A Review of Research on Fish Feeding Behavior Based on Computer Vision

Yongchao Yang, Liangquan Jia, Wei Long, Linhua Jiang*
School of Information Engineering, Huzhou University, Huzhou, China
**Corresponding Author.*

Abstract: With the development of aquaculture, monitoring fish feeding behavior is crucial for breeding efficiency and resource utilization. Traditional manual observation methods are inefficient and subjective, while computer vision technology provides a new solution for real-time quantitative analysis of fish feeding behavior. This article summarizes the key steps in monitoring fish feeding behavior, including fish species selection, image information collection methods, and details various quantitative methods applicable to feeding behavior analysis, such as area method, behavior feature statistics, image texture features, and Delaunay triangulation method. These methods each have their own advantages and can adapt to different research needs. Deeply understanding and quantifying the feeding patterns of fish not only helps optimize aquaculture management and improve resource utilization, but also provides scientific basis for ecological protection.

Keywords: Computer Vision; Fish; Feeding Behavior; Monitor; Quantitative Algorithm

1. Introduction

With the rapid development of the global aquaculture industry, fish, as important aquatic economic animals, have gradually attracted widespread attention from academia and industry in terms of their growth, reproduction, and feeding behavior. The feeding behavior of fish not only directly affects their growth rate and feed conversion rate, but is also closely related to the health and stability of aquatic ecosystems [1]. A deep understanding of the feeding behavior of fish is of great significance for improving the production efficiency of aquaculture and ensuring the ecological balance of water bodies.

Traditional research on fish feeding behavior mainly relies on manual observation and recording, which is not only time-consuming and labor-intensive, but also susceptible to subjective factors from observers, resulting in limited accuracy and reliability of data. Fish move rapidly in water, especially when feeding, and observers often find it difficult to capture their rapidly changing behavioral characteristics. A more efficient and objective monitoring method is urgently needed to comprehensively and accurately record and analyze the feeding behavior of fish.

In recent years, computer vision technology has used methods such as image processing and pattern recognition to automatically analyze and recognize the behavioral patterns of fish, overcoming the limitations of traditional observation methods. The study of fish feeding behavior using high-resolution camera equipment and advanced image processing algorithms can provide a solid theoretical basis for improving feeding methods in fisheries [2].

In the study of fish feeding behavior, due to the influence of different fish species' feeding habits, behavioral patterns, and ecological needs, selecting different fish species for research will have different experimental effects. Therefore, the first step is to clarify the appropriate monitoring target fish species. Next is the acquisition of image information [3]. By reasonably arranging camera equipment, selecting appropriate shooting angles and lighting conditions, the image quality can be maximized, ensuring the accuracy of subsequent analysis.

In the analysis and research of fish feeding behavior, after selecting fish species and collecting video materials, it is necessary to conduct a detailed analysis of the feeding behavior of the fish population. In order to achieve quantitative description of fish feeding behavior, researchers have proposed various algorithms, including traditional area method, behavioral feature statistical method, image texture feature method, and Delaunay triangulation method. These methods each have their own advantages and disadvantages, and it is necessary to choose the appropriate method for quantitative analysis based on the actual application scenario.

Although the above sampling analysis methods can achieve good feeding analysis results, there are still many challenges to achieving better intelligent feeding effects, such as how to improve the accuracy and robustness of algorithms, how to deal with image noise in complex water environments, and how to conduct real-time monitoring and analysis. These are all urgent problems that need to be solved in current research. Future research needs to explore the underlying mechanisms and influencing factors of fish feeding behavior on a multidisciplinary basis, combining knowledge from fields such as biology, computer science, and ecology.

The study of fish feeding behavior based on computer vision not only provides new technological solutions for aquaculture, but also provides scientific basis for ecological protection and resource management. Through in-depth research on the feeding behavior of fish, we can better understand the dynamic changes in aquatic ecosystems and promote sustainable development. This article will delve into this topic in depth, hoping to provide useful references and inspirations for research in related fields.

2. Selection of Monitoring Target Fish Species and Image Acquisition

2.1 Selection of Monitoring Target Fish Species

When studying the feeding behavior of fish, monitoring the selection of target fish species is a crucial step. The biological characteristics, ecological habits, and distribution of different fish species in water directly affect their feeding behavior. Reasonably selecting monitoring objects can not only improve the pertinence of research, but also provide a reliable basis for subsequent data analysis and result interpretation. When selecting target fish species, their economic value and ecological importance should be considered. Taking aquaculture as an example, common freshwater fish such as carp, grass carp, and green carp are widely farmed due to their high economic value [4]. The feeding behavior of these fish is directly related to aquaculture efficiency, so studying their behavior has important practical significance.

In addition, the feeding habits and behavioral characteristics of the target fish species are also important criteria for selection. Different fish species have significant differences in feeding methods, food preferences, and feeding frequency. Carnivorous fish such as sharks and eels usually have strong hunting abilities, while herbivorous fish such as carp and crucian carp mainly feed on aquatic plants and plankton. These differences not only affect their feeding behavior, but also have an impact on the selection of monitoring methods. When selecting target fish species, their feeding habits should be fully considered in order to develop suitable monitoring plans. The habitat characteristics of the target fish species are also important factors in selection [5].

Different fish species have varying adaptability to environmental factors such as water temperature, dissolved oxygen, and light, which can affect their distribution in specific water bodies. Some fish grow and reproduce well in warm waters, while others are more suitable for survival in cold waters. When selecting monitoring objects, it is necessary to consider the environmental characteristics of the research area and choose fish that are adaptable and easy to observe, in order to improve the effectiveness of monitoring.

In practical research, researchers can compare the characteristics of different fish species through the following table to assist in selecting target fish species.

Table 1. Comparison of Characteristics of Different Fish Species

Fish name	economic value	feeding habits	habitat characteristics	suitable water temperature	Main food sources
carp[4]	high	Herbivorous	freshwater	18-28°C	Water plants and plankton
Grass Carp[4]	high	Herbivorous	freshwater	20-30°C	Water plants and algae

Green Fish[4]	medium	Carnivorous	freshwater	18-25°C	Small fish and shrimp
Crucian carp[5]	medium	Omnivorous	freshwater	15-25°C	Water plants and plankton
ricefield eel[5]	high	Carnivorous	freshwater	20-30°C	Small fish, insects

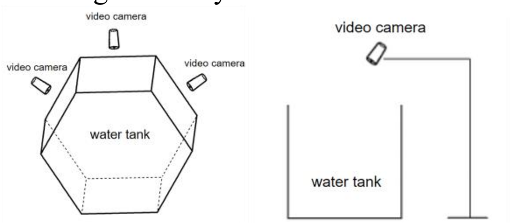
According to Table 1, it can be seen that different fish species have differences in economic value, feeding habits, habitat characteristics, and other aspects. These pieces of information provide important reference for researchers when selecting monitoring targets [6]. When selecting target fish species, the feasibility and technical conditions of the research should also be considered. Some fish species may not be suitable for long-term monitoring due to their slow growth rate, long reproductive cycle, or sensitivity to environmental changes. The maturity of monitoring technology can also affect the selection of target fish species. In the study of fish feeding behavior, the selection of target fish species for monitoring is crucial. Some fish species are active underwater and require high precision monitoring equipment; Others are relatively static and have lower monitoring difficulty. Researchers need to comprehensively consider technical conditions and the characteristics of target fish species to ensure smooth monitoring progress. When selecting fish species, it is also necessary to comprehensively consider factors such as economic value, ecological importance, feeding habits, habitat characteristics, and technical feasibility, in order to select the most representative fish for in-depth exploration and lay a scientific foundation for aquaculture and ecological protection.

2.2 Image Information Acquisition

In the real three-dimensional world, computer vision technology relies on computer simulation of human vision to obtain spatial images, process data, extract information, and finally use them for practical tasks such as detection, measurement, and tracking. The process of obtaining image information mainly includes several aspects such as selecting suitable equipment, determining the shooting environment, and optimizing shooting parameters [7]. To obtain high-quality images, it is necessary to first choose the appropriate image capture equipment. There are various types of cameras available on the market, such as high-definition cameras, motion cameras, underwater cameras, etc. In order to capture better data, it is necessary to choose the appropriate camera equipment for the experimental scene. If there is insufficient lighting, the image is prone to blur, which is not conducive to subsequent analysis. Therefore, when choosing a shooting time, try to choose a time with sufficient lighting. In addition, whether the water quality is clear or not is directly related to the clarity of the image. Turbidity of the water body will scatter light, and the image quality will decrease accordingly. So before image capture, it is necessary to properly treat the water body to ensure clear water quality.

In terms of setting shooting parameters, parameters such as resolution, frame rate, and exposure time need to be adjusted according to specific research needs. High resolution images can provide more detailed information, which helps to more accurately identify the feeding behavior of fish. Excessive resolution may result in a large amount of data and increase the difficulty of subsequent processing. When choosing a resolution, a balance should be made based on actual needs. Frame rate is also one of the important factors affecting the quality of data collection. A higher frame rate can capture fast feeding movements, but it also increases the storage requirements for data. Generally speaking, a frame rate of 30 frames per second is sufficient to meet the observation needs of most fish feeding behaviors. The setting of exposure time is related to the brightness and clarity of the image [8]. In environments with good lighting conditions, a shorter exposure time can be chosen to avoid overexposure caused by excessive light. In cases of insufficient lighting, it is necessary to extend the exposure time appropriately to ensure that the brightness of the image is moderate. By setting reasonable parameters, the quality of images can be effectively improved, laying the foundation for subsequent behavioral analysis.

There are two types of camera imaging methods: side camera and underwater imaging. Multiple side cameras can achieve three-dimensional detection, synchronously capturing fish body swing parameters from different angles, as shown in Figure 1-A. Watson et al [9] used three sets of cameras to form an underwater stereo video system in three coral reef areas in Hamelin Bay, southwest Australia, to study the relative density and species richness of temperate coral fish. Water cameras are suitable for non transparent water tanks and turbid water bodies, and can obtain parameters of fish movement through motion images of fish on the water surface. Guo [10] used a Nikon D9 camera to capture images from water, as shown in Figure 1-B. In the experiment, they collected videos of fish before and after feeding, and then captured frames every 1 second. They selected 300 sequence frame images with good imaging quality for processing and analysis.



A. Side camera B. Water camera

Figure 1. Schematic Diagram of Video Surveillance of Fish Behavior

After capturing images, preprocessing operations such as denoising, contrast enhancement, and image cropping are required [11]. Denoising can effectively eliminate clutter and interference in images, improving image clarity; Enhancing contrast helps to highlight the contours of fish, making them more prominent in the image; Image cropping can remove unnecessary background information and focus on the feeding behavior of fish. These preprocessing steps can significantly improve the accuracy and efficiency of subsequent analysis.

3. Quantitative Algorithm for Fish Feeding Behavior

The quantitative algorithm for fish feeding behavior mainly includes traditional area method, behavior feature statistical method, texture feature method, and Delaunay triangulation method. Quantitative analysis of fish feeding behavior can guide aquaculture personnel in scientific feeding, help improve aquaculture profits, and reduce serious losses caused by fish diseases and stress events [12].

3.1 Traditional Area Method

The traditional area method is a quantitative technique for fish feeding behavior based on image analysis, which mainly evaluates the feeding behavior of fish by measuring the area of their feeding area at a specific time. The basic principle of this method is to use image processing techniques to process the captured fish images, extract the area occupied by the fish during feeding, and calculate the area of that area. By comparing the changes in area under different time periods or experimental conditions, the feeding frequency and amount of fish can be inferred [13].

In practical applications, the implementation steps of traditional area method usually include several steps such as image acquisition, image preprocessing, region segmentation, and area calculation. Researchers need to choose appropriate equipment for image acquisition, usually using high-definition cameras or underwater cameras, to ensure clear fish images are captured. The image preprocessing process includes operations such as noise reduction and contrast enhancement to improve the accuracy of subsequent processing. Region segmentation is the process of separating fish from the background in an image. Common methods include threshold segmentation and edge detection.

After completing the region segmentation, researchers can use different algorithms to calculate the area of the fish feeding zone. Common calculation methods include pixel counting method and geometric shape method. The pixel counting method estimates the area by counting the number of pixels in the segmented area, while the geometric shape method calculates the area by fitting the geometric shape of the fish feeding area (such as rectangle, circle, etc.). Both methods have their own advantages and disadvantages. The pixel counting method is simple and easy to implement, but errors may occur when dealing with complex shapes; The geometric shape rule requires more complex analysis of the region, but can provide higher accuracy in the case of regular shapes [14].

Although traditional area methods have certain advantages in studying fish feeding behavior, they also have some limitations. This method has high requirements for image quality. If the image is blurry or poorly illuminated, it may lead to inaccurate region segmentation, thereby affecting the results of area calculation. The traditional area method usually only provides quantitative data and is difficult to analyze the feeding behavior patterns and habits of fish in depth. In the case of complex feeding behavior of fish, relying solely on area calculation may not fully reflect the true situation of their feeding behavior.

In order to overcome the limitations of traditional area methods, researchers have gradually begun to combine other technologies such as machine learning and deep learning to improve the accuracy of analyzing fish feeding behavior. By introducing these advanced technologies, researchers can more comprehensively capture the feeding behavior characteristics of fish, providing a more reliable basis for aquaculture and ecological protection.

3.2 Behavioral Characteristics Statistics Method

Behavioral characteristic statistics is a method of quantitatively analyzing the feeding behavior of fish, extracting their behavioral characteristics, and conducting statistical analysis. This method can not only reveal the behavioral patterns of fish during feeding, but also provide important data support for aquaculture and ecological research. By observing and recording the feeding behavior of fish, researchers can obtain a large amount of behavioral data and extract meaningful features through statistical analysis.

In the quantification of fish feeding behavior analysis, optical flow method and information entropy are usually used to calculate the swimming speed and turning angle information of fish schools, in order to quantify their feeding behavior. Firstly, use the optical flow method to calculate and calculate the swimming speed and turning angle of the fish swarm. If the Lucas Kanade optical flow algorithm based on local difference is used to extract feeding behavior information of fish schools, this algorithm can extract the swimming speed and turning angle of fish schools. Then divide the swimming speed and turning angle of the fish into intervals, calculate their statistical histogram, and calculate the joint statistical information of speed and turning angle. Finally, using information entropy to calculate the disorder of swimming speed and angle distribution information, quantifying the feeding behavior of fish schools. Researchers can calculate indicators such as swimming speed, turning frequency, and dwell time of fish during feeding. These indicators can reflect the activity level and behavioral patterns of fish during the feeding process [15]. This method has good detection results under good lighting and water quality conditions, and is suitable for net cage aquaculture.

The advantage of behavior characteristic statistical method is that it can reveal the regularity of fish feeding behavior through quantitative analysis. Through statistical analysis of a large amount of data, researchers can identify key factors that affect fish feeding behavior, such as water temperature, light, and bait types. This method can also be used to compare the differences in feeding behavior of fish under different environmental conditions, providing scientific basis for the management and optimization of aquaculture.

The statistical method of behavioral characteristics also has some limitations. The accuracy and reliability of data are affected by monitoring equipment and image processing techniques, which may lead to data bias. The feeding behavior of fish is influenced by multiple factors, and a single behavioral characteristic may not fully reflect their feeding patterns. In practical research, it is usually necessary to combine multiple methods for comprehensive analysis to obtain more accurate and comprehensive results. The statistical method of behavioral characteristics provides an effective quantitative analysis tool for the study of fish feeding behavior [16]. Through in-depth research on the feeding behavior of fish, important theoretical foundations and practical guidance can be provided for scientific management, ecological protection, and research on fish behavior in aquaculture. In the future, with the continuous development of computer vision technology and data analysis methods, the application of behavioral feature statistical methods in the study of fish feeding behavior will be more extensive and in-depth.

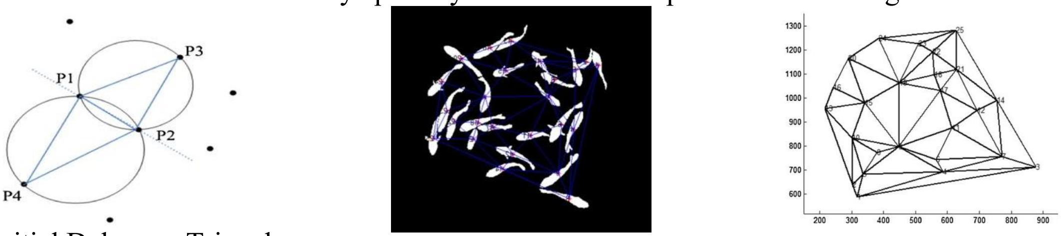
3.3 Image Texture Feature Method

In the study of fish feeding behavior, image texture feature method is an important analytical tool that can effectively extract and quantify the visual features of fish during the feeding process. Texture features not only reflect the details and structure of an object's surface, but also reveal the behavioral patterns of fish in different environments. By analyzing the texture of fish feeding images, researchers can gain a deeper understanding of fish feeding habits, preferences, and their relationship with environmental factors.

The image texture feature method is mainly based on the analysis of features such as grayscale distribution, texture direction, and roughness of the image. The commonly used texture feature extraction methods include gray level co-occurrence matrix (GLCM), local binary pattern (LBP), Gabor filter, etc. [17]. These methods each have their own advantages and disadvantages, and are suitable for different research needs. Gray level co-occurrence matrix (GLCM) is a classic texture feature extraction method that extracts a series of statistical features such as contrast, correlation, energy, and uniformity by calculating the spatial relationship between pixel gray values in an image. These features can effectively describe the texture information of the image. In the study of fish feeding behavior, researchers can determine the intensity and frequency of their feeding activity by analyzing the GLCM features of fish images before and after feeding. Local Binary Pattern (LBP) is a simple and effective texture descriptor that generates local feature vectors by binarizing the neighborhood of each pixel in an image. LBP has rotation invariance and illumination invariance, making it suitable for analyzing fish feeding behavior in dynamic scenes [18]. By extracting LBP features from fish feeding images, researchers can construct feature vectors of fish feeding behavior and use these features for classification and recognition. Gabor filter is a frequency domain analysis method that extracts texture features of different frequencies and directions by filtering images at multiple scales and directions. Gabor features have shown good performance in the study of fish feeding behavior, as they can capture subtle changes in fish feeding processes. Researchers can use Gabor features to analyze the feeding behavior of fish under different lighting conditions, thereby revealing the impact of light on fish feeding. In practical applications, the effectiveness of image texture feature methods often depends on appropriate feature selection and classification algorithms. Researchers usually combine multiple texture features for comprehensive analysis to improve the accuracy and robustness of recognition. By extracting and analyzing texture features from images of fish feeding behavior, researchers can obtain rich information and provide scientific basis for aquaculture and ecological protection.

3.4 Delaunay Triangulation Method

Delaunay triangulation is a widely used technique in computational geometry and image processing, particularly suitable for analyzing fish feeding behavior. When using Delaunay triangulation to analyze fish feeding behavior, the first step is to discretize the movement trajectory of the fish swarm. According to the Delaunay triangle connection method shown in Figure 2-A, by sampling continuous motion trajectories, key points are extracted to form a point set as shown in Figure 2-B. Use the Delaunay triangulation algorithm to process these points, and use the results of Delaunay triangulation to characterize FIFFB as shown in Figure 2-C. The calculated FIFFB represents the aggregation level of fish, and the smaller the value of FIFFB, the higher the aggregation degree. In the activity of fish schools, when not in a feeding state, the fish are dispersed; Only in the feeding state, fish gather for feeding activities. By analyzing the Delaunay triangulation data, researchers can obtain multidimensional information about the feeding behavior of fish. The area of the triangle can reflect the range of activity of the fish during feeding, while the circumference can indicate the degree of aggregation of the fish. The distribution of interior angles can reveal the movement patterns and relationships between fish during the feeding process. Zhou Chao et al. [19] used this method to calculate the centroid of fish through order moments, using the centroid as the vertex of the Delaunay triangulation. Then, based on the Delaunay triangulation results, the fish feeding behavior aggregation index (FIFFB) was calculated to quantify the feeding behavior of the fish population. The least squares polynomial fitting method was used to fit the FIFFB value after removing the reflection box. The results indicate that the use of FIFFB values can accurately quantify and analyze changes in fish feeding behavior, with a linear correlation coefficient of 0.945 with expert manual scoring.



A. Initial Delaunay Triangle B. Fish school keypoint set map C. Key point of FIFFB method

Figure 2. Delaunay Triangulation Image Processing (Reference [19])

In addition, Delaunay triangulation can also be combined with other image processing techniques, such as machine learning algorithms, to further improve the accuracy of fish feeding behavior analysis. By extracting features from the generated triangular mesh and combining it with deep learning models, researchers can achieve automatic recognition and classification of fish feeding behavior [20]. This method not only improves the efficiency of analysis, but also enables the processing of large-scale data, providing a more reliable basis for aquaculture and ecological research. The Delaunay triangulation method provides an effective tool for studying the feeding behavior of fish. By analyzing the geometric features of the movement trajectory of fish schools, it is possible to gain a deeper understanding of the feeding patterns and behavioral characteristics of fish. With the continuous development of computer vision technology, the application prospects of Delaunay triangulation method in fish behavior research will be even broader, providing more scientific support for aquaculture and ecological protection [21].

4. Expectation

With the continuous advancement of technology, the application prospects of computer vision technology in the study of fish feeding behavior are becoming increasingly broad. Future research will not be limited to existing monitoring and analysis methods, but will move towards more efficient and intelligent directions. The rapid development of deep learning technology has provided new possibilities for the recognition and analysis of fish feeding behavior. The performance of traditional image processing methods is often limited in complex environments, while deep learning algorithms, especially convolutional neural networks (CNN), can automatically extract features through training on large amounts of data, significantly improving recognition accuracy and robustness. Future research can further explore how to construct more complex network structures to adapt to the feeding behavior characteristics of different fish species, thereby achieving more accurate behavior recognition [22].

Combining multimodal data research will become an important trend. The feeding behavior of fish is not only influenced by visual factors, but also closely related to environmental factors such as water temperature, light, and bait type. By integrating computer vision, sensor technology, and data mining methods, researchers can establish a more comprehensive model of fish feeding behavior [23].This multidimensional data fusion will help to gain a deeper understanding of the feeding strategies of fish under different environmental conditions, providing a more reliable basis for the scientific management of aquaculture.

The development of real-time monitoring technology will also bring new opportunities for the study of fish feeding behavior. Traditional monitoring methods often rely on manual observation, making it difficult to achieve real-time data collection and analysis. With the advancement of camera technology and data transmission technology, the construction of real-time monitoring systems will become possible. By deploying multiple cameras in the water body and combining cloud computing and big data analysis technologies, researchers can obtain real-time feeding behavior data of fish and adjust breeding strategies in a timely manner. This not only improves the efficiency of monitoring, but also lays the foundation for intelligent management of aquaculture.

In terms of ecological protection, the application of computer vision technology is also of great significance. With the changes in the global aquatic ecological environment, the feeding behavior of fish is also constantly adjusting. Through long-term monitoring of fish feeding behavior, researchers can identify the impact of ecological changes on fish behavior, thereby providing scientific basis for ecological protection. Certain fish species may experience changes in their feeding behavior under specific environmental conditions, which could be a signal of ecosystem imbalance. By identifying these changes in a timely manner, relevant departments can take measures to protect the stability of the aquatic ecological environment.

Interdisciplinary collaboration will inject new vitality into the study of fish feeding behavior. The cross integration of multiple disciplines such as computer vision, ecology, behavioral science, and aquaculture will promote the in-depth development of research. Future researchers can draw on advanced technologies and methods from other fields, use artificial intelligence technology to optimize predictive models of fish feeding behavior, or analyze the relationship between fish behavior and the environment through ecological theoretical frameworks. This interdisciplinary collaboration not only enriches research perspectives, but also promotes innovation and development in scientific research.

The study of fish feeding behavior based on computer vision is currently in a rapidly developing stage, and future research will focus more on technological innovation and application. By continuously exploring new methods and technologies, researchers will be able to gain a deeper understanding of fish feeding behavior, providing strong support for the sustainable development and ecological protection of aquaculture. As research deepens, we look forward to uncovering more mysteries of fish feeding behavior and opening up new paths for aquaculture and ecological conservation.

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