Agro-Smart Caribe: Soil Moisture Measurement System

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Abstract. Advances in information and communication technologies provide precision agriculture with more efficient tools for agricultural monitoring systems and the possibility of crop irrigation automation. This paper presents the implementation of a crop field monitoring system based on wireless sensor networks (WSN) with moisture detectors, which are remotely controlled for data collection. The implemented WSN performs information gathering functions from the sensor nodes to the base station. The system is integrated into the internet cloud and together with the hardware and software configuration, adequate energy efficiency is obtained.

Keywords: Precision agriculture · Soil moisture · Wireless sensor networks · Communication protocols · Internet of Things

1 Introduction

Agriculture as the basis for the development of civilizations is the most important economic activity, and in addition to being a civilizing agent, it involves the fulfillment of certain social objectives, of which the increase in food production, economic viability and environmental sustainability are the most important, however, in terms of water use, worldwide agricultural irrigation accounts for 70% of water consumption [1] and there is not a sufficiently optimized process for this activity.

It is estimated that the world population will increase by just over 40% in the next 30 years, which demands a 60% increase in food production [1], then it becomes crucial to identify solutions that prioritize productivity and economic benefits in agriculture. In response to the above, a wireless sensor network was designed and implemented, whose main functionality is based on precision agriculture, to monitor soil moisture and improve the efficiency of water and energy use, using low-power electronic devices and communication systems that optimize the overall performance within the agricultural irrigation processes.

Supported by UTB.

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J. C. Figueroa-García et al. (Eds.): WEA 2021, CCIS 1431, pp. 1–13, 2021.
https://doi.org/10.1007/978-3-030-86702-7_36

2 Agriculture in the Colombian Caribbean

In Colombia, in 2016, the share of the agricultural sector in water demand represented 43.1% of the entire country. 90% of this sector is supported by soil moisture from rainfall and the rest represents the deficit that is met by crop irrigation [2]. Productivity is affected by poor technical assistance and some of the essential permanent crops have a water use efficiency of 50%. With the inclusion of technology, there is great potential for improvement in the country's production systems [3].

In a region it is important to know the local resources that allow an adequate quality of life and work for human beings. To frame the problem and the justification of the Agro-Smart Caribe project, it is necessary to describe the climate, soil and crops of the Caribbean Region.

The region includes territories of the departments of Atlantico, Cesar, Cordoba, Bolivar, Magdalena, Sucre, and La Guajira. In these areas, the climate is almost 70% tropical, due to its location is the hottest region of the country, throughout the year can reach temperatures of up to 30 °C [4].

Relative humidity fluctuates between 77% and 82.5%. Humidity is lower in the winter months, although it is still high. Rainfall, meanwhile, occurs mostly in summer, especially between October and December, decreasing in the winter. The driest month is March, while the rainiest is October [5].

The soils have high nutrient and sodium contents and low levels of organic carbon. Bolívar and Sucre are departments with slightly drier soils, with slightly faster drainage and less fertile conditions due to the lack of water reservoirs [6].

Agriculture in the region has 1.3 million hectares planted, of which 28.5% are cereals, 25.8% are bananas and tubers, 23.4% are agro-industrial crops, 12.4% are fruit crops and 10% are other crops (legumes, forestry, etc.). [7]

Droughts are prolonged and produce water shortages continuously in departments of the Region. In percentage terms: Guajira (67%), Magdalena (50%), Sucre (35%), Bolivar (32%), Cesar (28%), Atlantico (26%) and Cordoba (10%).

In the Colombian Caribbean, water demand represents 12.1% of the agricultural productivity unit (UPA) in the country [8]. An analysis of technical assistance in the region shows, worryingly, that only 8 out of every 100 producers received training in crop care [7].

Precision agriculture was born in the face of relevant difficulties of the last two decades in the rural sector, such as the reduction of the labor force, the increase in the average age of farmers and the negative impact of certain practices [9]. Figure 1 shows the general cycle of precision agriculture.

Among the technologies used for precision agriculture are wireless sensor networks (WSN). WSN are networks of autonomous terminals that communicate with each other. These networks facilitate the implementation of applications such as remote monitoring in large crop areas. Therefore, within the field of agriculture, for constant monitoring activities of crop conditions, it becomes a valuable technology in productivity. The implementation of a monitoring system guarantees the following advantages: high autonomy, a long useful life of the devices, appropriate coverage in the monitoring areas, lower cost, ease of

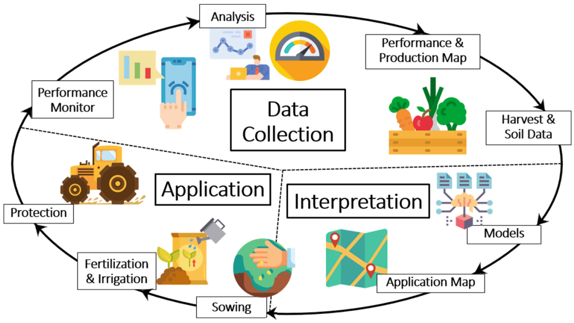

Fig. 1. Precision agriculture processes.

installation of devices, response time, low power consumption, accuracy, security, and the implementation of "IoT" (Internet of Things).

The Agro-Smart Caribe project, based on precision agriculture, contributes to the solution of the aforementioned problems. A prototype was developed for distributed soil moisture measurement dedicated to crops, based on wireless sensor networks together with a system capable of collecting, communicating, and storing data in the cloud.

3 Agro-Smart Caribe Architecture

To describe the monitoring solution implemented, the communication technology, hardware and software used to sense moisture in soils dedicated to crops is defined.

3.1 Communication Technologies

In the insertion of low-cost communication networks to assist agricultural processes, several types of data transmission protocols are identified with different characteristics that must be analyzed in search of a better solution according to the case study.

These communication protocols include: proximity technologies, personal area networks (PAN), wireless local area networks (WLAN), neighborhood and metropolitan area networks (WNAN and WMAN) and wide area networks (WAN). The latter are characterized by extending more than 50 km, which implies the use of licensed frequencies to avoid interference between different networks, as in the case of LoRaWAN, mobile communications (GSM) and Radio Frequency (RF) technologies.

Short-range technologies include Bluetooth, Ultra-wideband (UWB), Wi-Fi and Zigbee [10]. Table 1 shows a summary of the most important characteristics of the wireless technologies applied in agriculture.

Table 1. Main characteristics of wireless communication technologies.

Wireless communication technologies						
Technology	Frequency	Data rate	Range	Power	Cost	Application
GSM	Cellular bands	10 Mb/s	50 km	High	High	Mobile networks
Bluetooth	2.4 GHz	250 kb/s	20 m	Low	Low	Mobile credential
LoRa	<1 GHz	<50 kb/s	15 km	Low	Medium	Military, Space
Wi-Fi	2.4, 5 GHz	100 Mb/s	60 m	Medium	Low	LAN, Internet
ZigBee	2.4 GHz	250 kb/s	300 m	Low	Medium	Sensor networks

According to the information provided in Table 1, Zigbee technology was selected for the purposes of this project, since it has an adequate transmission coverage between devices, a sufficient data transfer rate, low energy consumption, low cost, good reliability and supports multiple devices in the same network. Additionally, it offers greater possibilities compared to other wireless protocols such as Bluetooth, since it allows using up to 65535 nodes distributed in subnets of 255 nodes, compared to the maximum 8 nodes possible in a Piconet subnet (Bluetooth). The Zigbee network architecture is presented in Fig. 2.

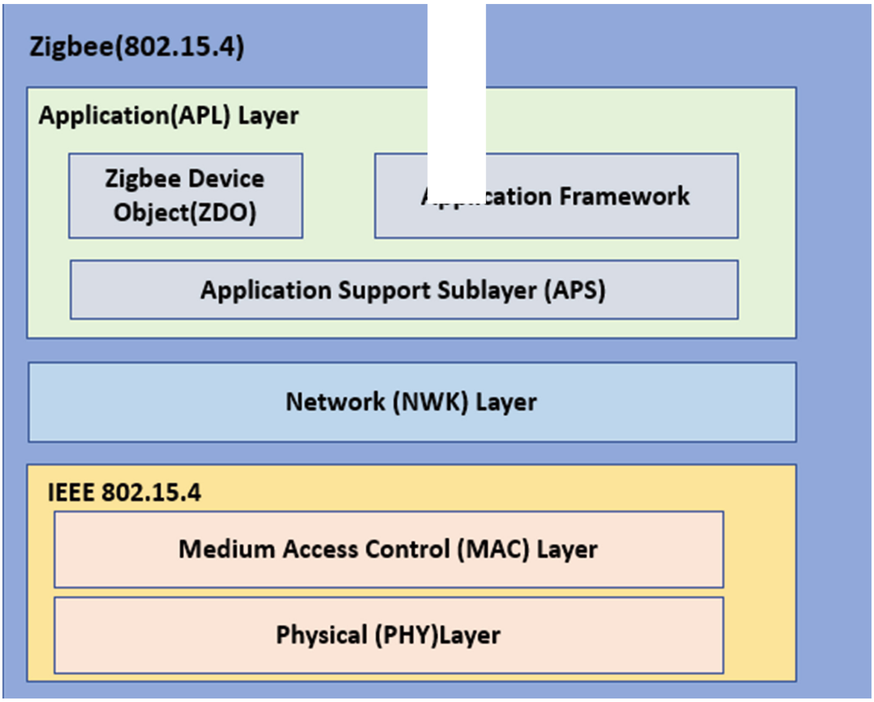

Fig. 2. Zigbee protocol stack

Each layer of the Zigbee protocol stack is described below:

- **Physical Layer:** the first concept of this protocol is to define the assigned bands and the number of channels for each band. There are 27 channels in total, one channel for the 868.3 MHz band, 10 for 915 MHz and 16 for 2.45 GHz. As an advantage, it is possible to maintain multiple communication channels on the same carrier frequency, by means of modulations such as BPSK, QPSK, and DSSS coding. For channel access, the method known as Carrier Sense Multiple Access with Collision Avoidance (CSMA-CA) is used, where the transmitter cannot use the channel if it detects that another node is using it to transmit. [11]
- **MAC Layer:** administers and manages access to the physical radio frequency channel, allowing the entry of nodes that are in the PAN or have been disconnected from it, thus managing RF data transactions between neighboring nodes. It also includes transmission retry and CSMA-CA acknowledgment, which generally makes use of the ACK frame between devices to verify errors when receiving packets [12].
- **Network Layer:** the network layer supports several topologies over which the transmission of information is carried out. The best known topologies are: star, cluster tree and mesh, as defined in the IEEE 802.15.4 standard. Networks implemented on this la[illegible]f the IEEE 802.15.4 standard must be self-organizing and self-maintain[illegible]n order to reduce overall costs to the consumer [13].
- **Application Layer:** this is the[illegible]rface Layer between the node and its users. It is divided into 3 sub-lay[illegible]
  - **Application Support Sub[illegible]r (APS):** coordinates communications between the network layer ([illegible]) and the different parts of the application layer.
  - **Zigbee Device Object (ZDO):** configures devices as coordinator, router or end-devices.
  - **Application environment:** generally an object seeks to have the functionality of an application. It is possible to address from 1 to 240 objects per device, of which 30 can operate at the same time [12].

3.2 Hardware

The structure of the moisture monitoring system is given set of sensor nodes, located in a cultivation area and the base station located in a protected site with Internet access. The network topology is a star configuration [10], where the nodes share soil moisture information with the base station to be transmitted to the IoT platform. The system schematic is shown in Fig. 3.

The following is a description of the Agro-Smart Caribe system from its 3 main components: the sensor nodes, the base station, and the internet cloud.

- **Sensor nodes:** contain a set of components to capture, process and send the variable to be measured to the base station. The modules are:
  - **Processing module:** represents the core of the sensor node and is composed of an Arduino ADK board with a MEGA 2560 microcontroller.

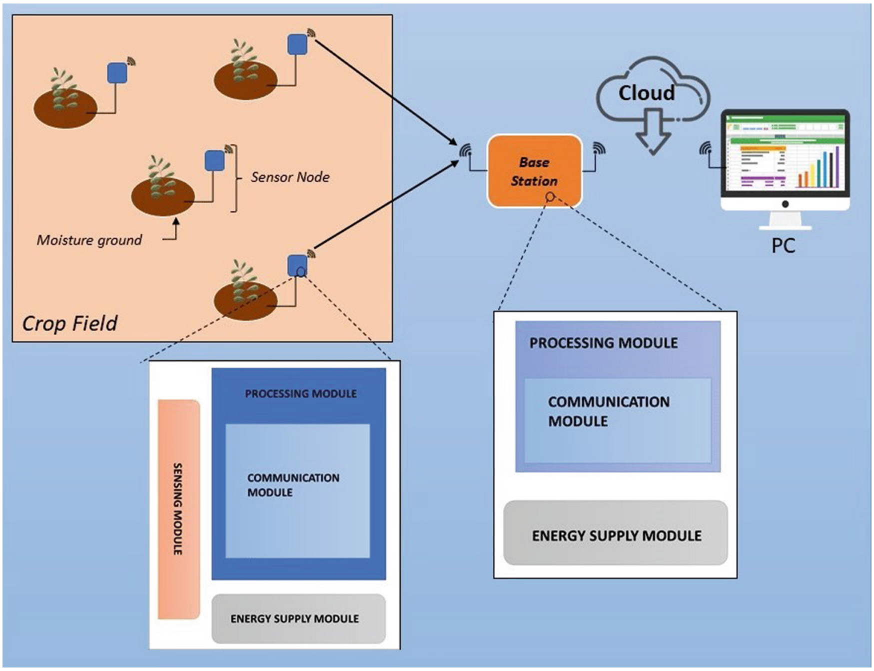

Fig. 3. General diagram of Agro-Smart Caribe

- **Communication module:** wirelessly communicates the sensor nodes with the base station. This module is based on the Zigbee protocol (IEEE 802.15.4) and the implemented device is the Xbee Pro S2C.
- **Sensing module:** it allows obtaining the physical magnitude of the humidity and then converting it to an electrical signal. It is composed of a FC-28 humidity sensor and a YL-38 conditioning card.
- **Power module:** comprises a rechargeable power supply, which corresponds to a 3.7 V lithium battery with a capacity of 5000 mAh.

– **Base Station:** facilitates the collection of the data sent by each sensor node and the processing and error control operations of the frames, and then transmits the data to the cloud. The components are:

- **Power module:** a conventional AC power supply and an AC-DC adapter with the following characteristics are used: 110/5 V at 3000 mA.
- **Communication module:**communicates the sensor nodes with the base station. This module is based on Zigbee technology and the implemented device is the Xbee Pro S2C in coordinator mode. There is also a wired/wifi connection for internet connection.
- **Processing module:**a raspberry pi 3b+ device is used. It allows to control, management, process and transfer of data between the WSN and the cloud.

– **Cloud:** computer service that processes and stores data through a network of servers. The Agro-Smart Caribe system uses an IoT platform that must be configured and programmed to store, process and manage the information on soil moisture under study.

Additionally, accessories were used to connect and ensure the protection of the electronic devices along with improving the stability of the sensor nodes located in the field. As shown in Fig. 4, the structure of each node is composed of a Dexon thermoplastic IP55 box of 18 × 14 × 8 cm, a 150 cm long tube with a diameter of half an inch, a 24 AWG conductor of 150 cm and an Xbee-Arduino adapter.

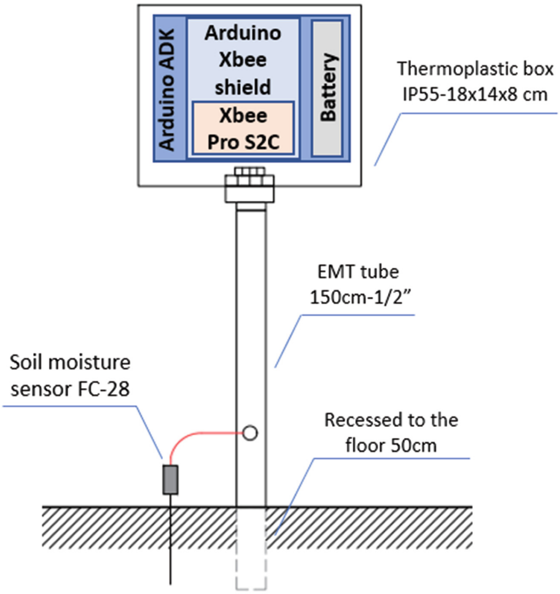

Fig. 4. Main components of a node structure

3.3 Software

To initiate the operation of the sensor network, a procedure is used that establishes a set of programmed steps in each device of the network. These programs are made with the objective of capturing, processing, storing and visualizing soil moisture data.

The processes implemented in the sensor network are illustrated in the flowchart in Fig. 5. It starts with the generation of an API broadcast frame [11] from the base station, which is sent to the sensor nodes using the Zigbee protocols. The nodes, upon receiving the request frame, proceed to measure the moisture of the ground through the FC-28 sensor. This data will be encapsulated in a new API frame and transmitted to the base station. The base station then stores the frames in its buffer and evaluates them to check if the information is correct. If there are errors or if the information is not received within a certain time, one or more unicast request frames are retransmitted to the corresponding node, where the number of possible retransmissions is defined by the user.

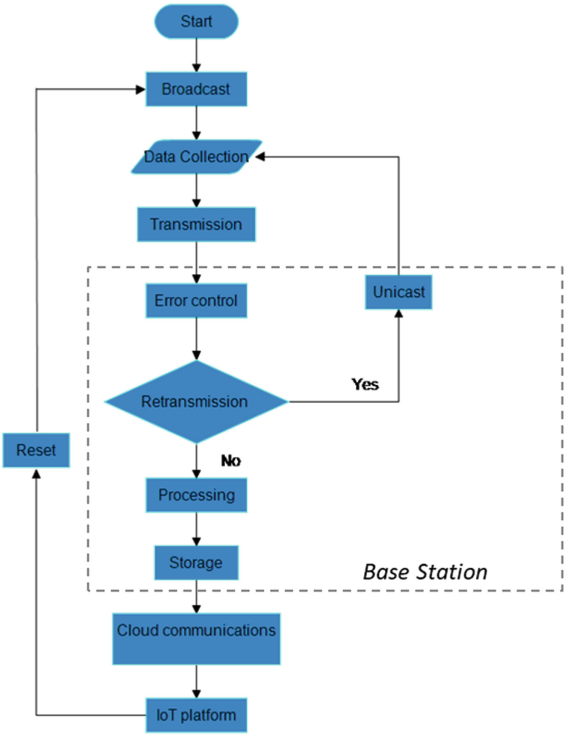

Fig. 5. General flowchart

For error control, the frames used in device communication are of fixed length. In this way the base station recognizes specific positions. Table 2 shows the structure of the designed frame and the position that each one occupies in the 16 bytes of the frame.

The frame fields called start byte, length, and the checksum (CRC) are used by the coordinator to detect errors and are unmodifiable in the process. This allows for better reliability of the moisture data provided by the sensor nodes.

Communication security is one of the strong points of ZigBee, implementing its security model according to the IEEE 802.15.4 standard. This provides access control mechanisms of the devices to the network with authentication, encryption

Table 2. Unicast frame structure

0x7E	MSB	LSB	0x90	ID Router	ID Network	Data	Checksum
1	2	3	4	5–12	13–15	16, 17	18
Start byte	Length		Frame type: transmission	Device addresses (global & local)		Content	Frame check

using symmetric key cryptography and integrity ensuring that the transmitted frames are not manipulated with message integrity checks.

To access the cloud, the client-server model incorporated in the TCP-IP protocols is used. On the other hand, the IoT platform performs the storage and processing operations of the soil moisture information under study, for its visualization in real time through the Agro-Smart Caribe interface.

4 Results

The project developed Agro-Smart Caribe allows to measure in a distributed way, the moisture of soil using a network of up to 12 sensor nodes in star topology together with the base station and access to the cloud.

For the implementation of the soil moisture measurement system Agro-smart Caribe, the following steps were carried out: i) location of the sensor nodes, ii) activation of the base station, iii) synchronization of the network elements, iv) parameterization of the graphical interface, v) registration, storage, processing, and visualization of soil moisture data, and vi) presentation of the performance of the communications network on the IoT platform.

The tests performed show an average frame transmission performance of 97.5%. On the other hand, the reliability of the moisture data obtained is 90% compared to tensiometric techniques, which is adequate according to studies on soil moisture, such as, the information of the Soil Water Characteristic Curve (SWCC) [14].

For the study of soil moisture, a range scale was established in order to define the soil type based on SWCC. Table 3 is presented below.

Table 3. Soil moisture classification

Moisture	Very low	Low	Medium	High
Bits	1023–850	850–400	400–300	300–200

Table 4 presents a test of the system in a plot with a configuration of 4 sensor nodes in star topology with the coordinator node and a sampling cycle of 3 h over a day.

The physical structure of the sensor nodes placed in the field is shown in Fig. 6. The communication (Xbee), processing (Arduino) and power (lithium

Table 4. Moisture record of the soil under study.

Cycle	1	2	3	4	5	6	7	8	9
Average (bits)	870	858	788	648	600	445	410	353	305

battery) modules are shown together with the thermoplastic box and the metal tube that protects the ground connection with the moisture sensors.

(a) Structure (b) Location

Fig. 6. Sensor nodes

For the visualization of the basic configuration of the measurement system and the captured data, an interface was developed as shown in Fig. 7.

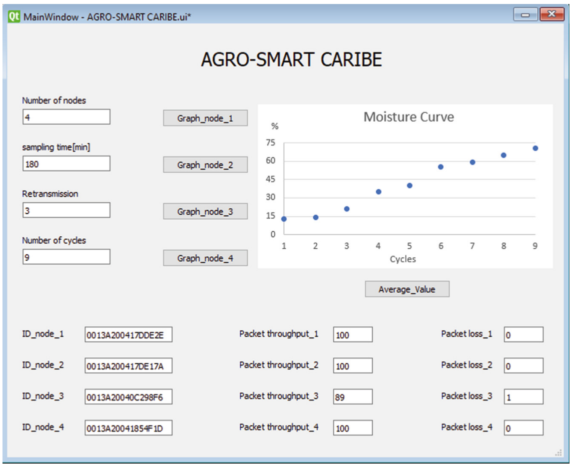

Fig. 7. Agro-Smart Caribe interface

5 Conclusions and Future Works

In the Colombian agricultural sector, agriculture accounts for 35% at the national level and 33% in the Caribbean region. In addition, the use of automated systems is lagging in the agricultural sector given that only 12 out of 100 producers have machinery dedicated to the production process, which translates into inadequate productivity for this region. For this reason, this area has enormous potential for agro-industrial exploitation given its diversification of agricultural flora and its size.

A project was developed to measure soil moisture in a distributed way called Agro-Smart Caribe, with a data reliability of 90%, an energy saving of 93% respect to other similar technologies and a loss of information packages of 2.5%, which allows a potential implementation in the rural Caribbean sector, providing farmers with an excellent monitoring and visualization of moisture in large areas for 24 h a day.

As a reference, the following illustrations show systems developed for soil moisture collection based on wireless sensor networks (WSN). Figure 8a shows the implementation of a WSN to measure moisture in a strawberry crop in Pasto, Colombia [15]. Figure 8b shows the use of this technology for the acquisition of crop parameters in Villa Clara, Cuba [16].

(a) (b)

Fig. 8. WSN implementations for crop moisture.

The cost-benefit ratio starts at a value of less than US$130 for each node of the prototype developed. Given the technological need exposed together with government plans, it is possible to massify the Agro-Smart system to increase productivity in the Colombian Caribbean Region.

In the future it is necessary to continue with the development of the automated irrigation system for crops that allows water distribution and flow control, according to the moisture information provided by the prototype developed for this purpose, along with a hydraulic system, a control mechanism, local storage of information, scalability, agricultural irrigation system (drip, sprinkler, subway) and add the reading of other variables such as temperature, pH, solar radiation, along with the chemical and physical composition of the soil and water.

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