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

D4.1

Architecture and user manual of the multi-modal interfaces

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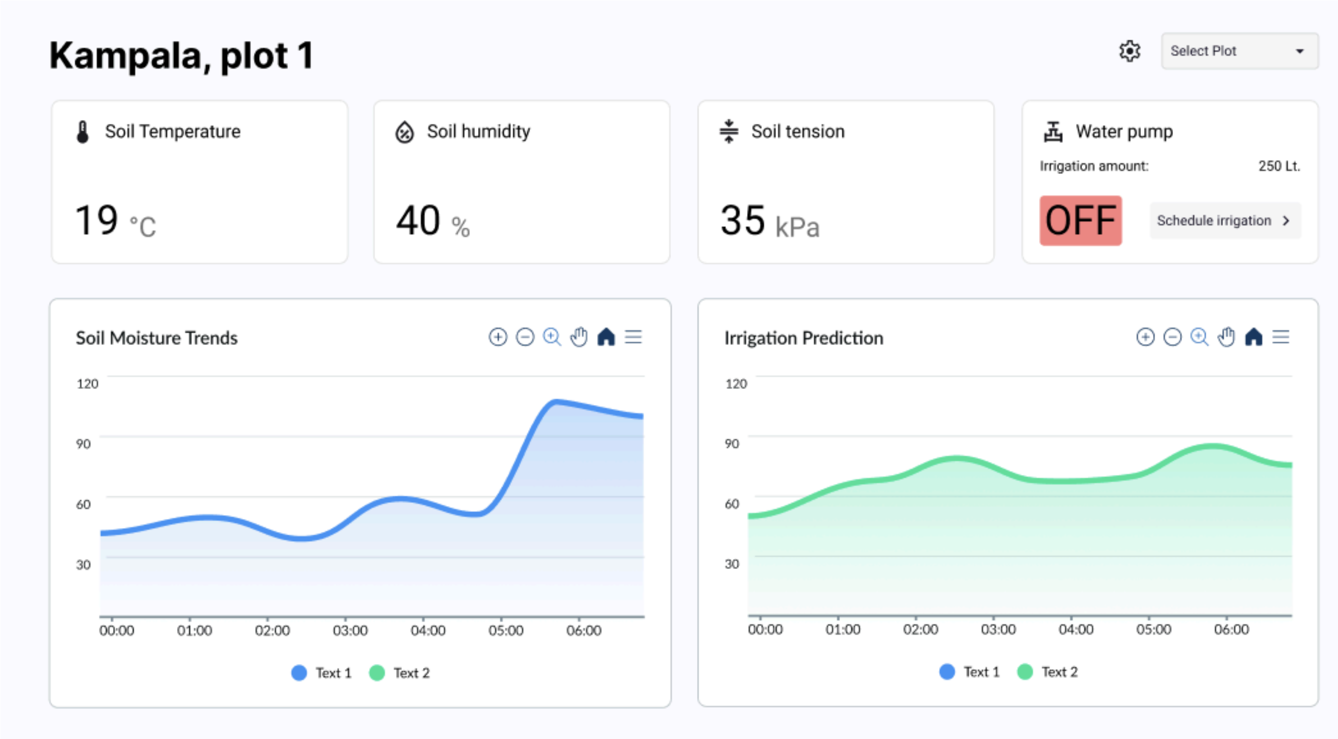
1. Introduction

Multimodal interfaces play a crucial role in enhancing user interaction with smart applications by leveraging multiple communication modalities. In the context of the irrigation prediction application, the integration of multimodal interfaces aims to provide users with seamless access to critical soil and irrigation information. This document outlines the envisioned functionalities, design considerations, technical implementation, and potential benefits of incorporating multimodal interfaces into the application.

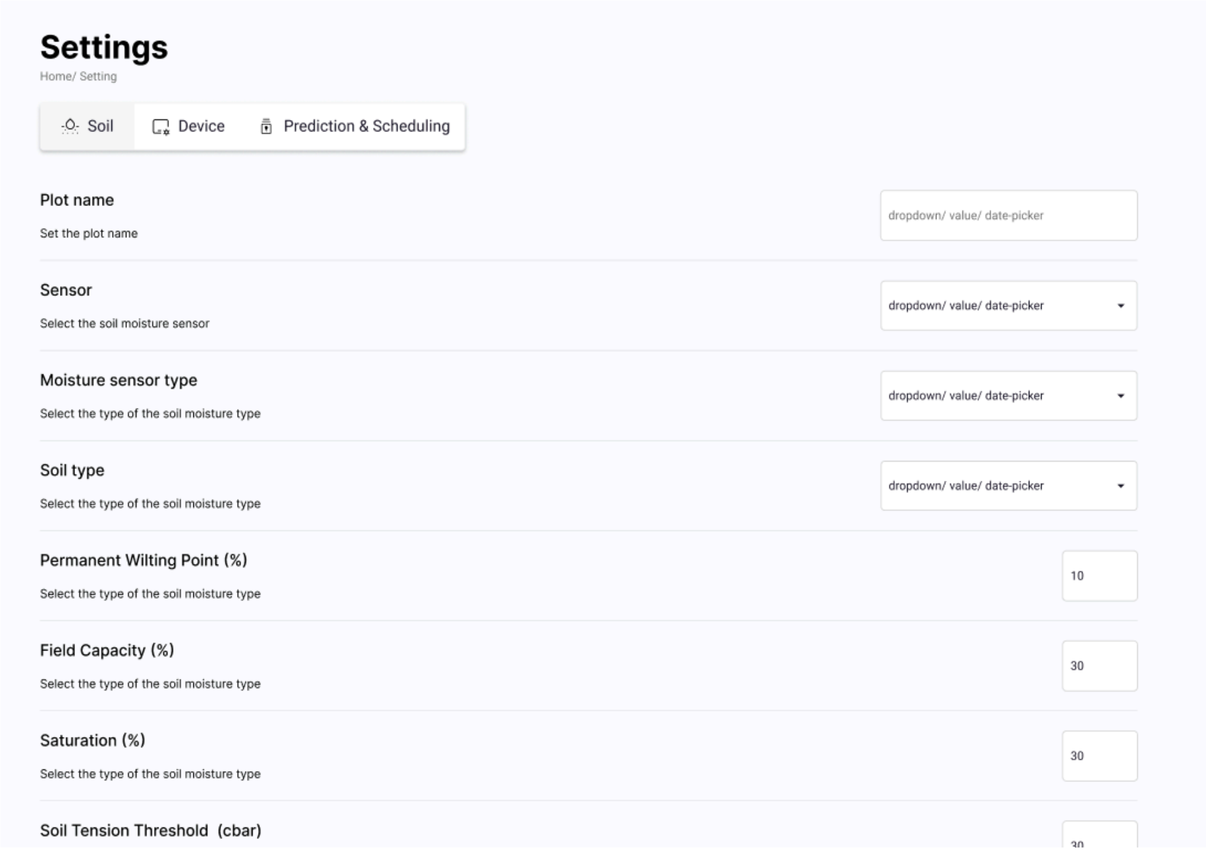
2. Graphical User Interface



Dashboard Overview: Irrigation Monitoring

This dashboard provides a real-time overview of soil and irrigation metrics for a specific agricultural plot e.g. ("Kampala, plot 1"). The interface is divided into key functional sections:

- **Sensor Data Cards (Top Row)**: Display current soil conditions e.g:
    - **Soil Temperature**: 19°C
    - **Soil Humidity**: 40%
    - **Soil Tension**: 35 kPa
    - **Water Pump Status**: Indicates that the pump is currently OFF, with a scheduled irrigation amount of 250 liters and a button for scheduling irrigation.
- **Soil Moisture Trends (Bottom Left Chart)**: A dynamic line graph visualizing soil moisture levels over time. The trend line shows measurements for two test datasets (Text 1 in blue, Text 2 in green), helping identify patterns in soil moisture changes.
- **Irrigation Prediction (Bottom Right Chart)**: A forecast graph showing predicted irrigation requirements or performance, based on recent trends and inputs.
- **Plot Selector & Settings (Top Right)**: Allows the user to select a different plot and access system settings.



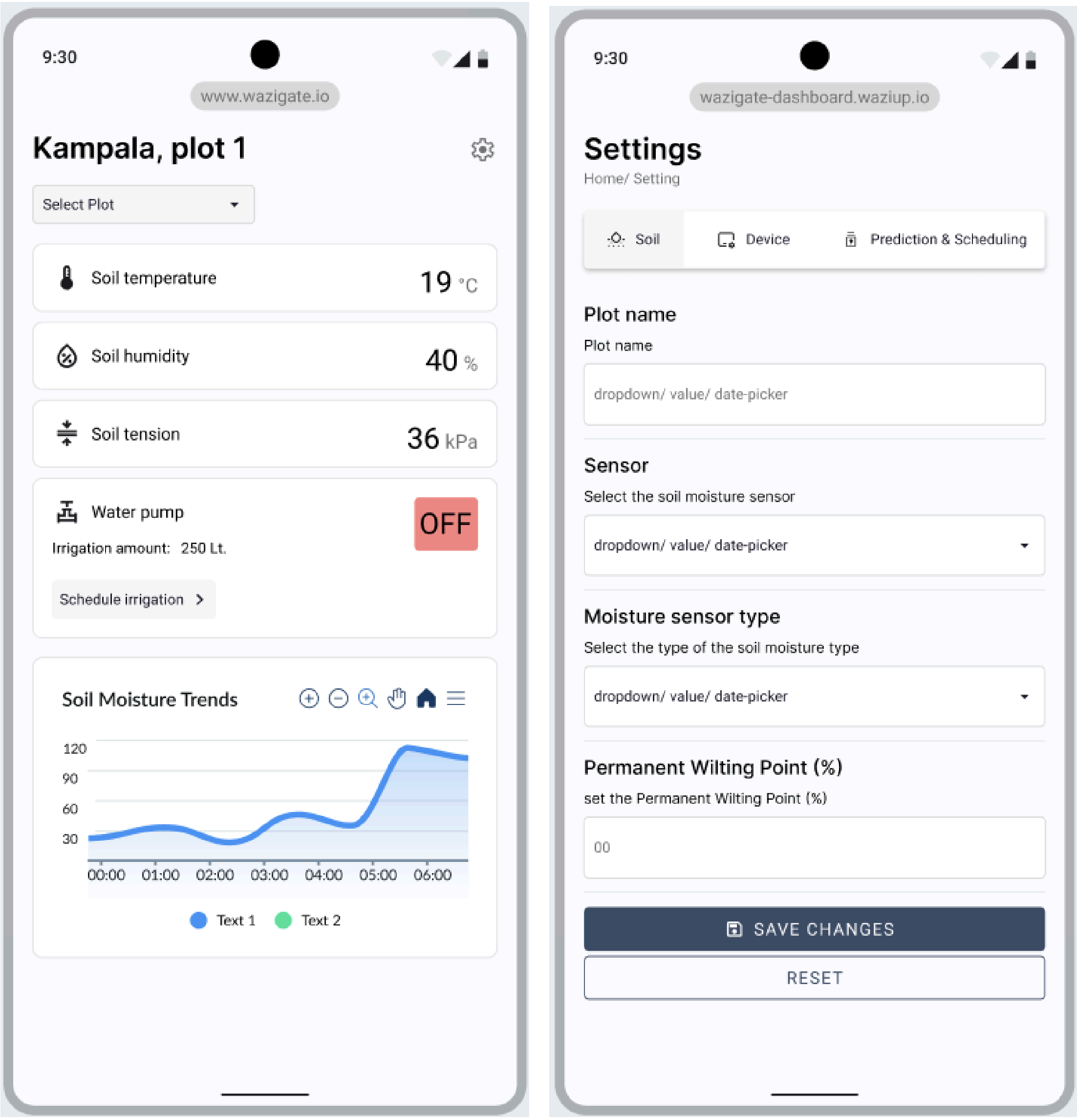
Settings Page: Irrigation Prediction Configuration

This page enables users to configure essential parameters that influence the irrigation prediction model for a selected agricultural plot. It is organized into three main configuration tabs: **Soil**, **Device**, and **Prediction & Scheduling**. The screenshot shows the **Soil** tab, which includes the following adjustable settings:

- **Plot Name**: Input or select the name of the plot for which settings are being configured.
- **Sensor**: Dropdown to select the soil moisture sensor installed on the plot.
- **Moisture Sensor Type**: Allows the user to specify the type/model of the soil moisture sensor.
- **Soil Type**: Dropdown to select the category of soil present in the plot (e.g., loamy, clay, sandy).
- **Permanent Wilting Point (%)**: The minimum soil moisture level below which plants cannot recover; set manually.
- **Field Capacity (%)**: Represents the maximum amount of moisture soil can retain after excess water has drained.
- **Saturation (%)**: Indicates the maximum soil moisture level when all pores are filled with water.

- **Soil Tension Threshold (cbar)**: A critical tension value used by the system to determine when irrigation should be triggered.

These configurations play a crucial role in calibrating the prediction engine and optimizing irrigation schedules based on accurate soil behavior and sensor data.



Mobile Interface: Dashboard and Settings Screens

The irrigation prediction application is fully responsive, offering a seamless user experience across devices. The screenshots above showcase the mobile-optimized views of the **Dashboard** and **Settings** pages.

- **Mobile Dashboard View**:
  The dashboard is streamlined for smaller screens, presenting key metrics and visualizations in a stacked layout for better readability. Users can quickly view critical information such as current soil moisture levels, sensor status, weather forecasts, and irrigation

recommendations without excessive scrolling or zooming.

- **Mobile Settings View**:
 The settings interface is adapted to a vertical, touch-friendly layout that ensures all input fields, dropdowns, and numerical entries are easily accessible. Users can efficiently update plot configurations such as soil type, sensor type, and threshold values with smooth navigation between sections using swipe gestures or fixed tab buttons at the top.

These mobile screens ensure that users can monitor and adjust irrigation parameters in the field or on-the-go, with no compromise in functionality or usability.

3. Display Integration

The application will utilize an OLED display mounted on the gateway's HAT (Hardware Attached on Top) to present key information directly to users. This provides an easily accessible, local interface for monitoring essential metrics. The display integration is designed to provide quick, actionable insights without requiring external devices.

2.1 Soil Information Display

The OLED display **will showcase critical soil metrics**, such as:

- **Soil Water Tension**: Measured using soil sensors to indicate water availability for plants. This information helps farmers understand water stress levels in the soil.
- **Volumetric Water Content (VWC)**: Displays the percentage of water contained within the soil. This metric provides insights into soil moisture levels, essential for effective irrigation planning.
- Next (calculated) **most suitable time to perform the irrigation**

Additional **indicators may include**:

- Soil temperature readings to assess environmental conditions.
- Battery status or energy consumption of the gateway.

In the following a preliminary prototype from another project (Prima Intel-Irris) is shown:

Figure 1: The OLED interface of the INTEL-IRRIS WaziApp on the WaziGate [1]

2.2 Irrigation Scheduling

The next calculated irrigation times will also be displayed, enabling users to anticipate and plan irrigation activities effectively. The schedule will be updated in real-time based on sensor readings and predictive models. Notifications about the duration of scheduled irrigation events can also be shown on the display, allowing users to prepare for operational needs. Depending on the setup of the irrigation system, e.g. whether a controllable pump/valve is installed. The irrigation schedule is either performed automatically or needs to be manually triggered, according to the recommended irrigation schedule.

2.3 QR Code for Application UI

A dynamically generated QR code will be displayed, linking users to the application's user interface hosted on the local network. This allows for a more detailed exploration of data and application settings through a web browser. The QR code will refresh periodically to maintain security and compatibility, ensuring that users always have access to the latest connection details, in case the DHCP of the local network assigns a different IP address to the WaziGate in the local subnet.

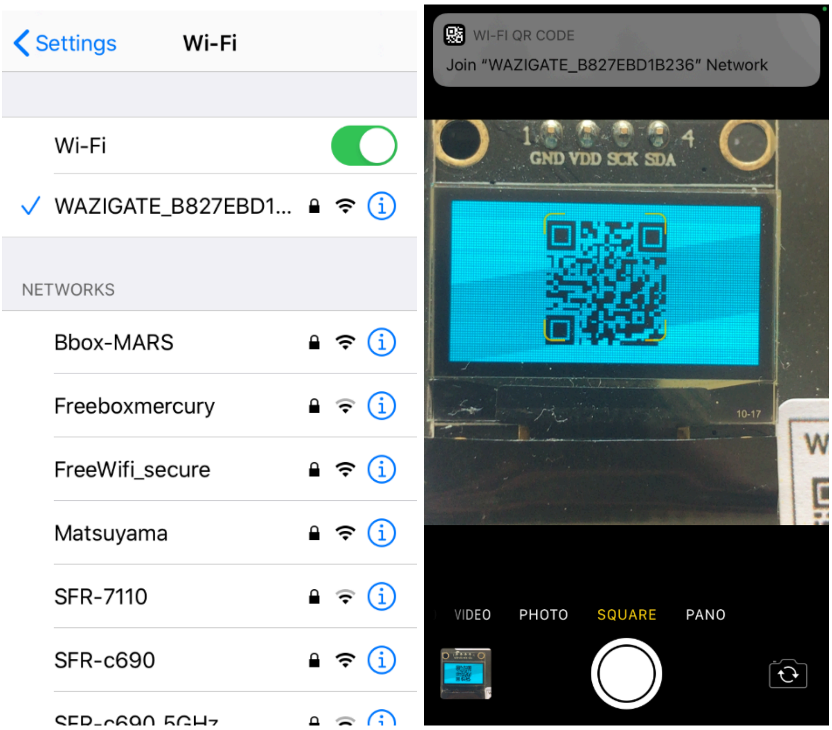


Figure 2: Automatic joining of WiFi network with QR code [1]

3. Email and SMS Notifications

To complement the OLED display, the application will provide an email notification system to inform users about significant updates and events. This ensures that critical information reaches the user even when they are not near the gateway.

3.1 Status Updates

Notifications will include updates such as:

- "You need to irrigate on a certain time, like tomorrow in the morning"
- "You need to irrigate now": Triggered when soil metrics indicate immediate irrigation is required.
- "An irrigation was scheduled": Sent when the application plans an irrigation event based on forecast data.
- "Irrigation completed": Confirmation that a scheduled or manually triggered irrigation event has concluded successfully.
- "An error occurred, please perform maintenance": If the system encounters an error manual interaction is needed, tell a user this state
-

3.2 Customizable Behavior

The notification system will adapt based on the application's configuration. For instance:

- If the application can actuate a pump, users will be informed of scheduled or completed irrigation actions.
- If manual intervention is required, notifications will provide actionable insights for users to make informed decisions.

Users can configure the frequency and content of email notifications to match their preferences and operational needs.

Voice Alerts

via Api: calls number, to read loud your posted message

4. Multimodal Interface Design Considerations

The following considerations will guide the development of the multimodal interfaces:

4.1 Usability and Accessibility

The OLED display must present information in a clear, concise, and visually appealing format to ensure readability. The QR code should be prominently displayed and periodically refreshed to maintain usability. Email notifications should be written in simple, actionable language to maximize clarity.

4.2 Scalability

The notification system should support multiple users and be configurable to accommodate varying preferences for email frequency and content. The system should also allow for integration with other devices or platforms, such as mobile apps or cloud dashboards.

4.3 Reliability

Ensure consistent performance of the OLED display and QR code generation, even under suboptimal network conditions. Email notifications must be reliably delivered and not flagged as spam. This may require integrating with professional email services.

4.4 Energy Efficiency

The OLED display and gateway components must be optimized for low power consumption, especially in remote or off-grid scenarios. Sleep modes or low-power states can be implemented to prolong battery life, if the gateway is deployed in a power constrained environment.

5. Future Enhancements

As the application evolves, additional modalities could be considered to further improve user experience:

5.1 Voice Alerts ->

Integration of audio notifications or voice assistants to provide real-time updates and instructions. This could be particularly beneficial for visually impaired users or situations requiring hands-free interaction.

5.2 Mobile App Integration

Development of a dedicated mobile application for push notifications and richer interaction with the application's data. This application could also be developed with the display of other applications in mind. This app could also include advanced features like historical data visualization, predictions, irrigations times and remote control capabilities.

5.3 Expanded Display Features

Utilize larger and higher-resolution displays for detailed graphical representations of soil data and weather data and also trends. Incorporate touchscreen capabilities for direct user interaction with the interface. This display has to be attached to the Raspberry Pi and needs some adoption of the WaziGates operating system.

5.4 Language Model Assistant

A language model could serve as an intelligent assistant for farmers, capable of interacting through multimodal inputs such as speech and text and outputs like speech and text. By integrating a Retrieval-Augmented Generation (RAG) system, the language model could query the application's API to fetch real-time predictions and irrigation schedules. Suitable pretrained large language models (LLM) such as OpenAI's GPT, Meta's LLaMA, Google's PaLM, or Cohere Command could be employed for this purpose. The RAG system would access APIs for field sensor data, weather forecasts, and satellite-derived soil information to enable the language model to calculate irrigation times independently. By utilizing historical data and predictive weather analytics, the assistant could generate precise irrigation schedules and provide actionable insights. A conversational interface would simplify complex data into intuitive advice, enhancing farmers' decision-making capabilities. Multimodal interaction would be achieved using tools like Whisper for speech-to-text and Tacotron 2 for text-to-speech, ensuring seamless user experience across different communication modalities. This approach would enhance the decision-making process for the farmer.

6. Conclusion

The proposed multimodal interfaces for the irrigation prediction application aim to provide users with an intuitive and versatile means of interacting with the system. By combining local display features, QR code integration and email notifications, the application ensures timely and accessible delivery of critical information. These interfaces will enhance user engagement, support efficient irrigation management, and pave the way for future innovations in precision agriculture.