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Red inalámbrica de sensores inteligentes para aplicaciones en agricultura de precisión

Wireless network of smart sensors for applications in sustainable precision agriculture

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Resumen

La agricultura en el siglo XXI se enfrenta a múltiples retos: tiene que producir más alimentos y fibras a fin de alimentar a una población creciente con una mano de obra menor. La agricultura moderna necesita herramientas y tecnologías que puedan mejorar la eficiencia de la producción, la calidad del producto, las operaciones posteriores a la cosecha y reducir su impacto ambiental. Este trabajo muestra el diseño de una red de sensores inalámbricos para agricultura de precisión con un nodo de 3 capas, Network Interface, Model Object Firmware and Transducer Interface, que se conectan a Smart Sensor y un nodo de Comunicaciones y alertas basado en fuzzy logic para detectar anomalías en cultivos agrícolas, la interconexión de los nodos se basa en un enlace Wi-Fi, mientras que la transmisión de datos entre los nodos se realiza a través de módulos de alto rendimiento de 2,4 GHz. El sistema de alerta de anomalías está basado en un sistema de lógica difusa tipo mamdani donde las reglas y niveles de membrecía son personalizados de acuerdo a la enfermedad o cultivo a inspeccionar, para las pruebas de este sistema se utilizaron las condiciones del tizón tardío en el cultivo de papa. El sistema propuesto tiene un gran potencial para monitorear variables agronómicas y detectar anomalías, lo que contribuirá a los agricultores a tomar decisiones oportunas en el manejo agronómico de sus cultivos agrícolas contribuyendo a una agricultura ambientalmente sostenible.

Palabras clave: Red de sensores inalámbricos, Agricultura sustentable, Agricultura de precisión.

Abstract

Agriculture in the 21st century faces multiple challenges: We have to produce more food and fiber with the goal to feed a growing population with a smaller workforce. Modern agriculture needs tools and technologies that are able to improve the efficiency of production, product quality, post-harvest operations and reduce the environmental impact. This paper shows the design of a network of wireless sensors for precision agriculture with a 3 layer node, Network Interface, Model Object Firmware and Transducer Interface, to detect anomalies in agricultural crops, the interconnection between the nodes is based on a Wi-Fi link, while the data transmission between the nodes is performed through high-performance 2.4 GHz modules. The alert system for anomalies is based on a Mamdani-type fuzzy rule-based system where the rules and membership levels are customized according to the disease

and crop of interest; we used the late blight conditions on a potato crop for the tests of the system. The proposed system has a great potential to monitor several agronomical variables and detect anomalies, which will contribute to farmers making opportune decisions in the agronomical management of their crops contributing to an environmentally sustainable agriculture.

Keywords: Wireless sensor networks, sustainable agricultre, precisión agricultura.

Introduction

Agriculture in the 21st century faces multiple challenges: it has to produce more food and fiber in order to feed a growing population with a smaller workforce, as well as more raw materials for a potentially huge bioenergy market, and has to contribute to the global development of the many developing countries dependent on agriculture, adopt more efficient and sustainable production methods and adapt to climate change (FAO, 2009).

Modern agriculture needs tools and technologies that can improve production efficiency, product quality, post-harvest operations and reduce its environmental impact. Automation in agriculture produces a fundamental contribution to what is now known as precision agricultura (Leo, 2003).

Precision agriculture represents an innovative technique that facilitates decision making in relation to the actions having to do with crops obtaining greater economic benefits and at the same time minimizing their environmental impact, such as applying the correct amount of inputs (water, fertilizers, pesticides, etc.) in the right place and at the right time to improve production and improve quality, while protecting the environment (WHO, 2018).

Technologies applied to precision agriculture have evolved through the advances of wireless telecommunications, the development of microelectronic devices and the large scale implementation of Internet of Things (IoT). IoT-based applications are currently being studied and exploited in many sectors, such as health care (Dayan, 1993), autonomous vehicles (Abbasi, 2014) and environmental monitoring (for example, air (Patil, 2016), water (Deepika, 2016) and fire monitoring). In this context, wireless sensor networks (WSN) are presented as one of the technologies with the greatest boom to boost precision agriculture through Internet of Things (IoT) technologies, due, among other reasons, to the possibility of its deployment in areas without infrastructure. In recent years, the development of numerous precision agriculture applications based on this technology has been assisted as a facilitating tool. Wireless nodes and sensors are normally powered by batteries or solar energy, which allows for easy deployment in the agricultural sector, have low power consumption, which allows for high autonomy (months, even years), together with their low cost and the characteristics of self-organization and self-configuration of the network make the technology especially suitable for the agricultural field of application. It is possible to integrate several types of sensors in a single wireless node, so that soil and crop conditions, such as temperature, humidity and light, among others can be monitored remotely and in real time. In addition, it can be affirmed that wireless sensor networks provide the flexibility necessary to reduce installation, data collection and maintenance times, and greater spatial and temporal resolution in the sampling of the variables of interest to what can be achieved with traditional methods, crucial factors to adapt to the specific conditions of agricultural environments. These techniques allow the improvement of the yield and efficiency of agricultural crops thus contributing to the development of sustainable agriculture (Kwak, 2011).

Among the most important technologies for the development of the WSN, are those based on Bluetooth (Araghi, 2012), Wi-Fi (Chaiwatpongsakorn, 2014) and Zigbee (Sieber, 2008) protocols. However, the requirements of this type of networks depend on the application, which has led to the emergence of a large number of protocols, standards, communication stacks and architectures, each addressing specific subsets of applications. Commonly, these architectures are structured as protocol stacks with different numbers of layers (Al-Fuqaha, 2014), allowing levels of abstraction between them and the use of different protocols. The simplest is based on three layers: the perception layer, the network layer and the application layer. However, as this architecture is considered too simplistic, other models with additional layers were proposed (Sethi, 2017). Although the most modern is based on five layers, the practical implementations of IoT systems commonly use four layers (physical and MAC layer, network layer, transport layer and application layer), following an IP based network architecture. This paper proposes a wireless sensor network for precision agriculture with a 3-layer node, Network Interface, Model Object Firmware and Transducer Interface, to interconnect them to Smart Sensor and a Communications and Alert node based on fuzzy logic to detect anomalies in agricultural crops, the interconnection of the nodes is based on a Wi-Fi link, while the transmission of data between the nodes is done through high-performance 2.4 GHz modules..

Materials and Methods

According to the need to make real-time and more efficient decisions that are successful for farmers to be more profitable, a monitoring system of agronomic variables was designed to feed a system based on fuzzy logic to estimate pests and diseases in agricultural crops, specifically in potato crops.

Microsensors are a solution to improve agriculture. For this case they have been coupled to a system using a Wireless Sensor Network (WSN). So called precision agriculture could help increase agricultural crop production, save harvest costs and protect crops against pesticide and fertilizer abuse. The sensor system must use the minimum amount of energy possible while operating in a wide range of scenarios. Energy consumption must have great scalability at all levels of the system, including signal processing, operating system, network protocols, and the integrated circuits.

The system consists of a network of nodes, smart sensors and a module for information analysis, prediction and communication (Figure 1).

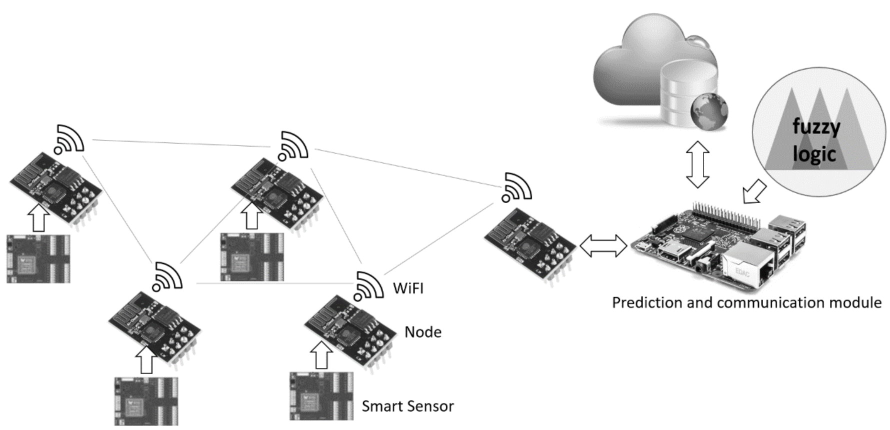

Figure 1. Wireless sensor network (WSN) architecture.

Network

The proposed network uses the mesh topology under the IEEE 802.11 standard, which defines the use of the two lower levels of the physical layer and data link layer architecture.

In addition, it works in the 5 GHz band and uses 802.11n which allows it to reach a speed close to 600 Mbps in physical layer.

Node

The node plays a fundamental role in the system, since they form the wireless network and allow communication with other nodes and sensors, it is based on the IEEE 1451.2 philosophy for resource management towards the intelligent sensor and gateway to communication network, Figure 2 shows the architecture of the node, which is composed of a set of layers in a software contained in a hardware based on a microcontroller esp8622.

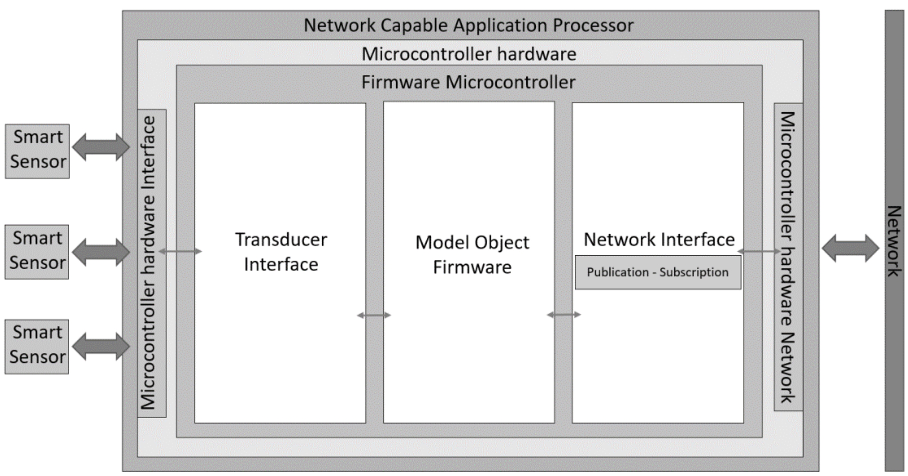

Figure 2. Network Capable Application Processor architecture.

Software:

It was developed in Python programming language and contains Network Interface, Model Object Firmware and Transducer Interface.

Transducer Interface:

It uses the SPI protocol as the communication base for the interconnection between the node and the smart sensor, which allows the plug and play mechanism for synchronization of the electronic sensor sheet towards the firmware object model.

Model Object Firmware:

It contains the firmware blocks based on the object model of the IEEE 1451.1 standard, and it describes the classes and their hierarchies of the object-oriented paradigm as shown in Figure 3.

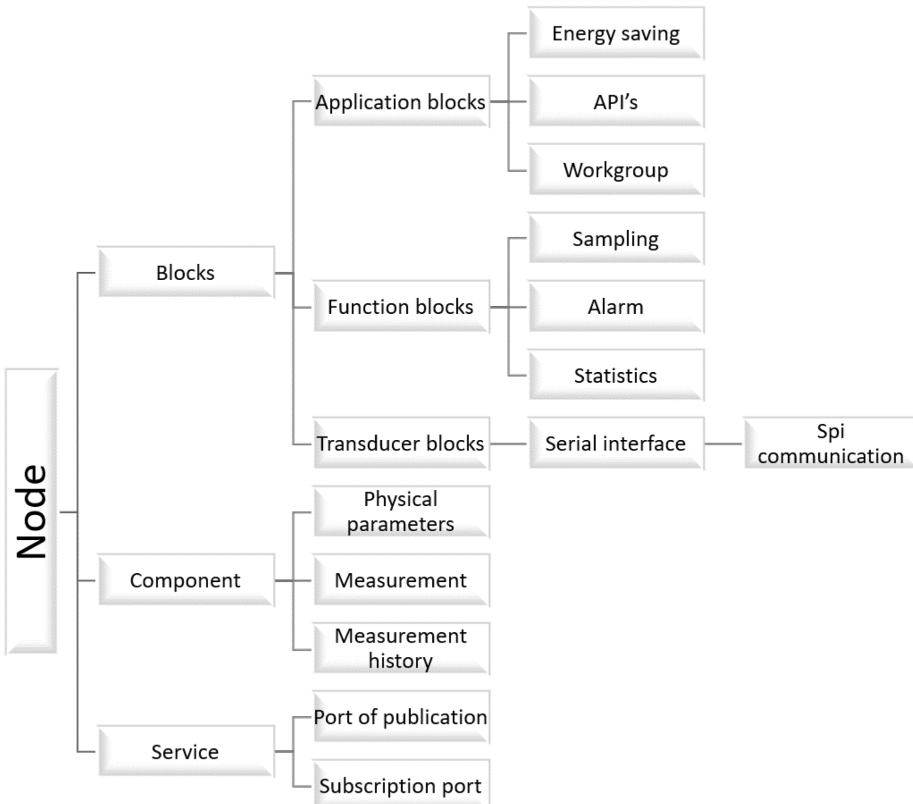

Figure 3. Class Hierarchy of Model Object Firmware.

The blocks are organized as follows:

• The Blocks contain Application blocks which manage the Api's, Energy saving, and Workgroup.

• The Function blocks handle the Sampling, Alarm and Statistics layers.

• The Transducer blocks contain the functions for the Serial interface and its derivatives such as Spi communication.

• The Component layer contains 3 blocks, the Physical parameters, Measurement and Measurement history.

• The Service layer contains the commands for operation of Publication and Subscription port.

Transducer Interface:

It is in charge of the Communication Model based on the network philosophy of the IEEE 1451.1 standard, it allows the connection between nodes and Smart sensors, through the SPI series communication protocol.

Hardware:

the node is based on the ESP8622 microcontroller. It contains a 32bit RISC CPU, Tensilica Xtensa LX106, an 80 MHz clock, 64 KB in its program memory, 96 KB of data memory. It has an external flash memory QSPI - 512 KB at 4 MB (figure 4).

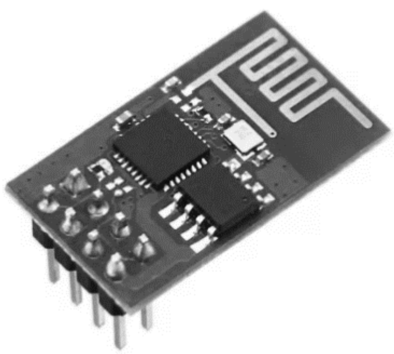

Figure 4. Node Hardware.

The communication function uses the IEEE 802.11 b / g / n Wi-Fi standard, It is integrated with the following: TR switch, balun, LNA, RF power amplifier and an impedance matching network Support WEP and WPA/WPA2 authentication. As an interface module it uses 16 GPIO pins (General purpose inputs/outputs) SPI, I^2C, I^2S interface with DMA Pins dedicated to UART, plus a UART only for transmission that can be enabled through the GPIO2 pin, in addition to an ADC converter 10-bit for analog signals.

Smart Sensor:

It provides information to the data obtained to support decision making and distributed processing, it is capable of performing functions such as the following:

• Pre-process of the measured values.

• Notification of measurements with digital signals and communication protocols.

• Decision making based on the conditions recorded separately from the microcontroller.

• Save mode of the calibration or configuration of its parameters.

Figure 5 shows the architecture of the smart sensor.

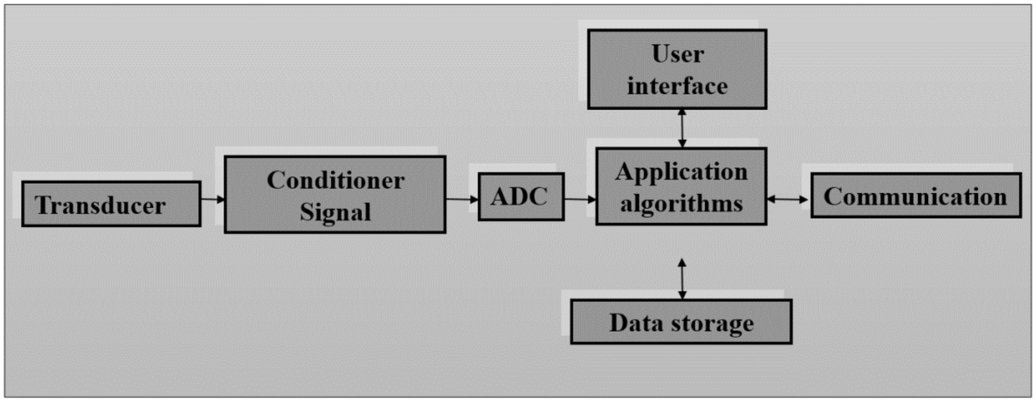

Figure 5. Smart Sensor Architecture.

Transducer:

This block contains the device capable of transforming or converting a certain manifestation of input energy, into another one different from the output, but of very small values in relative terms with respect to a generator, this module is compatible with capacitive and inductive inputs.

Application algorithms:

It is the base of the sensor, it is the one that processes the information digitized by the ADC and is the one who reprograms or stores configurations or parameters, it contains the algorithms for the user interface and the communication of information in the node.

User interface:

This block contains the configuration algorithms and parameters set by the user.

2.3 Prediction and communication module.

The prediction and communication module has the function of communicating and managing the information with all the nodes and making a direct link to the database in the cloud, in addition to containing the fuzzy lodge system algorithms that will determine the probability of the occurrence of some pest or disease in the agricultural crop.

Prediction function:

It is based on a series of rules that describe agronomic behavior based on environmental conditions that favor the appearance or proliferation of such pest or disease that for the case of study the favorable conditions for the appearance of late blight are used in potato cultivation (Carrasco, 1995).

The algorithm is based on a fuzzy logic system, with a Mamdani-type fuzzy inference engine, with 2 Temperature and PH inputs, and with 9 rules and an output that indicates the level of compatibility ranging from 0 to 1. Figure 6 shows the graphs that describe the membership levels of the temperature input variable, whose levels are low, optimal and high, using the “gbellmf” function for them.

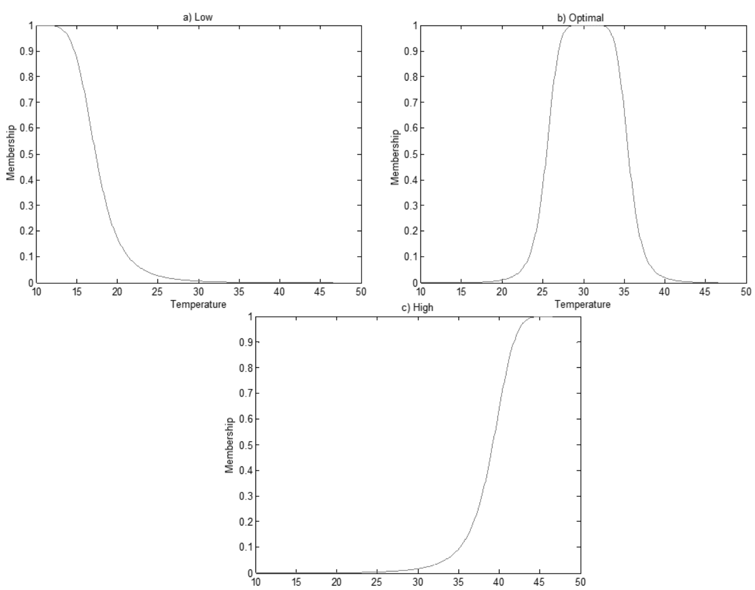

Figure 6. Membership levels of the temperature input variable.

Figure 7 shows the graphs that describe the membership levels of the PH input variable, whose levels are low, optimal and high, using the “gbellmf” function for them.

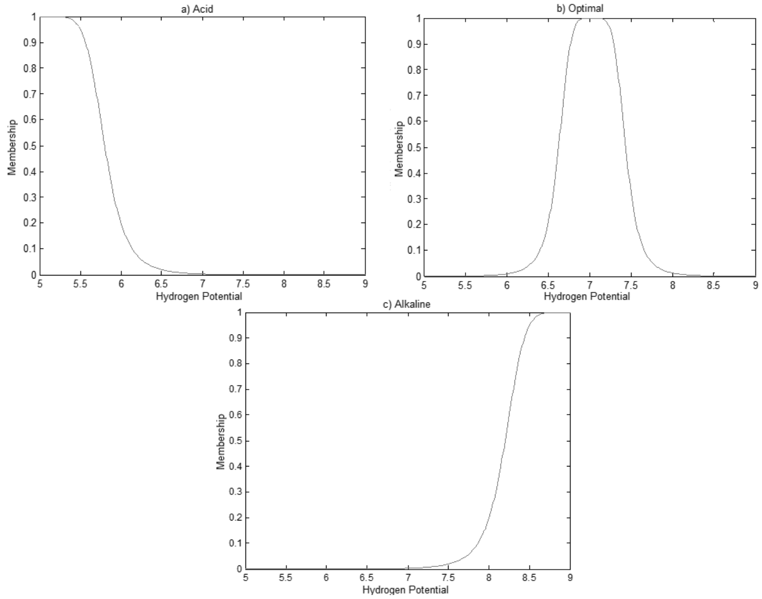

Figure 7. Membership levels of the PH input variable.

Soil pH is considered to be one of the main variables in soils, since it controls many chemical processes. It specifically affects the availability of plant nutrients, through the control of chemical forms of the nutrients. Plants absorb nutrients in the form of ions, and often occupy more cations than anions. However, plants must maintain a neutral charge in their roots.

The values were defined based on the optimal conditions; however, the potato is moderately tolerant to soils with some salinity and/or alkalinity. For the design of this input variable, we took into account the rate of change to adjust the type of curve, as well as the membership levels.

Table 1 shows the rules of diffuse inference for the appearance of late blight in potato cultivation [27].

Table 1. Diffuse system rules base.

Rule	**Rules base**
1	IF PH=ACID AND TEMPERATURE = LOW THEN COMPATIBILITY = HIGH

2	IF PH=ACID AND TEMPERATURE = OPTIMAL THEN COMPATIBILITY = HIGH
3	IF PH=ACID AND TEMPERATURE = HIGH THEN COMPATIBILITY = LOW
4	IF PH=OPTIMAL AND TEMPERATURE = LOW THEN COMPATIBILITY = LOW
5	IF PH=OPTIMAL AND TEMPERATURE = OPTIMAL THEN COMPATIBILITY = OPTIMAL
6	IF PH=OPTIMAL AND TEMPERATURE = HIGH THEN COMPATIBILITY = LOW
7	IF PH=ALKALINE AND TEMPERATURE = LOW THEN COMPATIBILITY = HIGH
8	IF PH=ALKALINE AND TEMPERATURE = OPTIMAL THEN COMPATIBILITY = OPTIMAL
9	IF PH=ALKALINE AND TEMPERATURE = HIGH THEN COMPATIBILITY = LOW

Figure 8 shows the membership levels that are used to determine the output level.

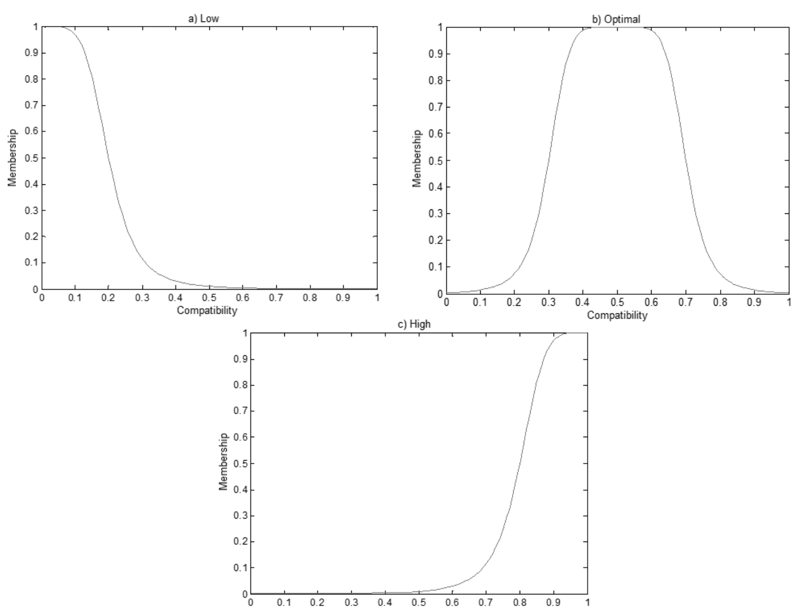

Figure 8. Membership levels of the output compatibility variable.

Results

The proposed model was subjected to a series of tests which are described below.

On the network:

Coverage tests: 10 sensors were placed at 80, 90, 100, 120 m distance between different nodes, up to the 100 m the communication was correct, however, after 110 m, there was a loss of packages, which is why we recommend that each node has at most 100 m distance from other terminals.

Energy saving tests: Tests were carried out to determine the battery durability levels of the nodes, for which the different energy saving modes were tested. The ESP8266 has three energy saving modes:

Modem-sleep: this saving mode allows us to deactivate the Station type Wi-Fi connection, established with an access point (router), when its use is not necessary and activate it again when needed. Typical consumption in this mode is 15mA.

Light-sleep: this saving mode allows us to maintain the Station type Wi-Fi connection, but reduces energy consumption at times when there is no information sent. Typical consumption becomes about 0.5 mA.

Deep-sleep: it is the mode that generates the greatest savings, but at the cost of leaving the board suspended. The only part of the board that works during this mode is Real Time Clock (RTC) to be able to restart it when the resting time is over. Here typical consumption becomes about 10 µA.

We analyzed the 3 operation modes, in modem-sleep mode it has the advantage of saving energy in the node, but the sensor can function normally. For a direct internet connection it would be a good option, but not in the mesh topology, so that operation mode was ruled out. In the light-sleep mode, the power consumption is higher, but perfect for the mesh mode. In the deep-sleep mode it is where there is a greater energy saving and as a consequence greater battery life, however, when the node is turned off there would be no communication in the mesh network, since there would be no repeaters for the sensors that are outside of coverage of the main node.

Under that analysis we determined that the best option was to use the deep-sleep mode, but in synchronous mode with the rest of the nodes, so that every 30 minutes the node will be switched on from the sensor while in operating mode in 20 seconds, in which all nodes will send their readings to the main node and then return to the inactive status.

In the predictive system:

The predictive algorithm was implemented in the RaspBerry pi 3, under the Rasbian operating system and programmed in the Python programming language. Obtaining the following output based on the system inputs, as shown in Figure 9.

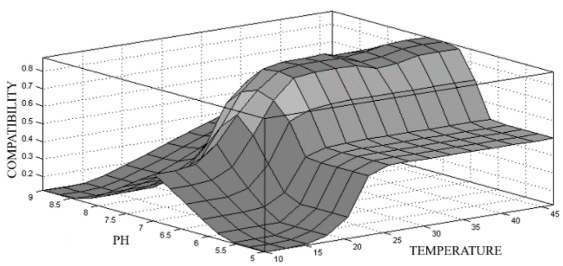

Figure 9. Map of the behavior of the compatibility level of late blight with the environmental conditions based on the fuzzy logic algorithm.

Conclusions

We developed the architecture of a WSN for precision agriculture applications, with a disease prediction module based on fuzzy logic, which in this case the membership functions were designed to predict the appearance of late blight in potato cultivation. However, the system can be adapted to any problem or disease of an agricultural crop, the low cost of the nodes and their high power make them ideal for gathering information at a medium scale. What is presented in this work is the initial stage of the development of the WSN, however in future works we plan to develop an IoT platform to manage system resources.

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