OSIRRIS

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

D2.1

Analysis, architecture & design of the low cost AI-capable Smart Tensiometer

Responsible: Waziup e.V.

Version: 1.0

Date: March 2023

Table of Contents

1. Introduction

The Osirris irrigation platform is an affordable, easily deployable and efficient irrigation system based on IoT and AI with the Edge computing architecture concept. We will research and develop a novel distributed AI model for irrigation, able to run both at the sensor level, and at the edge level. This model will use an inference engine to calculate the amount of water needed and the scheduling of irrigation.

The first component of the Osirris platform is the “Smart Tensiometer”, an embedded sensor system able to run light-weight AI models for automatic calculation of the local soil water content and plant water stress. The Smart Tensiometers will also be able to perform automatic calibration and corrections.

For this tensiometer, will use new polymer tensiometer technology with usage of new organic materials for moisture suction. This technology allows determining the complex permittivity of the soil. The smart tensiometer will be equipped with novel micro-controllers able to perform simple machine learning tasks. This will allow it to run light-weight AI models for automatic calculation of the soil water content and plant water stress, from the raw water tension measurements. The smart tensiometer will also be able to calibrate itself for the specific soil and crop type. The data collected will be used to further train the model, in order to adapt it to its local environment. This will reduce the installation complexity, as it is a key for a high acceptance of the approach.

This report details the architecture and design of the Smart Tensiometer. It is divided into 4 parts: the hardware architecture will be detailed in Section 2, the software architecture in the third section, deployment will be highlighted in section 5 and the last section will elaborate about the maintenance procedure.

2. Hardware architecture

2.1. Overview

In the following we want to introduce the Smart tensiometer. We will elaborate about its components and give some insights about the functionality and its abilities. Below there is an overview of the used components:

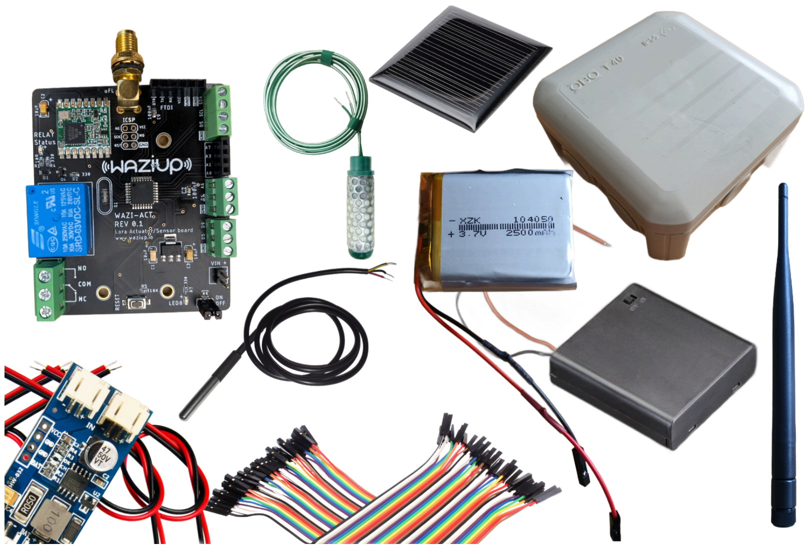

Figure 1: Components used for the prototype

2.2. Architecture and schematics

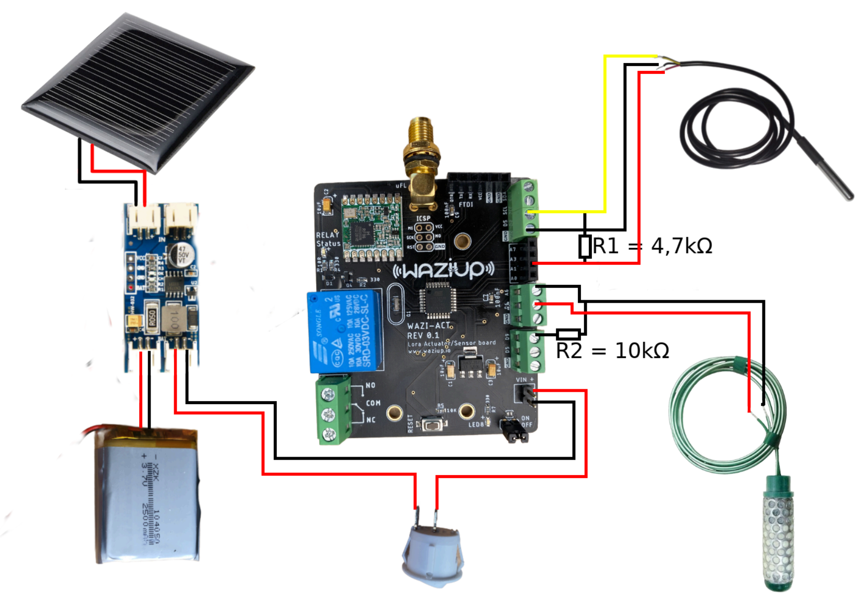

Figure 2: Wiring of the WaziSense V1 and additional components

2.3. Microcontroller + Radio

2.3.1. WaziSense v1

WAZIUP has a long experience with the ATMega328P microcontroller (Arduino Pro Mini, WaziDev, WaziSense and WaziAct). Given the relatively low computing requirements for the soil device, this microcontroller can be an efficient platform for Osirris. The Figure below shows the WaziSense V1 board, developed by Waziup.

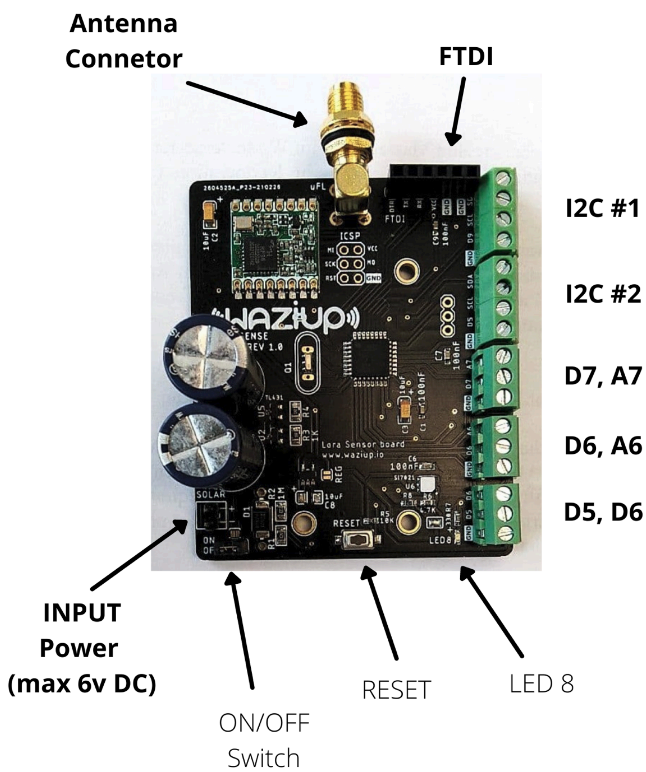

Figure 3: The WaziSense V1

WaziSense is a production-ready LoRa sensor node. It has a Si7021 sensor which measures Temperature and Relative Humidity and communicates with the I2C bus. It exposed a number of terminals which can be connected to external sensors e.g. soil moisture sensor The MCU, ATmega328p, is the same as Arduino boards and flashed with Arduino pro mini 3.3v 8Mhz bootloader. This is the same among all Waziup boards up to this time.

Wazisense can be used as a batteryless sensor node where it is deployed in the middle of nowhere and harvest energy from the environment for example via solar power. It utilizes a Super Capacitor circuit which can retain energy for multiple transmissions. The most recent experiment, we could transmit over 100 messages with a Spreading Factor of 12 on a single full charge of the Super Caps (each 20F).

2.3.2. WaziSense v2

The WaziSense v2 board is an iteration of the WaziSnese v1 board. It also uses the ATMega328P microcontroller and is a LoRa enabled device.

For self-sufficient operation, a low power consumption is important, that was one of the reasons to develop the next iteration of the microcontroller board WaziSense. The voltage regulator is now more efficient, allowing a substantially lower power consumption during deep sleep phases.

Additionally we added a MPPT solar charge controller to the board, which was formerly an extra component. A user can simply connect a solar panel, a battery, the antenna and sensors, this makes the deployment more easy and enables this solution to a wider range of users.

Another benefit of the new design is the improved, more easy to handle antenna. We used a Male U.FL connector instead of a SMA connector, the smaller connector is more convenient to waterproof, which is important for outdoor operation.

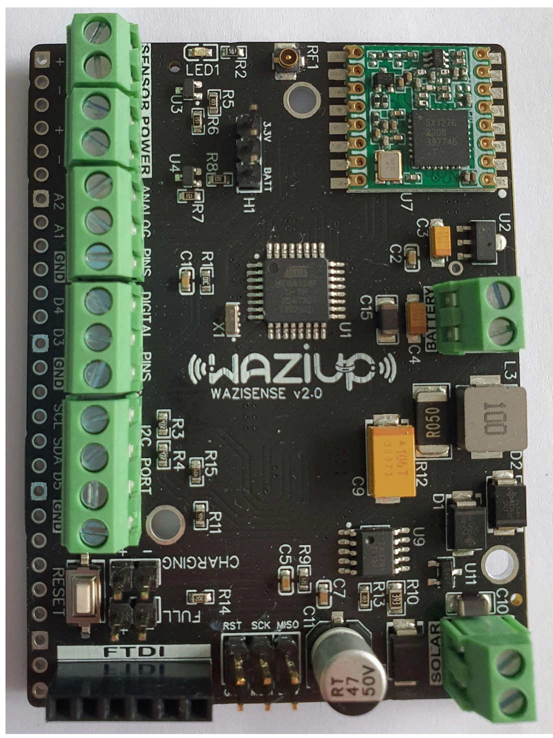

Figure 4: The WaziSense V2

2.4. Sensor part

The sensor choosed is the Watermark tensiometer. The Watermark can be connected to a microcontroller. There is a recommended procedure (https://www.irrometer.com/200ss.html) for reading from the sensor from Irrometer, the Manufacturer of the Watermark. There are also many tutorial videos (https://www.irrometer.com/videos.html#ag) to properly install the sensor.

Figure 5: Watermark tensiometer

To calibrate the watermark sensor it is also important to include a soil temperature sensor. With the help of the soil temperature and the resistance value of the watermark, the soil pressure can be calculated in kPa. This gives a good indication of the soil humidity and is until now used by many farmers around the world. A waterproof and resilient soil temperature sensor is the DS18B20 sensor, illustrated in the image below:

Figure 6: DS18B20 soil temperature sensor

2.5. Power

The WaziSense microcontroller boasts minimal energy consumption. Operating at 4 V, it consumes only 2.5 mA in deep sleep mode, resulting in a power consumption of 10 mWh. The device supports power supplies ranging from 3,3 V to 16 V. To cater to these requirements, we have devised two power options:

Option 1:

To collect data over a limited time span, the simplest and most cost-effective solution is to utilize a 4x AA battery holder directly connected to the WaziSense. A minimum of four cells is required to supply the necessary voltage.

Option 2:

For a self-sufficient and long-term power solution, we recommend harnessing solar energy to power the WaziSense microcontroller. This option enables the device to collect data over extended periods without requiring regular maintenance.

The components employed for Option 2 are as follows:

6 V MPPT solar charge controller:

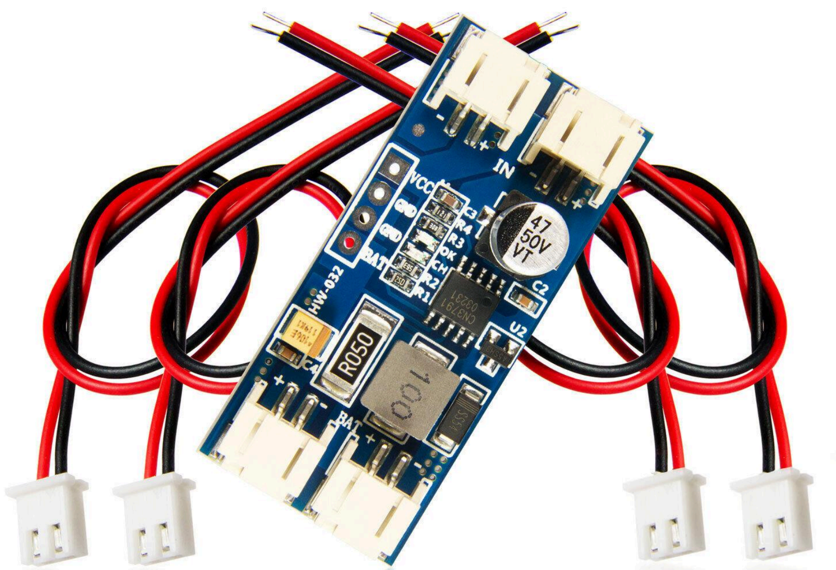

Figure 8: Solar panel charging controller: CN3791 MPPT

The solar charge controller takes the 6V input of the solar panel and charges the battery up to its designed voltage of 4,2 V. The maximum charging current is 2A, which cannot be supplied by the solar panel. The maximum power point tracking technology allows to utilize the power of the solar panel in an efficient manner. Additionally, the board also implements safety features such as short circuit and overcharge protection.

6 V, 1 W solar panel:

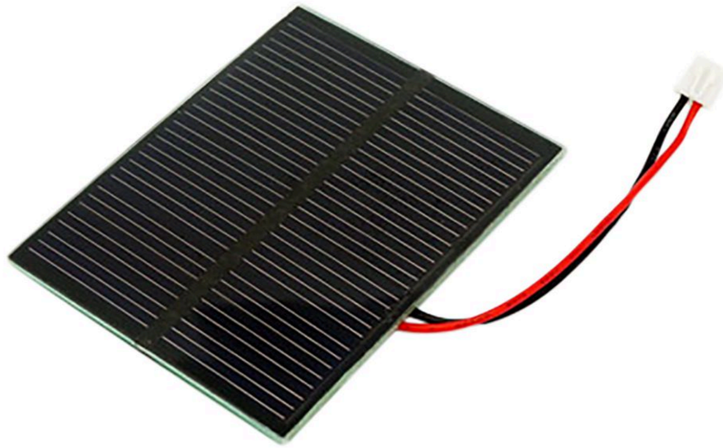

Figure 7: Solar panel (Seeed studio)

The solar panel delivers 6V at 166mA, which results in a peak power of 1 W and can recharge the batteries in 9h under optimal conditions. It is connected to a small charging controller (Figure below).

3.7 V, 2200mAh Li-Ion battery (approximately 10 Wh):

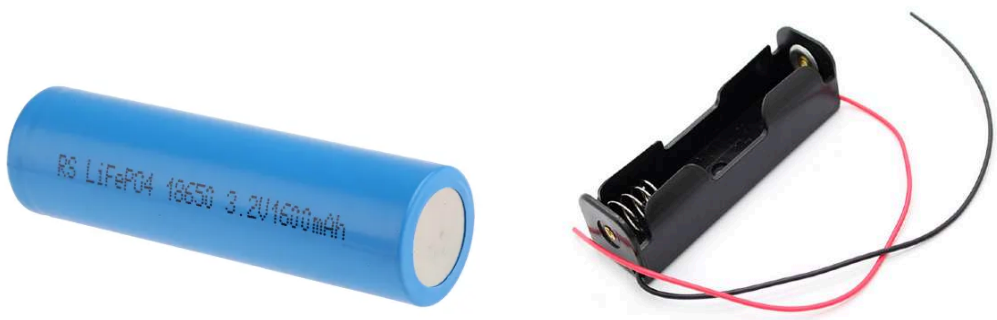

Figure 9: Li-Ion 18650 cell (left) 18650 cell holder (right)

18650 Lithium Ion batteries are a safe, reliable, long lasting and cost effective solution to store energy. That is why we choose them to power our prototype.

The solar charge controller optimizes power usage by tracking the "maximum power point" and efficiently utilizing the energy provided by the solar panel. Although the controller can accommodate larger panels, our power requirements are minimal, hence the use of a small panel generating only 0.3 W. Under optimal conditions, it would take approximately 34 hours of direct sunlight to fully charge the 10 Wh battery from 0-100% state of charge (SOC). In other words, the battery capacity employed is larger than necessary, but it serves as a buffer to ensure continuous device operation. When compared to the WaziSense, which features two super capacitors storing 0.0405 Wh of energy, the battery used in this setup can store 250 times more energy. Therefore, a battery with a capacity of only 10% (250 mAh) would still provide ample buffering capacity.

Additionally, we have incorporated a switch to facilitate external control over the device's power state. This feature proves advantageous as we aim to enhance waterproofing by applying silicone to the devices, mitigating the risk of failure. Further details on this waterproofing process will be covered in the subsequent step.

The Smart Tensiometer will be equipped with a small solar panel. This is necessary because the measurements we made shows that AA batteries will only last 2 months. With the new iteration of the microcontroller WaziSense (v2), the power consumption is down to 30% of the old WaziSense (v1). So 4x AA batteries will last 6 months.

2.6. Integration, assembling and casing

Easy integration and assembling into appropriate enclosure (i.e. box) is an important process for the low-cost sensor platform. The enclosure is a crucial issue and in order to reduce the cost off-the-shelves enclosures were used in the first prototype.

A transparent casing may be helpful to simply check whether the device is working or not and visualize some display directly through the casing in case a small OLED screen is attached to the device.

It may be also interesting with the transparent casing to have a luminosity sensor in order to take different actions for night periods, without the need of an actual Real Time Clock (RTC). However this is not a priority. Figure 14 illustrates some enclosures from https://www.polycase.com/.

The first prototype was assembled with commercial electrical boxes, the advantage here is that they are cost effective, easily available and certified waterproof. Disadvantages that also have to be mentioned here are: This box has to be modified to fit the components, holes for cables have to be drilled into the rubber seals to route the cables to the sensors, a clamp has to be screwed to the case to mount it to a pole, the solar panels have to be glued on top. The figure below shows the casing and components of the first prototype.

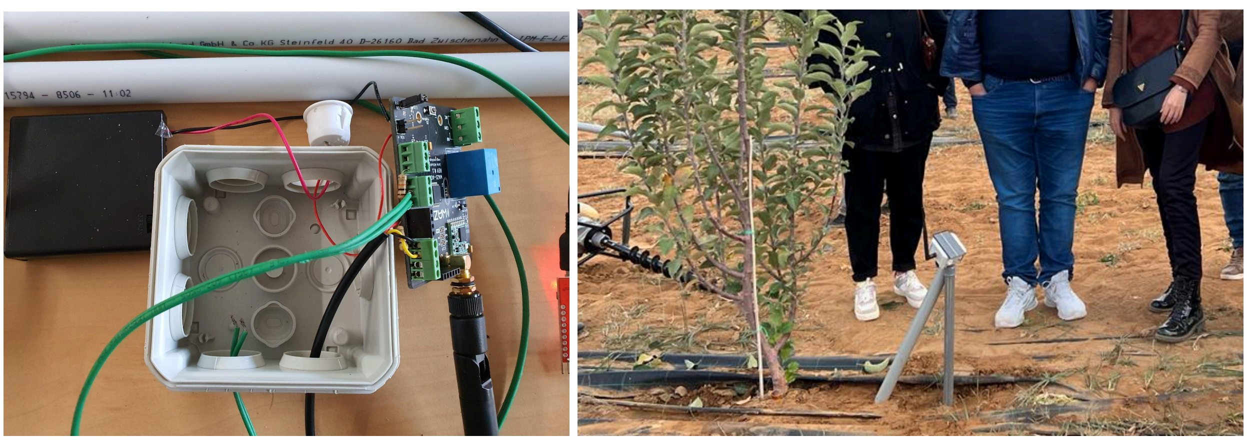

Figure 10: Smart Tensiometer V1 assembly (left) and deployed device in the field (right).

In the second iteration we want to improve the casing. But more on that in the third point of the outline. We also designed a new microcontroller with lower power consumption and integrated solar charging controller. This reduces the number of components that have to be encased and is also beneficial for the deployment of the devices in the field.

2.7. Components list

The following Table gives the list of components necessary for the Smart Tensiometer.

Part name	**Amount**	**Approx Price**	**Reference**
WaziSense	1	30	www.waziup.io
Antenna	1	0,20	www.waziup.io
Soil temperature sensor	1	2,10	DS18B20 temperatureSensor
Watermark Sensor (Irrometer)	1	54,85	Watermark
Solar panel	1	3,17	Solar panel
Charging controller	1	1,61	Charging controller
SMA Male to SMA Female	1	5,99	SMA to SMA
18650 Li-Ion Battery	1	1,69	18650
18650 Battery holder	1	0,37	18650 cell holder
Casing	1	1,44	OBO T40 IP55
FTDI connector	1	1,62	FTDI
10 kOhm resistor	1	0,01	-
4.7 kOhm resistor	1	0,01	-

2.8. Building

2.8.1. Pin Layout

To set up the soil moisture sensor and soil temperature sensor on the WaziSense device, follow the recommended pin layout and wiring instructions provided below:

DS18B20 Temperature Sensor:

- VCC: Connect the VCC pin of the DS18B20 temperature sensor to the A1 pin of the WaziSense.
- GND: Connect the GND pin of the DS18B20 temperature sensor to the GND pin of the WaziSense.
- IN: Connect the IN pin of the DS18B20 temperature sensor to the D5 analog pin of the WaziSense.

- Resistor: Place a 4.7kΩ resistor between the D5 and A1 pins of the WaziSense.

Note: Due to space limitations of the case used in this guide, please solder the analog pin (A1) from below the WaziSense PCB.

Watermark Soil Tension Sensor:

- VCC: Connect the VCC pin of the Watermark soil tension sensor to the D6 pin of the WaziSense.
- GND: Connect the GND pin of the Watermark soil tension sensor to the A6 pin of the WaziSense.
- Resistor: Install a 10kΩ resistor between the A6 and D9 pins of the WaziSense.

Connections made to WaziSense:

- Solar Panel: Connect the solar panel to the "IN" port of the solar charge controller.
- Solar Charge Controller: Connect the first "OUT" port of the solar charge controller directly to the battery. The positive terminal of the second "OUT" port should be connected to the switch, while the negative terminal is connected to the switch and then to the positive VIN port of the WaziSense. The negative "OUT" port of the charge controller is connected directly to the negative VIN terminal of the WaziSense.

Soil Moisture Sensor:

- Positive Lead: Connect the positive lead (red cable) of the soil moisture sensor to the "A1" port of the WaziSense.
- Negative Lead: Connect the negative lead of the soil moisture sensor to the "GND" terminal of the WaziSense.
- Signal Cable: Connect the signal cable (yellow) of the soil moisture sensor to the "D5" port of the WaziSense.

  Resistor: Bridge the "A1" and "D5" pins of the WaziSense with a 4.7kΩ resistor.

Watermark Soil Moisture Sensor:

- Positive Wire: Connect the positive wire of the Watermark soil moisture sensor to the "D6" pin of the WaziSense.
- Negative Wire: Connect the negative wire of the Watermark soil moisture sensor to the "A6" pin of the WaziSense.
- Resistor: To ensure accurate readings, bridge the "A6" and "D9" pins of the WaziSense with a 10kΩ resistor.

For a comprehensive visual representation and complete wiring diagram of all connections, refer to the provided "Wiring" resource.

Note: In this specific prototype, due to space limitations in the case, certain connections are made by soldering the wires at the back of the WaziSense PCB.

By following these guidelines and carefully establishing the connections, the soil moisture sensor, soil temperature sensor, and other components can be properly set up on the WaziSense device as described in this formal guide.

3. Encasing

3.1. First Iteration

Like stated before, the first version of the Tensiometers uses commercial off the shelf cases. In order to assure an uninterrupted operation, which is important in the data gathering process, we made some tests and fully submerged the devices, some of them leaked water to the inside. To ensure water tightness, it is essential to implement additional measures during the installation process. Due to limited space, the use of sealed connector types is not feasible. Instead, we recommend applying silicone to all cables that run inside the case from the sensors, as well as waterproofing the switch, antenna, and lid. This process can be carried out as follows:

1. Waterproofing the switch: Apply a layer of silicone around the switch, ensuring complete coverage and sealing.
2. Waterproofing the antenna: Carefully coat the antenna with silicone, making sure to cover all exposed areas thoroughly.
3. Waterproofing the lid: Apply a generous amount of silicone along the edges of the lid, creating a watertight seal when closed.

To enhance water resistance and minimize the likelihood of water or moisture breaches, we strongly recommend using a larger case and employing waterproof connectors. Consider utilizing one of the following connector types:

1. Aviation plug (IP68): This waterproof aviation connector, specifically the SP13 3-pin variant, offers reliable water tightness.
2. M20 IP68 Nylon Cable Gland with Locknut: This connector type, designed for waterproof applications, provides effective protection against water ingress.

By selecting a larger case and utilizing waterproof connectors, you can significantly enhance the waterproofing of the system, ensuring its integrity and reliability in water-prone environments.

The case of the microcontroller is now mounted to a pole, for that matching clamps are required. The selected pole is a sewage pipe, because of its availability and cost effectiveness. The design is illustrated below:

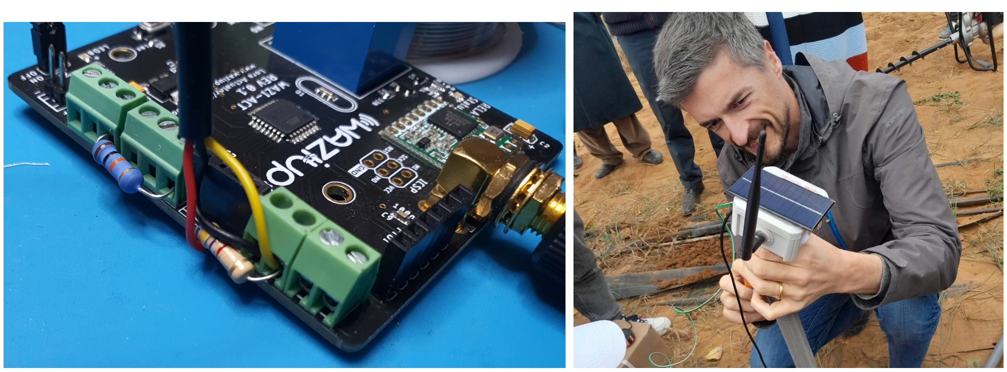

Figure 11: WaziSense microcontroller wired (left), Installation of the Smart Tensiometer (right)

3.2. Second iteration

In the second iteration, we have taken into consideration the findings from the first prototype to further improve the design. Our goal is to create a comprehensive solution by encapsulating all the necessary components within a single sewage pipe.

The central component of this design is the Arduino microcontroller, specifically the "WaziSense V2" model, which will be securely placed inside the cap of the sewage pipe. Additionally, the Li-Ion battery will be housed within the cap, ensuring a compact and integrated setup. To harness energy, we plan to position a solar panel on top of the cap. This allows us to utilize solar power for the operation of the microcontroller and other electronic components.

One of the primary advantages of this new design is the enclosed setup within the sewage pipe. All cables connecting the sensors will be protected from external elements, such as sunlight or potential interference from animals like rabbits. This safeguarding measure ensures the longevity and reliability of the system. Furthermore, this enhanced solution offers cost-effectiveness in comparison to the previous design. By consolidating the components into one sewage pipe, we reduce the overall material and installation expenses. Moreover, this design is practical and resilient, addressing potential vulnerabilities and enhancing the system's durability. In order to realize this concept, we intend to create a 3D model design of the cap that aligns with our specific preferences and requirements.

This second iteration leverages the lessons learned from the first prototype to create an optimized solution. By integrating the necessary components within the sewage pipe, protecting the cables, and incorporating renewable energy, we achieve a more practical, cost-effective, and resilient design for our system.

The next step in the process involves the fabrication of the 3D model of the cap for the sewage pipe. To accomplish this, we will utilize a 3D printer to bring our design to life. However, it is important to consider the choice of materials, as regular filaments like Polyamide (PA) can degrade over time due to exposure to various environmental factors. Therefore, we will conduct thorough tests with alternative materials that are known for their durability and resistance to UV exposure.

Some of the materials we will explore for the 3D printing of the cap include Acrylonitrile Styrene Acrylate (ASA), Polyethylene Terephthalate Glycol (PETG), Nylon, and Polycarbonate (PC). These materials are commonly employed in applications where UV exposure is a concern, such as outdoor brackets or functional parts. By testing these alternative materials, we can determine the most suitable option that offers long-term stability and maintains the integrity of the cap under different environmental conditions.

To further enhance the protection of the electronics housed within the cap, we will incorporate a lid. This lid will provide an additional barrier, encapsulating the microcontroller (WaziSense V2), battery, and antenna, safeguarding them from any rising humidity within the sewage pipe. This measure ensures the longevity and reliability of the electronics, mitigating the risk of damage due to moisture.

In addition to the technical considerations, this solution also offers space-saving advantages. By designing the system to fit within a standard locally available sewage pipe, we eliminate the need for extensive shipping of bulky components to foreign countries. This localization of resources reduces logistical complexities and helps prevent high shipping costs, making the solution more accessible and cost-effective for implementation.

Overall, the integration of alternative materials in the 3D printing process, combined with the inclusion of a protective lid and the use of locally available sewage pipes, enhances the practicality, durability, and cost-effectiveness of the system.

4. Software

4.1. Objectives/Tasks

The software embedded in the Smart Tensiometer plays a critical role in its functionality and performance. It is responsible for carrying out several important tasks to ensure accurate measurements, efficient energy consumption, and reliable data transmission. The key tasks performed by the software include:

1. Measurement Execution: The software orchestrates the process of measuring soil tension using the built-in sensors of the Smart Tensiometer. It controls the sensor activation, data acquisition, and conversion into meaningful values.
2. Calibrated Centibar Calculation: After acquiring the raw measurement data, the software applies calibration algorithms to convert the readings into calibrated centibar values. This calibration process ensures that the measurements accurately reflect the soil tension levels and provide reliable information for agricultural analysis.
3. LoRa Transmission: Once the calibrated centibar value is determined, the software utilizes the LoRa (Long Range) communication technology to transmit the value wirelessly to a LoRa Gateway. It formats the data into LoRa-compatible packets and manages the transmission process to ensure reliable and efficient data transfer.
4. Energy Consumption Management: The software incorporates energy management strategies to optimize the battery life of the Smart Tensiometer. It monitors the battery voltage level and implements energy-saving measures to extend the operational duration.
5. Low Battery Handling: When the battery level reaches a low threshold, the software dynamically adjusts the transmission interval. It reduces the frequency of data transmission to conserve energy and prolong the battery life. This adaptive behavior ensures that the Smart Tensiometer remains operational even with limited power supply.

By efficiently executing these tasks, the software embedded in the Smart Tensiometer enables accurate measurements, reliable data transmission, and effective management of energy consumption. It ensures that the device operates optimally, providing valuable soil tension data for agricultural monitoring and decision-making processes.

4.2. Architecture

Arduino is a microcontroller-based platform that consists of both a physical programmable circuit board and a piece of software, or IDE (Integrated Development Environment). The software architecture of an Arduino microcontroller is based on a simple programming language that is easy to learn and use. The Arduino IDE is used to write, compile, and upload code to the microcontroller. The code is written in C or C++ and is compiled into machine code that can be executed by the microcontroller. The microcontroller is responsible for controlling the input and output of the system, and for executing the code that is uploaded to it. The architecture of an Arduino microcontroller is designed to be simple and easy to use, making it accessible to beginners and experts alike.

4.3. Implementation

The software for the smart tensiometer will be developed using Arduino C, leveraging the power of the following libraries: WaziDev library and XLPP payload manager. These libraries provide essential functionalities and enable seamless integration of the device into the system.

To ensure accurate and up-to-date soil tension measurements, the tensiometer will sample the soil tension readings at regular intervals of 10 minutes. This frequent sampling allows for precise monitoring of soil moisture levels.

To transmit the collected data, the soil tension readings will be encoded using the XLPP (eXtensible Lightweight Protocol for Payloads) format. XLPP provides a compact and efficient way to encapsulate the data, making it suitable for transmission over LoRa. The encoded data will then be sent via LoRaWAN to the Gateway, which acts as a central hub for data aggregation. Upon receiving the data, the WaziGate will store it in its internal database. This local storage ensures data redundancy and immediate availability for subsequent processing.

Furthermore, if a cloud connection has been initialized, the WaziGate will synchronize all the collected data to the WaziCloud. The WaziCloud serves as a centralized cloud platform where the data can be securely stored, analyzed, and accessed remotely. This cloud integration enables convenient data management and allows users to retrieve and utilize the collected soil tension data from anywhere at any time.

By employing Arduino C and utilizing the WaziDev library, XLPP payload manager, and LoRa technology, the smart tensiometer system ensures reliable and efficient data transmission, storage, and synchronization, facilitating comprehensive monitoring and analysis of soil moisture levels for agricultural applications.

5. Deployment

The deployment process of the smart tensiometer is designed to be straightforward and user-friendly. To ensure a smooth deployment, it is important to follow a few preliminary steps. Firstly, the Smart Tensiometers (sensor devices) need to be assembled prior to the deployment. Additionally, the WaziGates operating system should be flashed onto an SD-card, and the cloud connection should be initiated. These initial steps lay the foundation for an easy on-site deployment. Here are the detailed steps to be followed:

1. Find suitable locations within the field based on the provided guide, which offers an overview of potential placement options.
2. Bury the sensor devices in various locations and depths based on the specific characteristics of the observed plants. This allows for accurate soil moisture measurement.
3. Power up the device.
4. Connect your smartphone or PC to the WaziGates hotspot.
5. Establish a connection between the WaziGate and an available WiFi hotspot. This can be achieved by connecting to a mobile phone that offers WiFi sharing functionality.
6. Add the device IDs of the Tensiometers to the WaziGate to enable receiving LoRa messages. This ensures that the WaziGate receives sensor values from the Tensiometers.
7. Install the Intel-Irris WaziApp through the WaziGate's internal App section.
8. Set up the WaziApp by configuring the plant and soil-specific parameters to align with the requirements of your specific environment.

Once these steps are completed, the system is ready for operation. However, it is important to note that a short data gathering phase is necessary before obtaining accurate predictions. During this phase, the WaziGate will collect data and analyze it to predict the soil moisture levels for the upcoming days. It will also calculate the anticipated time when a certain soil moisture threshold will be reached. This valuable information serves as an indicator for farmers, signaling when the soil is expected to become too dry for the particular soil and plant type, allowing for appropriate action to be taken.

5.1. Installation depth

The sensor should be buried in the root zone of the given plant. The following Table gives some examples.

Crop	Effective Rooting Depth[1] (inches)
Corn	40
Cotton	55
Soybeans	40
Rice	20
Sorghum	40
Bermuda Grass	6-18

Figure 12: Various root depth[1]

[1] Sheffield, R.E., and D.C. Weindorf, 2008. Irrigation scheduling made easy using the 'look and feel' method. LSU AgCenter Ext. Pub., Baton Rouge, LA.

6. Maintenance

The preliminary version of the device relies on 4x AA batteries as its power source and does not include solar panels. To ensure uninterrupted operation, it is necessary to replace the batteries every 6 months. Transmitting the battery voltage via LoRa to the gateway provides valuable information about the battery's charge level. Actuation rules can be set up to notify when a certain voltage level has been reached.

For the version incorporating a rechargeable battery and solar panel, maintenance efforts are further minimized. The primary consideration is to prevent obstruction of the solar panels by sunlight, such as through the accumulation of dust, dirt, or nearby vegetation. Additionally, it is advisable to periodically inspect the stability of the pole, typically once per season, to ensure it remains firmly in place.

The battery in this device has an average lifespan of approximately 8-10 years, while the remaining components are expected to have even longer lifespans.