Enhanced Hydroponic Agriculture Environmental Monitoring: An Internet of Things Approach

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Abstract. Hydroponic cultivation is an agricultural method where nutrients are efficiently provided as mineral nutrient solutions. This modern agriculture sector provides numerous advantages such as efficient location and space requirements, adequate climate control, water-saving and controlled nutrients usage. The Internet of things (IoT) concept assumes that various "things," which include not only communication devices but also every other physical object on the planet, are going to be connected and will be controlled across the Internet. Mobile computing technologies in general and mobile applications, in particular, can be assumed as significant methodologies to handle data analytics and data visualisation. Using IoT and mobile computing is possible to develop automatic systems for enhanced hydroponic agriculture environmental monitoring. Therefore, this paper presents an IoT monitoring system for hydroponics named ***iHydroIoT***. The solution is composed of a prototype for data collection and an iOS mobile application for data consulting and real-time analytics. The collected data is stored using Plotly, a data analytics and visualisation library. The proposed system provides not only temporal changes monitoring of light, temperature, humidity, CO_2, pH and electroconductivity but also water level for enhanced hydroponic supervision solutions. The ***iHydroIoT*** offers real-time notifications to alert the hydroponic farm manager when the conditions are not favourable. Therefore, the system is a valuable tool for hydroponics condition analytics and to support decision making on possible intervention to increase productivity. The results reveal that the system can generate a viable hydroponics appraisal, allowing to anticipate technical interventions that improve agricultural productivity.

Keywords: Hydroponics; Internet of Things; Mobile Computing; Smart Agriculture; Water Quality Monitoring;

1 Introduction

Hydroponic cultivation is an agricultural method where nutrients are efficiently provided as mineral nutrient solutions with several advantages such as pest problems reduction, continuous feeding of nutrients when compared to traditional agriculture

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methods [1]. However, this technique is expensive due to the energy investment compared to conventional soil agriculture [2]. Hydroponic agriculture can produce more food at a lower cost but also have several hidden expenses [3]. Hydroponic systems can be assumed as significant tools for agricultural environments such as plant factories with artificial lighting [4].

Nutrient composition and pH levels are important factors to maintain for enhanced plant factory environments [5]. Therefore, the pH and electrical conductivity (EC) supervision for nutrient status evaluation are common practices in hydroponic solutions used in greenhouse plant production.

On the one hand, hydroponic systems provide a significant opportunity for water saving in agricultural environments as it offers enhanced water efficiency by recycling the irrigation excess water. On the other hand, irrigation water recycling can be assumed as an achievable and significant practice in greenhouses environments which are growing in Mediterranean countries [6].

Hydroponics allows the usage of unsuitable areas for traditional agriculture which is the case of sterile and degraded soil areas. However, the hydroponics systems installation process is expensive and time-consuming [7].

Urban agriculture not only improves the self-sufficiency and resiliency of cities but also provide positive environmental and social advantages [8]. Hydroponic agriculture can be more easily applied to urban environments than open field traditional agriculture.

The basic idea of the Internet of Things (IoT) is the pervasive presence of a variety of objects with interaction and cooperation capabilities among them to reach a common objective [9], [10]. Is expected that the IoT will have a high impact on several aspects of everyday life and this concept will be used in several applications such as domotics, assisted living, e-health and is also an ideal emerging technology to provide new evolving data and computational resources for creating revolutionary software applications [11]. IoT can be assumed as a significant architecture for enhanced agricultural systems. Several IoT applications for environmental supervision using open-source and mobile computing technologies are reported in the literature [12]–[17]. An intelligent IoT based hydroponic system that incorporates pH, temperature, humidity, level, lighting sensing features and use deep neural network towards providing the appropriate control with an accuracy of 88% is proposed by the authors of [18]. The Titan Smartponics is a low-cost and fully automated hydroponic system that incorporate Arduinos, a Raspberry Pi, open source software for remote monitoring and control [19]. An IoT Hydroponic Farming Ecosystem (HFE) is easy to control and easy to use humidity, nutrient solution temperature, air temperature, pH and EC monitoring system to support non-professional farmers proposed by the authors of [20].

In this document, ***iHydroIoT***, an IoT monitoring system for hydroponics is presented. The collected data is stored using Plotly, a data analytics and visualisation library. The solution is composed of a prototype for data collection and an iOS mobile app for data consulting.

The rest of the paper is structured as follows: Section 2 is concerned to the methods and materials used in the implementation of the ***iHydroIoT*** solution; Section 3 demonstrates the system operation and experimental results, and the conclusion is presented in Section 4.

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2 Materials and Methods

The ***iHydroIoT*** has been developed to be a cost-effective solution that can be easily used by everyone. This solution uses an Arduino Uno as microcontroller unit, a Bluetooth Low Energy (BLE) module as a communication unit and several sensors. The data is collected using the ***iHydroIoT*** that is connected by serial interface with a Raspberry Pi 2 which is used as a server. The Raspberry Pi is connected to the Internet via Ethernet interface and is responsible for sending the data collected to Plotly service. Plotly is a Python framework for data analytics that can be used as a data visualisation tool for IoT. This framework is an open source JavaScript library for creating graphs and dashboards.

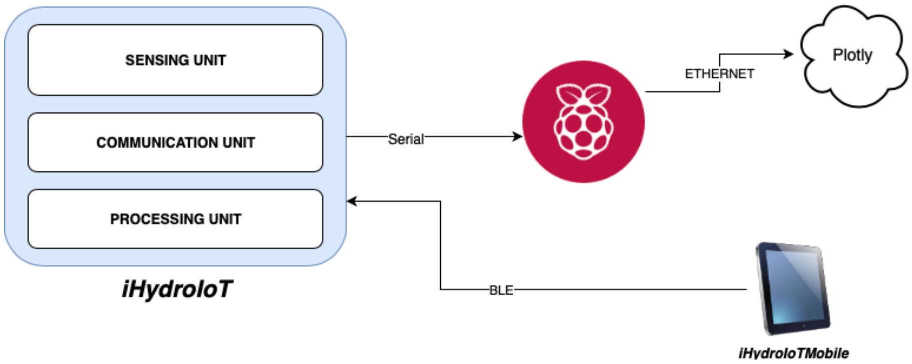

Fig. 1. ***iHydroIoT*** architecture.

The developed prototype use Arduino as a microcontroller to handle several sensor data such as light, temperature, humidity, CO_2, pH, EC sensors and water level sensors (**Fig. 2**). The selection of the sensors was made focusing on the cost of the system since the main objective was to test the functional architecture of the solution. Considering that the system is projected to be used in indoor environments where energy is easily accessible, there was no great concern regarding the selection of energy efficient sensors. Other sensors can be added for monitoring specific hydropic parameters. The BLE module is used for wireless data communication with mobile devices.

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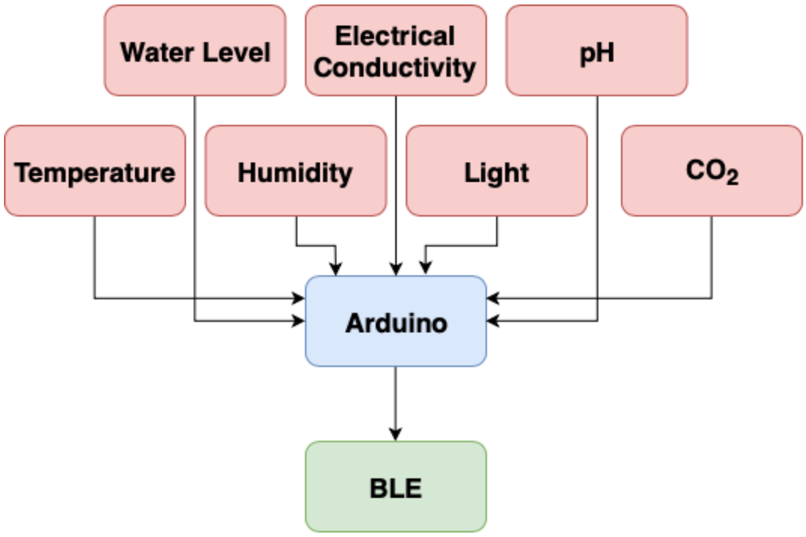

Fig. 2. ***iHydroIoT*** component diagram.

A brief introduction of the components used in the prototype is shown below:

- **Arduino UNO R3**: is a microcontroller board based on the ATmega328P, support 14 digital input/output pins (6 - PWM), 6 analog inputs, a 16 MHz quartz crystal. The board can be programmable with the Arduino IDE software via USB. The operating voltage is 5V, the recommended input voltage is 7-12V, and the limits for input Voltage is 6-20V.
- **Adafruit NRF8001**: is a BLE module developed by Adafruit that offers wireless communication between an Arduino microcontroller and a compatible iOS or Android (4.3+) device using UART interface.
- **LDR**: is a light-controlled variable resistor that can be assumed for light supervision as the resistance of the sensor decreases when light intensity increase.
- **LM19**: is an analog temperature sensor that operates over a −55°C to 130° C temperature range. The temperature error increases linearly and reaches a maximum of ±3.8°C at the temperature range extremes.
- **HIH-4000**: is a humidity sensor developed by Honeywell. The HIH-4000 support linear voltage output and is suitable for low drain, battery operated systems with a typical current draw of only 200 µA. This sensor has a 3.5% accuracy range and can be operated at a temperature range of -40 to 85ºC.
- **DFRobot CO_2 Sensor (MG-811):** is a CO_2 industrial quality module developed by DFRobot. It has MG-811 gas sensor onboard which is not only highly sensitive to CO_2 and less sensitive to alcohol and CO but also have low humidity and temperature dependency.

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- **DFRobot EC sensor:** is an analog EC meter of the aqueous solution to evaluate the water quality. This module detection range is 0~20ms/cm, the recommended detection range is 1~15ms/cm, and the temperature range is 0~40ºC.
- **DFRobot pH sensor:** is an analog 5V pH sensor, with a measuring range of 0-14 pH with a 0.1pH accuracy. This sensor can be operated within a temperature range of 0-60ºC and his response time is less than one **minute.**
- **DFRobot liquid level sensor:** is a photoelectric liquid level sensor that is operates using optical principles without mechanical parts. This sensor's output current is 12mA, and it can be operated in a temperature range of -25~105ºC. The low-level output is < 0.1 and the high-level output is > 4.6 V.The sensor's accuracy is ±0.5 mm.
- **DFRobot Water pump:** is an immiscible pump with 4.5~12V DC power supply, 100~350L/H of capacity and a power range of 0.5~5W.

The mobile application, designated as ***iHydroMobile***, was created using Swift programming language in Xcode IDE (Integrated Development Environment), and the minimum requirement is the iOS 10. The i***HydroMobile*** incorporates significant features for data consulting and to notify the hydroponic farm manager when the hydroponic agricultural environment has severe deficiencies. The mobile application has several features. Using this mobile application, the user can access to the real-time temperature, CO_2, relative humidity, pH levels, luminosity and EC. Furthermore, the application not only presents a data logger of the BLE communication but also allows the user to access the historical data and provides water pump management. This mobile application uses push notifications to notify the hydroponic farm manager when a parameter exceeds the setpoint defined.

The i***HydroMobile*** was two working modes, manual mode and automatic mode. In the automatic mode, the water pump is managed according to the sensor data for enhanced hydropic agriculture. The automatic mode was designed to increase agriculture productivity while minimises power consumption. Based on the values collected through the built-in sensors the water pump is controlled to be activated during the minimum time possible and only when necessary to promote energy efficiency. **Fig. 3** shows the mobile application executed on an iPad 3rd generation.

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Fig. 3. ***iHydroMobile*** mobile application.

BLE is a low-power wireless technology for single-hop communication which can be assumed as a significant approach for IoT [21]. Zigbee and BLE were developed for battery-powered. However, BLE outperforms ZigBee in terms of power consumption [22]. BLE uses the 2.4 GHz ISM frequency band with adaptive frequency hopping to reduce interference and includes 24 bit CRC and AES 128 bit encryption technique on all packets to guarantee robustness and authentication [23]. Therefore, this technology was selected to provide data communication between the mobile application and the i***HydroIoT*** prototype.

3 Discussion and Results

For testing purposes, the ***iHydroIoT*** was mounted inside a 21-liter aquarium with the following a dimension: 42 cm in length x 21 in width x 28 in height inside a laboratory of a Portuguese University (**Fig. 4**). The module is powered using a 230V-5V AC-DC 2A power supply. The tests show that under certain conditions the water and environmental quality parameters can be significantly lower than those considered as the high-quality conditions for hydroponics.

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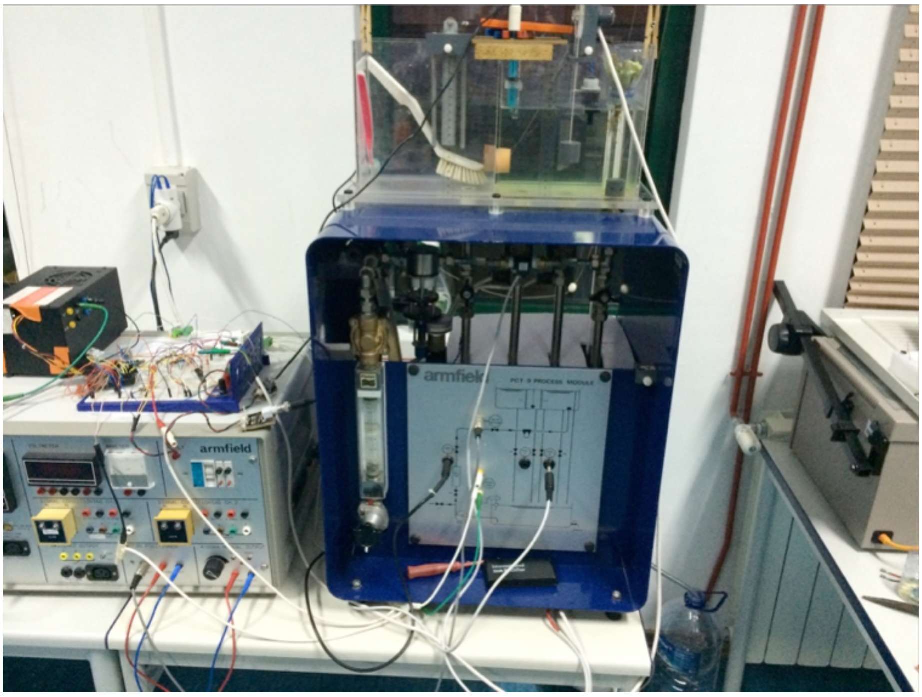

Fig. 4. ***iHydroIoT*** system prototype.

The ***iHydroIoT*** allows data consulting as graphical or numerical values using the mobile application or Plotly Web framework. A sample of the data collected by the system is shown in **Fig. 5-7**. **Fig. 5** represents EC in milliSiemens per centimetre (mS/cm), **Fig. 6** represents pH levels, and **Fig. 7** represents luminosity levels in lux.

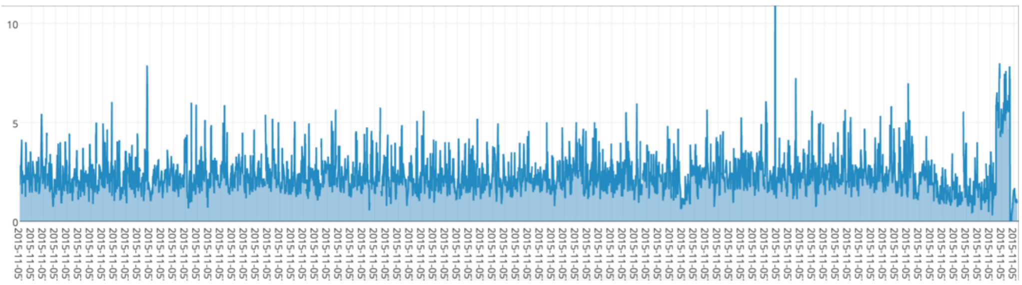

Fig. 5. EC (mS/cm) - data collected in the tests performed.

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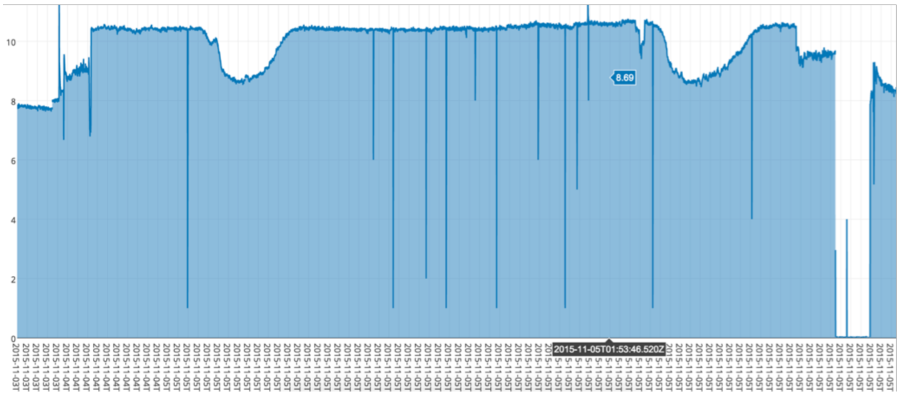

Fig. 6. pH - data collected in the tests performed.

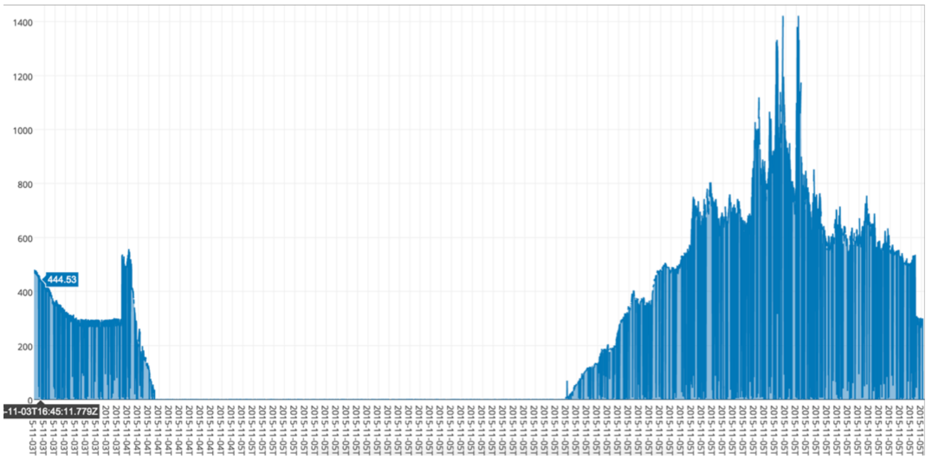

Fig. 7. Luminosity (lux) - data collected in the tests performed

The graphics displaying the hydroponic conditions provide a better perception of the monitored parameters behaviour than the numerical format. On the one hand, the mobile application also provides easy and quick access to collected data and enables a more precise analysis of parameters temporal evolution. Thus, the system is a powerful tool for hydroponics supervision and to support decision making on possible interventions to increase productivity. On the other hand, the proposed IoT approach provide temporal hydroponics data for visualisation and analytics which are particularly relevant to detect unfertile situations and plan interventions to promote a productive hydroponic environment.

The ***iHydroIoT*** data consulting features are perfectly suited to inspect the historical evolution of the hydroponic parameters and record insalubrious situations for further analysis. Furthermore, the effective productivity results can be compared with the

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monitored data which is particularly valuable for a correct evaluation and study of the cultivation methods used.

The proposed solution support push notifications feature (**Fig. 8**) aiming to provide the hydroponic farm manager with timely information and offer them the ability to react in real time to significantly improve hydroponic productivity. Based on values from literature, the maximum and minimum values are predefined by the system, but the user can also change these values for specific purposes. When the parameters exceed the maximum value, the user is alerted to take actions for enhanced hydroponics agriculture. The mobile application stores the history of notifications based on their severity.

Fig. 8. ***iHydroMobile*** push notification example

The results are very promising as the push notification feature allow the hydroponic farm manager to take action in time for enhanced hydroponics agriculture environments which will improve the productivity of the agricultural plant.

Using ***iHydroMobile*** is possible to supervise and identify poor water quality conditions and analyse the historical data to discuss possible interventions to improve the hydroponics parameters. The authors believe that the first step is to create reliable quality supervision systems through IoT for enhanced hydroponic agriculture.

Another important advantage of the proposed solution is the scalability associated with the modularity of the system. An installation can start using one station, and new modules can be added, over time, according to the needs of the plant.

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Abundant scientific research on infrared thermal imaging (thermography) applied to hydroponics can be found in the literature. Infrared thermography provides an efficient and effective noninvasive method to supervise the surface temperature distribution of a plant for enhanced hydroponics [24]. Infrared thermography (IRT) technology can be assumed as an important method for the precise supervision of plant diseases [25]. Thermography provides temperature visualisation over the leaf surface of plants and the leaf temperature variation shows concerned dehydration, caused by diseases [26]. Therefore, this imaging method should be considered for enhanced hydroponics. In the context of the studies being carried out on the IRT technology applied to the monitoring of trees (**Fig. 9**), the authors plan to correlate the proposed system results with thermography imaging methods in order to understand how these technologies can be connected for enhanced hydroponics.

Fig. 9. Laboratory tests on IRT applied to plants and trees.

As future work, the main goal is to make technical improvements, including the development of important notifications interfaces such as SMS or e-mail to notify the hydroponic farm manager when a specific parameter reports poor hydroponic conditions. The authors also plan to develop an integrated management Web portal for water quality analytics. This portal should allow the hydroponic farm manager to visualise enhanced dashboards about the water quality metrics for enhanced hydroponic agriculture. In addition, hardware and software improvements have also been planned to connect the developed prototype directly to the Internet using Wi-Fi communication technology. Furthermore, the data collected by the system should be stored using a database management system in order to provide enhanced data visualisations and analysis.

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4 Conclusions

In this paper, an IoT light, temperature, humidity, CO_2, pH, EC and water level monitoring system for hydroponics named ***iHydroIoT*** was proposed. This solution offers a feasibility method to monitor hydroponic agriculture systems in real-time and to guarantee the correct conditions for enhanced productivity.

With the proliferation of IoT and mobile computing technologies, there is a significant perspective to design automatic monitoring systems to improve productivity and quality of hydroponic agriculture.

The results achieved in the study conducted indicate a significant contribution to hydroponic supervision solutions based on IoT and open-source technologies. Using ***iHydroIoT***, the collected data can be especially valued to investigate and store the temporal changes of the monitored conditions in order to guarantee that they are established in the course of all the agricultural process.

Compared to existing systems, the ***iHydroIoT*** supports notifications to alert the hydroponic farm manager in a timely way for enhanced productivity; also, by supporting the history of the environment and water conditions, this system can be used to anticipate technical interventions that avoid unfavourable agricultural conditions.

This solution provides flexibility and expandability as the user can start with only one ***iHydroIoT*** unity and add more unities if needed regarding the dimension of the greenhouse. Nevertheless, the proposed solution has some limitations. The ***iHydroIoT*** needs further experimental validation to improve system calibration and accuracy. In addition, quality assurance (QA) and quality control (QC) have also been planned for enhanced product quality traceability. The authors have also planned software and hardware improvements to adapt the system to specific laboratory tests using thermographic experiments applied to wood and trees for enhanced hydroponics.

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