

Innovative Proposal for the Coffee Management of the Orozco Farm Using Devices from the Internet of Things (IoT)

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Abstract– *This article summarizes the most relevant aspects and results obtained from the project, whose purpose is to provide coffee growers with a clear guide on how the Internet of Things (IoT) and sensors work, and how they can use them to improve the efficiency of their coffee management. The implementation of this technology can give them access to real-time data that they did not know, which entails benefits for both the producers by being able to work in a more focused way, and the health of their crops and the environment by reducing the use of chemicals.*

Keywords– *Internet of Things (IoT), coffee, optimization, sensors, precision agriculture.*

I. INTRODUCTION

The Orozco coffee farm, located in Los Santos Zone of Costa Rica, has sought to maintain healthy crops to produce high-quality coffee. Since 2008, they have participated in the Nespresso AAA Sustainable Quality program [1], to continually improve and update.

Coffee producers face challenges in terms of climate variables, limited access to real-time information, and reduced ability to make data-driven decisions. The lack of innovative technologies, such as drones, satellite internet and the Internet of Things (IoT), limits their ability to improve the efficiency and sustainability of coffee production.

The Ministry of Science, Innovation, Technology and Telecommunications (MICITT) of Costa Rica, together with the Ministry of Agriculture and Livestock (MAG) of Costa Rica, seek to promote the use of IoT in agriculture through training and providing support to farmers to generate the foundations of the agriculture for the future [2].

II. JUSTIFICATION

This research seeks to explore the benefits of the Internet of Things (IoT) and its integration in coffee production. In the coffee sector, the problem lies in having large areas of land that require constant observation, but with a few available personnel [3].

Coffee growers face problems detecting diseases on time, which has led to a significant decrease in coffee production. Climate change also severely affects coffee plantation, reducing areas suitable for its production by 50% by 2050.

However, precision agriculture, an emerging technology, offers hope to the agricultural sector by allowing the capture and interpretation of field data to be able to predict and make more precise decisions that allow increasing productivity in a sustainable and profitable way [4].

III. THEORETICAL DEVELOPMENT

The Internet of Things (IoT) adoption has become a growing trend in several manufacturing industries, including agriculture. Using Internet-connected devices and sensors to monitor and control processes in real time provides many benefits, such as resource optimization, increased efficiency, and reduced costs [5].

Efficient management of coffee farms is essential to maximize the productivity and quality of coffee. In recent years, the application of emerging technologies has revolutionized the agricultural sector, and in particular, precision agriculture and IoT devices have shown great potential to improve the management and optimization of coffee farms.

A. Precision agriculture

Precision agriculture is a methodology whose objective is to seek improvements in the efficiency and profitability of agricultural production using advanced technologies and data-based approaches for decision making.

In addition, conceptually, precision agriculture is a new integrated form of crop information management, based on the existence of spatial and temporal variability of the minimum management unit in traditional agriculture [6].

Therefore, it is a set of techniques aimed at optimizing the use of agricultural inputs (seeds, agrochemicals, and correctives) based on the quantification of the spatial and temporal variability of agricultural production. This optimization is achieved with the distribution of the correct amount of these inputs, depending on the potential and need of each point in the management areas [7].

Consequently, coffee-oriented precision agriculture helps with the early detection of problems such as diseases, pests, and weeds, using technologies, such as sensors and satellite images, that can identify areas where coffee plants show signs of deterioration, stress or abnormal patterns. By using precision agriculture technologies, coffee producers can closely monitor critical variables, such as soil moisture, temperature, etc., in different areas of the cultivated area.

B. Internet of Things (IoT)

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The term Internet of Things (IoT) refers to scenarios in which network connectivity and computing capacity are extended to objects, sensors and everyday items that are not typically considered computers, allowing these devices to generate, exchange and consume data with minimal human intervention. However, there is no single, universal definition [8].

Consequently, it can be said that IoT refers to the interconnection of everyday devices and objects through Internet, allowing them to share and collect data efficiently. Now, within the IoT there are specialized sensors that are devices made up of sensitive cells that detect variations in a physical, chemical, or biological magnitude and convert them into electrical signals useful for a measurement or control system. A sensor is a device designed to receive information about a magnitude from the outside and transform it into another magnitude, usually electrical, that can be quantified and manipulated [9].

Therefore, IoT sensors are electronic devices that can collect data and send it over Internet. Regarding to the operation of an IoT sensor system, it is based on data captured through different types of sensors or transducers. These sensors may include, for example, soil moisture sensors, temperature sensors, luminosity sensors, air quality sensors, wind speed sensors, among others.

Sensors are devices that identify and react to data from physical environment [10]. Therefore, each sensor is designed to measure a specific parameter and is equipped with a corresponding detection technology. Now, regarding to the sensors used in precision agriculture, phenomena, sensors, and actuators are described below, as well as some of the sensors that are normally used to sense phenomena and modify behaviors. The information is shown in Table 1 [10].

TABLE 1
PHENOMENA, SENSORS AND ACTUATORS

Physical phenomenon	Sensor	Actuators
Temperature	Thermocouple Thermistor Thermostat	Heater Fan
Speed	Optocoupler Doppler effect sensors	AC/DC Motors Stepper motor Brakes
Position	Potentiometer Encoders Variable Linear Differential Transformers	Engine Solenoid Panel meters
Sound	Carbon microphone Piezoelectric crystal	Bell Buzzer Speakers
Force/pressure	Tensile tester Pressure switch Load cells	Elevators and jacks Electromagnet Vibrator

Light level	Light dependent resistors Photodiodes Phototransistors Solar cell	Lights and lamps Leds and displays
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C. Optimization through IoT Sensors

Optimizing coffee farms through IoT sensors is a revolutionary approach that seeks to improve the efficiency, productivity, and sustainability of coffee production. IoT sensors, also known as Internet of Things sensors, are electronic devices connected to the network that collect real-time data on various key agronomic variables, allowing more informed and accurate decision-making in farm management of coffee plantations.

The benefits that precision agriculture provides using IoT devices are the optimized management of farms, reduction in the application of pesticides and fertilizers, lower environmental impact, products with greater nutritional value, obtaining more precise information and traceability, cost reduction, among others [11].

D. Climatological Variables in Costa Rica

Regarding to the fundamental climatological variables that must be analyzed in Costa Rica, they include temperature, precipitation, humidity, solar radiation, wind speed and direction, among others. These variables are systematically monitored through weather stations located throughout the country, which collect data in real time. This data is analyzed and used by scientists, researchers, farmers, planners, and other professionals to better understand climate patterns and make informed decisions regarding resource management, crop planning, water management and biodiversity conservation.

Specifically, the impact on the growth and development of coffee is affected by temperature as a key and determining factor. In tropical climates [12], the average temperature of all months of the year is always higher than 18°C, in this way, thermal values lower than that amount will be found only in places of a certain altitude.

On the other hand, humidity is important to determine the amount of water available in the environment. Relative humidity can be monitored to evaluate optimal conditions for growing coffee. It is noted that an average relative humidity of 70 to 95% is recommended for Arabica coffee. The limitation due to this factor occurs when values equal to or greater than 90% are present, as it stimulates the attack of fungal diseases [13].

Consequently, monitoring the amount of rainfall is essential for irrigation and proper water management. Precipitation is the value of liquid or solid water that falls on earth's surface, which makes it one of the elements with the greatest variation in time and space [14].

Finally, the pH of the soil is an indicator of its acidity or alkalinity, which can influence the absorption of nutrients by plants. The soil pH sensors will allow monitoring and adjusting the pH if necessary. Coffee cultivation prefers slightly acidic soils, that is, soils whose pH ranges between 6 and 6.5. However, it is known to be tolerant to lower pH levels, obtaining excellent harvests in soils with acidity

levels of up to 3.1, if the physical properties are satisfactory [13].

E. Diseases that Attack Coffee

Finally, the pests and diseases that affect coffee cultivation have greatly damaged the production of the grain. Currently, the most important are “ojo de gallo” (*mycena citricolor*), “llaga macana” (*ceratocystis fimbriata*) and “la broca del café” (*hypothenemus hampei*); however, a disease that has gained relevance during the last decade has been called “crespera”. This disease was detected for the first time in the early 1980s in some places of the Central Valley [15]. Commonly the symptoms of “crespera” are confused with nutritional deficiencies [16]. All these diseases can be mitigated by knowing the climatological variables mentioned above, as well as by monitoring key agronomic variables.

IV. METHODOLOGY

The project focuses on applied research in technology to improve the management of coffee cultivation in Los Santos region, geographically located at south-central Costa Rica. A qualitative approach is chosen, using exploratory and descriptive studies to address a problem almost not studied in the coffee sector. Interviews and observation were carried out as data collection instruments, focusing on the owners of the coffee plantations and their collaborators. The population of interest are the owners of the coffee farms in the area, and a sample of 10 coffee growers were selected to obtain a broader vision of the problem. The analysis of the information was carried out using measurement techniques and the use of visual tools will be explored, such as mental maps, to explore and understand the organizational processes of the coffee farms to present the data in a more visual and easy way. The objective is to obtain valuable information that allows improving the management of coffee farms and promoting technological innovation in the agricultural sector. On the same way, documentary analysis was used to examine and delve deeper to determine the best option for implementing a sensor system with IoT in the Orozco coffee farm.

V. RESULTS

Below are explained the most important aspects of the results obtained through the interviews and observations necessary for the development of the infrastructure of an IoT system applied to monitor the coffee plantations of the Orozco coffee plantation, located in Los Santos. The fundamental purpose of this stage was to collect information that would allow a deeper understanding of the requirements and associated challenges to achieve future implementation on a coffee farm.

Through the interview instrument, it was possible to determine that in general they have large areas of land with an average of 2 to 3 hectares of land, which is important for the design of a proposal because since the land is so large, a long-range communication system had to be used to cover the entire land of the farm, as can be seen in figure 1. Then the approach was carried out to determine the state of maturity of this type of technologies in the area, and the data showed that in their entirety there was a lack of

knowledge of the subject and that of course they did not have a system of this type implemented on their farms, as can be seen in figure 2. This is a positive aspect since a window of possibilities opens with this project so many producers can start intelligent management of their farms through IoT devices.

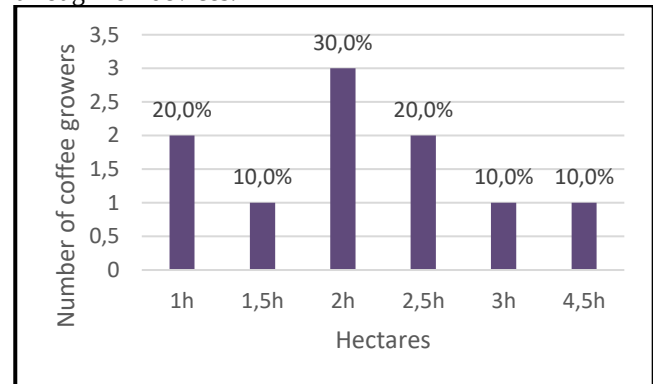


Fig.1 What is the farm size in hectares of coffee growers.

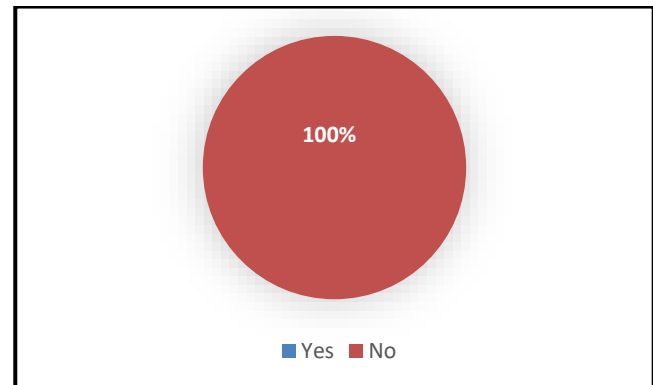


Fig.2 Did you use some type of technology in farm management.

When carrying out this research, it has been observed that most of coffee growers keep paper records or do not have an organized control. This indicates that having a system that generates monthly data would be a valuable tool to maintain a history of farms without the need to document everything on paper. In this way, the project seeks to offer a technological solution that facilitates the monitoring and recording of relevant data for the management of coffee farms, as can be seen in figure 3.

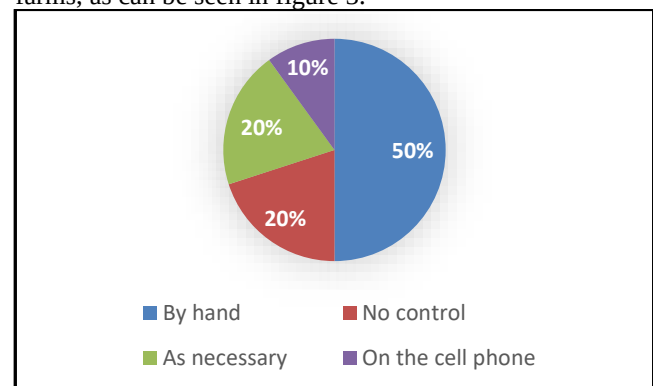


Fig.3 How do you manage your farm?

Common problems that coffee growers face in their daily work were identified, which provides a significant advantage, since no one better than the producers themselves to express which aspects affect their coffee crops the most. Various issues related to their farms were received, and among them the large area of land and the limited manpower to cover the entire farm stand out. These observations are especially positive for the project, since one of the main purposes of the Internet of Things (IoT) is to provide farmers with a real-time view of relevant data. In this way, the project seeks to address these problems and provide coffee growers with a tool that allows them to have better visibility and control over their farms, as can be seen in figure 4.

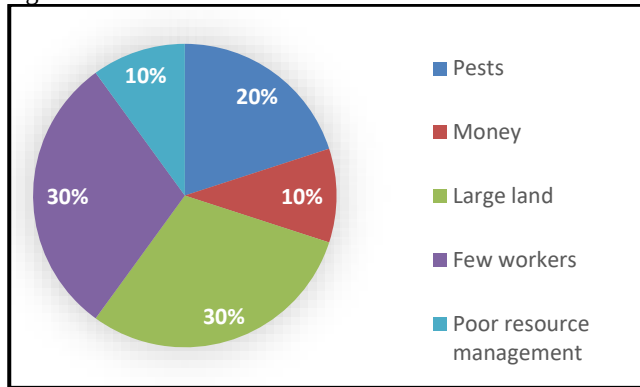


Fig.4 What are the main problems on your farm?

On the other hand, part of the findings stated that the budget of the coffee growers is limited, since they must extend their budget throughout the year. It means that acquiring this type of architecture could become an imbalance in their finances, and a strong reason for not using a cloud software which costs are high and therefore look for open-source platforms for an initial phase of the project where the budget is limited.

In general, another problem found lies in the lack of knowledge of the subject, which opens an opportunity to organize seminars and promote the adoption of these technologies in the country. By providing education and dissemination about the product, we seek to increase producers' knowledge and familiarity with new agricultural technologies, giving them the necessary tools to make informed decisions and take full advantage of the benefits they offer. Finally, for the farmer, having this data at hand it is very important, so the solution could really benefit their daily tasks and allow them to make decisions they were not able before [17]. In addition to being beneficial for coffee growers, this project opens new opportunities for transformation in coffee plantations around the county by implementing such innovative and functional technologies. The adoption of these technologies would not only improve the efficiency and productivity of coffee farms but would also address a significant change in the way farms are managed, promoting modernization and sustainable development in the coffee field.

VI. DISCUSSION OF RESULTS

We are immersed in the Fourth Industrial Revolution, which has altered not only production systems and technologies in industries, but has also transformed processes in agribusiness, giving rise to what is known as Agriculture 4.0.

Understanding the meaning of Agriculture 4.0 is essential for people or companies seeking to expand their operations in a more efficient and sustainable way, since this concept is based on digital agriculture with the purpose of optimizing the production chain in its whole [18].

Within this Agriculture 4.0 there is a set of technologies that are centralized in the digitalization of agricultural processes using equipment, software and systems that can reform the production procedure from start to finish streamlining it and making it more efficient in economic terms, as well as directing it towards sustainability.

Besides, among the technologies found in Agriculture 4.0 is the implementation of Internet of Things (IoT) devices which are helping in the management of farms that grow different products. Since 2015, the rise of connected and installed IoT devices has been increasing and it is expected that by 2025 there will be 75 million connected devices worldwide [19].

On the other hand, it is important to mention that the coffee sector has an approximate value of 200 billion dollars a year, distributed between 21.5 and 25 million farmers in 51 countries in Latin America, Asia and Africa, which produce 85% of the coffee beans of the world [20]. Consequently, the use of IoT devices in coffee farms can provide exceptional results, as it would completely transform the way coffee production is approached, not only by using sensors to measure variables but also in the optimal management of information in decision making.

The use of advanced sensors can allow real-time monitoring of critical variables such as soil moisture, temperature, and plant health. These real-time data provide valuable information for decision-making, allowing farmers to adjust agricultural practices in a precise and timely manner. The application of IoT devices can enhance operational efficiency and reduce expenses significantly, since by capturing information in real time and analyzing it, it is possible to detect optimization opportunities and make more informed choices, thus contributing to better supervision and control of the systems on the farm [21].

Energy efficiency can also experience significant improvements, for example, optimizing irrigation through humidity sensors can reduce water consumption, contributing to the environmental sustainability of the farm. Additionally, the ability to monitor and control energy use in real time can lead to more efficient management and the adoption of renewable energy sources where possible.

In addition, once data is collected by the sensors it must be stored and processed on a platform, which provides the coffee growers data through an information management tool that monitors, analyzes, and visually displays all the agricultural variables necessary for proper decision-making. It is important to mention that the tool is a free, open source which is decentralized, and has a coverage of up to 15 km at low speed that allows adequate operation

and most importantly without licensing costs [22] to reduce the budgets of coffee growers. In addition, today there are several free design tools to model and customize how the reports and alerts that the system would issue could be visually viewed.

Finally, in terms of profitability, the implementation of IoT can result in a quick return on investment for farmers, since the combination of cost savings, increased productivity and the creation of a more sustainable coffee brand can place the farm in a prominent competitive position in the market as the Orozco coffee farm is doing through the Nespresso AAA Sustainable Quality program.

In summary, the innovative proposal of integrating Internet of Things devices into Finca Orozco's coffee management can provide tangible results and benefits in several key aspects as improving operational efficiency and creating a more efficient supply chain which is transparent and sustainable. Besides, the adoption of IoT will propel the farm towards a more technological, profitable, and sustainable future in the coffee industry letting 4.0 technology to have a significant and inclusive impact on all participants in the coffee industry. In the same way, it is crucial to consider not only the general budget assigned to agriculture in the country, but also recognize that the investment in research and development must be an essential element in public policies. This promotes training and basic research in the regions, consolidating knowledge that allows intelligent use of emerging technologies. It is necessary to promote collaboration between the public and private sectors to guarantee effective implementation of 4.0 technology in the coffee industry, thus promoting sustainable and comprehensive growth [23].

VII. POSSIBLE PROTOTYPE FOR THE PROPOSAL

Going beyond the objectives of this project and after knowing aspects of technology 4.0 and the Internet of Things [24], below is a description of a possible prototype for the proposal.

A. Soil moisture sensor Dragino LSE0

This type of sensor measures soil moisture at different depths, it has the following technical characteristics: it has a 4500mA battery which allows its duration to be very long, especially for coffee-growing areas where there is no electricity; besides, it is compatible with LoRaWAN technology, has IP66 certification which is perfect for outdoors and finally it not only monitors soil humidity, but also measures its temperature.

B. Temperature and humidity sensor Dragino LHT65

These sensors measure the temperature and humidity of the air in the environment of the coffee plants. It has the following technical characteristics: It has a 2400 mA battery with a useful life of 10 years, it can maintain a record of 3200 data with date and time for detailed analysis, compatible with LoRaWAN technology, LED for power determine its status and finally can monitor temperatures around -40° and +80° degrees.

C. Rain sensor WSS-04

This type of sensor is responsible for determining if there is rain in the environment, so it is of great benefit to determine the moments in which the coffee plantation has gone through rainy weather, and it was not known. It also has a heating system to dry its surface and avoid get damaged.

D. Illuminance sensor WSS-05 three in one

This type of sensor measures the amount of solar radiation that reaches the coffee plants, but additionally offers the functionality of the two sensors mentioned above such as temperature and environment humidity, which becomes an excellent option to save costs and not having to acquire so many sensors. Some technical characteristics are: It has a measurement range of between 300 nm to 3000nm, this means the range that the sensor must measure solar radiation, it has a consumption of 4mA at 12V, it measures temperature in ranges of -30° at 70° degrees.

E. Soil pH sensor Dragino NSPH01

This sensor is responsible for measuring the pH of the soil to determine its optimal levels of minerals and vitamins: some technical characteristics of this sensor are Soil pH monitoring through temperature compensation, microSD slot, 8500 battery mA for long use.

F. Converter RS485-LN RS485 / Modbus to LoRaWAN

Converts RS485 devices such as the WSS-05 sensor to be compatible with a LoRaWAN wireless network, simplifying IoT installation and reducing installation and maintenance costs. It is important to emphasize that this converter is only necessary for models that do not have an antenna for a wireless network. To send the data collected by the sensors, different connectivity technologies are used, including Bluetooth, Wifi and Radio Frequency. However, due to the particularity of the project and the large rural areas, it is necessary to focus on LoRaWAN technology, a wireless technology that uses low consumption, but transmits data over long distances, which is the one especially used for IoT technologies [25]. Based on the author's theory, this long-range connectivity technology is ideal for rural areas or large coffee farms where network coverage is limited. This communication protocol allows sensors to send data to a centralized gateway over long distances at a low frequency.

G. Gateway or hub

To collect and process sensor data before sending it to the cloud, a gateway or hub is used. For the use case of the coffee plant and continuing with the Dragino family and maintaining correct compatibility, the Dragino WSC1-L gateway will be used, which is a gateway or Final Node compatible with LoRaWAN technology, special for outdoors. for its protection against water. Powered by an external 12V solar photocell and contains a built-in lithium-ion backup battery.

H. Cloud and analytics platform

The data collected by the sensors and sent through the gateway is stored and processed on a cloud platform. Based on the reduced budgets of coffee growers and that the options from well-known suppliers are quite expensive, the product of the company The Things Industries known as The Things Network could be used, since among its benefits we can mention that it is free, open and uses a decentralized code with a coverage of up to 15 km at low speed but fulfilling its function and most importantly without licensing costs. [22]

I. Applications and visualization

Once data is processed in the cloud, it can be presented through custom applications and visualizations. These applications allow farmers to monitor and make informed decisions. However, the development of applications focused on the IoT industry can be complex and expensive; however, there is a provider on the market that perfectly adapts to our proposed architecture with Dragino.

J. 4G connectivity

On the other hand, it is necessary to have a stable and high-speed internet connection through the 4G network to transmit the data collected by the sensors. This will allow real-time monitoring and two-way communication with IoT devices. For this requirement, there are many modem models on the market compatible with 4G SIM that allow delivering an internet signal to different devices for sending data to the cloud.

K. Solar panels

Since coffee farms are often located in rural or remote areas, it may be necessary to use solar panels to supply power to the sensors and IoT gateway. Solar panels capture solar energy and convert it into electricity to power devices autonomously. Solar panels are photovoltaic modules that capture energy and transform it into electricity, thanks to their silicon material to do this process [26]. A recommended model for these uses is the Renogy 100W Solar Panel, which offers very good efficiency characteristics, great durability and easy installation, making it a great candidate to be used in this type of projects.

L. Batteries or energy storage systems

In addition to solar panels, an energy storage system, such as batteries, is required to ensure a constant power supply to IoT devices even at night or on cloudy days. Continuing with the line of products offered by Renogy, a recommended model for these uses would be a 12V, 100AH deep cycle gel hybrid battery, which has the advantage of being gel so the liquid could not be spilled. liquid inside and its long useful life.

M. Support infrastructure

Finally, it is necessary to have a physical infrastructure that includes supports for the sensors, protection boxes, wiring and other elements necessary to guarantee the correct installation and operation of the IoT devices in the coffee plantation. This would be defined according to the topog-

raphy of the property in which the solution is implemented, where the wiring and protection boxes among other necessary infrastructures are considered. [27]

N. Diagram and Operation of an IoT infrastructure

In figure 5 you can see an installation diagram of a possible solution for an IoT sensor system of the Dragino family, in which there are different models of sensors for soil humidity, temperature and environmental humidity, solar radiation and of soil pH, there are two lines: a green one that shows the communication line and a red one that shows the electrical connection of the devices from the solar panel to the devices with an MPPT converter, this is sent to a main processing unit that is responsible for sending all the data to a cloud company that stores and processes this data so that it is finally displayed on a Dashboard that is easily accessible to the coffee grower.

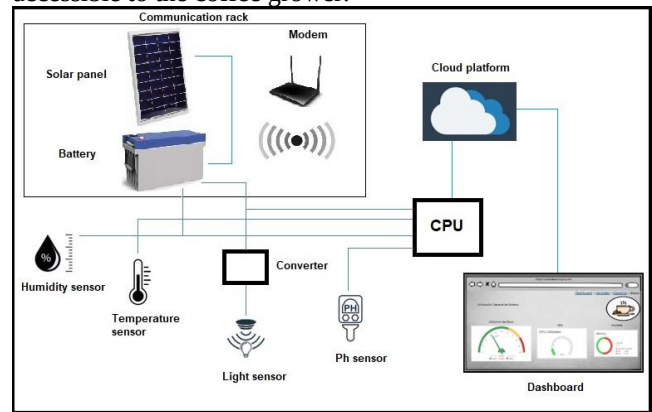


Fig.5 Sensors operating diagram.

VIII. CONCLUSIONS

Today it is important to provide coffee farmers with a clear understanding of how the Internet of Things (IoT) and sensors can improve efficiency in coffee management, suggesting a focus towards modernization and optimization of traditional agricultural practices.

This type of solution with this technology would save costs for coffee growers in terms of the use of agrochemicals and fertilizers, since through the sensors, diseases would be attacked specifically in certain areas, helping to avoid pollution, contributing to the preservation of the environment, and promoting agricultural practices that are more respectful of nature [28].

The adoption of technologies such as IoT and sensors can revolutionize the way coffee producers access information about their crops, offering them real-time data that they did not have before. This availability of data can enhance informed decision-making and more accurate management of coffee operations making possible to improve the production of the plant, which means an increase in the harvest and therefore a significant increase in the producer's finances [29].

Likewise, by monitoring climatic variables in real time, the sensors not only help the coffee grower determine if there is a possibility of pest growth but would also generate added value on specific weather conditions, allowing coffee growers to react faster and protect their crops. [30].

Finally, in this type of projects it is important to reflect thinking of a premise to the questions “What could I have developed to improve this process?” or “What impact the development that is carried out will have?” Therefore, from these questions about each task that is carried out daily, a world of possibilities opens, which until now, have not been possible. been contemplated and could become the solution to current major problems.

CONFLICTS OF INTEREST

All authors declare that we have no conflicts of interest at a financial, personal, professional, or institutional level that could influence the judgment of objectivity.

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REFERENCES

- [1] RRHDDIGITAL, “Quality and innovation, the perfect tandem: Nespresso Professional reveals how to create quality environments in workspaces”, 2022, [Online] Available: <https://www.rrhddigital.com/secciones/155464/calidad-e-innovacion-el-tandem-perfecto-nespresso-professional-desvela-como-crear-entornos-de-calidad-en-espacios-de-trabajo> [Accessed: Feb. 24, 2024].
- [2] Brecha Cero, “Costa Rica develops IoT training for family farmers”, 2021, [Online] Available: <https://brechacero.com/costa-rica-desarrolla-capacitacion-en-iot-para-agricultores-famili-ares/#:~:text=L%20iniciativa%20desplegada%20por%20el,los%20peque%C3%B1os%20y%20medianos%20agricultores> [Accessed: Set. 18, 2023].
- [3] Perfect Daily Grind Español, “Digital technologies: how they improve processes on coffee farms”, 2024, [Online] Available: <https://perfectdailygrind.com/es/2021/02/17/tecnologias-digitales-como-mejoran-los-procesos-en-las-fincas-de-cafe/> [Accessed: Set. 18, 2023].
- [4] A. Alvarado, “Precision Agriculture in Costa Rica. Panoramadigital”, 2022, [Online] Available: <https://www.panoramadigital.co.cr/la-agricultura-de-precision-en-costa-rica-el-futuro-ya-llego/> [Accessed: Nov. 12, 2023].
- [5] A. Morchid, “Applications of internet of things (IoT) and sensors technology to increase food security and agricultural Sustainability: Benefits and challenges”, 2024, [Online] Available: <https://www.sciencedirect.com/science/article/pii/S2090447923003982> [Accessed: Jan. 18, 2024].
- [6] J. Arcia, “From precise agriculture to precision agriculture. Revista Ingeniería Agrícola”, 2020, [Online] Available: <https://www.redalyc.org/journal/5862/586264607009/html/> [Accessed: Feb. 24, 2024].
- [7] A. Siles, “Agrotecnología se abre camino entre las parcelas de los productores”, 2022, [Online] Available: <https://www.larepublica.net/noticia/agrotecnologia-se-abre-camino-entre-las-parcelas-de-los-productores-ticos> [Accessed: Feb. 24, 2024].
- [8] K. Molina, “Report Towards the Information and Knowledge Society”. Editorial UCR, 2020.
- [9] O. Quiñonez, “Internet of Things (IoT)”, *Ibukku, LLC*, 2019.
- [10] National Institute of Biomedical Imaging and Bioengineering, “Sensors”, 2023 [Online] Available: <https://www.nibib.nih.gov/espanol/temas-cientificos/sensores> [Accessed: Nov. 12, 2023].
- [11] C. Pérez-García, “Design of a competitive intelligence area for an agricultural technology start-up”, Universidad de Chile, 2022, [Online] Available: <https://repositorio.uchile.cl/bitstream/handle/2250/188820/Diseno-de-un-area-de-inteligencia-competitiva-para-una-Start-Up-de-tecnologia-agricola.pdf?sequence=1&isAllowed=y> [Accessed: Nov. 12, 2023].

- [12] E. Flores, “Geography of Costa Rica”. *San José, Costa Rica: EUNED. Classic*, 1991.
- [13] M. Alvarado y G. Rojas, “Coffee cultivation and processing”, *San José, Costa Rica: EUNED, Classic*, 2007.
- [14] A. Brenes, “Elements of climatology: Their didactic application to Costa Rica”, *San José, Costa Rica: EUNED, Classic*, 1995.
- [15] L. Zamora, “Manual of recommendations for coffee cultivation”, 1 ed. *Heredia, Costa Rica: ICAFE-CICAFAE, Classic*, 1998.
- [16] M. Hidalgo, “The disease known as coffee crestring”, *Turrialba, Costa Rica: Boletín Informativo de La Regional Turrialba, ICAFE. Año 2. Número 1, Classic*, 2002.
- [17] P. Blanco, “Science will be key for the coffee sector in the face of climate change”, 2020, [Online] Available: Universidad de Costa Rica. https://federaciondefacteros.org/app/uploads/2019/12/Econom%C3%ADa-Cafetera-No.-30_Web.pdf [Accessed: Feb. 24, 2024].
- [18] BASF Agricultural Solutions, “Advantages of Agriculture 4.0 and farm management”, 2024, [Online] Available: <https://agriculture.basf.com/co/es/contenidos-de-agricultura/digitalizacion-agricultura-4-0.html> [Accessed: Feb. 24, 2024].
- [19] Statista, “Size of the Internet of Things market world-wide”, 2024, [Online] Available: <https://www.statista.com/statistics/512673/worldwide-internet-of-things-market/> [Accessed: Set. 18, 2023].
- [20] J. Aliaga, “The main drivers of arabica coffee prices in Latin America. Economic Commission for Latin America and the Caribbean”, 2021, [Online] Available: https://repositorio.cepal.org/bitstream/handle/11362/46729/1/S2100105_en.pdf [Accessed: Nov. 12, 2023].
- [21] Asesores Industrial System Engineering ISE, “IoT”, 2023, [Online] Available: <https://www.isecr.com/servicios/iot> [Accessed: Nov. 22, 2023].
- [22] Medina, E. (august 27th, 2019). The Things Network. [Online] Available: <https://www.thingsnetwork.org/community/barranquilla/post/the-things-network> [Accessed: Mar. 12, 2024].
- [23] F. Arroyo, “4.0 technologies in the development and growth of the Colombian economy: literature review from the coffee sector”, 2022, [Online] Available: https://repositorio.eafit.edu.co/bitstream/handle/10784/31753/HernanFelipe_ArroyoMeza_2022.pdf?sequence=5&isAllowed=y [Accessed: Set. 18, 2023].
- [24] Dragino. “Dragino products”, 2023, [Online] Available: <https://www.dragino.com/products/lora-lorawan-end-node/item/159-lse01.html> [Accessed: Feb. 24, 2024].
- [25] Becolve Digital, “What is LoRaWAN”, 2020, <https://becolve.com/blog/que-es-lorawan/> [Accessed: Nov. 12, 2023].
- [26] U.S. Department of Energy, “How Does Solar Work?”, 2024, [Online] Available: <https://www.energy.gov/eere/solar/how-does-solar-work#:~:text=Photovoltaics%20Basics&text=When%20the%20sun%20shines%20onto,cell%20C%20causing%20electricity%20to%20flow.> [Accessed: Feb. 24, 2024].
- [27] Freeway, “What is an IoT platform? What is the architecture of an IoT platform?”, 2024, [Online] Available: <https://freeway.com/es/que-es-una-plataforma-iot-cual-es-la-arquitectura-de-una-plataforma-iot/> [Accessed: Feb. 24, 2024].
- [28] PROCOMER, “IoT applications increase in the agricultural sector”, 2023, [Online] Available: https://www.procomer.com/alertas_comerciales/exportador-alerta/aumentan-aplicaciones-de-iot-en-el-sector-agricola/ [Accessed: Mar. 12, 2024].
- [29] Instituto Nacional de Innovación y Transferencia en Tecnología Agropecuaria, “Techniques for sustainable coffee production in the face of climate change”, 2017, [Online] Available: <https://www.mag.go.cr/bibliotecavirtual/F08-10929.pdf> [Accessed: Mar. 12, 2024].
- [30] Universidad de Costa Rica. “With sensors and techniques based on remote sensing, they study coffee cultivation to adapt its management to climate change”, 2021, [Online] Available: <https://www.ucr.ac.cr/noticias/2021/4/14/con-sensores-y-tecnicas-basadas-en-teledeteccion-estudian-cultivo-del-cafe-para-adaptar-su-manejo-ante-el-cambio-climatico.html> [Accessed: Feb. 24, 2024].