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Potential Applications of Data Mining in Aquaculture

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***Abstract* - Over 70% of the earth's surface is covered by oceans and inland water bodies, and they serve as an enormous source of valuable natural resources, livelihood and food security. Globally, as the demand for high quality nutrient rich seafood is increasing, the contribution of aquaculture has increased manifold and it is presently considered as one of the fastest growing food production sectors which is economically feasible for farmers and entrepreneurs. The progressive adoption of innovative sensor (optical, acoustic and biological) networks and technologies that are capable of analysing and revealing useful information from the existing aquaculture data has enabled the development of intelligent decision support systems based on data mining and artificial intelligence. The techniques and algorithms of data mining provides deeper insights on aquaculture and fisheries operations and realities by analysing the huge volume of scientific data and information that are available. Considering the research and developments in recent years and growing interest of aquaculturists on data science, in this review, we have consolidated and updated information on the possible applications of data mining, artificial intelligence and machine learning in different domains of aquaculture, from various scientific publications. This includes 1) an overview of data mining and machine intelligence in aquaculture; applications in 2) environment analysis; 3) feed management; 4) disease management; and 5) fish stock assessment. Along with these broad spectrum of aquaculture applications, we indicate the potential areas for further research and also the challenges in the adoption of data mining tools.**

Keywords—Aquaculture, Data mining, Decision support system, Fisheries, Machine Intelligence

I. INTRODUCTION

Similar to agriculture and animal husbandry, aquaculture is the farming of economically valuable aquatic organisms under controlled production conditions. According to FAO statistics, in 2018, the annual global aquaculture production was 114.5 million metric tonnes, which included 82.1 million metric tonnes of aquatic animals and 32.4 million metric tonnes of aquatic plants [33]. As we move towards precision or smart aquaculture, real-time monitoring of the production system and the behaviour and features of the cultured aquatic species is becoming very useful to predict, warn and control risks associated with the physical, chemical and biological properties of the aquaculture production environment [34]. The massive volume of complex data and information that are collected in commercial aquaculture farms using advanced sensor systems are increasingly integrated with computer database, networks and programmes for the extraction of potentially useful information that can support aquaculture managers and stakeholders in decision making. The use of computers in aquaculture farms has greatly enhanced the data collection, storage, retrieval, processing, analysis and reporting capabilities, as well as the speed and accuracy of the data management process. In the early stages of adoption, computer programs such as AQUASIM PC, desk1-2-3 and FISHY 2.0 were used in aquaculture operations. AQUASIM PC is a microcomputer-based modelling application for farm level business decisions based on market information and it was able to predict uncertainties in production and financial performance. In Desk1-2-3, farm data was recorded directly in a pocket computer, remotely downloaded to a desktop computer using a modem and centrally stored and analysed in a Lotus worksheet. FISHY 2.0 allowed fish farmers to collect, store and analyse data related to various aquaculture operations such as fish stock monitoring, feed management and harvesting, using a microcomputer program designed to be operated in a pond based and menu guided fashion [5]. Intelligent computation systems are increasingly being used in different operational scales, from simple mobile phones to complex supercomputers, for performing diverse tasks across various fields of application, that includes precision agriculture, animal husbandry and aquaculture. The recent developments in intensive aquaculture operations based on data mining and machine learning techniques highlights the enormous opportunities as well as the hard challenges that influences the adoption of these technologies in aquaculture production systems. With increasing use of computer vision systems and remote sensor networks, the field of marine sciences and aquaculture is employing advanced data processing pipelines and machine learning methods such as classification algorithms, support vector machines and artificial neural networks [18]. For instance, AquaSmart Horizon 2020 is a project that covers the technological advancement in data mining in aquaculture by converting data to actionable knowledge that is focused on evaluation and management of problems in aquaculture [25]. Considering the potential scope of data mining and machine intelligence in aquaculture, we have reviewed and consolidated the available scientific information about the utilization of data mining in aquaculture.

II. An Overview of Data Mining and Machine Intelligence Tools for Aquaculture

Data mining is the extraction or mining of useful knowledge from a data set or database, through a complex process that require multiple steps of iterations. Data mining methods are used to explore and analyse large volumes of unstructured data to discover hidden knowledge and useful information / patterns. Data mining is also known for its cross-disciplinary utility to extract knowledge and information from different life science databases [30], [22]. Particularly, computer data technologies such as data mining, machine intelligence and block chain could analyse large volumes of heterogenous data by collecting, organizing, storing and processing information to assist the decision making of commercial aquaculture stakeholders like producers, policy makers, researchers, wholesalers, retailers and consumers [17], [15]. The process of data mining includes the methodology to decode patterns within a complex data set and predict or forecast variations and risks from the available data. Data mining is particularly useful for outlier identification, clustering-classification of large heterogenous data, regression analysis and consolidation of data in the form of summaries and overviews. Data can be broadly categorized based on variety, volume and velocity. Variety usually refers to the type of available data such as unstructured, semi-structured and structured formats. The amount of data generated through online or offline modes in kilobytes or terabytes and stored in various databases are referred as volume. The frequency of data streaming from the source, i.e., whether the data are added or updated in batches, near real time and real time are referred to as velocity [26]. Machine learning algorithms acquires information from its training data set and provides data flow to the database by the enhanced data patterns received from the learning process. Machine learning and data mining algorithms are generally categorized into unsupervised and supervised algorithms [10]. Supervised learning maps data into input and output pairs that are namely predictor and response variables [14]. Examples of supervised machine learning and data mining algorithms are decision trees, boosted regression trees, Bayesian networks, random forests, support vector machines and artificial neural networks. Unsupervised learning infers the patterns within the data structure of the input data set without knowing its corresponding output variables. Examples of unsupervised algorithms are anomaly detection, hierarchical clustering, *k*-means clustering, *k*-nearest neighbours, neural network, independent or principal component analysis and apriori algorithm [10]. While data mining is essential for artificial intelligence applications that deals with the ability of machines to perform various tasks through previous learning experience. Artificial intelligence in itself is a more generic model of machine learning, with an ultimate goal to automate decisions in unknown situations by resembling cognitive skills of human intelligence namely computer vision, language processing, speech recognition and robotics [3], [6]. Artificial intelligence is a versatile field with developmental tools and knowledge representational techniques such as production rules, predicate logic, semantic nets and frames for problem solving associated with human intelligence. Reasoning in artificial intelligence derives logical conclusion and makes prediction from existing knowledge and information. There are different types of reasoning in artificial intelligence such as default reasoning, abstraction and generalization, analogy-based reasoning, procedural reasoning and formal reasoning [27], [5], [3]. Artificial intelligence also classifies search techniques into informed and uninformed search. Informed search includes heuristic search, A* search, greedy search and best first search. Whereas, uninformed search includes bidirectional search, depth first search, breadth first search, uniform cost search and depth limited search. LISP and PROLOG were the main programming languages used at the beginning and are still used along with Python, R and others [28]. On the application side, decision support system is an interactive computerized information system that facilitates decision-making by utilising data items and models to solve managerial related problems. There are three main components in a decision support system namely dialog, database and modelling components, with an integrated set of tools such as graphical user interface, logical algorithms, mathematical programs, simulation models and expert systems that can integrate and apply expertise in fish biology, water chemistry, production practices and culture system engineering [5]. Expert system can be referred as knowledge-based system, which when coupled with geographical information system and decision support system aids the decision-making ability of experts to solve complex problems in aquaculture and they are also used in diagnostic and therapeutic procedures in aquaculture [5]. Natural language processing tools perform discourse integration, parsing and linguistic, pragmatic and semantic analysis for generating and understanding the text associated in intelligent computer aided aquaculture [2], [27]. Computer vision is used for aquatic species monitoring, environment monitoring and ecosystem monitoring using visual data that can be processed by pattern recognition, deep learning models and image processing algorithms that are used from hatchery to harvest [35]. Machine vision systems also studies aquatic species in electro-magnetic spectrum regions and electrically perceives and understands an image and provides pixel level image information. For the process of image acquisition, lighting system, frame grabber, image acquisition board and the quality of optical sensor are important. After image acquisition, image processing has three phases such as pre-processing that removes noises and improves image quality; segmentation and feature extraction; and classification that identifies objects of different clusters [29], [23]. Deep learning algorithms that are often used with computer vision systems are highly accurate and stable, and has the capacity to be trained, learn and automatically extract essential features from nonlinear and complex dataset through multilayer process. Deep learning algorithms and analytical tools can be used to reveal, quantify and understand hidden information from enormous data for precision aquaculture practices such as identification of live fish, size classification, biomass estimation, behavioural analysis, feeding related decisions and prediction of water quality changes [16], [7], [31]. Robotics could automate aquaculture in the near-future by providing mobile robots for feed transportation and supply, fish feeding systems with an autodemand component and visual-trajectory controlled underwater robot for autonomous pond cleaning [19]. For instance, automated robotic aquaculture control systems may have a feeder, stationary or mobile aerator and other digital equipment for monitoring water quality and environment variables, deoxidize water basin and frighten fish-eating birds [8]. At present, several commercial data mining and machine intelligence solutions are available for aquaculture applications. For example, Umitron, eFishery and Observe Technologies for monitoring and control of feeding; LiquidAi, Osmobot and AquaManager for monitoring and control of water quality in aquaculture production systems; XpertSea, InnovaSea and CageEye for growth, biomass and behaviour monitoring; and AquaCloud and Aquaconnect for monitoring-forecasting disease outbreaks. The data mining and machine intelligence tools shown below drives these practical solutions that are used to enhance aquaculture production through technological advancements [Fig. 1].

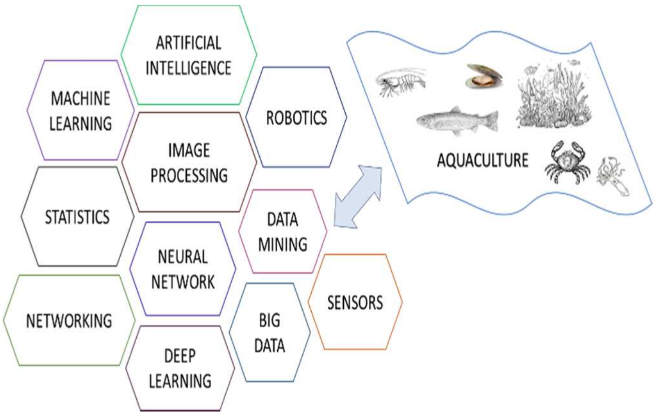

Fig. 1. Technologies utilized in Aquaculture

III. Data Mining Applications for Environment Analysis in Aquaculture

The enormous biological diversity, integrity and socio-economic significance of marine and freshwater ecosystems are threatened by deteriorating environmental conditions due to anthropogenic activities, pollution, habitat degradation, and global climatic change [11]. As in environmental impact assessment studies, the monitoring and control of the production environment in aquaculture systems includes the process of measuring physico-chemical properties of the rearing water, predicting adverse changes and mitigating associated production-economic risks by supporting decision-making in aquaculture context [12]. Data mining and machine intelligence tools assists this process by extracting knowledge from hidden patterns and complex associations in data obtained from aquaculture environment and ecosystem. Data science that exhibits machine learning and data mining algorithms and techniques; coupled with statistical methods; data visualization tools, expert systems and other computing resources are helpful in the knowledge discovery from available aquaculture environment data sources. The aquatic rearing environment data such as water temperature and oxygen level are essential for aqua farming, likewise data about strong temperature fluctuations that crucially affects the growth of marine organisms must also be analysed for effective production. In aquaculture data mining, input and output variables of its dataset are classified namely numerical and categorical; the synthetic and semantic data cleaning is done to generate meta data for optimizing and boosting production in aquaculture [4]. In Brazilian coastal zone an intelligent system is operated to integrate decision support system on the basis of ecosystem patterns and biological integrity by data mining and genetic algorithms, machine learning expert system, statistical methods, grid computing and data visualization. Principal Component Analysis is done to access data structure, and clustering of variables is done by ward method using spearman coefficient and then *k*-means clustering is done using euclidean distance and Apriori algorithm is used to relate environmental and biological interval of existing data by mining association rules. Artificial Neural Network maps and simulates the interconnected processing elements by neurons, state, strength and membranes that is processed into initial part as input layer, then the multiples of hidden layers and finally output layer. Methods such as error back propagation are used for training the network to generate neural network structure for analysing environmental conditions [24]. Principal component analysis and spatial analysis are potential tools to derive the factors responsible for water pollution and water quality in pond and cage culture of marine aquaculture by its physicochemical parameters and quality indicators of waters such as temperature, salinity, dissolved oxygen, pH, chemical oxygen demand, chlorophyll a, dissolved and suspended solids, phosphorus and inorganic nitrogen [32].

IV. Data Mining Applications in Feed Management in Aquaculture

Feeding is one of the most important activity for intensification of aquaculture farming process. Since huge wastage of feed leads to water toxicity, an automated feeding system are used that enables efficient aquaculture farms that ensure healthy growth of fish and reduced operational cost. In precision or intelligent feeding systems, the hardware component consists of a camera or acoustic sensors and feeder; and the software component consists of processing elements such as user interface that studies the pattern of tank and a communication interface that relays information electronically to the system. These hardware and software parts are interlinked together to identify fish species, gender, and count, which in turn develops suitable feeding program for the aqua farmers [1]. In aquaculture, fish feeding behaviour are classified as direct method that obtains data from the parameters such as shape, texture, dispersion, area, and swimming activity of fishes that is measured from its image and indirect method assesses the fish appetite, by analysing and measuring the excess feed present in the water. The adaptive Otsu algorithm efficiently segments and counts the fish feed pellets from the images with less than 8% error [9]. The high-pressure feed delivery systems along with computerized feeding systems are used to feed the fishes over a large area without the breaking up food pellets and can adjust quantity of feed given to the fishes depending on time of the day, water temperature, climatic condition [21]. An effective aqua farming can be done by considering data of feed distribution and delivery speed, data of nutrition and physical quality of feed, data of re-sampling and recounting of fish, health check-up data of fish and predator data that can stop the fish from consuming its feeds [9]. Fish feed is the major input in aquaculture that needs an efficient refinement and planning between feed manufacturers, farmers and fish producers for quality production of aquatic food products.

V. Data Mining Applications Of Disease Monitoring in Aquaculture

Fish disease can be classified as bacterial disease, fungal disease, parasitic disease, protozoan disease, and physical ailments and wounds. Fish disease spreads at high speed that creates difficulty in identification of the disease. In earlier period fish disease where identified manually that leads to delay in accurate diagnosis and treatment. Using image processing, machine learning and data mining techniques the fish health management can be timely monitored to have hygienic environment and regular vaccination. Anomaly detection, prediction, pattern recognition, decision support system and intelligent algorithms are some data mining methods that process physiological data along with sensors to measure the vital health parameters such as blood glucose, respiratory rate, heart rate and oxygen saturation in smart healthcare monitoring system. Data mining techniques such as data pre-processing is used to filter raw data to remove artefacts and high frequency noise; feature extraction discovers the main characteristics of data and provides knowledge for decision making and selection uses analysis of variance, threshold-based rules and Fourier transforms to provide high dimensional discriminative data; and modelling and learning methods provides expert knowledge and metadata using Neural Networks, Support Vector Machine, decision trees, Hidden Markov model, Rule-based reasoning, statistical tools, Frequency Domain/Wavelet Analysis, Bayesian network, Fuzzy state machine and Gaussian Mixture Models. For instance, a real-time automated fish disease diagnosis system diagnoses Epizootic Ulcerative syndrome in fishes that is caused by a fungal pathogen *Aphanomyces invadans*, using data mining and machine learning techniques namely features from accelerated segment test, principle component analysis, *k*-means clustering segmentation, histogram of oriented gradient features, feature detecting probabilistic neural network classifier and support vector machine classifier for extracting patterns from the input images and videos. Another novel fish disease identification approach uses the Unscented Kalman Filter with various covariance that classifies Non-EUS and EUS affected fish accurately by artificial intelligence and image texture analysis algorithms of Gray level Co-occurrence Matrix, Elman Neural Network and Back Propagation Algorithm. The testing in experiment and research is done using MATLAB simulation software with the images of EUS affected fish from real time database [13]. Data mining and machine intelligence algorithms along with sensors can thus be efficiently used to diagnose and medicate various fish diseases and enhances health management in aquaculture.

VI. Data Mining Applications for Fisheries Stock Assessment and Biomass Monitoring

In natural conditions, a biological fish stock is a shoal of fish that live in the same geographic area and breeds with each other when matured. Scientific assessment of fish populations is key to fisheries resource management by examining and considering fishing effects and other related factors. Stock assessment indicates the past and present status of a fish stock, the abundance-distribution of a fish stock and can also support predictions about future stock size and suggest measures to sustainably manage the fish stock. Stock assessments also provides vital scientific information which is necessary for the management and conservation of vulnerable fish populations. Presently available database related to fisheries and aquaculture production in India are namely FAO fish production data, ICAR fish production data, INCOIS environment data, farm data, and fish trade data from MPEDA FishExchange. Data mining provides intelligent search for knowledge discovery from the information stored in the databases and computer vision provides image segmentation for image analysing and clustering of segments based on image received through satellites and data are analysed based on various salinity levels in which different kinds of fish exist and water temperature and chlorophyll data are also analysed for identifying the fish stock, so that fishing can be done with ease [20]. On the other hand, just like precision livestock farming that uses modern sensor technology to monitor livestock and computational models to integrate different types of data, precision fish farming involves continuous monitoring of the aquatic animal biomass and supports predictive risk avoidance and farm decision-making. The use of emerging data mining and machine intelligence tools in aquaculture improves the efficiency of farming operations, the level of autonomy in production and improves the farmer's ability to control biological processes in fish farms. In the precision aquaculture framework, the operational, biological and environmental conditions at the cage, farm, bay, and ocean scales are continuously monitored; and this data is integrated with other available data sources and analysed to generate insight to stakeholders [63]. Geographical information systems integrated with software and hardware used for geographical data inputs, manipulation, storage, and presentation of geographical data are being utilized efficiently for aquaculture development [11]. The generation of enormous volumes of complex data from commercial aquaculture farms and data processing algorithms has already begun to have great impact on the seafood supply chain that includes producers, consumers, processors, wholesalers, retailers, management specialists and scientist [26].

Conclusion

The rapid development of technologies has bulked up aquaculture with large volume of data and there is big challenge in analysing hidden patterns and extracting expert knowledge. This role is easily and effectively performed by data mining and machine intelligence algorithms. Data are mainly collected from marine and inland aquaculture systems; and compilation, analysis and data interpretation are performed by complex algorithms. Challenges related to standardized data collection, defined data security and sharing protocols; timely upgraded processing speed; and user friendly and cost-effective data processing needs to be addressed. The application of data mining and machine learning tools in environment analysis, feed management, disease monitoring and fish stock assessment in aquaculture will be progressive. Further research should focus on improving the reliability and accuracy of these advanced tools and its integration in aquaculture decision support systems.

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