Increase of Productivity in Aquaculture Farming Systems Through the Implementation of Automated Technologies and Engineering Techniques: A Systematic Literature Review

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Abstract

This article carries out a systematic literature review of the technologies and methods applied in aquaculture rearing processes. It is intended to demonstrate that there are many opportunities for improvement in this sector, given that many of the aquaculture practices are still carried out in a rudimentary way. A review of related articles of techniques applied in aquaculture in different databases was made. Within different categories, the obtaining of beneficial results was evidenced due to the use of innovative technologies or methods. Some of the main results were: reduction in feed cost of up to 21%, increase in the size and weight of aquaculture species of up to 15% and 23% respectively, and energy savings of up to 58%, which demonstrates the obtaining benefits after the implementation of modern procedures.

Keywords
environmentally sustainable aquaculture, integrated aquaculture, pisciculture, ecological engineering.

1. Introduction
In recent years, aquaculture has been growing as an alternative for obtaining fish worldwide, reaching 46% in 2018. Asia is by far the main producing region, while Latin America and parts of Africa show constant growth, its production

is still marginal compared to its development potential (Food and Agriculture Organization [FAO], 2018). In this line, there is a loss in the effectiveness of aquaculture practices in developing countries, since many of these are still carried out in a rudimentary way, without the use of technology or production planning (Merino et al. , 2013). Similarly, current aquaculture farming practices in these countries, as is the case of Peru, are generally not carried out under sustainability, efficiency and competitive approaches (FAO, 2020), or strategies such as the development of research, adequate use of technologies, constant innovation, productive economy and human capital formation. Therefore, there are several opportunities for optimization that can be implemented in aquaculture in developing countries to achieve an overall improvement in productivity.

Given the above, the following research question is posed:

What research on the application of automation tools and engineering techniques to increase the productivity of aquaculture farming systems has been carried out during the last 20 years?

In order to contribute to the solution of the problem presented and answer the question posed, the purpose of this research will be: to analyze the improvements in the development of aquaculture production through the use of automation tools and engineering techniques during the last 20 years, through a systematic review of the literature.

“Aquaculture” is known as the set of techniques that focus on promoting and controlling the reproduction of aquatic species, in order to have a more abundant harvest. This cultivation implies the participation of external elements that improve production, such as the feeding process, the type of reserve, the reduction of harmful species, etc. The farming process also includes private or corporate ownership of the harvest, development and use of diverse systems, location, aquaculture practices, and the transportation required to obtain the final product (FAO, 2020). In this sense, for the aquaculture processes to be sustainable, it is essential for their productivity to be increased in such a way that their efficient management implies the maximum use of these, and in this way the production increases while maintaining the levels of the raw material.

According to Cerda and Meller (2020), they point out: "Gains in productivity and added value, through technological and productive innovation and decommoditization, are alternatives to be a competitive industry in the long term." Due to unexpected indices, such as high levels of mortality, prototypes can be designed and implemented to monitor physicochemical parameters, in order to identify the critical moments of the crop (Dussán et al., 2016). In this sense, for the results at the end of the aging to be optimal, several parameters must be taken into account, among which the following stand out: dissolved oxygen, pH, nitrogenous compounds, turbidity and alkalinity (Villalobos, 2019).

The adequate control of these parameters is generally given thanks to technological devices such as sensors and automated systems that allow their real-time management and therefore corrective actions are taken in an optimal and efficient manner. Any device that has the ability to vary a property in response to physical or chemical magnitudes, called instrumentation variables, and transform them with a transducer in electrical variables (Mitchell, 2007). Another component of these systems is the programmable board, which is one that has the ability to execute software made by a programmer. These devices can receive data, which is used by the program and allows the system to generate concrete actions. Programmable boards allow establishing the various connections between the board's microcontroller, sensors and actuators in a simple way (Arduino, 2021). These devices allow for more precise actions to be taken once a problem has been detected, and are a clear example of how technology can be used to improve aquaculture processes and their harvest.

An eventual implementation of automation technologies and engineering techniques, which have already been used in first world countries whose practices in aquaculture farming are much more developed and which have provided positive results, would represent an increase in the competitiveness and productivity of aquaculture of micro and small businesses (Berger, 2020). In this way, the present work will show the improvements in the main performance indicators of aquaculture breeding, and to deepen the theoretical and practical knowledge on the implementation of the more modern methods of this sector, in addition to offering information on the types and uses of the technologies in question.

The rest of the article will be organized as follows: Section 2 details the methodology to be used. Section 3 will describe the main results and findings of the research. In section 4 an analysis and discussion of the results obtained in the investigation will be made. Finally, section 5 will present the main conclusions of the research.

1.1 Objectives

Analyze the improvements in the development of aquaculture production through the use of automation tools and engineering techniques in America and Asia during the last 5 years, through a systematic literature review, where the influence of the use of technologies will be identified in improving the productivity of aquaculture processes.

2. Literature Review

For the literature review, four main groups of publications were identified: feeds for aquaculture species that provide an increase in the quality of the fish, water treatment systems in aquaculture rearing ponds, control of parameters through sensors and pest control through various techniques.

2.1 Feeds for Aquaculture Species

In developing countries, the daily feeding of the fish is distributed by people who, walking along the edges of the pond with a large spoon, throw the pellets at the fish. The amount that each fish receives is subject to the estimation of the human factor (Cerda & Meller, 2020).

The quality and type of feed is extremely important when talking about the volume of production in aquaculture. The health and proper development of aquaculture species will depend largely on the quality of the food they eat. To maximize the quality and size of the fish, researchers use various types of feed and techniques to improve the efficiency of their use. An article found talks about intensive feeding with pellets in monoculture (Edwards, 2015), and how an increase in the benefits of aquaculture farms in developed countries was observed thanks to the study and adequate planning regarding the type and level of its processes. As a result, China saw an increase in production from aquaculture farms from 12-15 ton/ha to 30-40 ton/ha.

With regard to alternatives to obtain a better feed performance, in an article a bacteria-microalgae integration was carried out in feeds for aquaculture species (Riquelme & Avendaño-Herrera, 2003), where investigations were carried out in laboratories in order to understand and take advantage of the interactions between bacteria and microalgae in marine and aquaculture systems. Proper bacterial control using modern techniques can significantly improve the quality of the aquatic environment. As a result, an increase of up to 67% in the size of molluscs fed with controlled mixtures of bacteria and algae was observed.

Continuing with the innovation in the types of feed, in another investigation, a Chinese organic system for aquaculture was described (Xie et al., 2013), where methods for the manufacture of organic feed were used in order to improve the qualities of aquaculture species. As a result, an increase in the length and weight of shrimps from 10.2 cm and 12.7 g to 11.8 cm and 15.7 g was observed. A reduction in the level of nitrogen and phosphorus in the aquaculture system is also observed.

The improvement of efficiency for obtaining food is also sought. Thus, in another article, the fish protein hydrolyzate or HPP was described (Cardoza et al., 2021), which refers to obtaining biological products resulting from the efficient use of the remnants from the fishing industry, which that allows the solubilization of the protein source to improve its nutritional and biological value. Subsequently, these products are used as the main source of food for other aquaculture species. The aquaculture and fishing industries annually produce residues that together represent more than 60% in productive volume. Using this technique could save costs, contributing to sustainable models such as the circular economy.

Finally, regarding technologies that increase feed efficiency, an article described an artificial intelligence system applied to aquaculture processes (Chrispin et al., 2020). For this, automatic dispensers were used to optimize the use of the food. Sensors were also used to measure the quality of the water and the behavior of the fish. As a result, a reduction in feed cost of up to 21% was achieved.

2.2 Water Treatment Systems

As water is a basic and fundamental resource for aquaculture production, strategies that can guarantee its highest quality and, consequently, a better development of the life cycle of aquaculture species must be chosen. For example, Colombia has one of the largest water supplies in the world, however, due to the distribution of this resource, it is evident that it is necessary to delve into the existing imbalances and the management of this resource in order to allow a greater aquaculture growth (Merino et al., 2013).

Various methods were collected that focus on obtaining benefits through adequate control of water resources and management of ponds.

In one article, an ecological pond aquaculture system was designed in China (Liu et al., 2021). In riparian areas such as the Huaihe River and the Yellow River, an aquaculture system was established in ponds whose design had ecological characteristics. These systems included biological floating beds, ditches, ecological ponds (lotus or rice) and water quality control, for basic carp and other special freshwater fish. Consequently, this system managed to increase the bonuses by more than 30% and reduce the aquaculture water exchange by 60% (Xu and Liu, 2015).

Similarly, a design of an ecologically friendly pond aquaculture system in China was featured (Liu et al., 2021). In northwestern and central China, in areas with high levels of alkalinity, an ecologically designed system for aquaculture farms was implemented. This system focused on separation, water filtration and alkaline drainage for basic carp, shrimp white-legged and Shanghai crabs. As a result, this system achieved reduced levels of alkalinity and salinity, which were lowered by up to 33%. It also managed to increase economic benefits by about 50% and became the preferred approach of alkalinity and salinity control (Zhu et al., 2018).

In addition, another investigation described the conditioning of aquaculture water through artificial wetlands (Pardo et al., 2006). Plant species have the ability to absorb nutrients and create conditions that promote the microbial breakdown of organic matter, so they can be used for water filtration. The use of these organisms for water treatment is known as a system of artificial or natural wetlands. As a result, Lin et al. (2005) showed that these systems have the capacity to remove up to 66% of suspended solids, 54% of BOD5, 66% of ammonium and up to 94% of nitrite from the effluent produced, in this case, by a crop of shrimp.

Following other methods, a multi-level ecological system with drainage treatment of a fish farm was designed as well (Liu et al., 2021). In China, in fringes of vegetation incorporated into the landscape to influence the ecological processes of different lakes, an ecologically designed multi-stage system based on the use of fingerlings of different species such as the oriental crayfish and the eastern river shrimp was implemented. As a result, when this system was applied to aquaculture ponds, it increased nitrogen and phosphorus reuse rates by about 50% and brought about a 15% increase in economic benefits (Liu, 2018).

Also mentioned in the previous article, a regulation system in ponds with biofilms was evaluated (Liu et al., 2021). In different estuaries such as the Yangtze and Pearl rivers, a regulation system that included the use of biofilms, underwater soil enhancements, catch-and-release rotation was built encompassing about 10 × 104 hm2. As a result, the levels of pollution in the grass carp systems were greatly reduced, and there was a substantial improvement in the quality of the harvest, water savings were increased by about 60%, and the efficiency of the overall process was increased by over 20% (Xu and Liu, 2015).

Finally, in another article it is stated that the use of combined submerged and flood/drain biofilters may offer the best solution for aquaculture wastewater treatment (Xiao et al., 2018). Sesuk et al. (2009), showed that submerged fibrous nitrifying biofilters (SFNB) could control TAN (total acid number) and nitrite effectively and were also capable of separating suspended solids (SS) from water, thus producing a clear effluent containing less than 20 mg SS/L. Nootong & Powtongsook (2012) indicated that SFNBs were able to maintain TAN and nitrite levels below 1.0 mg per liter when performing zero water exchange tilapia farming, and were able to handle inorganic nitrogen loads as high as 38.6 mg nitrites per liter daily when solids were removed from the biofilters every two weeks.

2.3 Control of Water Parameters

Among the main types of methodologies applied we have those oriented to the control of the main properties of the habitat for the rearing of aquaculture species. Maintaining a proper management of these characteristics is essential to ensure a high level of water quality, and therefore guarantee a good development of aquaculture species and achieve high levels of survival. Some of the main water parameters found in this review are: dissolved oxygen, pH, temperature and turbidity. In aquaculture, sensors are usually used to be able to quantitatively measure the aforementioned parameters, so that, in this way, specialized personnel can make decisions that allow them to be kept in the desired range.

Favorable results were found regarding this group of studies, which mention the techniques and the results obtained after their implementation. For example, in the aquaculture pre-fattening process, in an article about the acclimatization and conditioning of broodstock in captivity (Espinoza & Contreras, 2018), it is explained how an increase in the survival levels of the Cilus gilberti species (croaker) was achieved by controlling parameters such as: dissolved oxygen level, number of parasites, temperature and food quality. As a result, an increase in fish survival of up to 99% was evidenced.

In another article, mainly linked to the fattening stage, a feeding system with fuzzy logic technology for aquaculture systems was discussed (Li et al., 2020). Following those methods, to better meet the food demand of the fish, Soto-Zarazúa et al. (2010) designed a feeding system using fuzzy logic control technology to consider the temperature and dissolution of the water according to the age and weight of the fish. The oxygen condition determines the quantification of the feed, which as a result represents a saving of 29.12% of bait compared to the traditional bait feeder. The difference in growth between farmed fish is also reduced (Soto-Zarazúa et al., 2010).

The use of technologies that allow a more precise control of these parameters is also sought. In this way, in another article, an intelligent monitoring system was applied in aquaculture (Ma & Ding, 2018). For this, intelligent monitoring systems were used to improve the efficiency in the management of dissolved oxygen in aquaculture farms, obtaining an improvement in the times and amounts of energy used. As a result, a reduction in energy consumption of aerators of up to 58.4% was obtained.

Following the technological approach, in another investigation, an adaptive network-based fuzzy reasoning system (ANFIS) for automatic feeding in aquaculture ponds was implemented (Li et al., 2020). In a similar research (Zhu et al., 2018), automatic feeding was achieved in combination with an ANFIS, and the results showed that the feeding decision making accuracy of the model was 98% and the feed conversion factor (FCR) was reduced by 10.77% compared to the feeding table.

It is worth noting that research is being carried out to achieve remote monitoring of aquaculture ponds in aquaculture farmers in first world countries (Zhou et al., 2018). At the moment, to achieve better productivity in aquaculture in developing countries, an excellent first step would be the use of sensor technology to be able to have a quantitative analysis of the situation of the ponds and improve the decision-making process in them.

2.4 Pest control

Diseases in aquaculture farms are mainly caused by the presence of pests, which can be plants, animals, insects, microbes or other unwanted organisms that interfere with aquaculture activity, causing health problems and deaths in the harvest. (National Fisheries Health Organization [SANIPES], 2020). In this sense, it is important to carry out a periodic control of the fish farm to verify that no unwanted organism is found in the habitat of the farmed species in question.

An investigation evaluated the use of Bacillus bacteria in the sustainable development of aquaculture (Greeshma et al., 2021), detailing how Bacillus species are considered the most beneficial microbes for aquaculture. According to the article, there are several mechanisms through which positive effects can be obtained, such as improved growth, immune response and disease resistance in various aquatic organisms. As a result, increases of 26% in the survival of the Carassius carassius species were obtained. Mortality of the Cyprinus carpio species was also reduced by approximately 20%.

Regarding other biological methods, in an article about phage therapy in aquaculture (Ronda et al., 2003), it is described how Pseudomonas plecoglossicida is the main pathogenic bacteria of Japanese ayu fish. It was found that there are resistant strains born from antibiotic treatment and that these are the main reason for a high level of mortality in Japanese fish farms. As a result, a cumulative mortality of up to 65% was detected in the cultures that were treated with bacteria after 7 days, while on the other hand, a mortality level of only 22% was found when a phage treatment was used.

There are also chemical methods for pest control, which are based on the use of synthetic products such as antibiotics, parasiticides, anesthetics and disinfectants. However, the indiscriminate use of these products significantly affects the environment, so alternative methods that allow a more sustainable development are prefered (Mioso et al., 2014).

3. Methods

The research carried out is of a non-experimental type, due to the evaluation of the literature being a collection of information. It presents an interpretive paradigm due to the fact that it is intended to develop the concepts linked to the techniques and technologies for the production of aquaculture systems, as well as the establishment of a conceptual framework integrating the social and cultural reality for the explanation of the factors to be studied. In addition, it has a qualitative approach, which pretends to present the results of the systematic literature review with the aim of establishing the importance of the potential uses of the techniques that can be developed in the country. It is exploratory and descriptive in scope, because it covers general information regarding aquaculture production.

This article was based on a longitudinal (evolutionary) non-experimental research design since the articles reviewed are in a range of years from 2015 to 2021. In addition, a comparison was made with this data collection regarding the keywords.

The methodology for reviewing the scientific literature is based on obtaining secondary information from scientific articles published in Proquest, SciELO, Redalyc, Scopus, Google Scholar, Web of Science, Dialnet and Alicia indexed journals. After completing the search, taking into account the above criteria, a total of 80 articles were obtained, among which are mainly foreign publications.

The first criteria is the use of keywords, which are “feed for aquaculture species” and “water treatment systems”, “parameter control” and “pest control” in aquaculture. The second one is linked to the year of publication, for which articles published between 2000 and 2020 were selected. Finally, the third is related to language, for which articles in the Spanish and English languages were considered.

In the columns of the table below, four keywords used (feeding for aquaculture species, water treatment systems, control of water parameters and pest control) are described and the years of publication are placed in the rows, which range from 2015 to 2021, including a category of previous years. As seen in Table 1, most of the articles found in this literature review cover the topics of feeding aquaculture species and control of water parameters. It is observed that the highest number of articles found were from the year 2018, and the lowest was the year 2016.

Table 1 shows the distribution of the articles reviewed in this research, classified by year and keywords.

Table 1. Distribution of articles by year of publication and keywords

Year of publication	**Keywords**				**Totals**
	Feed for aquaculture species	**Water treatment systems**	**Control of water parameters**	**Pest control**	
Previous years	Riquelme & Avendaño-Herrera, 2003; Xie et al., 2013; Arroyo & Kleeberg, 2013; Baltazar 2007; Soto-Zarazúa et al., 2010	Merino et al., 2013; Pardo et al., 2006); Lin et al., 2005; Sesuk et al., 2009; Nootong & Powtongsook, 2012	Soto-Zarazúa et al., 2010; Arroyo & Kleeberg, 2013; Mitchell, 2007	Ronda et al., 2003; Mioso et al., 2014; Tomasso, 1994	16

2015	Edwards, 2015	Xu & Liu, 2015			2
2016			Dussán et al., 2016		1
2017	Joffre et al., 2017; Rojas-Molina et al., 2017		Alfaro et al., 2017*; Joffre et al., 2017; Rojas-Molina et al., 2017		5
2018	Zhou et al., 2018	Zhu et al., 2018; Liu, 2018; Xiao et al., 2018	Espinoza & Contreras, 2018; Ma & Ding, 2018; Zhu et al., 2018; Xiao et al., 2018		8
2019	Zhou et al., 2019		Villalobos, 2019		2
2020	Cerda & Meller, 2020; Chrispin et al., 2020	Berger, 2020	Li et al., 2020; Chrispin et al., 2020		5
2021	Cardoza et al., 2021	Liu et al., 2021	Arduino, 2021	SANIPES, 2020; Greeshma et al., 2021	5
Totals	13	11	15	5	44

Finally, according to the National Institute of Safety and Health at Work (2021), the stages in the aquaculture farming process according to the life cycle of the species in question are the following: Hatcheries, pre-fattening, fattening and commercialization. In this sense, the present work will only address the engineering techniques and automation technology applied during the pre-fattening and fattening process of aquaculture farming, in addition to the treatment of aquaculture water, since it is a fundamental element in it. The techniques and technologies used before and after said process, such as soil studies, acclimatization, fish biometry, among others, are excluded. Additionally, the articles are classified into four groups according to the applied technologies and methods, which are addressed below.

4. Results and Discussion

In the reviewed articles, various techniques and technologies were found that represented an increase in productivity after the implementation of a certain technique, mainly in the pre-fattening and fattening stages of the aquaculture species and, also, the care of the water resource. In Table 2, the articles were classified according to the three stages mentioned above.

The reduction in feed consumption in aquaculture represents quite considerable savings in aquaculture, since this concept represents about 70% of production costs in aquaculture farming. In this sense, aquaculturists must seek to reduce the feed conversion factor (FCA) to achieve greater productivity. After reviewing the literature, it was shown how automatic systems could achieve a reduction in said indicator through systems such as the ANFIS, in addition to food that could be made from fish waste.

With regard to water, the aim is to extract the maximum benefit given its scarcity and importance. In the articles reviewed, water treatment systems were designed with an ecological approach with quite positive results. It must be specified that the geographical location must be considered at the time of the implementation of these systems, given that some techniques are sensitive to environmental variables.

It is necessary to highlight that in the literature reviewed, the control of the physicochemical parameters of the water is essential for the optimal management of aquaculture rearing. Correct data collection will allow the personnel responsible for the aquaculture pond to take the necessary corrective actions, otherwise, adverse aspects may be generated in the farmed species. It should be noted that as breeding becomes more intensive, more measurement tools with greater precision are required.

In relation to pest control, it has been shown that the use of bacteria is beneficial to reduce fish mortality. These techniques require an adequate control of the water parameters and trained personnel for their respective monitoring. It should be noted that the use of bacteria has better results than the use of antibiotics in relation to the mortality indicator, as shown in the results described in this research. Additionally, the use of chemicals of synthetic origin applied to aquaculture can cause damage to human health and aquaculture species (Mioso et al., 2014).

It is also essential to mention the implementation of methods and technologies that focus on the efficient use of resources in aquaculture processes. The economic benefits obtained thanks to these practices can become an incentive for future research and a possible industrialization of the sector.

Table 2: Applications of technologies and techniques in a given process

Process / Technology or technique	**Water care**	**Pre-fattening**	**Fattening**	**Total**
Feed for aquaculture species	0	0	Riquelme & Avendaño-Herrera, 2003; Edwards, 2015; Xie et al., 2013; Cardoza et al., 2021; Cerda y Meller, 2020; Chrispin et al., 2020	6
Water treatment systems	Merino et al., 2013; Pardo et al., 2006; Lin et al., 2005; Sesuk et al., 2009; Nootong & Powtongsook, 2012; Xu y Liu, 2015; Zhu et al., 2018; Liu, 2018; Xiao et al., 2018; Liu et al., 2021	0	0	10
Parameter control	Ma & Ding, 2018	Espinoza & Contreras, 2018	Li et al., 2020; Soto-Zarazúa et al., 2010; Zhou et al., 2018	5
Pest control	0	Greeshma et al., 2021	Mioso et al., 2014; Ronda et al., 2003	3

5. Conclusions

Four major aspects of aquaculture breeding systems were evidenced: Food for aquaculture species, water treatment systems, control of parameters through sensors and control of pests and diseases. For this reason, it is considered ideal for aquaculturists to consider the importance of each of these aspects in the management of their ponds, since there is a lot of literature on the matter with techniques that they could implement in their environments.

On the other hand, there are also opportunities when talking about the use of new technologies and techniques, as they provide noticeable improvements in aquaculture, but this must go hand in hand with properly trained staff so that they can implement them according to their needs and boundaries. In this way, a better quality product can be obtained in greater quantities that can, in turn, provide a greater competitiveness in the market.

It should be noted that the acquisition of automation technologies not only requires trained personnel, but also requires adequate infrastructure and investment capital, which often means relatively high costs at the beginning of the project. That is why municipal and regional authorities should be encouraged to carry out campaigns and support programs for fish farmers who often can't afford such amounts, since this sector is in a global growth trend and can represent a very large economic benefit for the country.

There are also many opportunities to reduce the environmental impact of aquaculture farming. For example, it has been shown in the investigation that there are reflux systems that can benefit the effluents of aquaculture farms, improving the efficiency of the use of water, therefore lowering the consumption. Another approach would be to reuse fish scraps and use them to make fish feed, contributing to the circular economy and saving costs, which has been mentioned in previous articles. The nature of advances in aquaculture go hand in hand with environmental care, given its focus on efficiency and productivity. All in all, there are many ways to improve aquaculture farming and it can become a very important activity in the near future. It's a matter of knowing what tools are at our disposal and how we can implement them to obtain the most out of the marine resources.

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