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A Systematic Review of Arduino-based Projects on Aquaculture in the Philippines

A Research Proposal Presented to the Faculty of
Philippine Science High School Eastern Visayas Campus

In Partial Fulfillment of the Requirements in STEM Research 3

by

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Introduction

Background of the Study

Aquaculture, the cultivation of both plants and animals for the purpose of sustenance, benefits the most of us. With over 41 million people worldwide, aquaculture is one of the most employed areas (Finegold, 2009). This is because fishes contribute a good portion of the entire world's food product. In 2018, aquaculture products reached 96.4 million tons (FAO, 2020). The cheap yet nutritious products from this area of agriculture is the reason why it contributed so much.

Maintaining brimful production from this kind of agriculture requires full attention to its productivity causes, mainly the water quality where the fishes reside. Several parameters of water quality are to be monitored. These parameters are likely to fluctuate, making the monitoring of which extremely crucial. This is where modern technology comes in. Automation and machinery technology help overcome the current challenges of food production (Navarro et al., 2020).

Arduino is notorious in this area. Arduino is an open source platform used to create interactive objects, either by itself or with the aid of a computer software (Banzi and Shiloh, 2014). Due to its easy to use setting and ability to execute commands with precision, people tend to use Arduino for things like this (Badamasi, 2014).

Numerous studies about using Arduino-based projects have already been published. This study will review those studies systematically, for the sole purpose of giving a meticulous summary of the topic.

Statement of the Problem

Main Problem: How are Arduino-based projects used in aquaculture in the Philippines?

Sub-problems:

a) What are the most commonly used hardware in aquaculture in the Philippines?

b) What are the main challenges and opportunities in using this technology?

c) How effective is implementing these projects in aquaculture?

Significance of the Study

The results of the study will help people that engage with aquaculture and Arduino. By systematically reviewing previous literature on the topic, a meticulous summary can be given, allowing a deeper understanding on how Arduino-based projects benefit aquaculture. It can also inspire those not engaging on the topic. They may be intrigued, allowing more participants to join the field.

Scope and Limitations

The scope of this study is to give a summary of literature about how Arduino-based projects are used in aquaculture in the Philippines. The only probable limitation of the study is the inaccuracy of results. Setting where the study was conducted, demographics of the participants, maintenance of the devices, and other elements may not be provided in each study (Dahabreh, 2012). This may result in a vague conclusion of results, making the review inaccurate.

Review of Related Literature

Aquaculture

Aquaculture is the farming of aquatic organisms, such as fish, crustaceans, mollusks, and aquatic plants, aside from mammals and reptiles (Stickney, 2001). The History of Aquaculture follows the evolution of fish farming from its early beginnings to modern technologically advanced methods (Nash, 2010). Part of our past and present history, and it's needed in our future. Freshwater and marine foods are in excessive demand throughout the world, furthermore a developing quantity of its far farmed. Aquaculture contributed 43 percent of aquatic animal food for human intake in 2007 and is predicted to develop in addition to fulfill the future demand (Bostock et al., 2010). Aquaculture is a global, inevitable and a fast growing industry. Consisting of an extensive variety of species and manufacturing methods, with a whole lot of social, economic, nutritional, and environmental outcomes (Gephart et al., 2020). As a result, how aquaculture develops may have an effect on human health and the environment. Increasing the economy by diversifying income and food sources, while at the same time it increases the supply of food to households and improves nutrition (Frankic & Hershner, 2003).

Arduino

Arduino is an open-source platform used for building and programming of electronics (Banzi, 2009). It can receive and send information to most devices, or even via the net to command the specific electronic device.it makes use of a hardware known as Arduino Uno circuit board and software program application to program the board

(Badamasi, 2014). Arduino can be used to develop interactive objects, with inputs used to control the outputs. Projects created with Arduino can be standalone or communicate with software running on a computer. In addition, it used loads in microcontroller programing amongst different matters due to its user friendly or easy to apply setting, like several microcontrollers an Arduino is a circuit board with chip that can be programmed to do numerous variety of tasks, it sends information from the computer application to the Arduino microcontroller and sooner or later to the specific circuit or gadget with more than one circuits for you to execute the particular command (Gibb, 2010). An Arduino will let you examine information from input devices (Margolis, 2011). Today, the world we live in is becoming hugely technology dependent, which means that more technically skilled workers are needed to build and maintain the technology it needs. Many emerging technologies are interactive, making it easier to create environments where learning can be done by doing, receiving feedback, refining understanding and building new knowledge (Forcier & Descy, 1999).

PRISMA Method

The PRISMA statement is a 27-item checklist and a four-phase flow diagram aimed to help improve reports about systematic reviews and meta-analyses. It was derived from the QUOROM checklist through a three-day meeting with 29 participants. While the PRISMA checklist is extremely helpful, it is not perfect. The subjects PRISMA checklist encompasses the general needs of a systemic analysis, therefore it is necessary to introduce some steps on a case-to-case basis to fully cover the needs of an analysis. In conclusion, the PRISMA checklist is an excellent guideline as long as researchers can supplement it.

Methodology

Research Design

This study is classified as a Descriptive type of research design. The reason being is that this gives a descriptive summary of how Arduino-based projects are used in aquaculture by giving a systematic review of its past related literature.

Procedure

To get a systematic review on the topic, this study will use the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology. This method is the standardized method created to support systematic reviews of literature (Moher et al., 2009).

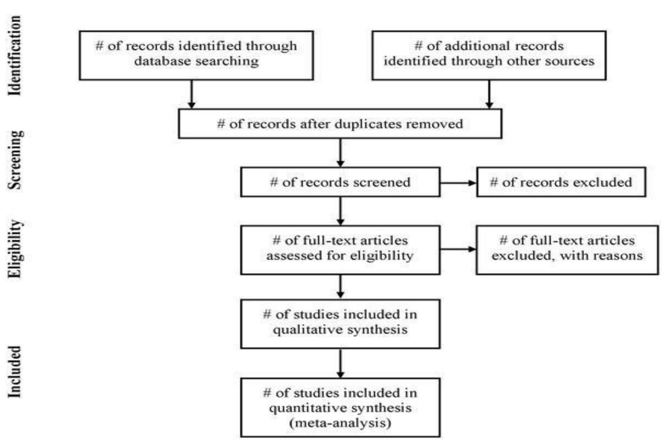

Figure 1: Flowchart of Screening Articles.
Retrieved from Moher et. al (2020)

Protocol and Registration

The Institute of Education Sciences has an existing review protocol closely related to the topic at hand. This review protocol helps and guides the review of research that deals with informing the What Works Clearinghouse (WWC) practice guide “Using Technology to Support Postsecondary Student Learning” (IES, n.d.) The review protocol can be found at https://ies.ed.gov/ncee/wwc/Docs/ReferenceResources/Postsecondary_Instructional_Technology_Protocol_1.1.pdf.

Eligibility Criteria and Study Selection

First and foremost, the study should be in the English language. Studies to be included must have quantitative data on their results. These data must be on water quality parameters, such as pH level, dissolved oxygen, temperature, ammonia, etc. (Africa et al., 2017; Sneha et al., 2017). Studies with controlled vs conventional setup comparison will be focused more, since these will give more insight towards the topic. Arduino must be applied in the study. Only studies conducted in the Philippines will be included in the review.

Information Sources and Search

All related journal articles to be reviewed will be searched through scholar.google.com.

Data Items and Data Collection Process

The data to be extracted from the study are the quantitative results. Information will be inferred from charts and graphs, if any. Data will be extracted individually and manually from each of the related journal articles.

Risk of Bias

Results may be inaccurate due to the setting where the study was conducted not being mentioned, demographics of the participants not being identified, maintenance of the devices not being monitored, and other elements that were not taken into consideration may not be provided in each study (Dahabreh, 2012).

Gantt Chart

Objectives of the study addressed	Activity done to address the objective	Schedule							
		1st Month				2nd Month			
Preparation of the journals to be synthesized	1. Search for the articles on scholar.google.com								
	2. Evaluate which journals will be included								
	3. Compile to one folder for easy access								
Extracting the data	1. Evaluate which data will be included in the review								
	2. Compile the data								
Synthesizing the data	1. Synthesize the data by using standardized mean difference.								
Writing the final paper	1. Compile the results and write the remaining chapters of the paper								

Table 1. Gantt Chart

Results and Discussion

1. Screening of Articles to be Included

There were a total of 424 studies searched on scholar.google.com by using the keywords “arduino-based devices on aquaculture Philippines”. By first screening the titles alone, the studies were cut down to 82. This is because the keywords might have been found inside the journals, but the research topic itself is not about applying Arduino to aquaculture. Among the removed studies, there are studies that applied not on aquaculture but agriculture as a whole. The specified scope of this study was solely devices in aquaculture. Some were in a language other than English. There are also studies that didn’t make use of any kind of device, so those were excluded. The location criteria was then used to evaluate. There were a total of 43 studies that were conducted outside of the Philippines, cutting down the number of studies to be synthesized to 39. Only 28 of the remaining studies used Arduino for the microcontroller of their main device. Some used Raspberry Pi as their controller (Valiente et. al, 2018; Tolentino, 2020), which is outside of the scope of this systematic review. One used a pre-made monitoring kit called Libelium Smart Agriculture Xtreme IoT Vertical Kit and Crop/ Plant Monitoring Sensor Kit (Farooq, et. al, 2019). Out of these 28, there were 9 studies that couldn’t be found of their copies of the full article, making the total number of studies to be analyzed to 19.

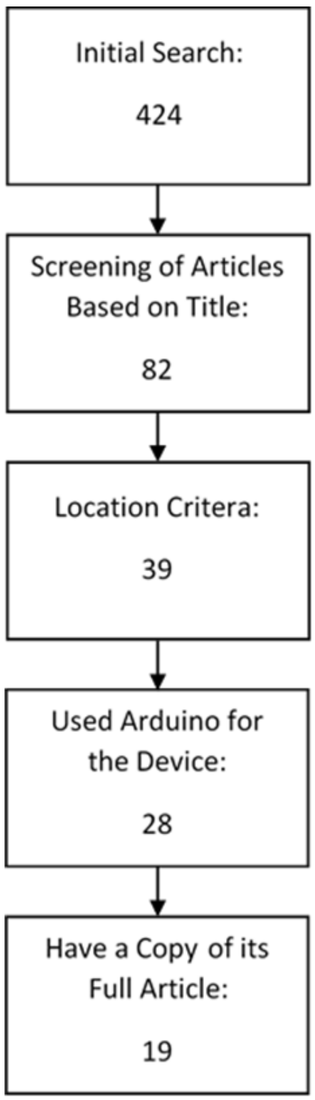

Figure 2. Flowchart of Screening of Articles

2. Hardwares and Softwares used in Aquaculture

2.1. Hardwares

Depending on the parameters that were monitored and automated as well as its extent of scope, the number of hardwares used in each device may vary. Based on the 19 devices we have in our analysis, the parameters that were monitored were temperature, potential of Hydrogen (pH) level, dissolved oxygen (DO), turbidity, totally dissolved solids (TDS), electrical conductivity (EC), water level, humidity, and light.

Rank	Frequency	Hardware		Rank	Frequency	Hardware
1	18 (94.73%)	Temperature sensor		8	1 (5.26%)	Bell siphon
1	18 (94.73%)	pH sensor		8	1 (5.26%)	Mist maker
2	9 (47.37%)	DO sensor		8	1 (5.26%)	Relay board
3	8 (42.10%)	Water level sensor		8	1 (5.26%)	MicroSD reader module
4	6 (31.58%)	GSM module		8	1 (5.26%)	Development board
5	4 (21.05%)	Turbidity sensor		8	1 (5.26%)	LCD w/ I2C adapter
6	3 (15.79%)	Humidity sensor		8	1 (5.26%)	Wifi module
6	3 (15.79%)	Water pump		8	1 (5.26%)	9 volts battery
6	3 (15.79%)	Feeder		8	1 (5.26%)	Charger
6	3 (15.79%)	Buffer solution dispenser		8	1 (5.26%)	LCD module
6	3 (15.79%)	Solenoid valve		8	1 (5.26%)	Control for cooler
6	3 (15.79%)	Light sensor		8	1 (5.26%)	ORP meter
7	2 (10.57%)	Solar panel		8	1 (5.26%)	NaHCO2 Distribution
7	2 (10.57%)	Air pump			1 (5.26%)	Cooling fan
7	2 (10.57%)	Water heater				
7	2 (10.57%)	Grow light				
7	2 (10.57%)	Aerator				
7	2 (10.57%)	LoRa				
8	1 (5.26%)	TDS sensor				

Table 2. Hardwares

GSM Module

Many devices in this analysis used a GSM module. GSM module is a hardware that utilizes GSM mobile phone technology. creating a road for data to a network. It is a kind of mobile Terminal Equipment and just like a phone, it requires a subscriber identity module (SIM) card to work (Yuchun et. al, 2011; Nasution et. al, 2017). D1, D2, D7, D8, D12, D13, and D19 all used this technology. D2 shows the efficacy of the GSM module by having sample messages sent using the module and were cross-checked to see its accuracy, just to show that it is indeed identical. The GSM module not only speeds up data transmission, but the text messages it provides also make water quality examination easier (Alave et. al, 2020).

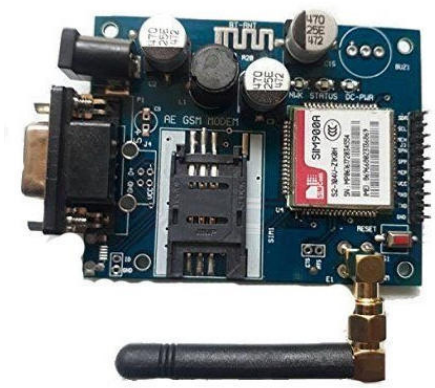

Figure 3. GSM Module. Retrieved from https://www.technolabcreation.com/sim900a-gsm-module-and-arduino-sending-and-receiving-sms-using-at-commands/

NodeMCU

NodeMCU is an Arduino-like device, having the traits of an open source and LUA programming language based firmware developed for the wifi chip ESP8266. It is a low-cost device with programmable pins and built-in wifi that can be powered through a micro-USB port. It can be versatile since it can be programmed through multiple programming environments (Parihar, 2019; Bento, 2018). NodeMCU was used by D7 and D18.

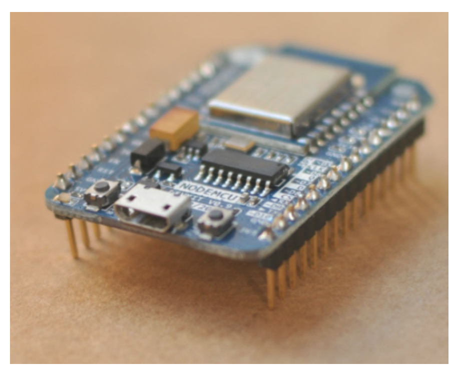

Figure 4. NodeMCDU. Retrieved from https://www.nodemcu.com/index_en.html

LoRa (LoRaWAN)

Long Range (LoRa) is a Low-Power Wide-Area Network (LPWAN) technology.It is a spread spectrum modulation technique, proprietary of Semtech (Bor et. al, 2016). It enables transmission of data over long ranges at very low frequencies. While LoRa is the physical layer and modulation technique, Long Range Wide Area Network (LoRaWAN) is the communication protocol (Haxhibeqiri, 2018). D13 used Adafruit RFM96W LoRa Radio Transceiver Breakout - 433MHz. This model can reach up to 600m distance without a single signal loss, and 700m but with intermittent data transmission (Monje et.al, 2019). In D18, 868MHz LoRaWAN was used as the medium of the data transferred to the Raspberry Pi for monitoring. The use of LoRa modules for data transmission is ideal for monitoring aquaculture settings since it lowers manufacturing costs and allows for longer-distance connection (Tolentino et. al, 2020).

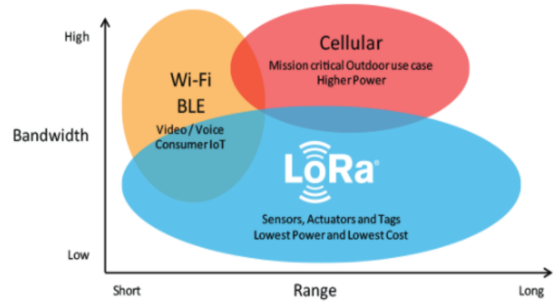

Figure 5. Lora. Retrieved from https://www.semtech.com/lora

Figure 6. Lorawan. Retrieved from https://www.semtech.com/lora

2.2. Softwares

Device	Has			Software used for developing				App/Web Server Name
	App	Web Server	SMS	App	Web Server	System training	Database/Data Gateway	
D1	✗	✗	✓	-	-	Arduino IDE	LabVIEW	-
D2	✗	✗	✓	-	-	Arduino IDE	-	-
D3	✗	✗	✗	-	-	Arduino IDE	-	-
D4	✗	✗	✗	-	-	Arduino IDE	-	-
D5	✗	✗	✗	-	-	Arduino IDE	-	-
D6	✓	✓	✗	Virtuino	ThingSpeak	Arduino IDE	-	-
D7	✗	✓	✓	-	MNS	Arduino IDE	MNS	-
D8	✗	✓	✓	-	PHP	Arduino IDE	-	-
D9	✓	✗	✗	Visual Basic	-	Arduino IDE		
D10	✓	✗	✗	MIT App Inventor IDE	-	Arduino IDE	-	AquaDroid
D11	✗	✓	✗	-	PHP	Arduino IDE	mySQL	-
D12	✗	✗	✓	-	-	Arduino IDE	msSQL	-
D13	✓	✗	✗	MNS	-	Arduino IDE	-	AquoSense
D14	✗	✗	✗	-	-	Arduino IDE	-	-
D15	✓	✗	✗	-	-	Arduino IDE	-	-
D16	✓	✗	✗	MIT App Inventor IDE	-	Arduino IDE	Temboo	AquaDroid
D17	✗	✗	✗	TinyWebDB	-	Arduino IDE	MNS	AquaDroid
D18	✗	✓	✗	-	JavaScript, PHP, CSS	Arduino IDE	-	TeamLapia
D19	✗	✓	✗	-	MNS	Arduino IDE	-	-

Table 3. Softwares (MNS = Mentioned but Not Specified)

2.2.a. Application Development

Virtuino

Virtuino is a graphical user interface (GUI) platform for IoT platforms, Arduino ESP and similar boards. Create stunning virtual screens on your phone or tablet to control any automation system via Bluetooth, WiFi, or the Internet (Cakir, et. al, 2020).

Figure 7. Virtuino. Retrieved from https://virtuino.com/

Virtuino, a web server application, used to monitor via IP address and monitoring values. D6 used its settings to virtually connect using an API key and channel ID.

ThingSpeak

ThingSpeak is a web-based and open source Application Programming Interface (API) that retrieves data, timestamps. and displays it for human and/or machine use (Maureira, nd.). Data sent through Hypertext Transfer Protocol (HTTP) via the internet are aggregated in Thingspeak in order to create a real-time display based on the cloud (Banjao et. al, 2020). D6 used ThingSpeak as the platform for the device to allow accessing and viewing the abiotic factors of the system.

Figure 8. Thingspeak. Retrieved from Banjao et. al, 2020

Visual Basic

Visual Basic (also known as “Visual Basic .NET”) is an object-oriented programming (OOP) language developed by Microsoft (Microsoft, n.d.). OOP is a programming style distinguished by the identification of classes of objects that are inextricably linked to its associated methods or functions. Creating type-sage apps with Visual Basic makes it quick and easy due to its user-friendly interface. The software user interface of D9 was developed with this.

Figure 9. Visual Basic. Retrieved from https://docs.microsoft.com/en us/dotnet/visual-basic/

MIT App Inventor IDE

With its drag-and-drop feature, app development has never been easier with the MIT App Inventor IDE. MIT App Inventor is an open source visual programming tool for designing and developing fully functional Android mobile apps (Pokress and Veiga, 2013; Tolentino et.al, 2017). It was originally owned by Google, but with its transfer to the Massachusetts of Institute of Technology (MIT), a couple of improvements were done. Tolentino et.al (2017), the creator of D16, suggested that using this tool is quite efficient since people can create an app without having to know how to code. D10 and D16 used MIT App Inventor for their applications. Using this tool, D10 developed the application that was serving as the Graphical User Interface (GUI) of the system that will show the water quality parameters of his aquaculture set-up. Just like D10, D16 used the tool in creating the system's GUI to allow parameter monitoring.

Figure 10. MIT App Inventor. Retrieved from https://appinventor.mit.edu/

TinyWebDB

TinyWebDB is an App Inventor component that allows you to persist data in a web database. TinyWebDB can be used to facilitate communication between phones and apps because the data is stored on the web rather than on a specific phone (Wolber, 2011). D17 used TinyWedDB to receive transmission and reception of the outputs included in internet remote access. In addition, TinyWeBDB transmits the plant canopy area obtained from the image processing to the database and for data visualization.

2.2.b. Web Server Development

PHP

PHP is a scripting language most commonly used in web development. Originally created by Rasmus Lerdorf (Lerdorf, 2006), its reference implementation is now produced by the PHP Group. PHP is especially suited to server-side web development. In D11, PHP was used to implement the water quality evaluation model which is then integrated into an online data storage system. PHP codes, along with JavaScript scripts, were used to transmit data from the database to the application's UI in D18.

JavaScript

JavaScript, often abbreviated JS, is an object-oriented programming language commonly used in applications and websites for client side web page behavior. It was initially limited to browsers and web pages, but it has since spread to a wide range of environments and applications (Pluralsight, 2014). D18 utilizes this programming language for their application. Together with PHP codes were used to transmit data from the database to the application's UI. Additionally JavaScript's utility were used to create the graphs and design of the application's design

CSS

CSS or Cascading Style Sheets, is a way to style and present documents. CSS allows the separation of presentation and content, allowing more freedom in designing web pages as well as enabling web pages to share formatting (Meyer 2017). It is utilized in D18 to design the graphs and dynamic design of the application together with HTML and JavaScript.

2.2.c. Database/Data Gateway

LabVIEW

Laboratory Virtual Instrument Engineering Workbench (LabVIEW) is a system-design platform and development environment for a visual programming language developed by National Instruments. It can be used to connect and implement database operations to local and remote databases using the LabVIEW Database Connectivity Toolkit software add-on. The add-on aids in performing common database operations without SQL usage while still providing complete SQL capabilities for those who need to use advanced database functions (National Instruments, 2021). LabVIEW was utilized in D1 as a way to extract and display the parameter data in real-time. It was also used to segregate the incoming data into their respective parameters.

Temboo

Temboo is a no-code platform that allows the creation of internet-connected automated systems. Users can use Temboo to connect any sort of hardware to any cloud service, making adapting current equipment and systems more easier. Temboo creates editable software code for the users that allows these connections to be made.

Temboo creates a passage for connecting sensor data to the cloud, allowing machine-automated systems to deliver real-time data (Temboo, n.d.). D16 used Temboo as the IoT gateway for its Gmail irregularity notification system. The Arduino of his set-up was responsible for generating and sending an email of data via Temboo every time there was an irregularity detected.

mySQL

mySQL is an open source relational database management system. SQL is a language programmers use to create, modify and extract data from the relational database, as well as control access to the database (Kofler, 2004). In D11, it is used to simply store data on the water quality.

2.2.d. System Development

Arduino IDE

Arduino IDE (Integrated Development Environment) is the official software used for programming Arduino projects. Almost all Arduino boards are compatible with this open source software. It is easily available for operating systems such as MAC, Windows, and Linux and runs on the Java Platform, which includes built-in functions and commands for debugging, editing, and compiling code in the environment (Fezari and Dahoud, n.d.).

D1 all through D19 used this software to train the systems of their aquaculture set-up. Each microcontroller continuously repeats a programmed cycle in which each assigned parameter is measured, compared to the range set as default, and adjusted if deemed necessary (Africa et.al, 2007; Defe and Antonio, 2018; Madrid et. al, 2018).

3. Arduino in Aquaculture

There are several types of Arduino Boards, each with its unique function. With the manufacturers constantly releasing updates along with new features, the number of boards keep increasing. It may seem impossible to choose what boards to use from the limitless amount of choices, but with this analysis, it can give conscientious advice on what to pick for an aquaponic or hydroponic system.

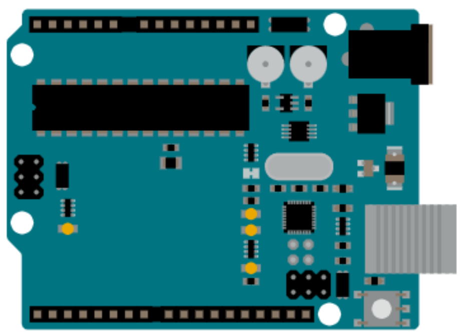

Figure 11. Arduino Uno. Retrieved from https://docs.arduino.cc/hardware/uno

Our literature uses either three of the numerous boards in the market. One is Arduino Uno. Arduino Uno is the “flagship introductory-level” board (Blum, 2020). It is used by people who are new to Arduino that plans to create their own devices. The board is based on the ATmega328P, a high performance, low-power, and replaceable microcontroller chip. It features 1kb of EEPROM, allowing it to keep its memory even after turning off. The board features a barrel plug connector which works well with a 9V battery (Arduino, 2022).

Another board being used is the Arduino Mega 2560, a board considered to be a better performing microcontroller compared to Uno. It is based on the ATmega2560 chip and just like the Uno, it

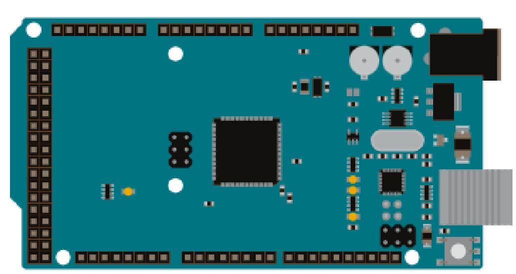

Figure 12. Arduino Mega 2560. Retrieved from https://docs.arduino.cc/hardware/mega-2560

features EEPROM, but with 4 times the amount of kilobytes. It has 54 digital, 15 of which supports Pulse Width Modulation (PWM), and 16 analog pins. It has four serial ports, allowing users to connect to several devices (Arduino, 2022).

Figure 13. Arduino Yun. Retrieved from https://docs.arduino.cc/retired/boards/arduino-yun

The next Arduino board that is being used in aquaculture is the Arduino Yun. When it comes to making Internet of Things (IoT) projects, or projects that connect several devices into one, Yun is the perfect board to use. It has the capability to easily utilize Linux's services, an operating system used commonly in the world of programming. The board is based on the ATmega32u4 chip and the Athereos AR9331. To allow the utilization of services from Linux, the Athereos processor supports a distribution of the OS based on Linino OS, part of Linux's OpenWrt project that targets embedded systems and devices (Fainelli, 2008). The board includes Ethernet and WiFi support in its system, allowing the remote transferring of data. It also has several ports, pins, and slots to sanction the diversity of projects (Arduino, 2022).

4. Spectrum of Arduino-technified Aquaculture

We noticed that not all Arduino-technified aquaculture technology has the same levels. Our sources suggest that there are multiple levels, which we will classify by using a spectrum modified from Sovacool and Del Rio's (2019) spectrum of smart home types. There are seven (7) levels of Arduino-technified aquaculture from lowest to highest: basic, isolated, bundled, automated, intuitive, sentient, and aggregation.

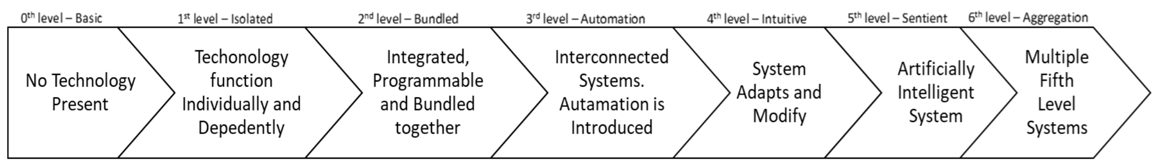

Figure 14. Spectrum of Arduino-technified Aquaculture

The spectrum starts at the zeroth level, or the basic. This aquaponic system does not have a single advanced technology in it. They would resort to traditional methods such as manual labor using hands and basic tools.

Isolated level would be the first level. Few technologies are present in the system. These technologies are not yet interconnected at this level. They function individually and dependently on the user. Examples of hardwares that are present in this level of the spectrum are digital weighing scale, air pumps, filters, etc..

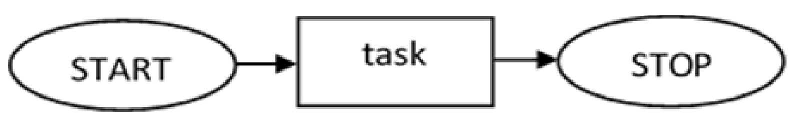

Figure 15. Level 1 - Isolated

The next and second level in the spectrum is bundled. First level technologies are bundled together to provide a better service. Programmable hardwares that can be adjusted to meet a preferred condition are now introduced. Examples of the aforementioned type of hardwares are heat rods that you can adjust depending on the specified temperature for the fish or aquatic plant to be cultivated. Another example is an adjustable air pump. Preferred dissolved oxygen (DO) content may vary depending on the fish in the tank (Doudoroff and Shumway, 1970). Behavioral changes may be observed in the fishes when DO content is not monitored (Kramer, 1987). By sampling the DO of the tank, we can adjust the aeration of the pump to satisfy the criteria of the fish (Africa, 2017).

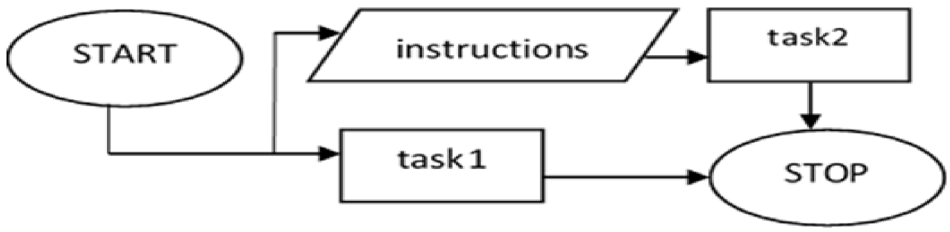

Figure 16. Level 2 - Bundled

Automation is now introduced in the third level. Hardwares that automatically execute based on its programmed schedule are now being used in the set-up. Systems begin to interconnect towards a single goal (Sovacool and Del Rio, 2019). An example of this is an automated feeder. Since hardwares are needed to be programmed to execute at a given time or condition, they need a platform that can serve as the brain of the commands. This is when Arduino comes in. Arduinos are used to program commands for electronics (Badamasi, 2014). With the help of Arduino, we can tell the hardware when, what, and how to do it (Badamasi, 2014). We can program a fish feeder when to dispense the food and how much is going to be dispensed.

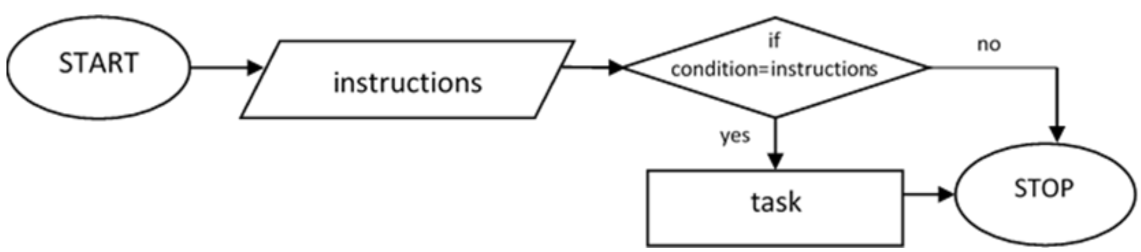

Figure 17. Level 3 - Automation

The fourth level is intuitive. The technology in the system can learn from past readings and modify its services to match the optimal condition needed for the aquatic plant and/or fish to be cultivated. One example of this is Africa's (2017) pH balancer of his aquaponic system. He measures the pH level of the tank through a gel-filled glass pH sensor. With this information uploaded to his Arduino, the system will know how much fish-friendly pH buffer solutions to dispense. It will dispense alkaline for low-pH while acid for high-pH.

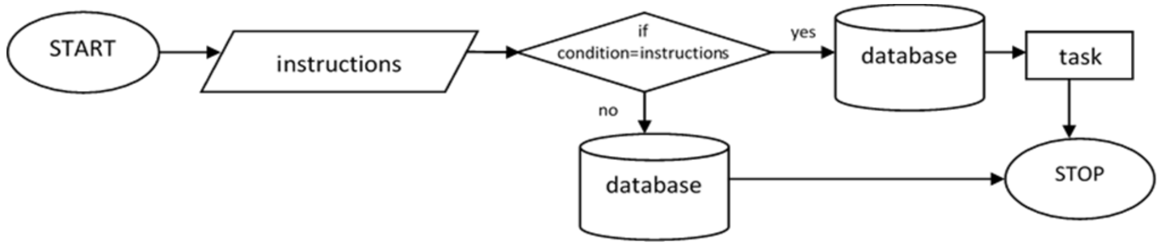

Figure 18. Level 4 - Intuitive

Fifth level now becomes almost aware or sentient. Systems at this level can automatically detect all parameters that are not within the preferred amount and automatically resolve the said parameter with their programmed hardwares. They can even set the range of the parameters to be balanced by analyzing the type of fish or aquatic plant placed in the tank. This is so that we can grow the products without the need of tweaking for any new variables that come to surface, since the technology is smart enough to adapt. Any system at this level is considered to be "artificially intelligent" (Sovacool and Del Rio, 2019).

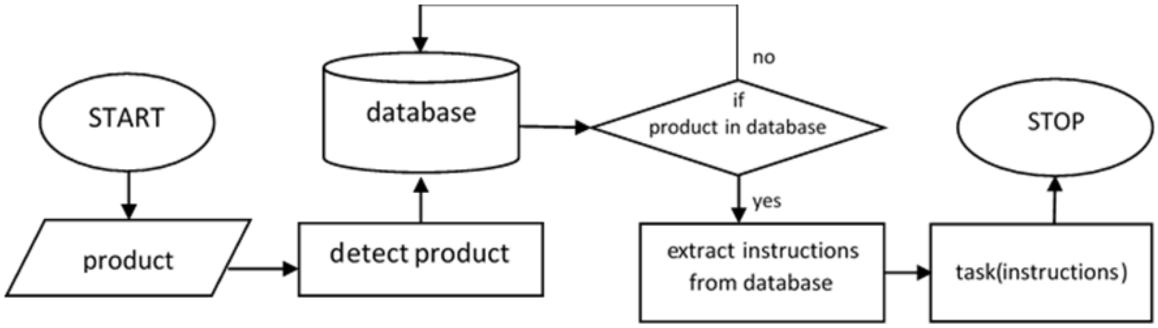

Figure 19. Level 5 - Sentient

The level where technology is already sentient may seem the final level of the spectrum, given its seemingly superior advancements, but actually there is something beyond that. The sixth and final level, also known as the aggregation level, comprises several level 5 technologies, creating a systematized community of technology, functioning towards a much more complex goal. Having an aquaculture set-up at this level would mean having separate level 5 technologies for the foundation (i.e. providing the animal or aquatic plant to be cultivated, may be bought in a market, caught from the wild, or bred from previous stock), cultivation of the products (what most projects' goals are now), harvest, and post-harvest (i.e. exporting to other countries, selling to local markets, distributing to the community). Basically having a level 6 system would mean having level 5 systems working together in a cycle to continuously and independently produce products without the need of labor work. Every task is handled by machinery and technology. So far, no Arduino-based projects are capable yet at this level.

5. Benefits of Arduino to Aquaculture

There are several notable results from the studies that can show the benefits of arduino to aquaculture. We can think of 3 ways how applying Arduino can help producing aquaculture products: portability, increase of quality (i.e. weight, area, length), and convenience.

Instead of using standard laboratory equipments, people can use Arduino that's significantly lighter and smaller in size. D2, despite only weighing 1.04 kg, measured temperature, pH, turbidity, and TDS while still falling under only ±5% error compared to using lab equipment. D3, on the other hand, had its actuators provide 100% accuracy in modification of water parameters, with only measuring 38cm x 38.5cm x 26.686cm in size. D14 and D15, being the same exact system, has a percent error less than or near to 5% for measuring Water Level, Water Temperature, Ambient Temperature, Relative Humidity, and pH. Both D14 and D15 did not provide exact measurements, but it is noticeably smaller when c to the image shown.

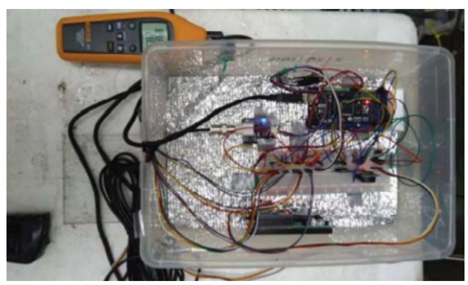

Figure 20. D14 and D15. Retrieved from Tagle S, et. al (2018).

Quality of fish, mainly determined by its weight, can significantly increase with the use of Arduino. Since water parameters where cultivated fishes and plants reside are regulated to its preferred amount, they would be living healthily. Thinning due to illness and lack of care would diminish because of this. D4 has proven this with its results. *Spirulina platensis,* the microalgae that was controlled using D4, has shown a 39.52% improvement rate based on the regression analysis conducted: controlled set-up having a 0.0519 growth while uncontrolled set-up having a 0.0372 growth rate. In addition both D5 and D8 received favorable reviews. D5 received a 93.8 performance rating from a group of evaluators, which we couldn't scale and contextualize since the rubric of rating wasn't provided. Thirty respondents believed in the viability of D8, with it gaining an average t score greater than the tabled value of 2.462. Unfortunately, the exact content of the questionnaire was not provided. In terms of weight, D18 showed 46.88% improvement on Nile Tilapia fishes on its controlled aquaculture system compared with the conventional aquaculture setup. Ultimately, D17 had the biggest improvement so far with over 539.22% improvement on the canopy area of lettuce plant compared to its conventional farm.

Convenience is achieved by using Arduino in aquaculture since we can have real-time monitoring on water quality parameters even from a remote location. Information is sent through short messaging service (SMS), the internet, or a local server and is stored in a database to allow viewing on-demand of previous readings. Another reason why using this technology is convenient is because it measures parameters and corrects it automatically without the need of manually tweaking the preferred amount for the cultivated product. These readings are shown in an embedded display in the system or a phone application/web server to allow remote viewing. The system sends updates via text on a specific time of day, depending when it was programmed to do so. Other devices utilized third-party platforms to relay and aggregate the data gathered from the hardware.

D1, D2, D7 and D12 each have an SMS system that allows users to get updated by receiving data regarding the parameters through text message. D12 used a software called FrontlineSMS to retrieve the data from the SIM900 GSM Module. While SMS systems already exist, using FrontlineSMS can give true portability since it works with a laptop, cable, and standard GSM mobile phones (Banks, 2006). The data is then sent to a msSQL vbscript to process it. In addition to D7's SMS system, they added a feature to view the stored readings by using a Web browser and a Local Area Network (LAN) or the Internet. D10 and D16 send their updates to the user through email whenever there is an abnormality detected and corrected in the parameters for logging.

6. Potential Problems and Challenges

When handling Arduino, it is inevitable to avoid problems at all times. Benefits always come with the risks it holds. D6 suggested that involving DO in one of the parameters to be monitored is inefficient since measuring it is hard. Measuring DO needs careful and periodic sampling and electrical isolation from the other sensors, otherwise failure is expected (Africa et. al, 2007). D7 discussed the problems an automated feeder may cause. Fish feeds thrown by the feeder/dispenser may only be in one direction. This may cause fish to gather in a single area. Some fishes may take advantage of other fishes just to reach the food and thus may cause fish injury/kill (Benito, 2020). DHT11 was incapable of showing decimal values, as shown by D14. This decreased the overall accuracy of the system, making the use of the sensor quite unreliable despite being used in multiple studies (Ambrosio et.al, 2019; Tagle et. al, 2018). D15's automation of parameters adjustment, specifically pH level, failed due to certain circumstances, forcing the researchers to manually adjust it. Because of an insufficient amount of balancing solution, the attempt failed, causing the pH level to suddenly decline. D18 advised the possibility of water spoilage. This is because fishes might not eat all of the feeds that were dispensed, causing the feed to settle at the bottom. The settled feeds will get spoiled, contaminating the water with it.

7. Suggested Recommendations by Literature

Several recommendations have been suggested by the inventors of the devices. The recommendations were ranked and categorized into brief classifications.

Rank (Frequency)	Suggested by	Recommendation
1 (3)	D9, D11, D15	Create app for accessibility
2 (2)	D1, D9	Improve hardware (durability, accuracy, waterproofing, etc.)
2 (2)	D1, D9	Improve database and wireless network capability
2 (2)	D2, D9	Environment-friendly and compact power source
2 (2)	D6, D11	Modify to work on other species
3 (1)	D2	Add more hardwares
3 (1)	D2	Add more parameters to monitor
3 (1)	D6	Add automation
3 (1)	D7	Periodic calibration
3 (1)	D17	Use image processing

Table 4. Suggested Recommendations

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Appendix I. List of Devices with its Author and Article Title

Device	Author, Year	Title
D1	Africa et. al, 2007	Automated Aquaculture System that Regulates Ph, Temperature and Ammonia
D2	Alave et. al, 2020	Portable Arduino-based Integrated Water Quality Analyzer with Real-time Data Transmitter
D3	Ambrosio et. al, 2019	Implementation of a Closed Loop Control System for the Automation of an Aquaponic System for Urban Setting
D4	Aquino et. al, 2018	A Vision-Based Closed Spirulina (A. Platensis) Cultivation System with Growth Monitoring using Artificial Neural Network
D5	Bacalla and Vinluan, 2019	Hydroponics Farm Monitoring Using Data Fusion and Fuzzy Logic Algorithm
D6	Banjao et. al, 2020	Development of Cloud-Based Monitoring of Abiotic Factors in Aquaponics using ESP32 and Internet of Things
D7	Benito, 2020	Enhanced Decision Support System for Automated Fish Feeder and Water Quality Detection with SMS Notification
D8	Clemente, 2019	Development of Online Hatchery Monitoring and Feeding Management System for Nile Tilapia
D9	Defe and Antonio, 2018	Multi-parameter Water Quality Monitoring Device for Grouper Aquaculture
D10	Galido et. al, 2020	Development of a Solar-powered Smart Aquaponics System through Internet of Things (IoT)
D11	Loyola and Lacatan, 2020	Water Quality Evaluation System for Prawn (Penaeus Monodon) Using IoT Device and Decision Tree Algorithm
D12	Madrid et. al, 2018	Real-Time Water Quality Monitoring System with Predictor for Tilapia Pond
D13	Monje et. al, 2019	Design and Implementation of AquoSense – a Water Quality Sensor System
D14	Tagle et. al, 2018	Development of an Automated Data Acquisition System for Hydroponic Farming
D15	Tagle et. al, 2018	Development of an Indoor Hydroponic Tower for Urban Farming
D16	Tolentino et. al, 2017	Aquadroid: an App for Aquaponics Control and Monitoring
D17	Tolentino et. al, 2017	Development of an IoT-based Aquaponics Monitoring and Correction System with Temperature-Controlled Greenhouse
D18	Tolentino et. al, 2020	Development of an IoT-based Intensive Aquaculture Monitoring System with Automatic Water Correction

D19	Velasco, 2020	Internet of Things Applied to Solar-Powered Smart Agricultural Monitoring System: A Prototype Development

Appendix II. List of Hardwares

Device	Hardware
D1	thermistor-based stainless steel sensor gel-filled glass pH sensor buffer solution dispenser water pump auxiliary air pump GSM module
D2	liquid pH sensor waterproof temperature sensor analog TDS sensor analog turbidity sensor GSM module
D3	bell siphon water pump DHT11 temperature and humidity sensor float switch water level sensor DS18B20 water temperature sensor E-201-C pH Sensor Fish feeder air pump ultrasonic mist maker LED grow lights relay board micro SD reader module
D4	submersible water heater solenoid valve temperature sensor pH sensor dissolved oxygen sensor cooling fan
D5	pH Meter Pro Analog Sensor Analog EC Sensor DS18B20 Temperature Sensor Ultrasonic Sensor Fuzzy Controller
D6	dissolved oxygen sensor pH level sensor EC sensor water level and temperature sensor
D7	water temperature sensor pH level sensor

	dissolved oxygen sensor water level sensor turbidity sensor
D8	GSM module pH level sensor ultrasonic sensor turbidity sensor dissolved oxygen sensor temperature sensor
D9	pH level sensor dissolved oxygen level sensor DS1821 temperature sensor Electrical conductivity(EC) sensor
D10	DS18B20 temperature sensors, pH sensors soil moisture sensor solar panels
D11	Gravity Analog Dissolved Oxygen Sensor For Arduino "Analog electrical conductivity sensor/meter(K=10) for Arduino" PH Meter Sensor Analog Kit "DS18B20 Full Waterproof Temperature Sensor for Arduino" Node MCU V3 ESP8266 Development Board CH340 1602 16x2 LCD with I2C Adapter Rechargeable Battery 9Volts "DC-DC 9V/12V to 5Volts Step Down Power Charger Bank Board" 3W 9V Mini Polycrystalline Solar Panel
D12	SIM900 GSM module dissolved oxygen sensor ultrasonic distance sensor temperature sensor pH sensor
D13	pH sensor EC sensor DO sensor temperature sensor
D14	DHT11 sensor one-wire water temperature sensor pH Pro Meter Sensor ultrasonic ranging sensor 4x20 LCD module photo resistive sensor
D15	DHT11 Temp and Humidity Sensor pH Pro Meter Sensor Ultrasonic Ranging Sensor Light Sensor One-wire Water Temperature Sensor
D16	12V DC Feeder Aerator Peristaltic Buffer Device Glass-electrode pH sensor DS18B20 Temperature sensor

	DFRObot Soil moisture sensor
D17	water/air temperature sensors aerator light intensity sensor control for cooler ISFET pH sensor grow lights feeder control for cooler buffer pump
D18	DFRobot ORP Analog Meter DFRobot Gravity: Analog Dissolved Oxygen Sensor Gravity: Analog Turbidity Sensor Gravity: Analog Electric Conductivity Sensor Waterproof Temperature Sensor DS18B20 DFRobot Industrial Analog pH Sensor NaHCO2 Distribution water pump solenoid valve Aquarium Heater
D19	GSM module Wi-Fi module solenoid valves Soil Moisture Sensor

Appendix III. List of Tables and Figures

A. Tables

B. Figures