Precision Irrigation with Cost-effective and Autonomic IoT Devices using Artificial Intelligence at the Edge

D2.3

Report on the test campaign of the low cost AI-capable Smart Tensiometer

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1. Introduction

The "test campaign of the low cost AI-capable Smart Tensiometer" presents a comprehensive analysis of the hardware and software components involved in predicting soil tension values. This report represents a critical phase in evaluating the performance and reliability of the Smart Tensiometer in agricultural applications.

The focus of this test campaign is to assess the functionality and accuracy of the Smart Tensiometer in forecasting soil tension values. Through systematic testing and analysis, we aim to provide an objective evaluation of its performance in real-world agricultural scenarios.

Our approach is rooted in rigorous experimentation and data analysis, guided by the principles of scientific inquiry. The primary objective is to validate the effectiveness of the Smart Tensiometer and identify any areas for improvement. In addition to assessing the functionality and accuracy of the Smart Tensiometer in forecasting soil tension values, this test campaign includes tests of ancillary components crucial to the system's operation. These tests include:

- **Testing of Solar Panel:** The performance of the solar panel in providing power to the Smart Tensiometer system will be evaluated to assess its effectiveness in sustaining operations under varying sunlight conditions.
- **Battery Life Test:** The battery life of the Smart Tensiometer system will be examined to determine its capacity to maintain functionality in the absence of sunlight or solar panel charging.
- **Testing of 3D Printed Casing:** Evaluation of Different Materials and Print Settings: Various materials and print settings will be tested to assess their impact on the durability and performance of the casing.
- **Watertightness Test:** The 3D printed casing will undergo testing for watertightness, with adherence to the IP55 standard, to ensure protection against environmental factors such as moisture and dust.

These additional tests aim to provide a comprehensive evaluation of the Smart Tensiometer system's performance and reliability under real-world agricultural conditions. Rooted in rigorous experimentation and data analysis, this test campaign seeks to validate the effectiveness of the Smart Tensiometer while identifying opportunities for enhancement and optimization.

2. Methodology

The Smart Tensiometer test campaign is aimed to evaluate the performance of the Smart Tensiometer in measuring soil tension and temperature in a controlled environment. The methodology involved the following steps.

Experimental Setup

A standard plant pot was selected as the testing apparatus and placed on a window bench in a controlled outdoor environment. The Smart Tensiometer, comprising a Watermark sensor and a temperature probe, was securely inserted into the soil of the plant pot at a depth of approximately 10 centimeters. The Watermark sensor and temperature probe were connected to a WaziSenseV2 Arduino based microcontroller, which recorded sensor values at 10-minute intervals throughout the duration of the test campaign.

The test campaign commenced with the activation of the Smart Tensiometer setup, allowing the sensors to begin monitoring soil tension and temperature. Sensor readings were recorded automatically by the WaziSenseV2 and send via LoRa to a WaziGate Gateway and stored for subsequent analysis.

The test campaign proceeded over a monitoring period of 4 months, during which soil tension and temperature data were continuously collected. Environmental conditions within the testing environment were maintained at stable levels to minimize external factors' influence on the experiment.

Regular checks were conducted to ensure the proper functioning of the Smart Tensiometer and the integrity of the collected sensor data. Any anomalies or discrepancies in the recorded readings were documented and investigated to identify potential sources of error.

Test setup

The following tests were conducted:

- A test of the solar panel's performance in powering the Smart Tensiometer system was conducted to assess its effectiveness in sustaining operations under varying sunlight conditions.
- A test of the system's battery life was performed to evaluate its capacity to maintain functionality in the absence of sunlight or solar panel charging.
- The 3D printed casing underwent testing to evaluate its performance in different materials and print settings, as well as its water tightness, which was validated by passing the IP55 test. Also, the fitment of the holes for the Arduino board, the mainboard tray, for the antenna clip mechanism.

Data analysis & evaluation

Upon completion of the monitoring period, the collected sensor data were analyzed to assess the Smart Tensiometer's performance in measuring soil tension and temperature. Statistical techniques and visualization tools were employed to interpret the data and derive meaningful insights.

The findings of the data analysis were evaluated to determine the accuracy, reliability, and consistency of the Smart Tensiometer's measurements. Any limitations or challenges encountered during the lab test were identified and taken into consideration in the final assessment.

The results of the Smart Tensiometer test campaign were compiled into a comprehensive report, documenting the methodology, results, and conclusions. Recommendations for future research or improvements to the Smart Tensiometer system were provided based on the insights gained from the test campaign.

By following this methodology, the Smart Tensiometer test campaign aimed to provide valuable insights into the performance of the Smart Tensiometer in measuring soil tension and temperature, contributing to the advancement of agricultural monitoring technologies.

3. Results

3.1. Measurements

The experimental setup involved the placement of a Watermark sensor and a temperature probe inside a plant pot on a window bench. These sensors were connected to a WaziSenseV2 device, which recorded soil tension and soil temperature values at 10-minute intervals. The following diagram gives an overview about their ranges.

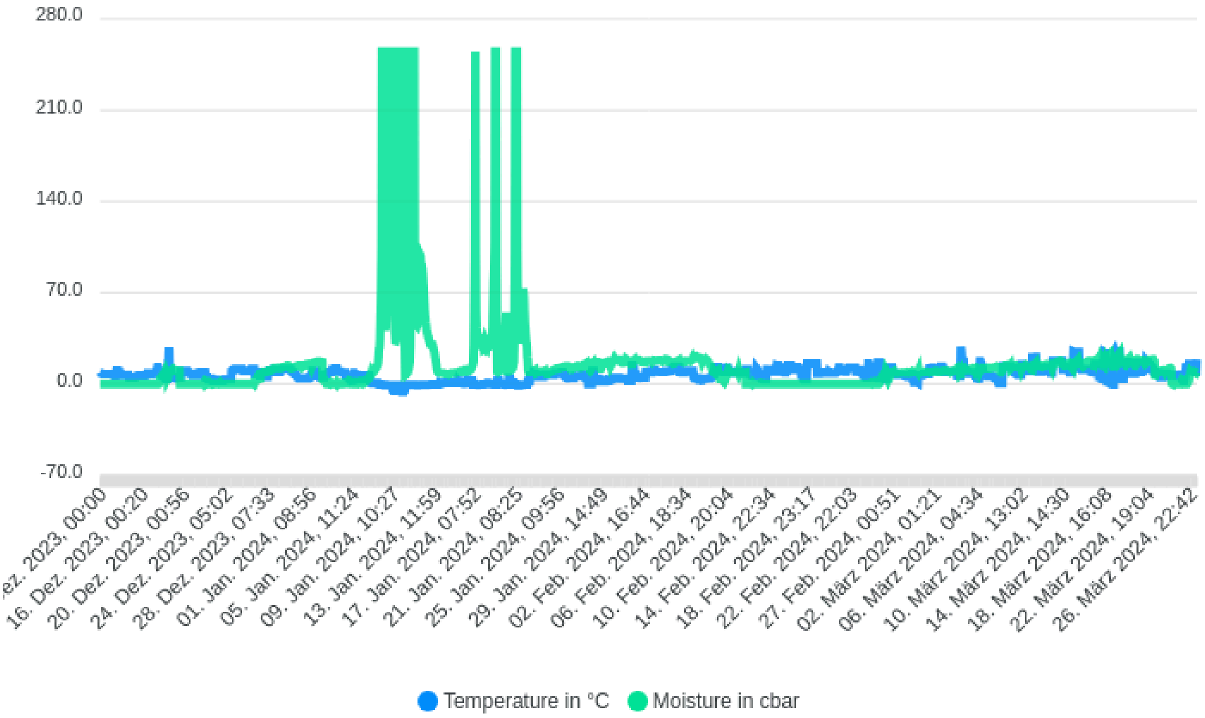

Figure 1: Soil tension and soil temperature of the local window bench test

The spikes in January represent the times when the air temperature had been below 0°C. In that case the soil tension sensor will read 255 cbar, which represents the driest value the tensiometer can read. This might not correspond with the state of the soil, but this can be neglected hence under those circumstances there would not be any irrigation needed and we do not have those conditions in places where the Smart Tensiometer is going to be deployed.

The results obtained from the window bench experiment revealed limitations associated with the detection of rainfall and artificial irrigation. Due to the presence of a roof above the window bench, minimal to non-existent rainfall directly affected the soil and plants in the pot. Consequently, the system faced challenges in distinguishing between natural rainfall and artificial irrigation events.

3.2. Predictive Capabilities - Initial results

The aimed goal of the system is to predict the soil state in a certain forecast horizon. This timespan is dependent on the type of crop and agricultural conditions, like climatic zone, soil type, season, the usual irrigation schedule and many more.

The system's algorithm is programmed to analyze changes in soil moisture tension. If a sudden drop in soil moisture tension occurs concurrently with no recorded rainfall, the system infers the occurrence of artificial irrigation. To facilitate this inference, a new feature called "pump state" is generated in the dataset. This mechanism is designed to operate effectively in typical field deployments where natural rainfall is prevalent and allows for the automatic detection of irrigation events based on predefined thresholds for soil moisture tension gradients. However, under the conditions of the window bench experiment, where natural rainfall is minimal, the system's ability to accurately differentiate between rainfall and artificial irrigation was compromised.

Because of the named shortcomings, in the lab test, the system can only achieve a mean percentage error of 25%. Whereas in other tests, with deployed devices we achieved a mean percentage error of 12,52%. The results are shown in the following table:

Table1: Results of the prediction capabilities, devices were deployed in a farm

Metric	Result
MAE	0.23
RMSE	0.35
MPE	12.52 %
R2	0.73

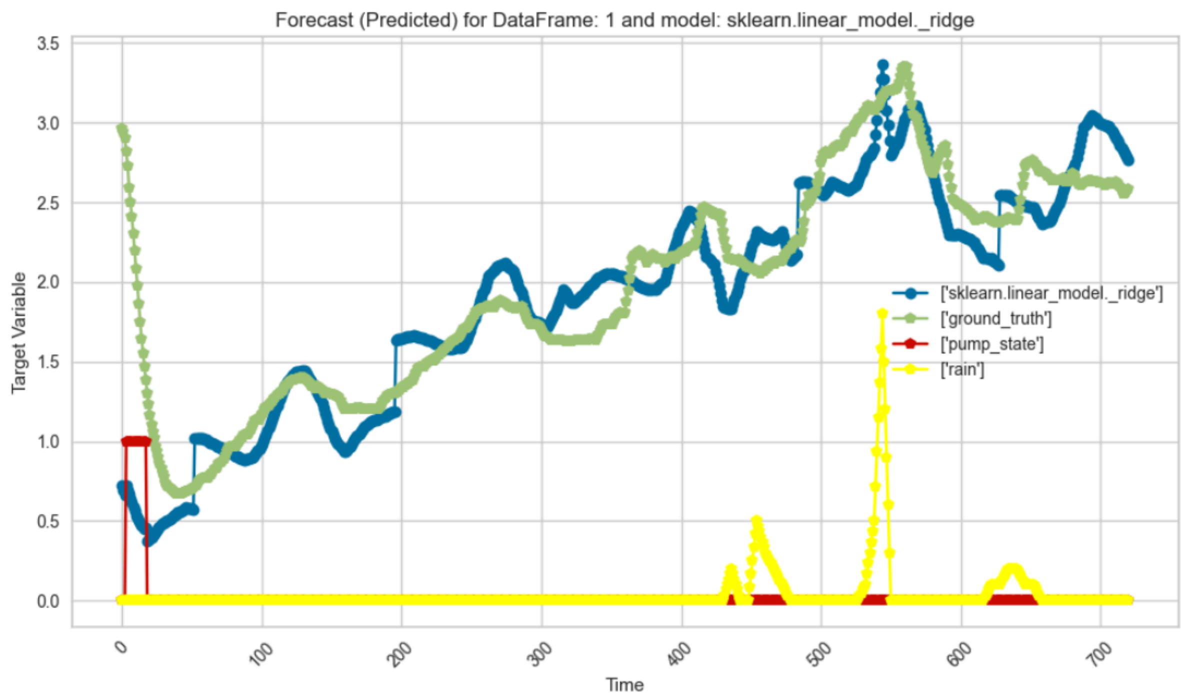

Figure 2: Shows results of a 5-day forecast. Green is the ground truth and blue chart is the prediction

More results on the predictive capability of the AI model will be reported in the D3.3 “Test report of the OSIRRIS light-weight AI irrigation model” and also in the D4.3 "Test report and performance of the OSIRRIS Irrigation system”.

3.3. Enclosure

The Case of the prototype was modeled from scratch in blender. There had been multiple approaches and iterations involved to validate the design. The final design is shown in the figure below.

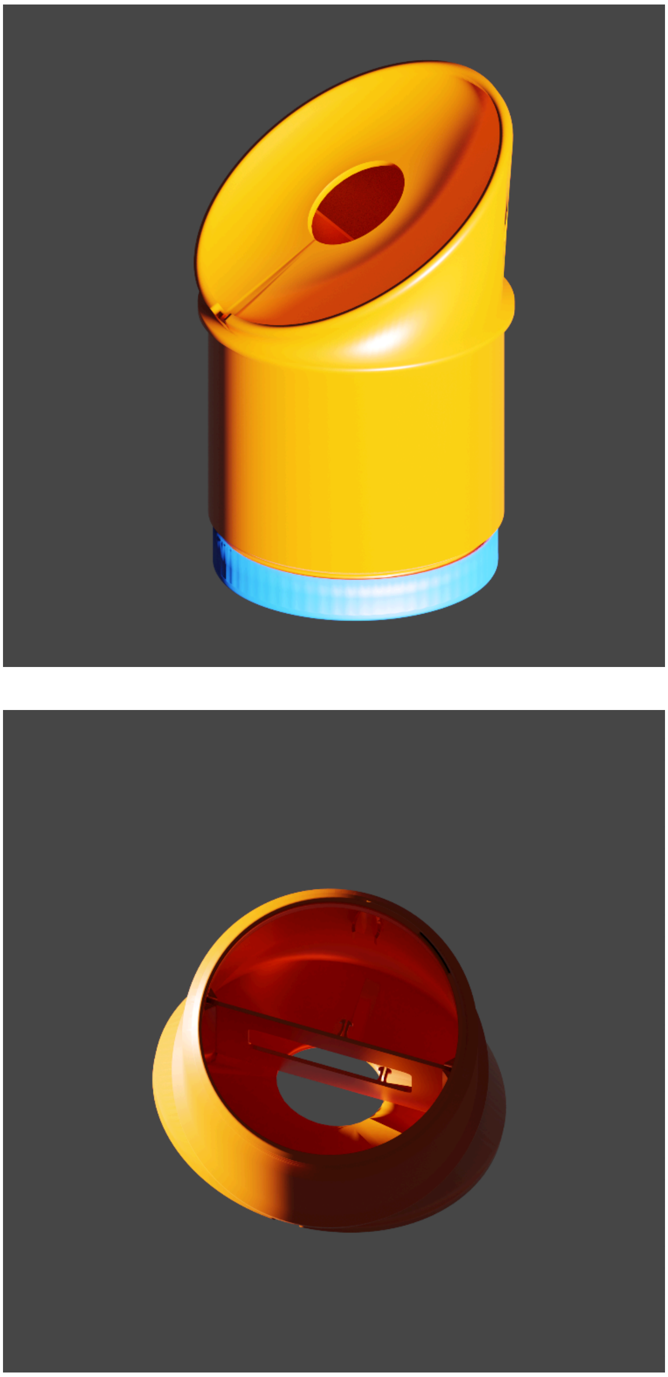

Figure 3: Models rendered in Blender

There were various tests conducted to ensure proper functionality. The results are listed in the following:

Sun degradation test

The model had been printed in an early iteration in ASA (acrylonitrile styrene acrylate). Afterwards it was placed in direct sunlight for a period of 4 months. It was printed with two outside, two bottom and three top layers in 0.15mm layer height. Consequently, the tested case has a thin outside layer. Since we have no other opportunity to conduct this test in an accelerated manner, we print the cases now with three outside and five top/bottom layers, to ensure higher resilience.

Proper fitment test

The model was adapted to fit all the following components:

- Solar Panel (68mm diameter)
- Internal LoRa Antenna 868 Mhz (with clip mechanism)
- WaziSenseV2 Arduino board (printed snap on standoffs on mainboard tray)
- Mainboard tray (slide in mechanism with snug fit)
- Holes for cable gland

A proper fitment test was conducted to confirm the device can be assembled and maintained in an easy manner. Thanks to the big screw-able cap, the case can be opened easily.

Dust/Waterproofing

Ensuring the resilience of the case against environmental elements is a pivotal consideration in its design and functionality. To validate its capacity to withstand such influences, a series of rigorous tests were conducted, aimed at upholding requisite standards.

A significant aspect of this assessment involved achieving water tightness in the thread of the lower cap, a process that demanded meticulous adjustments to achieve optimal fitment. Subsequent evaluations involved immersing the case, with its apertures meticulously sealed, in water. Through iterative refinement, including the integration of a self-printed TPU82A seal and exploration of alternative sealing methodologies inspired by conventional PET bottle caps, we successfully fortified the case against water ingress. Notably, the adoption of a wedge mechanism akin to that employed in PET bottle caps proved instrumental in enhancing the case's water resistance.

The effectiveness of these enhancements was validated through immersion tests, wherein the sealed case endured submersion in water at a depth of 30cm for a duration of 1 hour. However, upon integration with its components, subsequent tests revealed vulnerabilities in the nylon cable glands, designated as IP68-rated but exhibiting susceptibility to water ingress under prolonged submersion. It is worth noting, however, that despite these findings, past deployments utilizing identical cable glands have demonstrated commendable ingress protection in diverse geographical contexts.

Figure 4: Rudimentary, preliminary Waterproof testing for the case in an ensembled condition

While no specific tests were conducted to assess dust proofing, extrapolations from the observed water resistance suggest a commensurate level of efficacy in resisting dust infiltration.

3.4. Power management

Power consumption

The comparison revealed that the WaziSense v2 consumes significantly less power in sleep mode compared to the WaziSense v1, demonstrating approximately 23 times greater efficiency with the solar circuit active and approximately 105 times greater efficiency with the solar circuit inactive. This substantial reduction in power consumption enhances the overall energy efficiency of the WaziSense v2, making it a more sustainable and environmentally friendly solution for IoT applications.

On a single charge of an average 18650 cylindrical cell with 9,25Wh (3,7V at 2,5Ah), the WaziSenseV2 can send 25293 LoRa messages. That is equivalent to 181 days of operation, sending sensor values in an interval of 10 minutes.

Solar charging

The comparison to the former iteration of the WaziSense highlighted significant advancements in solar charging capabilities. The introduction of solar maximum power point tracking and charging for Li-ion/Li-polymer batteries in the WaziSense v2 represents a notable enhancement over its predecessor. This feature enables more efficient utilization of solar energy, ensuring optimal charging performance and prolonging battery life. Additionally, the WaziSense v2 incorporates programmable power rails that allow sensors and peripherals to be activated only when needed, further optimizing energy usage and maximizing the benefits of solar charging. Overall, these improvements underscore the WaziSense v2's enhanced functionality and suitability for off-grid and environmentally sustainable IoT deployments.

The solar panel has an advertised power of 2W at a voltage of 6V and a current of 350mAh. Other sources like the manufacturer's datasheet state a voltage of 6V and a constant current of 70mAh, this is equivalent to a power 0,42W. In our test we could achieve a maximum current of 48mAh at a voltage of 5,8V, this gives a power of 0,2784W. For our purposes this is plenty of energy. With a battery of 9,25Wh (3,7V at 2,5Ah), the battery can be charged from 0 – 100% in 33,2h. In Afrika we can assume to have 4 – 6 peak sun hours, that value is averaged over one year and means the hours where there is sun and no obstruction by clouds. This is illustrated in the map below.

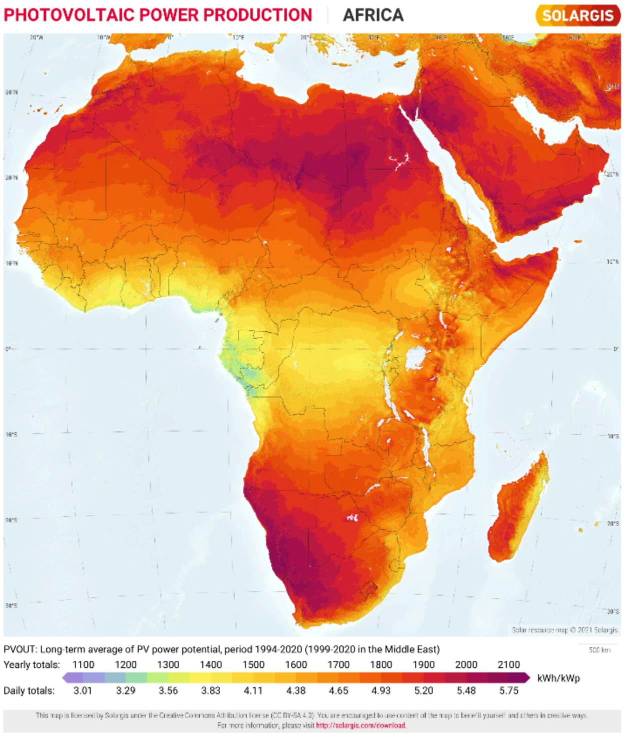

Figure 5: daily peak sun hours in yearly average [SOG]

In a conservative scenario we can estimate that the battery could be charged in 8,3 days. The WaziSense v2, explained in the section above, can run on a full charge of an 18650 battery with 9,25Wh (3,7V at 2,5Ah), for 181 days, transmitting every 10 min.

In 181 days, there are 724h of peak solar, if we assume 4h of peak solar in a daily average. But in that time, we only need to charge the battery once, so we would only need 33,2h of peak solar. That means we only need 4,6% of the average daily solar hours. This results in only 11min of not obstructed sunlight per day. So, we can assume that the solar panel does not need to be in bright sunlight, it can also be partly shaded.

4. Conclusion

In conclusion, the comprehensive evaluation of the Smart Tensiometer, as detailed in this report, has provided valuable insights into its performance and functionality in agricultural monitoring applications. The experimental setup involving the placement of sensors within a plant pot on a window bench facilitated the collection of crucial data on soil tension and temperature, offering a nuanced understanding of environmental conditions and their implications for irrigation management.

Despite the limitations due to the experimental setup's constraints, the Smart Tensiometer showcased promising predictive capabilities. The system's algorithm, although challenged by minimal natural rainfall, demonstrated potential for automatic detection of irrigation events based on predefined thresholds for soil moisture tension gradients. However, further refinement is necessary to address identified shortcomings and enhance the system's accuracy and reliability.

Moreover, the development and testing of the enclosure highlighted significant progress in ensuring resilience against environmental elements. Rigorous assessments, including water tightness tests and fitment evaluations, underscored the enclosure's robustness and suitability for deployment in diverse conditions. Additionally, advancements in solar charging capabilities, exemplified by the WaziSense v2, promise enhanced energy efficiency and sustainability, positioning the Smart Tensiometer as a viable solution for off-grid IoT applications.

In light of these findings, it is evident that the Smart Tensiometer holds immense potential for revolutionizing agricultural monitoring practices, empowering farmers with actionable insights for optimized irrigation management. Moving forward, continued research and development efforts will be essential to address identified limitations and unlock the full capabilities of this innovative technology, paving the way for enhanced productivity and sustainability in agricultural systems.

5. Sources

[SOG] https://solargis.com/maps-and-gis-data/download/africa