Internet of Things Applied to Agricultural Irrigation Systems in Pasture Grasses

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***Abstract*—Irrigation in agricultural systems is responsible for most of the world's fresh water consumption. In this paper, we focus our study on applying the concepts and tools of the Internet of Things (IoT) to irrigation systems for pasture grasses. In this particular case, we study an IoT-based architecture for irrigation systems using weather forecasting, that based on its availability controls the decision of watering. The result of the proof of concept of the proposed architecture shows the potential for water savings, resource optimization, and the challenges of a real and widespread application.**

***Index Terms*—Pasture grasses, Precision Agriculture, Internet of Things.**

I. Introduction

Agricultural activity represents an important part of the global economy, especially in countries rich in biodiversity such as Colombia. Indeed, the environmental and sustainability challenges are requiring new systems of agricultural labor management that in some way contribute to improve the efficiency and reduce the impact of this important activity.

Therefore, irrigation systems are nothing new, on the contrary, they have been used throughout history. The use of irrigation systems in Colombia dated back to 1991, and still representing an important advance in the implementation of this kind of technology [1]. The authors reach an efficiency for irrigation systems up to 95%, reducing the water consumption in a considerable way [2]. However, the implementation of these kind of systems faces challenges like high cost of maintenance and execution, lack of infrastructure, and farmer's low technical skills.

Then, to propose a solution for the systematic control of the natural resources, it is important and suitable to perform in Colombian farms, since it would represent an increase on the optimization of agricultural transactions and an important advance in terms of smart automation for a major economic activity.

Due to the importance of this type of technology in the socioeconomic environment of the country, this document presents our first advances in research on the design and implementation of an intelligent irrigation system based on Internet of Things (IoT). In this particular case, we focus our research on the production of pastures, which represent the main food for much of Colombia's agriculture and livestock.

We propose an architecture and a methodology for an automated irrigation system using IoT tools, looking for a new system that makes the irrigation performance more effective, ensuring greater production of agricultural products and reducing environmental risks.

This paper is organized as follows. In section II, we introduce some concepts of Internet of Things and Pasture Grasses. In section III, we explain the proposed solution architecture. In section IV, we discuss the results of the proof of concept.

II. Literature Review

In this section, we summarize many concepts of Internet of Things and soil conditions for optimal pasture grasses irrigation. Firstly, we review different approaches of Internet of Things applied to smart farms. Secondly, we review the characteristics of pasture grasses and their soil requirements.

A. Internet of Things

The Internet of Things will be an essential technology for a functional intelligent farm itself, its use provides a basis for a new generation of agricultural management information systems. This enables smart farms to become active nodes in business-to-business (B2B) solutions and agricultural value chains [3].

It is the central axis for the operation of our system. The main objective of the Internet of Things is to create an intelligent world where reality, the virtual and the digital converge in order to create more intelligent environments [4].

This concept has been implemented in everyday objects to provide, with this kind of technology, greater intelligence to the mode of transport, industries, buildings and even cities. Looking for a convenient way in which it could interconnect everything through smart networks. With the objective of being able to access any information at any time, in any place and using low resources. In short, it seeks to make intelligent devices using different types of technologies. This system allows the communication among themselves and also with humans in the same way, focus on seeking the way to increase the efficiency of these interconnected devices. Obtaining improvements in the implementation area where one of these smart devices is located [4].

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Because on-farm deployment technologies include the immersive nature of the environment, such as proximity to animals, rural context, mobility, radio interference caused by the animals themselves, information storage limitations, and data transmission difficulties [5]. These energy constraints are a widespread problem that often frustrates network longevity; likewise, the cost of execution also becomes a determining factor in remote monitoring scenarios.

According to the above, implementing an irrigation system must start the generation of virtual intelligence without so much dependency on electronic networks. In more specific terms, from intelligent devices to a smart grid system through the operation of the internet. A prerequisite for such systems will be the capability to:

1) Operate with real-time increasing and diverse data flows.
2) Handle noisy, incomplete, and sometimes contradictory data.
3) Capture, correlate and combine data in real-time.
4) Dynamically affect network behavior to timely alter data capture, data routing, or data recording regimes.
5) Facilitate orchestrated detection activity through the ability of individual network nodes to reason, operate, and collaborate within a collective, recognizing the coexistence of both individual and common objectives. This demands the embracing of distributed intelligence and multi-agent approaches.

B. Pasture Grasses

The seed of pasture grasses is mainly used during the dry season. It is also a common practice among small and medium-sized farmers around the country. This is based on the generation of grass forages that ensures the correct feeding of the cattle, besides maintaining optimal agricultural control in the field of sowing [6]. This type of grass is highly useful in warm environments of the most arid lands, which is perfect to use in terms of intelligent irrigation.

It is important to emphasize that is necessary to use a resistant agricultural product to climatic changes such as pasture grasses. Irrigating this kind of crops use a significant amount of water [7].

Irrigation systems are used to help the growth of crops, the maintenance of landscapes, and the re-vegetation of the soil in dry areas and during periods of low rainfall [8]. These systems intend to reach an optimization for agricultural development. The main improvements that should be obtained from agricultural processes in the following objectives:

1) To provide the necessary moisture in order that the crops could develop.
2) To assure the crops against droughts of short duration.
3) To refresh the soil and the atmosphere in order to improve the environmental conditions for the vegetable development.
4) To dissolve salts contained in the soil.
5) To reduce the probability of natural drains.
6) To give temper (proper condition) to the land.

These characteristics are important to get high quality pasture grasses production [9] . As mentioned above, we present an automated irrigation system, that keeps working with no or minimum manual intervention. Almost all systems with different irrigation modes (drip, spray, surface) can be automated with the help of timers, computer sensors or mechanical devices [10].

One of the main objectives of the study is to be able to incorporate each of the above-mentioned characteristics within an automated irrigation system by using the Internet of things as our central theoretical axis within the electrical and electronic operation of the system.

III. Architecture

Our architecture is composed of four layers, displayed in Fig. 1. The first layer integrates the climate prediction obtained from OpenWeatherMap API, which is the application system specialized in weather forecasting data. The second layer is composed of different network communications protocols (LoRaWAN/GPRS/GSM/3G) to be used depending on the connectivity issues and network constraints around the testing area. The third layer includes the motherboards, in our particular case we chose the Raspberry Pi because of the convenience of programming and associating it with Python language and integrated with internet connection modules (e.g. LoRaWAN modules), also this layer contains the decision algorithm and the control system designed for the optimization task. Finally, we have a fourth layer where the nodes related to the sensors and the actuators are located.

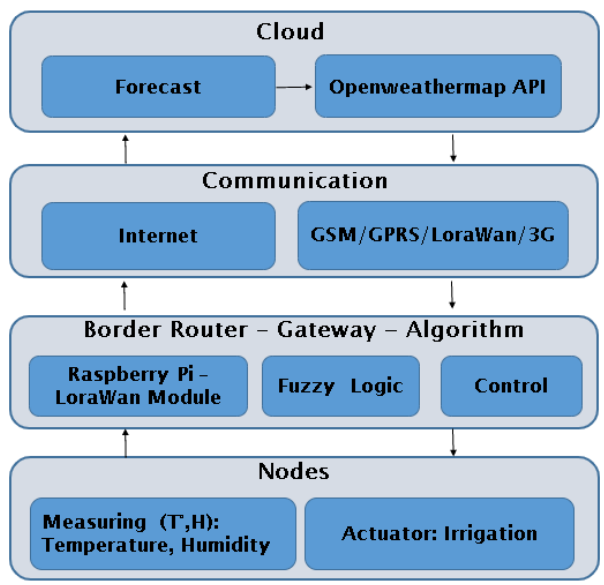

Fig. 1. Layers of the proposed architecture

As mentioned above, the weather forecast data is acquired through the use of the OpenWeatherMap API, which allows us to obtain the hourly forecast report or a daily report, in addition to this, it allows us to get historical climate data from its database of the delimited area.

This is the first information that our system needs, since these data are analyzed according to the conditions proposed in the decision algorithm in order to define the input data that will allow us to obtain the reference of our control system.

Weather prediction is important because it allows the system to decide on whether or not to activate the irrigation system, taking into consideration the forecasts obtained from the API, which allows a better water resource management, since if it rains, a considerable amount of water used for irrigation will be wasted.

Communication protocols are required to be able to process the data with the algorithm and analyze each outputs obtained through the API; this is where the second layer is mainly used for. Our architecture proposes the possibility of communicating with cloud services through Internet protocols or, low bandwidth and low-cost WAN networks such as LoRa. With this framework there are two ways to access the forecast information, because in some cases the quality of the Internet on farms can be quite unstable, for that reason, we propose the use of LoRaWAN because it uses an unlicensed band of the radio spectrum and this facilitates the configuration of a network and its use.

The third layer allows us to analyze each data-set sent from the API through the communication protocols, set the reference, and perform the system control. This layer contains a LoRaWAN module which is connected directly to the Raspberry Pi; this module can work bidirectionally, which means that using the same module, a receiver can be transformed into a transmitter at any time and vice versa. This makes it a suitable module for this application, because it needs a bidirectional communication to send the sensor data to the cloud but also needs to receive the data sent by the API.

Additionally, it should be mentioned that the Raspberry Pi can be connected to the internet with an Ethernet connection cable or by using a WiFi USB adapter.

The decision algorithm based on Fuzzy Logic can also be found in the third layer of our architecture. This algorithm has established conditions which allow us to analyze according to forecasting if the irrigation system should be activated and how much reference about soil moisture would result. Finally, in this layer is located our control system. In this case, a proportional control is used, because this is a fairly slow system with a fairly high delay. The error signal used by the P-type controller is the set-point value obtained by the fuzzy logic algorithm minus the measured soil-moisture.

In the last layer of our architecture, two types of nodes can be found: The measurement nodes which are composed of temperature and moisture sensors and the actuator nodes which are responsible for activating the irrigation system. Each of these nodes are interconnected creating a network in which the nodes can be receivers and transmitters.

A. *Fuzzy Logic System*

A decision algorithm based on Fuzzy Logic is essential to obtain a reference in which the control system can perform properly. In our particular case, a fuzzy logic system fits perfectly because a precise mathematical relationship between input variables cannot be formulated, so we can apply a fuzzification to the variables and relate them to a membership function and handle with linguistic relationship, which is the main advantage of fuzzy logic.

With the "fuzzification" process, we have the possibility to create different categories from a range of values, also called the universe of antecedents, and to endow different categories with a linguistic character that will later be used to formulate the fuzzy rules. We can observe an instance of a membership function after the "fuzzification" process for the crisp input temperature in Fig. 2.

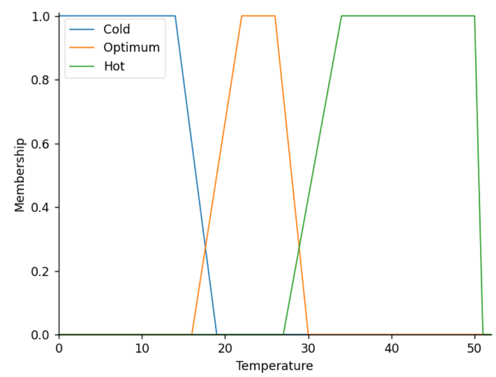

Fig. 2. Temperature Membership Function

It should be noted that there are different membership functions (Gaussian, Trapezoidal, Triangular, etc.), in our case, we chose the graphs that best fit the ranges and categories of the inputs. We can observe the fuzzy logic algorithm process in Fig. 3, where the execution of the complete logic system is shown.

In the Fig. 3 we can look the different stages in the fuzzy logic system, starting with the "Fuzzification" process, then we execute the inference stage based on a groups of fuzzy logic rules, which is the main feature in which this kind of systems are used for.

To elaborate the categories of each membership function in order to create the fuzzy rule set, the ranges that can be obtained must be taken into account. For this purpose, we use the values based on the irrigation study in [11], and based on this, assign the linguistic labels. Then, we set the linguistic labels, as shown in Table I.

TABLE I
INSTANCE OF COMBINATION OF INPUTS CONDITIONS

Precipitation (%)	Precipitation (mm)	Temperature	Humidity
Likely	Slight	Cold	Low
Likely	Slight	Cold	Optimum
Likely	Slight	Cold	High

And, the corresponding result of the conditions for the output linguistic values showed on Table II.

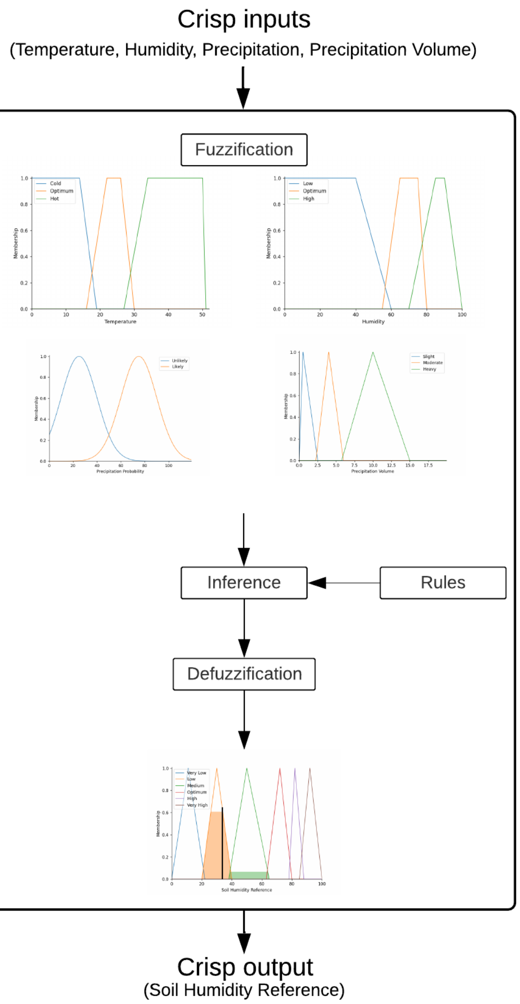

Fig. 3. Fuzzy Logic System

Due to the high number of input linguistic labels, the number of rules set up from the permutations of each variable set, results in 54 rules, that is the reason why we only show an instance of this group, however, we can observe the total set of rules in the algorithm in [12].

B. Control System

This irrigation system is considered a continuous system with a high delay, which allows implementing a simple control shown in Fig. 4. For this reason, we decided to use a proportional control that can be carried out by an Single Loop Control - SLC controller.

TABLE II
INSTANCE OF RESULTING OUTPUTS

Soil Moisture Reference
Low
Medium
Optimum

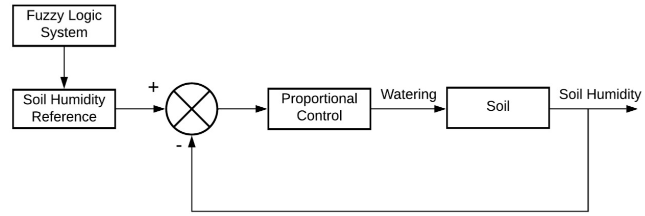

Fig. 4. Control System

As shown in Fig. 4, the reference of this control system is the soil moisture obtained from the Fuzzy Logic Algorithm, therefore, the controller input in this case would be the error between the soil moisture reference obtained by the algorithm and the soil moisture measured directly by the sensors. It is important to note that the proportional parameter of the controller is an adjustable value that depends on the characteristics of the soil in which this irrigation system is installed. Finally, as an output of the controller we have the amount of Water that will be irrigated to the crop, which is the power of the irrigation system.

IV. Concept Results

We executed a test with the crisp input values shown in the Table III, with the purpose of observing the performance and characterization that would make the fuzzy logic algorithm.

TABLE III
CRISP INPUTS VALUES FOR TESTING

Precipitation (%)	Precipitation (mm)	Temperature	Humidity
73.0	7.82	27.56 °C	81%

With the above crisp inputs, we obtain the following soil moisture reference, shown in Fig. 5, with the fuzzy logic algorithm.

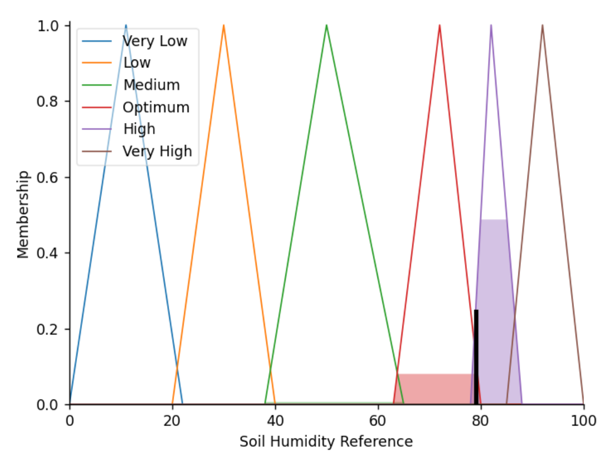

Fig. 5. Soil Moisture Reference Result

We can also obtain the different values for the soil moisture reference with the input variables obtained from the API forecast in a period of 48 hours, this allows us to see the evolution of the response of the algorithm every hour during two days with different variations of the parameters of temperature and humidity, as shown in Fig. 7 and Fig. 6.

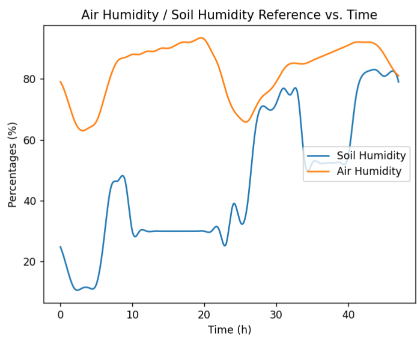

Fig. 6. Soil Moisture and Air Humidity over Time

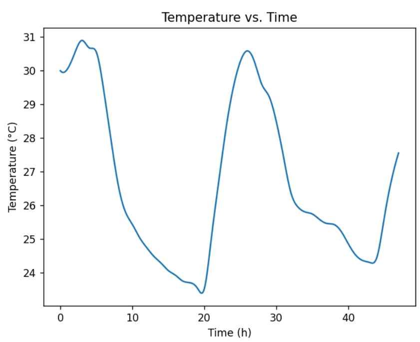

Fig. 7. Temperature change over Time

It should be added that the values of soil moisture and air humidity are not equal, they are correlated with each other, but this complex relationship must include other environmental variables such as temperature, pressure, wind, among others.

Additionally to the soil moisture measurement, we also carry out real-time measurements of soil temperature and air humidity using sensors embedded directly in the test field. This allowed us to obtain the data shown in the Fig. 8.

The measured data are connected directly to a cloud service (Ubidots) that allowed us to keep a remote record of the site where the test is executed, this graph as well as the temperature allows us to specify with greater adherence to reality the rules that were developed for the fuzzy logic system and obtain greater accuracy in the soil moisture reference, we can observe this information in Fig. 9.

V. Conclusions and Future Work

In this paper, we propose an architecture based on Internet of Things concepts and methodologies in order to implement smart irrigation systems. From all the above we can conclude the following:

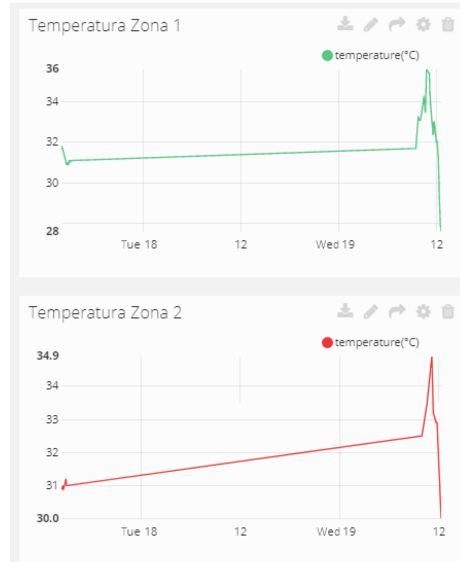

Fig. 8. Temperature Dashboard

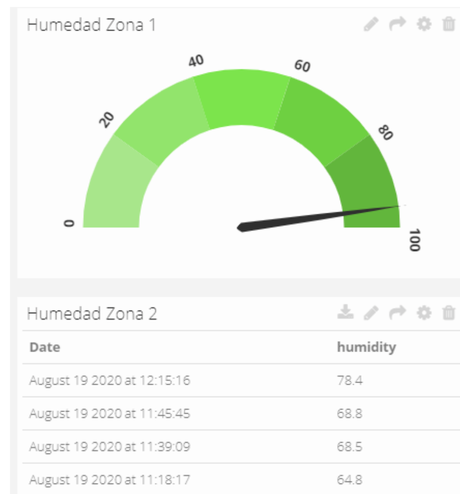

Fig. 9. Soil Moisture Dashboard

1) Crop irrigation is a slow process that consumes a lot of water and many hours. In this architecture, we propose how to carry out the irrigation taking into account the factor of precipitation in terms of volume and probability of occurrence, allowing in this way an adequate use of the water.
2) For this application where we integrate IoT tools with irrigation systems taking into account the weather forecast, it was necessary a fuzzy logic base, because through the API we obtain the data about rain precipitation and its intensity. Depending on this, we can obtain a reference parameter of soil moisture without the need to correlate the input variables with an approximate mathematical model, therefore, this allows the fuzzy logic algorithm to work properly for this specific type of application.

In the future it is planned to design and implement all the required instrumentation for the start-up of this optimized irrigation system with the technology of the Internet of things. Also, integrated this with the architecture proposed above based on Raspberry PI and network communication protocols modules, with the advantage that this motherboard can compute the fuzzy logic system and at the same time can be integrated with the SLC for the control system, and also with the aim of optimizing the cost of hardware integration in order to make a widespread implementation, so that it can be easily acquired in the crop fields looking for an efficient irrigation for pasture grasses and which takes into account different environmental factors.

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