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REVIEW ARTICLE DERLEME MAKALE

A REVIEW OF SMART FISH FARMING SYSTEMS

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Abstract:

This paper reviews smart fish farming systems that demonstrate how complex science and technology can be made easy for application in seafood production systems. In this context, the focus of this paper is on the use of artificial intelligence (AI) in fish culture. AI mimics some of the capabilities of human brain via its Artificial Neural Network (ANN) in performing certain tasks in a fish hatchery that are crucial for aquaculture systems. Water quality is of utmost importance for survival, growth and all other living activities of captive stocks of fish. The AI-based systems can be designed for controlling the main parameters of water quality such as salinity, dissolved oxygen, pH and temperature. This systems approach uses software application that runs on an application server connected to multi-parameter water quality meters such as those offered by YSI. The software captures these parameter values from YSI device and checks if they are within the optimum range. If not, then an alarm system is triggered for immediate remedial action that can be executed by personnel handling the hatchery management roles. This improves accuracy, saves cost and action time to ensure sustainability life-supporting system in the hatchery. Despite complexity in evolving this system, the application is simple enough to be operated by an organized fish farming community. Because this study introduces a rather new approach to aquaculture management, presentation of a detailed background scenario was deemed necessary to put the pertinent issues in the right perspective.

Keywords: Smart, Fish farming, Innovation, Technology, Community benefits

Introduction

A great deal of knowledge has been generated in aquaculture and this has contributed to industrialization of this sector. Industrialization is associated with introduction of technology since a large number of parameters have to be controlled in modern-day aquaculture systems. Some of these operations require sophisticated tools and specially designed facilities which have evolved through intensive research and a great deal of innovation. Advancements in technology generally have supported the modernization of aquaculture since many products of technology not developed specifically for application in farming systems have found applications in this area. Some technological inventions are tailor-made for aquaculture operations. For example, design of semi-submersible cages, automatic time-controlled feeders and water recirculating and remediation systems require specific technology applications based on sound scientific knowledge. The visible benefits from technology have provided a supporting basis for advancing the aquaculture systems to the next higher level which is the application of computer controls and artificial intelligence (AI) for a greater degree of automation, effective management and decision-making.

Researchers working with fish stocks have been using empirical statistical and mathematical models expressed in equation form for evaluating length-weight relationship, condition coefficient, food electivity index, food conversion ratio and specific growth rate among other parameters. These measurements are widely used to assess the condition of cultured fish and effect of certain factors to modulate the system to improve production efficiency. There are qualitative components that constitute biological or environmental complexities which are beyond the capabilities of statistical formulas or models to solve. In such situations, application of AI is helpful and requires developing means to automate or mimic the computational processes of the brain to exercise control on culture systems. Artificial Neural Networks (ANN) and fuzzy logic are the main fields of AI for simulating, to some extent, human intelligence in machines. Neural network models are designed to emulate the core principles of the central nervous system which includes the pathways through which the sensory nerves carry the sensation perceived by sensory receptors to the brain in the form of an electrical impulse while motor nerves carry the brain's message to effector organs where it is translated into action. ANN is a very simplified model of this sort of neural processing. It is worth emphasizing that these systems are nowhere near the complexity of human nervous system. Probably, it is no exaggeration to state that the human brain as the one of the most complex matter in the universe. The brain functions require many interconnected processing elements called as 'neurons'. Data fed at one end of the network produces output at the other end. In between these ends are layers of neurons. ANN despite being inspired by neurons in the brain, do not actually simulate neuron mechanisms. They are in much smaller number and much simpler than their biological neuronic counterparts.

ANN is designed for dealing with data and signal processing within a designed system where knowledge is embodied in the form of parameters of a dynamical system. In a hatchery system where there is fish (a biological entity) and non-biological components (water quality parameters such as temperature, pH, and dissolved oxygen, salinity) and the waste produced by fish, the analytical gadgets can quantify the chemical changes that can be channeled to a central command system (programs in a computer) which responds by sending signals (motor pathways) to regulators (for example, aerators, water flow control devices) which in turn act according to information fed into the system in the form of algorithm. As aquaculture progresses in this 21st century, ANN will be built in smart models comprising highly complex and sophisticated algorithms that require enormous amount of computer processing using specially developed software programs.

Aquaculturists realize that by controlling the environmental conditions and system inputs (for example, dissolved oxygen, salinity, feeding rate and stocking density), physiological rates of cultured species and metabolic outputs (for example, ammonia, pH and growth) can be regulated. These are exactly the kinds of practical measurements that will allow commercial aquaculture facilities to optimize their efficiency by reducing labor and utility costs, and decreasing the environmental impacts. Anticipated benefits for aquaculture process control systems are: (1) increased process efficiency, (2) reduced energy and water losses, (3) reduced labor costs, (4) reduced stress and disease, (5) improved accounting, and (6) improved understanding of the process (Phillip, 2000). A small number of AI systems available today have limited applications and these are based on a proven methodology for implementing management systems that are both intuitive as well as inferential.

The purpose of applying process control technology to aquaculture in developed countries encompasses many socio-economic factors, including variable climate, high labor costs, increased competition for water supply and land resources and a regulatory bureaucracy. These factors are pushing aquaculture industry there toward the use of intensive, recirculating, water filtration systems and off-shore pens and cages (Fridley, 1993; McCoy, 1993; Lee, 1995; Hayden, 1997; Helsley, 1997).

High efficiency, automated control systems should: (1) simultaneously reduce the need for high quality make-up water and the volume of pollutant-laden effluent for land-based recirculation systems, and (2) reduce labor costs for on-site supervision and normal feed wastage associated with off-shore aquaculture (Lee, 1995).

Use of computer monitoring and automation in aquaculture is a new development. The applications are visible in algae and food production (Lee, 1993), feed management (Hoy, 1985), filtration systems (Whitson *et al*., 1993; Lee *et al*., 1995; Turk *et al*., 1997; Lee *et al*., 2000), vision systems (Whitsell and Lee, 1994; Whitsell *et al*., 1997), environmental monitoring and control (Hansen, 1987; Ebeling, 1991, 1993; Munasinghe *et al*., 1993; Rusch and Malone, 1993) and integrated systems management (Lee, 1991; Lee *et al*., 1995, Lee *et al*., 2000 and Turk *et al*., 1997). A good example of AI based system in aquaculture is that of aquaculture solar thermal water heating system control. The system consists of solar collector unit to supply hot water during the day hours, biogas heater as auxiliary unit during the night and cloudy days, storage tank to keep water temperature at high degree and thermostatic valve to control hot water flow rate to the pond. The principle of operation of this system can be explained through the three layers of an AI based aquaculture system (Figure 1). The input layer requires input of data such as air temperature, pond temperature and error, the hidden layer performs various logical calculations from the input provided by the input layer and the output layer provides water supply based on the time of the day and weather.

This movement toward intensification and automation parallels the development of other forms of agriculture which share many characteristics with intensive aquaculture systems, and all these are commodity markets.

Some computer programs can even mimic the actions of acknowledged process experts (Bechtold, 1993, 1994). They require defined rules (‘if’ and ‘then’ statements) or graphical knowledge (flow charts or logic trees) to be formulated by process experts. This necessitates the rather tedious task of recording a process expert knowledge into the form of rules and then validating the expert system against the expert decisions. Often, experienced process experts find this process antagonistic, especially when they contradict the outcomes of their earlier rules. The process requires a patient expert and an even more patient computer programmer to refine or change the rules. The most significant consequence of a knowledge-based expert system is that it provides a process expert the ability to quickly distribute intelligence throughout the aquaculture industry.

AI contributes to decision-support systems with a focus on interactive problem-solving and experiential learning in knowledge-based systems. Utilizing knowledge that captures the semantics and pragmatics of the real-world problem-solving settings will certainly help in the growth of aquaculture industry with reduced risks and more profit without cost inflation.

An AI tool called as ‘Expert System’ (ES) is being used in some aquaculture industries motivated towards technology-intensive culture. It is a kind of computer program which can help in finding solution to some aquaculture problems by simulating the experts. ES stores a vast knowledge and experience of experts and practitioners in a certain domain and assists the farmers in applying the right method to solve their problems related to captive stocks. This goes beyond the generic thinking to specific knowledge application in a systems approach.

Jiang *et al*. (2012) stressed the importance of case-based reasoning (CBR) to capture, store and reuse knowledge as a core component of a decision-support. CBR is a reasoning method that solves a new problem by examining how a similar problem was solved before. This method comprises a problem statement, a solution and an outcome, and has four steps:

1. Retrieve- a new problem described as a query case.
2. Reuse –taking up this case and either reusing it directly or adapting it to a solution that fits the query case.
3. Revise –taking the solution for evaluation, generally by applying it and getting it examined by a domain expert, and
4. Retain –learning it from the revised problem-solving experience by updating it to a case base.

AI tools provide a basis for decision-support, with a focus on interactive problem-solving and experiential learning in a knowledge-based system, utilizing knowledge that captures the semantics and pragmatics of real-world problem-solving setting with application in aquaculture.

Why AI in modern aquaculture?

a) Before KM tools and collaborative workspaces were available, people had to access centrally managed and controlled databases. New knowledge creation and knowledge sharing were based on the productivity of a few people in a central team which, by comparison, was a slow process. The AI systems can be designed in a way that stakeholders can participate in new knowledge creation from their experiences in a meaningful way and blend it with knowledge generated by scientific trials, and the whole process becomes faster and easier than before. This also obviates the need for centrally controlled databases. AI systems are adaptable based on information that might emerge as a result of experiments conducted using new approaches under changing conditions.

b) Knowledge bases enable people in a research institute or industry to create, collaborate, develop, and access new knowledge, more often as participants, to rapidly generate feedback and even create and edit new knowledge, where appropriate.

c) Knowledge bases give a full context to a knowledge topic by structuring 'what, why, who, where, when, how' sort of queries.

d) It is good that some of the knowledge bases like wikis do not require involvement of the IT department, although their support should be acknowledged. This means that knowledge bases can be created rapidly by the users themselves which will be very helpful in the aquaculture sector, as most of the stakeholders might not be tech savvy and thus they can also make use of KM tools to contribute to the knowledge base and retrieve vital information using these tools.

Application of AI based software in water quality management system

Water quality management in aquaculture: Water quality is a critical factor when culturing any aquatic organism. Optimal water quality varies by species and must be monitored to ensure growth and survival. The quality of the water in the production systems can significantly affect the organism's health and the costs associated with getting a product to the market. Water quality parameters that are commonly monitored in the aquaculture industry include temperature, dissolved oxygen, pH, alkalinity, hardness, ammonia, and nitrites. Water quality directly affects the growth of aquaculture stocks, leading to a decline in production and economic benefits. Some of the most important parameters to consider while monitoring the water quality are pH, dissolved oxygen, salinity and water temperature.

Need for automation in water quality management: Water quality management is an essential part of aquaculture, and generally requires human intervention whenever there is a change in any one of the parameters that results in deterioration of quality of the rearing medium. In order to minimize human intervention which would result in cost saving and timely solution of the problem the automation via development of an AI system would enable such type of an operation.

The user interface consists of four input boxes which will capture the values for salinity level, pH level, dissolved oxygen and temperature of the water of the fish tank. The logic is programmed in the four buttons for checking the optimum levels of the four parameters. This acts as the 'brain' of the software program which does the logical calculations and determines if the levels are within the optimum range or out of it.

Artificial neural networks in water quality management system

We know that artificial neutral networks to some extent replicate the functions of the brain, thus the water quality management system can also use the same principles in determining the range for the four parameters of the water that are captured through the input layer via the YSI device. The software code captures the values via a hardware interface, and after the values have been captured the hidden (or logical) layer then performs the logical calculations using various “if” “else” conditions to check whether the values are within the optimum range or not. If the values are out of the range, then the application displays remedial solutions and also at the same time triggers an action via an AI based device which performs the actual remedial solutions. As an example, a software prototype developed for Asian sea bass in our hatchery stores the range of critical water quality parameters: salinity (10 – 30 ppt), dissolved oxygen (4-9 ppm), pH (7.5-8.5) and temperature (26-32°C). The so-called brain of the system stores codes for the four parameters that can check if the captured values are within or outside the range. The program can be connected to an alarm system to notify the hatchery staff if the values are outside the range. Also, color coding can also be selected for each parameter and also for values which are above or below the critical range to inform the hatchery personnel the exact nature of the problem involving the water quality parameters.

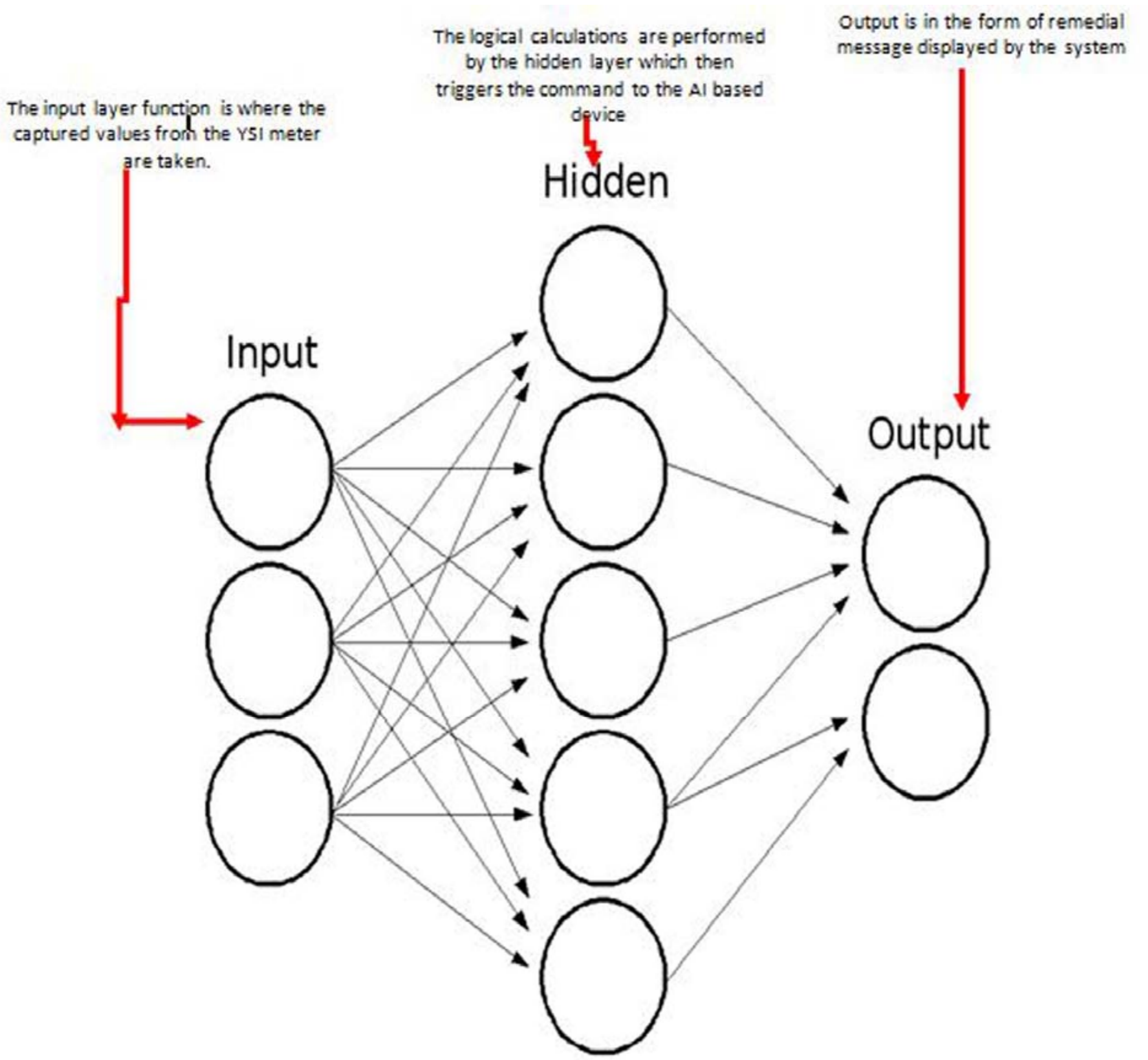

Figure 1. Artificial neural network (https://en.wikipedia.org/wiki/Artificial_neural_network)

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Conclusion

Smart aquaculture system described in this paper makes best use of available knowledge, resources and technology to increase production efficiency of aquaculture systems with reduced inputs and costs. Aquaculture industry can benefit by leveraging the broadband and digital technology in which many countries, including Malaysia, have made significant progress. It serves as a showcase of applying innovative approaches to increasingly important seafood production systems by way of aquaculture. The instrumentation technology has advanced in recent decades and sophisticated gadgets such as those offered by YSI can continuously monitor water quality with a payload of multiple sensors. It is practically feasible to align the sensors to wireless communication system to build an integrated sensor-network-wireless platform which can provide an accurate digital and real-time monitoring of aquaculture water quality (temperature, salinity, pH, dissolved oxygen, in a local or remote way through hand phone. The remedial action which is handled by a neural arc connected to robotic facility requires separate hardware design and operating program. Besides monitoring and control of water quality, this sensor-digital combination will also help share information among farms by way of common devices and apps, increase the ability to analyze diverse information from more sources using cloud computing.

The anticipated next step is aligning the AI with robotics. AI is the most important and exciting area in robotics. AI system installed in a computer gathers data and facts through sensors or human input. Based on the program developed, the computer runs through the various actions and predicts which action will be most appropriate based on the collected information. Obviously, the computer will solve the problems it is programmed to solve. On its own, a computer does not have the analytical ability. The robot software is in the form of commands that tell a mechanical device (robot) what functions to perform and control its action. In a robot which can be used for aquaculture operations, the information flow programming is based on the concept that when the value of a variable (for example, dissolved oxygen) changes, the value of other variables (for example, dissolved gases in water, fish survival) should also change, and the robot through ANN should respond by mechanical control for finding solution to the problem. The system can be operated using mobile phones operating on android operating system, tablet computers or personal computers. With penetration of mobile phones to all sections of the society even in interior areas, this will be a convenient tool to manage aquatic farming as the main or supplementary food producing system.

Robot's domain or its capabilities are limited for specific applications. Aquaculture is a complex process where there are many variables, for examples, dissolved gases, pH, stocking density and food consumption among others. Certainly, software programs will be complicated and so will be the roles of a robot. There will be certain roles that despite the information it receives, the robot might not be able to solve the problem except to alert the hatchery operators to take the action. Take the case of fish stocking density in a hatchery tank. A single sensor in the form of a webcam can be connected to image detector in a computer that processes the image based on shape, color, and uses AI to inform which species and how many of them have survived a treatment. At this stage of knowledge, removal of dead fish specimens and addition of new specimens can be handled by human beings working in the hatchery.

AI and robotics will increasingly find application in aquaculture in the current century as we go away from the coastal aquaculture to the deep sea where sea conditions are rough and extended human presence is neither economical nor practical for operations such as feeding the fish or regular daily monitoring.

Controlling the problem of biofouling is yet another important operation well suited for fish farming. It is quite well known that biofouling reduces water exchange in a sea cage, leading to shortage of oxygen-rich water entering the facility. This reduces fish growth, increases incidence of diseases and causes mortality. The cage also becomes heavier and its lifespan reduces. It requires a great deal of human labor to keep the cage free from biofouling. The net cleaning operations can be performed by robots.

References

Bechtold, W.R. (1993). A practical guide to expert systems: Part A. *Instrumentation and Control Systems,* 66, 41-43.

Bechtold, W.R. (1994). A practical guide to expert systems: Part B. *Instrumentation and Control Systems,* 67, 75-78.

https://en.wikipedia.org/wiki/Artificial_neural_network

Fridley, R.B. (1993). Constraints to marine aquaculture: what role can engineering and technology play? In: J.K. Wang (ed.), *Techniques for Modern Aquaculture* (pp. 1-7). American Society of Agricultural Engineers, St. Joseph, MI.

Hansen, E. (1987). Computer-aided control and monitoring of aquaculture plants. In: L.G. Balchen (ed.), *Automation and Data Processing in Aquaculture (pp. 187-192).* Pergamon Press, Oxford.

Hayden, A. (1997). Current and potential regulation of open ocean aquaculture. In: C.E. Helsley (ed., *Open Ocean Aquaculture 1997: Chartering the Future of Ocean Farming (pp. 3-14), Proceedings of the International Conference University of Hawaii Sea Grant College Program*, Honolulu, HI.

Helsley, C. (1997). Open ocean aquaculture conference summary, commentary and thoughts for the future. In: Helsley, C.E. (ed.), *Open Ocean Aquaculture 1997, Chartering the Future of Ocean Farming,* Proceedings of the International Conference (University of Hawaii Sea Grant College Program, Honolulu, HI.

Hoy, L.B. (1985). A microcomputer-based system for feed control, temperature control and temperature recording in an experimental fish hatchery. *Computers and Electronics in Agriculture* 1, 105-110.

Jiang, H., Ding, W., Ali, M. & Wu, X. (2012). IEA/AEE, pages 104-113. Springer-Verlag, Berlin.

Lee, P.G. (1995). A review of automated control systems for aquaculture and design criteria for their implementation. *Aquaculture Engineering* 14, 205-227.

Lee, P.G. (2000). Process control and artificial intelligence software for aquaculture. *Aquacultural Engineering* 23, 13-36.

McCoy, H.D. (1993). Open ocean fish farming. *Aquaculture Management* 19, 66-74.

Munasinghe, L., Gempesaw, C.M., Bacon, J.R., Lussier, W.W. & Konwar, L. (1993). AMACS: a user-unfriendly windows-based aquaculture monitoring and controlling software. In: Wang, L.K. (ed.), Techniques for Modern Aquaculture, (pp. 71-80), American Society of Agricultural Engineers, St. Joseph, MI.

Phillip, G.L. (2000). Process control and artificial intelligence software for aquqaculture. *Aquacultural Engineering* 23, 13-36.

Rusch, K.A. & Malone, R.F. (1993). A microcomputer control and monitoring strategy applied to aquaculture. In: L.K. Wang, L.K. (ed.). Techniques for Modern Aquaculture (pp. 53 – 60), (American Society of Agricultural Engineers, St. Joseph, MI.

Turk, P.E., Lawrence, A.L. & Lee, P.G. (1997). Design and operation of an environmentally isolated marine shrimp broodstock culture system using closed, recirculating water filtration. In: *Advances in Aquacultural Engineering* (pp. 209-218), Northeast Regional Engineering Service, Cornell, NY.

Whitsell, A., Whitson, L.L. & Lee, P.G. (1997). A machine vision system for aquaculture: real-time identification of individual animals and estimation of animal activity. In: Advances in Aquacultural Engineering (pp. 112-128), Northeast Regional Agricultural Engineering Service, Cornell, NY.

Whitson, L., Turk, P. & Lee, P.G. (1993). Biological denitrification in closed recirculating marine culture system. In: *Techniques for Modern Aquaculture* (Wang, J.K., ed.), (pp. 458-466), American Society of Agricultural Engineers, St. Joseph, MI.

Whitson, L., Turk, P. & Lee, P.G. (1993). Biological denitrification in closed recirculating marine culture system. In: Wang, J.K. (ed.), Techniques for Modern Aquaculture American Society of Agricultural Engineers, St. Joseph, MI.