A digital twin for smart farming

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***Abstract*—This paper presents a digital twin in the agriculture domain by leveraging the technologies developed by Sensing Change and the Smart Water Management Platform projects. The Sensing Change project developed a soil probe whereas the SWAMP project is currently developing an Internet of Things platform for water management in farms. This paper leverages the technologies developed by those projects by building an initial digital environment to create a cyber-physical-system (CPS) so farmers can better understand the state of their farms regarding the use of resources and equipment. We conclude that our system can gather data from the soil probe and display its information in a dashboard which enables for further deployment of more soil probes and other monitoring and controlling devices to create a fully operating digital twin.**

***Index Terms*—Internet of things, agriculture, smart farming, digital twin, digital smart farming.**

I. Introduction

Agriculture plays a key role in the development of many countries and is critical in the achievement of the Sustainable Development Goal 2 of "Zero Hunger" [1]. According to the Food and Agriculture Organization (FAO), agricultural output needs to increase by 40% from 2012 to 2050 to meet the requirement of an estimated population of 10 billion people by 2050 [2]. One approach to improve production includes the innovative use of technologies such as apps, drones, and machinery alongside social, organizational and institutional transformations.

The use of fresh water in agriculture is responsible for 70% of the total amount of fresh water used in the world [3]. This presents a compelling case for the development of technologies such as the internet of things (IoT) to lessen the amount of water used in agriculture as well as to raise the amount of food produced on farms.

Most of the available fresh water on Earth is used by irrigation systems and 40% of fresh water used in developing countries were lost by leakage and overirrigation [4]. Factors as climate change and world population expansion became a global challenge for fresh water availability, mainly in rainfall scarcity regions [5] which demand another perspective over irrigation systems and its optimization to ensure food security to the growing population [6]. Suitable irrigation, controlled by field sensors, plays an important role in agriculture because underirrigation or overirrigation causes crop yield to decrease [7]. In this context, artificial intelligence (AI) can optimize the farming process through plant conditions data collected and compute it with high performance and low cost [8], keeping crop yield at normal criteria and decreasing water waste, consequently improving the accessibility of potable water [6].

To leverage this global concern, a digital twin model based on the internet of things can be implemented in farms to adequately recognize their current environment. This means that a virtual representation of a farm should be able to not only gather information from the farm but should act based on the analysis and decisions made by the systems. This paper presents the primary development of a digital twin for smart farming using IoT to control an irrigation system based on the farmer's and/or AI decision. This paper is arranged as following: section 2 illustrates how IoT has been used in agriculture, section 3 defines the concept of digital twin in the agriculture domain, section 4 outlines the development of the digital twin, section 5 explains the first results and analysis, and finally section 6 presents the conclusions.

II. Internet of things in agriculture

The advancement of technologies in agriculture using IoT in the literature consists mainly of exploratory studies that show systems operating in small pilots [9]. The use of IoT in agriculture can be classified into two categories: the first one including the development of equipment and devices used on farms in order to obtain information about the soil, crop quality, weather conditions etc [10], [11]; and the second one including the development of platforms that are used to store, organize, analyze and visualize data to improve decision making [12], [13].

When reviewing the literature regarding the use of information and communication technologies (ICT) in agriculture the term smart farming emerges. Even though the concept of smart farming is already been in use in the past years, there is still room for a formal definition of the term that encapsulates the

This research is a result of Sensing Change project funded by Royal Academy of Engineering - UK and SWAMP project (ID 777112) and has been jointly funded by European Commission in Europe and MCTIC/RNP in Brazil, under the H2020 (EU2.1.1 Industrial Leadership calll) EUB-02-2017 IoT Pilots call.

978-1-7281-1780-5/19/$31.00

technologies that are currently in use regarding the agriculture field. Smart farming involves the incorporation of information and communication technologies into machinery, equipment, and sensors for use in the cyber-physical farm management cycle. [14], [15].

This concept creates a perception that encapsulates several technologies such as IoT, Big Data, Artificial Intelligence (AI), Process Management, etc. The literature indicates that the use of ICT in agriculture is a developing topic that still has some challenges to overcome, nonetheless, many benefits arise with the use of these technologies.

III. Digital twin for smart farming

The work of [16] declares that a digital twin model is one in which the data flowing between a physical and a digital object is done automatically as it is possible to see in fig 1. A digital twin is capable of associating information concerning the farm and business by adopting technologies such as big data, IoT, AI, etc and is capable to actuate based on the decision made automatically by the system.

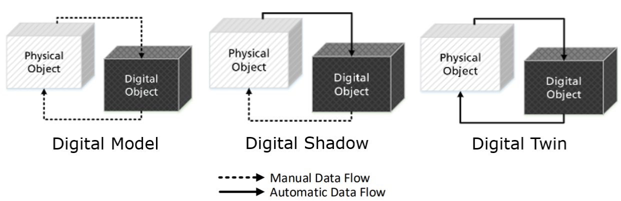

Fig. 1. Digital Twin concept [16]

A digital twin for a smart farm or a digital smart farm is proposed by further expanding the concept of smart farming. A digital smart farm is implemented by building small services to comprehend the information of a particular system such as an irrigation system, a seeding system, etc, and connecting it together in a cyber-physical system. This enables to integrate multiple systems together and for farmers to fully understand how their farms are performing. By using a digital smart farm it is possible to adapt the farm to variations in climate, weather, markets, water restrictions, etc.

IV. Digital Smart Farming system

This section outlines a digital smart farm based on two projects (The Sensing change and SWAMP projects) and is divided as follows: subsection A summarizes the two projects mentioned before, subsection B explains the system design with its hardware and devices and subsection C depicts the system architecture with the cloud services and other elements.

A. Related works: Sensing Change and SWAMP projects

The system used in the Sensing Change project had as premises the use of low-cost commercial devices and materials, and the potential to use in any sort of agriculture practice [17]. It consists of three main components: a monitoring station; a smartphone application and a cloud system shown in Fig. 2. This project developed a monitoring system for a farm that could gather and analyze information. However, the decision making and actions were done by the farmers.

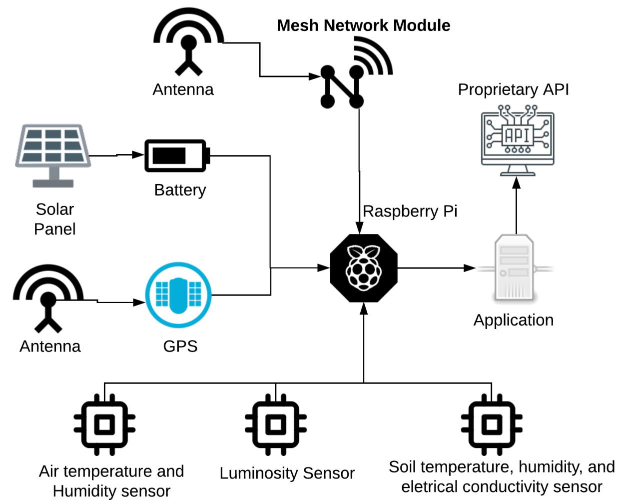

Fig. 2. Sensing change system diagram [17]

On the other hand, the SWAMP project is developing an IoT-based smart water management platform for precision irrigation with a hands-on approach in four distributed in Brazil, Italy, and Spain [18]. The SWAMP platform can be configured and deployed in different ways thus making up different SWAMP Systems, customized to deal with the requirements and constraints of different settings, countries, climate, soils, and crops. This means that it is possible to have the decision-making process done completely by the farmer or by an automation system or a mix of both. The SWAMP architecture is divided into five layers, as depicted by Fig. 3.

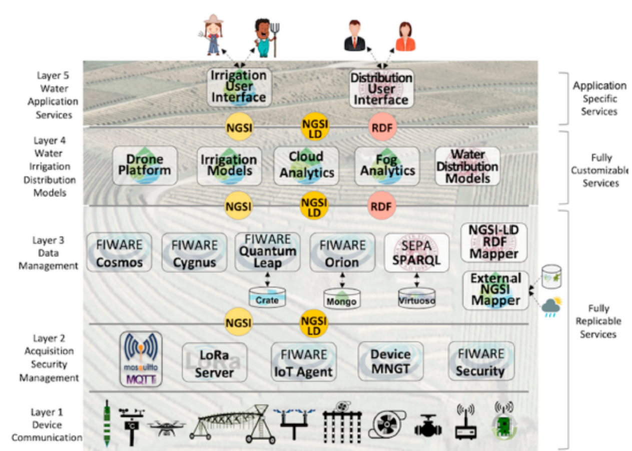

Fig. 3. SWAMP project architecture layers

B. System design

The system consists of a field-installed probe that collects information on air temperature and humidity (DHT22), ambient light (BH1750), geospatial position (Venus GPS), ground temperature at 7 cm depth (DS18B20), and soil moisture at depths of 7cm, 28cm, 50cm and 72cm (CSMv1.2). Probe signals are sent to a Raspberry Pi-3 module using: I_2C bus (CSM v1.2 and BH1750); GPIO (DHT22); serial bus (Venus GPS); and One-Wire bus (DS18B20). An ADS1115 module is also used for the CSMv1.2 A/D signal conversion. The Raspberry module runs a Python script to read this data, showing values in percent soil moisture. After that, the script creates a payload with all probe data and sends it through the IoT agent for subscription to the Orion broker. Figure 4 shows a prototype of the system used for laboratory testing. The probe seen in the figure is a final model design that will be used in the field.

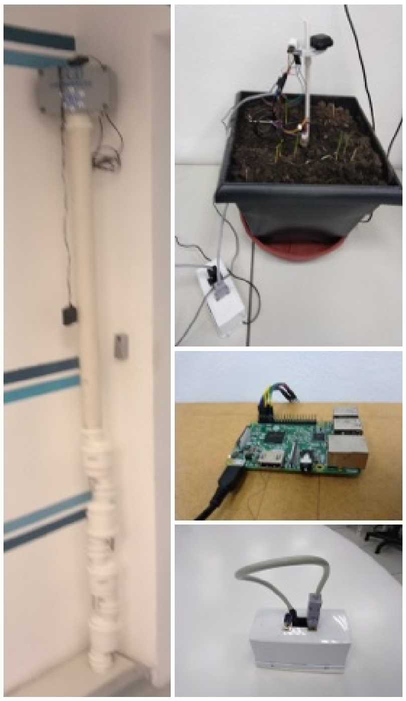

Fig. 4. System design

C. System architecture

In the farm, there are multiple devices and systems deployed such as soil probes, weather stations, irrigation systems, seeders, harvesters, etc. These devices and equipment are connected to the cloud through a gateway that sends information to an IoT Agent. Fig. 5 indicates the system architecture proposed and the services used in this architecture.

- Fiware IoT Agent: A service that translates multiple communication protocols to the one used inside the cloud
- Fiware Orion: Is a Context Broker that allows you to manage the entire lifecycle of context information including updates, queries, registrations and subscriptions
- Mongo DB: is a document-based database used to store the last updated information in a complex structure
- Draco: is a Generic Enabler is an alternative data persistence mechanism for managing the history of context cite Draco
- MySQL: is an open-source relational database management system that is used to store time-series data. cite MySQL
- Grafana: is the open-source analytics and monitoring solution to create dashboards to visualize data

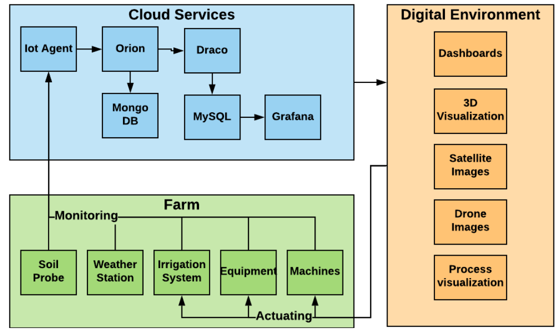

Fig. 5. System Architecture

This digital environment is designed to inform, in a visual way, the information collected using IoT as well as to send information to the systems based on the decision-making process done inside this digital environment. At this moment it is only possible to visualize information on dashboards. Nevertheless, to fully develop the digital smart farm all the other environments are required must be developed in a integrated view. The data collected and analysed in the cloud as visualized in the digital environment should be input in the physical system thought the cloud or by connecting Programmable Logic Controllers (PLCs) into the irrigation system, equipment and machines.

V. First results and analysis

Fig 6 indicates the first results obtained by the system in a testbed inside our lab. The soil moisture sensor was calibrated based on the thermogavimetric measurement [19]. This first experiment indicates that the probe is able to send data to the cloud and that it is possible to show this data in a real time dashboard. It is noticeable that there is an abnormal drop in air humidity and air temperature which indicates a hardware and/or communication problem that should be further addressed.

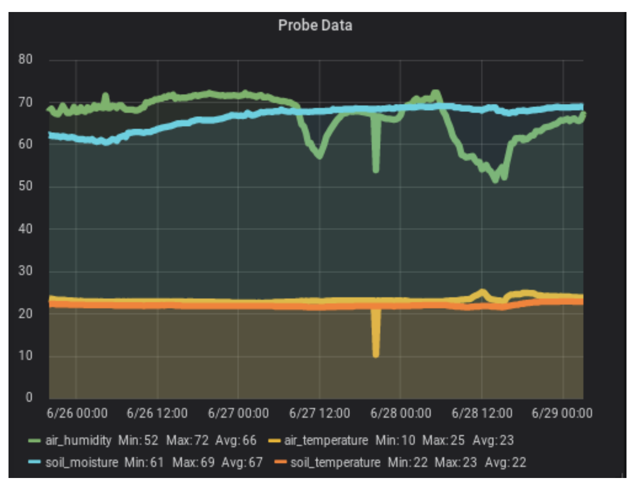

Fig. 6. Dashboard with probe data

Fig 7 shows field data been collected with a local weather station. This weather station can collect data such as air temperature and humidity, wind velocity and direction, rainfall, solar radiation, dew point, rain forecast and rain probability, that is then used in the Penman-Monteith equation to extract the reference evapotranspiration (ETo) [20]. The ETo represents the amount of water, in mm, that the reference crop uses which is then used as a metric to calculate the crop evapotranspiration by multiplying the ETo times crop factor (Kc) for the given crop [21].

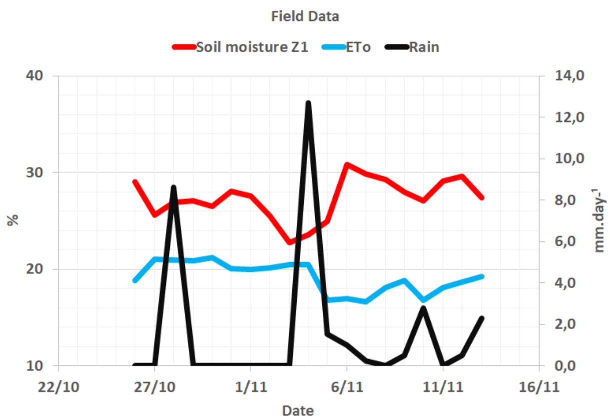

Fig. 7. Field data collected

The first results indicates that the system works and is able to send data to the cloud to be used in dashboards and spreadsheets. It is also possible to extract the ETo using the local weather station and show the water patterns in the soil. It is noticeable that in fig 7 after each rainfall there is an increase in the soil moisture and that in dry periods the soil moisture decreases.

VI. Conclusion

By using the digital twin model and the internet of things technology farmers can connect different assets and systems to have a bigger picture of the different aspects and parameters that impact the farm's behavior and the final yield production and resource consumption. This is a key feature that enables farmers to make better decisions and to decrease the environmental impact in water, land and soil resources. This paper indicates the initial stages to develop a digital smart farm. However, the final implementation of a digital smart farm is only possible when multiple systems act together in order to represent all the processes involved in the farm.

This research indicates that the system design and cloud implementation are working and can be used in the deployment of the next steps which are the development of IA algorithms and the other digital contexts. By having the final system working it will be possible to understand the resource consumption in farms and the impact in crop yield. This enables a sustainable development and increases food security for the global population.

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