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Testing the Variation in Performance of a Coil-Based Soil Moisture Sensor with Soil-Core and Air-Core Deployments

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1. Introduction and motivation

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- Traditional sensors face challenges as soil heterogeneity affects their performance and moisture fluctuations cause measurement variations.
- Coil-based sensors detect moisture through changes in electrical properties (impedance, resonant frequency), offering high sensitivity, durability, and fast response times.
- Soil moisture monitoring is crucial for agriculture, climate change studies, and ecosystem research, as it optimizes irrigation, minimizes water waste, and reduces plant stress.
- Main Results:
  - Similar performance: R^2 =0.95 (soil core) and R^2= 0.93 (air core).
  - No significant differences according to the T-test.
  - Low coefficients of variation: 0.43% (air core) and 0.25% (soil core).

Objective of the Study: The simplicity of the air-core design justifies the slight performance loss, making it a practical and efficient option for agricultural and

Study Contributions: The new air-core sensor configuration does not significantly reduce performance compared to the soil-core sensor.

2. Related Work

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- Schwamback et al. (2023): Explored the balance between cost and precision in soil moisture sensors, highlighting the potential of low-cost sensors for agricultural applications.
- Basterrechea et al. (2021): Developed and calibrated soil moisture sensors using inductive coils and electromagnetic fields.

Basterrechea et al. (2021): Differentiated between wet and dry soils but did not address the effects of varying soil entry into the coil core or alternative measurement methods.

Recent studies aim to improve the accuracy, affordability, and adaptability of soil moisture sensors for various soil types and moisture levels.

3. Proposal

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Conductivity Sensor Description:

- Composed of two coils: a primary coil (80 turns) and a secondary coil (40 turns).
- Operates on the principle of magnetic field induction, where changes in soil moisture affect the voltage in the secondary coil.
- Coils are mounted on a 25 mm diameter tube and covered with epoxy for protection.
- Generates a solenoidal magnetic field when current flows through the primary coil.

Sensor Characteristics (Table I):

- Primary coil: 80 turns, 0.4 mm copper diameter, 25 mm coil diameter, 1 layer.
- Secondary coil: 40 turns, similar specifications to the primary coil but with a different ratio.

3. Proposal

Signal Conditioning Circuit:

- Transforms the sensor's AC signal to DC using a diode bridge.
- Filters and stabilizes the signal to obtain a smooth, stable output voltage.
- Final voltage (Vout) is sent to a server for processing via a node circuit.

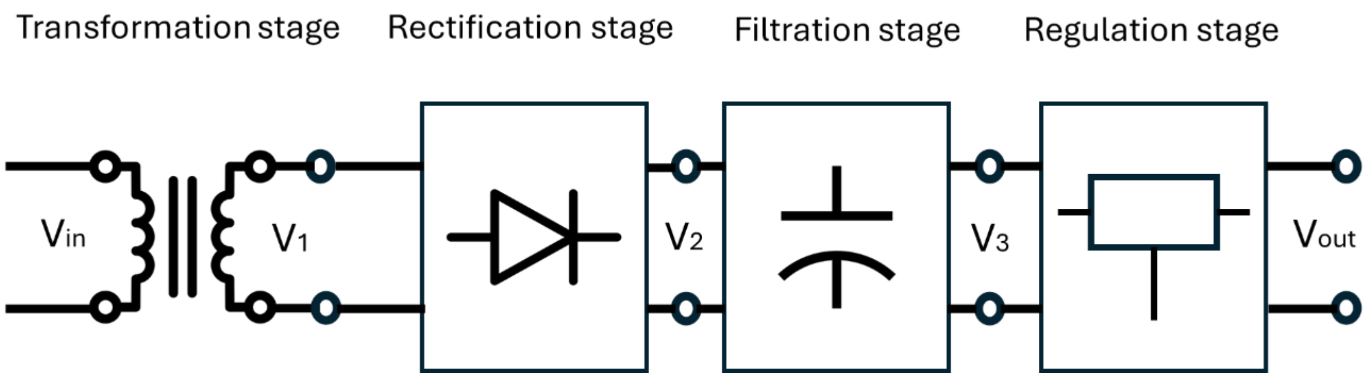
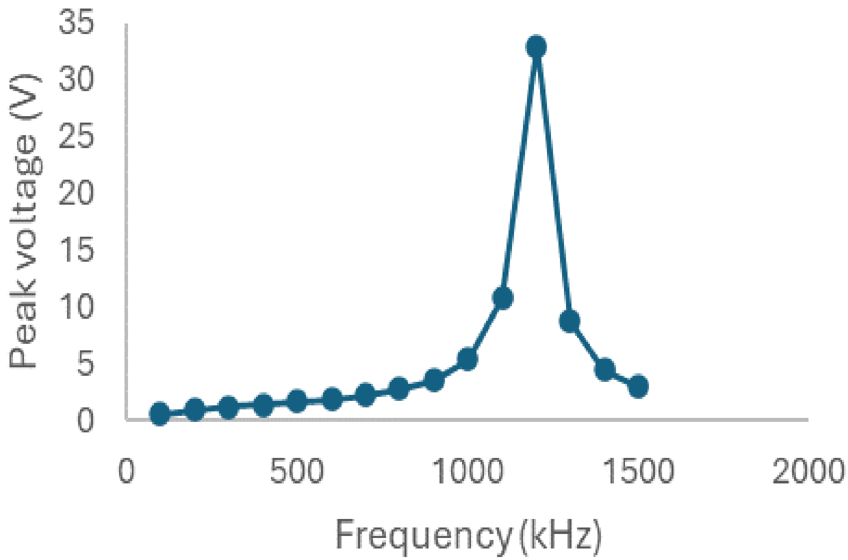


Diagram of signal filtering stages.

3. Proposal

Peak Frequency and Sensor Power Supply:

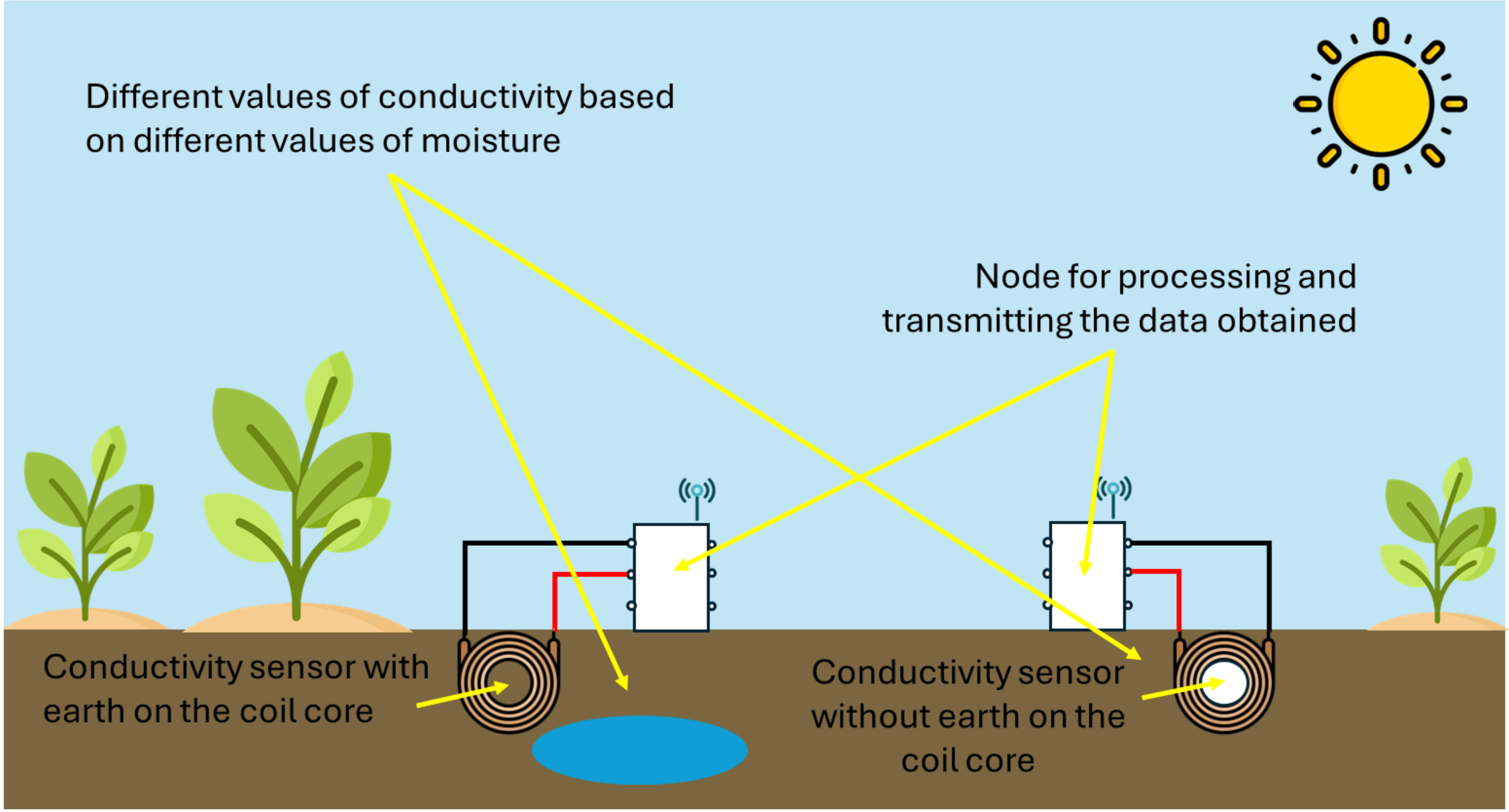
- Primary coil powered by a function generator with a sinusoidal signal (9V amplitude).
- Resonance peak frequency determined through a frequency sweep; identified at 1200 kHz, critical for sensor operation.



Arrangement of the coil in the ground with or without earth in the core.

3. Proposal

Sensor Deployment Configurations:



Explanatory drawing of the sensor settings.

4. Test Bench

4. Test Bench

Materials Used:

- Pots: Polypropylene, tapered design, 13 cm height, 9 cm minimum diameter, 13 cm maximum diameter.
- Soil: Commercial organic substrate (peat, manure, NPK fertilizer, perlite), pH 6, 97% organic matter, 700 g per pot.
- Water: Deionized water, measured using a 250 mL Fisherbrand crystal beaker.
- Equipment: Laboratory balance with 0.1 g precision (NAHITA BLUE), soil moisture sensors.

Soil Moisture Levels:

- Four levels: 0, 50, 75, and 100 mL of water added to pots.
- Moisture levels expressed as Gravimetric Water Content (GWC), Volumetric Water Content (VWC), and water per meter of soil (L/m^2) (summarized in Table II).

4. Test Bench

Data Gathering System and Procedure:

- System: Coupled coils attached to a tube connected to a rectifier circuit and Arduino ADC for data collection.
- Air-core sensor: Core left empty and sealed to prevent soil entry.
- Soil-core sensor: Core filled with soil.
- Procedure: Sensor placed to ensure full soil coverage, with data recorded every 45 seconds; 5 data sets averaged for each condition.

Statistical Analyses:

- Regression models include correlation coefficients, R2R^2R2, p-values, slope (a), and y-intercept (b).
- Confidence and prediction intervals established for models.
- Paired T-test used to compare data from the two configurations.
- Coefficient of variation calculated to assess performance consistency between calibrations.

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5. Results

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5. Results

A. Comparison of calibration curves

Data	Correlation coefficient	Adj. R2	p-value	a	b
Soil-core	-0.977	95.03	<0.0001	2918	-8.38
Air-core	-0.969	93.31	<0.0001	2940	-7.76
All data	-0.968	93.51		2929	-8.07

Data of Calibration Regression Models

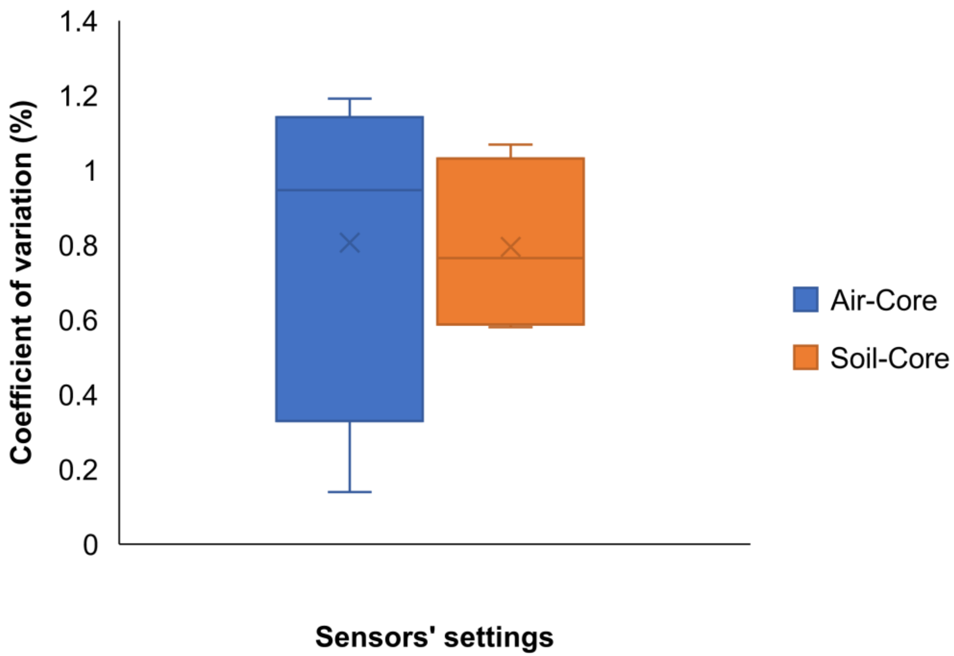
4. Test Bench

B. Comparison of Paired Data:

- T-Student Test Result: $p=0.002$: No significant differences between air-core and soil-core data.
- Conclusion: Air-core sensor performance is comparable to soil-core, and data from both can be used interchangeably.

5. Results

C. Comparison of differences between gathered data in each pot



Coefficient of variation of the 3 experimental replicas.

6. Conclusion

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- Despite filling a portion of the sensor's sensing volume with air, the air-core sensor's performance is comparable to the soil-core sensor.
- Metrics evaluated include calibration regression models and the coefficient of variation.
- Calibration R^2 : 0.95 for soil-core sensor and 0.93 for air-core sensor.

Future work: Evaluate the effect of filling the sensor core with soil through repeated burying and unearthing to measure variability, conduct experiments with different soil types and assess the impact of roots on data gathering.

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