Aquaponics – A Symbiotic and Sustainable Farming Technique

Akshatha Venkatesh Prasad
Electrical Engineering
Systems Engineering and Engineering Management
South Westphalia University of Applied Sciences
Soest, Germany
venkateshprasad.akshatha@fh-swf.de

***Abstract*— The traditional farming techniques are causing more harm than good, and this can be seen through deteriorating soil quality and crops that are harmful to humans due to rampant usage of chemical fertilizers/pesticides. Aquaponics is one of the farming techniques that can be opted for instead. The Aquaponics system comprises growing plants in mineral solvents alongside the breeding of fish. The below study was undertaken to build an Aquaponics system where plants and fish help each other grow, making it a symbiotic relationship. The system was built outdoors using an open aquarium with five tilapia fish, two grow beds, Arduino Uno, sensors (to monitor the pH, temperature, humidity, liquid level, and the soil moisture content), electric pumps, and an automatic fish feeder. After programming the sensors and configuring other components, four different plants' growth was monitored over the span of seven days. All the plants grew well in this short duration, and it was observed that salad cucumber (Cucumis sativus) grew the most with a height of 8.1 centimeters. The experiment required a minimum amount of water, caused no soil damage, and produced completely organic plants. This Aquaponics system is just one example to show that it is possible to grow plants and breed fish in one's backyard.**

Keywords*— Aquaponics, aquaculture, hydroponics, Arduino Uno, chemical-free organic products, water recirculation

TABLE OF CONTENTS

I. INTRODUCTION

With the continuous depletion of water levels and the overuse of agricultural lands, crops are deteriorating, and there is excessive usage of chemical fertilizers. Also, with the increase in awareness and demand by urban consumers, restaurants, and hotels for chemical-free organic products and out-of-season produce, it becomes imperative to look out for alternatives to current farming methods. Aquaponics, as an alternative, fits the requirement.

Aquaculture is a process of breeding fish, and hydroponics is a process of growing plants using mineral nutrient solutions; a combination of these forms a symbiotic system called Aquaponics. Fig. 1 shows a typical Aquaponics system. The aquaculture system pumps the wastewater containing ammonia into the plant bed. Ammonia is then converted into nitrites that are further converted into nitrates using nitrifying bacteria. The plants absorb the nitrates and simultaneously purify the water. The purified water is recirculated back into the fish tank.

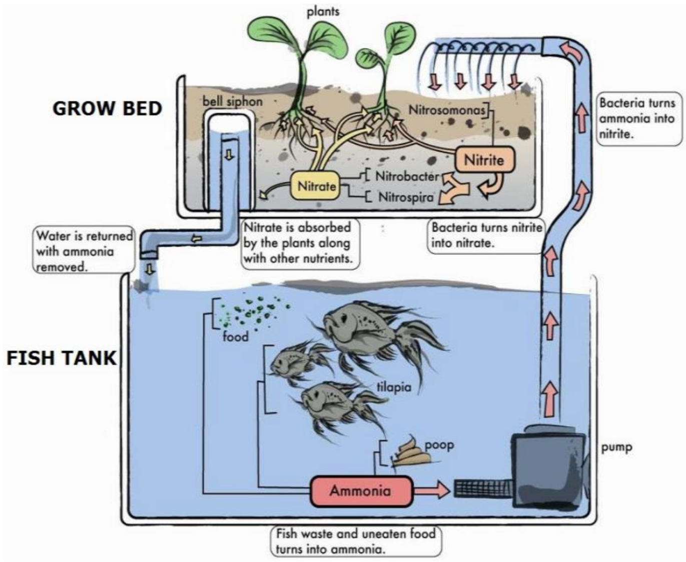

Fig. 1. Typical Aquaponics system [1]

In an article by Spectrum India, the writer has explained the need to change the nature of farming as the current food production is not enough to feed everyone. Aquaponics is highlighted as hope amid these problems. The method is identified to be reliable to grow organic plantations without requiring large acres of land. In the USA and Australia, Aquaponics is already being recognized as a farming alternative. In India, one of the earliest Aquaponics farms is the Red Otter Farms, a 10,000 sq. ft. land that produces 150 kilograms of organic vegetables delivered to customers at their doorsteps. Several other Aquaponics projects were introduced that became a huge success, and more are in progress [2]. M. Mamatha and S. Namratha studied the comparison between a controlled and an uncontrolled Aquaponics system. The Aquaponics system was continuously monitored using temperature, water level, and pH sensors in the controlled method. The uncontrolled system was left unsupervised without any sensors. Results showed that the controlled Aquaponics setup was a better system to maintain pH levels, avoid algae growth, and enhance plant growth [3]. R. Biernatzki and R. Meinecke have proposed an Aquaponics system that uses the concept of a closed greenhouse combined with Thermal Energy Storage (TES). In colder countries such as Germany, indoor Aquaponics systems have to be set up to maintain the temperature. Hence, the system can be placed near a coal mine to use the mine water for its heat [4].

The main objective is to build a sustainable Aquaponics setup. The approach will be using an outdoor fish tank with tilapia fish, grow beds, Arduino Uno, sensors, electric pumps, and an automatic feeder, and the results will be in terms of the rate of growth of four different plants.

The remaining part of the paper covers the methodology, results, benefits, and conclusion. In the methodology section: a) the biological setup containing the fish tank and grow bed is explained; b) the block diagram of the Aquaponics system is described; c) the working and hardware configuration is explained; d) the software used to program the sensors is introduced. The results depict the growth of the four plants over seven days. Finally, the benefits of growing plants in this Aquaponics system are observed, and the conclusion includes the improvements that can be made to the approach in the current study in terms of automation of the entire system.

II. METHODOLOGY

A. Biological Environment

i. Fish Tank

In this system, an outdoor fish tank was used where the ratio followed was one fish to 10 liters of water. Thus, five tilapia fish and 55 liters of water were added to the fish tank. Additionally, neem (Azadirachta indica) and tobacco (Nicotiana tabacum) were mixed in the water as they play the role of organic pesticides for the system [5].

ii. Grow Beds

The two grow beds having an area of 2700 centimeters square were layered with different materials such as wood chips and lava rocks to set up a natural filtering mechanism. A grow bed is also home to microbes that will break down the ammonia to nitrates for the plants to consume and thrive.

The following were the plants used in the Aquaponics setup:

- Spinach (Spinacia oleracea)
- Chilies (Capsicum frutescens)
- Salad cucumber (Cucumis sativus)
- Beans (Phaseolus vulgaris)

B. Block Diagram

Fig. 2 represents the block diagram of the Aquaponics system. As shown, the sensors monitor the parameters of the Aquaponics system and work as programmed by the Arduino Uno. The liquid level sensor monitors the water in the fish tank, and the output is determined through Light Emitting Diodes (LEDs) and a buzzer. The electric pump recirculates the water in the setup, and the automatic feeder provides food for the fish.

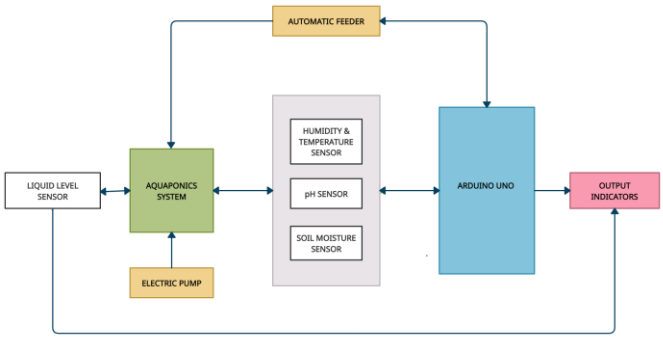

Fig. 2. Block diagram of the Aquaponics system [*]

C. Hardware

i. Arduino Uno

Arduino Uno is the microcontroller board that was used for this experiment. Arduino is an open-source platform that consists of a programmable circuit board and software to run the programs. The sensors are connected to the circuit board as shown in fig. 3, and the program from the Integrated Development Environment (IDE) is uploaded through the Universal Serial Bus (USB) cable to the board [6].

Fig. 3. Arduino Uno board [7]

Arduino Uno board was used in this system because of its intuitive coding platform, simple code structures, and cost-efficient feature. The microcontroller houses both analog and digital pins, giving the advantage to connect and use both analog and digital sensors. For example, in this Aquaponics system, the soil moisture sensor gives an analog output, whereas the temperature sensor gives a digital output.

ii. Humidity and Temperature Sensor

Stable temperature and humidity levels aid the growth of the plants and fish. In this system, the Digital Humidity and Temperature (DHT11) sensor was used to measure temperature and humidity.

Fig. 4 shows the connections between the DHT11 sensor module and the Arduino Uno board, where only the digital and power pins are used. The capacitive humidity sensors and a thermistor assess the surrounding air and provide a digital output. There is a moisture-holding substrate between the two electrodes of the capacitor that acts as a dielectric to sense humidity. Any change in humidity levels is reflected in terms of a change in capacitance value. For temperature measurement, there is a decrease in the resistance value of the negative coefficient thermistor with the increase in temperature [8].

Fig. 5 shows the practical implementation of the DHT11 sensor.

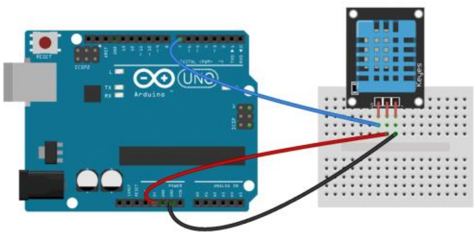

Fig. 4. DHT11 circuit [9]

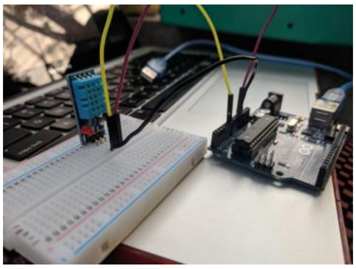

Fig. 5. Practical implementation of the DHT11 sensor [*]

iii. pH Sensor

The optimal pH of the water should be in the range of 6.8-7.0 for an Aquaponics system. If the pH becomes more acidic, a base should be added to bring the pH back up. In order to prevent the pH increase beyond 7.0, the alkaline particles from the water should be filtered. Hence, it is important to check the pH at least once a day [10].

SEN0161 was the pH sensor used for this setup, along with the Arduino board and a pH probe, as shown in fig. 6. The sensor measures the hydrogen ion concentration when the pH probe is immersed in a solution and generates an output in terms of voltage. If a solution has more hydrogen ion content, it is acidic; else, it is alkaline. Fig. 7 shows the practical implementation of the SEN0161 sensor and pH probe.

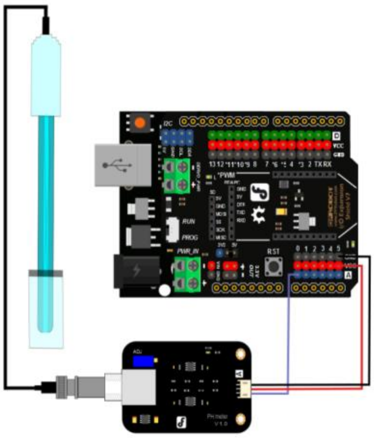

Fig. 6. SEN0161 circuit [11]

Fig. 7. Practical implementation of SEN0161 sensor and pH probe [*]

iv. Soil Moisture Sensor

In this system, the FC-28 soil moisture sensor was used. As shown in fig. 8, the sensor is connected to the analog pins of the Arduino Uno board.

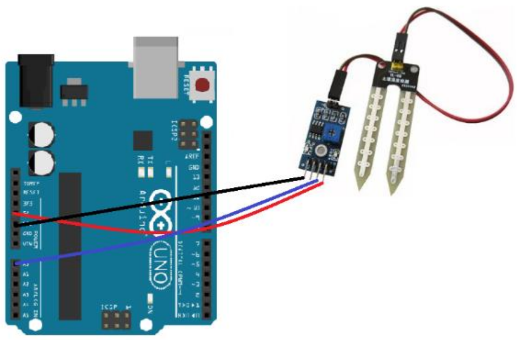

Fig. 8. FC-28 circuit [12]

The two probes of the sensor were inserted into the grow beds to measure the volumetric content of water. The grow bed conducts more electricity, and there is less resistance when the moisture content is high. In dry grow beds, the conduction of electricity is poor, indicating low moisture content [12].

Fig. 9 shows the practical implementation of the FC-28 sensor.

Fig. 9. Practical implementation of FC-28 sensor [*]

v. Liquid Level Sensor

As the water is continuously recirculated between the grow bed and the fish tank, the water level drops after every cycle. Hence, a liquid level sensor was used for the system. The components used to build this sensor are shown in table I.

TABLE I
COMPONENTS USED TO BUILD THE LIQUID LEVEL SENSOR [13]

Component	Quantity
BC547 transistor	4
220-ohm resistor	6
LED	3
Buzzer	1
9V Battery	1
Connecting wire	6

Fig. 10 represents the circuit diagram of the sensor that indicates four levels of water – A, B, C, and D. Levels A, B, and C are indicated using LEDs. Once the tank is full when the water reaches level D, the buzzer is triggered [13]. Fig. 11 shows the practical implementation of the liquid level sensor.

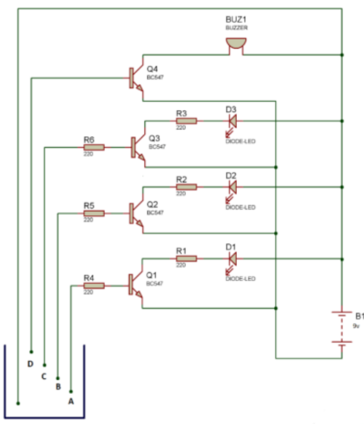

Fig. 10. Liquid level sensor circuit [13]

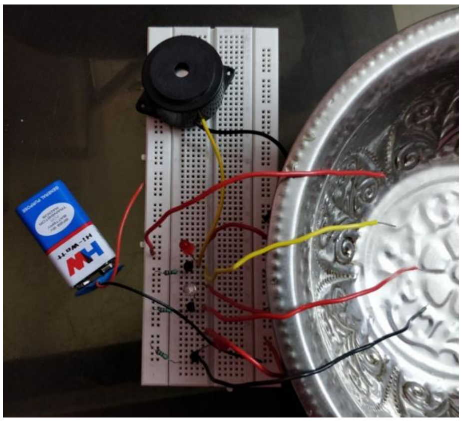

Fig. 11. Practical implementation of the liquid level sensor [*]

vi. Automatic Feeder

The fish were fed every 24 hours using the automatic feeder made of a plastic bottle, a servo motor, and a piece of cardboard. Fig. 12 shows the connections between the servo motor and Arduino Uno that was programmed to move the cardboard piece once a day at 5 AM IST [14].

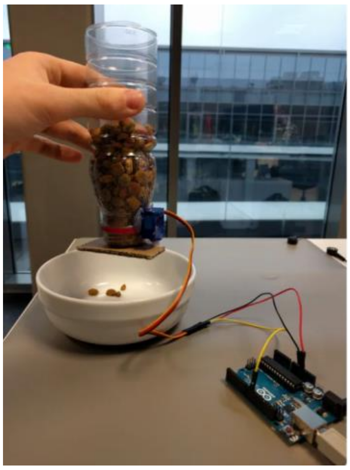

Fig. 12. Automatic feeder circuit [14]

vii. Electric Pump

An electric pump was built using basic components and household items shown in table II to recirculate water between the fish tank and grow bed [15].

TABLE II
COMPONENTS USED TO BUILD THE ELECTRIC PUMP [15]

Component	Quantity
9V DC motor	2
Syringe tube	2
9V Batter	2
Switch	2
Aluminium sheet	2
Wooden block	2
Bottle cap	6
Pipes	4
Connecting wire	10
Glue gun	1
Sand paper	2

Fig. 13 shows that when the switch is turned on, the DC motor receives a 9V supply and starts to rotate. The rotatory movement will draw water through the inlet pipe and pump it out through the outlet pipe. Fig. 14 represents the practical implementation of the electric pump.

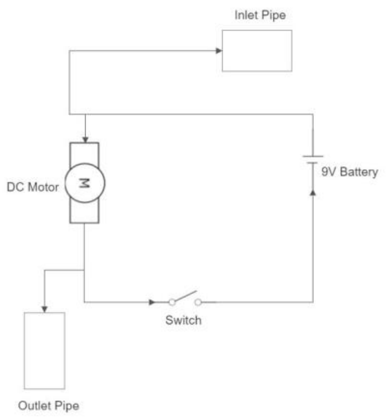

Fig. 13. Electric pump circuit [*]

Fig. 14. Practical implementation of the electric pump [*]

D. Software

The platform used for programming is the Arduino IDE. The codes written using this software are called *sketches* that are saved with the file extension *.ino* [16].

Traditionally, an Arduino board can run a maximum of two scripts at a time. But, for this system, all the individual codes were merged into one master script, and a loop () function was used to run the code infinitely. Fig. 15 shows a typical Arduino IDE with the code for the DHT11 sensor.

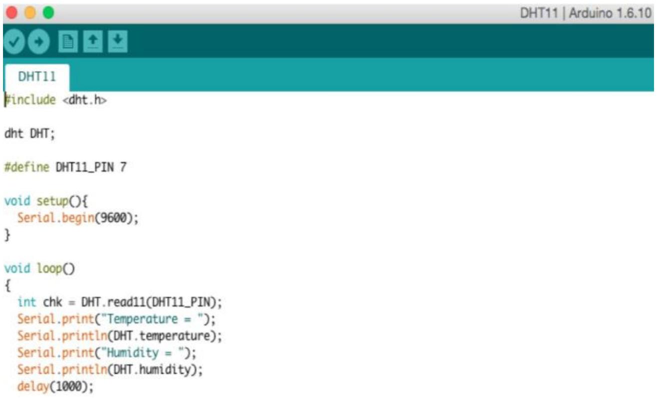

Fig. 15. Arduino IDE [*]

III. RESULTS

Post components assembly and configuration, the Aquaponics system was ready for the research study. The seeds were sown, and the plant growth was measured for seven days. The observations are represented in table III and fig. 16.

Fig. 17 to 20 show the plants on the second and seventh days. It was observed that salad cucumber grew the most with a height of 8.1 centimeters.

TABLE III
PLANT GROWTH FROM DAY 1-7 [*]

Plant	Growth in centimeters						
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Spinach	0	1.1	1.9	2.5	3.6	4.5	5.4
Chilies	0	0.9	1.5	2.3	3.2	4.3	5.2
Salad Cucumber	0	1.3	2.2	4.1	6.5	7.3	8.1
Beans	0	1.2	2.1	3.9	5.4	6.3	7.5

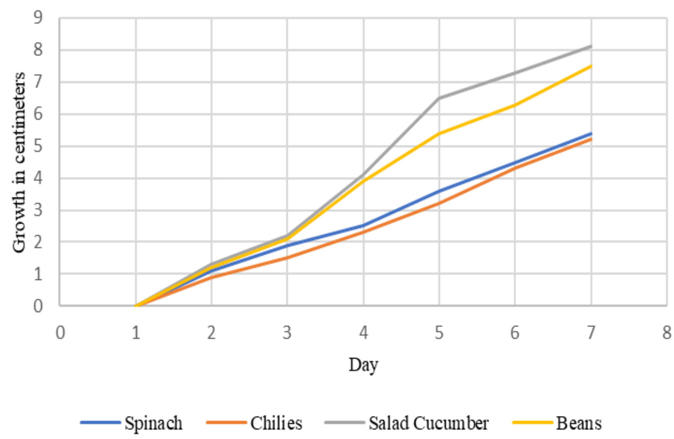

Fig. 16. Graph showing the rate of growth of the four plants [*]

Fig. 17. Spinach and chilies that grew on the Aquaponics grow bed; Day 2 [*]

Fig. 18. Spinach and chilies that grew on the Aquaponics grow bed; Day 7 [*]

Fig. 19. Salad cucumber and beans that grew on the Aquaponics grow bed; Day 2 [*]

Fig. 20. Salad cucumber and beans that grew on the Aquaponics grow bed; Day 7 [*]

IV. BENEFITS

Based on the study, the following benefits could be drawn:

- *Minimal water usage*: The tank was filled with 55 liters of water initially, after which the same water was recirculated between the grow bed and fish tank.
- *No soil damage*: There is no harm done to the soil as the plants are grown in grow beds.
- *Optimal space utilization*: The space occupied by the system is significantly less. In this case, one fish tank was used to grow four different plants. More water + more fish = more plants.
- *Faster growth rate*: The growth rate of the plants is faster as they directly absorb the nitrates from the grow beds.
- *Organic produce*: The plants are chemical-free and completely organic.
- *Lesser initial setup costs*: Components such as the electric pumps and the fish feeder are built using basic household items.
- *Minimal human intervention*: There is minimal human effort as the sensors continuously monitor the system and indicate if there is anything wrong.

V. CONCLUSION

It is observed that Aquaponics can be used to produce healthy and organic plants and fish. The system can be set up outdoors as well as indoors. Therefore, the Aquaponics system can be constructed in households to grow plants for daily consumption.

The Aquaponics setup can be improved further by incorporating: a) Internet of Things (IoT), a technology where objects (devices with an IP address) can be connected and controlled by users through the internet; b) a camera monitoring system. The sensor readings can be fed to an IoT application on a real-time basis, along with the visuals of the Aquaponics system. The user can monitor the system from anywhere through the application. The main advantage of using IoT and a camera system is the drastic reduction in the need for humans near the setup around the clock.

If farmers switch to Aquaponics to grow crops, they need not wait for the right weather or worry about the location. Additionally, their income can be increased by selling both plants and fish grown in the Aquaponics system.

Aquaponics is not recognized as a farming technique but an experiment in most parts of the world. Once people start preferring Aquaponics as the general way to grow crops, changes can be observed in terms of saving water and improved soil on a larger scale.

REFERENCES

[1] Angela, "About Aquaponics System", *Aquaponictrend.blogspot.com*, 2020. [Online]. Available: https://aquaponictrend.blogspot.co m/2018/11/abo ut-aquaponics-system.html. [Last updated: 09-Dec-2020] [Accessed: 18- Dec- 2020].

[2] "Aquaponics Farming | Spectrum India Online", *Spectrum India Online*, 2020. [Online]. Available: https://spectrumindiaonline.com/aquaponics-farming/. [Last updated: 23-Apr-2019] [Accessed: 18- Dec- 2020].

[3] M. Mamatha and S. Namratha, "Design & implementation of indoor farming using automated aquaponics system", *2017 IEEE International Conference on Smart Technologies and Management for Computing, Communication, Controls, Energy and Materials (ICSTM)*, 2017.

[4] R. Biernatzki and R. Meinecke, "Closed greenhouse concept integrating thermal energy storage (TES) applied to aquaponics systems", *2014 49th International Universities Power Engineering Conference (UPEC)*, 2014.

[5] R. Menon *et al.*, "Small Scale Aquaponic System", *International Journal of Agriculture and Food Science Technology*, vol. 4, no. 9, pp. 941-946, 2013. Available: https://www.ripublication.com/ijafst_spl/ijafstv4n9spl_15.pdf [Last updated: 2013] [Accessed: 12- Feb- 2021].

[6] "What is an Arduino? - learn.sparkfun.com", Learn.sparkfun.com, 2013. [Online]. Available: https://learn.sparkfun.com/tutorials/what-is-an-arduino#what-does-it-do. [Last updated: 26-Feb-2013] [Accessed: 18- Dec-2020].

[7] V. Badami "A tour of the Arduino UNO board", HackerEarth Blog, 2016. [Online]. Available: https://www.hackerearth.com/blog/dev elopers/a-tour-of-the-arduino-uno-board/. [Last updated: 21-Oct-2016] [Accessed: 18- Dec- 2020].

[8] "DHT11 Sensor Definition, Working and Applications", ElProCus - Electronic Projects for Engineering Students, 2020. [Online]. Available: https://www.elprocus.com/a-brief-on-dht11-sensor/. [Last updated: 18- Dec- 2020]. [Accessed: 18- Dec- 2020].

[9] S. Campbell, "How to Set Up the DHT11 Humidity Sensor on an Arduino", Circuit Basics, 2015. [Online]. Available: https://www.circuitbasics.com/how-to-set-up-the-dht11-humidity-sensor-on-an-arduino/. [Last updated: 18- Dec-2020]. [Accessed: 18- Dec- 2020].

[10] R. Sallenave, "NMSU: Important Water Quality Parameters in Aquaponics Systems", Aces.nmsu.edu, 2016. [Online]. Available: https://aces.nmsu.edu/pubs/_circulars/CR680/welcome.html. [Last updated: Oct-2016]. [Accessed: 18- Dec-2020].

[11] "PH_meter_SKU__SEN0161_-DFRobot", Wiki.dfrobot.com, 2020. [Online]. Available: https://wiki.dfrobot.com/PH_meter_SKU__SEN0161_. [Last updated: 18- Dec- 2020]. [Accessed: 18- Dec- 2020].

[12] “Arduino and Soil Moisture Sensor -Interfacing Tutorial”, Circuitstoday.com, 2017. [Online]. Available: https://www.circuitstoday.com/arduino-soil-moisture-sensor. [Last updated: 18- Dec- 2020]. [Accessed: 18- Dec- 2020].

[13] Jayant, "Simple Water Level Indicator Alarm with Buzzer", Circuit Digest, 2015. [Online]. Available: https://circuitdigest.com /electronic-circuits/simple-diy-water-level-indicator-alarm-circuit. [Last updated: 15-May- 2015]. [Accessed: 18- Dec- 2020].

[14] "Automatic Arduino Pet Feeder", Instructables.com, 2017. [Online]. Available: https://www.instructables.com/Automatic-Arduino-Pet-Feeder/. [Last updated: 23-Feb-2017]. [Accessed: 18- Dec- 2020].

[15] Electric Pump: "How to Make a Water Pump [Water Turbine]", YouTube, 20-Nov, 2016. [Video file]. Available: https://youtu.be/ZpwYPlIAN2I. [Accessed: 18- Dec- 2020].

[16] "Arduino - Environment", *Arduino.cc*, 2015. [Online]. Available: https://www.arduino.cc/en/guide/environment. [Last updated: 07- Sept- 2015]. [Accessed: 18- Dec- 2020].

[*] Own figures and tables.