SSRG International Journal of Electrical and Electronics Engineering
ISSN: 2348-8379/ https://doi.org/10.14445/23488379/IJEEE-V11I10P122

Volume 11 Issue 10, 216-222, October 2024

Original Article

Automation in Agriculture: Design and Evaluation of an Intelligent Robot for Maize Planting with Automatic Irrigation

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Received: 14 August 2024 Revised: 13 September 2024 Accepted: 15 October 2024 Published: 30 October 2024

Abstract *- This paper presents the design, development, and implementation of a system consisting of a robot and remote irrigation system based on Internet of Things (IoT) technology to optimize the corn planting process and improve agricultural productivity in Peru. The robot consists of sensors, as well as a central node for actuator activation and a web server interface. The robot determines irrigation actions through soil moisture sensors, as well as the state of the climate with humidity and temperature sensors, and data is obtained in real-time as the system is running. The pilot implementation shows the effectiveness of the robot against ideal and disturbed terrains, obtaining high performance in terms of accuracy and sowing of corn seeds, demonstrating the feasibility and effectiveness in a real working situation for agricultural use. This approach promotes more efficient and accurate work in the planting of corn, promoting sustainability for use in agriculture in Peru and offering a technological expansion in supply and improvement of current agricultural production.*

Keywords *- Agricultural robot, Automatic irrigation, Image processing, Artificial vision, IoT.*

1. Introduction

The agricultural sector in Peru faces significant challenges in terms of efficiency and sustainability, especially in maize cultivation. Despite the importance of this crop in the Peruvian diet and economy, traditional farming practices often lack accuracy and precision efficiency in navel point detection and fruit rotation vector prediction, with 79.79% success at harvest. In [2], a bottom-up approach for 2D position estimation of multiple pedunculate tomatoes is proposed, highlighting its high performance in key point and distal peduncle detection, which promises applications in robotic harvesting and harvesting priority determination.

The evolution of autonomous navigation in agriculture is highlighted in [3], focusing on the importance of the effective implementation of artificial intelligence, the development of accurate and affordable sensors, and the collaboration needed to ensure optimal performance. In between agricultural machinery and agronomy to move forward. In this context, there is a need to explore innovative solutions that integrate automation in agriculture, specifically in the corn planting process. This study focuses on the design and evaluation of an intelligent robot for corn planting, with a special focus on the implementation of an automatic irrigation system. Conventional farming practices for maize cultivation in Peru face considerable obstacles, from lack of precision in seed distribution to manual irrigation management. Variability in soil conditions and water availability presents an additional challenge to obtain consistent and sustainable yields. The need to maximize efficiency in the use of resources, especially water, becomes crucial in a context where climate change and scarcity of water resources are growing concerns; according to the SENAMHI Arequipa report, the absence of rainfall is decreasing due to the El Niño phenomenon; therefore, the water resource is affecting the supply for the sector.

This study addresses the problem through the design and evaluation of an intelligent robot specifically adapted for corn planting in the Peruvian agricultural environment. The automation of this process, combined with an automatic irrigation system, seeks to improve accuracy in seed placement and efficient water resource management. The goal is to overcome current challenges, increase the efficiency of corn planting, and contribute to the sustainability of agriculture in Peru. The seeding robot can be included in more crops such as tomato, oats and rice, helping more agricultural fields expand its use to other sectors.

2. Related Works

In the review of existing literature for the improvement of automated fruit harvesting, a method is presented in [1] that uses RGB images to estimate the position of citrus fruits.

Using the FPENet model, a high sector is achieved. A robust approach is presented in [4], where an apple-harvesting robot with multiple arms is developed, facing a decrease in manpower. A recognition and localization algorithm based on stereo vision and deep learning is proposed, resulting in reduced localization error and improved harvesting efficiency.

The creation of an autonomous localization and navigation system for agricultural robots is described in [5], with emphasis on creating and updating maps and localization accuracy in greenhouses, facilitating autonomous routes and meeting the required specifications. The challenge of accurate agricultural crop sensing is addressed in [6], employing RandAugment (RA) to improve sensing performance through geometric and photometric transformations. The YOLOv3 model with transformations achieves significant improvements and is implemented in a robotic harvesting system.

Rice seedling detection and classification using UAV is explored in [7], using a deep learning approach with adaptive filtering and recurrent neural network models, demonstrating improvements compared to other models. Apple detection in commercial orchards is addressed in [8] using two neural network models interfaced with deep learning. The SSD-Mobilenet and Faster R-CNN models achieve high accuracy rates, improving yield predictions for growers. For pitaya harvesting, [9] proposes an autonomous mobile robot system based on the Artificial Intelligence of Things (AIoT), combining 2D SLAM and AI object recognition for efficient navigation and harvesting. The accuracy of the recognition model reaches 96.7%.

The application of SLAM technology in agricultural environments is explored in [10], highlighting the theory, development, and applications of this technology for map building and navigation of agricultural robots, as well as the challenges and future directions. The creation of the TomatoPlantfactoryDataset is presented in [11], benefiting automated sensing in control systems, robotic operation and yield estimation in plant factories. A two-stage deep learning-based approach for apple detection and classification is described in [12], using YOLOv7 and EfficientNet-B0 models to improve the effectiveness of autonomous harvesting and avoid damage. The efficiency and functionality of agricultural crop harvesting are addressed in [13] by kinematic and dynamic analysis of hybrid robots combining open and closed-loop manipulators.

The use of 2D LIDAR SLAM in mobile agricultural robots is proposed in [14] as a positioning scheme in hidden winches, achieving autonomous navigation accuracy in static environments. Traditional Japanese orchard automation is explored in [15] using a LIDAR-based spraying system and machine learning algorithms, demonstrating the ability to compute real-time routes and operate safely in pesticide spraying tasks. Taken together, these works represent significant advances in automated fruit harvesting and autonomous navigation in agriculture, addressing key challenges and presenting innovative solutions to improve efficiency and accuracy in these processes.

3. Methodology

This paper presents the development of an integrated system for intelligent planting and irrigation of corn, all monitored and controlled by means of IoT technology. The design of the mechanical model is done using Auto CAD inventor software, which is presented in this paper.

Stainless steel of 1/24” inch thickness is used as the main material for the design of the chassis of the seeder robot and lead acid batteries; one of the advantages of using stainless steel and batteries of this type is to increase the weight of the robot, which reduces the sliding of the wheels in the field and protects the robot from incorrect navigation, besides this material does not present corrosion due to work in wet areas in furrows and irrigations obtaining greater robustness. The dimensions of the seeder robot are 80cmx70cmx60cm; these measures allow us to accommodate the components necessary for the proper functioning of the seeder robot, see Figure 1.

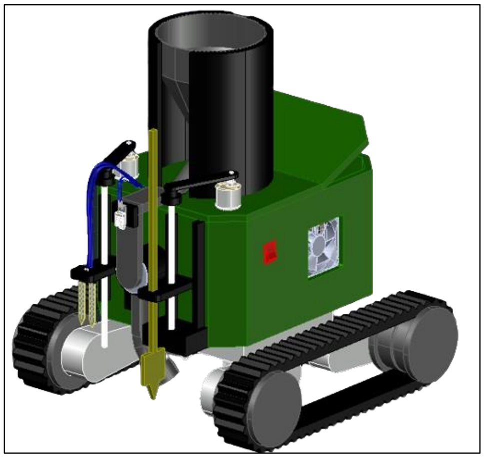


Fig. 1 3D design of the seeding robot

The land where the seeder robot works must be previously prepared, free of weeds; due to the fact that the sowing land will not always comply with these requirements, a robust and closed-loop control was implemented for the wheels in charge of the robot traction; this control was made based on the PID control tuning with the ZIEGLER-NICHOLS method, because the robot seeks precision and continuous work, this type of control is adequate against disturbances such as stones, difficulty in terrain and improve its precision in the placement of seeds.

Making the corresponding captures in an initial open loop system, the digital encoder type sensors incorporated in the motors were used, driving the motor at maximum speed controlled by the drivers, obtaining the corresponding Kp, Ki and Kd variables to apply it to the system.

4. Developed System

The electronic part of the seeder robot is composed of the Arduino Mega2560 module that controls the movement of the seeder robot thanks to its 4-motor crawler system with its respective drivers, a drilling system for the implantation of the seeds as well as the soil humidity reading; temperature and environmental humidity sensors for the feedback of the automated irrigation system; the closing and opening system of the seed hopper with a capacity of 1.5 kg. A NODEMCU ESP32 WiFi module is incorporated to monitor the seeder robot sensors and control the robot (See Figure 2).

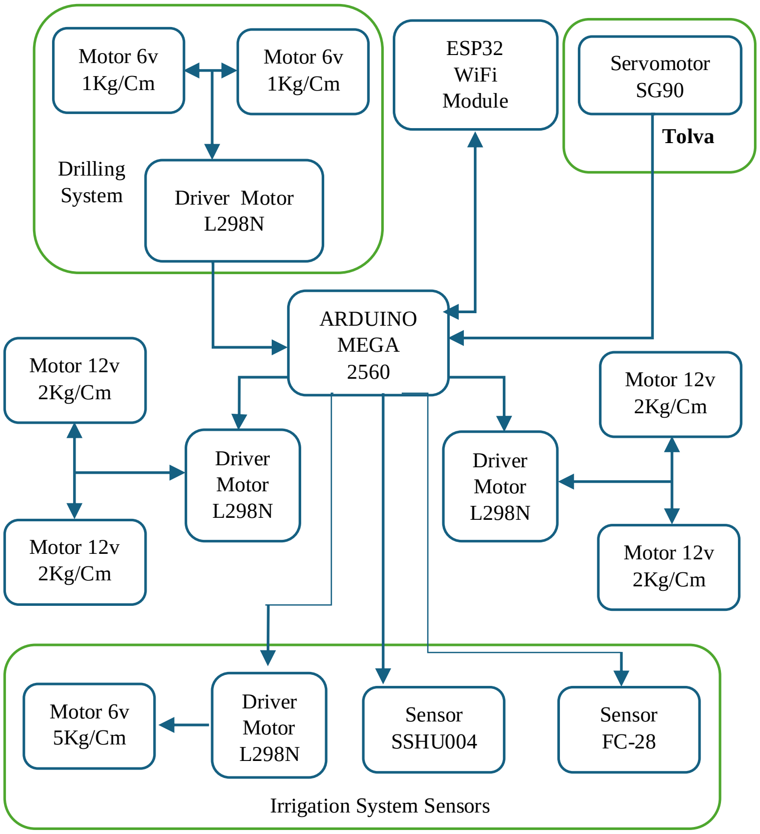


Fig. 2 Electronic diagram of the seeder robot

4.1. Seeder Robot Electronics

The L298N dual-channel drivers are used to control the 4 12V motors that are involved in the movement of the seeder robot. Due to the implementation of a PID control, the amperage consumption in this driver is variable and independent; 4 drivers of this model were used, which allows us a unique control; the relative consumption captured with this control was 0.5Amp in stable and almost ideal for the seeding, on the other hand in rough terrain and with disturbances the relative measurement of 2Amp was obtained offering a maximum torque for the mentioned difficulty.

The ARDUINOMEGA module with the ATMEGA 2560 microcontroller offers us a considerable amount of inputs and outputs; due to the fact that this robot is a functional prototype; These are available for further improvements, the programming was done in the ARDUINOID software being a program OPENSOURCE which is very friendly with C++ programming, also implemented the NODEMCU ESP32 module for WIFI communication, this communication is used for the operation of devices and reading data on the robot such as temperature and humidity sensors, soil moisture, alert on valves and alert for stagnation, starting the process by making the hole in the ground with a drilling system (See Figure 3) based on a motor and ½" inch trowel type drill bit, complying with the appropriate measures for corn planting, while this process is being carried out, the robot obtains the soil moisture with the capacitive sensor, to later carry out the seed expulsion, this is achieved with a thrust system based on a worm screw which is driven by a geared motor on the front of the robot, If another crop such as rice, tomato or oats is desired, this value must be increased, the process ends with the following advance of 20-25 cm between holes, in the same way for another crop such as rice the advance between holes must be modified by programming to 30cm, in the case of tomato 50cm and oats 15cm.

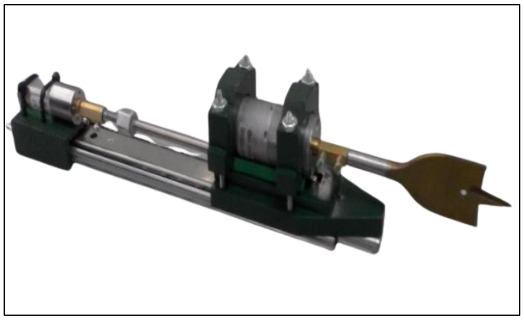


Fig. 3 Drilling system design

The reading of the soil moisture sensor is done by means of the capacitance difference existing in the 2 electrodes of the sensor, which will be embedded in the agricultural soil to obtain data and perform subsequent actions; therefore, the captured value is amplified in a 0-5V analog signal converter circuit to be able to perform the reading in the ARDUINO MEGA.

Likewise, the reading of data in the humidity and ambient temperature sensor is done by a capacitive sensor and a thermistor, which measures the surrounding air, both integrated in the same integrated circuit which facilitates the reading of data through a digital pin of the ARDUINO MEGA, thus obtaining the data of agricultural temperature and humidity. The sensors used are code AM2302 and the capacitive soil sensor V1.2, both of which are commercially available for replacement in case of malfunction or dust contamination.

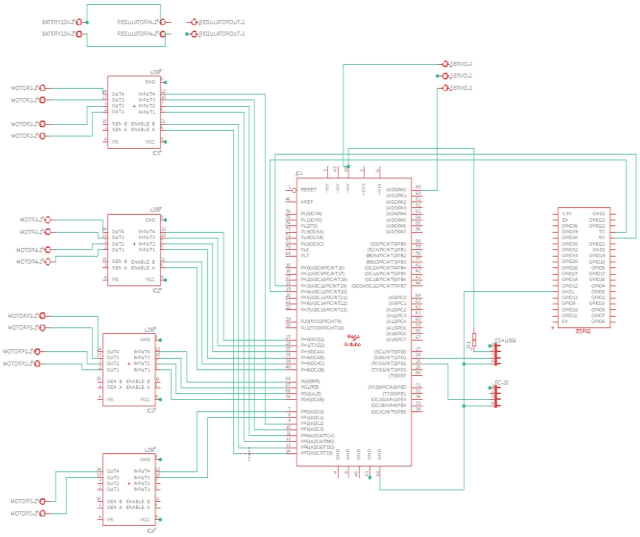


Fig. 4 General schematic of the seeding robot

The internal connection of the seeder robot starts from the ARDUINO MEGA module in which the digital outputs are used to enable the driver and analog outputs for the PWM control necessary for the PID control applied in the system and the connection through the UART1 port to the ESP32 as a remote communication device (See Figure 4).

4.2. Electronics of the Irrigation System

Regarding the electronic part of the intelligent irrigation system, we have 3 12V solenoid solenoid valves, which have already been implemented in an irrigation system in the field where robot performance tests will be carried out.

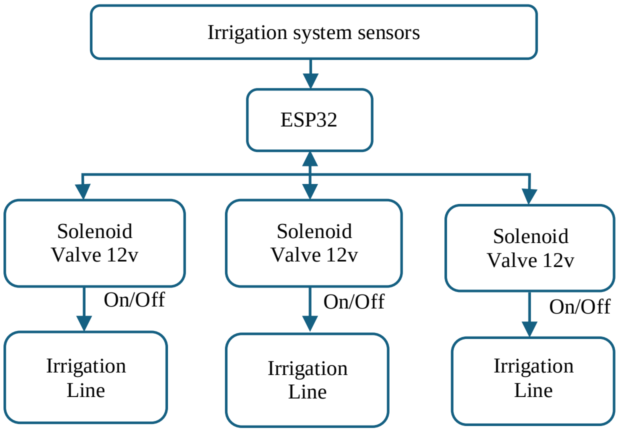


Fig. 5 General schematic of the seeding robot

Upon receiving the data from the temperature and humidity sensors, as well as the soil humidity, the solenoid valves are activated or deactivated to supply water to the crops, achieving a significant saving of water resources (See Figure 5).

4.3. IOT System

The system has a remote drive using wireless communication in irrigation electronics. The node MCU ESP32 module offers communication via WIFI, which was used to create a web server link (See Figure 6), where variables such as ambient humidity and temperature, as well as soil moisture and valve actuation, are covered.

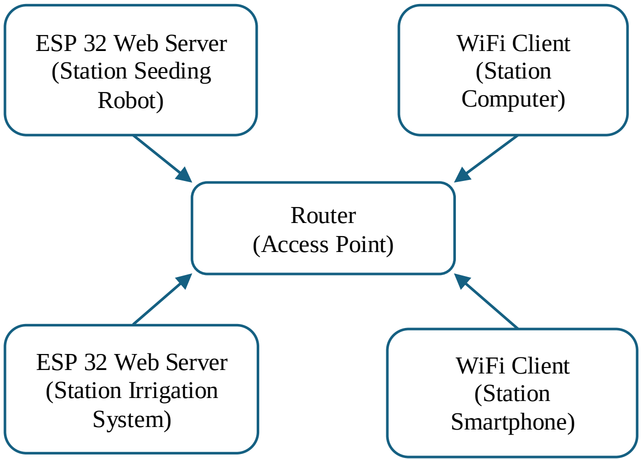


Fig. 6 Wireless communication for sending and reading data

The irrigation system has different electronics than the one used in the robot (See Figure 7); the opening and closing of valves are controlled by power transistors chosen in order to last over time because they do not generate mechanical wear as power relays; this control module has LEDs which indicate the opening and closing of valves, obtaining a green glow in opening and red glow in closing.

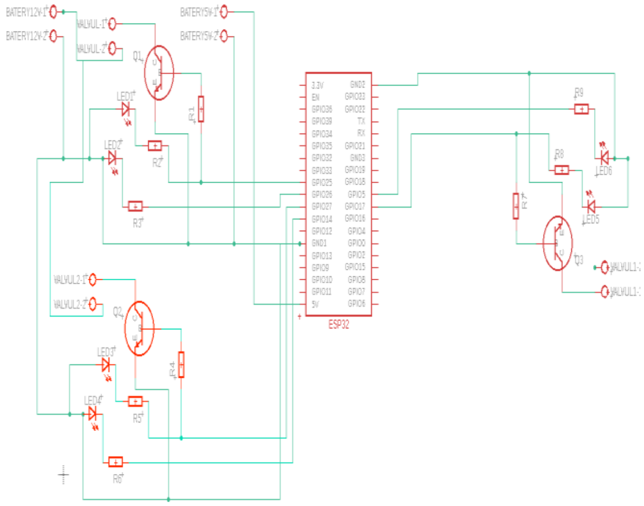


Fig. 7 General schematic of the seeding robot

This interface will allow easy interaction between the crop field and the farmer in charge, prioritizing the places where there is less irrigation either by soil factors or even if there are changes in temperature where there is too much heat or a decrease in temperature, sending alerts in both cases so that the farmer can perform the respective actions. Where the valve opening control is directed by furrows depending on the average moisture in the soil of the crop field, the operation is automatic or manual. It will depend on the variables captured by the capacitive soil moisture sensor (See Figure 8).

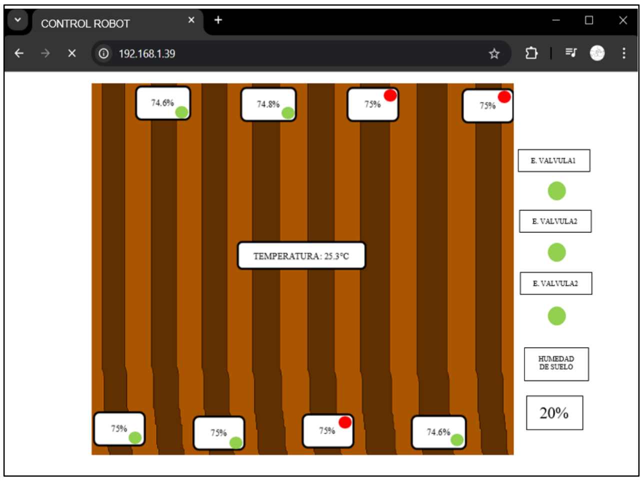
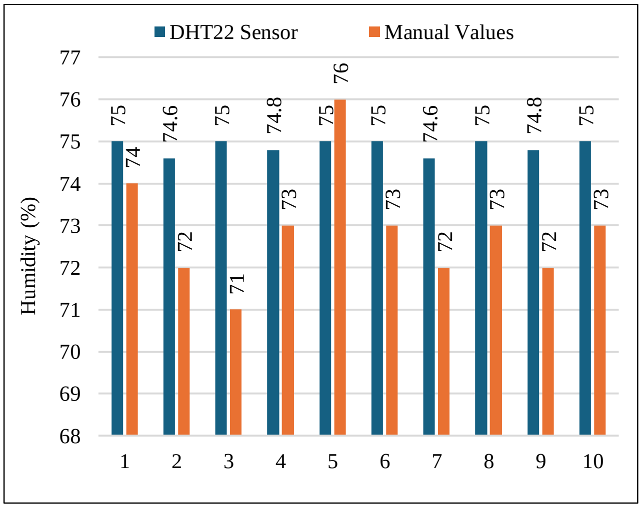


Fig. 8 Robot control in web server

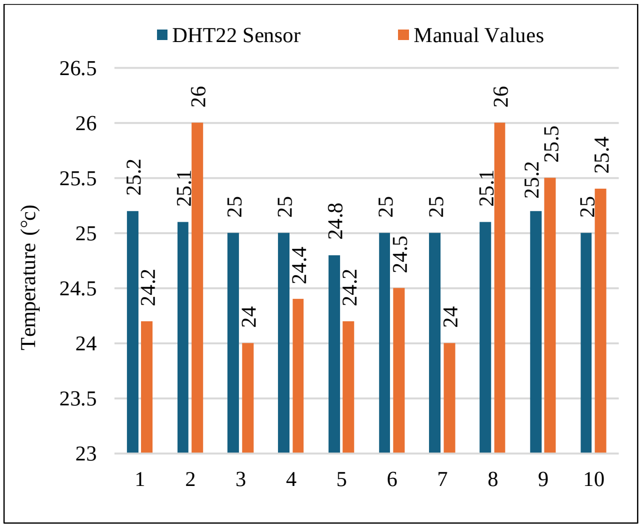
5. Test and Results

To evaluate the effectiveness of the robot, the pilot implementation was carried out in a real sowing environment, using a field of 800m2 with dimensions of 200m*40m located in Carmen Alto, Cayma, Arequipa. Performance tests were carried out, which covered the entire planting period, obtaining empirical data on performance, planting accuracy and autonomy generated in this agricultural sector.

The operation of the temperature and environment sensor was evaluated by comparing manual readings and obtaining variables that show high accuracy in terms of fast readings for a more optimal control due to the average values made by the Arduino Mega2560 (See Figure 9). The readings of the soil moisture sensor are performed in parallel while the robot performs the drilling; it captures the soil moisture data to obtain the necessary variable for the irrigation of the crop. To save water resources and to make comparisons between manual irrigation with hoses and a water pump without control for opening or closing and automated irrigation, the variables were taken in each section of arable land in the sowing area (see Figure 10).



(a) Humidity sensor



(b) Temperature sensor

Fig. 9 (a) Comparison of values for (a) Humidity, and (b) Temperature sensor accuracy.

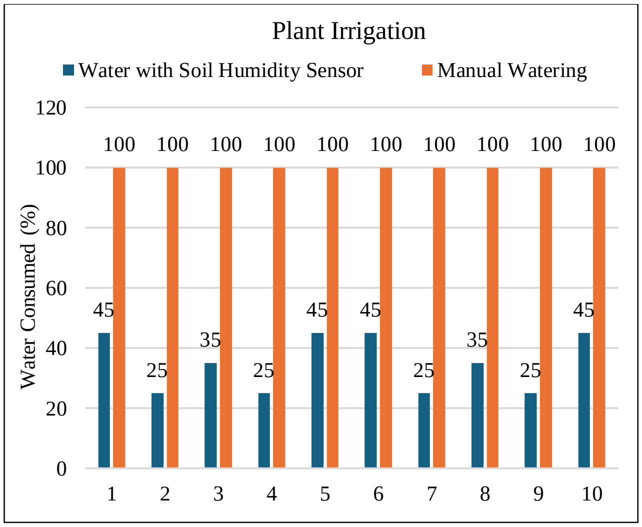


Fig. 10 Comparison of total water used in irrigation

Empirical values of precision were also acquired in terms of the corresponding distances in each perforation made for the placement of the seeds, considering the use of a PID control that makes the robot more robust; a comparison was made with the control implemented and without it, obtaining very favorable results in terms of mobility in the agricultural land, since it is disturbed by stones or level imperfections (See Figure 11).

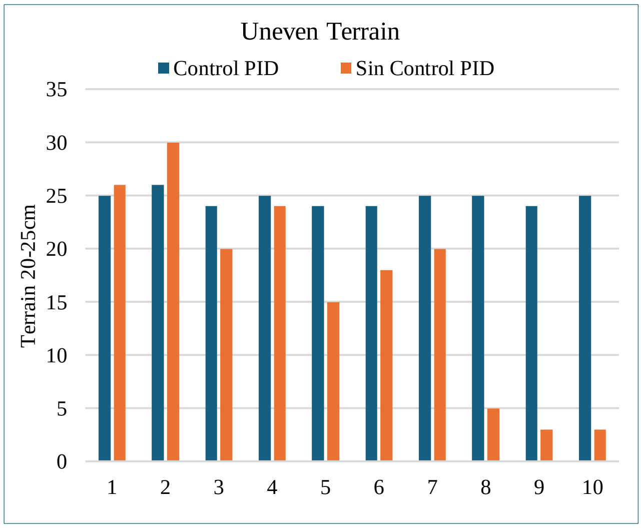


Fig. 11 Comparison of distances traveled between 25cm orifices with and without PID control

Additionally, a comparison was made between the performance of a farmer and the seeding robot, obtaining favorable results in terms of accuracy and time, which are the main factors in terms of the advantages of the equipment, in addition to the fact that the farmer does not measure soil moisture (See Figure 12). Finally, the reliability in the use of this robot should be highlighted since a control monitored by the NODEMCU ESP32 allows obtaining data to an interface in which variables such as temperature, soil and environmental humidity can be visualized, which makes it easier to control the process of planting and cultivation of corn.

The results obtained are satisfactory for the farmer because this system shows high potential in the land and high precision in terms of planting and proper use of seeds, generating greater productivity and savings in terms of water resources and inputs.

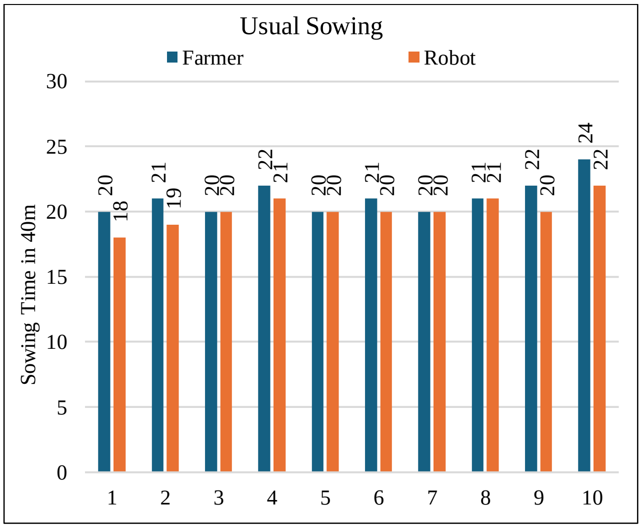


Fig. 12 Comparison in sowing of land at 40m

6. Conclusion

This study has demonstrated the effectiveness of using a robot designed from a deficiency indicated by the user in the process of planting corn, along with an automated irrigation system based on IoT technology to improve the use of resources such as water and inputs needed in planting.

The results obtained show the high reliability of the device for work in any agricultural environment to be used, in addition to informing farmers in an accurate and timely manner of the current planting situation in terms of variables such as humidity and ambient temperature, soil moisture, among others.

In conclusion, the development and system of this robot allow the agricultural sector to offer a sustainable and efficient solution for corn planting, improving productivity in any agricultural environment, thus contributing to the sustainability of this sector.

Acknowledgements

The authors express their sincere gratitude to the Universidad Nacional de San Agustín de Arequipa for their invaluable support and collaboration throughout the research process.

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