.01 dB/°C
- Resolution: 0,25MHz (Frequency);
 6mdB (Attenuation (dB))
- Trace Noise: 10mdB

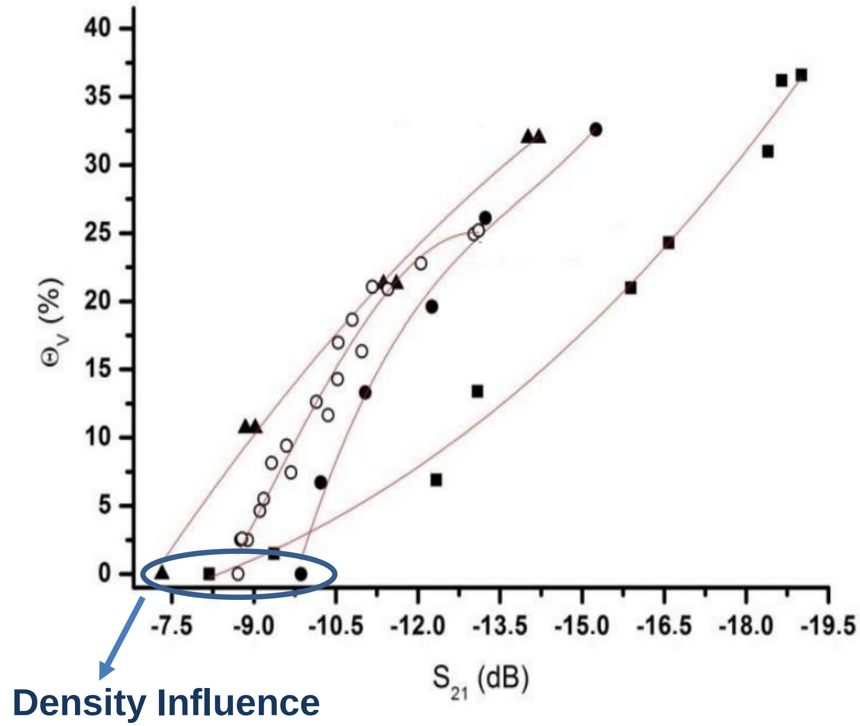
Results

Repeatability = 93.0 %

Reproducibility = 98,9 %



The relation between |ε* | versus the average of S21 (dB) shows the repeatability and reproducibility of the system developed were calculated.



S21 measured with the developed system and the volumetric soil moisture θV (%). **The four** (04) samples used are Cerrado Soil (squares), Kaktus Soil (open circles) and Glass Beads (triangles)

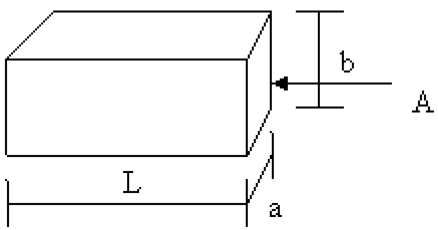
III. SYSTEM FOR MEASURING THE APPARENT ELECTRICAL CONDUCTIVITY OF SOILS ECa.

System for measuring the apparent electrical conductivity of soils ECa.

- Soil apparent electrical conductivity (ECa) originated from the measurement of soil salinity, a very pertinent problem in arid zones associated with irrigated agricultural crops and areas with shallow water tables.
- Soil ECa is greatly influenced by a vast combination of physical and chemical properties of the soil, such as:
  - Soluble salts;
  - Mineralogy and clay content;
  - Amount of water present in the soil;
  - Volumetric density;
  - Organic matter;
  - Soil temperature.

Principle of apparent electrical conductivity measurement:

- The electrical resistance is then calculated by the followings equations:



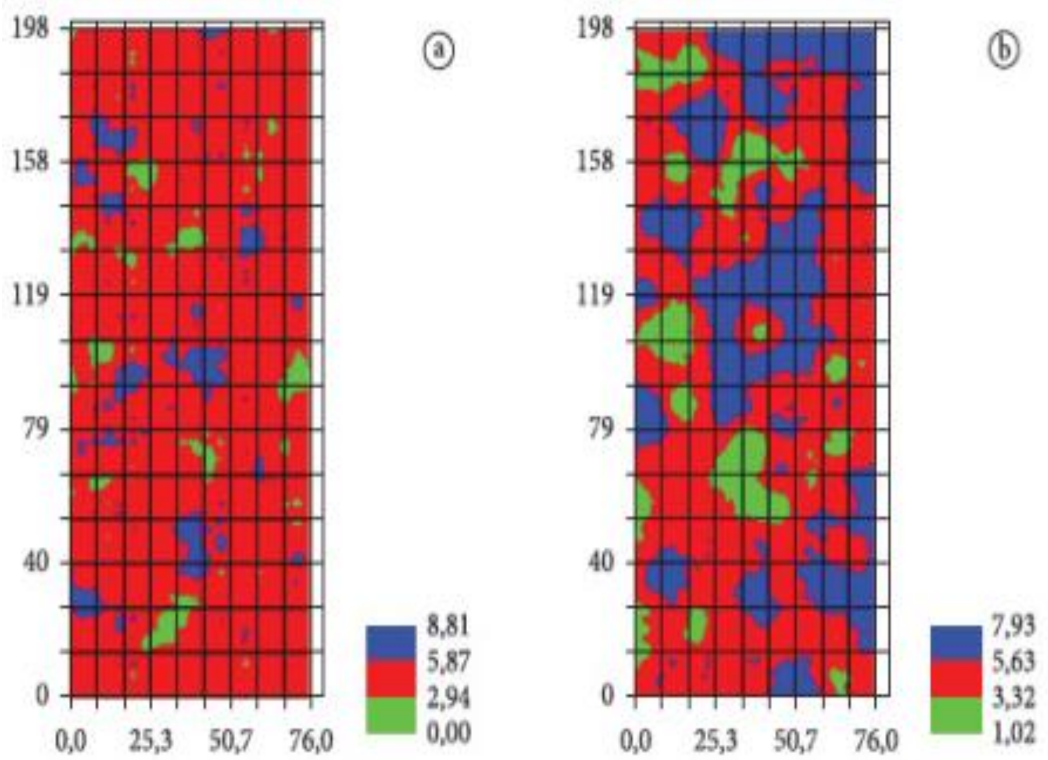
$$V = R \cdot I \qquad R = \rho \frac{L}{A}$$

- Electrical conductivity, σ, is defined as the inverse of electrical resistivity, so we have:

$$\sigma = \frac{1}{\rho}$$

Result

Apparent electrical conductivity measurement system.



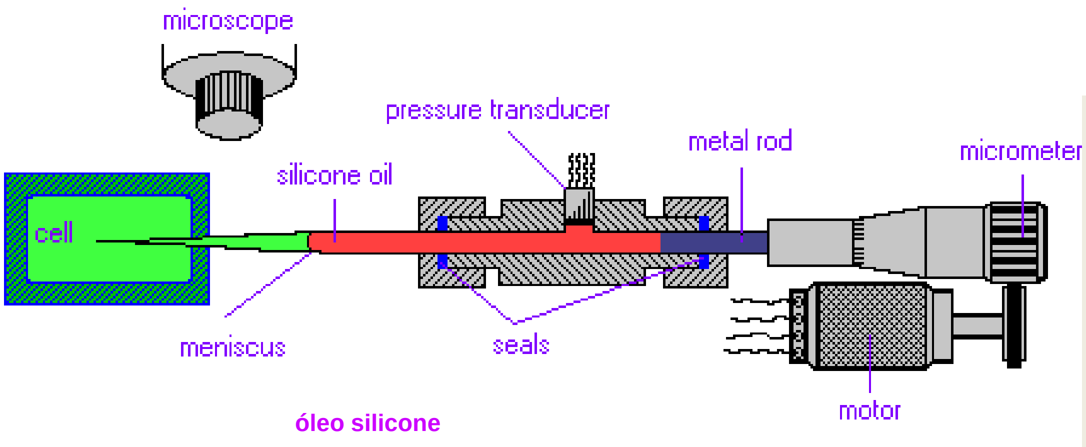
Maps of homogeneous zones of apparent soil electrical conductivity, a - ECa at a depth of 0.3 m; b - ECa at depth 0.9 m, grapevine crop, semi-arid region, Brazil

IV. SENSOR FOR MEASURING WATER AND PLANT RELATIONSHIPS.

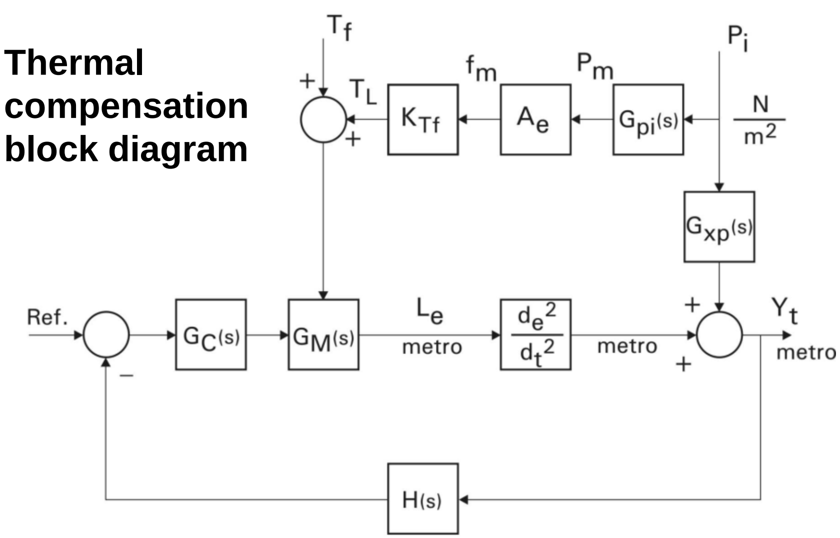
It consisted of a glass capillary connected to a chamber filled with oil that punctured the cell wall, thus establishing a hydraulic connection between the cell sap and oil content.

Using an optical microscope, it was possible to measure the movement of the oil/cell sap boundary, the meniscus, and then by raising or lowering the oil pressure inside the chamber mechanically until the meniscus returned to its original position, one could measure the pressure with a sensor in the oil chamber.

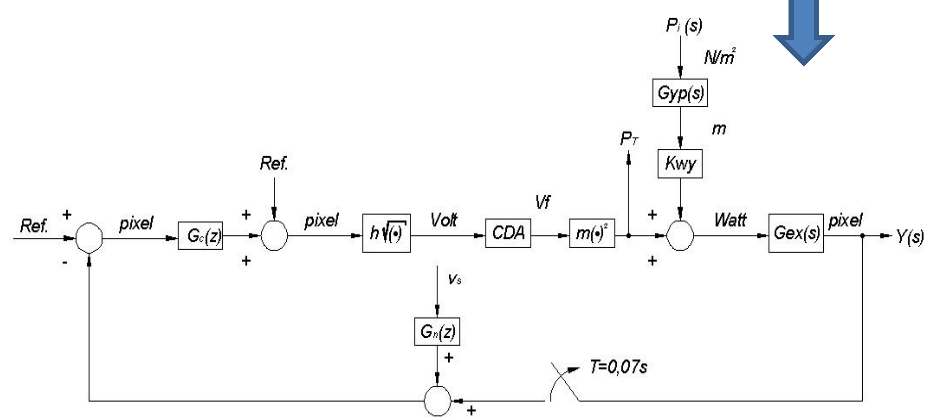
Pressure probe: mechanical compensation version



Thermal compensation block diagram

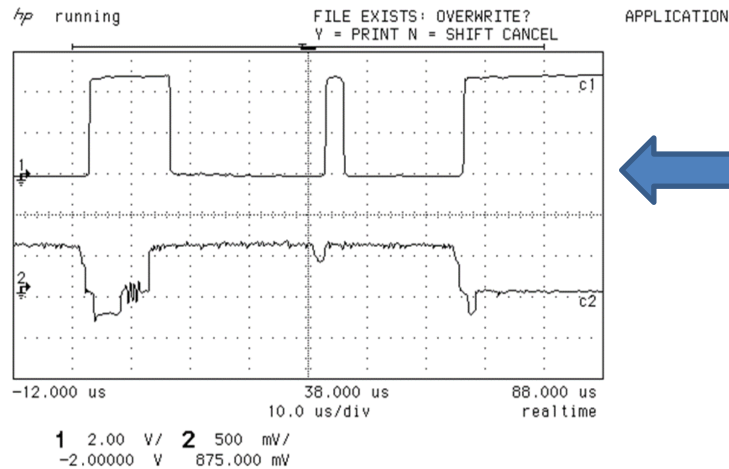


Thermal compensation block diagram

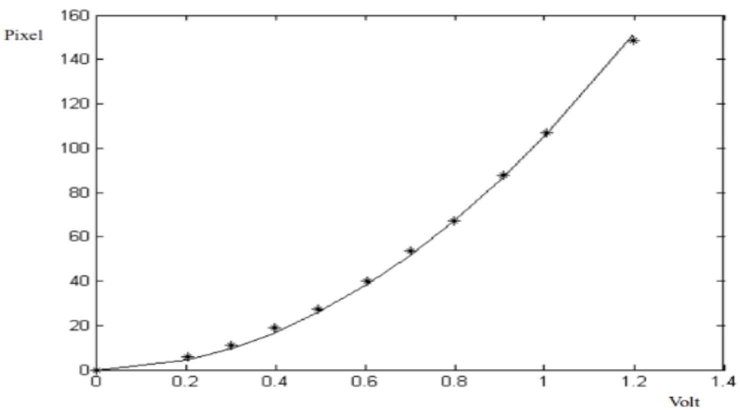


Meniscus video image

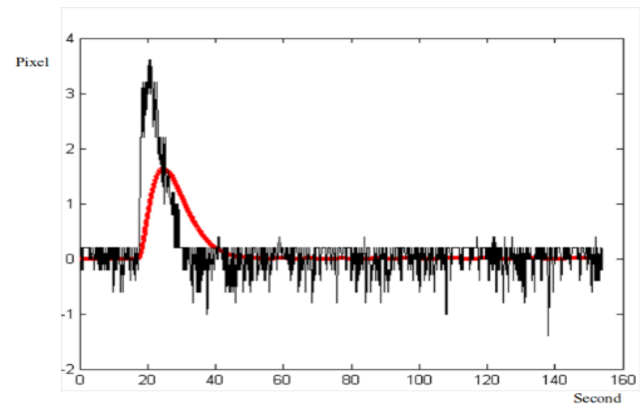
One line
vídeo signal



Digitized
signal



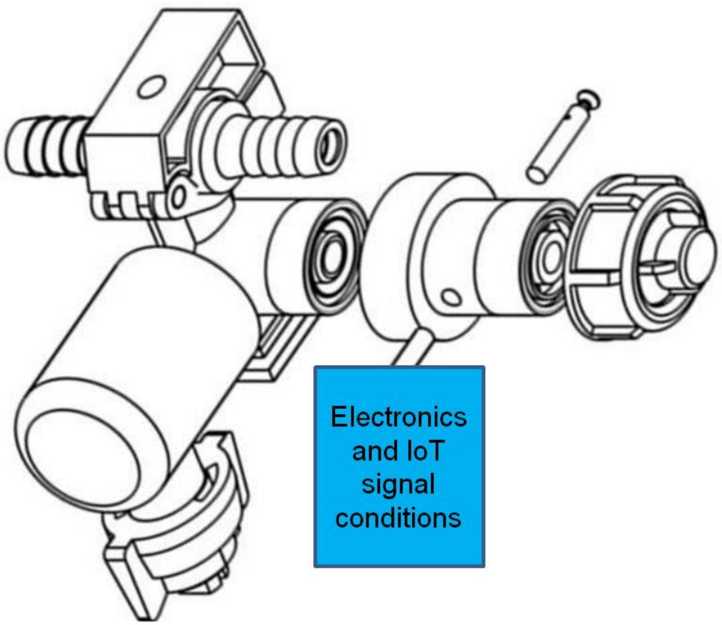
1. Quadratic behavior between electric power in volt and meniscus' displacement.



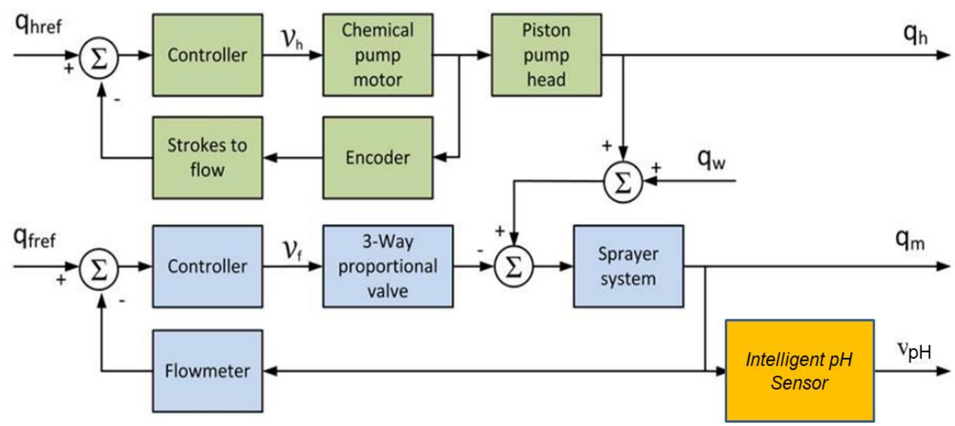
PID action: origin position after a pressure step at the tip of the capillary. Red : simulated response; black measured response

V. SENSOR FOR THE pH REAL TIME MEASUREMENTS IN AGRICULTURAL SPRAY SOLUTION

Intelligent spray pH sensor.

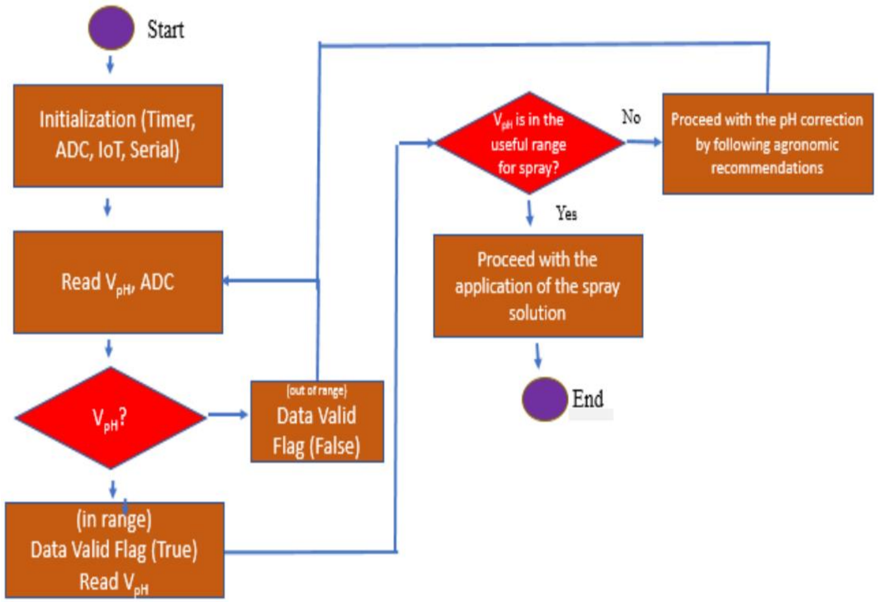


Technical draw of the intelligent pH sensor assembled on the nozzle for direct injection sprayer



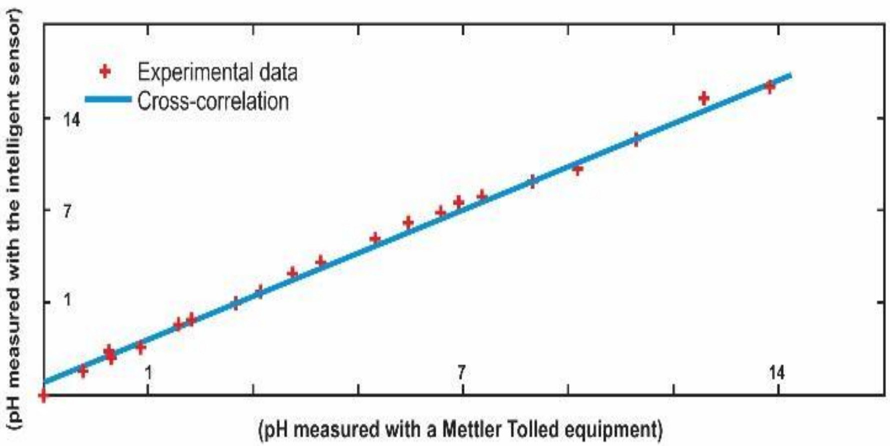
Block diagram for the fungicides, herbicides or insecticides, mixture control, and the intelligent pH sensor

Intelligent spray pH sensor.



Computational Flow diagram for the real time measurements and flag related to the spray solution pH evaluation.

Result



Calibration Curve and comparison with values obtained with prepared solutions with well-known pH values

Opportunities and prospecting for the medium and long term.

- Study and investigation of the influence of soil temperature and density, using microwave techniques;
- The study of water relations in plants are cutting-edge areas such as Plant Phenotyping;
- The intelligent pH sensor could be in the form of a flag, which shows a confidence level of the spray solution quality;

CONCLUSIONS

- **Microwave technique** is a non-destructive methodology, easy measurement of soil water, portability, the use of non-ionizing radiation, speed in the measurement with low cost;
- The use of the **apparent electrical conductivity** of the soil has demonstrated as an important tool for precision agricultural work, its ease, simplicity and practicality lead to time and cost savings in carrying out decision-making in the areas of management and spatial variability of study areas;
- The **physical model** of the pressure probe was improved, and an **automated pressure gauge** was developed to investigate the **displacement of the meniscus** in the observation of the water-plant ratio;
- An **intelligent sensor to measure the pH of spray systems** based on direct injection was presented. That can be useful to avoid losses in agricultural production.

Acknowledgments

Embrapa

- Valentim Monzane.

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Embrapa

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Thank You!

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