An IoT-Based System Architecture for Monitoring Hydroponic Growing in Urban Agriculture

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Abstract. Urban agriculture allows taking advantage of the free spaces on the roofs, in such a way that you can have fresh vegetables for consumption. Particularly, hydroponic cultivation has become a very interesting alternative for vegetable production using water mixed with a nutrient solution instead of soil. This paper presents a system architecture, based on the IoT paradigm, for monitoring variables in hydroponic urban growing. This architecture involves five layers, and allows monitoring a set of variables that are relevant for this activity. Based on this architecture, a monitoring system was implemented and then evaluated through experiments performed on the roof of a house in Peru. The results show that the system prototype works properly, opening opportunities for urban agriculture in the region.

Keywords: IoT-based system architecture · Remote monitoring · Growing parameters · Hydroponic cultivation · Urban agriculture

1 Introduction

In recent years, urban agriculture has taken high precedence. Houses and buildings are becoming increasingly green, because of cultivation of flowers, plants, and vegetables. In some countries, e.g., China and Japan, the population has grown considerably and it is possible that in the coming years there will be a food crisis [1]. Urban agriculture appears as an alternative that can help address this situation, taking advantage of the free spaces on the roofs of houses and buildings [2]. In China, a country that promotes this type of agriculture, there is a total rooftop space of one million hectares potentially useful for growing vegetables [3].

People who work in urban centers usually spend large time periods outside home. Therefore, they do not have much time to dedicate to agriculture. Automating part of the process of growing plants or vegetables is a common approach to follow by these

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people [4]. It requires few intervention of people in the crop and can be used as leisure activity.

In urban agriculture, the use of IoT-based solutions is quite frequent. This implies the use of sensors, wired and wireless communication networks, RFID technology, Internet, and data management [5]. Currently, urban farmers need consistent and timely crop information to make decisions. Using IoT-based systems it is possible to make the farmer monitor the crop environment and control it remotely through the network infrastructure [6].

In urban agriculture, hydroponic cultivation has become quite popular because it is carried out in the water (without soil) mixed with a nutrient solution (essential nutrients for proper growth and development of the plants). The water can circulate or be static, but it will always require oxygenation for optimal plant growth. To improve the growth of hydroponic plants, permanent monitoring of the variables must be carried out and the most important thing is to control the readjustment of the nutritive solutions, such as chloride, potassium, calcium, magnesium bicarbonate, sulfate, ammonia, nitrite, and nitrate [7].

For a plant to improve its growth and reduce production time, it must grow in a natural environment. In order to ensure that, some factors must be controlled, e.g., temperature, pH level, electrical conductivity, air humidity, and nutrient solutions. Each of these factors is difficult to control daily and have a considerable influence on the quality of the crop [8].

As a way to support the development of IoT-based solutions, particularly for hydroponic cultivation in urban areas, this research work proposes a system architecture for monitoring the most important variables for optimal plant growth. The next section presents the background that helps understand the application domain. Section 3 discusses the related work. Section 4 describes the system architecture design. Section 5 explains the system and implementation. Section 6 presents a preliminary evaluation of the system. Section 7 presents the conclusions and future work.

2 Background

2.1 Urban Agriculture

According to The Food and Agricultural Organization, urban agriculture is any kind of production in homes or plots in urban areas [9]. Urban agriculture is a very dynamic concept that encompasses a diversity of agricultural systems, such as production for self-consumption, commercialization, and also home processing of products. This type of agriculture can also be defined as any food-growing activity, carried out in urban environments, and usually in idle spaces, both horizontally and vertically, internally or externally (Fig. 1). It is an emerging topic in the agribusiness sector that has been widely discussed in government and academic circles, given its growing importance as alternative for food in increasingly urbanized societies.

Fig. 1. Urban agriculture on the rooftop

Increasingly, the world population (7.7 billion in 2020) is concerned with obtaining healthier and higher quality food. Therefore, restaurant owners and chefs are seeking to acquire food grown in the vicinity of where they will be consumed, or even grow them in these establishments [10]. The objective is to obtain the raw material at the time of preparation, so that the dishes offered have the greatest possible load of nutrients ensuring their freshness. To meet this end, several restaurants and other food establishments turn to urban agriculture as source of raw material.

2.2 Hydroponics Production

Hydroponic production is the art of growing plants using water, instead of soil as is traditionally done. It has been questioned as to whether hydroponic production is more efficient than land production [1]. An experimental study reported by Gashgari et al. [1] showed a competitive analysis between the growth of the plant, both in the hydroponic system and using soil. For the experiment both production systems received the same conditions of germination and growth, the experiment was carried out on different types of plants for a month. The results showed that the hydroponic plants germinated and grew faster than the plants in the soil.

There are several techniques for hydroponic cultivation; among the most important are the Nutrient Film Technique (NFT) and Floating Root (RF). NFT is a cultivation strategy where the roots of the plants are directly in contact with the nutrient solution. The advantage of this technique is that the nutrient solution is collected, and also supplied, through the PVC channels to the roots. On the other hand, the FR is a technique in which there is a rectangular tank with water (like a small pool) and technopor floating sheets that cover the entire surface of the tank. The roots of the plants remain in contact with the water, that must be oxygenated daily from time to time. Oxygenation can be applied manually or through air pumps [11]; Fig. 2 shows a NFT system.

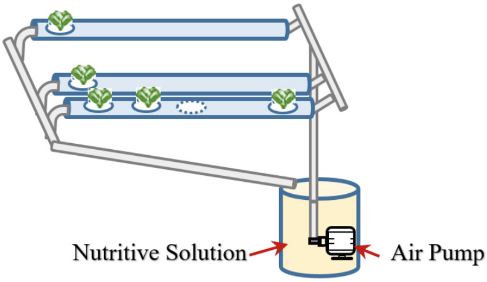

Fig. 2. Diagram of a NFT system

2.3 Nutritive Solutions

In hydroponic cultivations, the nutrient solution provides essential chemical elements for plant growing. However, there is no solution suitable for all types of plants; therefore, each solution must be analyzed and prepared according to the requirements for a specific crop. Moreover, in the cultivation of some vegetables (like lettuce), different ways of managing the supply of nutrients can be adopted, influencing thus the nutritional status of the plants and quality of the harvested product.

Hoagland et al. [12] proposed this nutrient solution that contains all the elements necessary for the growth of a plant. The concentrations of elements are maximum without producing toxicity or saline stress, and its formula is composed of macro and micronutrients.

2.4 Relevant Variables to Be Monitored

The typical variables to be monitored in these systems are the following ones:

- **Temperature.** The temperature of a hydroponic crop (T) is high relevant for the optimal growth of the plants, and the recommended temperature is 22 °C. This temperature may vary during the day and at night; however, it should be always between 17 °C and 28 °C.
- **pH.** The pH of the nutrient solution is also relevant for vegetables in general, and particularly for lettuce. The pH determines the solubility of the nutrient, mainly phosphorus (P) and calcium (Ca2+), avoiding their precipitation. This variable must be always between 5.5 and 6.0. The nitrate ratio (NO3−) affects the quality and production of fruits, and the assimilation of ammonium (NH4+) depends on the luminosity.
- **Electrical conductivity.** Electrical conductivity (EC) is the resistance offered by the material to the passage of electric current, it is one of the factors that determine the growth, development and yield of crops. Depending on the type of crop, the EC can vary between 1000 $\frac{\mu S}{cm}$ y 3000 $\frac{\mu S}{cm}$. In the case of lettuce, the optimum EC is between 1500 $\frac{\mu S}{cm}$ y 2500 $\frac{\mu S}{cm}$.

2.5 IoT Paradigm

Internet of Things (IoT) is the grouping and interconnection of devices or objects, through a public or private network, that has the objective of exchanging data. The devices or objects can be sensors, machines and interfaces that work without human intervention [13]. Among the most important areas that use IoT-based applications are, e.g., healthcare, manufacturing, electricity, agriculture, and security.

On the other hand, there are several architectures for IoT systems; all of them are layered. The simplest ones involves 3 layers (application, network, and perception) and the more complex usually have 5 layers (object, object abstraction, object management, application, and business) [14].

2.6 Telegram Social Network

Telegram is a cloud-based instant messaging system, that is also cross-platform and open-source service. Users only needs a phone number to create and validate their account. Users can send private messages to their contacts, and create join channels and public chat groups. It has several advantages over WhatsApp, for instance, it allows creating groups with 200,000 members, and sending files up to 2Gb in size. The most important advantages of Telegram are two: 1) it allows the user to log in from various devices, and 2) it makes the APIs freely available to users [15].

One of these APIs, called “Bot API”, is based on the HTTP protocol. It allows applications to create bots with Botfather to perform several tasks, such as synchronization with other services, incorporation of tools, customizing functions, or receive notifications.

The use sensors and IoT-based solutions to support hydroponic agriculture allow systems to improve their control of crop variables (T, pH EC), and thus to obtain better quality products. The amount and time of irrigation, and the supply of nutrients can also be automated in such a way that resources can be optimized. The values read by the sensors can be informed, through Telegram or other channel, to the farmer by a software application. This allows having sustainable, automated agriculture with stored data that can help farmer make better and on-time decisions.

3 Related Work

In Thailand, Changmai et al. [6] carried out an investigation in which they state that intelligent agriculture is the application of IoT-based solutions to cultivate plants, with the main objective of saving in labor or resources, carrying out a more detailed control in irrigation and fertilization. These researchers developed a smart system to support the growing of hydroponic lettuces. Using that system, they investigate the benefits of using an IoT solution instead of regular hydroponic farming. The system can monitor the growing environment and automatically adjusts the nutrient solution, air temperature and air humidity. The results show that smart farming of lettuces has on average about 36.59% more weight, 17.2% more leaves and 13.9% more stem diameter than those grown with regular hydroponic approaches.

In Indonesia, Crisnapati et al. [8] carried out a study that allows monitoring and collecting information from the hydroponic cultivation on NFT. They used an IoT system and a web application see the values reported by the sensors. The results show that the web system works as intended for monitoring a traditional NFT hydroponic system; however, the nutrient concentration is still controlled manually, therefore, it requires one person to do it every day, which implies costs to the farmers.

4 System Architecture

This section presents the system architecture design, and also its implementation. The system allows monitoring growth variables in vegetable cultivation using an IoT-based approach.

4.1 Architectural Design

Figure 3 shows the architecture proposed to support IoT-based hydroponic urban growing, which involves 5 layers: sensing, micro-controlling, data transmission, data processing and application. Next we explain each of them.

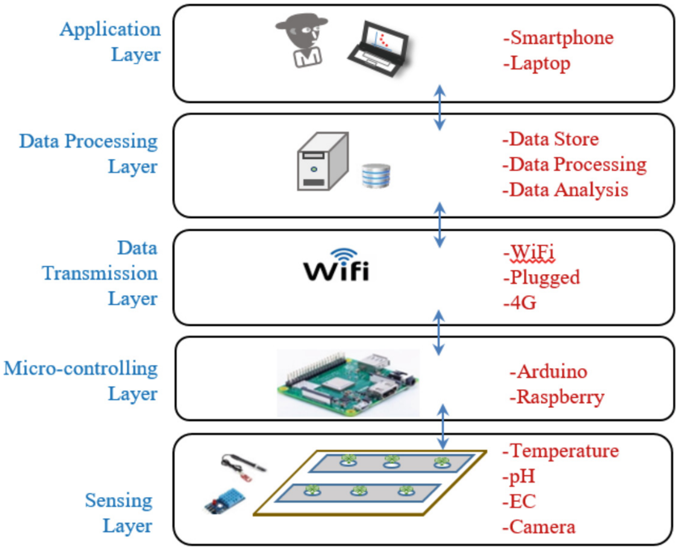

Fig. 3. System architecture for IoT-based hydroponic urban growing

- **Sensing Layer.** This layer includes all the sensors that are installed in the hydroponics modules, for example, temperature, pH, electrical conductivity, humidity, and UV radiation. In addition, it is possible to use external devices, such as regular or thermal cameras. These devices are used to measure the variables that are used for the growth of the plant; usually, this data is read in an electrical pulse. The sensors used must be carefully calibrated to have correct readings.

- **Micro-controlling Layer.** This layer involves the use of electronic devices that allow interpreting the data read by the sensors; that is, it transforms the values read by the sensors into values that can be stored. In this layer there is a variety of devices, e.g., Raspberry Pi, Arduino, ESP32, and ESP8266. The read data must be tested or validated to ensure that we are having correct readings.
- **Data Transmission Layer.** This layer is responsible for the communication between the microcontroller and Internet. The collected data must be sent to a server in the cloud that stores the data. The data transmission layer can use several communication segments, implemented using different technologies like WiFi, 3G/4G/5G, LoRa, and Bluetooth. Transmitting data in an accurate and timely manner is an important aspect for the system decision making. In case of interferences or communication fails, the sensed data should be kept in some way; for instance, stored temporarily in memory and then updated when the communication link is reestablished.
- **Data Processing Layer.** In this layer the raw data is stored, but also processed to obtain information and knowledge. Usually, the large volume of data that is collected requires to use big data and mining techniques for its correct management. A misinterpretation of the data could lead to confusion or poor decision-making from the farmer.
- **Application Layer.** This layer is the most important for the farmers, because through an application they are able to visualize the recorded values, and also receive notifications or alerts. These services allow visualizing the information of the data read by the sensors, and it should be shown in a friendly way, e.g., using graphs or statistical charts that are easy to understand by the farmer. Some alternatives are web or mobile applications, that include a control panel for viewing data, receiving notifications and alerts.

5 Implementation of the System Architecture

In this section we present the components of an IoT-based system, based on the proposed, developed to support a particular IoT-based urban plantation. Such a system was used in an experiment to determine the suitability of the proposed architecture. Next we explain the implementation of each layer.

5.1 Sensing Layer

The system uses three types of sensors: Temperature, pH and EC acquired from Whitebox Labs; and also a camera for Raspberry Pi. Figure 4 shows the sensors used as follows: item A) shows the integrated circuit and pH sensor probe, B) indicates the integrated circuit and the temperature probe with BNC connector, C) the integrated circuit and the electrical conductivity sensor probe, D) shows the camera that automatically takes pictures and feeds to the system.

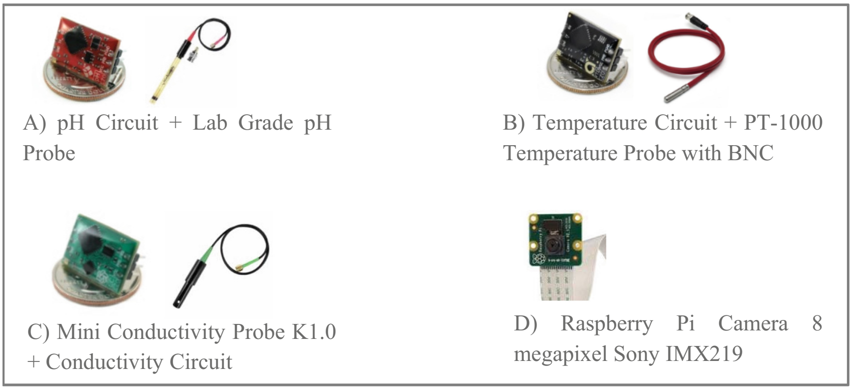

Fig. 4. Sensors used in the implementation

5.2 Microcontrolling Layer

The system uses a Raspberry Pi and a tentacle for the sensors as part of the microcontrolling layer (Fig. 5).

Fig. 5. Microcontroller used in the implementation

5.3 Data Transmission Layer

The system uses a Fiber Optic, service provided by a private telecommunication company, to connect the sensing area and the cloud. Then, the Raspberry Pi uses an IP wired network to collect data from the sensors. Figure 6 shows the system prototype.

Fig. 6. Data transmission infrastructure

5.4 Data Processing Layer

The system stores the collected data in a relational database Mysql 5.x, hosted on Hostgator.com. Then, the system processes the collected data using SQL queries and autonomous algorithms, in order to obtain information and knowledge that can help into the hydroponic cultivation process.

5.5 Application Layer

This system includes three applications. The first one is a web application, implemented in PHP, that shows information to the farmer (Fig. 7). For instance, the evolution of the monitored variables in a time window.

Fig. 7. Website showing the evolution of the temperature

The second application is a Telegram bot that uses commands (Table 1) to request values of particular variables.

Table 1. Telegram bot commands

Command	Description
/ph	Request for the pH value
/temperature	Request for the temperature value
/ec	Request for the Electrical Conductivity value
/photo	Request for the photo

The third application is an autonomous service that communicates the Telegram bot with the camera, allowing the users (farmers) to take photos and know the growth of the vegetables when they wish. These photos could also be (manually or autonomously) analyzed to determine size, color or maturity of the plant, and also if it is being invaded by insects or bugs that eat the plants. Similar to the photo request, there are also other information that can be informed through Telegram, e.g., the temperature and pH value of the cultivation (Fig. 8).

Fig. 8. pH information sent through telegram

6 System Evaluation

The evaluation was carried out on the roof of a house in Cusco, Peru, in which lettuce and parsley was grown. Only the lettuce plantation was monitored using the IoT-based system.

The lettuce and parsley were planted in different planting periods. The lettuce planting began with germination from April 15 to May 14, 2021 (30 days of germination); and the harvest took place on June 21 (35 days in the hydroponic system). The entire process from seed planting to harvest lasted 65 days. In case of the parsley, its cultivation followed a regular process.

The system worked properly along the cultivation period. After concluding these periods, we asked the farmer on the experience of cultivating with and without the supporting system. He highlighted that using the system allows him to perform a more relaxed and comfortable work. He felt to be under control of the production when used the system, and thinks that the quality of the obtained lettuce was higher that the parsley, and also compared to other lettuce plants cultivated using the regular hydroponic system.

7 Conclusions and Future Work

This work proposes a five-layers architecture based on IoT, and designed to support hydroponic cultivation of vegetables. The system was implemented using an IoT infrastructure, and three applications to support the farmer in the cultivation process. Then, this system was used to cultivate lettuce on a rooftop in the city of Cusco, Peru.

The results show that the prototype works properly and it is suitable to notify the farmers through Telegram, for instance, when the temperature exceeds the normal value for plant growth. The farmers also count on a web application to view historical data, and get pictures of the plan in real-time.

Although the results are still preliminary, the farmer participating in this process felt comfortable and under control of his production when used the system. He also indicated to be available to continue using the system, hopefully a large scale and involving other type of vegetables.

For future work, it is intended to do more tests with other types of plantations such as tomato, celery and leek; and it is also intended to add fans to cool the environment when the temperature is very high, and heaters when the temperature is lower than allowed.

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