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Smart irrigation: data capture process based on knowledge management

Riego inteligente: proceso de captura de datos basado en gestión del conocimiento

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ABSTRACT:

This paper presents the process of acquiring environmental data that feed an intelligent irrigation control system, which based on the calculation of the evapotranspiration of a crop manages to calculate the water needs of the crop to supply them. It presents the problem of irrigation because a solution based on the Internet of Things (IoT) is considered satisfactory, specifying the variables involved in the process and the characteristics of the data produced by the sensors. After this, it develops the process of capturing data on an IoT architecture based on knowledge management and with the sensing, communication, and analytical phases, referring to the R software components that have been developed to carry out this process, culminating with the projections of irrigation analytics. As irrigation is the main aspect of crop yield, a need inherent to the field sector that is not yet automated and that seeks solutions to the conditions of the Colombian countryside is supplied.

RESUMEN

El presente artículo describe el proceso de adquisición de datos medioambientales que alimentan un sistema de control de riego inteligente el cual, basado en el cálculo de la evapotranspiración de un cultivo, logra calcular las necesidades hídricas del mismo para suplirlas. Luego de plantearse la problemática del riego, y la justificación de una solución basada en Internet de las Cosas (IoT) como satisfactoria, se precisan las variables que intervienen en el proceso y las características de los datos que producen los sensores; se desarrolla el proceso de captura de datos sobre una arquitectura IoT basada en gestión del conocimiento con las fases de: sensado, comunicación y analítica, refiriendo los componentes del software R que se han implementado para realizar este proceso, culminando con las proyecciones de analítica del riego. Al ser el riego el aspecto principal del rendimiento de un cultivo se concluye que se suple una necesidad inherente al sector del campo -que aún no está automatizado- proponiéndose una solución para las condiciones específicas del campo colombiano.

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1. Introduction

The economic and social development of a country depends on the possibility of supplying food by establishing production infrastructures in its territory or by forming networks of commercial exchanges with other countries. The production of surplus food for exportation is also considered a development engine.

An increase in the population assisted by their right to feed properly depletes resources for agricultural production and pushes the boundary of the agricultural frontier which means a decrease in the amount of forests and native ecosystems of the regions replacing them with crops; it goes against sustainable development [1]. The decrease in resources has been generated processes of transgenic food production, uses of urban farms instead of land and even the inclusion of new technologies in the value chain of each product. This seeks the increase the amount of food produced; This is still an unfinished practice because the demands for food will always be inherent in the human being.

The application of water to agricultural soils to water crops is one of these technologies and the Food and Agriculture Organization of the United Nations (FAO) has estimated that proper management of water resources will represent a more significant increase in the yields of crops that set all other production practices together [2]. In Colombia, in 90% of the crops, irrigation is not technified or is partially done through rudimentary technologies, with little or no incorporation of specialized robust systems since irrigation technology must respond to the specific combination of soil, crop, and climate, among other variables. Failure to develop it properly generates problems as water losses, that is, a low efficiency in the use of the resource, washing of natural nutrients under the area where the roots develop, low crop yields due to lack or excess of water in different parts of the crop lowering the yield of these [3].

Among those technologies that can be transferred to cultivation is the Internet of Things (IoT) as a paradigm that links data collection, transport, and subsequent application to generate information and knowledge [4].

With the interest of forming the triple helix (which is the group formed by the academy, industry and government) the government through the Ministry of Information and Communications Technologies (MINTIC) financially and logistically support the union of universities together with the companies to form the Center of Excellence and Appropriation of Internet of Things (CEA-IoT) in order to generate technical and technological development based on IoT for the city and the country. This on technological platforms of Microsoft, Intel and Hewllet Packard [5], this is the most ambitious step taken by the government to promote the use and development of IoT.

While IoT-based solutions provide an ecosystem rich in applications and understanding, they come with a new variety of complexity and confusion. In its development report of this paradigm, IoT Analytics presents 5 stages in the development of a specific application, which are the device, communication, cloud services, applications and security [6].

Therefore, using new technologies to give greater yields to agricultural production by IoT becomes relevant, taking environmental and climate information both locally and generally to estimate the water needs of crops. This postulate is the basis of this work, where a review of the particular needs of crop irrigation is done, the technology with which it is currently carried out and the benefits it presents to then propose a system based on the IoT paradigm and jointly with knowledge management, create a new tool that allows generating better crop yields by controlling the use of water in it.

2. Irrigation

The term irrigation refers to a set of methods of applying water to the soil so that it is distributed homogeneously. The design and projection of specific soil situations, climate, water availability, irrigation districts and current management have their own characteristics for each case, the knowledge of these processes and the interaction of their parts is established in agricultural production , which gives information to predict the behavior of the crop and design an irrigation system that increases the yield and improves the quality of the final products by ensuring to the plant component an adequate amount of water.

To apply water to a crop, the farmer must answer four essential questions, these are Why irrigate? What is the yield motivation when controlling irrigation? When to irrigate? That is, the frequency and criteria to choose that frequency. How much to irrigate? As a function of time and volume of flow. How to irrigate? Which responds to the way water is applied to the soil. This defines irrigation as the timely and uniform application of water to a soil profile to replenish the water consumed by the crop between two consecutive irrigations [3], taking into account that the soil surface is not being irrigated, but the profile is being irrigated in depth. This article made an approach to the first question and by means of IoT it seeks to answer the second and third questions.

The loss of water in the plant is carried out by two different processes, the one releases water to the atmosphere through perspiration, the second from the oil surface to the atmosphere through the evaporation process, the two processes are related with the plant, the climate, type of soil, stage of crop development and this process is known jointly as evapotranspiration [7].
Surface irrigation is the main way to apply water to a crop to supply the evapotranspirated water from the previous irrigation, whose main objective is to maintain a constant and maximum perspiration rate throughout the irrigation season.

3. FAO Penman-Monteith equation to estimate evapotranspiration

The FAO Penman-Monteith method was developed using the definition of the international reference crop with characteristics as an assumed height of 0.12 m, surface resistance of 70 s/m and an albedo of 0.23 (it is the percentage of radiation that any surface reflects respect to the radiation that affects it) and that represents the evapotranspiration of an extensive surface of green grass of uniform height, actively growing and adequately watered, this is represented by the equation:

$$ET_0 = \frac{0,408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0,34u_2)}$$

Where

ET_0	Reference Evapotranspiration
Rn	Crop surface radiation
Ra	Extraterrestrial radiation
G	Soil heat flow
T	Average air temperature
U_2	Wind speed
e_s	Saturation vapor pressure
e_a	Actual vapor pressure
$e_s - e_a$	Vapor pressure deficit
Δ	Steam pressure curve slope
γ	Psychometric constant

4. Data

The data refer to the characteristics of the variable nature of the Penman-Monteith Equation which allows the calculation of the amount of water to be replenished in a crop. Reference can be made to annual, monthly, weekly or daily data to use the equation, where each frequency implies a daily or weekly correction of the necessary data [8]. These data correspond to:

- Location: The height above sea level (m) of the area for which the Et_o is determined and its latitude (degrees, north or south) must be specified. These data are necessary to adjust some climatic parameters to the local mean value of atmospheric pressure (function of site elevation above sea level) and to calculate extraterrestrial radiation *(Ra)* and, in some cases, the maximum duration of insolation (N).
- Temperature: The use of the average air temperature instead of the maximum and minimum temperature results in a lower saturation pressure (s), and therefore a lower vapor pressure deficit $(e_s - e_a)$, resulting in a lower estimate of reference evapotranspiration.
- Humidity: In case the actual vapor pressure values are not available, these may be derived from the maximum and minimum relative humidity.
- Radiation: Daily (average) net radiation is expressed in Megajoules per square meter per day (MJ/m^{2}dia^(-1).
- Wind: It is important to verify the height at which the speed is measured, since wind speeds measured at various heights above the ground surface have different values for sure.

5. Process of knowledge management in irrigation

Knowledge management allows the systematic identification, grouping, ordering and sharing of knowledge related to organizations to meet present and future needs, seeking to identify and exploit existing knowledge resources as acquired and to develop growth opportunities [9].
This process shares its development with corporate learning by seeking [10]:

- Identify, collect and organize existing knowledge.
- Facilitate the generation of new knowledge.
- Initiate innovation and development processes through the reuse of knowledge that will allow for an improved business performance.

The way to implement a knowledge management process has features as [11]:

- Detect: In this process knowledge sources are located.
- Select: The knowledge model is chosen.
- Organize: It is the moment where the representation of the model is structured.
- Filter: We generate automated queries to access information.
- Present: Focused on encompassing and expanding the range of human understanding.
- Use: It is specified in the act of applying it to the

problem object of resolution.
This relationship is presented in Figure 1.This relationship is presented in Figure 1.

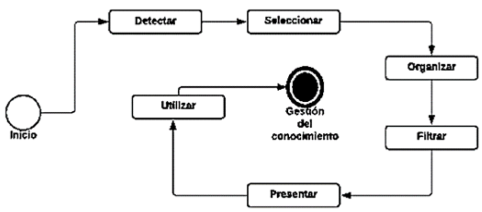

Figure 1. Spiral of knowledge management [11].

6. The IoT paradigm

The Internet of Things (IoT) is a paradigm that encompasses various types of technologies and different configurations of them to obtain data on the environment in which it is installed and convert these into useful information for specific purposes, which It usually consists of three layers. A layer of sensors allows you to collect data of interest, a communications layer provides transport of that data to a site where it can be stored where another layer analyzes and extracts information from them.
Various organizations worldwide have defined the concept of Internet of Things [12] from their vision, nurturing the theoretical development of this ecosystem as CASAGRAS (Coordination and support of activities and standardization with RFID) defining IoT as a connected global network infrastructure of physical and virtual form with objects through data capture and communication capabilities.

6.1. IoT protocols

It is possible to build an IoT system with existing protocols on the Web even if they are not efficient with respect to the new protocols, HTTP and Web Sockets are common standards together with XML or JSON in loading information; When we use an HTTP web standard, JSON provides an abstraction layer for developers to create a persistent application. However, there are light communication protocols [13] that were developed to solve the problems of transmission speed limits and bandwidth in IoT devices such as:

- **XMPP**

XMPP has its roots in instant messaging and has expanded into audio and video calls, collaboration, lightweight middleware, content syndication and XML data routing. The strength of XMPP is addressing, security and scalability; This makes it ideal for IoT oriented applications.

- **CoAP**

Although the Web is available for use in IoT solutions, it is very heavy for the different types of services that are planned to be offered. CoAP uses UDP so certain HTTP functionalities replicate in CoAP transparently distinguishing between confirmed and unconfirmed messages. Requests and responses are handled asynchronously. All headers, methods, and status codes are encoded which reduces the upper part of the protocol, however, you need a protocol analyzer to identify network problems [14]

- **.MQTT**

Message Queue Telemetry Transport (MQTT) is an open protocol developed and optimized for devices with low bandwidth, high latency or unreliable networks. It is an extremely lightweight publishing/subscription protocol ideal for connecting devices to networks with minimal bandwidth, using basic TCP. The objective of MQTT is large networks of small devices that need to be controlled from a server, it is not designed for device-to-device transfers or multicast sending data to multiple MQTT receivers is simple and provides control tools to individual devices. The protocol provides telemetry and has been used by Facebook in its messaging application due to the low bandwidth required in addition to the following advantages:

- It is open-source free of additional payments and easy to adapt.
- Follow one too many distributions of information.
- Small message headers.
- Multiple levels of quality of service.
- Simple command messages.
- Agnostic in data type.
- Durable connections.

6.2. IoT platforms

Some platforms allow the integration of the different layers to the IoT paradigm which have different use alternatives, for the development AWS IoT was used, one of the most complete due to the integration with flexible cloud service techniques. They have a core to install in more than 100 types of hardware and provide communication with their cloud integrating Lambda application services for IoT integration, they offer their own FreeRTOS operating system for their deployments, in addition to this integration with the development tools of the Amazon suite.

In the stage of discovering and linking data, an ontology-based on W3C sensor networks was used [15], this process is performed to hierarchize the data and be consumed by a Mashup which is a system that consumes data from different sources. The structure of the ontology is grouped into modules, classes, and relationships and is presented in Figure 2.

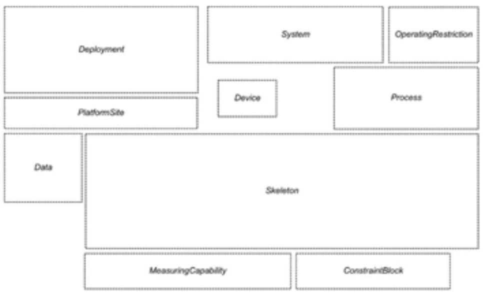

Figure 2. Ontology modules for sensor networks [15].

7. Relevant sensor studies in agriculture

How to capture data when performing agricultural processes is a field of study because the way sensors interact, are located or how their sensitivities are influenced is relevant to the development of a robust system.
The wireless connection present in the sensing stage has been discussed by several authors where they have defined the hybrid Wireless Sensor Network as promising within the sensing of important variables in farms. The difference between a hybrid system and a terrestrial one is the wireless network of underground sensors that communicate in the soil, this seeking to eliminate a communication stage for soil sensors that come to the surface that can interfere with the actions of the farmer and the development of the agricultural process. A framework was developed on land consisting of 50% sand, 35% silt and 15% clay. The experiment related several types of soil density from 5 % to 25 % and three different transmission frequencies (433, 868 and 915 MHz) [16] taking into account channel losses, bit error rate and maximum transmission distance in variables such as soil type, volumetric water content, and distance between nodes, it was shown that radio signal losses are lower at low frequencies and low density on the ground, in addition, the deployment of a deep node affects the attenuation of the signal at 433 MHz determining the best way to perform a communications node at different depths.
This wireless connection is also analyzed from the way it interacts with the cloud, the high capacity to generate data along with storage and processing, as well as elasticity and pay-per-use, make the cloud a viable solution to IoT-based implementations for agricultural processes [17]. In addition to the cloud, implementations have been made on local servers seeking to emulate the concept of computing in the fog or on the roof showing that web applications for databases and mobile systems facilitate real-time acquisition for effective monitoring. These tools when implemented with open source solutions save money and allow a high degree of integration and robustness. Joining Android applications with control systems stored locally using a server-based on Linux, Apache, MySQL, PHP, Perl or Python is a solution for working with large volumes of data [18], the sensor nodes are adapted with an operating system version for small devices known as TinyOS and mounted on a communications system such as 6LoWPAN giving results in which the architecture is efficient for data analysis.
In developing these ideas concerning the application of data science to interpret agricultural information, middleware platforms have been integrated which, through WSN, interoperate these data to generate specific applications focused on the market for the sale of agricultural assets [19].

8. Sensors

Among the instruments taken into account to collect data in the field, those with current certification in the country were prioritized by the National Accreditation Agency of Colombia (ONAC), an institute responsible for certifying the sensors used by the measuring instruments to validate that their measures are suitable for the referenced process [16]. Based on this, a weather station validated abroad was chosen with the respective sensor standards (NIST that refer to the National Institute of Standars and Technology in the US), this led to the choice of the MA3081 PRO weather station with the certified sensors presented in table 1.

Sensor	Precision
External humidity	+- 3% RH entre 33% y 90%
External temperature	+- 0.4 F (0.2 C)
Barometric pressure	+- 0.03 pul Hg (0.1 hPa)
Wind speed	+- 2 mph (0.9 m/s)
0.2 mm rain	+- 4%

Table 1. Sensor characteristics. Source: own.

The sensors have frequency characteristics, this is the amount of time that passes between one measurement and another, as seen in table 2.

Data	Frecuency
Wind speed	2,5 a 3 sec
Direction of the wind	2,5 a 3 sec
Accumulated rain	20 a 24 sec
Rain intensity	20 a 24 sec
Outside temperature	10 a 12 sec
Outside humidity	50 sec a 1 min
Solar radiation Wind	50 sec a 1 min

Table 2. Sensor data frequency. Source: own.

8.1. Data usage interface

The data is transferred by the MQTT protocol to a broker that is configured to create a JSON structure of the information with the following description (data values are examples of these):

CurrentDataClimatic	Value	CurrentDataClimatic	Value
dewpoint_c	23.1	solar_radiation	123.2
dewpoint_f	73.6	temp_c	34
heat_index_c	39.4	temp_f	93.2
heat_index_f	102.9	uv_index	0
precip_rate_inh	0	wind_degrees	135
precip_rate_mmh	0	wind_dir	"SE"
precip_today_in	0	wind_gust_kmh	5
precip_today_mm	0	wind_gust_mph	3.1
pressure_hpa	986.4	wind_speed_kmh	1.1
pressure_inhg	29.1	wind_speed_mph	0.7
pressure_mb	986.4	windchill_c	34
relative_humidity	53	windchill_f	93.2
report_date	"2019-12-25 21:19:34+00:00"	report_date_locale	"2019-12-25 16:19:34-05:00"
Station			
altitude	5	created_locale	"2018-03-15 17:15:05-05:00"
brand	"Meteoagro"	elevation	175.95
country	"Colombia"	latitude	5.45399237
state	"Caldas"	longitude	74.66312408

Table 3. Characteristics of data in JSON format. Source: own.

9. Data Analytics

To close the data capture cycle and appropriate the measurement of the environmental records from the sensors, R program was carried out which consults the JSON every 10 minutes to update a data frame that becomes the database of the system to be operated, and extract relevant information that allows the calculation of evapotranspiration.

Among the results presented by the developed system is the monitoring of the related variables in the JSON that provide information on how conditions change in the field. This serves to remotely monitor the environmental behavior of the terrain and is useful for creating basic control systems in the presence of rain and things like that; This monitoring is presented in Figure 3.

Figure 3. Data report of the analytical platform. Source: Own

Just as a report of each variable is presented, the temporal information of each one is grouped for its visualization and incidence analysis, the variables such as temperature, dew point, humidity, precipitation, pressure, solar radiation, UV index and speed of the wind in figure 4 and figure 5 shows the development of this monitoring for temperature and precipitation variables. The temperature is also important because the crops to reach their point of greatest production need specific temperature and humidity conditions, which allows generating heat dissipation systems or in the case of precipitation, creates artificial barriers to control excess natural water in the crop.

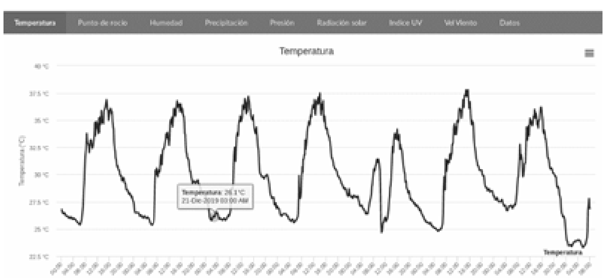

Figure 4. Time temperature record. Source: own.

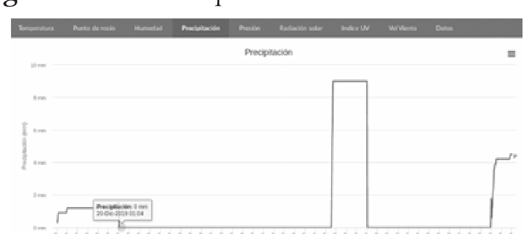

Figure 5. Record of precipitation over time. Source: own.

In this way, a tour of the data capture process has been presented under the Internet of Things paradigm supported by an ontology of sensor networks organized by a knowledge management structure for subsequent analysis by data science and present relevant data for the irrigation of a crop.

10. Conclusions

The plant returns 90% of the water it receives to the environment, so controlling its flow is important for its correct development, the advancement of technologies provides important tools to organize and take control of processes that in a classical way they have been approached by high-cost solutions, which allows developing increasingly affordable systems for different types of producers and with greater efficiency.

The plant needs an irrigation system that guarantees the availability of water when there is no rainfall in the crop to obtain effective growth, without falling into deficiency or water saturation. The method proposed by the FAO is used for the measurement of ET since a knowledge management system is adaptable to be fed by meteorological variables coming from sensors located in strategic points of the crop, which is in direct line with the proposal developed.

It is a valid way to open lines of work based on data quality, its appropriation and description, creating scenarios such as transferring the SSN ontology standard to JSON because it is in XML.

The adoption of agricultural technologies in the country has not been carried out to a large extent because the crop, depending on very specific factors such as the environmental conditions of the land and its physical characteristics, needs very homogeneous spaces to be automated, so for companies are not profitable to develop a technology in a country in which these characteristics change every 100 meters. This despite having been an impediment becomes a challenge that opens the space to the development of networks of sensors and artificial intelligence systems that solve the problems of Colombian agriculture.

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