A Monitoring System of Crops and Meteorology Parameters by Bringing Together Physical Sensors and Computer Vision Cameras

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***Abstract*—Mediterranean countries have been facing severe droughts in recent years, leading to water restrictions for consumers and farm owners in the most affected areas. This situation has resulted in increased interest for investing in smart systems to monitor crops, aiming to reduce resource usage and improve crop quality. Existing sensor devices typically measure only a limited selection of physical parameters, such as soil moisture, air temperature, and relative humidity, among others. Furthermore, these devices are usually deployed in various parts of the fields and require different power sources. In this paper, we present a system that gathers data not only from physical sensors but also from cameras to implement computer vision models that enable the monitoring of aspects such as insect presence and plant diseases. These tasks are conceived within the AerOS framework. The system consists of a set of electronic devices designed and developed by ourselves, a heterogeneous wireless network for communication among all devices, and a server to manage the network, store the data, process it, and present it to users. All these components are housed in an anti-vandalism case and powered by a single power source, consisting of a solar panel and a battery. This integrated system expands the features of conventional agriculture monitoring systems.**

Keywords-agriculture; IoT; monitoring; heterogeneous network.

I. INTRODUCTION

The use of sensing devices in agriculture has experienced a significant growth in recent years. It has been fueled by severe droughts and other adverse conditions farmers have suffered, with special dificulties in the Mediterarnean area subject to irrigation water restrictions mandated by local governments. These events have led to the development of multiple Internet of Things (IoT) solutions for agriculture, specifically employing low-cost components [1]. This choice of components is primarly motivated by the limited economic resources that farmers may have. However, this also leads to devices that cannot cope with the weather conditions to which they are exposed for long, or sensors that do not provide reliable readings. Thus, it is necessary to invest in quality materials to ensure the correct performance of sensing devices. Furthermore, these devices are often placed in rural areas without access to the power grid, requiring the provision of alternative sources of power such as batteries and solar panels [2]. However, when a set of devices is deployed, the cost of these materials to power each device increases. Therefore, combining some of these devices to be powered by the same set of solar panel and battery may alleviate the higher cost of quality components.

New technological solutions aimed at solving agricultural challenges are including not only sensor data, but also data from images that get analized [3]. But deploying cameras on fields is not done in a straightforward manner [4]. Powering the camera is one of the limitations that need to be faced. However, there are suitable solutions on the market that include solar panel powering. The main challenge cameras face is communication. Pictures and images require higher bandwidth than the numerical values (telemetry) obtained from sensors, resulting in the need for high-bandwidth connectivity. 5G can provide high connectivity to agricultural systems, but the cost of endowing every device with 5G connectivity would be prohibitive, as each will require a SIM card module and a contract with a service provider for each SIM card. Thus, new approaches would benefit from adapting to the different wireless communication needs of each device.

Heterogeneous wireless networks consist of several wireless technologies that are used within the same wireless network [5]. A set of gateways enable the information encapsulated in messages to change their format according to the standards of the required wireless communication protocols. This allows cellular technologies such as 4G and 5G, long-range low-bandwidth technologies, such as LoRa (Long Range), and medium-range high-bandwidth technologies such as WiFi to provide wireless connectivity to agricultural smart devices. These types of solutions adapt to different transmission needs, facilitating the deployment of telemetry sensor devices with low bandwidth requirements at far distances from the gateway using LoRa, and high-bandwidth demanding cameras to transmit pictures and videos using WiFi or 5G/4G communication. The flexibility heterogeneous wireless networks provide can be leveraged by solutions that required seamless connectivity to manage systems that operate in the edge-cloud continuum. Meta operating systems such as AerOS [6] are vouching for developing distributed solutions with cross-domain resource orchestration for different type of use cases, including agriculture. Therefore, considering the aforementioned needs, in this paper, we present a system for crop and meteorology monitoring in agricultural fields that include physical sensors and cameras collecting images intended for computer vision solutions. It comprises a weather-resistant anti-vandalism encapsulation and provides connectivity to heterogeneous wireless devices using a common power source for all devices.

The remainder of the paper is organized as follows. Section 2 reviews the related work. The methodology is detailed in Section 3. Section 4 discusses the results. Lastly, the conclusion and future works are written in Section 5.

II. RELATED WORK

Monitoring soil moisture and other soil parameters has been the main focus of precision agriculture for many years. As a result, there have been many works dealing with this topic. Park et al. presented a system that monitored soil moisture, atmospheric temperature, and relative humidity using low-cost sensors and open-source software [7]. The system also included a water pump to control irrigation. Experiments were conducted at a soybean cultivation. The results showed that the system was able to maintain soil moisture at 40%. Chen et al. introduced a high-density in-situ solution for soil moisture monitoring using the Narrow-Band Internet of Things (NB-IoT) protocol [8]. Thus, the devices required a SIM card to communicate. They used an RS485 soil moisture sensor and tested battery life. The results from one year of tests showed better spatial-temporal accuracy of soil moisture, lower cost, and better energy consumption performance using NB-IoT than other technologies such as ZigBee [9].

Favorable meteorological conditions are also paramount for good crop development. However, optimal weather is rare. Therefore, many works focus on monitoring weather parameters to adopt solutions to adverse climatic events. Khan et al. implemented a low-cost solution for weather monitoring [10]. It was comprised of an Arduino Mega, operating as a control system, and sensors for wind speed, wind direction, rain, solar irradiance, and CO2 concentration monitoring. The gathered data was then transmitted to the cloud. Marwa et al. proposed a system that monitored temperature, humidity, and rain in real time using the S-THB-M008 and S-RGB-M002 sensors [11]. Data were sent to a cloud server that included a MySQL database. Their climatic monitoring system was tested in Tunisia for one year. The results revealed the correct performance of the system. Moreover, Rajapaksha et al. designed a handheld weather station for monitoring barometric pressure, air temperature, air humidity, soil moisture, and carbon monoxide [12]. The device uses an ATMEGA 2560 Microcontroller, a power unit with removable and rechargable batteries, an LCD display, a sensor panel, local storage, a micro-USB charging port, and a common port to connect external sensors. The device also allowed for SMS alerts when temperature thresholds were exceeded.

As soil and meteorological aspects are both indispensable in precision agriculture systems, some works have included sensors intended for these two aspects in their solutions. Placidi et al. proposed a Wireless Sensor Network (WSN) for low-cost soil water content monitoring [13]. Their solution included a photoresistor, a temperature sensor, a low-power microcontroller, and a solenoid valve. Tests were performed in Silty Loam and Loamy Sand, with a non-constant sensitivity for the low-cost volumetric water content sensors. Furthermore, the parameters of the non-linear fitting equation were optimized to correlate the analog voltage output to the reference values for the volumetric water content. Singh et al. designed an irrigation system for precision agriculture in urban environments [14]. The system was based on soil and weather conditions including soil moisture, air temperature, relative humidity, wind speed, and wind direction. The system was tested for two months and the data was displayed using the Thingspeak platform.

Lastly, a growing number of works have begun proposing the use of heterogeneous wireless networks in agriculture. Sanjeevi et al. introduced a scalable WSN using devices comprised of air temperature, air humidity, air pressure, and pH sensors, as well as an Arduino board [15]. Tests were performed to determine the performance of a heterogeneous network with WiMax, WiFi, and LTE wireless technologies, showing that each technology can be advantageous depending on the network requirements of the deployment. Furthermore, Jose Agustín Rodríguez-Mejía et al. proposed a heterogeneous WSN for precision agriculture that combined LoRa, Bluetooth Low Energy, Zigbee, and WiFi using low-cost Heltec Wireless Stick V3 devices [16]. The selection of the wireless technology is based on the content to be transmitted and the Received Signal Strength Indicator (RSSI). The tests concluded that their solution was efficient and reliable.

The solution presented in this paper includes soil and weather monitoring as well as a camera and the use of a heterogeneous communication network to transmit the data from the different devices to the servers. This way, we combine the key aspects necessary for up-to-date precision agriculture solutions, and provide a reliable source of data and images to feed Artificial Intelligence models.

III. METHODOLOGY

This section describes the implementation of the hardware of the system and the software development.

The system consists of a base station that houses all the sensing devices, batteries, and the solar panel (see Figure 1.) It features an anti-vandalism enclosure with weather-proof materials and the solar panel on top, shielding the inside. Inside, the Suspended Particulate Matter (SPM) sensor, temperature sensor, humidity sensor, wind speed sensor, solar irradiance sensor, soil moisture sensor, and batteries are placed on the different shelves of the housing. The gateway is installed vertically hanging on one of the walls of the enclosure. The camera is placed on the outside of the enclosure to get a full vision. Furthermore, the camera includes its own solar panel for power supply that is also placed on the outside of the enclosure. The additional powering system was engineered to guarantee the operation of the gateway and sensing devices during nighttime and cloudy days.

A. Hardware implementation

The sensors included in the base station are distributed into several sensing devices. Namely, a meteorology and soil

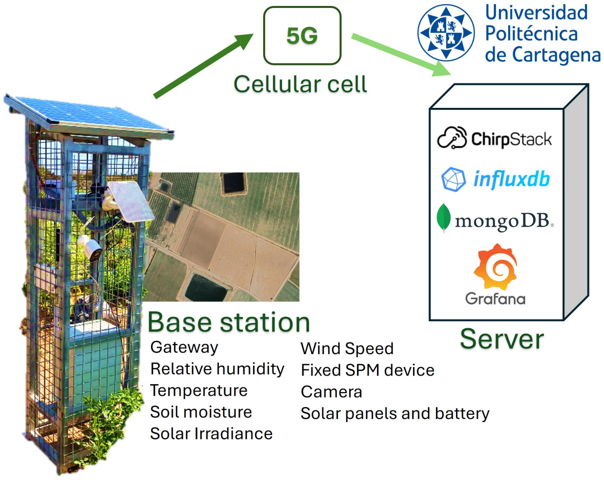

Figure 1. Architecture of the system.

Figure 2. System deployed in anti-vandalism enclosure.

monitoring device that includes the air temperature, humidity, wind speed, solar irradiance, and soil moisture sensors. It is important to highlight that the wind sensor requires a higher voltage power supply than the other sensors. Another device with a case that allows air flow through it includes the SPM sensor. Lastly, the camera is deployed on its own.

Figure 2 shows a detailed view of the inside and outside of the enclosure with the different sensing devices. The meteorology and soil monitoring device is composed of the following elements. The Arduino board itself provides a standard 5V power output, which is shared to power all sensors. However, the wind sensor requires a Direct Current (DC) amplifier to step up the voltage from 5 to 12 volts to ensure its proper functioning. Another consideration is the data output of each sensor. Data obtained from these sensors include parameters such as environmental and soil humidity, temperature, wind speed, radiation, and the battery charge level of the device. To access the sampling values of soil moisture, radiation, and battery voltage, the analog pins on the Arduino board are used. Other sensors, such as the temperature and environmental humidity sensor, operate under the Inter-Integrated Circuit (I2C) communication protocol. Therefore, the SDA and SCL pins were used to facilitate the connection, as their output is not directly connected to an analog pin. Lastly, the wind sensor, poses a particular challenge due to the fact that the Arduino board has an internal Analog-to-Digital Converter (ADC) operating in a 0 to 3.3 volts range, while the wind sensor's proportional output operates in a wider range of 0 to 5 volts. To address this mismatch, we have employed an external analog-to-digital converter capable of processing these inputs and generating a compatible output with the I2C protocol. This converter is powered by the Arduino board and uses a pin of the ADC to send data to the board.

The SPM device is made of a suspended particle sensor with a 0.35 to 40 µm particle range and a data aquisition frequency ranging from 1 to 30 seconds [17]. The SPM sensor is connected to the Arduino board through the Serial Peripheral Interface (SPI) interface. The Arduino board has LoRa connectivity and uses this wireless technology to transmit data to the gateway.

The RAK gateway has LoRa, WiFi, and 5G connectivity. The SPM device and the meteorology and soil monitoring device transmit their data through LoRa to the gateway. Conversely, the camera, requiring higher bandwidth, sends images and video to the gateway through WiFi. The gateway is equipped with a SIM card and uses 5G/4G to send the data to the cellular cell of the service provider. If there is no 5G connectivity in the area, other cellular technologies could be used as long as video traffic can be transmitted.

Regarding the power supply for the devices, two distinct sources are used: a solar panel and a battery. The Arduino boards, the gateway, and the battery are connected through a charge controller. While the solar panel generates power, it ensures that the battery is charged and the Arduino boards and gateway are powered. However, when the solar panel does not provide enough power, the battery takes over as the power source for the system until the solar panel starts generating power again or until the battery is depleted. The battery can last up to 5 days in adverse weather conditions with no sunlight. This is the standard for solar panel infrastructures in the area.

B. *Server implementation*

On the server side, the managmenet and processing of the information generated by the sensors to obtain a meaningful and easily interpretable visual representation of the data is programmed. This step is crucial, as it allows better understanding the performance and behavior of the device under different conditions.

The server at the UPCT receives all the data using the LoRaWAN communication protocol. The network server is the Chirp-Stack open-source LoRaWAN server [18]. When the network server receives the messages from the field devices, the acquired data is stored in a database. Due to the different characteristics of the data, including numerical values and images, two types of databases where used. InfluxDB was the choice for storing and managing time series data [19]. The decision to use InfluxDB is made to its ability to handle large volumes of real-time data and its efficient structure for time series storage, which is well suited for the numerical data gathered from the sensors. Conversely, MongoDB was used to store images, which could not be stored using InfluxDB [20].

Once the databases were configured and running, Grafana [21] was integrated into our system. Grafana allows interactive dashboards with graphs, tables, and other visual elements, making it easier to interpret and analyze the data stored in InfluxDB. Furthermore, Grafana can also embed images and videos retrieved form MongoDB. To achieve the final graphical representation, the necessary queries were made to visualize the extracted data as effectively as possible. Line graphs were chosen to represent the evolution of humidity levels, temperature, wind speed, solar radiation, and soil moisture over time. These line graphs help in identifying trends, seasonal patterns, and significant changes in the sensor data. Additionally, the battery status of the device was presented using pie charts. These charts provide a quick and clear view of the battery charge percentage, which is crucial for evaluating the device's autonomy and energy efficiency. Nevertheless, while line and pie charts were used for our current purposes, Grafana offers a wide range of visualization options. Dashboards can be customized and adapted according to the user specific needs and preferences as well as the requirements of each project.

IV. RESULTS

In this section, we present the results from the base station deployed on the fields. These results show some relevant observations from different time periods.

Figure 3 shows the overview of the Grafana dashboard for our system. The user interface was designed so that one can easily view the current values from the sensors. This includes different sizes of particulate matter (PM01, PM2.5, and PM10), wind, solar radiation, humidity, soil moisture, and temperature. Furthermore, the map with the location of the base station and the real-time video from the camera is also displayed on the dashboard.

PM01 2.68 µg/m^3

PM2.5 7.71 µg/m^3

PM10 20.88 µg/m^3

Wind 0.18 m/s

PPFD 1225.81 PPFD

Humidity 48.57 %

Soil moisture 47.00 %

Temperature 23.2 °C

Figure 3. Grafana dashboard of the system.

The graphs plotting the time-series data for each sensor are also available in another Grafana dashboard. Figure 4 illustrates an extract of temperature data for the variation in temperature experienced at different hours of the day. As it can be seen, nights and early mornings are always the periods with the lowest temperatures, whereas it rises in peak sunlight hours.

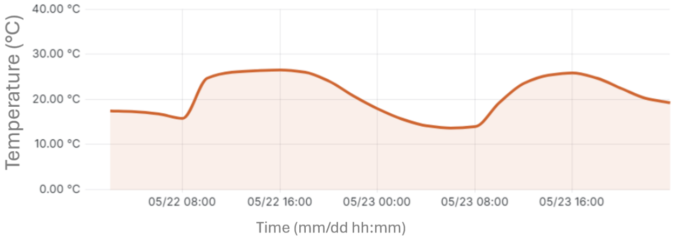

Figure 4. Temperature readings.

Humidity readings are represented in Figure 5. The graph indicates that humidity rises at nightime and decresaes through the day up to mid-afternoon. This can vary depending on the time of year.

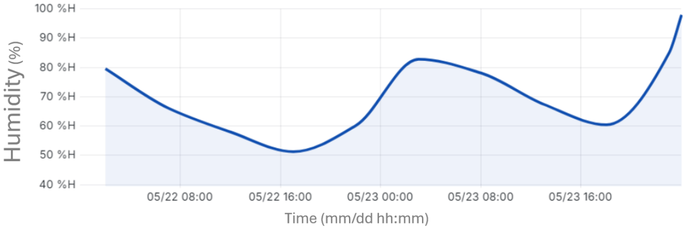

Figure 5. Humidity readings.

Regarding radiation, it can be observed that it is much higher during sunlight hours. The small variations observed in Figure 6 are due to the clouds creating shadows, as they reduce the brightness and radiation captured by the sensor. Then, light is reduced at night. The fields under monitoring are close to a small town and some light might be appreciated at night.

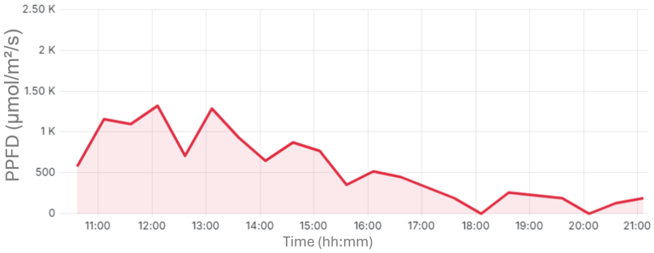

Figure 6. Solar radiation expressed in Photosynthetic Photon Flux Density (PPFD).

As for the wind sensor, the readings in Figure 7 show that wind is strongest in the afternoon on the field. According to the Beaufort scale, this would correspond to grade 3, which indicates a gentle breeze. It can also be seen that wind readings are more abrupt than other parameters.

Figure 8 depicts the readings for the suspended particulate matter. The particles with a bigger size such as PM10 have higher concentrations. Conversely, the particles with lower

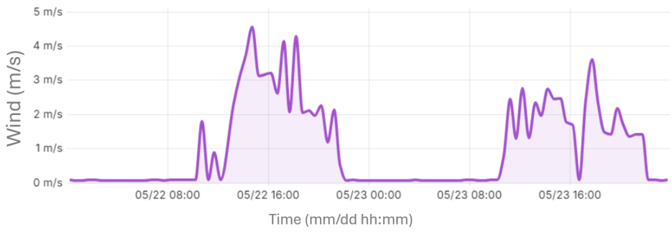

Figure 7. Wind speed readings.

sizes, such as PM2.5 and PM1 have smaller concentrations. Particle concentrations on fields can increase due to several reasons. Strong winds, dust storms, or agricultural machinery working can contribute to higher outcomes.

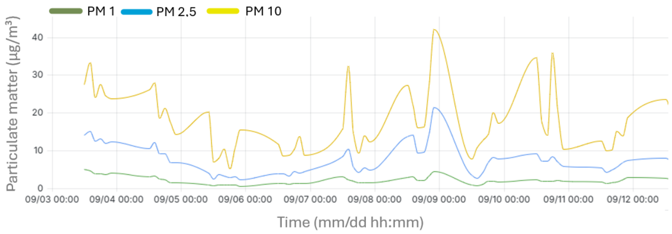

Figure 8. SPM readings.

The readings regarding soil moisture are represented in Figure 9. It can be observed that soil moisture was decreasing during the night but it increases again after the drip irrigation system is turned on in the morning.

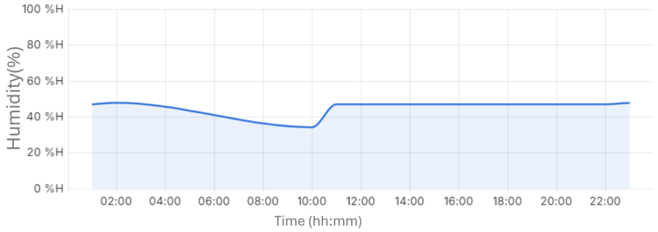

Figure 9. Soil moisture readings.

Lastly, Figure 10 shows the device's battery level and the incoming voltage. These values help users to monitor potential battery issues during periods of low sunlight.

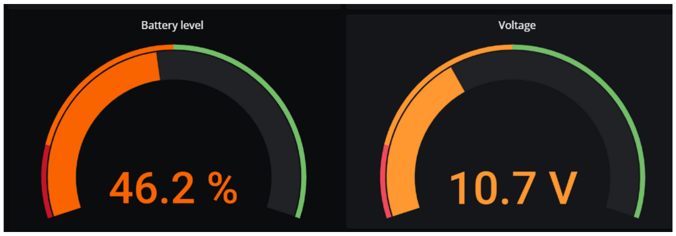

Figure 10. Baterry readings.

The images gathered by the camera of our solution are being used for developing computer vision tools for agriculture. The images collected from the fields can be used to feed Artificial Intelligence (AI) engines and detect different aspects from plants, including plant diseases (see Figure 11) or pests [3].

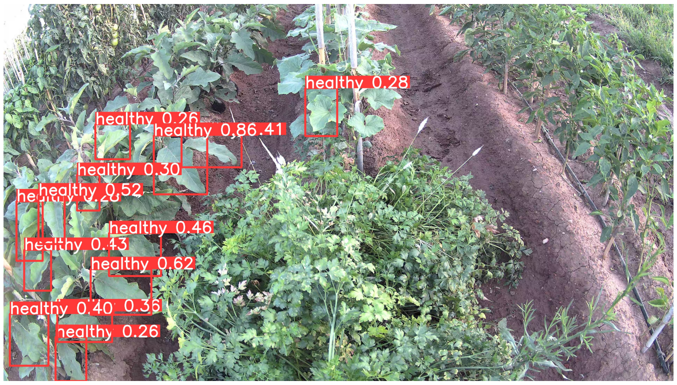

Figure 11. Output from computer vision plant disease detection feature.

The output from the sensors and computer vision features presented in this section can help farmers improve their irrigation schedules and determine if plants are being affected by a disease, alerting the farmers in case the results are positive. Nonetheless, there are no anomalies in the results presented in this paper.

V. CONCLUSION AND FUTURE WORK

The adverse climatic conditions faced by Mediterranean countries have led to the need to implement solutions for monitoring meteorology and soil parameters that affect the crops of these areas. This type of system helps reduce water consumption for irrigation and simultaneously optimize crop growth and production. However, existing approaches typically include only a limited selection of parameters. This paper presents a system for crop and metheorology monitoring intended for precision agriculture. It includes a camera to perform computer vision, increasing the number of features that can be provided to the users. The devices were placed in a custom-made anti-vandalism enclosure. Moreover, a heterogeneous wireless network was deployed to ensure all types of data, with their respective bandwidth requirements, could be transmitted. It included WiFi, LoRa, and 5G connectivity. Finally, the proposed system is powered by renewable energy, so it can be placed anywhere in the field, providing positioning independence.

For future work, this system will be used as part of an agrivoltaic solution to monitor meteorologic and soil parameters, as well as serving as a gateway for other devices deployed to monitor other parts of the fields or greenhouses, and the energy produced by the solar panels of the agrivoltaic system. Furthermore, more computer vision models will be developed to increase the available features and/or detecting options.

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