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ARTICLE

Application of Fourth Industrial Revolution Technologies to Marine Aquaculture for Future Food: Imperatives, Challenges and Prospects

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ABSTRACT

This study was undertaken to examine the options and feasibility of deploying new technologies for transforming the aquaculture sector with the objective of increasing the production efficiency. Selection of technologies to obtain the expected outcome should, obviously, be consistent with the criteria of sustainable development. There is a range of technologies being suggested for driving change in aquaculture to enhance its contribution to food security. It is necessary to highlight the complexity of issues for systems approach that can shape the course of development of aquaculture so that it can live-up to the expected fish demand by 2030 in addition to the current quantity of 82.1 million tons. Some of the Fourth Industrial Revolution (IR4.0) technologies suggested to achieve this target envisage the use of real-time monitoring, integration of a constant stream of data from connected production systems and intelligent automation in controls. This requires application of mobile devices, internet of things (IoT), smart sensors, artificial intelligence (AI), big data analytics, robotics as well as augmented virtual and mixed reality. AI is receiving more attention due to many reasons. Its use in aquaculture can happen in many ways, for example, in detecting and mitigating stress on the captive fish which is considered critical for the success of aquaculture. While the technology intensification in aquaculture holds a great potential but there are constraints in deploying IR4.0 tools in aquaculture. Possible solutions and practical options, especially with respect to future food choices are highlighted in this paper.

1. Introduction

Aquaculture has grown dramatically in the past five decades, with total fish production from this sector amounting to 82.1 million tons [1]. It is widely recognized as a potential sustainable solution for food security and an answer to the need for cost-effective animal protein with low-carbon and ecological footprint. Fish

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demand is projected to increase in the range of 112.1-114.1 million tons by 2030, requiring an additional 30-32 million tons of fish [2-4]. This is a great challenge that requires a real transformation. Landings from capture fisheries are unlikely to increase due to depletion of resources and impairment of ocean ecosystem [5]. Aquaculture production should increase to ensure adequate supplies.

Aquaculture has recently surpassed the capture fisheries in production and is expected to share 62% of the food fish by 2030 [6]. The incremental research and developments have been going on and have contributed significantly to positioning of aquaculture to where it stands today. However, it is inconceivable to meet this high level of demand without transformation. Because the seafood demand has outweighed production, there is a need for a fast-track approach to producing fish using disruptive innovations and technologies that hold promise for revolutionizing the aquaculture industry.

Fourth Industrial Revolution (or IR4.0) offers a range of technologies, and some can be adapted for aquaculture systems. It is appropriate to apply the term 'Aquaculture 4.0' to aquatic farming driven by these disruptive technologies. Some interesting work has appeared in this area [7-11]. When the sustainability is taking a center stage in food production, it is necessary to generate a strategic framework comprising the purpose or goals and drivers aligned with the United Nations' Sustainable Development Goals (SDGs) to resonate with the global narrative.

Aquaculture 4.0 envisages more automation in selected functions, bridging the physical and digital operations through cyber-physical systems using computers for monitoring and algorithmically controlling different mechanisms and processes, and regulating the production by closed-loop data. Potential areas of application of Aquaculture 4.0 technologies are highlighted in this paper together with the reasons for transformation, challenges and prospects with special focus on future food choices.

2. Technology Intensification

Certain new terms such as 'precision aquaculture', 'smart aquaculture' and 'digital farming' are associated with technology intensification in aquaculture. These terms are often used interchangeably but there are subtle differences. Precision aquaculture refers to use of digital techniques in monitoring and optimization of the culture system. This implies regulating the supply of inputs in amounts exactly needed to prevent waste, reduce cost and minimize environmental impacts. Smart farming envisages application of information and data technologies in effective ways for better results. Digital aquaculture combines elements of precision aquaculture and smart aquaculture to advance the technology intensification for Big Data analysis, use of web-based platforms and machine learning among other innovative tools.

Disruptive innovations and technologies of Aquaculture 4.0 are believed to hold key to transforming aquaculture towards seafood security targets. A comprehensive review of the application of various technological tools, including sensors, robots, 3D prints, drones and artificial intelligence (AI) in aquaculture development has been published recently [12]. Aquaculture industries, and R & D organizations are giving increasing attention to embracing modern technologies wherever feasible and affordable. It is being considered as a way of making a major turnaround in aquaculture. Many disrupting solutions are aimed at achieving better output with reduced resource inputs, improved nutritional quality of the harvest, and compliance with the sustainability criteria. This will offer a fast-track approach to meeting the fish production targets through four possible ways:

- Greater intelligent automation of the various operations.
- Bridging the physical and digital world through cyber-physical systems using computers.
- Monitoring and algorithmically controlling different mechanisms.
- Regulating production steps by closed loop data.

Inputs for deployment of modern technologies are in the form of data collections through IoT concept such as wireless network sensors and the analysis of big data with the techniques of AI. For a start, some selective technologies can be tested for their potential outcomes in terms of sustainable production.

Aquaculture 4.0 is closely associated with the aforementioned technology-intensive aquatic farming. Fore [13] has outlined main steps in modern aquaculture systems (Figure 1) that are aimed at: 1) Improving the accuracy, precision and repeatability in the farming processes, 2) Facilitating a greater degree of automation or inbuilt controls in regular monitoring of the farming system, 3) Providing a dependable decision support system characterized by a computerized program for collecting and analyzing the data, and synthesizing information that can be used to solve the problem by computer algorithms or human intervention or both, and 4) Reducing dependencies on manual labor, and subjective assessments.

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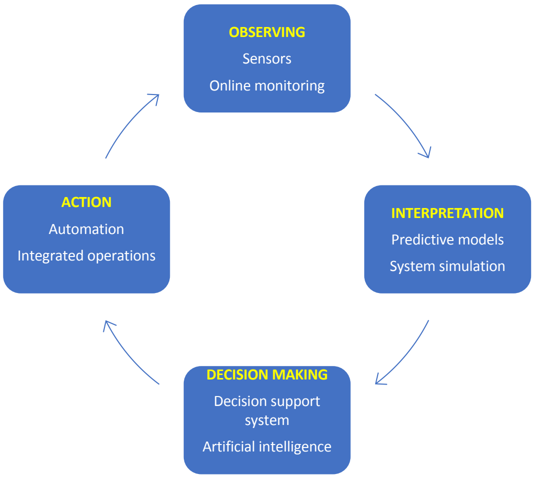

Figure 1. Key steps in the production process.

The overall objective through all these interventions is to improve productivity, resource efficiency, environmental sustainability and economic benefits. The fish stocked in cultural facilities should be able to perform and express its biological activities. These bio-responses need to be observed (Step-1) and interpreted for assessment of fish condition (Step-2) which will form the basis for making decisions on whether or not any interventions are needed (Step-3), and enforcing actions based on the decision for expected outcomes (Step-4). These steps in the production process can be assisted by appropriate technologies.

A model of digital aquaculture system comprising the various tools of technology is presented in Figure 2.

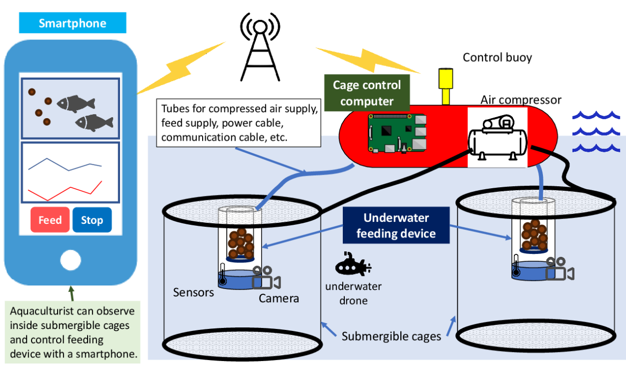

Figure 2. Model of a smart aquaculture system. Reproduced with permission from Tetsuo and Kobayashi [14].

System integration that involves connecting the various aquaculture sub-systems to function as a whole or complete unit of operation as can be seen from Figure 2 is the key to success of an intelligent aquaculture [15].

Among the Aquaculture 4.0 technologies, AI is receiving an increasing interest. In a complex system of aquatic food production, AI deployment can happen in many ways. It requires aligning the biological data with computers and understanding how the system works for solving specific problems. Basically, these procedures involve Artificial Neural Network (ANN).

ANN is a computational model inspired by neural network of the human nervous system. It mimics the pathways of brain function where the sense organs perceive stimuli that are transmitted through sensory nerves to the brain that decides how to respond to the stimuli and sends the information through motor nerves to the effector organs to act accordingly. This provides the foundation of AI where flow of information happens through algorithmic pathways.

ANN comprises Nodes which in biology are termed as Neurons (or nerve cells) [16]. There are multiple nodes arranged in three layers: Input Layer, Hidden Layer and Output Layer (Figure 3).

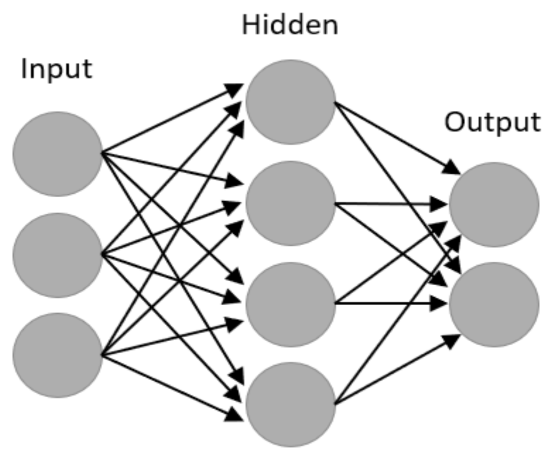

Figure 3. Three layers of nodes in ANN.

• Input layer: Comprises the Input Nodes that bring information from external environment into the network and pass it on to the hidden layer. Information processing and computation are not carried out here.

• Hidden Layer: Comprises nodes that have no direct connection with the outside environment (and hence the name 'hidden' nodes). Their role is to perform computations and to transfer the information to the output nodes.

• Output Layer: Consists of nodes that are responsible for transferring the information to the effector organs which act according to the instructions to produce the end-result or outcome.

Nodes from these adjacent layers have connections between them. When an input (stimulus) enters the node, it gets multiplied by a weight value [17]. Weight represents the strength of the signal (or impulse) and determines how much influence the input will have on the output. Weights are the real values associated with the stimulus. Because all inputs (stimuli) are not equal, therefore, weight values are different.

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Weights are applied within the nodes of the hidden layer. There is a system in the hidden layer called as an 'Activation Function' - that takes the input delivered by input nodes and multiplies it by Weight. Hidden layer also carries out distillation or filtration of inputs (information/ stimuli). It identifies and selects only the important information from the inputs, leaving out the information that is redundant or of no major consequence. If the input (impulse) is relevant and important (higher weight) it is processed for a response. If weights are close to zero, they have lesser importance and stimuli with such weights are filtered out while those of higher weights are retained and processed for response by the fish. There is one more entity called 'Bias' (b). Bias is added to the weighted sum and fed through Activation Function as a constant value (=1) which is the Bias Unit. By adding the value '1' the Bias creates a non-zero y-intercept in the linear regression. This enables the ANN to fit the data when all inputs are equal to zero, or in other words, to generate an output when input is zero. It allows shifting linearity to either right or left to help the model to fit the given data. Diagrammatically, this pathway can be shown in Figure 4.

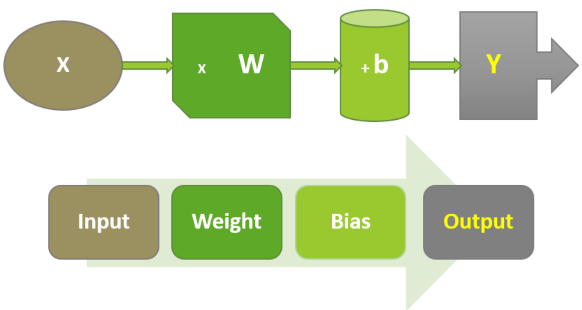

Figure 4. Response transmission pathway in ANN.

Mathematical transformation of this pathway can be expressed by the equation:

Input (X)→ x Weight (W) +Bias (b) → Output (Y).

Each input (X) is assigned a 'weight' (W) value based on its relative importance to all the other inputs. Transformation of input into valuable output forms the basis of mathematical constructs where the hidden layer is located between the input and output of the algorithm, and in which weights are applied to the inputs and directed through an Activation Function as the output. Bias is a mathematical entity that is applied to introduce non-linearity in the ANN model. Therefore, Bias is a constant which helps the model in a way that it can fit best in a regression and is an additional parameter in the neural network which is used to adjust the output along with the weighted sum of the inputs. In other words, Bias is an assumption made by a mathematical/ computer model to make the target function easier to process. Bias unit is not connected to or influenced by the input layer activity. It is a fixed value that is added but this role does not amount to any 'real activity' (unlike the weight). Thus, the steepness of the sigmoid curve depends on the weight of the inputs, not the Bias. This is evident from the simple formula:

Output = sum (inputs x weights) + bias

From a biological perspective it is better to explain that the Activation Function is not any structural or anatomical entity but a functional process in the form of mathematical equations that determine the output of a neural network [18]. All input values are close to Zero before weight is applied but once multiplied by weights and summed up they get accumulated, requiring rationalization to keep them in an acceptable range for appropriate output. Activation Function also helps in normalizing the output of each neuron. This envisages reorganization of weighted data and data cleaning by eliminating duplicate and redundant data. After normalization in the Activation Function, it is possible to generate output that is needed by a fish to respond to conditions it is exposed to.

As mentioned earlier, the node (neuron) receives a series of inputs (stimuli) and these are acted upon by Weight and Bias for transformation of input data in the hidden layer, and then the information moves into the next (output) layer of the ANN that tunes it to produce the desired outcome in a specified range for the effectors to react. Complexity of neuronal network requires such a normalization for a rationalized output. Since there are many factors in the cultural environment in which the fish is exposed, the simpler form of the equation: Input (X) x Weight (W) + Bias (B)→ Output should transform into the following formula:

Output, Y = f (X1 x W1 + X2 x W2 + X3 x W3) + b.

Neurons of the hidden layer apply the 'Activation Function' (f) to the weighted sum of the inputs because of which the fish responds differently according to the nature of stimuli and the needs of the situation. Activation Function provides the type of non-linearity between the inputs and outputs that is biologically logical under a real-world situation. It deserves emphasis that the linear models cannot characterize the nature of relationship between input and output. Without this (Activation Function), the ANN can only generate linear models that do not represent the practical possibilities because most real-world data is non-linear. Response of any aquaculture animal in a cultural system or even in the wild is inherently nonlinear in nature. To elaborate it further, it characterizes a situation

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where there is no straight-line or direct relationship between an independent variable and a dependent variable. ANN models the input-output that defines the complexity of the perception and processing of the response mechanism in the fish.

In ANN, the Weight and Bias can be considered as learnable parameters. In biological systems, this amounts to rationalization but in ANN these parameters (Weight and Bias) are randomized and adjusted toward the desired values for the correct output. This is where machine learning is involved. Because the hidden layer has many neurons and without activation function there will be a combined linear output in response to different inputs. If that is the case, fish response to multiple stimuli will be the same with full energy mobilized into it! Addition of Bias reduces the variance and hence introduces flexibility by addition of a constant value to the sum of Input + Weight. This is done by shifting the result of Activation Function towards the positive or negative side. Weight reflects the strength of the connection. It determines the amount of influence a change in the input will exert on the output. A low Weight value will have no change on the input, and alternatively a higher Weight value will markedly change the output. If Weight value is low, it means that the sensation (stimulus) is within the threshold limits of the fish, and it is not necessary for the fish to react.

3. Constraints and Options

The main factors constraining technology intensification are: 1) Reluctance to change, especially in the case of small enterprises, 2) Investment risk that weighs heavily in decision-making in large-scale enterprises, 3) Shortage of skilled human resources, and 4) Lack of gainful employment opportunities for graduates who have the knowledge for high-tech operations.

The prospects for aquaculture sector to transform would be brighter with the realization of the inability of the current systems to meet the fish production targets and when significant benefits from technology-intensive systems become apparent. Another reason which will influence market perception will be when the consumers demand to know the methods of growing food and tracer technology gains a foothold.

There are three directions for the future growth of aquaculture industry: Optimization of existing cultural systems, genetic modification and new species as future food.

3.1 Optimization of Existing Culture Systems

Aquaculture industry has a track record of improving the rearing systems. Knowledge and technological interventions have always supported the production and diversification of aquaculture. As a result, aquaculture has grown at the rate of 7.5 - 9 % annually to emerge as the fastest developing food sector [19,20]. Yet, barring a few selected species of fish, the success in commercial-scale seed production of even the high-value fish remains elusive. Most of the seed supplies still come from wild populations. Captive breeding of bivalve molluscs and sea cucumbers is not always successful. Commercial-scale production of lobster seed in hatcheries remains a challenge. Established aquaculture systems such as those for high-value finfish (groupers, seabass), shrimp and crab have been increasing production to meet the demand in the face of stabilization or decline of capture fisheries using the existing infrastructure. These systems require input of new knowledge for meeting the requirements of sustainable development.

3.2 Genetic Modification

Certain genetic modifications have demonstrated a quantum increase in fish growth. Growth rate of some transgenic fish can be increased by 400-600% while simultaneously reducing the feed input [21]. Genetically engineered tilapia has been reported to put on weight 300 % faster [22]. Genetically modified Atlantic salmon attains market size in half the time (16-18 months) compared to the conventional one that takes 32-36 months [23].

Potential candidate species are certainly those that fetch a high price in the market. In Malaysia and many other countries, the giant grouper (*Epinephelus lanceolatus*) is highly valued but so far there are no attempts for gene transfer in this species. Nevertheless, such high-value species remain possible candidates. Even with the state-of-the-art farming methods, good care in the hatchery and rich diet, the giant grouper could not gain 1 kg/year. Obviously, there are limits to growth. Growth can be modulated but it remains within the range set by the genetic and physiological factors. Giant grouper grows to 2.5 meters and attains 400 kg of body weight in about 35- 40 years or even more, gaining about 600 g/year or 1 kg/18 months [24]. Farmed groupers are reared for about for one year and are generally harvested for marketing when 400 - 600 g.

Producing genetically modified organisms (GMOs) is a controversial topic. Although market forces see benefits, but conservation biologists are concerned about the ecosystem implications of GMOs in case of their entry into the wild.

Consumer perception about GMOs is divided between acceptance and rejection. Resolution of this issue will take time. Future food security challenges and climate change

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adaptations will probably shape the cost/benefit analysis of genetically modified fish. For now, the aquaculture can remain focused on the non-controversial methods of production.

3.3 New Species as Future Food

While optimization of culture systems of currently used species will continue its transformation trajectory, new species can be tested for potential development as future seafood. Being new candidates, it will be easier to apply modern technologies for starting from scratch for sustainable production since it will be free from the legacies of the existing infrastructure and practices.

As a dynamic sector, aquaculture has been diversifying and adapting over time for better production and sustainability. However, now the food security challenges are different and require more efforts for screening new candidate species and selecting those that possess biological attributes needed for sustainable aquaculture. The criteria for selecting new species should be based on multiple qualities. Currently, out of 33,600 species of finfish recorded so far, only 608 species have been tried for aquaculture [3]. The number of invertebrate species is much higher. Of these, there are only 10 top farmed species, and this number includes shellfish as well as seaweeds in addition to finfish.

3.3.1 Criteria for Selection

❑ Adaptability to captivity at high-stocking density.

❑ High rate of survival and fast growth.

❑ Acceptance of artificial diets and nutritional efficiency.

❑ Ability of physiological systems to accept interventions aimed at developing farmed fish as functional food.

❑ Resilience to the effects of climate change and other external drivers.

❑ Amenability to farming in compliance with sustainability requirements.

❑ Consumer preference and marketability.

3.3.2 Advantages of Selecting New Species

(1) Aquaculture industry can make a fresh start, without the need for replacing the existing expensive culture infrastructure.

(2) Culture systems for the new species can be designed in response to prevailing challenges.

(3) Leveraging of past experience.

(4) New systems could offer scope for:

a) Disruptive innovations.

b) Green technology based on circular / decarbonized production models.

c) Potential for developing into functional seafood system through bioencapsulated ration or other means.

4. Tilapia (*Oreochromis niloticus*) as a Model

Tilapia (*Oreochromis niloticus*) is the subject of an ongoing study. It is a commercially important fish globally. Tilapia ranks among the top 10 farmed species in the world that are expected to drive future growth of aquaculture and is expected to yield 7.3 million tons a year by 2030 [6]. Being one the most thoroughly investigated finfish in the world, the data generated on its performance in culture systems offers a great deal of insights needed for AI application. Some basic attributes of tilapia specifically suitable for AI application in areas such as stress detection include:

❑ A strong receptor-effector system.

❑ Well-defined behavioral changes in response to environmental factors (stressors).

❑ Sensory systems having a remarkable ability of perceiving external stimuli and provoking reaction in a way that helps the fish adjust to the prevailing conditions.

Stress-detecting algorithms can help in timely mitigating stress and even prevention, and in optimizing culture conditions. Reducing stress on captive fish is vitally important for sustainable production [25].

The stress response of the fish has been documented by several authors in the past [26-34]. A simplified response of tilapia to stress factors is shown in Table 1. A real-life response system is complex, depending on many factors. The response is modulated by magnitude of stress factors and their possible interdependence, and duration of exposure. This should be considered in algorithm development. Still, such data provide a scientific basis for developing algorithms to detect and mitigate the stress factors for optimizing the culture conditions.

Table 1. Response of tilapia to stress factors.

Variable	*Fish response*
Temperature, °C	Decrease in opercular movement with temperature decline.
DO, mg/l	Reduced random movement, decline in swimming activity. Increased surfacing, crowding, sluggish response to stimuli.
Salinity, ppt	Increased opercular rate, increased vertical movement, disorientation, exhaustion, more time at bottom.
Unionized ammonia (mg/l)	Initial shock, increased agitation followed by decline, increased vertical movement, disorientation.

The fish is exposed to different stimuli at the same time

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in the culture system or wild environment and reacts as appropriate. The stress factors that serve as stimuli may be:

➢ Decline in dissolved oxygen
➢ Increase in nitrite and ammonia
➢ Rise in water temperature
➢ Visual factors
➢ Auditory factors
➢ Others

Their perception and transmission are depicted in Figure 5.

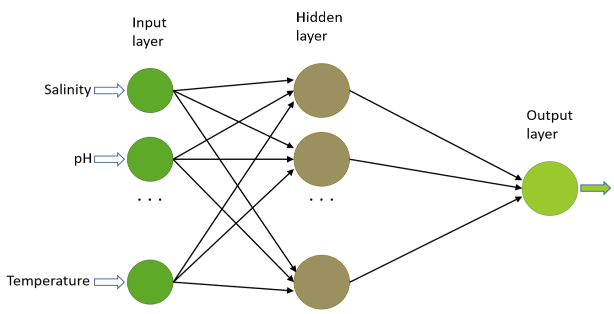

Figure 5. Architecture of multi-layer perception network for prediction of selected water quality parameters.

These stimuli are different in scale and in producing physiological effects in the fish. Their lethal effects are unequal. The stimulus-response, therefore, cannot be a linear process. Thus, in a real-world situation the fish cannot live with the same (or linear) response to factors that are profoundly different. Specific nature of visible response provides the basis of algorithm development. Learning from the fish's stimuli filtering system for response prioritization and modulating an effective outcome are necessary for mathematical constructs of AI. Just as there are different impulses or stimuli or stress factors, there should be multiple algorithms to perform the calculations on the input data to be able to compute the output (=biological response of fish). A biological ANN model that maps the inputs and outputs is complex and has a high level of dimensionality to factors such as dissolved oxygen deficiency, spike in ammonia concentration or change in salinity, thus requiring big data and analytics.

An Ongoing study on stress-detecting algorithm for Tilapia aquaculture optimization through artificial intelligence intervention consists of following components:

(1) Data collection: pH, temperature, salinity, and DO) 10 minutes for 1 month.

(2) Summation of the data.

(3) ANN design specifications.

(4) Network designing.

(5) Testing the ANN design by comparing the actual data with the predicated data output.

For practical purposes and prompt mitigation action, a real-time monitoring of cultural conditions through sensors and the fish's visible (behavioural) response through visual analytics will be required. Use of sensors will be for water quality measurement, but information of monitoring and assessment of fish behaviour and condition will also be very helpful in managing the cultural system. Production efficiency will be high if the fish is in a physiologically robust condition that supports faster growth and health.

The process would involve consolidation of sensor-generated data and computer (digital) vision through interactive interfaces that provide a scientific basis for timely action and data interpretation for Decision Support System (DSS). DSS is a computerized system for collecting and analyzing data, synthesizing the required information to support an efficient decision-making for solving problems in aquaculture systems. It will comprise integrated components in the form of: Physical objects ("things") such as sensors, software and other multiple technologies, real-time analytics and machine learning, stocked fish, and transfer of data over a network without human-to-human or even human to computer interaction. This defines the IoT in a digital aquaculture system with specific features for: Automation of control systems, real-time monitoring of water quality and stocked fish, reduced dependencies on technical personnel, doing away with subjective assessments and improved production efficiency.

5. Future Food Choices

As pointed out earlier, digitalization of existing aquaculture systems can be gradually increased, but it will be more practically convenient and cost-effective to develop aquaculture 4.0 systems for certain future foods, especially microalgae, seaweed and mushrooms.

There is nothing very technical about this popular term 'Future Food'. Some authors define it as food that we will be eating in 20 years' time, but it is better to refrain from fixing any year or decade as it seems arbitrary. Food security is a challenge for the world and is likely to get bigger in near future. What we will be eating in the future is a matter that is receiving a great deal of attention (Table 2). When it comes to seafood, we expect to consume:

(1) More of the same food that we are consuming now.

(2) Same seafood produced in different ways.

(3) Same seafood raised by different culture systems (for example. organic farming).

(4) New species as functional food.

(5) 3D-printed seafood.

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Table 2. Trends in future seafood.

Known types of foods currently harvested		Advantages from future farming
Species in the current production systems	*Species in the future production systems*	
Fish, shrimp, crab from capture fisheries or aquaculture.	Organic fish, shrimp, and crab produced through certified organic aquaculture methods.	Better for health.
Lobster from the wild population.	Hatchery-produced and farmed lobster.	Increase in supply. Decrease in overfishing pressure.
Fish farmed as primary food.	Fish as functional food through bioencapsulated/ fortified diet.	Specific health benefits.
Microalgae harvested from the sea.	Commercial-scale production under controlled conditions.	Exploring the potential of new species could open many horizons for their use as functional or regular food for humans.
Mushroom (Fungi).	Known or new species raised through agri-aquaculture systems "Mush-aquaculture".	Mushrooms are a source of nutraceuticals and therapeutic substances, and bioactive compounds of functional significance.

Application of AI and other tools of current technologies to future aquatic food is practically more plausible due to a number of reasons: 1) Opportunity to select species that can be grown on a fast track, 2) Determining amenability of new species to technology-intensive farming systems, 3) Shaping the production systems consistent with the sustainability requirements, and 4) Using species according to their: a) ability to accept nutrient fortification and bioencapsulation, b) qualities that make them acceptable as functional food when modulated, c) biological capacities for accepting integration into a system of macro-cascading for eco-friendly spinoff benefits or socio-economic dividends, and d) suitability for organic aquaculture. These topics have been elaborated in this paper.

6. Emerging Area: Imitation Seafood

There is a growing interest in imitation seafood. Several plant-based recipes for imitation fish are being developed, for example, raw tuna and salmon. The 3D printed imitation seafoods are opening a vast horizon of new opportunities. This is an area with enormous potential for:

- ❑ 'Secret' recipes
- ❑ Innovation
- ❑ Entrepreneurship
- ❑ Graduate employment
- ❑ Start-ups.

Making plant-based fish alternative will require interdisciplinary collaboration involving aquaculture, food science and technology, culinary art, psychology and economics.

Interdisciplinary research is making it possible to produce vegetable-based products that taste like a fish. With more efforts it might be possible to process tomato or other vegetables into a product that resembles the taste of grouper, hump-head wrasse or other species! This topic can inspire researchers of all ages and backgrounds to push the boundaries of innovation and entrepreneurship. However, momentum for such future foods should develop for the sake of human health, environment, creating new areas for entrepreneurship and life-long learning.

It requires changing the mindset. In the words of a protagonist of regenerative agriculture, Charles Massy "Today's problems cannot be solved with today's mind", and thus, we need to change our mindscapes before we can change our food security landscapes.

Promising sources of ingredients for imitation seafood are seaweeds and mushroom among others. Malaysia has a vast coastal marine area for seaweed farming. The growing conditions are favorable. Mushrooms are easy to farm under certain agri-aquaculture systems due to their survival and growing conditions in a tropical climate. They do not carry out photosynthesis and, thus, there is no need for vast sun-exposed areas. Fibrous nature of mushrooms offers the advantage to turn them into products that in some way resemble that from animal sources. Furthermore, mushrooms do not have a strong taste or flavour, and this helps in culinary processing for imitation. Use of mushrooms in such future foods will intensify interest in exploring the most suitable edible species out of the thousands that are known to occur.

There are good and bad practices that can be associated with the imitation seafood (Table 3).

Table 3. Good and bad practices requiring attention.

	Good practices
1.	Environment-friendly.
2.	Spare animals from the stress of captivity, cruelty and sacrifice.
3.	Free of seafood poisoning risk.
4.	Free of zoonotic infection concerns.
5.	Easy to manipulate nutritional and organoleptic quality by culinary processing.
6.	Easy to develop into functional food.
7.	Produced according to demand and save the product from loss in case of supply chain disruption.
	Bad practices
1.	Counterfeit food products containing false claims of functional properties or even containing harmful substances.

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7. Solutions

Quality control offers the best solution to curb malpractices in the imitation seafood business. Once the consumer interest picks up, the market is likely to expand and the public will be better informed. The nature of ingredients, quality assurance, price, awareness campaigns and consumer appeal will determine their success in the market. Certification procedures, traceability and blockchain will be needed to ensure that only quality product enters the market and consumers get what is claimed by the producers of the food item on the label. Blockchain has the capability to trace the entire lifecycle of food products from origin to consumers. It can help combat fraud in the food market, boost transparency in operations involved in processing. It will be possible to track and trace any seafood in the market and might emerge as the solution to the critically important food safety.

8. Conclusions

Aquaculture has grown rapidly over the recent decades. With the stagnation in capture fisheries landings, aquaculture should further enhance its contribution to seafood supply and food security. It has reached a stage that the trend of incremental change can shift towards transformation using IR4.0 technologies. There is an urgent need to examine if the current research and development efforts are following a system / systems / systemic or systematic approach. Investment in future food necessitates a serious introspection for an outcome-based and solution-oriented research that is linked to market demand and societal welfare, and is also rooted in environmental sustainability.

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References

[1] SOFIA. The state of world fisheries and aquaculture. Food and Agriculture Organization, Rome, Italy, 2020.

[2] Kobayashi, M., Msangi, S., Batka, M. et al. Fish to 2030: The Role and Opportunity for Aquaculture. Aquaculture Economics and Management, 2015, 19 (3), 282-300.

[3] Cai, J. and Leung, P.S. (2017). Short-term projection of global fish demand and supply gaps. Fisheries and Aquaculture Technical Paper no. 607, Food and Agriculture Organization, Rome, Italy, 2017.

[4] FAO. The state of world fisheries and aquaculture. Food and Agriculture Organization, Rome, Italy, 2018.

[5] Mustafa, S. and Saad, S. Coral Triangle: Marine biodiversity and fisheries sustainability. In: Leal Filho W., Azul A.M., Brandli L., Lange Salvia A., Wall T. (eds) Life Below Water. Encyclopedia of the UN Sustainable Development Goals. Springer, Cham, Switzerland, 2021.

[6] WB. Fish farms to produce nearly two-thirds of global food fish supply by 2030. The World Bank, Washington, DC, 2014.

[7] Mustafa, F.H., Bagul, A.H.B.P., Senoo, S. and Shapawi, R. A review of smart fish farming system. Journal of Aquaculture Engineering and Fisheries Research, 2016, 2 (4), 193 - 200.

[8] Vik, J.O. Digi Sal: Towards the digital salmon- from a reactive to a proactive research strategy in aquaculture. Norway University of Life Sciences, Oslo, Norway, 2016.

[9] Lu, H. D., Yu, X., & Liu, G. Q. Abnormal behavior detection method of fish school under low dissolved oxygen stress based on image processing and compressed sensing. Journal of Zhejiang University (Agriculture and Life Ences), 2018, 44(4), 499- 506.

[10] Chen, Y. Q., Li, S. F., Liu, H. M., Tao, P. Application of intelligent technology in animal husbandry and aquaculture industry. 14th International Conference on Computer Science & Education (ICCSE). IEEE, Toronto, ON, Canada, 2019.

[11] Helland, S. How digitalization is refining aquaculture research. The Fish Site. The Fish Site, Hatch Accelerator Holding Limited, Cork, Ireland, 2020.

[12] Mustafa,S., Estim, A., Shapawi, R., et al. Technological applications and adaptations in aquaculture for progress towards sustainable development and seafood security. IOP Publishing, Bristol, UK, 2021.

[13] Fore, M. Precision fish farming: A new framework to improve aquaculture, Part 1. Global Aquaculture Alliance. New Hampshire Avenue, Portsmouth, USA, 2019.

[14] Tetsuo, I. and Kobayashi, T. Smart aquaculture system: A remote feeding system with smartphones. Proceedings of the 2019 IEEE 23 International Symposium on Consumer Technologies, pages 93-96. DOI: v10.1109/ISCE.2019.8901026.

[15] Li, D. and Li, C. Intelligent aquaculture. World Aquaculture Society, Los Angeles, USA, 2021.

[16] Ogajanovski, G. Everything you need to know about neural netyworks and back propagation- machine learning easy and fun. Towards Data Science, Media, Canada, 2019.

[17] Alammar, J. A visual and interactive guide to the basics of neural networks. Creative Commons Attribu-

  DOI: http://dx.doi.org/10.36956/sms.v3i1.378

tions, 2018.
[18] Nizrak, A. Comparison of activation function for deep neural networks. Yildiz Technical University, Istanbul, Turkey.
[19] SOFIA. The state of world fisheries and aquaculture Food and Agriculture Organization, Rome, Italy, 2018.
[20] IFFO. Aquaculture. IFFO Marine Ingredients Organization, London, UK, 2021.
[21] Towers, L. Importance of transgenic fish to global aquaculture- a review. The Fish Site, Hatch Accelerator Holding Limited, Cork, Ireland, 2016.
[22] Muir, W.M. The threats and benefits of GM fish. EMBO Report, 2004, 5 (7), 654 - 659.
[23] Williams, D. Genetically modified salmon to hit US markets. CGTN America, Washington, DC, 2019.
[24] Tucker, J.W. Species profile: grouper aquaculture. Southern Regional Aquaculture Center (SRAC), Publication No. 721. Fort Pierce, Florida, USA, Division of Marine Science Harbor Branch Oceanographic Institution, 1999.
[25] Aerts, J. Stress in aquaculture: a rough guide. The Fish Site, Hatch Accelerator Holdings, Cork, Ireland, 2019.
[26] Fernandes, M.N., Rantin, F.T. Relationships between oxygen availability and metabolic cost of breathing in Nile tilapia (Oreochromis niloticus): aquacultural consequences. Aquaculture, 1994, 27:339-346.
[27] Moreira, P.S.A. and Volpato, G.L. Conditioning of stress in Nile tilapia. Journal of Fish Biology 2004, 64, 961-969.
[28] Jian-yu, X., Xiang-wen, M., Ying, L. et al. Behavioral response of tilapia (Oreochromis niloticus) to acute ammonia stress no0nitored by computer vision. Journal of Zhejiang University. Science, 2005, 812 - 816.
[29] Xu, J., Liu, Y., Cui, S. et al. Behavioral responses of tilapia (Oreochromis niloticus) to acute fluctuations in dissolved oxygen levels as monitored by computer vision. Aquaculture Engineering 2006, 35, 207 - 217.
[30] Barreto, R.E., Volpato, G.L., Faturi, C.B., et al. Aggressive behaviour traits predict physiological stress responses in Nile tilapia (Oreochromis niloticus). Marine and Freshwater Behavior and Physiology, 2009, 42,109-118.
[31] Barreto, R.E., Miyai, C.A., Sanches, F.H.C. et al. Blood cues induce antipredator behavior in Nile Tilapia conspecifics. PLoSOne, 2013, 8: e54642.
[32] Hassan, M., Zakariah, M.I., Wahab, W. et al. Histopathological and behavioral changes in Oreochromis sp. After exposure to different salinities. Journal of Fisheries cand Livestock Production, 2013, 1, 103. DOI: 10.4172/2332-2608.1000103.
[33] King, M. and Sardella, B. The effects of acclimation temperature, salinity, and behavior on the thermal tolerance of Mozambique tilapia (Oreochromis mossambicus). Journal of Experimental Zoology Part A Ecological and Integrative Physiology, 2017, 327(7) https://doi.org/10.1002/jez.2113.
[34] Panase, P., Saenphet, S. and Saenphet, K. Biochemical and physiological responses of Nile tilapia, Oreochromis niloticus Lin subjected to cold shock of water temperature. Aquaculture Reports, 2018, 11, 17-23.