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## IoT-Based System Prototype to Control Maize Cultivation on an Agroecological Farm

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**Abstract:** The purpose of this study was to develop and test a prototype IoT-based system for maize cultivation control at an agroecological farm. The novelty of this study lies in addressing the crisis of depletion of natural resources, food scarcity, and reduction of production costs through innovative and sustainable solutions to support future food and environmental security initiatives. The impact on the problem is that the implementation of automation techniques in Colombian agriculture could reduce costs, improve the quality and consistency of crops, and increase the competitiveness of farmers in the market. The methodology involved four phases: number evaluation, monitoring the operation of the IoT, design and implementation of the electronic system, and testing and maintenance. The research was conducted using a quantitative theoretical-practical approach. The results allowed us to provide solutions and contribute to XBee S2C technologies, the integration of a monitoring and control system that operates over long distances, managing real-time data, automating processes with a high degree of security for irrigation, and improving decision-making and efficiency in water management. The study enabled the implementation of RF devices, which helped ensure secure communication between nodes without data loss, which is essential for irrigation control systems.

**Keywords:** precision agriculture, maize cultivation, internet of things, sensors, control system.

## 基于物联网的系统原型用于控制农业生态农场的玉米种植

### 摘要:

本研究的目的是开发和测试一个基于物联网的原型系统，用于农业生态农场的玉米种植控制。这项研究的新颖之处在于通过创新和可持续的解决方案来解决自然资源枯竭、粮食短缺和降低生产成本的危机，以支持未来的粮食和环境安全举措。对这个问题的影响是，在哥伦比亚农业中实施自动化技术可以降低成本，提高作物的质量和一致性，并提高农民在市场上的竞争力。该方法涉及四个阶段：数字评估、监控物联网的运行、电子系统的设计和实施以及测试和维护。这项研究采用定量的理论实践方法进行。结果使我们能够提供解决方案并为XBee

S2C技术、远程运行的监控和控制系统的集成、管理实时数据、高度安全的灌溉自动化流程以及改善水管理的决策和效率做出贡献。该研究实现了射频设备的实施，有助于确保节点之间的安全通信而不会丢失数据，这对于灌溉控制系统至关重要。

**关键词：**精准农业、玉米种植、物联网、传感器、控制系统。

## 1. Introduction

Several of the sustainable development goals (SDGs) established by the United Nations (UN) for 2030 are focused on promoting projects to alleviate global hunger, achieve food security, and improve nutrition by promoting smart and sustainable agriculture. This is in response to the problems associated with traditional agriculture where various environmental factors, such as global warming, can affect the quantity and quality of food, generating great concern due to the growing worldwide demand for food [1]. Therefore, the implementation of new and innovative technologies, such as the internet of things (IoT), is necessary.

By using sensors to capture large amounts of data for subsequent analysis [2], IoT can help promote smart and sustainable agriculture. IoT can be understood as a worldwide network of components connected to the internet that are embedded in many objects, with the ability to obtain data on physical and electrical variables. It was estimated that in 2014, there were about 16 billion such components. By 2020, this number had grown to 41 billion [3], and it is believed that by 2025, the figure will reach 75 billion, covering various sectors [4]. In this sense, the pervasiveness of IoT facilitates technologies such as databases, Big Data, and machine learning that, through the development of artificial intelligence algorithms, are capable of identifying behavioral patterns that enhance conditions in sectors such as health, education, economy, and, notably, agriculture [5, 6], where it is necessary to control variables such as temperature, pH, and humidity to make more efficient use of fertilizers, water, and energy used in irrigation systems [7].

This gives rise to the concept of precision and smart agriculture, which relies on the use of communication networks and technologies such as GPS and wireless sensors to capture and transmit relevant data for the industry [8].

This is of vital importance, particularly for the agricultural sector, which requires more optimal planting processes at farms [9] and where the IoT devices installed must obtain data repeatedly, which will allow farmers to know the current status, make faster and more accurate decisions in the face of emerging environmental situations, and make crops more productive and profitable [10].

The literature review identified research by Badran

and Kashmoola [11], Brewster et al. [12], Delnevo et al. [13], González et al. [14], Madruga et al. [15], Maraveas et al. [16], Nageswara and Sridhar [17], Sierra et al. [18], Vera et al. [19], and Wongchai et al. [20], related to the IoT and precision agriculture where sensors are used to measure humidity and temperature, among other variables, which laid the conceptual, methodological, technical, and practical foundations of this research.

During the 20th and early 21st centuries, maize was the most produced cereal, surpassing wheat and rice. In industrialized countries, maize is primarily used as fodder, raw material for the production of processed foods and ethanol. In contrast, in some Latin American countries, production is intended for human consumption. Maize accounts for almost 16% of total caloric intake in Asia, Latin America, and Sub-Saharan Africa. In Colombia, it is one of the main crops for the food sector, with an expected production growth of 6% and demand of 9% between 2018 and 2030 [21]. The harvest time is almost 6 months and it does not require large amounts of water and fertilizers for its growth, in addition to providing a large amount of essential micronutrients, such as iron, zinc, and vitamin A, essential for growth and disease prevention, which is why it is one of the main foods called to combat world hunger [22].

Unidad Central del Valle del Cauca (UCEVA) is a higher education institution located in Tuluá, Colombia. Currently, it has an agroecological farm that is primarily used as a center for research and academic training for Environmental Engineering and Agricultural Engineering students. They have been working on precision agriculture for various crops such as maize, plantain, banana, and fruit trees.

In maize cultivation, the permissible soil moisture deficit ranges between 50% and 55%, and the ideal temperature is between 24°C and 35°C. When the temperature is high, the root loses the ability to absorb water. Temperatures in Tuluá range from 23°C to 37°C. In addition, the farm has sandy soil, which is not optimal for the healthy growth of this crop; therefore, it is important to control and monitor these variables.

For these reasons, the present project aims to develop a prototype IoT-based system to monitor humidity and temperature variables and control the irrigation system of maize crops at the Agroecological Farm at UCEVA.

## 2. Methodology

The research was carried out under a quantitative approach of theoretical-practical nature. The system prototype was implemented through the following four phases (Fig. 1):

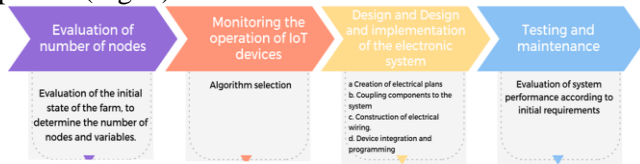


Fig. 1 Methodology (The authors)

Evaluating the number of nodes required and the variables that affect the maize cultivation: the initial state of the farm and the area assigned for the crop, which is 40 m<sup>2</sup> (5-m front x 8-m depth), were evaluated to identify which devices were adequate for monitoring and how many were necessary. After this evaluation, we determined that eight nodes were necessary. The selected devices were Arduino Nano, Arduino UNO, and XBee. The variables to be sensed were also identified according to the needs of the farm, establishing minimum and maximum ranges for temperature (24°C and 34°C) and humidity (80% and 100%).

*Monitoring of the operation of the devices:* A monitoring of some processes that integrate an IoT system was conducted, in this case, which algorithms would be the best for the variable control part. Also, what other things could adhere to the project in relation to the amount of information obtained and the operation of the equipment before starting the project.

*Design and implementation of the electronic system:* Once the variables and required performance of the devices were identified, the technology to be used was established. The following steps were taken: a) creation of electrical drawings in compliance with the already imposed specifications; b) coupling of components to the system; c) construction of the electrical wiring; d) integration and programming of devices.

*Testing and maintenance:* With the help of the agronomist in charge of the farm and other advisors, the system's performance was evaluated according to the initial requirements.

### 2.1. Research Objective

Research on maize crop automation addresses several significant factors. Maize is a plant with high nutritional properties, notably high carbohydrate, vitamin, and essential mineral contents. Additionally, its versatility allows it to be consumed in various forms and transformed into flour for long-term preservation, facilitating its storage and distribution.

Maize cultivation presents challenges that justify automation, such as the need for constant monitoring and adequate irrigation. These tasks, traditionally performed by specialized personnel, increase production costs. Automation presents itself as a viable

solution for reducing these costs and increasing agricultural efficiency and productivity.

### 2.2. Application of the Findings

In Colombia, the climate and geography are ideal for maize cultivation, which is fundamental to local cuisine. The implementation of automation techniques in Colombian agriculture could reduce costs, improve crop quality and consistency, and increase farmers' competitiveness in the market. This will have positive economic and social impacts, promoting more sustainable and efficient agricultural development.

## 3. Results

### 3.1. Technology Description

In the implementation of the sensor network, XBee technology and Arduino were used. The XBee modules belong to the S2C series, each with its own development board. This series was selected due to its economic accessibility, range with respect to distance, compatibility with other technologies, and scalability with respect to programming. The Arduino models used included NodeMCU, Arduino Nano, and Arduino UNO. NodeMCU boards were selected based on their built-in IEEE 802.11 b/g/n Wi-Fi module, which allows for internet connection. For this reason, they were used in the central node. Arduino Nano was selected because it is inexpensive and the final nodes require devices that are easy to implement and program. Arduino UNO was used because it can be powered with 12 V, the same required by the solenoid valve for irrigation control. Also, the RF modules and an H-bridge were added to this node to control the motor.

The solenoid valve used was the EBOWAN HSY4K model, which is designed for low-viscosity fluids and water. The operating voltage is 12 VDC, with a solenoid current of 320 mA, nominal power of 8 W, nominal diameter of 8 mm, operating temperature range of -5°C to 60°C, and water outlet pressure between 0.02 and 0.8 MPa. The minimum required pressure is 0.02 MPa or 3 PSI, and it operates in a unidirectional manner.

In two-way valves, typically, those that operate in three different modes are used, depending on their intended use. These modes can be direct, indirect, or mixed or combined action, and each of these categories can be normally closed (N.C.) or normally open (N.O.), depending on the function it is going to perform; either it is closed and when it receives the signal to the solenoid, it opens for a few seconds or is open; when it receives the signal, the solenoid cuts the flow. The H-bridge to control the solenoid valve allows motor activation via a 5-V pulse sent by Arduino UNO. The H-bridge allows a DC electric motor to rotate in both directions (forward and reverse).

An SHT10 sensor, a precise and industrial-grade instrument, was employed. This sensor is capable of

measuring temperature and humidity and is compatible with Arduino. It possesses a humidity measurement range of 0~100% RH with an accuracy of  $\pm 4.5\%$  RH. For temperature measurements, its range extends from  $-40$  to  $+123.8^{\circ}\text{C}$  with an accuracy of  $\pm 0.5^{\circ}\text{C}$ . The sensor exhibits a response time of 8 s and operates at a voltage range of 2.4-V to 5.5-V DC. The sensor's connections are as follows: Yellow: Data, Blue: CLK, Black: GND, and Brown: 5VDC.

As for the power supply type, two types of batteries were used: one 12-V and five 6-V batteries. The batteries are of the stationary type and specially designed for continuous-use applications with medium-high consumption; they can be completely discharged and recharged without any damage. The 12-V battery was the reference MAGNA MA 7-12, and the 6-V battery was the MAGNA MA 4-6. Each end node had an approximate consumption of 0.0416 A and a duration of four days before discharge. The control node had an approximate power consumption of 0.0729 A and an approximate duration of 4 days before discharge, and the central node had an approximate power consumption of 0.0833 A and an approximate duration of 2 days before discharge.

### 4. Design Stage

#### 4.1. Sensor Network

For the sensor network design, the adaptation of the irrigation system, and the implementation of the remote system for the activation of the solenoid valve that allows the passage of water, the area of the maize cultivation, the separation of 80 cm between each row, and the separation of 15 cm between each plant were considered (Fig. 2).

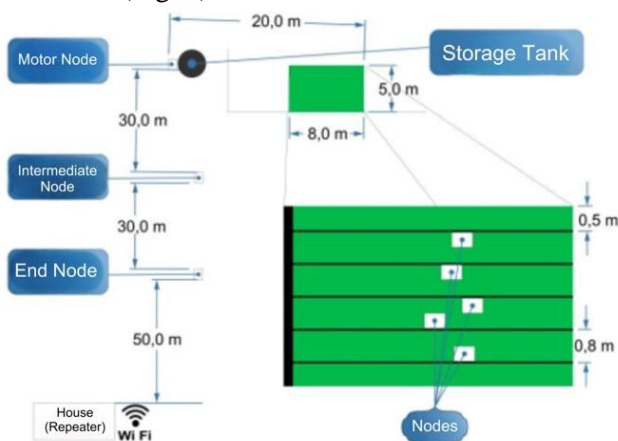


Fig. 2 Distribution of the nodes used (The authors)

The sensor distribution was carried out with a network with star topology, which offers various benefits in terms of connectivity and security.

The sensor network is composed of a central node that receives data from the end nodes and uploads them to the application through the internet. The central node has an RF device, which provides wireless connectivity, and a microcontroller that processes the

received information and uploads it to the network by sending the data in the JSON format using the HTTP header with the GET method.

In addition, the network includes seven end nodes. Six of the end nodes are responsible for sending the humidity and temperature data obtained by the sensors to the central node, while a seventh node controls the irrigation system for the crop. Each end node is composed of an RF device to send data to the central node or receive a command to turn on the irrigation system. The irrigation system includes a solenoid valve that opens or closes depending on the soil moisture and temperature; therefore, six of the end nodes have sensors to monitor the variables that need to be controlled.

The nodes communicate with each other using the IEEE 802.15.4 protocol, and the data are formatted as JSON files and sent over the internet through a Wi-Fi module that uses the IEEE 802.11g protocol (Fig. 3).

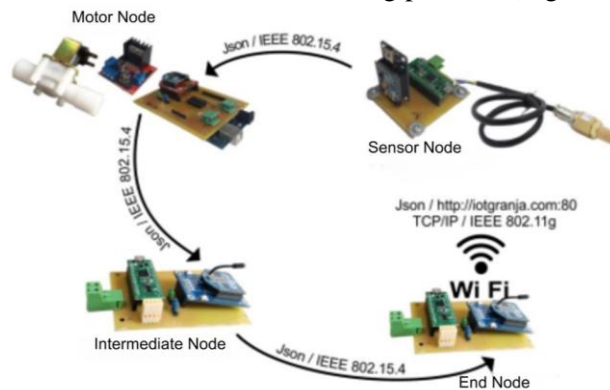


Fig. 3 Sensor network (The authors)

#### 4.2. Electronic Circuits of the Nodes

The design of the nodes was based on a block diagram, as shown in Fig. 4. Here, we describe the process of each node until reaching the central node.

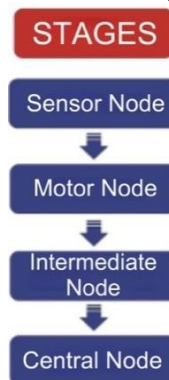


Fig. 4 Block diagram of the sensors (The authors)

*Sensor node:* In Fig. 5, a block diagram of each of the sensor nodes located on the farm is shown.



Fig. 5 Block diagram of the sensor node (The authors)

**Motor node:** Fig. 6 shows the block diagram of the node that enables irrigation control in cultivation.

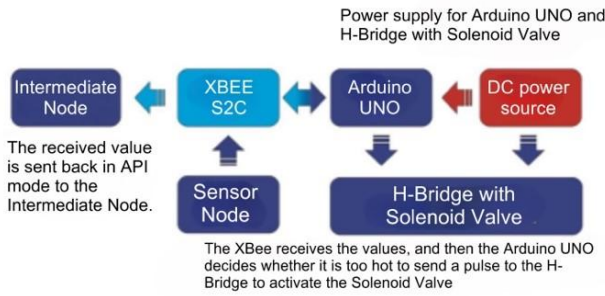


Fig. 6 Block diagram of the motor node (The authors)

Fig. 7 shows a schematic of the motor node.

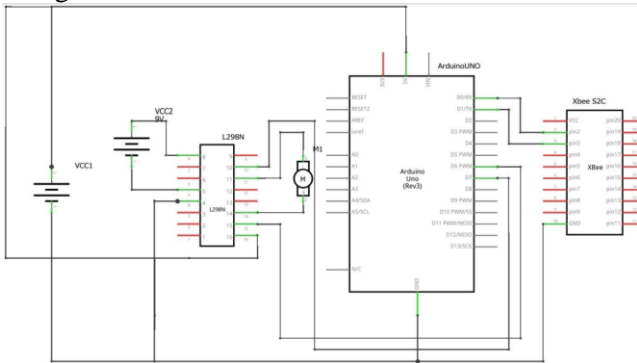


Fig. 7 Schematic of the motor node (The authors)

**Intermediate node:** Fig. 8 shows a block diagram of the intermediate node, which acts as a bridge between the sensor nodes and the central node.

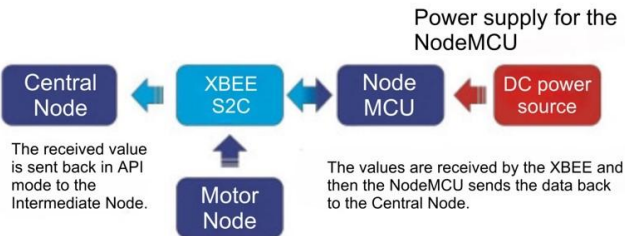


Fig. 8 Block diagram of the intermediate node (The authors)

Fig. 9 shows a schematic of the sensor nodes.

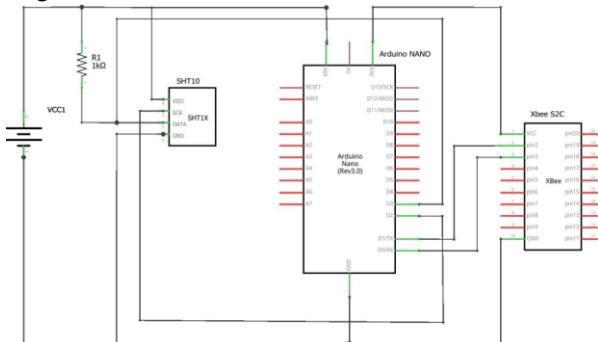


Fig. 9 Schematic of the end nodes (The authors)

**Central node:** Fig. 10 shows a block diagram of the central node, which receives data from the intermediate node and allows data transmission to the internet.

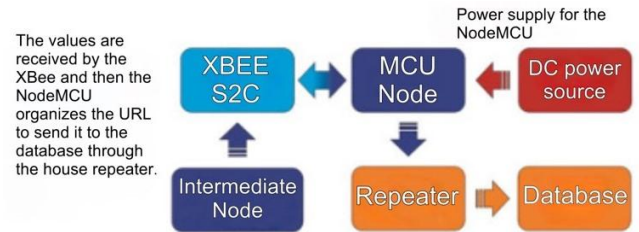


Fig. 10 Block diagram of the central node (The authors)

Fig. 11 schematizes the central node.

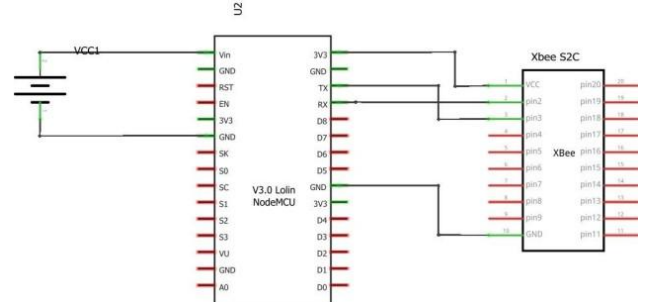


Fig. 11 Schematic of the central node (The authors)

### 4.3. Printed Circuit Board for the Irrigation Control Module

For the module, an Arduino Nano was used to control the irrigation system and the XBee. This system has a solenoid valve that opens or closes depending on the soil moisture and temperature. For this reason, six of the sensor nodes have sensors to monitor the variables that need to be controlled. Fig. 12 shows that the traces are connected to the driver, which allows for the transformation from 12 V to 5 V, which is the voltage required by the solenoid valve.

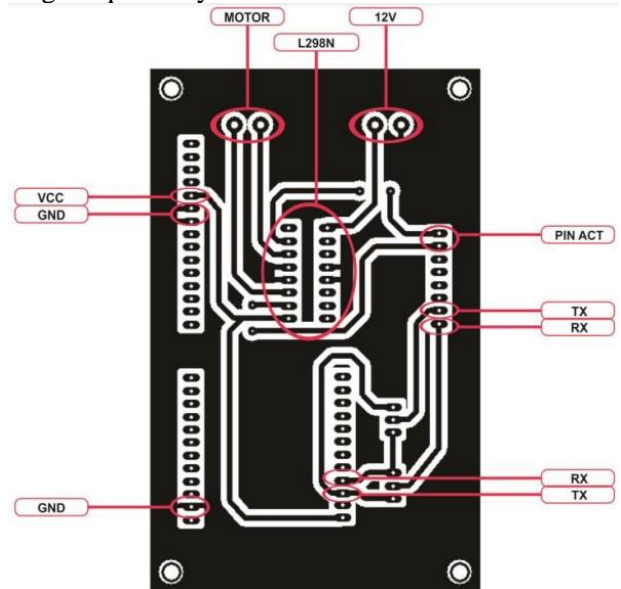


Fig. 12 Printed circuit board for the irrigation control module (The authors)

### 4.4. Printed Circuit Boards for the Soil Monitoring Module

Two circuits were designed for soil monitoring. Both circuits were implemented using Arduino Nano, XBee, and temperature and humidity sensors (Fig. 13). The second printed circuit board has the same design as

the first circuit board, except that the XBee is positioned in an inverted manner to facilitate interconnection, as shown in Fig. 14.

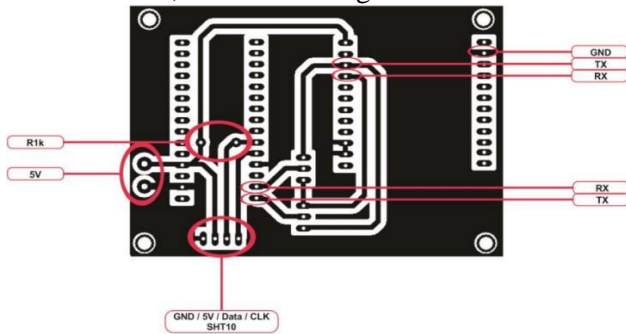


Fig. 13 Printed circuit board for the irrigation control module (The authors)

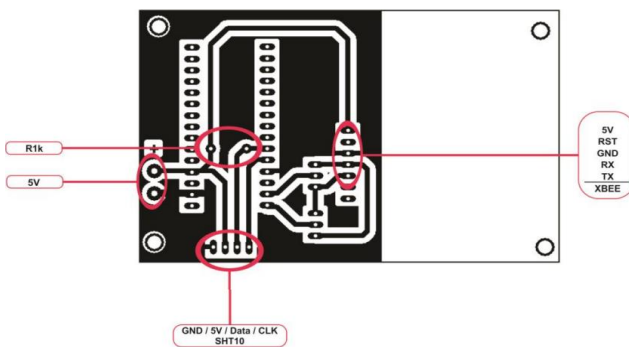


Fig. 14 Printed Circuit Board 2 for the soil monitoring module (The authors)

#### 4.5. Printed Circuit Board for the Central Node Data Reception Module

This was designed to receive data from end nodes and send them to the application over the internet in the JSON format using the HTTP header with the GET method. This printed circuit board is connected to NodeMCU and does not have a sensor because it is the central node (Fig. 15).

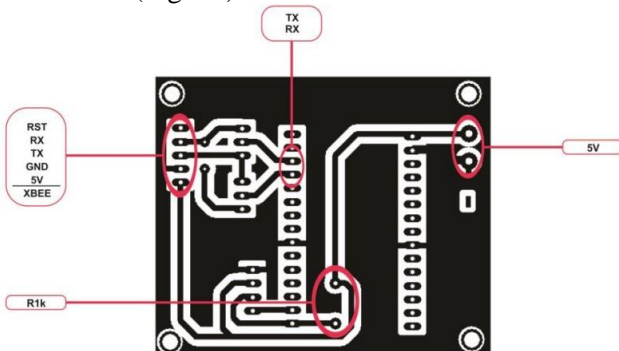


Fig. 15 Printed Circuit Board 2 for the data reception module of the central node (The authors)

#### 4.6. Diagram of Data Control Deployment

Variable logging was designed and implemented as an all-or-nothing control for opening the solenoid valve. An API was used for data reception, providing secure and structured data transmission. Fig. 16 shows the deployment diagram for the entire system and the path that the sensed data take to reach the database for storage.

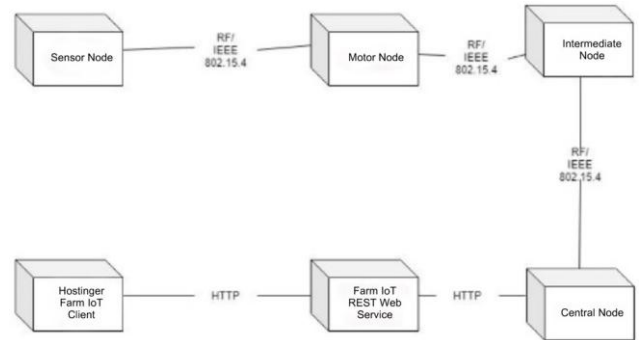


Fig. 16 Diagram of data control deployment (The authors)

## 5. Implementation

### 5.1. Nodes

The system shown in Fig. 17 corresponds to the implementation of the entire system as a whole, composed of: a) the power supply battery and system startup to enable its operation; b) the sensor located 15 cm in the crop soil; c) the Arduino Nano, which functions as a bridge for the inclusion of XBee S2C, which sends the data.



Fig. 17 Implementation of one of the nodes, Arduino Nano and XBee S2C (The authors)

### 5.2. Data Transmission Frames

In Fig. 18, a frame sent from Node Sensor A to the node motor can be observed, written in hexadecimal every 8 bits.



Fig. 18 Data transmission frame between Sensor Node A and the motor node (The authors)

### 5.3. Soil Temperature and Humidity Monitoring System

Fig. 19 shows the system implemented at the agroecological farm. It is responsible for sensing soil variables. In this case, there are five nodes, each with a sensor located at a depth of approximately 15 cm and responsible for providing the central node with temperature and humidity readings. Each node is protected from rain and sunlight by an acrylic box.



Fig. 19 Soil temperature and humidity monitoring system (The authors)

### 5.4. Irrigation System

Fig. 20 shows the implemented irrigation system, which has a 250-L supply tank to feed the crop irrigation system. The irrigation system works by gravity, and the passage of water required to supply the crop is controlled by a solenoid valve that is either activated or deactivated depending on the soil variables. For this reason, each sensor must be at an appropriate depth, ensuring a reading that allows for timely activation or deactivation.



Fig. 20 Irrigation system (The authors)

The monitoring system operates with eight nodes. There are five nodes that allow sensing crop variables; another node enables proper functioning of the irrigation system by allowing the passage of water.

### 5.5. Source Code for Operating the Central Node

This code is oriented for the operation of the central node, which receives data from the bridge node (solenoid valve) and sends it to the database (Internet). This node is always active waiting for data to be received. The following is the implemented source code.

```
#include <XBee.h>
XBee xbee = XBee();
XBeeResponse response = XBeeResponse();
ZBRxResponse rx = ZBRxResponse();
long XBee_Addr64_MS;
long XBee_Addr64_LS;
#include <ESP8266WiFi.h>
const char* ssid = "12345";
const char* password = "abcd1234";
const char* host = "192.100.0.1";
//const char* login = "alvaro";
//const char* clave = "12345";

void setup() {
  Serial.begin(9600);
  xbee.begin(Serial);
  pinMode(2,OUTPUT);
  digitalWrite(2,HIGH);
  delay(10);
  Serial.println();
  Serial.println();
  Serial.print("Conectandose a ");
  Serial.println(ssid);

  WiFi.mode(WIFI_STA);
  WiFi.begin(ssid, password);
  digitalWrite(2,LOW);

  while (WiFi.status() != WL_CONNECTED) {
    delay(500);
    Serial.print(".");
  }
  Serial.println("");
  Serial.println("WiFi conectado");
  Serial.println("Direccion IP: ");
  Serial.println(WiFi.localIP());
  digitalWrite(2,HIGH);
}

void loop() {
  String sample = "";
  digitalWrite(2,HIGH);
  xbee.readPacket();
  if (xbee.getResponse().isAvailable()) {
    Serial.println(xbee.getResponse().getApiId());
    if (xbee.getResponse().getApiId() ==
        ZB_RX_RESPONSE) {
      xbee.getResponse().getZBRxResponse(rx);
      for (int i = 0; i < rx.getDataLength(); i++) {
        sample += (char)rx.getData(i);
      }
      Serial.println(sample);
    }
  }
}
```



```

XBee xbee = XBee();
XBeeResponse response = XBeeResponse();
ZBRxResponse rx = ZBRxResponse();
ZBTxStatusResponse txStatus =
ZBTxStatusResponse();
long XBee_Addr64_MS;
long XBee_Addr64_LS;
int XBee_Addr16=0;
boolean Slp = false;
boolean Sen = false;
#include <SHT1x.h>
#define dataPin 3
#define clockPin 2
SHT1x sht1x(dataPin, clockPin);
#include <LowPower.h>

void setup() {
  Serial.begin(9600);
  xbee.begin(Serial);
  //pinMode(2,OUTPUT);
}
void loop() {
  String sample;
  float temp_c;
  float temp_f;
  float humidity;
  temp_c = sht1x.readTemperatureC();
  temp_f = sht1x.readTemperatureF();
  humidity = sht1x.readHumidity();
  xbee.readPacket();

  if (xbee.getResponse().isAvailable()) {
    Serial.println(xbee.getResponse().getApiId());
    if (xbee.getResponse().getApiId() ==
ZB_RX_RESPONSE) {
      xbee.getResponse().getZBRxResponse(rx);
    }
    }else if (xbee.getResponse().isError()) {
      Serial.println("Error reading packet. Error
code: ");
    }
    Serial.println(xbee.getResponse().getErrorCode());
  }
  //delay(2000);
  if (temp_c >= 100 & humidity < 0 ){
    Sen = false;
  }else{
    Sen = true;
  }

  if(Slp == true){
    delay(500);
    for (int i = 0 ; i < 225 ; i++){
      LowPower.powerDown(SLEEP_8S,
ADC_OFF, BOD_OFF);
    }
    Slp = false;
  }
}

String x1 = String(temp_c,DEC);
String x2 = String(humidity,DEC);
uint8_t data[] =
{'B',x1.charAt(0),x1.charAt(1),x1.charAt(2),x1.cha
rAt(3),'
','B',x2.charAt(0),x2.charAt(1),x2.charAt(2),x2.cha
rAt(3)};

XBeeAddress64 addr64 =
XBeeAddress64(0x0013a200, 0x41517349);
ZBTxRequest zbTx = ZBTxRequest(addr64, data,
sizeof(data));
//ZBTxRequest zbTx = ZBTxRequest(addr64,
XBee_Addr16,
ZB_BROADCAST_RADIUS_MAX_HOPS,
ZB_TX_UNICAST, data, sizeof(data),
xbee.getNextFrameId());
if(Sen == true){
  xbee.send(zbTx);
  delay(500);
}
if (xbee.readPacket(500)) {
  if (xbee.getResponse().getApiId() ==
ZB_TX_STATUS_RESPONSE) {
xbee.getResponse().getZBTxStatusResponse(txStatus);
  if (txStatus.getDeliveryStatus() ==
SUCCESS) {
    digitalWrite(13,HIGH);
    Slp = true;
  } else {
    digitalWrite(13,LOW);
  }
} else {
}
delay(500);
digitalWrite(13,LOW);
}
}

```

### 5.7. Source Code for Irrigation Control

The purpose of the code is to activate or deactivate the solenoid valve, which controls the irrigation system, depending on the humidity and temperature readings of the sensors. The solenoid valves are activated at temperatures above 34°C and deactivated at temperatures below 25°C. On the other hand, the solenoid valve is activated at humidity below 80% and deactivated at humidity above 80%.

This node also serves as a data bridge, meaning that it receives and delivers data from the end nodes to the central node. This is due to the limited internet network range and the distance between the central device and the end nodes. It also reduces the distance and ensures that the reception of data from the central nodes is

optimal. The implemented source code is shown below.

```

#include <XBee.h>
XBee xbee = XBee();
XBeeResponse response = XBeeResponse();
ZBRxResponse rx = ZBRxResponse();
long XBee_Addr64_MS;
long XBee_Addr64_LS;

void setup() {
  Serial.begin(9600);
  xbee.begin(Serial);
}

void loop() {
  String sample;
  xbee.readPacket();
  if (xbee.getResponse().isAvailable()) {
    Serial.println(xbee.getResponse().getApiId());
    if (xbee.getResponse().getApiId() ==
ZB_RX_RESPONSE) {
xbee.getResponse().getZBRxResponse(rx);
for (int i = 0; i < rx.getDataLength(); i++) {
  sample += (char)rx.getData(i);
}
  Serial.println(sample);
  XBee_Addr64_MS=(uint32_t(rx.getFrameData()[0])
<< 24) + (uint32_t(rx.getFrameData()[1]) << 16) +
  (uint16_t(rx.getFrameData()[2]) << 8) +
rx.getFrameData()[3];
  XBee_Addr64_LS=(uint32_t(rx.getFrameData()[4])
<< 24) + (uint32_t(rx.getFrameData()[5]) << 16) +
  (uint16_t(rx.getFrameData()[6]) << 8) +
rx.getFrameData()[7];
  Serial.print("Addr64 MS: ");
  Serial.print(XBee_Addr64_MS,HEX);
  Serial.print("\n");
  Serial.print("Addr64 LS: ");
  Serial.print(XBee_Addr64_LS,HEX);
  Serial.print("\n");

  if(sample != ""){
    digitalWrite(2,LOW);
    String Adree1 = String(XBee_Addr64_MS,HEX);
    String Adre1 = "";
    String Adree2 = String(XBee_Addr64_LS,HEX);
    String Adre2 = "";
    String ID = "";
    String TEMP = "";
    String HUM = "";
    int Temp=0;
    int Hum =0;

    if (Adree2 == "4151734c"){
      Adre1 += "0013A200";
      Adre2 += "4151734C";
    }
    if (Adree2 == "417688cd"){
      Adre1 += "0013A200";
      Adre2 += "417688CD";
    }
    if (Adree2 == "417688b6"){
      Adre1 += "0013A200";
      Adre2 += "417688B6";
    }
    if (Adree2 == "410a3ede"){
      Adre1 += "0013A200";
      Adre2 += "410A3EDE";
    }
    if (Adree2 == "410a3edf"){
      Adre1 += "0013A200";
      Adre2 += "410A3EDF";
    }
    if (Adree2 == "415c98e4"){
      Adre1 += "0013A200";
      Adre2 += "415C98E4";
    }
    ID += sample.charAt(0);
    TEMP += sample.charAt(1);
    TEMP += sample.charAt(2);
    TEMP += sample.charAt(3);
    TEMP += sample.charAt(4);
    Temp=TEMP.toInt();

    HUM += sample.charAt(7);
    HUM += sample.charAt(8);
    HUM += sample.charAt(9);
    HUM += sample.charAt(10);
    Hum=HUM.toInt();

    sample = "";
    uint8_t data[] =
{ID.charAt(0),TEMP.charAt(0),TEMP.charAt(1),TEM
P.charAt(2),TEMP.charAt(3),"ID.charAt(0),HUM.cha
rAt(0),HUM.charAt(1),HUM.charAt(2),HUM.charAt(3
),' ', Adre1.charAt(0),Adre1.charAt(1),
Adre1.charAt(2), Adre1.charAt(3),Adre1.charAt(4),
Adre1.charAt(5), Adre1.charAt(6),
Adre1.charAt(7), ' ', Adre2.charAt(0),Adre2.charAt(1),
Adre2.charAt(2), Adre2.charAt(3),
Adre2.charAt(4), Adre2.charAt(5),
Adre2.charAt(6),Adre2.charAt(7),};

    XBeeAddress64 addr64 =
XBeeAddress64(0x0013a200,0x4155F796);
    ZBTxRequest zbTx = ZBTxRequest(addr64, data,
sizeof(data));
    ZB_BROADCAST_RADIUS_MAX_HOPS,
    ZB_TX_UNICAST, data, sizeof(data),
xbee.getNextFrameId());
    xbee.send(zbTx);
    if (Temp >= 34 || Hum <= 80){
      digitalWrite(7,HIGH);
      delay(60000);

```

```
digitalWrite(7,LOW);
}
if ( Temp < 25 || Hum > 80){
  digitalWrite(7,LOW);
}
}
else if (xbee.getResponse().isError()) {
  Serial.println("Error reading packet. Error code: ");
  Serial.println(xbee.getResponse().getErrorCode());
}
delay(100);
}
```

Fig. 21 and 22 show the hysteresis curves for temperature and humidity. The temperature curve exhibits a hysteresis of 9°C, while the humidity curve shows a hysteresis of 20%. The purpose of these curves is to ensure that the solenoid valve does not turn on or off at uncertain levels, which can occur due to noise in the system. Increasing the hysteresis range eliminates the possibility of system instability due to noise.

For both implementations, the API mode was used for data transmission and reception to ensure the security of the procedure. In addition, this mode provides confirmation that the data are received.

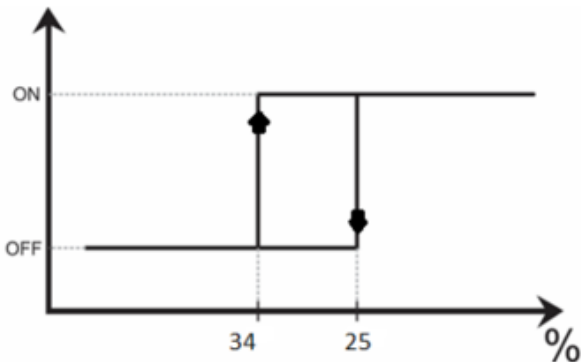


Fig. 21 Hysteresis curve for temperature (The authors)

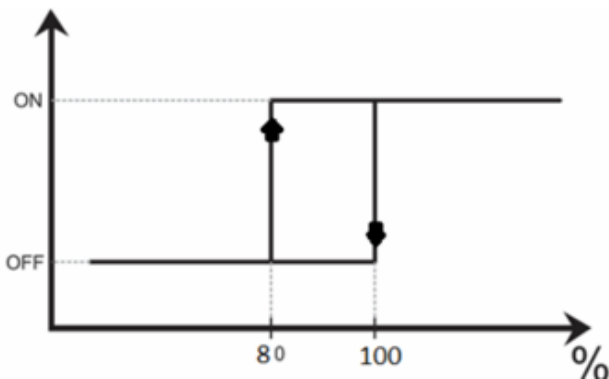


Fig. 22 Hysteresis curve for humidity (The authors)

### 5.8. Cultivation Control Application

The purpose of the application is to facilitate the visualization and management of maize cultivation in real time and from any locations. This functionality enables the farm manager to accurately assess whether the crop is at critical points.

For the operation of the application, it was necessary to acquire a space on a public hosting

platform that implements an SSL certificate to authenticate the identity of the website, enables an encrypted connection, and executes an RESTful web service. A database was created on the server with three tables. The Node table stores node identification (primary key), node alias, and IP address. The 'detalle\_nodo' table stores the data captured by each node, i.e., node identification, humidity, temperature, and capture date. Finally, the 'users' table stores the relevant data of users with access to the application.

Two files were created in the PHP language on the application server. One file inserts the information captured by the sensors into the database through a GET request from Arduino to the rented hosting, which performs data validation (Fig. 23). The other file is executed through a GET request via a URL and returns a JSON with the information of the queried node (Fig. 24).



Fig. 23 Screenshot of data from a sensor (The authors)

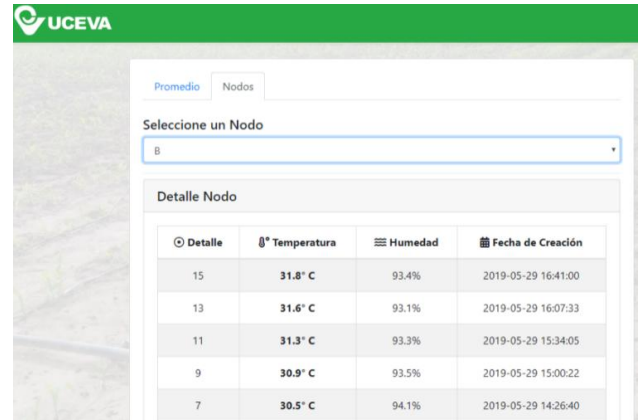


Fig. 24 Node details (The authors)

The application also allows real-time monitoring of the current state of the humidity (Fig. 25) and temperature (Fig. 26) variables captured by the sensor network through dynamic graphs. In both graphs, the "y" axis shows the data as a function of the variable, and the "x" axis shows the number of samples taken.

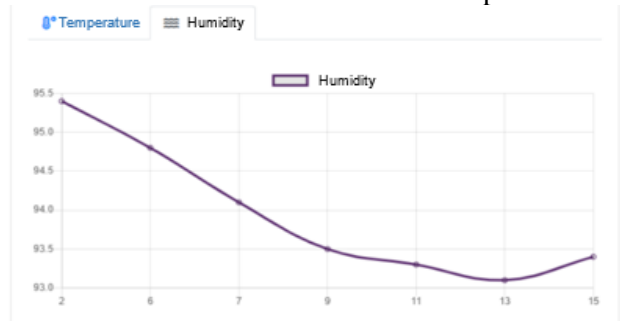


Fig. 25 Temperature graph (The authors)

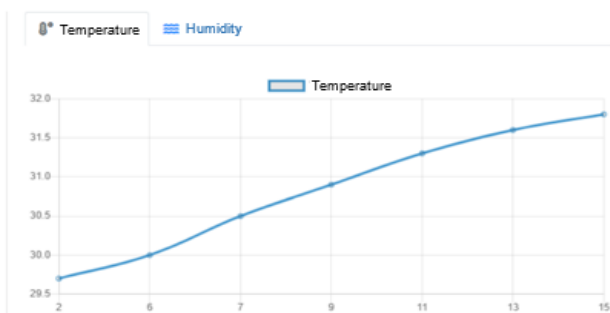


Fig. 26 Humidity graph (The authors)

## 6. Conclusions

This project facilitates the application of the IoT technology in agriculture by providing a realistic view of its use and the integration of the different technologies involved and demonstrates their performance in practice.

The implementation of RF devices helped ensure secure communication between nodes without data loss, which is essential for irrigation control systems. The bandwidth provided by the XBee devices was essential due to the considerable distance between each node, thus eliminating the necessity for alternative RF devices.

Among the important findings of this project is the difference between the theoretical values and the values obtained in practice. XBee S2C devices theoretically have a range of 120 meters outdoors, but in practice, their range was a maximum of 60 meters due to obstacles between each node, such as plants and trees. This finding was an inconvenience for the project because the main node required an Internet connection to transmit the monitored data. Therefore, this node had to be located near the internet access point, which was approximately 150 m from the cultivation area, necessitating the installation of an additional Internet repeater and positioning the central node near it. Additionally, to ensure data transmission and reception, two nodes were used as bridges to shorten the distance between the end nodes and the central node. These bridges receive and send data to the central node.

Another important finding is the performance of alkaline batteries, which must also consider the consumption of microcontrollers. These batteries last approximately two months because the XBee S2C devices have relatively low consumption, but the microcontrollers responsible for processing the information and determining how the data are sent increased the consumption, reducing the battery life to two days. This difference is significant compared to what was theoretically studied, so it was necessary to install higher-power batteries to achieve greater autonomy for each node.

The control prototype was tested under two climatic conditions. The first period was when the days were very rainy, so the humidity was very high and the temperature was very low. Over time, the weather

changed to a dry state, generating more heat, meaning that humidity was lower and temperature was higher. In this scenario, irrigation control was more active, which, according to the researchers, allowed them to determine whether the prototype was successful and met the stated objectives.

After the project development, it was determined that IoT facilitates data management and the interconnection of devices at a considerable distance, making it easier to know the current state of the cultivation from any location concerning the monitored variables through the designed web application. This helped better interpret what was happening in real time on the farm and allowed us to obtain a historical record of the monitored variables, determining their general state and condition.

Finally, for future implementations and prototype improvements, it is recommended to implement the project in a larger area to determine whether the proposed approach can improve crop productivity on a large scale. Finally, we encourage the use of other types of sensors to expand the number of variables that can be controlled during cultivation.

## References

- [1] ZHANG P., ZHANG J., and CHEN M. Economic impacts of climate change on agriculture: The importance of additional climatic variables other than temperature and precipitation. *Journal of Environmental Economics and Management*, 2017, 83: 8–31. <https://doi.org/10.1016/j.jeem.2016.12.001>
- [2] NUÑEZ D., BENAVIDES E., RODRÍGUEZ G., and SALAZAR D. Propuesta de una Plataforma de Bajo Costo Basada en Internet de las Cosas para Agricultura Inteligente. *Cumbres*, 2020, 6(1): 53-66. <https://doi.org/10.48190/cumbres.v6n1a5>
- [3] CASTRO D., CORAL W., CABRA J., COLORADO J., MÉNDEZ D., and TRUJILLO L. Survey on IoT solutions applied to healthcare. *DYNA*, 2017, 84(203): 192-200. <https://doi.org/10.15446/dyna.v84n203.64558>
- [4] BENITEZ V., PACHECO J., MORENO J., and NUÑEZ C. Autonomic Face Mask Detection with Deep Learning: An IoT Application. *Revista mexicana de ingeniería biomédica*, 2021, 42(2): 160–170. <https://doi.org/10.17488/rmib.42.2.13>
- [5] LASSO CARDONA L. A. Technological trends: A focus on citizen security. *Ingeniería Solidaria*, 2021, 17(1): 1–28. <https://doi.org/10.16925/2357-6014.2021.01.02>
- [6] QUEIROZ D. M. D., COELHO A. L. D. F., VALENTE D. S. M., and SCHUELLER J. K. Sensors Applied to Digital Agriculture: A Review. *Revista Ciência Agronômica*, 2020, 51(5): e20207751. <https://doi.org/10.5935/1806-6690.20200086>
- [7] MONTOYA E., COLORADO S., MUÑOZ W., and GOLONDRINO G. Propuesta de una Arquitectura para Agricultura de Precisión Soportada en IoT. *Revista Iberica de Sistemas e Tecnologias de Informacao*, 2017, 24: 39-56. <https://doi.org/10.17013/risti.24.39-56>
- [8] ISLAM N., RASHID M., PASANDIDEH F., RAY B., MOORE S., and KADEL R. A Review of Applications and Communication Technologies for Internet of Things (IoT) and Unmanned Aerial Vehicle (UAV) Based Sustainable

- Smart Farming. *Sustainability*, 2021, 13(4): 1821. <https://doi.org/10.3390/su13041821>
- [9] LIMA G. C., FIGUEIREDO F. L., BARBIERI A. E., and SEKI J. Agro 4.0: Enabling agriculture digital transformation through IoT. *Revista Ciência Agronômica*, 2020, 51(5): e20207771. <https://doi.org/10.5935/1806-6690.20200100>
- [10] SEGUI PADRÓN G. G., & ARTELES BRITO J. F. Proposal of a 5G service for smart agriculture in Cuba. *Revista Cubana de Transformación Digital*, 2022, 3(1): e135. <https://rctd.uic.cu/rctd/article/view/135>
- [11] BADRAN A., & KASHMOOLA M. Smart Agriculture; Farm Irrigation System Using IoT. *AL-Rafidain Journal of Computer Sciences and Mathematics*, 2020, 14(2): 75–83. <https://doi.org/10.33899/csmj.2020.167340>
- [12] BREWSTER C., ROUSSAKI I., KALATZIS N., DOOLIN K., and ELLIS K. IoT in Agriculture: Designing a Europe-Wide Large-Scale Pilot. *IEEE Communications Magazine*, 2017, 55(9): 26–33. <https://doi.org/10.1109/MCOM.2017.1600528>
- [13] DELNEVO G., GIRAU R., CECCARINI C., and PRANDI C. A Deep Learning and Social IoT Approach for Plants Disease Prediction toward a Sustainable Agriculture. *IEEE Internet of Things Journal*, 2022, 9(10): 7243–7250. <https://doi.org/10.1109/JIOT.2021.3097379>
- [14] GONZÁLEZ CÁRDENAS J. O., FIGUEROA MILLÁN P. E., AMEZCUA VALDOVINOS I., and BENAVIDES DELGADO J. R. Diseño arquitectural de una plataforma IoT para la monitorización ambiental aplicada en viveros de plantas de Ornato. *3C TIC: Cuadernos de desarrollo aplicados a las TIC*, 2022, 11(1): 223–249. <https://doi.org/10.17993/3ctic.2022.111.223-249>
- [15] MADRUGA A., ESTEVEZ A., SOSA R., GARCIA C., and SANTANA I. Red de Sensores Inalámbricos para la Adquisición de Datos en Casas de Cultivo. *Ingeniería*, 2019, 24(3): 224–234. <https://doi.org/10.14483/23448393.14437>
- [16] MARAVEAS C., PIROMALIS D., ARVANITIS K. G., BARTZANAS T., and LOUKATOS D. Applications of IoT for optimized greenhouse environment and resources management. *Computers and Electronics in Agriculture*, 2022, 198: 106993. <https://doi.org/10.1016/j.compag.2022.106993>
- [17] RAO R. N., & SRIDHAR B. IoT based smart crop-field monitoring and automation irrigation system. Proceedings of the 2nd International Conference on Inventive Systems and Control, Coimbatore, 2018, pp. 478–483. <https://doi.org/10.1109/ICISC.2018.8399118>
- [18] SIERRA J., MEDINA B., and VESGA J. Management system in intelligent agriculture based on Internet of Things. *Espacios*, 2018, 39(8): 20. <https://www.revistaespacios.com/a18v39n08/18390820.html>
- [19] VERA J., CONEJERO W., MIRA-GARCÍA A. B., CONESA M. R., and RUIZ-SÁNCHEZ M. C. Towards irrigation automation based on dielectric soil sensors. *The Journal of Horticultural Science and Biotechnology*, 2021, 96(6): 696–707. <https://doi.org/10.1080/14620316.2021.1906761>
- [20] WONGCHAI A., SHUKLA S. K., AHMED M. A., SAKTHI U., JAGDISH M., and KUMAR R. Artificial intelligence - enabled soft sensor and internet of things for sustainable agriculture using ensemble deep learning architecture. *Computers and Electrical Engineering*, 2022, 102: 108128. <https://doi.org/10.1016/j.compeleceng.2022.108128>
- [21] GOVAERTS B., VEGA D., CHÁVEZ X., NARRO L.A., SAN VICENTE GARCIA F. M., PALACIOS-ROJAS N., PÉREZ M., GONZÁLEZ G., ORTEGA P., CARVAJAL A., ARCOS A. L., BOLAÑOS J., ROMERO N., VANEGAS Y. F., ECHEVERRÍA R. G., JARVIS A., JIMÉNEZ D., RAMÍREZ-VILLEGAS J., KROPFF W., GONZALEZ C., NAVARRO-RACINES C. E., ORDÓÑEZ L., PRAGER S. D., and TAPASCO J. *Maíz Para Colombia Visión 2030*. Centro Internacional de Mejoramiento de Maíz y Trigo, México, 2019. <https://repository.cimmyt.org/entities/publication/a67bf02b-f3b4-4971-8e19-4773a56342fe>
- [22] DONOVAN M. Innovación agrícola para combatir el hambre oculta. *Centro Internacional de Mejoramiento de Maíz y Trigo*, 2019. <https://www.cimmyt.org/es/noticias/combatiendo-el-hambre-oculta-con-la-innovacion-agricola/>

### 参考文献:

- [1] ZHANG P., ZHANG J., 和 CHEN M. 气候变化对农业的经济影响：温度和降水以外的其他气候变量的重要性。环境经济与管理杂志，2017，83：8-31. <https://doi.org/10.1016/j.jeem.2016.12.001>
- [2] NUÑEZ D., BENAVIDES E., RODRÍGUEZ G. 和 SALAZAR D. 基于物联网的低成本平台提案农业情报。孔布雷斯，2020，6(1)：53-66. <https://doi.org/10.48190/cumbres.v6n1a5>
- [3] CASTRO D., CORAL W., CABRA J., COLORADO J., MÉNDEZ D. 和 TRUJILLO L. 医疗保健领域物联网解决方案调查。动力，2017，84(203): 192-200. <https://doi.org/10.15446/dyna.v84n203.64558>
- [4] BENITEZ V., PACHECO J., MORENO J. 和 NUÑEZ C. 自主面罩检测深度学习：物联网应用。墨西哥生物医学工程杂志，2021年，42(2)：160–170. <https://doi.org/10.17488/rmib.42.2.13>
- [5] LASSO CARDONA L. A. 技术趋势：关注公民安全。《团结工程》，2021，17(1)：1–28. <https://doi.org/10.16925/2357-6014.2021.01.02>
- [6] QUEIROZ D. M. D., COELHO A. L. D. F., VALENTE D. S. M. 和 SCHUELLER J. K. 应用于数字农业的传感器：综述。农业科学杂志，2020，51(5)：e20207751. <https://doi.org/10.5935/1806-6690.20200086>
- [7] MONTROYA E., COLORADO S., MUÑOZ W. 和 GOLONDRINO G. 物联网精准农业建筑方案。伊比利亚信息系统和技术杂志，2017年，24：39-56. <https://doi.org/10.17013/risti.24.39-56>

- [8] ISLAM N., RASHID M., PASANDIDEH F., RAY B., MOORE S. 和 KADEL R. 应用和通信技术综述基于物联网 (IoT) 和无人机 (UAV) 的可持续智能农业。可持续发展, 2021, 13(4): 1821。 <https://doi.org/10.3390/su13041821>
- [9] LIMA G. C., FIGUIREDO F. L., BARBIERI A. E. 和 SEKI J. 农业4.0: 通过物联网实现农业数字化转型。农业科学杂志, 2020, 51(5): e20207771。 <https://doi.org/10.5935/1806-6690.20200100>
- [10] SEGUI PADRÓN G. G., & ARTILES BRITO J. F. 古巴智慧农业5G服务提案。古巴数字转型回顾, 2022年, 3(1): e135。 <https://rctd.uic.cu/rctd/article/view/135>
- [11] BADRAN A. 和 KASHMOOLA M. 智能农业; 使用物联网的农场灌溉系统。拉菲丹计算机科学与数学杂志, 2020年, 14(2): 75–83。 <https://doi.org/10.33899/csmj.2020.167340>
- [12] BREWSTER C., ROUSSAKI I., KALATZIS N., DOOLIN K. 和 ELLIS K. 农业中的物联网: 设计欧洲范围内的大规模试点。IEEE通信杂志, 2017年, 55(9): 26–33。 <https://doi.org/10.1109/MCOM.2017.1600528>
- [13] DELNEVO G., GIRAU R., CECCARINI C. 和 PRANDI C. 用于植物病害预测以实现可持续农业的深度学习和社交物联网方法。IEEE物联网杂志, 2022年, 9(10): 7243–7250。 <https://doi.org/10.1109/JIOT.2021.3097379>
- [14] GONZÁLEZ CÁRDENAS J. O., FIGUEROA MILLÁN P. E., AMEZCUA VALDOVINOS I. 和 BENAVIDES DELGADO J. R. 在生活环境监测应用中设计物联网平台架构奥尔纳托植物玫瑰。3C TIC: TIC的应用程序, 2022, 11(1): 223–249。 <https://doi.org/10.17993/3ctic.2022.111.223-249>
- [15] MADRUGA A., ESTEVEZ A., SOSA R., GARCIA C. 和 SANTANA I. 用于数据采集的无线传感器网络文化之家。工程师, 2019, 24(3): 224–234。 <https://doi.org/10.14483/23448393.14437>
- [16] MARAVEAS C., PIROMALIS D., ARVANITIS K. G., BARTZANAS T. 和 LOUKATOS D. 物联网在优化温室环境和资源管理中的应用。农业中的计算机和电子技术, 2022, 198: 106993。 <https://doi.org/10.1016/j.compag.2022.106993>
- [17] RAO R. N. 和 SRIDHAR B. 基于物联网的智能农田监测和自动化灌溉系统。第二届国际会议论文集发明系统与控制, 哥印拜陀, 2018年, 第478-483页。 <https://doi.org/10.1109/ICISC.2018.8399118>
- [18] SIERRA J., MEDINA B. 和 VESGA J. 基于物联网的智能农业管理系统。埃斯帕西奥斯, 2018, 39(8): 20。 <https://www.revistaespacios.com/a18v39n08/18390820.html>
- [19] VERA J., CONEJERO W., MIRA-GARCÍA A. B., CONESA M. R. 和 RUIZ-SÁNCHEZ M. C. 基于介电土壤传感器的灌溉自动化。期刊园艺科学与生物技术学报, 2021, 96(6): 696–707。 <https://doi.org/10.1080/14620316.2021.1906761>
- [20] WONGCHAI A., SHUKLA S. K., AHMED M. A., SAKTHI U., JAGDISH M. 和 KUMAR R. 人工智能支持软传感器和物联网以实现可持续发展使用集成深度学习架构进行农业研究。计算机与电气工程, 2022年, 102: 108128。 <https://doi.org/10.1016/j.compeleceng.2022.108128>
- [21] GOVAERTS B., VEGA D., CHÁVEZ X., NARRO L.A., SAN VICENTE GARCIA F.M., PALACIOS-ROJAS N., PÉREZ M., GONZÁLEZ G., ORTEGA P., CARVAJAL A., ARCOS A.L., BOLAÑOS J., ROMERO N., VANEGAS Y.F., Echeverria R.G., JARVIS A., JIMÉNEZ D., RAMIREZ-VILLEGAS J., KROPFF W., GONZALEZ C., NAVARRO-RACINES C.E., ORDÓÑEZ L., PRAGER S.D. 和 TAPASCO J. 玉米哥伦比亚愿景2030。玉米和玉米粒国际研究中心, 墨西哥, 2019。 <https://repository.cimmyt.org/entities/publication/a67bf02b-f3b4-4971-8e19-4773a56342fe>
- [22] DONOVAN M. 农业创新。玉米和玉米粒国际梅乔拉米恩托中心, 2019年。 <https://www.cimmyt.org/es/noticias/combatiendo-el-hambre-oculta-con-la-innovacion-agricola/>