Communication technologies used in hydroponics systems

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***Abstract* — This paper, an integrated system based on communication technologies for monitoring and management of the hydroponics systems. This system aims to provide the ideal environment for plants to grow, a system where pH, temperature, electric conductivity, lux, humidity and TDs are constantly monitored. Additionally, with the use of simple mechanisms, this paper's architecture provides automation/control of hydroponic systems either for small or large sample sizes.**

Management of resources in a hydroponics set-up would become easier and more efficient based on the success and results of this study.

Keywords* — *Agriculture,Communication,IoT,Hydroponic, Management,Microcontroller,Sensor

I. 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 methods.

However, this technique is expensive due to the energy investment compared to conventional soil agriculture. Hydroponic agriculture can produce more food at a lower cost of water. Hydroponic systems can be assumed as significant tools for agricultural environments such as plant factories with artificial lighting [1], and that's why they can be fully automated if the needs of the environment and plants are met.

In this paper, I will first define some research questions to guide me when choosing adequate papers for my subject. After the study, I will conclude with the answers to these questions.

In this paper, I will explain how the hydroponic system can be automated through sensors and microcontrollers and how can it be transmitted to an end user. I will explain in detail the sensors I studied (ex: pH sensor), which one of the communication technologies are adequate for each farm size and which microcontroller (Raspberry Pi, Node MCU, Arduino) should be used based on the information it has to process. Additionally, I will talk a little about how the information should be presented to the end user depending on what purpose the farm has, such as home or work.

II. Methods

A. Research Questions

RQ1: What various communication systems can be used to control/automate hydroponic farming systems?

RQ2: How can communication systems help control and automate farming systems?

RQ3: How does a communication system control/automate hydroponic farming systems?

B. Search Strategy

At first, I started searching for the topic communication technology, hydroponic systems, agriculture/farming and excluded IoT from my search (NOT "IoT") because I wanted to be more specific, it gave me 34 papers but few of them actually talked about the research questions so I decided to include IoT.

After including IoT, it gave me 72 papers but some of them diverged too much from the topic so I had to be a little more specific with the wording.

At last, I got a search of 46 papers (on IEEE, "*(Monitoring OR Automation) AND (Communication technology OR IoT) AND (hydroponic) AND (Agriculture OR Farming)"*) and some were really on point with the research questions so I chose this query.

All papers were searched between the year 2017 and 2021. The databases I used were: Web of Science, ACM Digital Library, ScienceDirect and IEEE Xplore. The PubMed database was excluded as my research does not infer medicine.

After I searched every database, I got a total of 71 papers and now I have to include/exclude the papers following a certain criterion I define.

C. Inclusion and Exclusion Criteria

I divided the inclusion/exclusion of papers into two phases: the first one where I read the title, abstract and keywords and exclude everything that goes off-topic with my research questions. The second phase is more me meticulous because I have to read in depth what each paper included, from the first phase, talks about and see if it answers the research questions.

D. PRISMA flow diagram

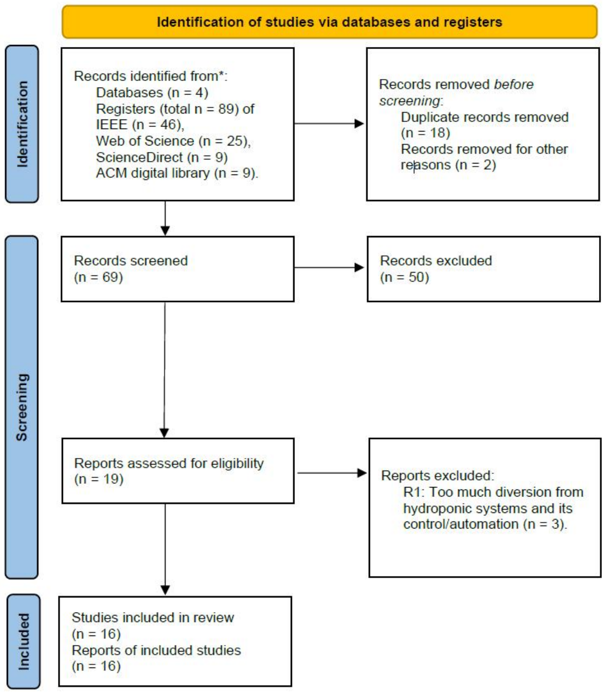

Figure 1 - PRISMA diagram flow

R1 Was used because it was too much diversion on some papers about the main topics: hydroponic systems and control/automation.

Table 1 Explanation to why papers R1 were excluded from research.

Author	Why it got rejected	Reference
H. Andrianto, Suhardi, e A. Faizal	Started diverging from automation systems to how a greenhouse works which is not related to my topic	[2]
T. Namgyel *et al.*	Started diverging from automation systems to explain how the LED works in that specific system which is not related to my topic	[3]
Helmy, E. U. Sari, T. A. Setyawan, A. Nursyahid, K. A. Enriko, e S. Widodo	Started diverging from automation systems to calculate the formulas for better nutrient concentration on hydroponic systems which is not related to my topic	[4]

E. Data extraction and Synthesis

In the papers I chose, there are two types of paper. The ones who talk in general about the control/automation of hydroponic systems, presenting the various types of technology that can be used and explaining how some work, which is great to learn the concepts and start my paper. And the ones that talk about a specific example of a certain type of technology which is great if I have to give an example for my paper or if I want to go into depth on a certain topic.
The first type of paper focuses on talking of various technologies that can communicate and monitor a hydroponic system, more specifically about LoRa technologies (wireless protocol designed specifically for long-range, low-power communications) like WIFI, BLE (Bluetooth low energy) and other radio frequencies. This type of paper also includes how they measure the parameters of the hydroponic system with sensors and how they collect the data in real-time and communicate between the user and the system.
Group 1: 7 papers are included in this category [5]–[11].
The second type of paper is more specific and I'm going to start talking about the papers that use web/cloud technology to monitor and communicate with the hydroponic system.
Group 2: 3 papers use web/cloud technology that use a responsive web framework, such as Bootstrap for the front-end, JQuery and JavaScript libraries and communicate through this technology [12]–[14].
There is 1 paper that uses mobile technology to communicate with sensors at the hydroponic system [15].
Group 3: 4 papers use micro-controllers as a means to communicate with the hydroponic system [16]–[19].
Finally, there is 1 paper that combines the use of micro-controller and mobile technology together to detect the nutrition of the hydroponic system [20].

Table 2 Summary of the selected papers related to hydroponic systems and automatio

Group and/or Author	Study aims	Platafom/Sensors/Technology used
Group 1 (S. Rathod, S. Dhanan, S. S. Harsha, S. Choudhary, e S. K. P S. Ruengittinun, S. Phongsamsuan, e P. Sureeratanakorn O. N. Samijayani, R. Darwis, S. Rahmatia, A. Mujadin, e D. Astharini R. Vidhya e K. Valarmathi N. Cristian, M. Jose, V. Juan, Q. Jose, P. Jesus, e V. H. Benitez P. Sherubha, C. Bharathipriya, M. M. Iqbal, P. Ganesh, e S. P G. Marques, D. Aleixo, e R. Pitarma)	To explore various types of automation/control systems on hydroponic systems	AI, Data Base, Microcontrollers, Web technologies, Sensors
Group 2 (P. N. Crisnapati, I. N. K. Wardana, I. K. A. A. Aryanto, e A. Hermawan M. K. Hafizi Rahimi, M. H. Md Saad, A. H. Mad Juhari, M. K. Azhar Mat Sulaiman, e A. Hussain S. Park e J. Kim)	To develop web/cloud technology that use a responsive web framework, such as Bootstrap for the front-end, JQuery and JavaScript libraries and communicate through this technology to the hydroponic systems	Web technologies, Sensors
Group 3 (R. Perwiratama, Y. K. Setiadi, e Suyoto M. S. Mohan, D. Abishek, J. Hemchander, S. Mayukha, M. Kangotra, e N. K. Soundarya J. Chaiwongsai S. Adhau, R. Surwase, e K. H. Kowdiki)	To use microcontrollers to communicate with the sensors on hydroponic systems	Microcontrollers, Sensors
M. Rukhiran e P. Netinant	To use standalone mobile technology to communicate with the sensors on hydroponic systems	Mobile, Sensors
P. Sihombing, M. Zarlis, e Herriyance	To use microcontrollers and mobile technology to communicate with the sensors on hydroponic systems	Microcontrollers, Mobile, Sensors

III. Results and Discussion

A. Analysis and Results

Anyone who wants to grow crops hydroponically should pay special attention to the design of hydroponic systems. One important element of a functioning hydroponic system is monitoring water quality. In the cultivation of traditional plants, they absorb nutrients from the soil. In order for hydroponic plants to get the nutrients they need, water in the hydroponic system must be enriched with nutrients. Water enriched with nutrients must be monitored carefully to ensure that the nutrient level is not too low (inhibits growth) or too high (potentially toxic).

In my research, I will try to build an architecture of a semi-automatic system with sensors and communication technology to the end user. For that matter, I will first analyse all my selected papers and do some proper research on sensors and communication technologies.

First, I will start by analysing the information I got from the papers:

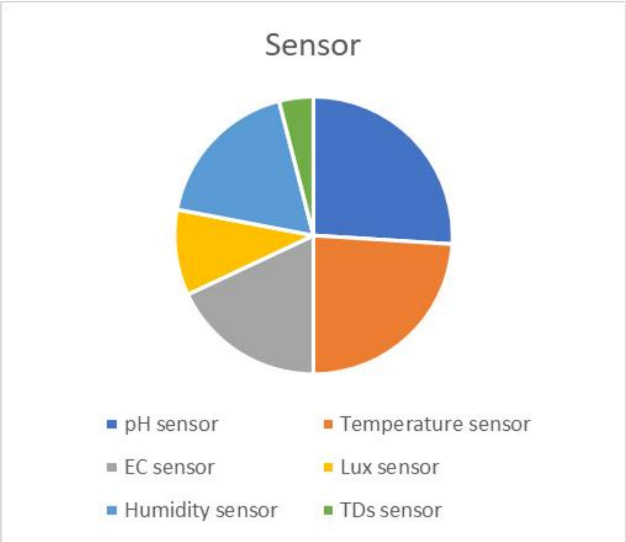

Figure 2 - Research articles sensors

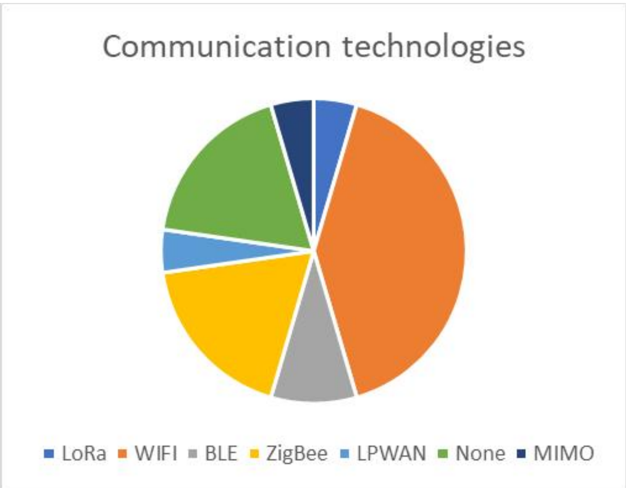

Figure 3 - Research articles communication technologies

Before reaching a result, I will start by explaining each one of the sensors and their utility on the system:

pH sensor – pH meters are an electronic device that serves to measure the pH (degree of acidity or basicity) of a liquid (there is a special electrode that serves to measure the pH of semi-solid materials). pH meter consists of an electrode to an electronic device that measures and displays the pH value.

Temperature sensor – A temperature meter is an electronic device that serves to measure the temperature of the water, this measurement is needed because plants submerged in water need to be at ideal temperatures because they can start slowing their growth (which is not efficient) or even die.

EC sensor – EC means electric conductivity. EC meters are an electronic device that serves to measure plant growth through the quality of water, usually turbine water means more resistance to electric conductivity which is bad for the plants.

Lux sensor – Lux meter is a tool used to measure the amount of light intensity somewhere. The amount of light intensity needs to be known because basically, plants need light to photosynthesise. To find out the magnitude of this light intensity, a sensor that is sensitive and linear to light is needed.

Humidity sensor – A humidity meter is an electronic device used to measure the amount of water and moisture in a particular object. This device serves to observe the hydration of the plants because on hydroponic agriculture we neither want dry nor over-watered plants.

TDs sensor – TDs means total dissolved solids. TDs meters are a tool that can measure TDs (total dissolved solids) and a high TDs level means you have an abundance of dissolved solids in your water, which typically includes minerals. Over time, the constant presence of these minerals in your water can lead to scale buildup in your pipes and appliances which shortens their lifespan and effectiveness. By knowing your TDs level, you can determine whether you need something to combat this issue, like a Salt-Free Water Conditioner or a water softener, especially hard water.

While analysing, I concluded that these 6 sensors have a good balance to be integrated into my architecture because the pH sensor, EC sensor and Temperature sensor help maintain the environment of the plants while the Lux sensor and humidity sensor help maintain the well-being of the plants. Additionally, the TDs sensor helps maintain the durability and quality of the cables and equipment on the tank which is also needed for a good environment.

When it comes to communication technologies, I could observe that the research papers used the two most common technologies: ZigBee and WIFI.

When the authors use ZigBee it’s because they are doing indoor testing or on a little yard outside (they use ZigBee for small sample sizes).

When the authors use WIFI it’s because they are doing outside testing (used on large sample sizes).

I will use both these technologies to develop my architecture.

A microcontroller is needed in this automation system because we need some computer to process the information gathered from the sensors and then send it to the end user.

In terms of architecture there is only the microcontroller left to discuss:

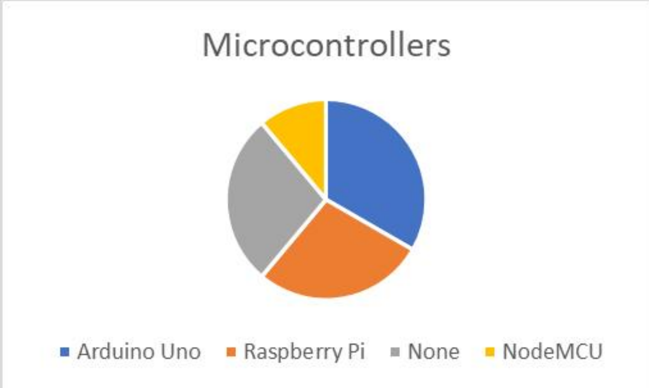

Figure 4 - Research articles microcontrollers

In the research papers, people seem to choose one of these micro-controllers and never explain why, so I am going to do some research on what is the difference between them and choose the one I think it's correct for my architecture.

Table 3 Raspberry Pi vs Node MCU vs Arduino Uno [21]

	Raspberry Pi	Node MCU	Arduino Uno
Clock Speed	1.5GHz	160MHz	16MHz
RAM	1GB +	128KB +	2KB
Cost (varies)	5€	10€	22€
Pinout	40 (no usable pins and no analog)	16 (11 usable pins and 1 analog)	22 (14 digital usable pins and 8 analog)
Advantages	Works as a mini computer, data can be processed instead of being sent to a cloud	Most versatile/ balanced in IoT, has built in WIFI module	User friendly and easy to learn, low energy consumption and huge support community
Disadvantages	Overkill for most IoT projects (too much capacity for little use)	Least known of them all	Low processing power, most expensive

After pondering for a while, I concluded that I will use two micro-controllers, one for each situation, the situation being a large area of hydroponic agriculture and a indoor area of hydroponic agriculture.

I will use on my architecture a Raspberry Pi on large area agriculture because it is a scalable solution and it will be able to process the data before sending it to a cloud or end user directly.

I will use on my architecture a Arduino on indoor area agriculture because it is better for personal use since it's easier to implement and has a low energy consumption which is better for a house, plus, it supports ZigBee which is a much better solution than WIFI or even BLE.

B. Proposed Architecture

My system architecture will consist in 6 sensors, 2 types of communication technology (one in each situation) and 2 types of microcontrollers (one in each situation).

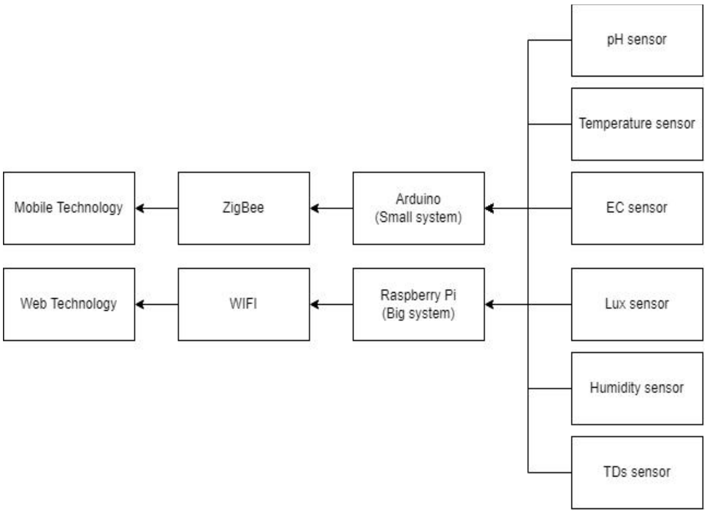

Figure 5 - System architecture

I chose to do two variants in one architecture because from the papers I've read and analysed on small agriculture you always opt for an easy-to-implement micro-controller and low energy consumption, a low range low interference (because it can affect the send/receive of data with other radio waves) communication technology and a clean and easy to access interface for the user to easily interact with.

For large agriculture, you always opt for the strong processor of data (small computer, Raspberry), large range communication technology and an interface that can easily be tweaked at any time because you will need to scale the interface (especially if it's work-related).

At first, I was only doing an Arduino for both big and small systems but after I compared the 3 micro-controllers, I came to the conclusion that an Arduino Uno wouldn't be able to handle large agriculture areas, so I changed to a Raspberry Pi because it's a much better solution for a lot of data coming in a short time.

In this architecture, I also choose the technology at which the end user will see the results because from the research papers I've read people tend to prefer mobile technology at home (for small things), while web technology permits a much more professional and scalable communication between the user and the farm, and I do have to agree it's more user friendly.

IV. Conclusion

In this paper, an architecture for IoT lux, temperature, humidity, pH, EC and TDs sensors was proposed. This architecture includes 2 variants, one for large-scale and one for small-scale hydroponic farming. The large scale proposes a Raspberry Pi to process and collect the data from the sensors then send it via WIFI and get to a website (Web technology) where the end user will be able to visualize the information and manage the system. The small scale proposes an Arduino Uno to process and collect the data from the sensors then send it via ZigBee (to avoid interference) and get the information processed on a cloud where in the end the user will be able to visualize and manage the system through the phone.

This architecture was designed after studying the research papers about this same topic where I discovered a pattern which people always use Raspberry Pi and WIFI for large-scale farming and Arduino Uno and ZigBee for small-scale farming, and After doing my own research I can agree it's a very efficient and economic way.

Duo to the automation of hydroponic systems being a work in progress that is not implemented in many countries, as shown in the figure bellow, it's being tested in countries with a lot of shores and I could observe that 4 of these papers have origin in India (considered a poor country) which shows they are trying to integrate the agriculture among the population duo to the hydroponic agriculture being compact (it can save many lives from hunger).

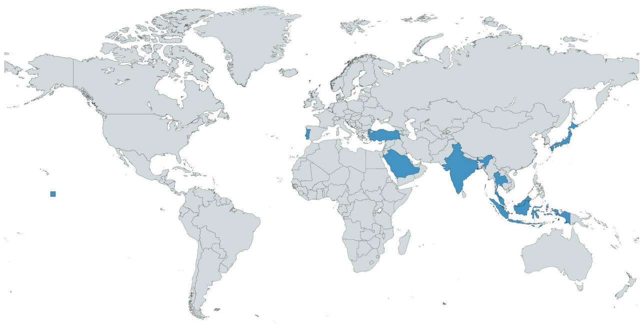

Figure 6 - Countries that developed the research papers I integrated (Blue)

Additionally, there is another concern which is that many countries still prefer the traditional non smart farms over automatic hydroponic systems, because these systems consume 90% less water and can avoid pesticides which is praiseworthy for the environment.

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