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ORIGINAL ARTICLE

Temperature-Humidity Recording System Applied to a Hexapod Robot for Artificial Pollination in Agriculture

Sistema de registro de temperatura-humedad aplicado a robot hexápodo para polinización artificial en la agricultura

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ABSTRACT: This paper presents the research results in the design of a radio frequency module to send humidity and temperature data to a Host-Local for management of information in a database. The operability of the system was achieved through the design of a Graphical User Interface, which was designed in JAVA language. The emitter module is installed on the back of a hexapod robot, designed for complex walks in agricultural lands, which in the future has the mission of carrying out artificial pollination processes. The technical objectives of the project are referred, as well as the maps of the software design through the UML diagram resource, the description of the layers of the software architecture for sending data, the design of the GUI and its connection with the local database created in MySQL. Finally, the graphic evidence of the operation of the system, the assembly in the hexapod robot and the technical conclusions with goals to work on future results are shown.

Keywords: Transmitter Module. Database, Graphical User Interface, Software Architecture..

RESUMEN: En el presente artículo se expone los resultados de investigación, en el diseño de un módulo de radio frecuencia que permite el envío de datos de humedad y temperatura, a un Host-Local para la administración de la información en una base de datos, la operatividad del sistema se logró por medio del diseño de una Interfaz Gráfica de Usuario, la cual se diseñó en lenguaje JAVA, el módulo emisor es instalado en el dorso de un robot hexápodo, diseñado para caminatas complejas en terrenos de agricultura, que a futuro tiene la misión de realizar procesos de polinización artificial. Se exponen los objetivos técnicos del proyecto, también los mapas del diseño de software a través del recurso de diagramas UML, la descripción de las capas de la arquitectura de software para el envió de datos, el diseño de la GUI y su conexión con la base de datos local creada en MySQL, finalmente se muestran las evidencias gráficas del funcionamiento del sistema, montaje en el robot hexápodo y las conclusiones técnicas con metas para trabajar en resultados a futuro.

Palabras clave: módulo emisor, base de datos, Interfaz Gráfica de Usuario, arquitectura de software.

INTRODUCTION

Robotics in agriculture is a topic that has become relevant in the context of the digital revolution, whether it is called agriculture 4.0 (automation) or the new definition of agriculture named 5.0 (robotics and artificial intelligence), it is a dichotomy of merely theoretical discussion, but in practice, IoT technologies, BigData, augmented reality, machine learning, etc., are tools that are covering new terrains to transmute the forms of popular, mechanized or automated agriculture into the new formats of the robotization of the field.

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Robotics contains a range of multiple formats from VANT's or, better known as drones, to android-type robots that one day, not too far away, will be a tool of science fiction applied to our reality of technological evolution. Robots inspired by insect zoomorphology is one of the many strands of the types of application robots that are under development. Among them are robots of hexapod format, which are devices bio-inspired in insects, arachnids and others. Tripod, quadrupeds and hexapods robots are common, among whose advantages is the easy adaptation to complex terrains. Due to its anatomy, a hexapod robot can move in complex terrain thanks to the mechanical flexibility of its links that allow to maintain its center of mass at a stable equilibrium point. (Barrientos, 2002; Zabalza y Ros, 2007; Medina, 2016; Miret, 2016; Mercader, 2017; Rubio y Daniel, 2017; Alvarado *et al.*, 2019; Pomba, 2019). On the other hand, the acquisition of data during the walk of these robots for the collection of information in a database is an essential task existing different ways to perform this activity, from the collection of records to be stored in memories in the creation of a history, to the sending in real time of the collection data with IoT tools (Thompson y Aguayo, 2009; Medina, 2016; Mickle, 2016; Miret, 2016; Cajal, 2018; Marlin P. Jones and Associates inc, 2018; Pomba, 2019).

Some systems inspired by the displacement of hexapod-type robots are found in works such as "Implementation of a mapping and localization system to a hexapod robot focused on the exploration of the environment and temperature monitoring" Alvarado *et al.* (2019), on the other hand, works such as: "Design and Implementation of a Simultaneous Location and Mapping System (SLAM)" Barrientos (2002); Narváez y Yandún (2013); Cajal (2018), allow the mapping of robots in complex walking processes, applying intelligent algorithms for the improvement of processes. Finally, in relation to data acquisition applied in agriculture, telemetry techniques are implemented for the creation of LAN networks in the punctual administration of greenhouses, as explained in: "Wireless monitoring system for greenhouse crops" (González *et al.*, 2012).

MATERIALS AND METHODS

General Characteristics of the Project

The expected result is a prototype of a hexapod robot, explorer of complex terrains for application of artificial pollination on crops, while the goals of the project are divided into: short, medium and long term. For this purpose, various activities will be carried out in a virtual laboratory for simulation and testing, as well as the manufacture of devices ranging from the fuselage to the complementary modules, to finally carry out physical tests. The design of an RF module for the acquisition of temperature (°C) and humidity (%RH) samples with a geolocation matrix will be carried out for their storage in a Local-Host (Local Database Access Point). As an analysis product there are: 1) RF Receiver Module 2.4 Ghz with COM connection; 2) and RF Emitter Module 2.4 Ghz gadget type for surface mounting on the back of hexapod robot. These elements constitute only one phase of all those that make up the final objective. The diagram in Figure 1 shows the goals of the project.

Technical objective of the implement: Design of a system for acquisition of temperature-humidity data in remote form.

Technical specifications:

- 2.4 Ghz RF wireless transmitter and receiver module with 2 Mbps data sending range and low power consumption;
- Design of PCBs in SMD format with component installation ergonomics;
- Hardware firmware design and high-level interface for dynamic management and easy operation;
- Mounting flexibility for robot fuselage emitter module;
- Protective housings for receiver module.

Software requirements: Graphical User Interface (GUI) for control and administration of the remote system, in the management and administration of temperature and humidity sampling at the geolocation point obtained.

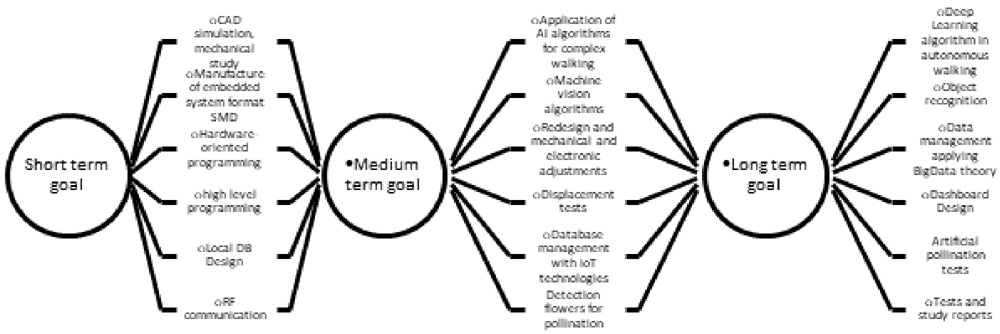

FIGURE 1. Engineering goals for hexapod robot in artificial pollination processes (Own Authorship).
Application Requirements.

Software Use Case Specifications: These are specified in Table 1.

Process for Selecting the Humidity-Temperature Sensor

The temperature and relative humidity data are captured by an HTU21D sensor; the decision point of the data acquisition device was not mere coincidence. To perform a deep search of the different sensors, the authors placed as a primary aspect the following criteria:

1. Accessibility of product purchase
2. Sales stock
3. Avoid imports
4. Technical operational characteristics

Most temperature and humidity sensors offer precision ranges ranging in relative humidity from ±2%RH to ±5%RH with an average humidity hysteresis: ± 1% RH, and in temperature ±2°C to ±1°C with approximate measurement times of 50ms-2s, for this the technical study of the datasheets of the sensors available from the discriminative search criteria described above, resulted in the report set out in Table 2.

From the technical, financial and logistical points of view, the most viable option to purchase the product was the HTU21D sensor, which offers a balance between performance and price, with which the incorporation of this device is the key to the first phase of the robot for the collection of temperature-humidity samples in complex terrains (TE. Connectivity, 2015).

General Application Architecture

The captured data of temperature (°C) and relative humidity (%RH) will be distributed remotely via wireless to a transceiver device with Half Duplex mode interconnection, having the data package the structure of "Address-Packet-Bit_paridad" by wireless communication of Radio Frequency (RF) at 2.4 GHz with a transmission rate of 2 Mbps. This is achieved

TABLE 1. Description of use case of the General Desktop Application (Own Authorship)

Use case	Specifications
Actor	User
Description	Desktop application in form format, with options to make COM connection, wireless data acquisition viewer, connection with local database for the management of batches of records, query, modification and deletion of data.
Preconditions	Compatible with Windows 10 operating system or higher, installer in ".exe" form compatible with JDK 17.0.1 and .Net Framework 3.5 or higher as minimum requirements. No internet connection required
Activities	• COM port connection management • Sending data by COM port • Deployment of input data in real time • Management of information protection in Local-Host database • Query batches of records by date range or all records • Deletion and editing of stored records

TABLE 2. Technical report of production of the mechanical body of the hexapod robot (Own Authorship)

Sensor Type	Temperature (°C)			Humidity (%RH)			Measurement Time	Interface
	Range	Precision	Resolution	Range	Precision	Resolution		
DHT11	0-50	<±2	1	20-80	±5	1	1 - 6 s	Digital
DHT22	(-40) -80	<±0.5	0.1	0-100	±5	0.1	2s	Digital
HTU21D	-40-125	±0.3	0.01	0-100	±2	0.04	>0.5 s	I²C
SHT3x-DIS (SHT30) (SHT31) (SHT35)	(-40) - 125	±0.2 ±0.3 ±0.3	0.015	0-100	±1.5 ±3 ±2	0.01	8s for RH >2s for temperature	I²C
SHT1x (SHT11) (SHT15)	(-40)-123.8	±0.5@25 ±0.4@5-40	0.1	0-100	±3.5 ±2.0	0.03	4s for RH 5-30s for temperature	I²C
SHT7x (SHT71) (SHT75)	(-40)-123.8	±0.5@25 ±0.4@ 5-40	0.1	0-100	±3.5 ±2.0	0.03	4s for RH 5-30s for temperature	I²C
AMT1001	0-50	0.5	1	20-90	±5	1	10s	Analogic
HDC1080	5-60	±0.2	0.1	0-100	±2	0.1	15s	I²C
BMP280	(-40)-85	±1	0.01	0-100	±3	1	2ms	I²C

with the implementation of a pair of transceiver modules from the Nordic nRF24L01 family (Nordic, Semiconductor, 2018; Wrapper , AutoCloseable, 2020). The location will be managed by a GPS module GY-GPSV3-NEO based on the IC NEO-6M-0-001 according to Ublox (2011), which returns geolocation of latitude and longitude. The flow of data transmission can be seen in the communication diagram shown in Figure 2.

The Operational Description of the Information Flow Matrix-UML Class Diagram can be seen in Table 3.

RESULTS AND DISCUSSION

JAVA-Based Desktop Application

The database is implemented locally to store log information according to the sample collection periodicity of °C%RH.

The first storage and management section runs in the embedded control system under a storage structure in linked lists in queue format, so the dequeuing of information is done by wired connection or wireless request to the main system. The information that reaches the computer is stored in a Local DATABASE managed by XAMMP in MySQL with the generic Port "3306". The COM information received is mediated by JAVA through the ORACLE driver "mysql-connector-java", known as JDBC (Java Database Connectivity), which is the driver that contains the APIs to make a connection and intercommunication with the SQL language Pal (2020); Wrapper AutoCloseable, (2020); Oracle (2022) for the administration of commands, both DDL (Data Definition Language) and DML (Data Manipulation Language) (IBM, 2021). With the use of DML support, an algorithm is implemented to query, insert and update the information of the local database created.

The interaction with the user was achieved by designing a GUI in the "Apache NetBeans" IDE, which can be seen in Figure 3.

The graphical interface has five important blocks that can be seen in Table 4.

For the design of the Graphical User Interface (GUI) in its programming architecture, the object-oriented paradigm based on the JAVA language was used. With the help of the *Swing* components, the user dashboard was designed, thus structuring a program based on packages, interfaces and classes. A complete map can be seen in the UML class diagram (Figure 4).

Tables 5 and 6 explain the operability of the UML class diagram.

Embedded Receiver and Transmitter System

The electronic and mechanical manufacturing processes of the system of emission and reception of humidity-temperature data were carried out. In the case of the receiver module, it was designed under an ergonomics and adaptability approach. Applying CAD

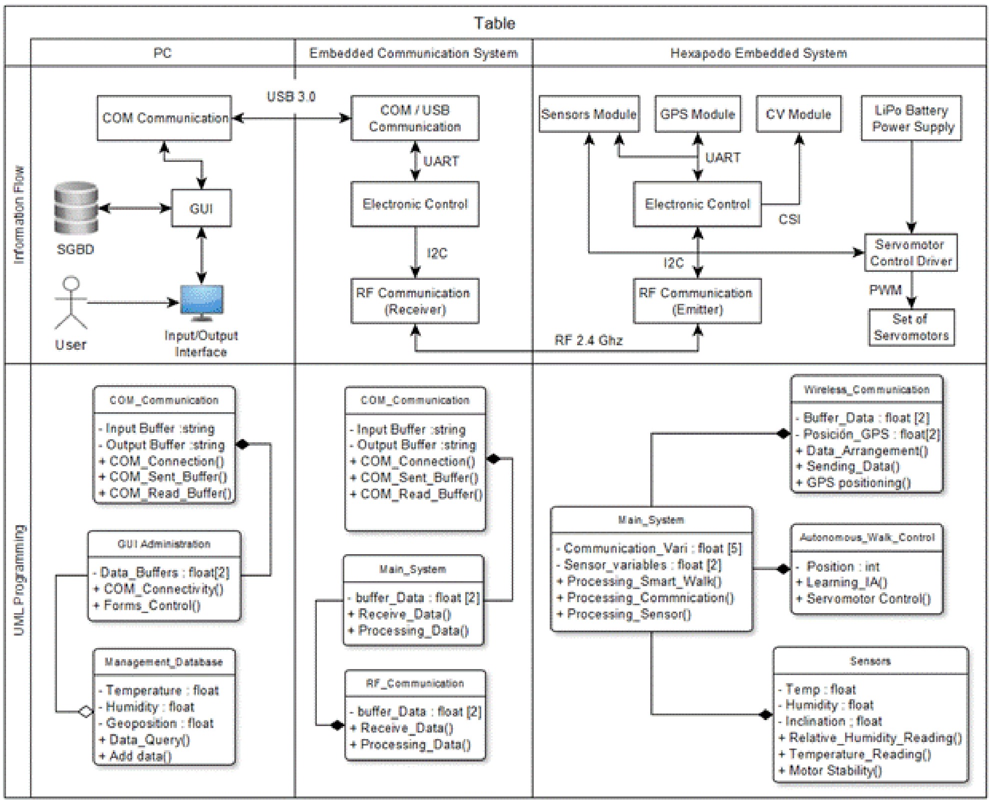

FIGURE 2. Information Flow Matrix-UML Class Diagram (Own Authorship).

TABLE 3. Operational description of the Information Flow Matrix-UML Class Diagram (Own Authorship)

Section	Description
Hexapod Embedded System	The "Electronic Control" interconnects the components to distribute the flow of information data, for this the embedded system of the robot is based on 2 processing sections: 1. ATMEGA 2560 MCU 2. Raspberry Pi 4 Model B The first is a microcontroller that is responsible for processing GPS data, sensors, RF communication and servo motor driver control. With this strategy, the information is purified, to leave the processing of the artificial vision to the "Raspberry" and thus, not saturate with threading tasks to the CPU and maximize the processing times. Making use of the OpenCV library; an algorithm was designed in Python code to expose the image and separate it into channels, which implements the operations to perform the NDVI calculation. With this, an array of pixel blocks is subsequently generated and a complete mapping or coloring of the image is executed, making it feasible to execute a multiprocess algorithm for the timely detection of crops. This is achieved with the implementation of a NoIR module that has a Sony IMX219 sensor of 8 megapixels, with the quality of not using infrared filters, which allows to obtain a near-infrared processing band. Connection is achieved by means of a CSI-2 interface (Camera Serial Interface 2) that operates on the physical layers MIPI C-PHY and/or MIPI D-PHY. The purified data are sent to the nRF24L01 transceiver, which sends the information buffers to the "Embedded Communication System", for timely debugging. These are data from the process of instrumentation, localization and detection of Computer Vision. For the control of the servo motors, a Pca9685 driver was used, which communicates by I^2C protocol with 12-bit output in 4us resolution at 60 Hz operating frequency. For this, a LIPO type battery of 1300mah 11.1v 3s 30c was implemented, which allows obtaining the necessary current for the power of the 18 servomotors that make up the electromotive system. At this point, it should be clarified that the Pca9685 driver has the supported management of 16 control channels, so the other 2 surplus servo motors are controlled directly by the ATMEGA 2560, through its PWM pins and the programming algorithm.
Embedded Communication System	This unit contains a Main PCB that manages Half-Duplex communication with the "Hexapodo Embedded System", serving the module as an intermediary for data traffic management. The nRF24L01 transceiver interconnects wirelessly with the robot, when the information is mediated by the main card, in this way the management is carried out by RS-232 protocol intercommunicated by a UART / USB interconnection driver. The information is sent to the computer to be processed and deployed by a Graphical User Interface.
PC	The intercommunication between the "Embedded Communication System" and PC, is carried out through USB interconnection, being the information received and sent under this protocol. The operational form is managed by a Graphical User Interface, designed in JAVA language, making use of the classes for the design of the GUI, management of DBMS and UART communication. This way, the graphic result allows operating the system remotely. Among the most important activities are the processing of the temperature and humidity variables provided by the robot, also the geolocation points of the sample points, the antecedent of the detection of computer vision, etc.

systems, the protective housing was designed in 3D printing with PLA+ material, and the PCB was manufactured in SMD format. The result can be seen in Figure 5.

In the case of the receiver module, the electronics were embedded to create a fixing device by means of 4 screws in the corners for fastening in the hexapod robot. The power and data connection between the module and the robot is made with a 5-pin male-male Jst-xh 2.0 mm type cable, the manufacturing result of the module can be seen in Figure 6.

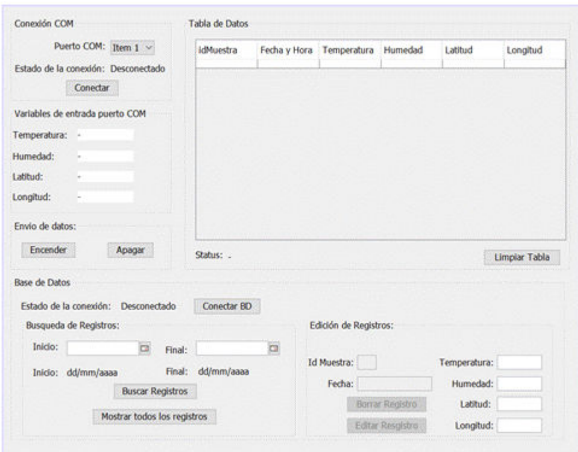

FIGURE 3. Main control form (Own Authorship).

Module Installation in Hexapod Robot

The general proposal of the hexapod robot for the exploration of complex agricultural land has as its long-term objective the process of artificial pollination, so that the attachments it has available are modules that intend to be installed according to the continuous progress of technical development. The general shape proposes a six-limbed robot with three degrees of freedom on each leg, in this way the emitting module (°C-%RM-Latitude/Longitude) is installed at the top of the central fuselage of the hexapod, with the purpose of dispersing the little

TABLE 4. Operational description of the Information Flow Matrix-UML Class Diagram (Own Authorship)

Section	Description
Conection COM	Contains a ComboBox component to select the COM ports available when the Connect() method of the JavaMySQL connection class is run.
COM port input variables	Composed of 4 labels where the data of the String supplied by the COM connection are returned, the reception is a String with the format "temperature + humidity + longitude + latitude". With the help of the substring() method it is possible to separate the string and perform the possible "cast" if necessary and prepare it for sending to the Local DATABASE or table.
Sending data	Composed of two Button's, the first allows the request activation and the second sends the deactivation command.
Data Table	This instance is linked to the "Databases" GrupBox, through the *MouseClicked* event displaying the updated records for the foreground user. The important function is to trigger the update and consultation of data in real time.
Databases	This block is subdivided into three parts: 1. *Connection status:* Which allows the monitoring of the connection and if it fails, the manual activation and deactivation of the connect () method of the Packages "*connection*" 2. *Record Search:* It is a context of attachments to perform the search of records. Two options are provided, the first allows searching for records from a start point to the end of dates for which a SQL query of the conjunction type (operator and) is invoked to delimit the search spectrum in a delimited space of the database. In the second option a "SELECT * FROM" query is implemented to display in the "*Data Table*" all the records stored in the MySQL Local DATABASE 3. *Editing records.* Linked to the click event of the *JTable* that has six *TextField* and two *Button's*. The *TextField's* expose the captured values of the string decomposition received from the COM connection, which are manifested from the *MouseClicked* event of the *JTable,* displaying the data and enabling the option to delete and edit, respectively, to perform the delete and update options of the *Querys* executed by the "*Statement*" interface.

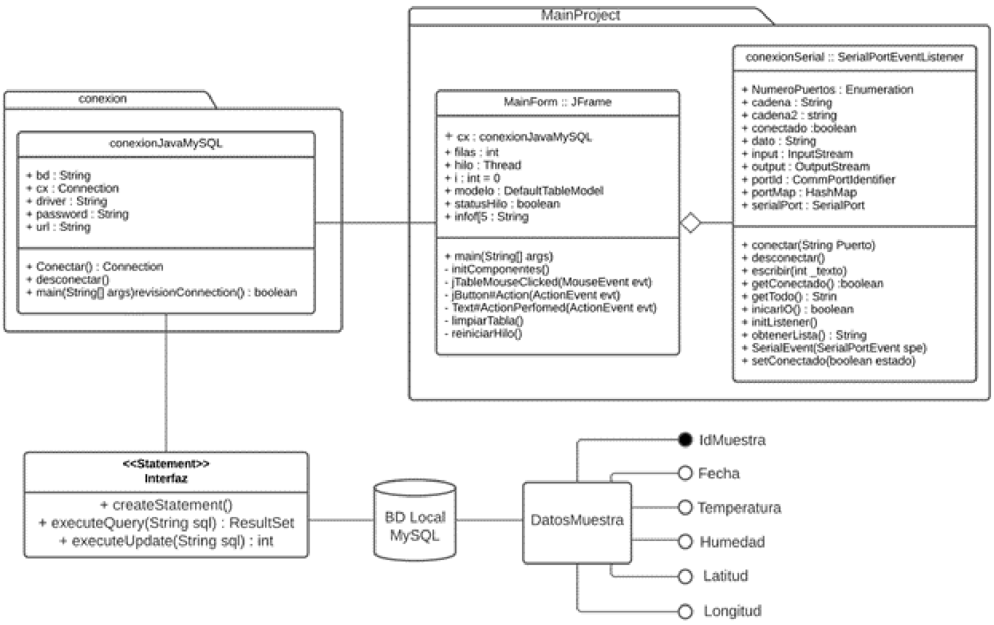

FIGURE 4. UML Diagram of Classes of the Main Operation Form (Own Authorship).

weight in its center of gravity and also expose the antenna in good position to send the data in RF format during the exploration process (Figure 7).

Real-time testing

The data that enters in the form of *String* are separated by the algorithm and reported in the table. A "*JPanel*" is also sent to accuse the reception of the data and the writing in the MySQL database. Figure 8 shows the real-time results of the information flow described in Diagram 1, where the issuing module sends the remote temperature and humidity information, and the emitting device receives it to be sent and processed by the JAVA application for management in the Local DATABASE. The "Clean Table" button removes the records from the table, so it is possible to perform two types of query, by start and end dates as shown in Figure 9.

TABLE 5. Description of packages and classes of the Main Form (Own Authorship)

Packages	Clase	Description
MainProject	MainForm	It is a *JFrame* that contains the graphic architecture shown in Figure 1, composed of 7 main public attributes that allow obtaining, from the implementation of *Thread's*, the data of the serial connection to display the information in the *jTable, jTextField* and *JLabel* of the data acquired by the receiver. Subsequently, it has a public method and six private methods, which are the main actions of the user interaction components, with the initialization of the components, the objects that interact with the click events and the action they perform, and finally the background methods to stabilize the functionality of the program.
	Serial Connection	This class is an aggregation of the "MainForm" class. Depending on whether the COM connection is successful or not, it is possible to continue operating the main Form (performing actions as a query of the information of the local database). It is composed of 10 public attributes and 10 methods, which together guarantee the COM connection between the receiving module and the form.
conexión	conexionJavaMySQL	They form a strong association with the "MainForm" class, since the operation of querying and safeguarding information in the Local DATABASE depends on the success of the connection. To do this, the package contains the "JavaMySQL connection" class that depends on the mysql-connector-java library, configuring its 5 attributes as follows: *bd="bdhexapodotemphumgps"; url="jdbc:mysql://localhost:3306/"; user="root"; password=""; driver "com.mysql.cj.jdbc.Dri"*. The interconnection to the Local DATABASE can be done and using the "Statement" Interface, operate the instructions of the Data Manipulation Language (DML) of SQL.

TABLE 6. Description of the communication components of the Main Form (Own Authorship)

Component	Description
Interfaz <<Statement>> (ORACLE, 2022)	Allows using creation, to execute queries and updates of SQL commands for the administration of the Local DATABASE.
BD Local MySQL	Local BD called "*bdhexapodotemphumgps*" managed by *XAMMP* in *MySQL* with the generic Port 3306, which contains a table called "*Sample Data*" that has as *Primary Key* the *IdSample* field and associated with the fields: Date, Temperature, Humidity, Latitude and Longitude, all of the string type for the *n* number of records that are intended to be managed.

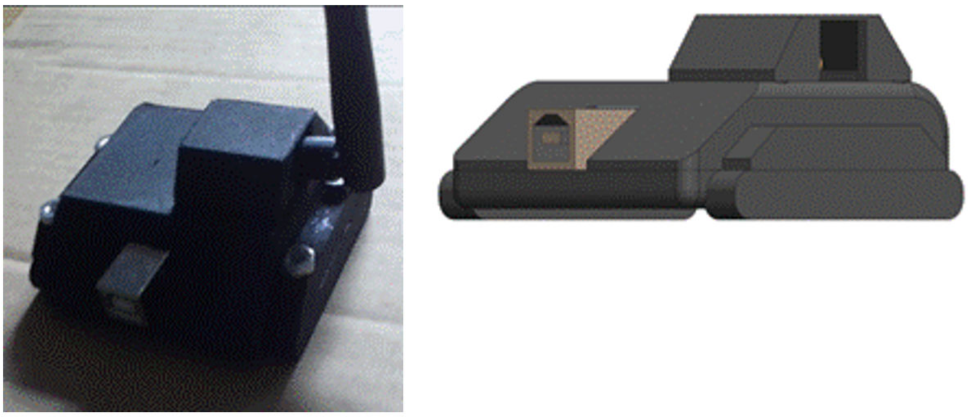

FIGURE 5. Prototype of information receiver module.

It is also possible to select the records in the *Record Editing* container in which the updated fields with the selected information will be placed, if any of the four fields are modified and the "*Edit Record*" button is clicked. This record will be edited both in the table and in the local database. If a record is selected from the table and the "*Delete Record*" button is clicked, the record will be deleted from the table and the local database (Figure 10).

CONCLUSIONS

The instrumentation for the collection of data in agriculture is a tool with a high spectrum of application, later the administration of the data obtained must be assisted by computer systems that allow flexibility in the work of purification. The present project showed evidence of a computer system oriented to agricultural processes, in which the reporting of results is oriented to the technical processes of hardware design and especially software. By making these efforts available, it is possible to create complex systems that will help farmers in the future in the knowledge and use of precision agriculture techniques, through computer systems that accuse or have refined and flexible information that allows decision making. In this first phase, the sending of two variables was reported, but the software can be enhanced to be able to manage more data. It is obvious that the hexapod robot can expand its qualities and must be equipped with other actuators or instruments that allow the collection and processing of signals, which from the beginning was considered in its mechanical design to make it modular in the processes of agriculture in which it has to perform the task of pollination.

Different resources of the software engineering were used to represent the results such as the tables of each use case, the UML diagrams, the operating tables of the parts of the software, etc. Much of the time for system design was focused on software design at both the hardware, GUI and database levels.

The project as a whole is a sub-sphere of the totality that composes it, the acquisition of wireless samples, will allow in the future the remote operability of the hexapod robot in the exploration of complex terrains in agriculture. Duplex communication will allow the sending and receiving of data for exploration processes. In the future, when the computer vision module is incorporated, it is intended to perform exploration in crops to implement invasive pollination techniques in some crops such as flowers. The control points will take the geoposition and the taking of temperature and humidity for later study, therefore, this phase was indispensable to be designed and implemented to continue with the robotics designs in

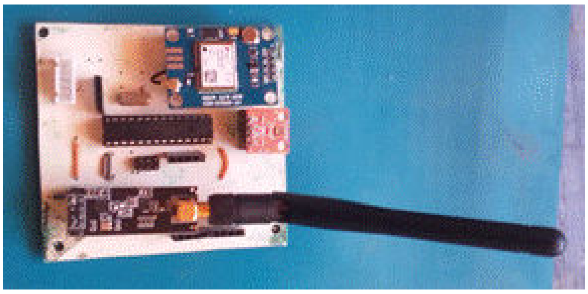

FIGURE 6. Prototype of information emitting module.

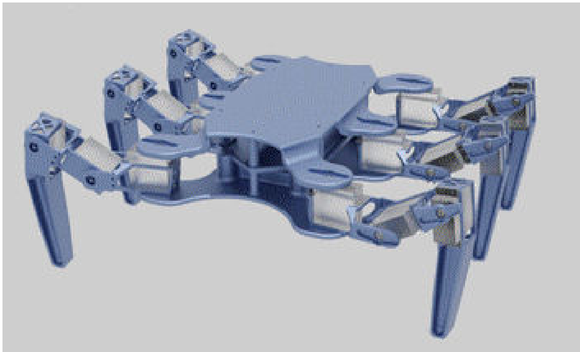

FIGURE 7. 3D simulation in Belnder of isometric view of hexapod robot explorer of complex terrains in agriculture (Own Authorship).

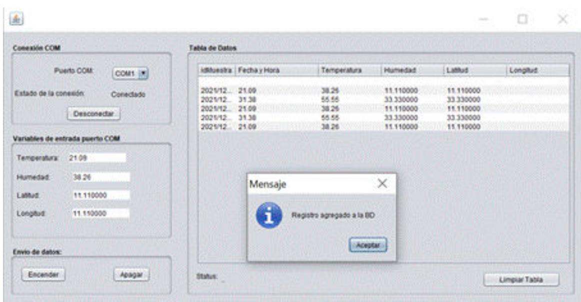

FIGURE 8. Desktop application in the process of receiving information and safeguarding registration in the Local DataBase.

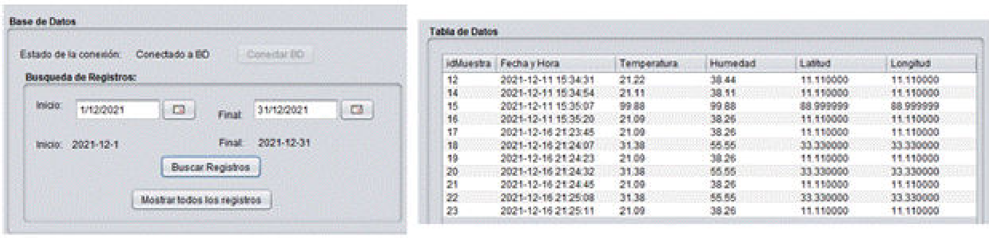

FIGURE 9. Search for registration by date range.

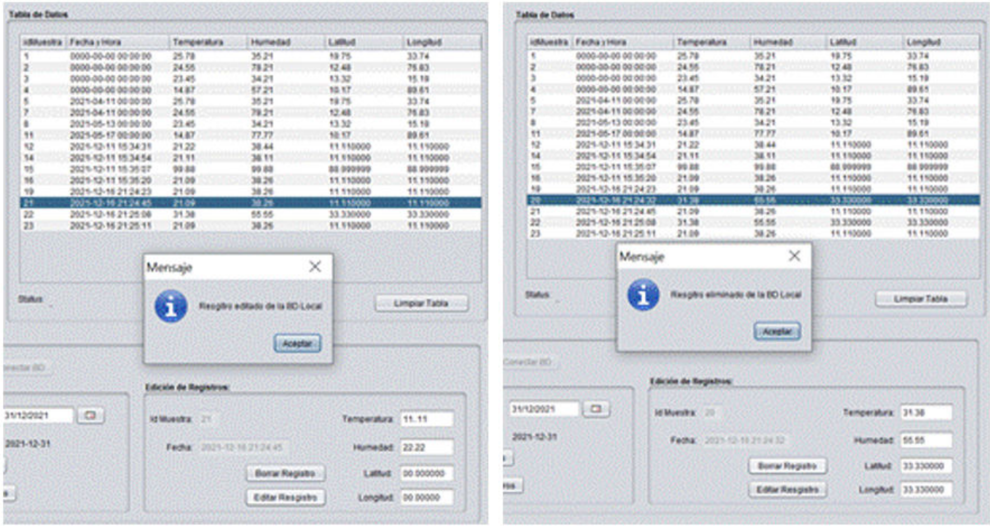

FIGURE 10. Updating and deleting records.

the future. Finally, the importance that this type of project brings in agriculture, places Mexico on the road to technological independence showing evidence of the engineering and research capacity the country, as well as in computer systems, electronics, instrumentation and robotics. Together they are factors for the development of precision agriculture tools.

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