POLITECNICO DI TORINO

Master's Degree in Electronic Engineering

Master's Degree Thesis

Design of a Graphic Interface for Precision Agriculture

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Summary

This thesis delves into the integration of sensor data from agricultural monitoring nodes, emphasizing the utilization of The Things Network Storage Integration to access historical data. It investigates the implementation of Grafana dashboards for comprehensive data visualization and leverages geospatial information for monitoring and actuation nodes.
Central to the study is the creation of an interactive dashboard solution, combining high-resolution satellite imagery with GPX data to provide geographical context to sensor information. Authentication methods are explored, ensuring user-specific access to dashboard data. The research extends the temporal scope beyond the standard 30-day period by importing historical data, addressing the limitations commonly encountered in such systems.

By synthesizing IoT technology with advanced data visualization tools, this work aims to offer insights and practical solutions for precision agriculture. The amalgamation of historical data retrieval, geospatial visualization, and tailored user access control underscores the potential of IoT in optimizing agricultural practices....

WAPPFRUIT

Acknowledgements

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Chapter 1

Introduction

1.1 Background and Context

The advent of digital technologies has substantially transformed various sectors, including agriculture, where the integration of advanced computational tools is increasingly crucial. These technological advancements enable enhanced precision in resource management, optimization of financial inputs, and effective time utilization. Specifically, in agriculture, this progression is epitomized by projects like WAPPFRUIT, which utilizes real-time soil matric potential data to optimize irrigation practices in orchards, thereby conserving water and increasing operational efficiency.

The WAPPFRUIT project, developed in the Piedmont region of Italy, is a prime example of how Internet of Things (IoT) technologies can revolutionize agricultural practices. By deploying a network of sensors, this project collects critical data such as soil humidity and water tank levels, which is visualized through Grafana, providing actionable insights. These technologies allow farmers to manage resources more effectively, overcoming the limitations of traditional farming that typically relies on experiential knowledge and physical labor.

1.2 Objectives and Scope

The primary objective of this research is to conduct a detailed comparative analysis between traditional farming methods and modern IoT-enhanced practices, as exemplified by the WAPPFRUIT project. This analysis focuses particularly on the impact of data visualization in agricultural decision-making processes.

1.2.1 Addressing Literature Gaps and Practical Challenges

Literature Gaps: Existing research extensively documents the technological aspects of precision agriculture, yet there is a significant gap in studies that combine real-time data utilization with user-centric dashboard designs. This project aims to fill this gap by demonstrating how customized data visualization can influence operational efficiency and decision-making in farming.

Practical Challenges: Precision agriculture faces several practical challenges, including:

1. **Data Overload:** Farmers often struggle with the vast amounts of data collected, which can be difficult to interpret and use effectively. This project develops a method to simplify data presentation through intuitive dashboard interfaces, making the data more actionable for everyday farming decisions.

2. **Real-Time Decision Making:** Traditional methods typically do not incorporate real-time data, limiting responsiveness to changing conditions. By integrating IoT devices with Grafana dashboards, this research showcases how real-time data can be leveraged to enhance irrigation practices, ultimately conserving resources and optimizing crop yields.

3. **Scalability and Customization:** Many existing solutions are not scalable or customizable to various types of farms and crops. The WAPPFRUIT project addresses these issues by implementing scalable IoT solutions that can be tailored to different agricultural needs and environments.

1.2.2 Objective Clarification

This thesis specifically investigates how these technological interventions can transform agricultural practices by:

- Improving water management efficiency through the precise timing and amount of irrigation.
- Enhancing the usability of complex datasets by employing advanced data visualization tools.
- Providing empirical evidence of the benefits of IoT in agriculture, thus supporting broader adoption and investment in smart farming technologies.

The scope of this study encompasses not only the technological implementation but also the practical application in three distinct agricultural settings. This allows for a robust evaluation of the technology's impact across different environmental conditions and agricultural practices, thereby offering a comprehensive overview of its effectiveness and adaptability.

1.3 Literature Review

This section delves into existing literature on the application of IoT in agriculture, particularly focusing on the use of data visualization tools like Grafana. It reviews previous studies that have documented the benefits of real-time data access in agricultural settings and how such access influences operational decisions. The literature review also explores the functionalities of InfluxDB and Grafana, highlighting their role in handling large volumes of sensor data and facilitating effective data visualization and analysis.
A review of both academic sources and practical implementations provides a comprehensive overview of the current technologies and methodologies in agricultural data management, establishing a foundation for the comparative analysis conducted in this thesis.

1.4 Project Methodology and Implementation

The methodology involves analyzing data collected from microcontrollers and sensors deployed across three different farms, each equipped with six types of soil sensors. These sensors are installed at strategically identified points to capture essential parameters like soil moisture, volumetric water content, and temperature. The data collected provides a detailed view of the environmental conditions across different sections of the farms, which is then visualized using Grafana to assess the effectiveness of irrigation practices.

1.4.1 Technological Framework

The integration of advanced IoT technologies is crucial for the efficiency of smart agricultural systems. Among the technologies deployed in the WAPPFRUIT project, two custom electronic systems, WAPPSEN and WAPPACT, play pivotal roles.

WAPPSEN This system is responsible for reading data from digital sensors, specifically TEROS 11 and TEROS 21, which measure the volumetric water content and matric potential at various soil depths (-20 cm, -40 cm, and -60 cm). Enclosed within an IP65-rated protective box, WAPPSEN nodes are deployed directly in the field to ensure accurate real-time data acquisition.

WAPPACT Operating alongside WAPPSEN, WAPPACT controls the actuation of irrigation based on the data received. It engages and disengages bistable solenoid valves linked to the irrigation system, effectively regulating water flow to the crops as needed. The operation of WAPPACT is characterized by its responsiveness and energy efficiency, with modes that adjust based on the irrigation demand.

1.4.2 Data Communication and Management

Both WAPPSEN and WAPPACT utilize LoRa (Long Range) technology, a cornerstone for IoT applications requiring wide-area coverage and low power consumption. The systems communicate via LoRaWAN to a central network server that routes information to the internet, enabling remote monitoring and management. The Things Network (TTN) serves as the project's chosen LoRa provider due to its extensive coverage and reliability. In the development of IoT-based smart agricultural systems, pivotal devices such as WAPPSEN and WAPPACT play crucial roles. These devices are integral in gathering and processing field data, optimizing irrigation strategies, and enhancing productivity in agricultural operations.

(a) WAPPSEN **(b)** WAPPACT

Figure 1.1: Photos of the developed IoT motes, WAPPSEN and WAPPACT, used in the WAPPFRUIT project for real-time monitoring and actuation based on agricultural data.

1.4.3 System Architecture

The WAPPFRUIT project showcases a cutting-edge system architecture that integrates various components essential for optimizing agricultural operations through smart technologies. This system architecture is designed to support efficient data flow and sophisticated data processing capabilities, from the in-field sensors right through to the end-user interface.

Sensor and Device Network Central to the architecture are the WAPPSEN and WAPPACT units, which play pivotal roles in data collection and actuation respectively. WAPPSEN units are equipped with TEROS 11 and TEROS 21 sensors to measure volumetric water content and matric potential at various soil depths, enhancing the precision of the irrigation processes. The data collected by these sensors are crucial for determining the exact irrigation needs of the crops.

LoRaWAN Communication The architecture employs LoRa (Long Range) technology, utilizing its low power consumption and wide-area network capabilities to transmit data over long distances. This is crucial in rural agricultural settings where traditional connectivity methods are often unfeasible. LoRaWAN provides a reliable, scalable, and secure network framework, which allows devices like WAPPSEN and WAPPACT to communicate seamlessly with the central network server.

Data Handling and Analysis Data transmitted over the LoRaWAN is received by a gateway that connects to a central network server, which in turn routes the information to the internet. This setup ensures that data from the field sensors is quickly processed and made available to end-users. The project utilizes The Things Network (TTN) for its network services, known for its robust performance and extensive coverage.

Integration with Cloud and Analytical Tools The architecture is also integrated with cloud-based platforms and analytical tools that enhance data visualization and management. This integration allows for sophisticated data analysis, which is critical for making informed decisions regarding crop irrigation and management. For instance, cloud services host the irrigation algorithm that automates watering decisions based on real-time data, significantly optimizing water use and improving crop yields.

System Resilience and Security Ensuring the resilience and security of the data is paramount, given the system's reliance on IoT technologies. The architecture includes security protocols to protect data transmission and storage, ensuring that sensitive agricultural data is safeguarded against unauthorized access and breaches.

The diagram below illustrates how these components integrate to form a cohesive system that efficiently manages and processes agricultural data from the field to the farmer.

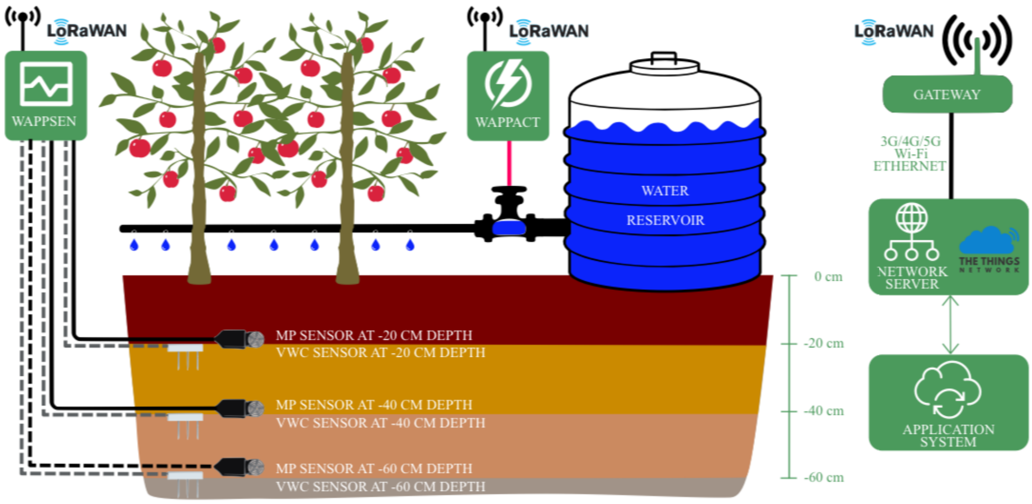


Figure 1.2: Detailed system architecture of the WAPPFRUIT project, showcasing the integration with LoRaWAN (Long Range Wide Area Network).

1.4.4 Installation Points for Sensor Nodes

The deployment of sensor nodes across the WAPPFRUIT project fields was strategically planned to ensure comprehensive data collection from the environment, crucial for the precise management of irrigation practices. The installation was meticulously designed to cover all critical areas within the orchards, with each site tailored to the unique agricultural requirements and characteristics of the specific crops grown, including apples and kiwis.

Sensor Types and Configuration Each node was equipped with TEROS 11 and TEROS 21 sensors to measure volumetric water content and matric potential, respectively. These sensors were installed at varying depths (-20 cm, -40 cm, and -60 cm) to capture a detailed profile of the soil's moisture and ionic content, which directly influence the plant's water uptake capabilities.

(a) TEROS11 Sensor

(b) TEROS21 Sensor

Figure 1.3: Detailed view of the sensor devices used in the WAPPFRUIT project

Strategic Placement The sensors were distributed across three distinct sites to enable a comparative analysis of irrigation techniques. The placement of these sensors took into account factors such as soil type, crop type, and expected water distribution patterns. This strategic distribution helps in generating highly accurate data that reflects the micro-variations within each field, thereby optimizing the irrigation schedules and techniques used.

Experimental and Conventional Sites Each of the three sites included both conventional and experimental setups. The conventional sites followed traditional irrigation practices, while the experimental sites utilized the data-driven insights provided by the WAPPFRUIT system for a more optimized irrigation approach. This side-by-side setup allows for a direct comparison of the effectiveness and benefits of intelligent irrigation systems over traditional methods.

Data Utilization The data collected from these sensors is transmitted in real-time to the central system, where it is analyzed and used to adjust irrigation protocols dynamically. This ensures optimal water usage and enhances crop growth by adjusting water supply based on actual crop needs, rather than a fixed schedule.

Below are the illustrations depicting the installation points at each site, detailing both the conventional and experimental setups for an optimal comparison of irrigation practices.

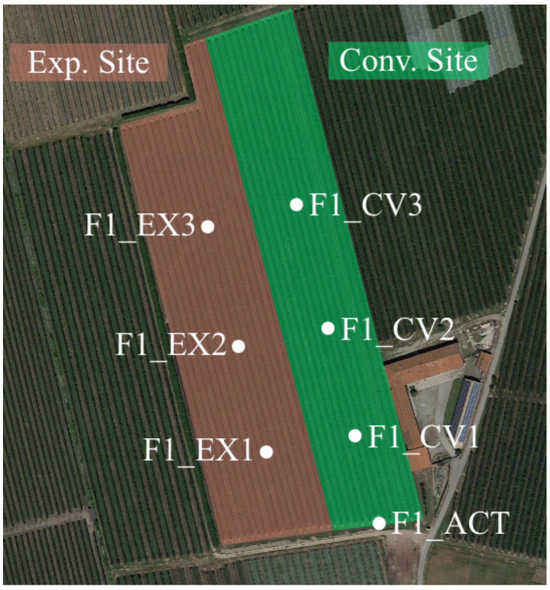


Figure 1.4: Farmer 1's site, illustrating sensor distribution and field layout.

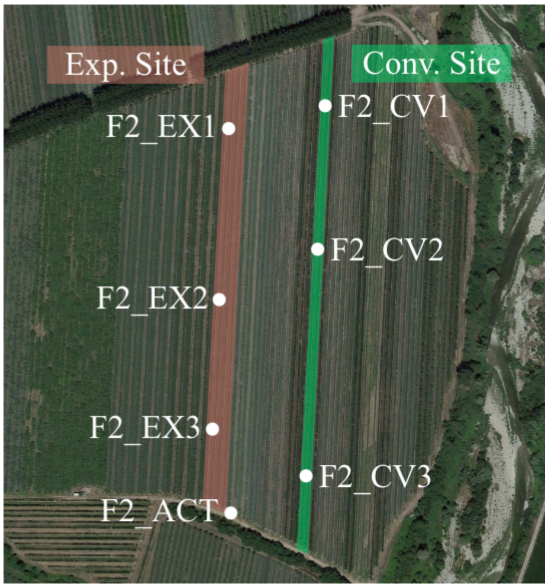


Figure 1.5: Farmer 2's site, highlighting the areas with denser sensor deployment.

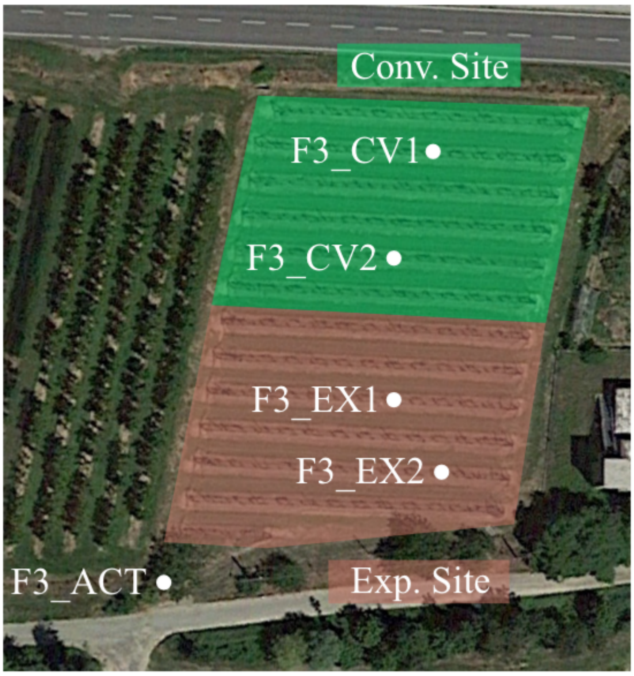


Figure 1.6: Farmer 3's site, showing sensor locations in both experimental and conventional areas.

1.5 Project Results

The WAPPFRUIT project achieved significant outcomes in terms of water savings and maintaining crop yields, which are instrumental in illustrating the efficacy of smart agricultural practices enabled by IoT technologies.

1.5.1 Water Conservation and Crop Yield

Through the implementation of the WAPPFRUIT system, the project demonstrated an average water savings of approximately 40% across the different orchard sites compared to traditional irrigation methods. This substantial reduction in water use did not adversely affect the crop yields, which remained comparable to those obtained through conventional irrigation practices.

Water Savings The project's advanced irrigation system, which utilizes real-time data on soil matric potential from sensors, allows for precise water management. This system adjusts the irrigation schedules based on the actual needs of the crops, rather than relying on fixed schedules that may over or under water the plants. As a result, water usage was optimized, leading to significant conservation of this critical resource.

Crop Yield Stability Despite the reduced water usage, the crop yield and quality were maintained at levels similar to those achieved through traditional methods. This result underscores the potential of IoT-based systems to enhance sustainability in agriculture without compromising productivity. The crops monitored during the project included various types of fruit trees, demonstrating the system's applicability across different types of orchards.

1.5.2 Technological Impact

The project also highlighted the role of technology in enhancing the efficiency of agricultural operations. The use of LoRaWAN technology for communication between sensors and the central system was crucial in ensuring timely data transmission, which is key for real-time irrigation management.

Sensor Accuracy The precision of the TEROS 11 and TEROS 21 sensors in measuring soil conditions played a critical role in the successful implementation of the project. These sensors provided accurate data on soil moisture and matric potential, which informed the irrigation algorithms used to optimize water distribution.

System Responsiveness The responsiveness of the WAPPACT system in adjusting irrigation valves based on sensor data was a key factor in the success of the project. This responsiveness ensured that water was supplied efficiently and only when needed, thereby reducing wastage and enhancing the sustainability of the irrigation practices.

1.5.3 Future Directions

The positive results from the WAPPFRUIT project indicate that expanding the application of such IoT-based systems could lead to broader improvements in agricultural water management. Future work will focus on refining the sensor technologies, improving data analysis algorithms, and exploring the scalability of the system to larger agricultural operations.

These findings have significant implications for the adoption of smart agriculture technologies worldwide, offering a viable solution to the challenges posed by traditional irrigation methods and the growing need for sustainable agricultural practices.

Chapter 2

Aim and implementation

2.1 Aim

The sensor data is transmitted to the microcontroller and subsequently forwarded to the InfluxDB website for data collection and visualization. However, InfluxDB imposes a time limitation, displaying data only for the past 30 days. Consequently, this thesis aims to bridge this limitation by establishing a connection between InfluxDB and Grafana. This connection seeks to exhibit not only the recent 30-day data but also historical data, spanning from the project's initiation to the most recent 30-day period. This historical data has been archived as Excel files.

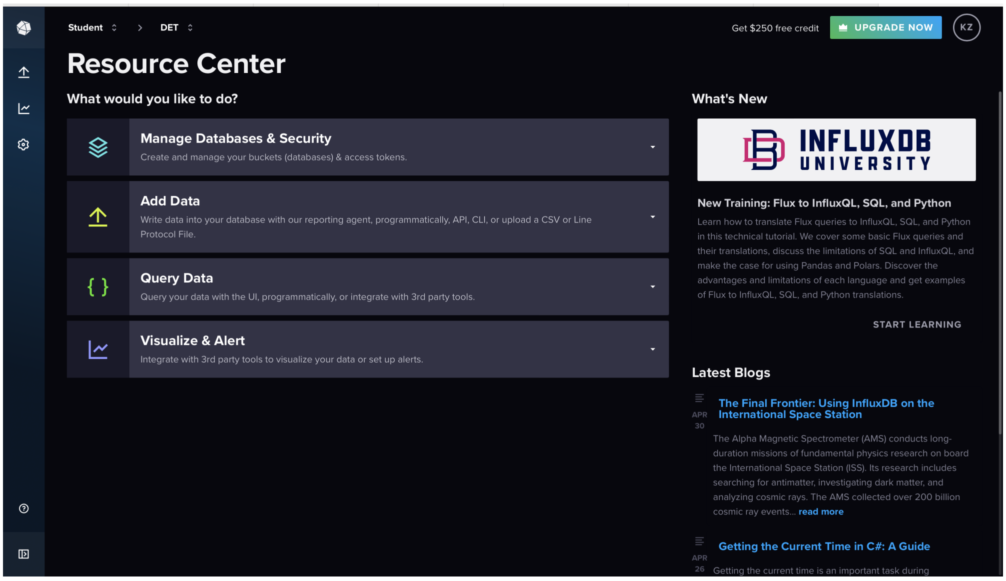
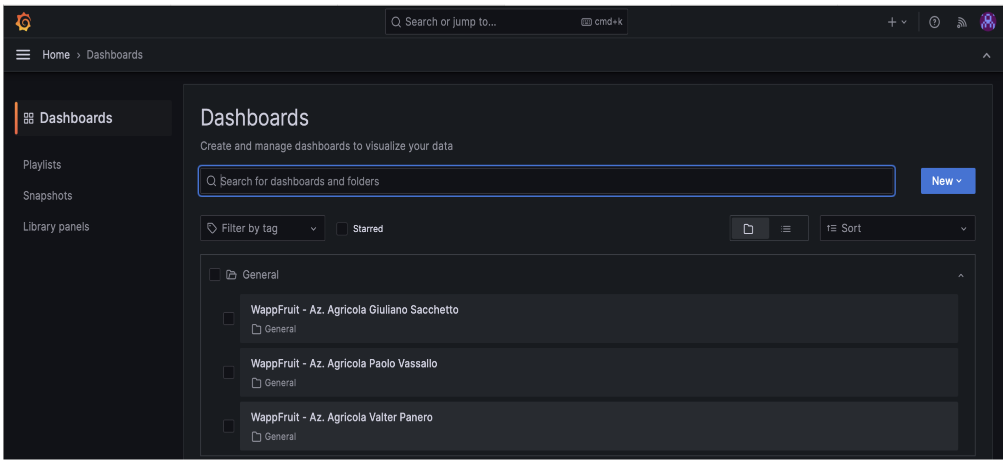


Figure 2.1: InfluxDB interface

2.2 Initial Setup Process

To begin, install Grafana locally on the server and set up an admin account. Within Grafana, create three distinct dashboards, one for each farmer. Each dashboard should contain relevant farm data represented through graphs and include satellite images aligned with their respective farm locations.



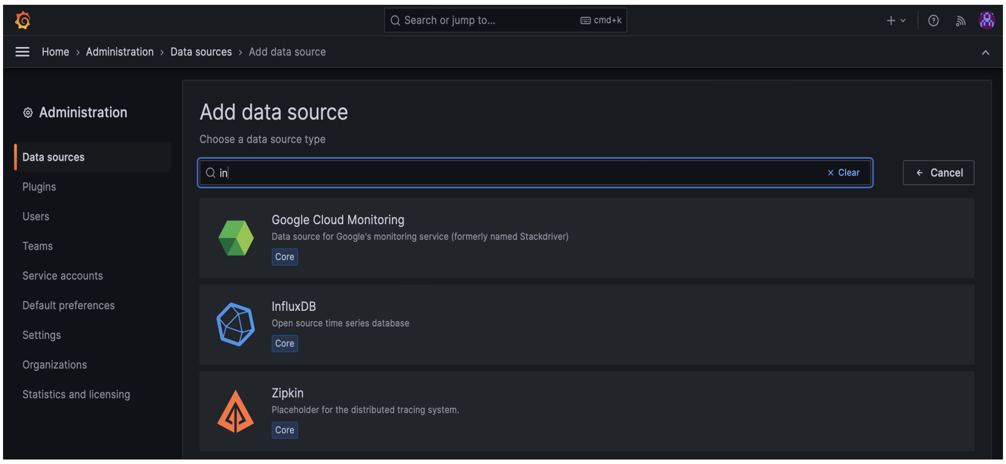
(a) Dashboard

(b) Subsection of dashboard

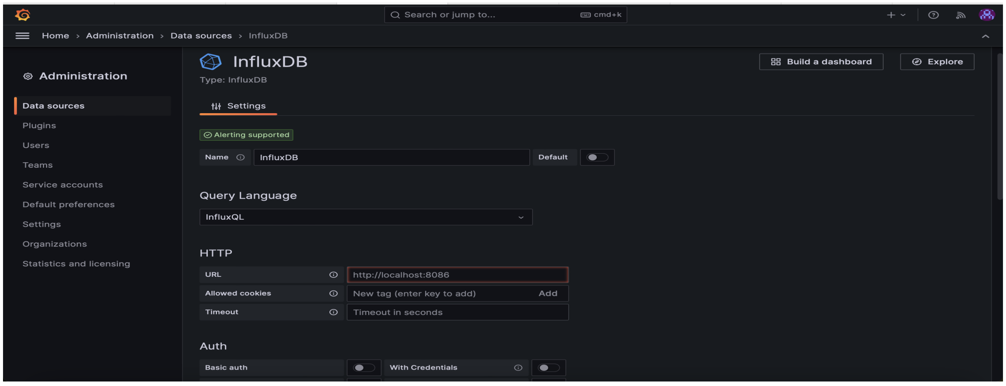
Figure 2.2: Dashboard screenshots showing various features

2.3 Establishing Data Sources

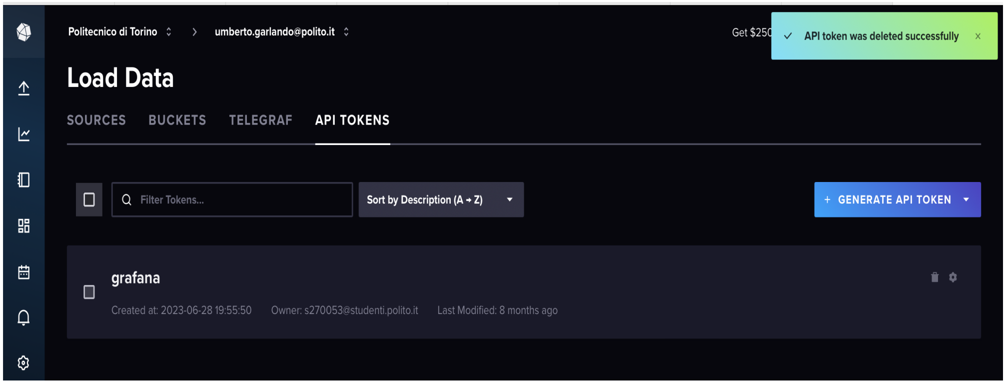
To visualize the collected data within Grafana, it's essential to establish a data source. Given that the data is collected and stored on InfluxDB, this platform must be defined as a data source within Grafana's settings. The necessary details, including the username, password, and token of InfluxDB, need to be configured within Grafana.



(a) Grafana-sources



(b) Grafana-Token



(c) InfluxDB-Token

Figure 2.3: Establishing Data Sources

2.4 Panel Creation

Each category of sensors and their corresponding location requires a dedicated panel for visualization. Opting for the Time Graph mode is crucial for effective comparison purposes within the panel.

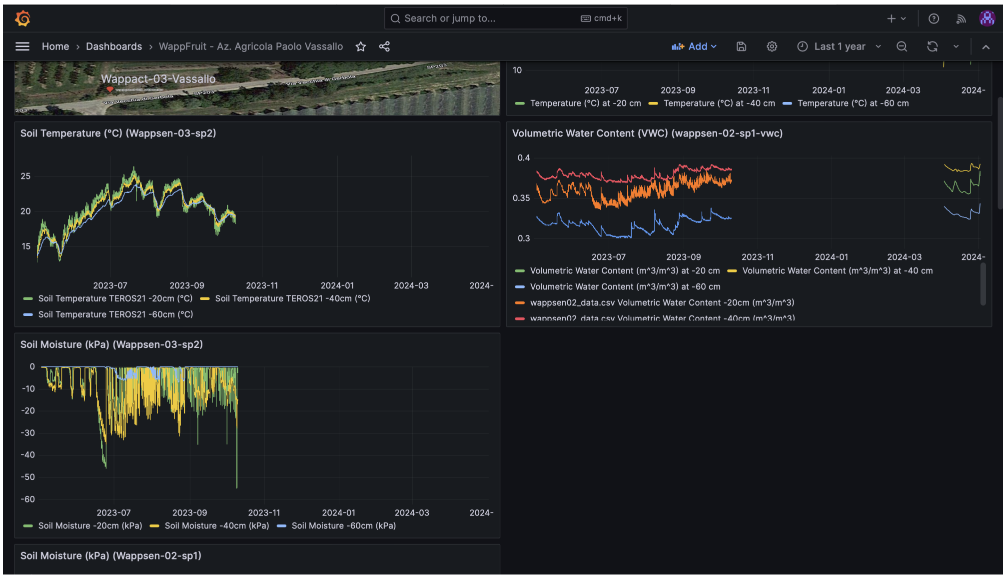


Figure 2.4: Panel interface

2.5 Visualizing Data from the Data Source

To display data on the graph, it's essential to craft query code that specifies names and values for the visualization. This query code enables the accurate representation of the desired data on the graph.

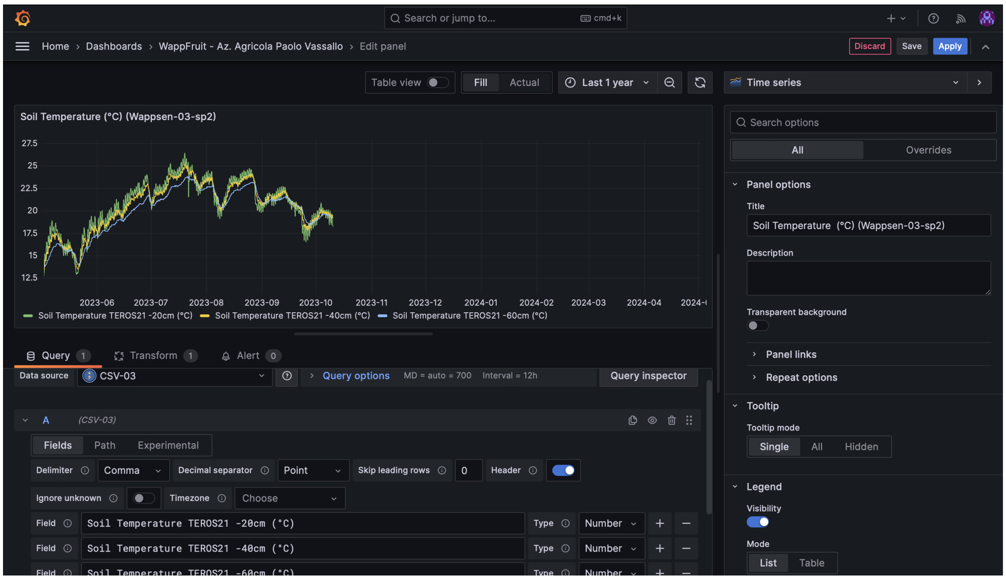


Figure 2.5: Query code

2.6 Adding Historical Data

The aim of this thesis is to visualize both historical and recent data simultaneously to enable a comprehensive analysis of trends over time. Since Grafana is hosted locally, historical data must be stored on the server as an Excel file to ensure easy integration. To achieve this, an Excel data source needs to be added within Grafana's data sources settings. After providing the file's location, specific configurations are required to align the historical data with live sensor data.

The integration process includes setting up time synchronization options to ensure that data from different sources aligns correctly on the timeline. Additionally, data types and formats should be standardized to facilitate seamless visualization. In the graph, it is crucial to differentiate the historical data from live data visually. This is typically done by assigning distinct colors to each dataset, as indicated in the dashboard.

On the Grafana dashboard, multiple soil temperature readings at various depths are plotted over time. The historical data should ideally mirror the formatting and scaling of the live data to provide an accurate comparative analysis. Specific settings, such as the graph's time range and data aggregation methods, need careful adjustment to maintain the integrity and relevance of both data types.

Furthermore, the query editor panel of Grafana, as shown, plays a vital role in managing and modifying the data queries that fetch and process the soil temperature measurements. Proper setup here ensures that all collected data is accurately represented and efficiently processed, enabling detailed and meaningful insights into soil temperature variations and their impact on agricultural practices.

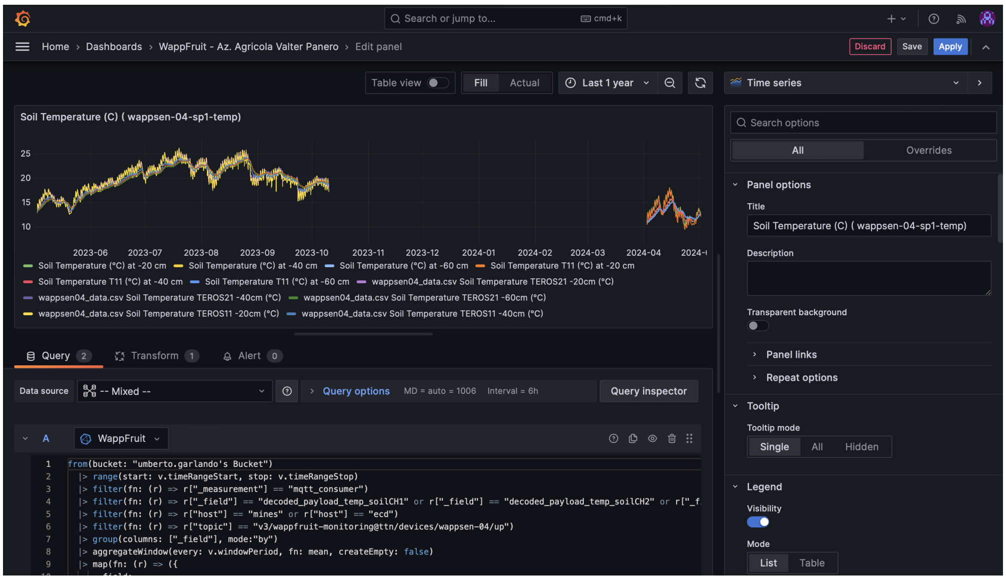
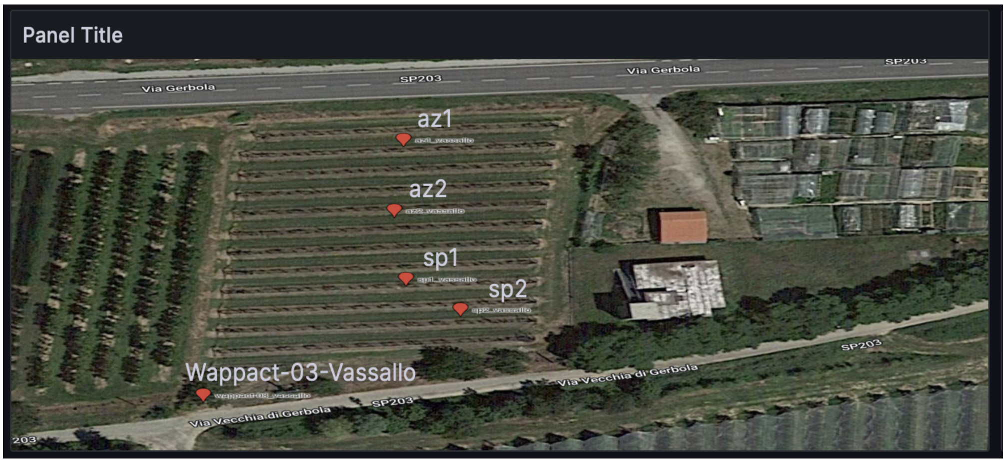


Figure 2.6: History data

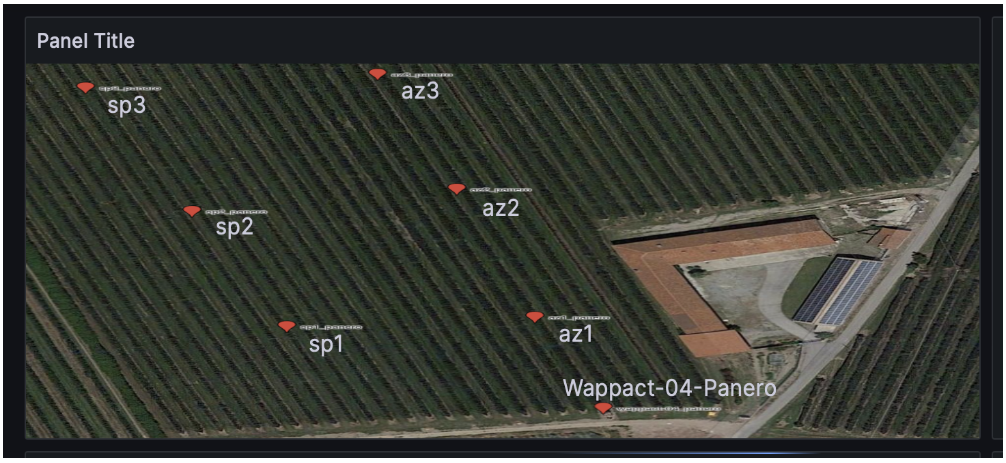
2.7 Satellite Picture Integration

For each farmland in this project, a high-resolution satellite image has been procured and stored in a specific location accessible by Grafana. To visualize these images within Grafana, a new panel needs to be created. Within the panel settings, the image mode should be selected. To enhance clarity, consider overlaying the panel picture with the names of the nodes corresponding to their locations on the farm.

(a) Farmland 1



(b) Farmland 2



(c) Farmland 3

Figure 2.7: Satellite Pictures

2.8 Personalization of Dashboard Access

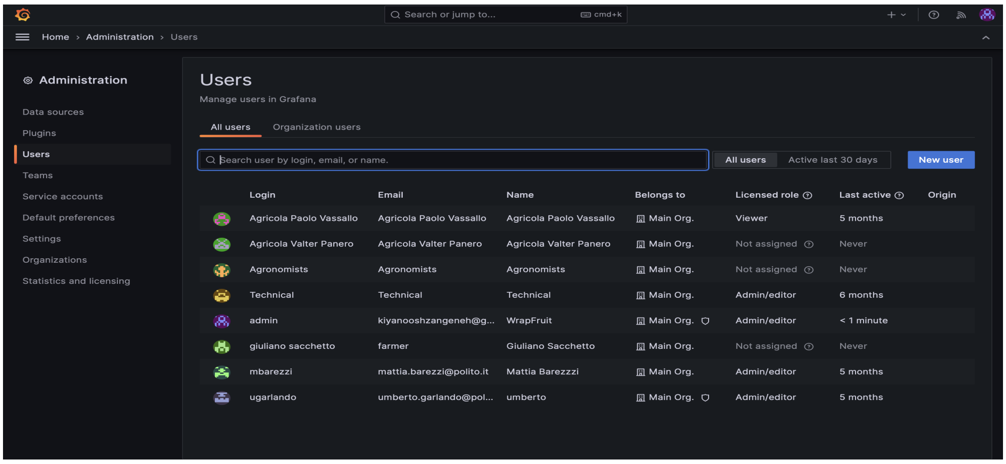
For this project, dashboard access has been meticulously tailored to cater to the unique needs of different stakeholders involved, ensuring both efficiency and security in data management. Four distinct access modes have been established:

1. Administrators like the 'Technical' user shown in the screenshots have full control over the Grafana environment. This role allows complete access to all dashboards, including capabilities to modify, add, or delete content. Administrators can manage user accounts, edit permissions, and oversee all backend processes to maintain the integrity and security of the data management system.

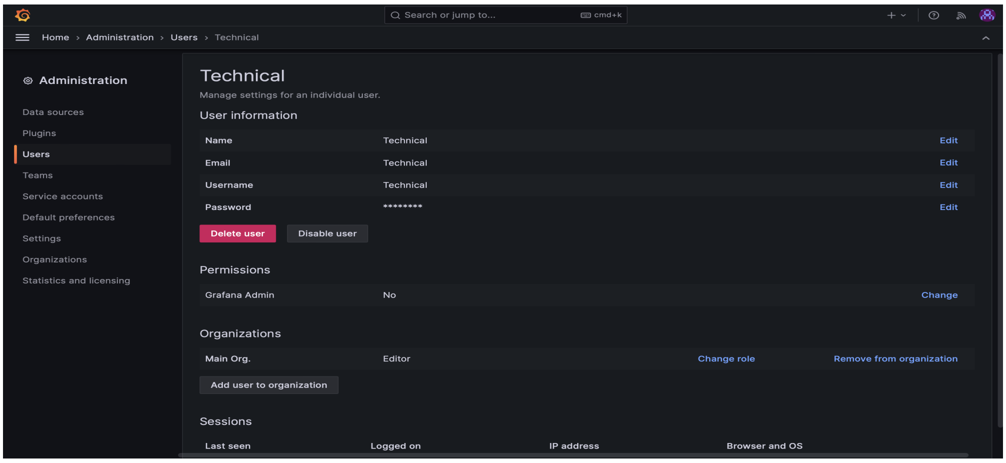
2. This mode provides technical staff and project assistants with access to all dashboards, specifically designed to facilitate troubleshooting and resolution of issues. While they can view and interact with all system settings, their access is restricted from making any permanent changes to user roles or deleting critical data, focusing instead on operational stability and data accuracy.

3. Individual farmers are provided with customized access through unique usernames and passwords. As illustrated in the user list for 'Agricola Paolo Vassallo' and 'Agricola Valter Panero', these users have restricted access tailored to only view data relevant to their specific farmland. This mode ensures farmers can monitor critical information pertinent to their agricultural activities without accessing broader system functionalities.

4. A general access level is available for public users or external stakeholders who need insights into the project but do not require detailed operational data. This mode provides non-editable, read-only access to predetermined sections of the dashboard, promoting transparency and public engagement without compromising the security of the data.



(a)



(b)

Figure 2.8: Personalization user

Chapter 3

Conclusion and Future Perspective

This thesis has explored the integration of Internet of Things (IoT) technologies with advanced data visualization tools, demonstrating significant advancements in the field of precision agriculture. Through the deployment of the WAPPFRUIT project, it was possible to achieve a meticulous balance between technological innovation and practical agricultural needs, leading to optimized irrigation practices and enhanced resource management.

3.1 Comprehensive Review of Project Outcomes

The project effectively leveraged IoT devices to collect and visualize data in real-time, which enabled precise monitoring and management of agricultural resources, particularly water. The integration of Grafana for data visualization proved crucial in transforming raw data into actionable insights, which allowed for immediate adjustments to irrigation practices, significantly improving water usage efficiency.

3.1.1 Technological and Agricultural Impacts

- **Operational Efficiency:** The real-time data acquisition and visualization tools have streamlined the decision-making process, reducing the reliance on traditional, often inefficient, farming methods.

- **Resource Conservation:** By employing sensor-based monitoring systems, water usage was optimized, contributing to conservation efforts and reducing the environmental footprint of agricultural practices.

- **Scalability and Adaptability:** The systems developed are scalable and adaptable to various agricultural environments, demonstrating the versatility and potential for broader application.

3.2 Future Research Directions and Challenges

While the project has shown promising results, the future of IoT in agriculture presents several exciting avenues for further exploration and also poses certain challenges:

3.2.1 Expansion and Adaptation

Future studies could focus on expanding the use of IoT systems to different types of crops and more diverse environmental conditions. This would help in understanding the scalability and adaptability of the technology across the global agricultural spectrum.

3.2.2 Integration with Emerging Technologies

Integrating IoT with other emerging technologies such as artificial intelligence (AI) and machine learning could further enhance predictive analytics in agriculture, making it possible to anticipate needs and adjust practices even more efficiently before issues arise.

3.2.3 Addressing Technological Challenges

The deployment of IoT technologies in remote or rural areas often faces challenges such as limited internet connectivity and the high cost of technology deployment. Future research should also aim to address these challenges, making the technology more accessible and cost-effective for all farmers.

3.3 Final Thoughts

In conclusion, this thesis not only achieved its stated objectives but also paved the way for future advancements in precision agriculture through IoT. The findings underscore the transformative potential of integrating real-time data visualization into agricultural practices, which can significantly enhance the sustainability and productivity of farming globally. The continued exploration and adaptation of these technologies hold the promise of revolutionizing agriculture, making it smarter, more efficient, and more sustainable.

Keywords: IoT, precision agriculture, data visualization, sustainable farming, resource management, future directions in IoT.

Appendix A

Appendix

A.1 Additional Query Codes

The following code is used for analyzing Soil Temperature data collected through IoT devices deployed in the field. This code demonstrates how to query, filter, and process temperature data from various soil depths using Flux language in an InfluxDB environment.

A.1.1 Query Code for Soil Temperature Analysis

```
from(bucket: "umberto.garlando's Bucket")
  |> range(start: v.timeRangeStart, stop: v.timeRangeStop)
  |> filter(fn: (r) => r["_measurement"] == "mqtt_consumer")
  |> filter(fn: (r) => r["_field"] == "decoded_payload_temp_soilCH1" or r["_field"] == "decoded_payload_temp_soilCH2" or r["_field"] == "decoded_payload_temp_soilCH3" or r["_field"] == "decoded_payload_temp_soilT11_CH4" or r["_field"] == "decoded_payload_temp_soilT11_CH5" or r["_field"] == "decoded_payload_temp_soilT11_CH6")
  |> filter(fn: (r) => r["host"] == "mines" or r["host"] == "ecd")
  |> filter(fn: (r) => r["topic"] == "v3/wappfruit-monitoring@ttn/devices/wappsen-11/up")
  |> group(columns: ["_field"], mode:"by")
  |> aggregateWindow(every: v.windowPeriod, fn: mean, createEmpty: false)
  |> map(fn: (r) => ({
      _field:
        if r["_field"] == "decoded_payload_temp_soilCH1" then "Soil Temperature (°C) at -20 cm"
        else if r["_field"] == "decoded_payload_temp_soilCH2" then "Soil Temperature (°C) at -40 cm"
```

```
        else if r["_field"] == "decoded_payload_temp_soilCH3" then "Soil Temperature (°C) at -60 cm"
        else if r["_field"] == "decoded_payload_temp_soilT11_CH4" then "Soil Temperature T11 (°C) at -20 cm"
        else if r["_field"] == "decoded_payload_temp_soilT11_CH5" then "Soil Temperature T11 (°C) at -40 cm"
        else if r["_field"] == "decoded_payload_temp_soilT11_CH6" then "Soil Temperature T11 (°C) at -60 cm"
        else r["_field"],
      _value: r._value,
      _time: r._time
    }))
  |> yield(name: "mean")
```

Listing A.1: Flux query for analyzing soil temperature at different depths.

A.1.2 Query Code for Matric Potential Analysis

```
from(bucket: "umberto.garlando's Bucket")
  |> range(start: v.timeRangeStart, stop: v.timeRangeStop)
  |> filter(fn: (r) => r["_measurement"] == "mqtt_consumer")
  |> filter(fn: (r) => r["_field"] == "decoded_payload_soil_moiCH1" or r["_field"] == "decoded_payload_soil_moiCH2" or r["_field"] == "decoded_payload_soil_moiCH3")
  |> filter(fn: (r) => r["host"] == "mines" or r["host"] == "ecd")
  |> filter(fn: (r) => r["topic"] == "v3/wappfruit-monitoring@ttn/devices/wappsen-13/up")
  |> group(columns: ["_field"], mode:"by")
  |> aggregateWindow(every: v.windowPeriod, fn: last, createEmpty: false)
  |> map(fn: (r) => ({
      _field:
        if r["_field"] == "decoded_payload_soil_moiCH1" then "Soil Matric Potential at -20cm"
        else if r["_field"] == "decoded_payload_soil_moiCH2" then "Soil Matric Potential at -40cm"
        else if r["_field"] == "decoded_payload_soil_moiCH3" then "Soil Matric Potential at -60cm"
        else r["_field"],
      _value: r._value,
      _time: r._time
    }))
  |> yield(name: "last")
```

Listing A.2: Query for analyzing soil matric potential at different depths using the WAPPFRUIT monitoring system.

A.1.3 Query Code for Volumetric Water Content Analysis - Wappsen-14

```
from(bucket: "umberto.garlando's Bucket")
  |> range(start: v.timeRangeStart, stop: v.timeRangeStop)
  |> filter(fn: (r) => r["_measurement"] == "mqtt_consumer")
  |> filter(fn: (r) => r["_field"] == "decoded_payload_vwcCH4" or
    r["_field"] == "decoded_payload_vwcCH5" or r["_field"] == "
    decoded_payload_vwcCH6")
  |> filter(fn: (r) => r["host"] == "mines" or r["host"] == "ecd")
  |> filter(fn: (r) => r["topic"] == "v3/wappfruit-monitoring@ttn/
    devices/wappsen-14/up")
  |> group(columns: ["_field"], mode:"by")
  |> aggregateWindow(every: v.windowPeriod, fn: last, createEmpty:
     false)
  |> map(fn: (r) => ({
      _field:
        if r["_field"] == "decoded_payload_vwcCH4" then "
    Volumetric Water Content (m^3/m^3) at -20 cm"
        else if r["_field"] == "decoded_payload_vwcCH5" then "
    Volumetric Water Content (m^3/m^3) at -40 cm"
        else if r["_field"] == "decoded_payload_vwcCH6" then "
    Volumetric Water Content (m^3/m^3) at -60 cm"
        else r["_field"],
      _value: r._value,
      _time: r._time
    }))
  |> yield(name: "last")
```

Listing A.3: Query for analyzing volumetric water content at different depths for Wappsen-14.

A.1.4 Query Code for Temperature Analysis - Wappsen-01

```
from(bucket: "umberto.garlando's Bucket")
  |> range(start: v.timeRangeStart, stop: v.timeRangeStop)
  |> filter(fn: (r) => r["_measurement"] == "mqtt_consumer")
  |> filter(fn: (r) => r["_field"] == "
    decoded_payload_temp_soilCH3" or r["_field"] == "
    decoded_payload_temp_soilCH2" or r["_field"] == "
    decoded_payload_temp_soilCH1")
  |> filter(fn: (r) => r["host"] == "mines" or r["host"] == "ecd")
  |> filter(fn: (r) => r["topic"] == "v3/wappfruit-monitoring@ttn/
    devices/wappsen-01/up")
  |> group(columns: ["_field"], mode:"by")
  |> aggregateWindow(every: v.windowPeriod, fn: last, createEmpty:
     false)
```

```
  |> map(fn: (r) => ({
      _field:
        if r["_field"] == "decoded_payload_temp_soilCH1" then "
 Temperature (°C) at -20 cm"
        else if r["_field"] == "decoded_payload_temp_soilCH2" then
  "Temperature (°C) at -40 cm"
        else if r["_field"] == "decoded_payload_temp_soilCH3" then
  "Temperature (°C) at -60 cm"
        else r["_field"],
      _value: r._value,
      _time: r._time
    }))
  |> yield(name: "last")
```

Listing A.4: Query for analyzing temperature at different soil depths for Wappsen-01.