IMT AUTOMATED GARDEN AND SMART CAMPUS: SENSORS, EMBEDDED SYSTEM, DASHBOARDS AND DATABASE

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Abstract. *This work presents an overview of the IoT architecture deployed in the Automated Garden and Smart Campus of the IMT, covering sensors, embedded systems, LoRaWAN communication, gateway and visualization tools. By consolidating evidence from previous projects, the study confirms the functionality of soil moisture sensors, a meteorological station and the data flow via LoRaWAN protocol that transmits environmental measurements to the network server for decoding and real-time visualization through Node-RED and Grafana dashboards. Despite the functional infrastructure, the analysis shows the absence of a database for structured long-term storage of sensor data, limiting historical analysis and the application of well-trained machine-learning methods. The work therefore documents the current system and highlights the need for a centralized database to support future research, including artificial neural network models for decision support in precision agriculture.*

Keywords. *Internet of Things, Automated Garden, Smart Campus.*

Introduction

Precision agriculture has become one of the main drivers of modernization in the agricultural sector, propelled by advances in the Internet of Things (IoT) and by the availability of long-range, low-power wireless communication systems. The integration of sensors, embedded systems, and analytical platforms has enabled continuous monitoring of environmental and soil variables, increasing production efficiency and reducing waste, especially reducing water usage. Recent studies indicate that IoT-based agricultural solutions already form a consolidated ecosystem of sensors, communication protocols, and analytical platforms dedicated to crop automation and decision support (Farooq *et al*., 2019).

Within this technological ecosystem, LoRaWAN networks, particularly the LoRaWAN protocol, stand out for enabling robust long-distance communication with low energy consumption, making them well suited for agricultural and environmental applications in open-field scenarios (Teixeira & Almeida, 2017). The ability to integrate soil sensors, meteorological stations, and embedded systems into a continuous data flow facilitates the development of complete monitoring structures, encompassing every stage from data collection to visualization.

In this context, the IMT Smart Campus serves as a fundamental infrastructure, integrating LoRaWAN gateways, servers, and tools such as Node-RED and Grafana.

Objectives

The main goal of this work is to analyse, organize, and document the technological infrastructure that constitutes the automated garden system and the IMT Smart Campus, integrating sensors, embedded systems, LoRaWAN communication and dashboards. Based on this survey, the study seeks to develop a consolidated understanding of the different elements that compose IMT's IoT ecosystem.

Within this scope, the target is to study in detail the functioning of the sensors used in the garden, including both soil moisture sensors and the equipment embedded in meteorological stations. In addition, it intends to understand and document the system's communication flow, from data collection in the field to its transmission via LoRaWAN, reception by the gateways, decoding in Node-RED, and subsequent visualization in dashboards.

Finally, this work aims to define the next stage of the project, which involves creating a centralized database to store long-term sensor measurements. This structure will provide reliable historical data and support future analyses, enabling the application of artificial intelligence methods for pattern identification, forecasting, and data-driven decision making in precision agriculture.

Development

The monitoring system used in the automated garden (Figure 1) and in the IMT Smart Campus is structured as a distributed IoT architecture that integrates soil and atmospheric sensors, embedded devices, long-range wireless communication, and tools for data processing and visualization (Coelho *et al.*, 2020) (Pasquini, 2020). This architecture follows the typical model of IoT-based agricultural applications, in which data are collected directly in the field, transmitted through a low-power network, and subsequently processed on servers and dashboards that enable continuous monitoring of the observed variables.

In the sensing layer, devices installed in the garden, such as capacitive soil moisture sensors and environmental sensors embedded in meteorological stations, perform periodic measurements and send this information to embedded boards equipped with LoRa modules. These devices are responsible for preparing the readings and transmitting them using the LoRaWAN protocol, which is well suited for agricultural applications due to its low energy consumption and extended communication range. Thus, the first stage of the data flow consists of acquiring the measured variables and transmitting the data by radio frequency to a gateway.

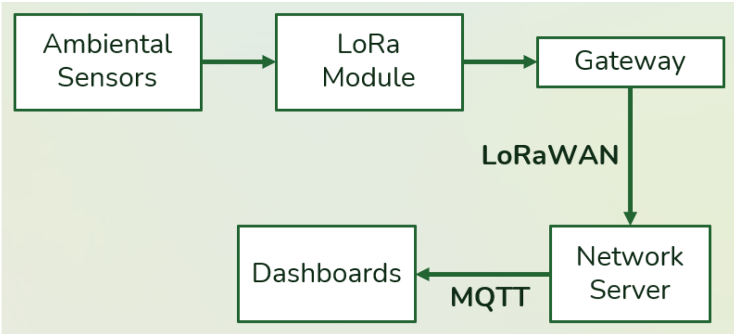
The gateway serves as the reception point of the network, collecting the LoRaWAN packets sent by the sensors and forwarding them to IMT's network server. This stage validates, organizes, and makes the data available for processing, acting as the bridge between the physical sensing environment and the computational layer. Once registered on the server, the data proceed to the processing system, implemented primarily in Node-RED, which decodes the received payload, interprets the numerical values, and structures the information for dashboard visualization and storage.

Figure 1 – Picture of the automated garden (IMT Smart Campus)

These tools allow real-time monitoring of soil moisture conditions, temperature, humidity, precipitation, and other relevant environmental variables, supporting both rapid analysis and medium-term behavioural diagnostics. Visualization plays a fundamental role in precision agriculture, as it transforms raw data into accessible information for analysis and decision-making.

In this way, the IoT architecture employed in the IMT Smart Campus combines sensors, LoRaWAN communication, gateways, Node-RED processing and dashboards, illustrated on Figure 2. This establishes an effective foundation for an integrated agricultural monitoring system.

Figure 2 – Block diagram showing the dataflow.

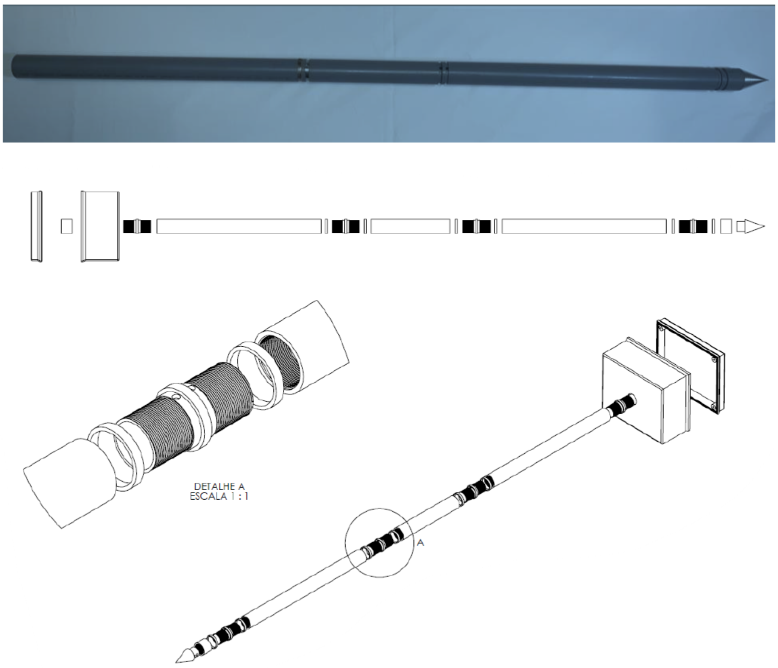


The foundation of the IoT system employed in the automated garden and in the IMT Smart Campus (https://smartcampus.maua.br/) consists of sensors integrated with embedded devices responsible for data collection, initial processing, and transmission. Each type of sensor plays a specific role in characterizing environmental conditions.

There are 3 soil moisture sensors implemented in the IMT Automated Garden. They were built in the IMT Research Center and operate at three measurement depths, enabling the monitoring of distinct layers of the soil profile. This multi-level structure allows the system to respond more accurately to moisture variations and contributes to more efficient irrigation decisions. According to studies the choice of capacitive sensors is justified by their favorable balance of cost, durability, and accuracy, particularly when compared to resistive sensors, which are more susceptible to corrosion and instability (Barros *et al*, 2020).

The calibration of the soil moisture sensors was essential to ensure reliable measurements. The procedure consisted of comparing the readings from the custom-built capacitive sensor with those from a commercial soil hygrometer used as a reference. Both devices were tested under eight conditions, including fully wet and fully dry environments, as well as several measurements taken simultaneously in the soil. Using these paired readings, linear interpolation curves were generated for each sensing level, allowing the conversion of raw sensor values into estimated moisture percentages. Although the reference sensor had limited precision, the calibration provided consistent results and enabled the practical use of the developed sensors in the IMT garden. One of the sensors represented in Figure 3, as well as a 3D model.

Figure 3 – Design of Soil Moisture Sensor (Barros *et al*, 2020).



In addition to soil moisture sensing, the system incorporates environmental monitoring through a meteorological station by Khomp capable of measuring temperature, humidity, precipitation, solar radiation, atmospheric pressure, and wind speed and direction (Figure 4). Since the sensor is a commercial device, it already comes pre-calibrated and therefore does not require additional calibration. The data collected by the station plays a fundamental role in agricultural monitoring, as atmospheric variables directly influence crop development. Therefore, the integration of meteorological stations with soil sensors provides a more comprehensive view of the agricultural environment, making it possible to correlate climatic conditions with soil behavior and plant responses.

The collection of this information is performed by embedded devices equipped with LoRa modules, which are responsible for periodically reading the sensors and transmitting the data to the gateway. A recurring feature in these implementations is the use of deep-sleep cycles, a strategy that drastically reduces energy consumption and extends the lifespan of devices, especially when powered by batteries or autonomous field systems. The cycle is set to collect data every eight minutes. (Farooq *et al*., 2019).

Figure 4 – Khomp weather station (Assanti *et al*, 2024).

Thus, the combination of soil sensors, environmental sensors, and embedded devices establishes the physical layer of the IoT system in the automated garden. This layer, responsible for the direct acquisition of environmental variables, underpins the subsequent flow of communication, processing, and data analysis.

Wireless communication is one of the central elements of any IoT architecture applied to agricultural monitoring, especially when sensors are distributed across open and distant areas. The transmission of data collected in the automated garden and meteorological stations is carried out using LoRa technology integrated with the LoRaWAN protocol. This choice aligns well with agricultural applications, in which the communication infrastructure must support long distances, continuous operation, and battery-powered devices.

LoRa technology uses Chirp Spread Spectrum (CSS) modulation, a technique that spreads the signal in frequency and time, ensuring greater robustness against interference and enabling reception even of very weak signals. The use of this modulation is highlighted by the fact that LoRa can achieve communication distances of up to 15 km in rural areas (Teixeira & Almeida, 2017).

Above the LoRa physical layer lies the LoRaWAN protocol, responsible for organizing the sensor network, defining access mechanisms, addressing, and security, as well as enabling communication among dozens or even hundreds of devices and gateways. LoRaWAN can be described as a protocol structured in star topology, in which end-devices send messages directly to a gateway, which then forwards the packets to the network server. The network server handles validation, filtering, duplicate removal, and the distribution of the decoded content to upper-layer systems (Teixeira & Almeida, 2017).

The gateway (Figure 5) plays an essential role as the intermediary between field sensors and the storage and visualization services; it acts as the bridge between the sensors and the Network Server. After receiving the LoRaWAN messages, the gateway sends the data to the network server via a fixed Ethernet connection, from which the payload is forwarded to systems such as Node-RED for decoding and processing. This integration between layers ensures that the entire data flow of the automated garden is maintained securely and with low maintenance.

Figure 5 – Gateway Kerlink Wirnet iStation 923 (Assanti *et al*, 2024).

The combined adoption of LoRa and LoRaWAN is therefore justified by typical requirements of precision agriculture: low power consumption, long communication range, ease of deployment, and the ability to support multiple sensors distributed across different areas. The data flow follows this structure: sensors transmit their measurements via LoRa to the gateway, which receives these packets and forwards them to the network server, where message validation and availability to the upper layers of the system take place.

In the garden monitoring system, gateways operating in the 915 MHz band, compatible with the LoRaWAN standard used in Brazil, are employed. A gateway is used to receive messages from the meteorological station and send them to the Smart Campus through an Ethernet connection. Its configuration includes IP address settings, port assignments, and OTAA authentication, ensuring secure and stable communication between the end devices and IMT's server.

Once received, the data are forwarded to the network server, which performs essential functions such as message validation, integrity verification, and routing of the payload to application services. The server manages traffic, authenticates devices, and organizes the incoming data.

The data path between the gateway and the network server follows the MQTT (Message Queuing Telemetry Transport) protocol, widely adopted in the IoT ecosystem for its lightweight nature, efficiency, and low overhead. MQTT enables asynchronous, decoupled, and highly scalable transmission of sensor data, allowing multiple services to consume information simultaneously, thus, supporting bidirectional communication. Despite limited resource requirements, the protocol offers a robust and efficient solution for data routing in agricultural IoT systems (Assanti *et al*, 2024).

In this way, the Smart Campus network infrastructure integrates LoRa modules in field devices, dedicated gateways for receiving and retransmitting packets, the network server for managing the network, and the MQTT protocol for distributing the data. This structure ensures continuous communication and allows all subsequent layers of processing, visualization, and storage to operate efficiently and cohesively.

Results and Discussion

The results of this study are based on the analysis of documents from previous projects that make up the infrastructure of IMT's automated garden. This analysis made it possible to understand the functioning of the sensors, embedded devices, LoRaWAN communication, gateway, network server, and visualization tools, revealing how the system operates across its different stages.

Regarding the soil sensors, previous work clearly demonstrates that the capacitive sensor developed at IMT was manufactured, calibrated, and deployed in the field. Reports from the IoT garden document the physical installation of the sensor in the soil, as well as its integration with the LoRa-enabled board used to transmit the collected data. These documents also show that, after each deep-sleep cycle, the boards resume operation and periodically send the readings, confirming the sensor's active participation in the IoT data flow. Together, these records indicate that soil moisture sensing is already consolidated in terms of installation, communication, and operational calibration (Dias *et al*, 2019).

Similarly, the environmental sensors present consistent results. The Khomp meteorological station, adopted in atmospheric monitoring projects at IMT, collects essential variables for tracking the development of wheat crops (Assanti *et al*, 2024). The analyzed reports reinforce that the station provides precise and continuous data, serving as a robust source for characterizing atmospheric conditions and enabling direct correlations between climate behavior and crop responses. Thus, the combination of soil sensors and the meteorological station provide a comprehensive and reliable view of the garden's environmental conditions.

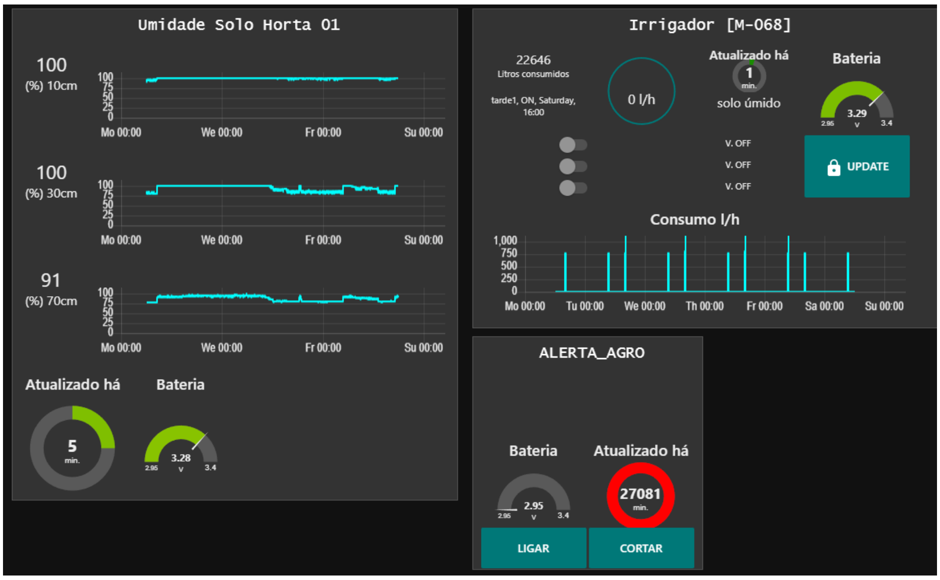
With respect to wireless communication, the results indicate that the field devices successfully transmit data to the gateway using the LoRaWAN protocol operating in the 915 MHz band. Dashboards from the Smart Campus show packets consistently reaching the network server, demonstrating stable communication between sensors, gateway, and network server. This evidence confirms that the LoRaWAN data flow is correctly configured and fully functional.

The processing and visualization stage is also well established, with diagrams and screenshots demonstrating the use of Node-RED to decode the received packets. Figure 6 illustrates operational dashboards in Smart Campus displaying time-series plots of soil moisture sensors. This dashboard can be accessed by: https://smartcampus.maua.br/node/dash/#!/3?socketid=mN_tl8JUsvGM8p1hAAKi.

These platforms enable real-time observation of sensor behavior and allow rapid responses to unexpected changes, while also providing valuable data for more complete diagnostics.

On the other hand, the analysis of the upper layers revealed an important limitation: although the data are received and stored in the network server, there is no long-term database on the system capable of maintaining a historical record. Such a resource will be crucial for future stages, including the development of an Artificial Neural Network (ANN) to predict behaviors and indicate possible actions to be taken. The use of AI could recommend the ideal flow rate for the irrigators, helping conserve water and making the garden more sustainable. For this reason, the creation of a historical storage mechanism, capable of supplying structured data to an ANN, for example, becomes essential.

Figure 6 – Monitoring sensors in Smart Campus Mauá.



Thus, the results clearly show that the automated garden and the Smart Campus infrastructure operate consistently across the sensing, transmission, visualization, and monitoring stages. At the same time, they reveal the absence of a long-term storage layer, which would ideally constitute the next developmental step for the garden projects.

Conclusion

The present work provided an integrated analysis of the IoT architecture used in the automated garden and the IMT Smart Campus, consolidating information from different projects and reports to form a clear and structured understanding of the current system. Based on documentation from various papers on the automated garden, it was verified that both soil sensors and atmospheric sensors operate reliably, with records showing the physical installation of devices, the periodic transmission of data via LoRaWAN, and the correct reception of this information by the gateways and the IMT network server.

Furthermore, the processing and visualization stages were found to be well established, with Node-RED and Grafana dashboards demonstrating the ability to present environmental data in real time. The decoding and display flows of these data indicate that the Smart Campus already possesses an operational chain capable of transforming raw sensor readings into useful information for monitoring and analysis.

On the other hand, although the collected data are forwarded to the network server and made available to dashboards, there is no long-term database capable of storing complete time series of the monitored variables. This limitation restricts historical analysis and the development of decision-support tools based on artificial intelligence, which rely heavily on large volumes of consistent and coherent data.

Thus, as a natural continuation of this study, the development of a dedicated database is proposed to organize the information collected in the Smart Campus, structured to enable future applications of computational methods such as artificial neural networks for predicting agricultural variables.

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