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A review on image processing for fish disease detection

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Abstract. Fish disease is considered the main cause for production and economic losses by fish farmers. Fish disease detection and health monitoring is a demanding task by manual method of human visualization. Therefore, any potential approach that is fast, reliable and possesses high automation supports an interest in this issue. Nowadays, with the current emergence in the technology revolution, image processing has been extensively used in disease detection field, especially in human and plant, aiding the human experts in providing the right treatment. Image processing technique offers opportunities to improve the traditional approach in achieving accurate results. Besides, several steps in image processing are adopted including image acquisition, image pre-processing, image segmentation, object detection, feature extraction and classification. The objective of this paper is to briefly review the work established in the fish disease detection field with the use of numerous classification techniques of image processing, including rule-based expert system, machine learning, deep learning, statistical method and hybrid method. The present review recognizes the need for improvement in these image processing approaches that would be valuable for further advancement in terms of performance.

1. Introduction

The fishery sector plays an important role in providing the world population with major protein supply and as a major contributor to the global food security. Fish demand continues to rise as the world's population increases and the benefits of fish as a source of animal protein are recognized. In 2018, world fish production reached 179 million tons [1]. Approximately 156 million tons out of the global total cover the human consumption which proportionate significantly to an average of 20.5 kilos per head. Furthermore, 52% of the total number of fishes consumed by human which is equal to 81.3 million tons that represented the aquaculture, while the rest accounted for the capture fisheries sector. In both developed and developing countries, the consumption of fish has shown a clear trend of fish demand for the past years [1]. In response to the global demand, there is a growing interest in aquaculture sector since it is a more sustainable way to provide continuous fish supply. Thus, it is crucial to ensure that the aquaculture sector remains sustainable in terms of economy and ecology.



Several issues emerge from existing practices as the aquaculture fish industry grows, including the regular incidence of infectious diseases in the farms or hatcheries, and the environmental problems that create a constraint to the production of fish [2]. Fish disease is one of the most prominent threats faced by many fish farms, therefore requires rapid tools for reliable detection apart from experiences and fish health expertise. Parasitic, viral, bacterial, and fungal infections are the most common sources of infection [3]. Additionally, combination of stressful environments in farms induced by high stocking rate and deteriorating environmental factors worsened the frequency and severity of diseases [4].

In majority of the cases, fish disease is identified by fish owner or fish health expert on the site [5], based on their knowledge and expertise in diagnosing and treating the fish [6]. An outbreak due to infectious diseases and associated with mortality often overwhelm the aquaculture system, limiting the capacity to deal with routine fish health issues and compounding the problem. Nonetheless, traditional way of human visualization leads to substantial gaps due to lack of accuracy, time-consuming and prone to various illusions [7], [8]. Besides, diseases may spread to large areas; thus, monitoring process is considered a challenging task. Therefore, these problems demand solutions that can provide a reliable and timely detection of diseases.

Revolution in computer science offers possibilities and opportunities to develop new method that can solve or reduce problems in the existing method. Over the past 20 years, researchers have explored on the development of image processing in the field of fish disease detection. A number of literature reported various types of classification technique including statistical methods, rule-based expert system, machine learning, deep learning and hybrid method [3], [6]–[7], [9]–[19]. Subsequently, these advance techniques that were proposed in aquaculture focused on providing early and accurate detection of the diseases. Machine Learning, for example, has shown promising success in other fields such as the ImageNet [20] where accuracies exceed human level perception. In consideration of that, attainment of such performance in disease detection is the primary objective of ongoing research efforts.

The goal of this paper is to review previous studies based on image processing in fish disease detection, particularly on classification procedure of the relevant symptoms and input analysis that would influence the performance. Therefore, this review looks into the performance of the method proposed based on the result achieved under certain conditions. Furthermore, this paper aims to assist the readers in providing an overview of the methods suitable for other domain applications which indirectly supports its applicability in different cases.

The organization of this review is divided into four main sections. This section explains the purpose of conducting a review. Then the second section synthesizes the scientific literature on image processing techniques developed in the field of fish disease detection. The third section discusses the trends and challenges in this field in order to identify future research priorities for development. The last section concludes the image processing application.

2. Fish Disease Detection

Infected fishes usually can be examined according to visible marks including lesions, erosion, cuts, redness, swellings, and lumps on either skin, gills, eyes or scales [2] of the fish. Some of the disease presents a complex visible pattern which cannot detect anomaly. Thus, it is important to grasp the domain of the issue by having a detailed analysis before developing any model for fish disease detection. For this matter, problems that arise in disease detection must first be recognized before potential strategies for dealing with them in a computer-based framework can be investigated further [21]. As a consequence, various models have employed different parameters to detect fish diseases, such as description input of visible external signs and symptoms, behaviour signs, water conditions, captured image of the infected fish, microscopic images and others [5]. Meanwhile, image-based monitoring and analysis is considered extremely valuable for early detection and addressing complex pattern identification duties in decision-making of fish disease detection. There are several image processing techniques that have been proposed in the field of fish disease based on statistical methods, Artificial Intelligence (AI) and hybrid methods. However, studies related to image processing techniques in current practice are still limited. Therefore, this study discusses the current state of art in the field of image processing for detection of fish disease based on previous studies.

2.1. Workflow of Image Processing

Image processing is among the most promising technologies for enhancing raw images gathered from external sources such as cameras, satellite sensors, space probes, aircraft, and others [22]. Image processing techniques could greatly improve the quality of the original image and prepare for machine interpretation. The hand-crafted image processing in fish disease detection involves a fundamental procedure to extract and classify features from infected fish that is commonly implemented in several steps. Ammar and Neama [7]; and Hu et al. [14] summarized their work into four steps, which are image acquisition, image pre-processing, feature extraction and classification. Park et al. [9] added another step of object detection before feature extraction process in order to confirm the presence of the interested object which was pathogen. On the other hand, Jovanovic et al. [15], Shaveta et al. [16], Waleed et al. [18] and Hitesh et al. [23] incorporated image segmentation process before feature extraction in their methodology. In comparison, Hitesh et al. [23] included dimensionality reduction step using Principal Component Analysis (PCA) before segmentation process, while, Shaveta et al. [16] included this step after feature extraction. In most cases, at the end of the process, the proposed model was tested using images allocated for testing or images obtained from the users. The validation of each model is usually done after all the aforementioned processes based on common indexes such as accuracy, precision, sensitivity and specificity. To sum up, the general workflow of image processing in fish disease detection is as shown in Figure 1.

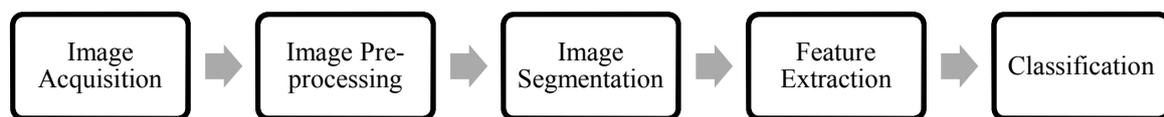


Figure 1. General workflow of image processing for fish disease detection

2.2. Image Pre-processing and Segmentation

In general, pre-processing is the first step in improving the quality of input colour captured from different environments in image-based applications. At this stage, noise and unwanted items are removed from the image using various techniques designed for image resizing, smoothing, and enhancement [24]. Park et al. [9] considered emphasizing pathogen areas in microscopic images using a variety of techniques for the purpose of noise reduction, edge detection, morphological operations, background extraction, and object detection. They used 3×3 mean and edge sharpening filters at the beginning of pre-processing to minimize the salt and pepper noise and to highlight the edge feature of the microscopic image. Besides, the unimportant spectrum of histogram analysis was removed during levelling process in red/green/blue individual plane and the rest of the spectrum were equalized. The edge region in RGB space was discovered through several steps of edge detection masks. Binarization using thresholding was done at the last stage of pre-processing.

In the study by Hitesh et al. [13], K-means clustering was used to segment the colour features of infected areas present in the images. This clustering technique was used successfully in plant disease detection, skin colour detection, and leaf disease classification [8]. Apart from these, Hu et al. [14] determined to crop the live images acquired by GRPS into 32×32 , 64×64 , 128×128 , 256×256 , 512×512 window sizes using automated software before manually filtering the unqualified images that do not show full skin of the fish. After the selection, the images were filtered by 3×3 media filter similarly as in [9].

In the study by Jovanović et al. [15], the collected videos were pre-processed by dividing each frame into 64×64 pixels size of blocks, hence producing around 100 000 images dataset for training. However, the distribution was irregular because more than half of the features appeared to be in the normal class. Then, the codebook of the SIFT descriptors was retrieved from each image and applied K-means clustering algorithm to group these descriptors into a fixed size codebook. Meanwhile, the study by Divinely et al. [6] and Shaveta et al. [16] undertook the pre-processing step by applying filter to remove noise, normalize the intensity of the image and utilized morphological operations at the pre-processing stage. Additionally, Shaveta et al. [16] adapted histogram equalization to equalize and improve the

image and Canny's edge detection technique was used on image to remove the irrelevant information while retain the useful information. On the other hand, Ammar and Neama [7] reduced the noise present in the microscope sample images via Gaussian filter and removed the unrelated background to obtain the *Ichthyophthirius multifiliis* parasite image by GrabCut algorithm. Moreover, Gujjala et al. [17] segregated the video collected into frames followed by noise removal using Unscented Kalman filter (UKF). In other study, Waleed et al. [18] applied different colour spaces (RGB, Ycbr and XYZ) on input images during pre-processing phase. For segmentation, they utilized the Gaussian distribution to measure the probability of any infected area.

2.3. Classification

Classification in image processing is established upon the fundamental value of pattern recognition and achieved a high level of independence. Furthermore, classification of extracted features into specific classes can be done using one technique or combination of various techniques [5] depending on the performance obtained. Even though features for human, plant and fish are distinct and unrelated to one another, however, the basis is to extract and classify the features according to colours, shapes and textures.

2.3.1. Statistical Methods

In the study by Park et al. [9], automated fish disease detection system was proposed to detect three common types of parasites which are white spot, trichodina, and scuticociliate. The system was established based on the training and testing processes using microscopic images collected from various sources. In the study, principal component analysis (PCA) was adapted as a solution to reduce dimension of feature vector and thus minimize the time taken for classification. As the classification, the correlation coefficient was calculated between input feature vector and all the registered feature vectors (previously analyzed and extracted features). From that, the final pathogen was determined based on minimum coefficient. The model achieved 90% correct detection rate and 87% correct recognition rate using 30 microscopic parasites. Nonetheless, the authors assumed that further works on scale-invariant feature transforms need to be executed and to expand current scope of diseases to others like bacteria and virus in order to have more vigorous and proper system.

Meanwhile, Lyubchenko et al. [10] discussed at the possibility to detect and measure infected regions as a method to study fish diseases based on colour image segmentation ideology. This kind of detection was carried out in such way that the marker regions were detected from the images and the total proportion of the infected areas was calculated based on the marked regions. Colour feature was selected as the standard criteria to determine the disease area as reported in the study. Besides, in the situation where other object was present in the whole image was considered when calculating the infected area. Therefore, the fish body portions were firstly measured from the entire images and followed by the measurement of the infected portion from the fish body areas. The authors acknowledged that their method was imperfect as there was possibility of error in the marked areas of infected region due to automatic allocation. The advantages of this method, contrarily, included the capacity to change the dimension of the marker throughout the process of colour selection to prevent occurrence of falsified points, competency to analyse regions that were scarcely recognized over visualization, and the capability to dissociate skin regions by varying levels of destruction.

2.3.2. Artificial Intelligence (AI)

Artificial Intelligence (AI) has evolved in the past 60 years and is defined as computerized programmed that imitates the human capability of thinking, reasoning and learning [25]. Meanwhile, Kaplan and Haenlein [26] describe AI as "a system's ability to correctly interpret external data, to learn from such data, and to use those learnings to achieve specific goals and tasks through flexible adaptation". AI empowers machines to execute rational functions and intelligent behaviours such as solving problems, object and text identification, and ruling decision that can be solved by experts [27]. Initially considered as a science fiction, now, AI has become a popular topic since it has shown great success in various areas such as medical health, philosophy, mathematics, engineering, neuroscience, cyber security, financial industry, psychology, logistics, education and agriculture due to the automation principles

behind it [28], [29]. Additionally, huge advancements in computer science, along with increase in processing strength and efficiency, have paved way for development of the fundamental technologies required for the emergence of AI [30]. Furthermore, AI has existed for decades as a branch of computer science which divided into following subfields, including expert system, machine learning, natural language processing, intelligent robot, fuzzy logic and deep learning that produces a more advance technology and robust application [31].

2.3.2.1. Rule-Based Expert System

The early work by Duan et al. [3] developed a web-based tele-diagnosis system (T-Vet) in conducting online diagnosis (synchronous) and offline diagnosis (asynchronous) which allow farmers to send multimedia information like images, graphics, and text as the input. Also, this system's knowledge base was established based on more than 300 rules, and 400 images and graphics which are capable to detect 126 specific illnesses types that affect nine species of common freshwater fishes. Consultation on treatment of the disease were done by comparing the input acquired from the user with the system's knowledge base. Meanwhile, Zhang et al. [11] adopted Parsimonious Covering Theory (PCT) as the core reasoning algorithm for their intelligent decision support system for fish disease/health management. It is a form of algorithm to formalize reasoning of the diagnostic, which can match the user's inputs with the rules in knowledge base and problem-solving is represented in algorithms that support a hypothesize-and-test inference process. Yet, this method is limited by its knowledge and unlikely to perform well as a real expert.

2.3.2.2. Machine Learning

Another approach using image processing was proposed by Hitesh et al. [13], to diagnose disease that cause severe mortality to freshwater fishes which is Epizootic Ulcerative Syndrome (EUS). The features of EUS infected fish images were recognized and processed by PCA to form the feature vector. Then, the feature vectors were classified specifically using Euclidian distance. However, as reported in the paper, the authors only used four EUS infected images as their test run, demonstrating that the study has a drawback in terms of the small dataset used, despite the accuracy of greater than 90% obtained from this method. They intend to study using neural networks, genetic algorithm, support vector machines and fuzzy logic for further improvement of the performance, robustness, and accuracy of the model.

On the other hand, Hu et al. [14] introduced a new pilot system to classify six common infected fish species, which includes grass carp, black fish, chub, wuchang fish, bighead carp and red bellied pacu based on colour and texture features. As concluded by the authors, colour and texture features are the most practicable to classify species of fish. The texture features, as well as the eight colour features were extracted from the selected rectangle fish images using grayscale histograms (GH) and grey level co-occurrence matrices (GLCM). In this case, the classification process was performed using one multi-class support vector machine classifier, MSVM since it can perform well with limited dataset. The one-against-one algorithm was used to build the MSVM classifier, with each trained-on data from two classes. However, this study leads to misclassification, as the silver carp would sometimes be recognized as the other fish, also, the sub-images of fish skin were manually selected.

Meanwhile, Jovanović et al. [15] developed automated splash swimming behaviour detection as an early prevention step for the infectious fish disease outbreaks. One of the characteristics of unhealthy or stressed fish is the abnormal swimming form or pattern, fish jumps and splashes, which can be observed from the surface of the water. This approach aims to provide information about the surface water condition which is competent in giving important insight of the current environment in fish cages. Scale Invariant Feature Transform (SIFT) was fused with Bag-of-Words (BoW) or Vector of Locally Aggregated Descriptors (VLAD) descriptors during the detection phase since these algorithms demonstrated outstanding performance in image classification and reduced the work to obtain final descriptors, respectively. For this study, Support Vector Machines (SVM) model which was used by Hu et al. [14] was also utilized in this study to classify the normal and flash swimming behaviour according to the texture extracted from security footage of fish production facility collected using an unmanned drone. Although higher accuracy for classifications was obtained in which more than 87 %,

few false detections of splashing were also recorded during the process. In this case, the authors mentioned that those false detections were removed during filtration procedure.

Other than that, [7] introduced image-based model to detect the Ich (*ichthyophthiriasis* or white spots) disease. Similar to [9], this study also utilized microscopic images as the dataset. They compared various algorithm models for classification and found that Logistic Regression algorithm achieved the highest accuracy of 92.8% in comparison to Gaussian Naive Bayes (Gaussian NB), K-NN, Decision Tree, SVM and Naive Bayes. Therefore, the detection was done using Logistic Regression Machine Learning algorithm combined with Ant Colony Optimization (ACO) to classify into two classes (infected and non-infected white spot images). The ACO was used to reduce irrelevant information from dataset and selected the best principal component from each class for training. This study describes an enhancement of the standard Ant Colony Optimization that is a wrapper-based way of improving classification performance with lesser data features extracted. The authors also evaluated the performance of the model with unbalanced classes. From the classification report, the model answered four images true from class one and one image false, and also answered no images false from class two and nine images true. Nevertheless, the authors planned to use dataset collected from another fish farms, applied to other type diseases and to revise the algorithm to deep learning.

Apart from study by Hitesh et al. [13] to detect Epizootic Ulcerative Syndrome (EUS) disease caused by *Aphanomyces invadans*, Shaveta et al. [16] proposed several combinations of techniques and looked at the highest accuracy achieved from the best combination. Based on the study, corner detector, Features from Accelerated Segment Test (FAST) descriptor gave better result compared to object detector, Histogram of Gradient (HOG) descriptor. Because of its fast performance, it is appropriate for actual video processing applications. Although FAST tends to depend on a threshold, but it is not crucial during selection of the competent threshold. In the paper, dimension of the features was also reduced using PCA before classification was conducted. The EUS infected and non-infected images were classified using either Neural Network (NN) or K-Nearest Neighbour (KNN) in this situation. According to the result obtained by the authors, PCA-FAST-NN combination was proven to be an excellent combination as the accuracy achieved was 86%, which was the highest compared to HOG-PCA-KNN, FAST-PCA-KNN and HOG-PCA-NN combinations.

As opposed from the study by [14] and [21], Divinely et al. [6] used Probabilistic Neural Network (PNN) algorithm for the classification process to help fish farmers identify Epizootic Ulcerative Syndrome (EUS). The probability of mis-classification was minimized using this technique. However, the drawback of PNN is that all training samples must be stored and used in classifying new patterns [32]. The authors achieved 90% accuracy using the combination of CWT-GLCM-PNN. While, Gujjala et al. [17] proposed another EUS detection approach using Elman Neural Network by back propagation (EBP) algorithm with GLCM as feature extractor. Although EBP algorithm may experience low convergence and poor generalization, but the overall performance of using this model gave 98% classification efficiency.

2.3.2.3. Deep Learning

Waleed et al. [18] proposed on the automatic approach to detect Epizootic ulcerative syndrome (EUS), Ichthyophthirius (Ich) and Columnaris diseases in fish farms. In the study, they compared the performance of using different Convolutional Neural Network (CNN) architectures (ResNet18, ResNet50, ResNet101 and Alex-Net) on the collected image dataset in different colour spaces. Based on classification results, the authors identified that Alexnet CNN to be the best deep neural network architecture since it outperforms other architectures during testing stage. Furthermore, the highest testing accuracy of 99.0446% was achieved by Alexnet in the XYZ colour spaces followed by 97.4522% accuracy achieved by ResNet101 architecture in the RGB colour space. Yet, the authors intend to utilize the usage of Raspberry hardware circuit and GSM800 for the measurement water's temperature and pH, and for sending notice to users' mobile phones as their future work.

2.3.3. Hybrid Methods

An upgraded version of conventional ES is introduced by Lou et al. [19], which involved combination of rule-based reasoning with image-based retrieval technology. Lou and the team considered that it was

troublesome for users to review the images of potential candidates of the disease as suggested by the system and to choose the right images that are similar to the current symptoms. Moreover, this situation might lead to inaccurate results as the knowledge of the users is very limited. Thus, an image retrieval technology was also associated in the study, by searching for similar cases from the database based on the images captured and uploaded by users to the system. For this situation, a simple and supervised machine learning algorithm which is SVM was used to compare and match the user submitted images with the disease feature image in the database.

In a different study, Han et al. [12] also discussed on the same concept in aiding fish breeders and fish vets by providing a direct and fast detection of infected olive flounder, an Asian flatfish within two stages process. The system proposed the possible diseases from the characteristics and conditions selected by user during the early stage of the process. When the problem became more complex, the system needs more input before finalizing the analysis. In the second stage, the system uses digital image recognition technique to discover pathogen from the microscopic image. The microscopic image obtained from user input is compared with the microscopic image present in the database. For the classification, they utilized correlation coefficient calculation as proposed by Park et al. [9]. The researchers acknowledged that the input from real cases should be incorporated in the system and extra effort was needed to improve the feature extraction techniques during the second stage.

3. Trends and Challenges

Technology advancement in image processing make it possible for fish disease detection to be done automatically. Image processing is found to have the ability to aid fish experts in providing early screening and detection to fish breeders. Based on the review done in this study, the earlier applications of image processing in fish disease detection appear to be expert system methods. Yet, expert system is subjected to error in detection process even when there is just tiny irregularity and distortion of the rule. Although knowledge acquired for rule-based can be easily converted into simple programming rules, but the performance of this approach depends on the knowledge and skills of the experts which can be influenced by flaw of experts' knowledge. In case-reasoning, rules involved is less control over the decision process and can be studied from previous solved cases. However, this kind of rule-based requires large number of cases to train the system which is considered time-consuming. With the limitation in expert systems, technology is now shifting towards more advanced and automated techniques such as machine learning and deep learning.

Unlike other studies in fish species classification and recognition that used underwater images as the dataset for the model, based on the researchers' knowledge, limited study has proposed using underwater dataset in fish disease detection field. For this reason, more studies are required to give an overview of the real underwater situation as this will increase the reliability to the method proposed. Simultaneously, capturing high-resolution underwater images considered as challenging task since underwater images frequently suffer from colour distortion, low contrast, poor visibility and hazy [33]. Therefore, in order to overcome these challenges in underwater environment, underwater image enhancement procedure needs to be incorporated. Yet, the trend of using image processing in developing early detection model is relying on the major factor which is the availability of larger datasets. Despite having early detection system, user's information perspective is still lacking since the system is established based on the assumption on the users' needs. It also requires long-term maintenance and support in order to keep the system at the forefront when implemented in the field. Comparing the studies made in image processing, deep learning algorithm has an advantage against other methods since it is proven to be fast, high automation property and performance-wise. To the best of the researches' knowledge, Convolutional Neural Network (CNN) which is proposed by Waleed et al. [18] is the recent research in this field with significant result achieved so far. The accuracy obtained of more than 99% is considered a benchmark for future researches.

Likewise, to reach to a certain extent of automation within specific time, it relies not just on the current technology development, but also on the nature of disease. After all, finding the right method to analyse heterogenous and diverse dataset is always among the major challenges encountered in this field. Nonetheless, most of the systems and techniques proposed so far only aim to solve problem related to a specific disease or species. Since the focus is only on particular cases, most of the methods are able to

achieve high performance. This adaptability over accuracy issue is normal in many fields, and therefore must be viewed and taken into consideration.

4. Conclusion

It can be concluded that several efforts had been brought up in the direction of fish disease detection with the help of image processing although there are scarce studies been conducted. Overall, it can be implied that based on the previous studies of fish disease detection, image processing can be done with minimum time and efforts, and is also more reliable in providing better alternative to the manual technique conducted by fish experts. Besides, with the help of image-based model, early detection of diseases can be accomplished to prevent the diseases from spreading. This is very useful in monitoring application of fish disease. Furthermore, development of image processing technique is able to contribute to a more advanced technique with higher automation principles and accuracy behind the techniques. This paper attempts to provide a conclusive review of image processing application in fish disease detection.

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