Wireless Sensing Module for IoT Aquaponics Database Construction

Abraham Reyes-Yanes[1], Sofia Gelio[2], Pablo Martinez[3], and Rafiq Ahmad[1]
[1] Department of Mechanical Engineering, University of Alberta, Edmonton, Canada
[2] Department of Electric and Electronic Engineering, University of São Paulo, Butanta, Brazil
[3] Department of Civil and Environmental Engineering, University of Alberta, Edmonton, Canada
Email: {reyesyan, pablo1, reyesyan}@ualberta.ca, sofigelio@usp.br

***Abstract*—The interest in aquaponics has been increasing in the last years since it may become one of the solutions for food scarcity around the world and the need for green and sustainable technologies in the food industry. Nevertheless, an aquaponics process is quite complex and the need for further studies about the parameter's relationships that establish a base for future technological implementations is needed. This research project presents the development of a framework that involves the creation of a wireless sensing module that uses a pH, electroconductivity, water temperature, light resistor, air humidity, and air temperature sensor and the connection to a database capable of storing and linking the information to a quality assessment tool that can be used for future smart applications towards the feasibility of aquaponics at commercial scale.**

***Index Terms*—aquaponics, wireless sensors, smart database, quality assessment**

I. Introduction

Aquaponics is a farming method that has been capturing the attention of academia and practitioners alike in recent years and the global interest of adopting this technology at commercial levels is increasing [1]. Aquaponics combines two well-known technologies of the farming research field: Recirculating Aquaculture Systems (RAS) and hydroponics [2]. This symbiotic environment relies upon the relationship built from the effluent of the RAS, a water full of nutrients but also high levels of toxic ammonia, and the hydroponic system, which takes advantage of the nutrients for plants' growth and serves as a water biofilter that reduces the levels of ammonia to healthy levels as water is recirculated towards the aquaculture tanks. This working principle is the reason why aquaponics is known as a green and sustainable technology that deserves the attention and technological advances from the research community in order to scale it at commercial levels and increase the beneficial impacts of its applications in scarcity areas as a means of food production and environmentally friendly interaction.

Due to the symbiotic nature of aquaponics, the relationship between parameters associated with its correct performance is complex and needs attention [3]. Parameters such as Dissolved Oxygen (DO), Electroconductivity (EC), pH, water temperature, Salinity (SL) in the water circulated, and light intensity, humidity, and temperature in the environment at the growing beds impact the growth rate and quality of the crops and fishes. However, the effect of these parameters on aquaponic systems needs to be further studied and intelligent tools, based on Industry 4.0 principles, can be conveniently created with this purpose.

Research efforts have been made towards the development of monitoring systems and posterior visualization of relevant aquaponic parameters, but only a few of them are aiming at modeling each parameter interaction and thinking of future autonomous smart implementations. Nagayo *et al.* implemented a GSM Arduino-based monitoring and control system capable of sending alert messages to the users when certain measurements reach dangerous levels, such as temperature, relative humidity, light, pH, water level, DO, EC, TDS, and salinity. A Graphical User Interface (GUI) was then designed to display the information and the generated data could be extracted from the system using NI LabView [4]. Odema *et al.* created an IoT-based aquaponics system that allows remote monitoring and control of the sensed parameters such as EC, temperature, humidity, pH, and DO. The authors used a Modbus TCP standard protocol to pull measurement data from the sensing nodes of a supervisory computer [5]. Vernandhes *et al.* used an Arduino connected to a web server through an Ethernet Shield. A GUI was then created for real-time monitoring and control, enabling users to remotely switch on or off the exhaust, pumps, and mist makers [6]. Wang *et al.* utilized an Arduino and a WRTnod with a sensor acquisition module. The module contained different sensors to provide real-time data on temperature, humidity, light, water level, and DO in an aquaponic system.

The data was sent wirelessly to the control and management system, which stored the data, processed it, and sent it to the server. Finally, the user could analyze the data and make data-driven decisions to control each aquaponic component [7].

Even though these contributions have been useful and contribute to the enhancement of aquaponics, remote monitoring, and control of system parameters are not

Manuscript received January 19, 2021; revised April 21, 2021.

doi: 10.18178/ijeee.9.2.43-47

enough anymore. The construction of smart decision-support models capable of predicting and correlating parameters will exponentially increase the adoption of aquaponics, by reducing costs and increase the overall flexibility. To build algorithms and predictive models for aquaponic systems, the availability and robustness of the acquired data are key to obtain accurate representations of the system itself. Since its inception and to become a database for prediction and control tools, data needs to be well-structured and defined. On a more recent work [8], the authors developed a vision-based framework to estimate two key parameters of the growing beds of aquaponics systems: growth rate and fresh weight estimation of crops.

In the proposed work, a Wireless Sensing Module (WSM) is designed and implemented in an aquaponics grow bed to gather information about six different parameters related to the water quality and air condition. Then, a framework to store the data and interact with online performance metrics is presented to promote future applications of smart algorithms and prediction tools. The construction and successful deployment of this work will promote the building of solid models to monitor and predict the behavior of aquaponics systems with less human intervention and lead to the adoption of smart technologies for optimal parameters autoregulation and precision farming. In the following sections, the module development, working framework, experimentations, and results are presented.

II. Module Development and Experimentation

A Wireless Sensing Module (WSM) is fabricated to sense six different parameters: pH, Electroconductivity (EC), water temperature, air humidity, air temperature, and light intensity using an Arduino as the controller. This module sends the data wirelessly to a database locally stored in the main controller (Raspberry Pi). The main controller and the Arduino can communicate through an access point using a Wi-Fi module installed in the Arduino controller. The main controller is running a parallel process capable of estimating the growth rate and predict the fresh weight of the crops from pictures of the current state of the grow bed using two different cameras [8] and store these performance metrics along the sensed values received. In addition to that, the database is uploading to the server all the pictures obtained from the aquaponic environment. Fig. 1 shows the process just introduced. The components for the construction of the module are listed next.

- 1 Arduino UNO USB Microcontroller
- 1 Liquid PH Value Detection Sensor
- 1 Analog Electrical Conductivity Sensor
- 1 DS18B20 Water Temperature Sensor
- 1 DHT22 Air Temperature and Humidity Sensor
- 1 LDR Sensor
- 1 ESP8266 Wireless Sensor
- 1 2- Channel Relay Module
- 1 5v Power Supply

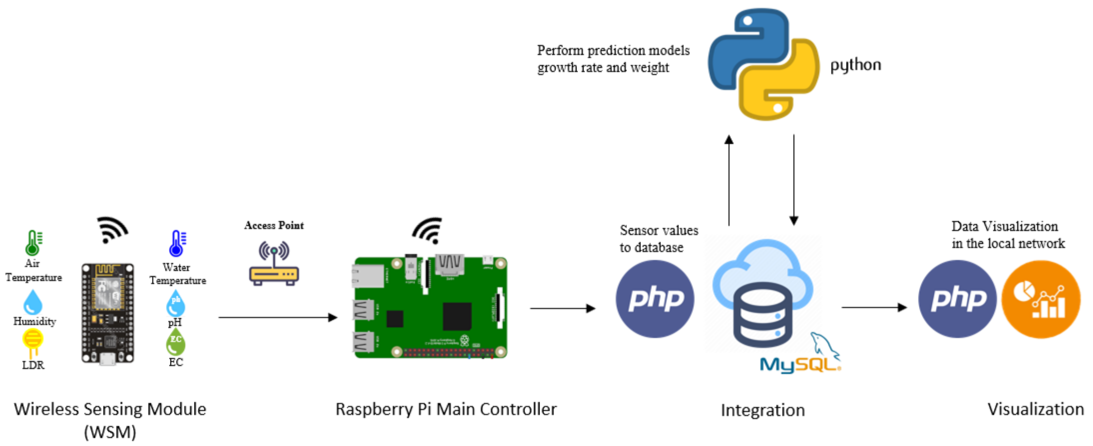


Figure 1. Process schematics of WSM construction and working principle.

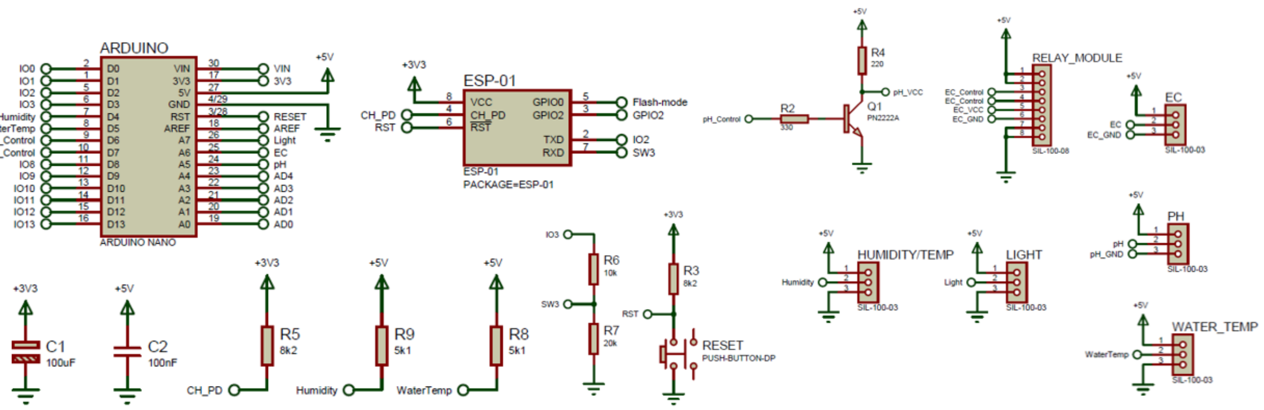


Figure 2. SWM connection schematics.

For the construction of the wireless sensing module, first, the six sensors are connected to the Arduino as needed. In some cases, transistors or resistors are required by the sensor manufacturers. Two of the sensors (EC and pH) use individual modules with BNC connectors. These two sensors need specific calibrations with different solutions and mathematical relations. For this type of sensors and to avoid noisy readings by aliasing, a 2-channel relay is then installed to power the sensors at different times and execute the readings asynchronously. The Wi-Fi module is installed in the Arduino using the serial ports. Fig. 2 shows the main connections required for the WSM using the aforementioned components.

Second, the sensors are physically placed in the grow beds of the aquaponic system, namely on the hydroponic component. Further work will include the placement of different sensors in the fish tanks and biofilters of the Aquaponics environment. To place these sensors some fixtures and bases were 3D printed to be attached to the NFT channel as shown in Fig. 3.

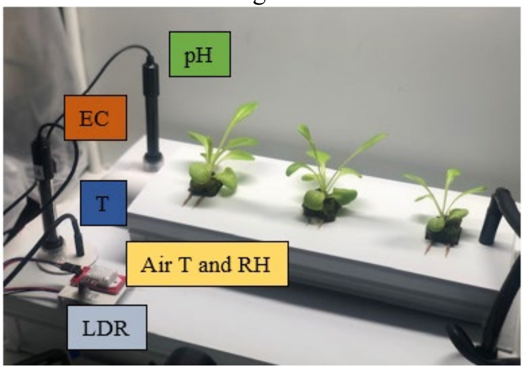


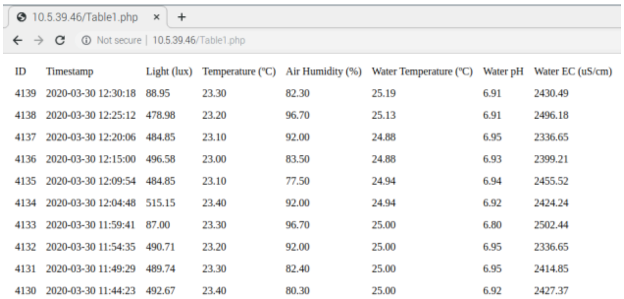
Figure 3. WSM experimental setup.

III. RESULTS

The WSM is designed to extract data in real-time and serve as a feeding process for smart algorithms as a well-studied, balanced, and designed database. Herein the importance of the module to communicate wirelessly, supporting the commercial scaling deployment with the ability to link several modules installed at different locations and send the data to a main controller, following the Distributed Control Systems (DCS) in automation [3].

The WSM is tested for a 14-day lapse in an experimental setup with an NFT channel as the hydroponics component of the process. There, *Little Gem Romaine Lettuce* is the crop selected for this study. The database is constructed following the process described and showed in Fig. 1 and the setup to grow the crops and the explanation of the components is detailed in a previous work [8].

To start the process, the Arduino controller in the WSM starts to retrieve the values from the sensors and send them as unique values through the Wi-Fi antenna to the main controller every five minutes. This main controller is responsible of execute the parallel actions that refer to the evaluation of the growth rate and fresh weight estimation. Once these sensed values are received, the main controller formatted and insert them in a MySQL database at the local level using PHP. Next, the database is uploaded to the server and displayed through PHP. Fig. 4 shows an image from the database displayed in the server. The database can be accessed through an IP address and is formatted to display a unique ID and a timestamp value to identify the correspondence with external processes. Each of the sensing measurements are displayed with the correct labels in columns such as light, temperature, air humidity, water temperature, water pH, and water EC.


10.5.39.46/Table1.php
Not secure | 10.5.39.46/Table1.php

ID	Timestamp	Light (lux)	Temperature (°C)	Air Humidity (%)	Water Temperature (°C)	Water pH	Water EC (uS/cm)
4139	2020-03-30 12:30:18	88.95	23.30	82.30	25.19	6.91	2430.49
4138	2020-03-30 12:25:12	478.98	23.20	96.70	25.13	6.91	2496.18
4137	2020-03-30 12:20:06	484.85	23.10	92.00	24.88	6.95	2336.65
4136	2020-03-30 12:15:00	496.58	23.00	83.50	24.88	6.93	2399.21
4135	2020-03-30 12:09:54	484.85	23.10	77.50	24.94	6.94	2455.52
4134	2020-03-30 12:04:48	515.15	23.40	92.00	24.94	6.92	2424.24
4133	2020-03-30 11:59:41	87.00	23.30	96.70	25.00	6.80	2502.44
4132	2020-03-30 11:54:35	490.71	23.20	92.00	25.00	6.95	2336.65
4131	2020-03-30 11:49:29	489.74	23.30	82.40	25.00	6.95	2414.85
4130	2020-03-30 11:44:23	492.67	23.40	80.30	25.00	6.92	2427.37

Figure 4. Example of database entries.

Fig. 5, on the other hand shows the values recorded for 3 days during the experimentation part displayed in continuous measurement plots.

At this point, the database is fully accessible and can be used for a variety of basic implementations such as remote monitoring or trending visualization. The next step in the process and which makes this setup more valuable is the linking in real-time of the sensed values database with the outputs from the parallel process that estimates the growth rate and the fresh weight of the crops. The main processor then, link the tables based in the time where the records were measured and establish the final database with sensed values (light, air temperature, air humidity, water temperature, water pH and EC) and the parameters extracted from the images of the plants that are shown in Fig. 6. This final database is then a complete scenario of the status of the system in real-time and will be used in future work to deploy and predict parameter relationships and optimal levels.

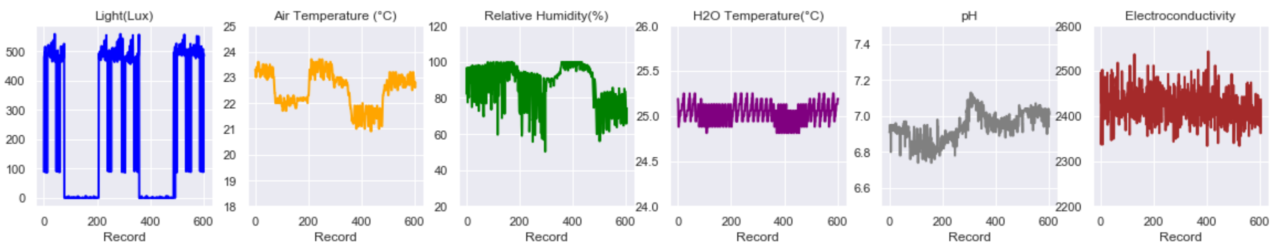


Figure 5. Example of time series of database records.

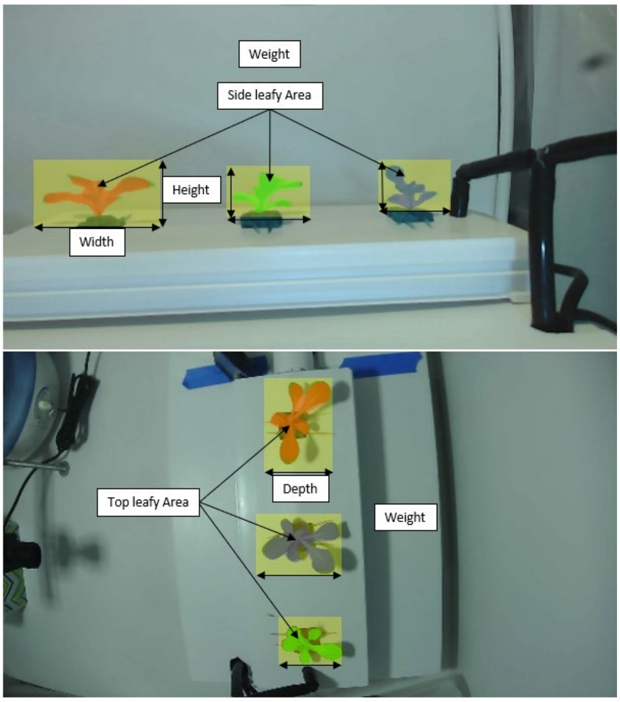


Figure 6. Illustration of WSM results.

IV. Conclusion

The presented WSM is a valuable contribution to the adoption of smart technologies and prediction tools in Aquaponics systems. As stated before, the construction of well-designed databases is an important step between this transition, here the importance of promoting the work in data acquisition systems and knowledge-based systems developments in this area [9]. This work is the third part of a series of four towards the adoption of prediction tools and cyber-physical systems in aquaponics where the first one built a bridge between automation and biological understanding, the second one proposes a performance metric tool to evaluate growth rate and fresh weight estimation and the fourth one will close the main scope with smart prediction tools in aquaponics. At this point, due to the available resources and the limitations from internal regulations about animal experimentations the sensors were just located in the hydroponic component. Future work will include sensors in the aquaculture tank such as dissolved oxygen, ammonia, nitrites and nitrates, salinity, dissolved solids, among others.

The main contribution of this method proposed is the ability to link online measurements (regular monitoring systems) to real time performance metrics. In this case, the values from the sensors (which reflects the current state of the systems) are linked to the performance of the plants in terms of growing rate and fresh weight, opening the possibilities to perform further analysis about correlations between optimal parameters. Here, the feedback loop time can be reduced and the control systems in place can be adjusted with live data to improve the output of the process. Further work can include the calibration of sensors to work with less error due signal disturbance [10].

Also, the high flexibility of this system offers the opportunity to adopt it at a commercial scale since it is not limited to standalone execution and it communicates with a central controller that processes the data and can receive information from multiple locations.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Abraham Reyes-Yanes and Sofia Gelio conducted the research, developed the necessary software and experiments presented, and wrote the initial draft of this paper. Pablo Martinez and Rafiq Ahmad supervised the research, edited the paper, and are responsible for the funding acquisition; all authors had approved the final version.

Acknowledgment

The authors acknowledge the financial support of this work by the Council on Science and Technology (CONACYT) (File No. 2018-000039-01EXTF-00050) and Transportes Pitic Scholarship. Also, the authors acknowledge the financial support from the Natural Sciences and Engineering Research Council of Canada (NSERC) (Grant File No. ALLRP 545537-19 and RGPIN-2017-04516).

References

[1] D. C. Love, *et al.*, "An international survey of aquaponics practitioners," *PLoS One*, vol. 9, no. 7, p. 10, Jul. 2014.

[2] R. Junge, B. König, M. Villarroel, T. Komives, and M. Jijakli, "Strategic points in aquaponics," *Water*, vol. 9, no. 3, p. 182, Mar. 2017.

[3] A. Reyes-Yanes, P. Martinez, and R. Ahmad, "Towards automated aquaponics: A review on monitoring, IoT, and smart systems," *J. Clean. Prod.*, vol. 263, p. 121571, Aug. 2020.

[4] A. M. Nagayo, C. Mendoza, E. Vega, R. K. S. Al Izki, and R. S. Jamisola, "An automated solar-powered aquaponics system towards agricultural sustainability in the Sultanate of Oman," in *Proc. IEEE International Conference on Smart Grid and Smart Cities*, 2017, pp. 42-49.

[5] M. Odema, I. Adly, A. Wahba, and H. Ragai, "Smart aquaponics system for Industrial Internet of Things (IIoT)," in *Proc. the International Conference on Advanced Intelligent Systems and Informatics*, 2017, vol. 845, pp. 844-854.

[6] W. Vernandhes, N. Salahuddin, A. Kowanda, and S. P. Sari, "Smart aquaponic with monitoring and control system based on IoT," in *Proc. Second International Conference on Informatics and Computing*, 2017, vol. 2018-Janua, pp. 1-6.

[7] D. Wang, J. Zhao, L. Huang, and D. Xu, "Design of a smart monitoring and control system for aquaponics based on OpenWrt," in *Proc. the 5th International Conference on Information Engineering for Mechanics and Materials*, 2015, pp. 937-942.

[8] A. Reyes-Yanes, P. Martinez, and R. Ahmad, "Real-time growth rate and fresh weight estimation for little gem romaine lettuce in aquaponic grow beds," *Comput. Electron. Agric.*, vol. 179, no. 105827, Dec. 2020.

[9] R. Ahmad, S. Tichadou, and J. Y. Hascoet, "A knowledge-based intelligent decision system for production planning," *Int. J. Adv. Manuf. Technol.*, vol. 89, no. 5-8, pp. 1717-1729, Mar. 2017.

[10] M. A. Soriano, F. Khan, and R. Ahmad, "Two-axis accelerometer calibration and non-linear correction using neural networks: Design, optimization, and experimental evaluation," *IEEE Trans. Instrum. Meas.*, vol. 69, no. 9, pp. 6787-6794, Sep. 2020.

Abraham Reyes-Yanes is a master student at the University of Alberta in the Mechanical Engineering Department. He received his bachelor's degree in 2015 from Hermosillo Institute of Technology (ITH) in Mechanical Engineering with specialization in mechanical design and automation. His research interests include computer vision, automation, control, and smart systems in agriculture.

From August 2014 to February 2015, he held a position as a research intern in the Polymer Engineering Center in the University of Wisconsin-Madison. After that and right before moving to Canada to start his master studies.

Mr. Reyes-Yanes worked in automation and maintenance planning in automotive and manufacturing industries. He is currently Research Assistant in the LIMDA group in the University of Alberta. Mr. Reyes-Yanes is a CONACyT scholarship recipient and a volunteer in the Aquaponics Association.

Sofia Gelio da Silva is a bachelor's in Electrical and Electronics Engineering student at São Paulo University. From January 2020 to March 2020, she held a research assistant position in IoT-based data acquisition in the Laboratory of Intelligent Manufacturing, Design and Automation (LIMDA) at the Department of Mechanical Engineering of University of Alberta, Canada. Her research interests include smart systems and internet of things (IoT).

Pablo Martinez is a PhD Candidate in the Department of Civil and Environmental Engineering in the University of Alberta. He holds an MSc in Mechanical Engineering from the University of Alberta, Canada, and a BSc in Electromechanical Engineering with a specialty in Electronics and Control Systems from the Universidad Pontificia de Comillas (ICAI), in Madrid, Spain. Mr. Martinez's research interests are around BIM-based cyber-physical systems and machine vision, including implementing inspection systems and automated quality control and productivity analysis within construction processes.

He is currently the team lead for the aquaponic-related research in the LIMDA Lab under Dr. Ahmad supervision. Mr. Martinez is a NSERC funded student and received the Alberta Graduate Excellence Scholarship (AGES) in 2019 for his research.

Dr. Rafiq Ahmad is an Assistant Professor in the Department of Mechanical Engineering. He is the director and founder of the Laboratory of Intelligent Manufacturing, Design and Automation (LIMDA). He has obtained his PhD in Mechanical Engineering from Ecole Centrale de Nantes, France, and post-doctorate from the University of Luxembourg.

Dr. Rafiq is a board member of International Society of Automation (ISA-Edmonton section, Co-UofA Student Section Advisor), specialty editor of the International Journal of Industrialized Construction, and steering committee member of the international ICCMA conference.