An Innovative Smart and Sustainable Low-cost Irrigation System for Smallholder Farmers' Communities

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***Abstract*—The agricultural sector has several difficulties today in ensuring the safety of the food supply. However, the Internet of Things (IoT) has recently come to light as a promising remedy with several cutting-edge uses in smart farming. The study presents the design and development of a low-cost and full-featured fog-IoT/AI system. The system has been created using open-source platforms that monitor agro-field data in real-time. However, the smallholder community is hesitant to adopt technology-based solutions. The PRIMA INTEL-IRRIS project aims to make digital and smart agricultural technologies more appealing and available to these communities by advancing the idea of intelligent irrigation "in-the-box" This study explains a low-cost fog-IoT/AI system of version 1.0 fully targeted toward smallholder farmer communities (SFCs) and how it may provide the notion of intelligent irrigation "in-the-box" concept.**

***Index Terms*—IoT, Low-cost, fog-AI, Smart farming, Irrigation.**

I. INTRODUCTION

The food and agriculture organization (FAO) claims that small-scale farming significantly contributes to rural economies and food security. On the other hand, smallholders usually, deal with a range of restrictions that reduce their ability to produce profitably and advance the economy [1]. However, smallholder farmer communities (SFCs) have not benefited from adopting solutions to increase irrigation efficiency because of the high starting costs and the high skill levels needed to understand the technology. Significant limitations restrict SFCs productivity and profit potential. As a result of a variety of crucial issues, including a lack of agricultural expertise, financial resources, climate change, and market access to address these challenges, we propose in this research a low-cost (260$) smart farming system for monitoring and prediction that will assist SFCs in forecasting future data in order to compute their water demands and properly scheduled irrigation. In terms of accuracy and error reduction, the system outperforms.

In this context, the goal of the PRIMA INTEL-IRRIS project (http://intelirris.eu/) is to increase the visibility and accessibility of digital and smart agricultural technologies among small and medium-sized farms. To meet the needs of this community, the suggested solutions must be economical, easy to implement in the field, and, most importantly, adaptable to current agricultural techniques [2],[3]. As a result, by inventing a low-cost, smart irrigation control system, INTEL-IRRIS hopes to transform the view that SFCs have of what was formerly highly expensive technology. INTEL-IRRIS also hopes that by using the "intelligent irrigation in a box" idea, they can make smart irrigation systems as easy to set up and use as home appliances, with a small investment compared to how much money they make. This paper proposes a low-cost, sustainable irrigation system that helps smallholder farmers manage irrigation more efficiently by providing a low-cost, open-source, autonomous, and easy-to-use smart irrigation control system that benefits from IoT capabilities, as depicted in Figure 1. We will implement the "Intelligent Irrigation in a Box" idea by presenting a sensor/control/actuator-based "plug-and-sense" system using significant technological advances from the last few years, including IoT, artificial intelligence (AI), and decision support system (DSS). This technology may be linked with existing irrigation infrastructure [5], allowing It is to be controlled according to smallholders' customs. Using sensor technologies, the provided platform collects critical physical phenomena such as soil moisture, air temperature, air humidity, water level, water velocity, and light intensity by

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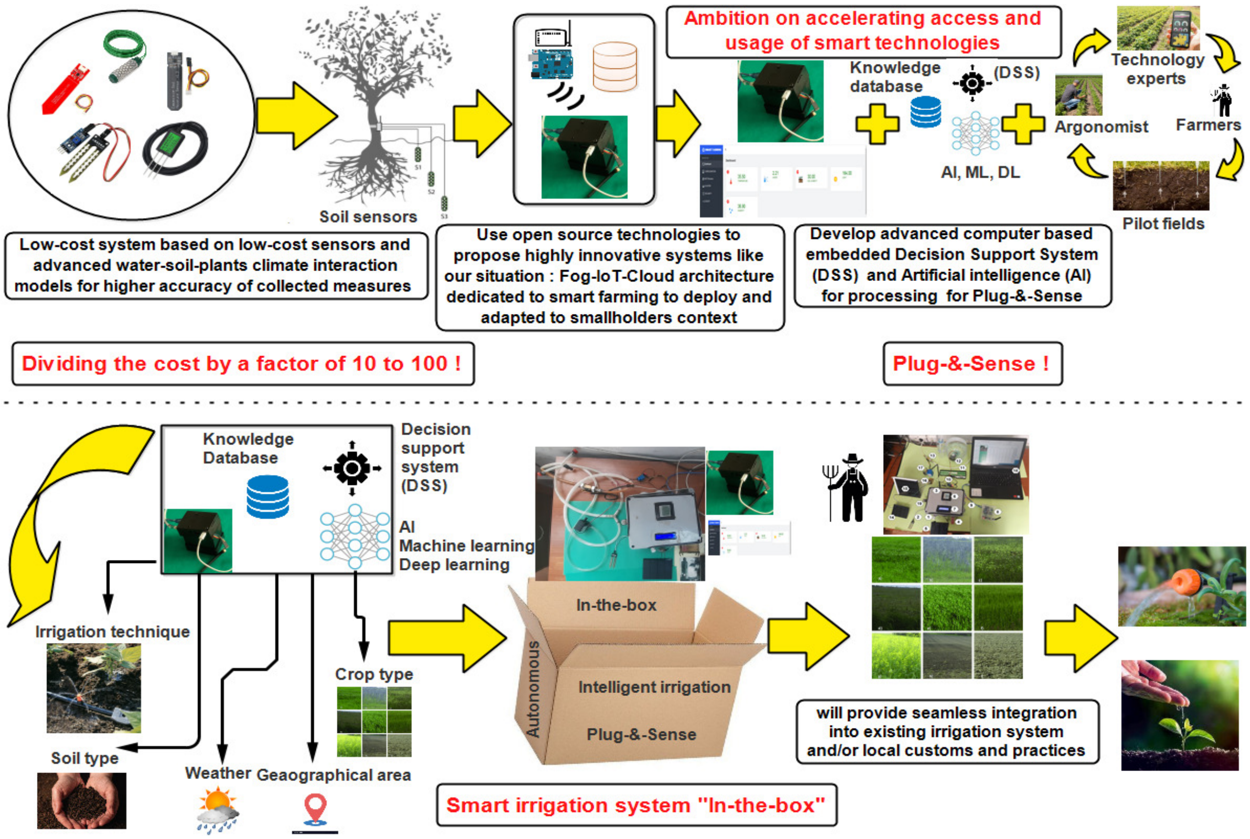

Fig. 1. Overview of influence factors that have an impact on any selected method of irrigation in precision agriculture.

a DL methodology. Consideration is given to a novel Fog-IoT-Cloud platform for storing, analyzing, and using vast volumes of acquired data to assist SFCs in managing the irrigation mechanism efficiently.

Our main contributions are summarized as follows:
(i) The design and development of a low-cost fog-IoT/AI system of version 1.0 fully targeted toward smallholder farmer communities (SFCs).
(ii) Predicting the soil moisture for a particular plot in the next few days based on field sensory data and weather forecast data using Long-Term Memory Recurrent Network (LSTM) based models and Grid Recurrent Unit (GRU) based models.

The rest of the paper is structured as follows: Section II will expand on how intelligent technologies may be offered and implemented effectively for SFCs by detailing the INTEL-IRRIS aims and strategy and the critical technical components of our proposed operational architecture. The INTEL-IRRIS fog-IoT/AI system, at the heart of the architectural design discussed in this paper, will then be presented in Section III. Finally, conclusions and future trends are given in Section IV.

II. SUPPLYING SMALLHOLDER FARMERS WITH SMART TECHNOLOGY

A. A summary of the INTEL-IRRIS and PNR projects

As stated earlier, INTEL-IRRIS [6] aims to make digital and intelligent agricultural technology more appealing and accessible to small and medium-sized farms. However, a compromise will be made to accomplish the primary aim: to create a low-cost irrigation system that SFCs can implement out of the box. The soil moisture sensor component follows a basic, resilient, cost-effective design that has been substantially influenced by several do-it-yourself projects and prior contributions [6,7,8].

Unlike low-cost sensors that often offer unreliable data, INTEL-IRRIS will significantly improve the quality of collected data with : (i) improved calibration of various sensors; (ii) the calculation of the needed amount of water based on the farm's soil texture and crop coefficient; and (iii) prediction of environmental factors based on field sensory data using DL.

B. Smart and Sustainable Irrigation System

The smart farming system architecture depicted in Fig. 2 collects, transfers, and processes physical parameters obtained from small-scale farming (soil moisture, air temperature, air humidity, water level, water flows, the intensity of light, combustible gas, etc.) in order to improve irrigation efficiency by deploying a low-cost, open, autonomous irrigation control system based on IoT and AI techniques. [13]. The irrigation scheduling algorithm determines the amount of water required to maintain maximum production potential without wasting water (i) for a particular crop, (ii) at a specified time, and (iii) for a specific soil type. The following section summarizes the proposed platform's details.

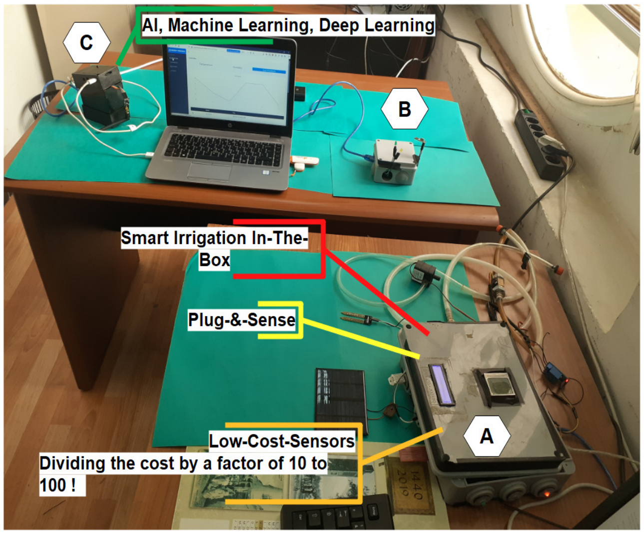

Fig. 2. Global View of our proposed operational architecture.

C. Hardware Architecture

As illustrated in Fig. 2, the network component of our platform is supplied via multi-hop communication between box A (the sensor layer) and box B (the gateway node) up to box C (the fog layer). Finally, a virtual machine (VM) is created on the Azure cloud to deploy multiple anomaly detection and prediction models. In addition to using NRF24L01 modules for wireless communication and Arduino boards as microcontrollers, we also intended to use Raspberry Pi 3 B+ boards as a fog layer.

D. Software Architecture

Using open-source development tools, we created a software architecture to reduce bandwidth, latency, cost, load balancing, and scalability, as shown in Fig. 3. Using the Message Queuing Telemetry Transport (MQTT) protocol, communication between the gateway and server is established. The TCP transport layer protocol ensures dependable data transmission (COAP uses UDP). Because of this, it is encrypted with SSL, supports quality of service (the QoS parameter 2: requires messages to be delivered exactly once), and has a much shorter message header than HTTP.

E. Box A: Sensors Layer

Box A, which depicts the field data gathering tool, falls short of the total of 140$. An ATmega328 microprocessor reads the output from these sensors. For around two dollars, it may be used to construct a cheap design strategy for the Arduino. As seen in Fig. 4, this box's sensor layer devices are designed to collect data from smallholder farmers and transmit it using the NRF24L01 radio module, which is available for roughly 5 dollars and enables the supply of a radio communication layer with an SPI interface. The farmer can examine the data and keep an eye on the crops in real-time since data may be kept in a private database or in the cloud to construct a dataset. Fig. 4 provides a comprehensive description of the box's sensors. Then, we set the NRF24L01 module to write mode and supply the destination address; we read the sensor values using the analogRead () function on the pin data; if the data changes often, we normalize the collected data. Following that, we transmit six (6) packets in a row, one after the other. These packets are necessary to detect a fog layer anomaly; otherwise, we would send a packet every hour. The Fog level evaluation must be performed before delivering a packet with this module to establish a baseline for identifying aberrant behavior. The DHT22 sensor, for example, can measure temperatures ranging from -40 to +80°C. To prevent unneeded alarms from being raised and to adjust the frequency of sensing data collection to get clean data, this unclean data must also be adjusted following the behavior of each sensor and considering past data.

F. Box B: Gateway Node

Box B transmits the packets to the fog layer, but it does not get the full 32$. In listening mode, we set up the gateway node by supplying the node address from whence the packets come, the channel number (122), and the data structure; if the data is received, it changes to sending mode, where we provide the address of the next node.

G. Box C: Fog Layer

Fog computing facilitates the operation of computation, storage, and networking services between end devices and cloud computing. Box C permits data to be transmitted to the internet network, but not to a total of 90$. We picked a Raspberry Pi 3 B+ type board since it has adequate hardware resources for processing and is based on the Linux kernel, making it compatible with most languages and AI libraries. It needs a 5V power supply, an external Wi-Fi 802.11 card, and an Ethernet connector to connect to the internet. We are using Python to create a concurrent TCP server (one thread per request), and we are starting by loading the prediction models from disk into the main memory (the kind of "*. tflite" files after the conversion to Tensorflow Lite). When a request comes, a thread handles the receiving and preprocessing, resulting in the prediction. If we are looking for anomalies, we must compare the model outputs to an error threshold and provide the answer. On-demand, we can also utilize the service to adjust the error levels of the various models. The server regularly delivers messages that include information such as the node's IP address, available resources (RAM, CPU), and network latency. NodeJS listens on the serial port "/dev/tty0" at 115200 baud. We extract the measurements whenever new data is written to the port (separated by commas). We verify that all of the sensors are operational. This information is saved in the MySQL database for the time being. Finally, we produce a structured package including the latest six readings of each sensor, which must correlate to the detection model anomaly entries. Then we transmit the latter to the Python-implemented service, which includes the various models; after receiving the answer, we check for anomalies. An HTTP server configured using the "Express" module and listening on port 7000 sends

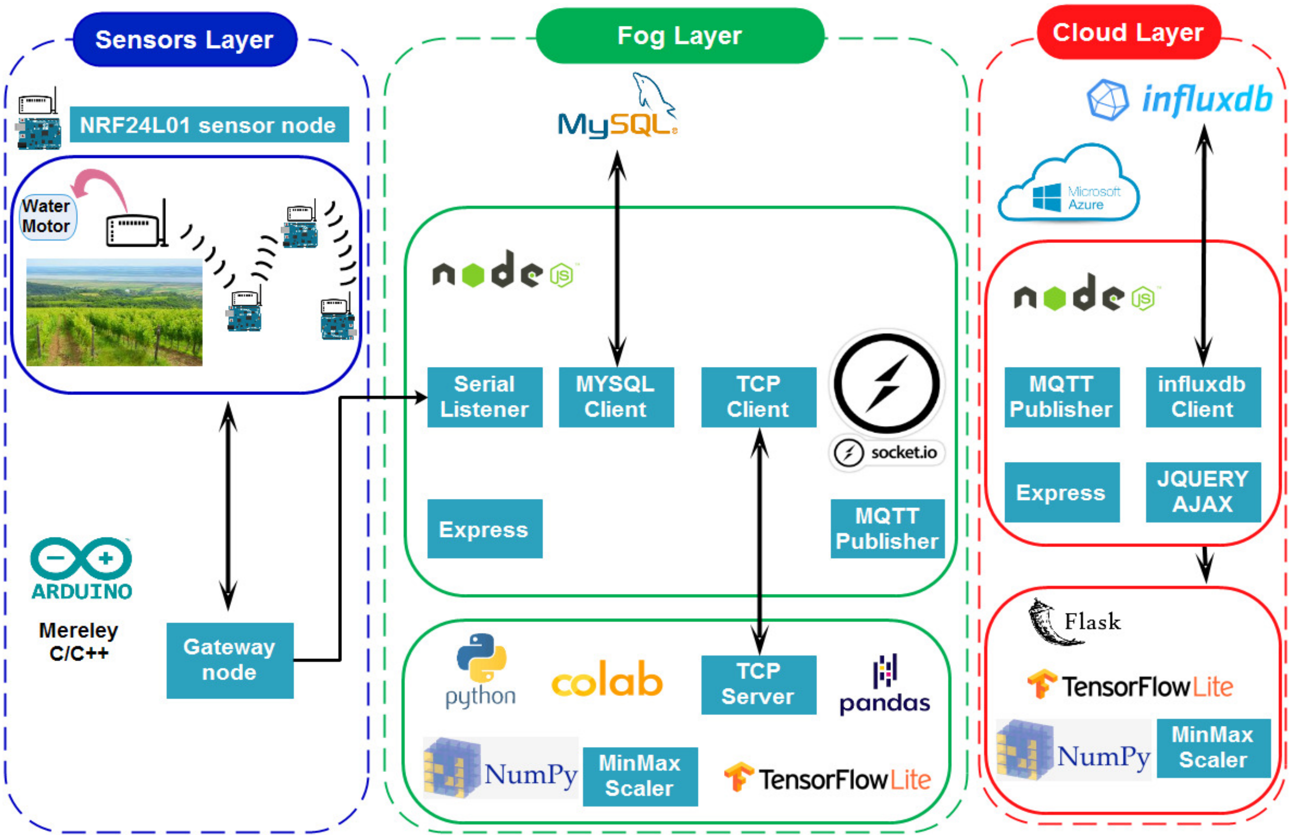

Fig. 3. Global View of our software architectural proposal

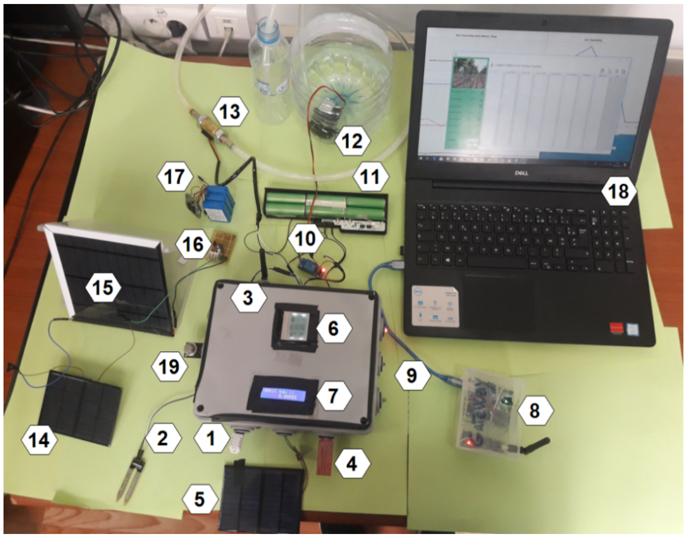

Fig. 4. Global View of Box A. [Legends 1: DHT22 Sensor (8$), 2: Soil moisture Sensor (5$), 3: NRF24L01 module with adapter (9$), 4: Water level Sensor, 5: Light sensor (2$),, 6: LCD display nokia (8$), 7: LCD display I2C (9$), 8: Gateway node (32$), 9: LEDs notification (2$), 10: Relay Switch (5$), 11: Power supply 12 V (12$),, 12: Water pump (10$), 13: Water flow sensor (9$), 14: Solar panel ZW85X115-12 (2$), 15: Solar panel 6V (2$),, 16: amplifier (5$),, 17: Power supply 9 V (10$),, 18: PC] The mega Arduino card (38$), and NRF module are in the Box.

the application pages to the browser. The route to each page is specified, and communication occurs via the ”WebSocket” protocol. Every hour, a temporal event is triggered, which transmits the last received packet if none has come, allowing us to forecast it. The integrated Wi-Fi card is employed as an access point for configuration and adjusting the thresholds of anomaly detection models (leaving a means to reach the local network). Finally, data visualization from the gateway is required to assist the developer during maintenance. We investigated adding slave nodes that handle resource-intensive processing to enhance computing power and load balancing. The cluster interacts using a wireless network created by the Wi-Fi card included in the Raspberry Pi 3 B+ cards.

H. Cloud Layer

We suggest using cloud services to store significant volumes of data generated by sensors in order to guarantee the accessibility and availability of our platform everywhere and at any time. Furthermore, we utilize them to anticipate future meters, ensuring scalability and more resources when our platform is overloaded (elasticity). A free student offer was provided to us, and we will utilize it to create a VM with a public IP address that we can access via the remote desktop protocol (RDP). As seen in Fig. 5, Influx DB offers a limited free cloud service, so setting up a user’s dashboard for data analysis and monitoring is straightforward.

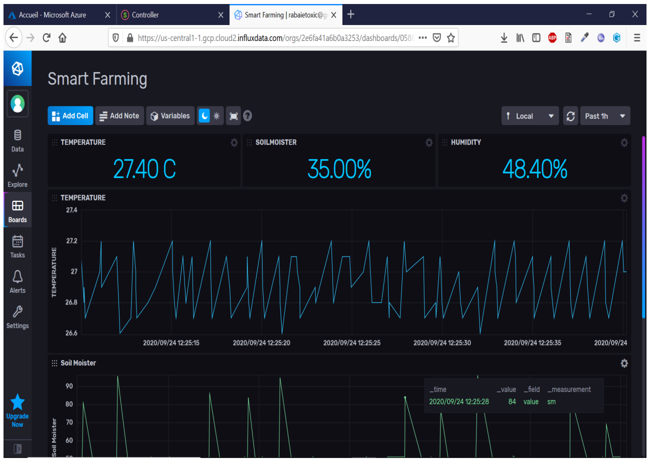

Fig. 5. Monitoring and analysis of data on the cloud service.

III. THE FOG-IOT/AI SYSTEM OF VERSION 1.0

A NodeJS-based web service collects and processes data for the SFCs before regularly sending them to the cloud architecture. The dashboard is fully integrated and provides general device and sensor administration, a straightforward interface, and a basic data visualization module. Figure 6 shows the dashboard and the web interface that lets SFCs use a smartphone to interact with the dashboard. Box C (Fog layer) enables offline AI training. It is an environment in which developers and consumers may perform artificial intelligence and machine learning operations. As mentioned in our previous work [1, 11] findings, four datasets are employed in this study, each with complementary and distinctive properties relevant for creating and evaluating LSTM and GRU techniques. Our goal was to develop a machine learning model that could use historical data to forecast the soil moisture for a specific plot over the next several days. One of the challenges was designing robust algorithms that can be trained with incomplete data (for example, missing data points) and unclean data (for example, many outliers). The resulting models will help SFCs plan their irrigation schedules and predict water demands. The GRU-based model beats the LSTM-based models by a small margin. Even after many moves ahead, the models developed are correct. Following that, box C is used to run the whole soil moisture prediction model as a standard model, as seen in Figs. 7 and 8. To avoid the overfitting issue, we used a callback technique to use the model that performed better on the validation set. Table 1 demonstrates that the GRU model is more accurate than LSTM and that error rises with the number of steps, furthering the model's accuracy.

IV. CONCLUSIONS AND FUTURE TRENDS

This article introduced the INTEL-IRRIS low-cost and fog-IoT/AI system of version 1.0 developed by University of Oran1 aimed for SFCs. We presented an IoT-based smart farming system to anticipate environmental conditions in order to improve irrigation choices, based on a novel Fog-IoT-Cloud platform using DL methods and open-source technologies for

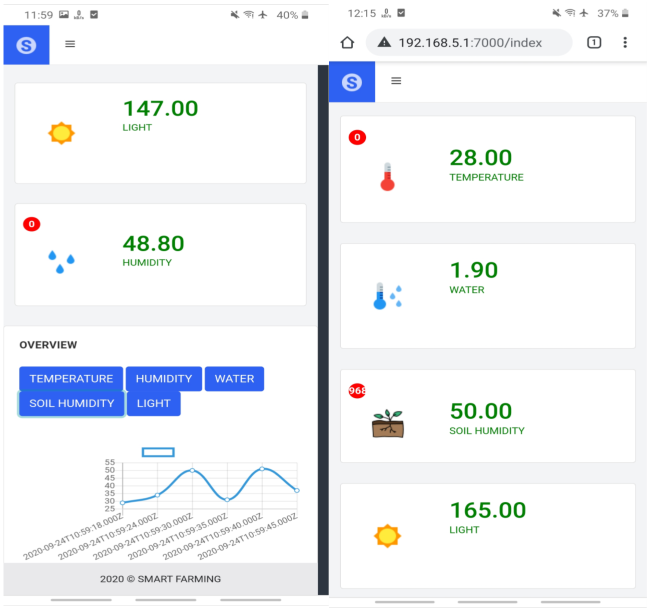

Fig. 6. The fog-IOT/AI system of version 1.0 dashboard with generic sensor data visualization.

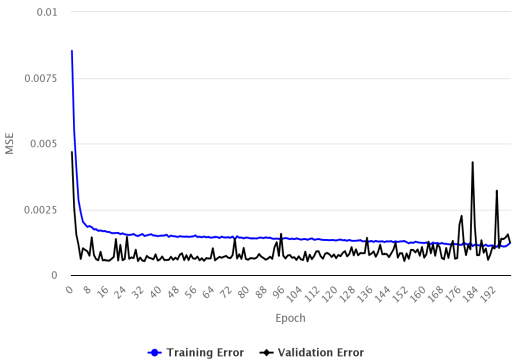

Fig. 7. Plot of Model Loss on Training and Validation of Soil-Moisture using LSTM-based models (average per day).

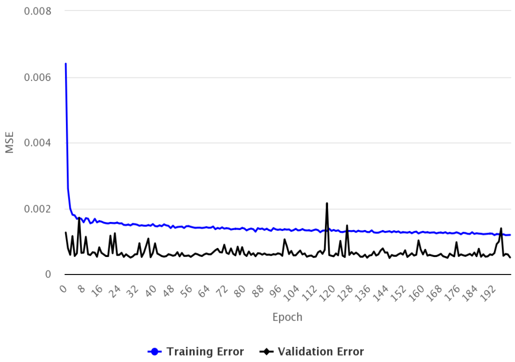

Fig. 8. Plot of Model Loss on Training and Validation of Soil-Moisture using GRU-based models (average per day).

TABLE I
RESULTS OF THE PREDICTION MODEL OF THE SOIL-MOISTURE (DAY)

Models	GRU			LSTM		
Step forward\Error	MSE	RMS	MAE	MSE	RMS	MAE
1	9.899e-05	0.00994	0.00890	3.9833e-05	0.00631	0.00304
2	0.00064	0.0253	0.0247	0.00011	0.01054	0.00634
3	0.001475	0.0384	0.03723	0.000199	0.01413	0.01017
4	0.0025	0.0502	0.0477	0.000295	0.01718	0.013828
5	0.00426	0.0652	0.0625	0.00041	0.02029	0.017698
6	0.00698	0.0835	0.08127	0.00054	0.02336	0.02128

more definitive results. This platform will need more research that takes into consideration several perspectives:

1) To enhance the precision of the acquired data, we will increase the accuracy of low-cost sensors using autonomous and remotely managed techniques for improved calibration of the different sensors. As a consequence, our water-soil-plant-climate interaction models will prescribe more correct measures.
2) Design and implementation of precision PA-based Low Power Wide Area Networks (LPWAN) technologies such as Lora and Sigfox. These approaches are designed to conserve energy, like the Long Range Wide Area Network (LoRaWAN), for enhancing the irrigation efficiency of large-holder farmers.
3) Offer the ”out-of-the-box” function, meaning that the control component that recommends irrigation is integrated into the IoT gateway and as a result, does not need an internet connection, as implemented by WAZIUP partner [14].
4) Water quality monitoring for smart agricultural water supply Finally, we want to use LSTM and Holt winters to build a novel technique to detecting abnormalities in our fog-IoT smart farming platform.
5) Traditional machine learning systems need centralized data gathering and processing, which is becoming more unfeasible due to efficiency issues and rising data privacy concerns. Federated learning has been a popular study subject in smart agriculture due to these qualities.

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