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Near-infrared imaging to quantify the feeding behavior of fish in aquaculture

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ABSTRACT

In aquaculture, fish feeding behavior under culture conditions holds important information for the aquaculturist. In this study, near-infrared imaging was used to observe feeding processes of fish as a novel method for quantifying variations in fish feeding behavior. First, images of the fish feeding activity were collected using a near-infrared industrial camera installed at the top of the tank. A binary image of the fish was obtained following a series of steps such as image enhancement, background subtraction, and target extraction. Moreover, to eliminate the effects of splash and reflection on the result, a reflective frame classification and removal method based on the Support Vector Machine and Gray-Level Gradient Co-occurrence Matrix was proposed. Second, the centroid of the fish was calculated by the order moment, and then, the centroids were used as a vertex in Delaunay Triangulation. Finally, the flocking index of fish feeding behavior (FIFFB) was calculated to quantify the feeding behavior of a fish shoal according to the results of the Delaunay Triangulation, and the FIFFB values of the removed reflective frames were fitted by the Least Squares Polynomial Fitting method. The results show that variations in fish feeding behaviors can be accurately quantified and analyzed using the FIFFB values, for which the linear correlation coefficient versus expert manual scoring reached 0.945. This method provides an effective method to quantify fish behavior, which can be used to guide practice.

1. Introduction

The fish feeding process is one of the most important aspects in managing aquaculture tanks, where the cost of fish feeding is around 40% of the total production costs (Atoum et al., 2015; Chang et al., 2005). The inefficiencies of the feeding task associated with intensively cultured fish systems result in considerable financial loss for aquaculturists and negative environmental impact. So the efficient feeding strategies are very important (Føre et al., 2011; Wu et al., 2015). Information about the feeding behavior would be a valuable input into the process of developing efficient feeding management strategies, it holds important information for aquaculturist. Methods of continuously monitoring and quantifying the behavior of fish show potential for assessing the feeding process, and it reflects the fish feeding status and is important to fish production and culture (Kristiansen et al., 2004; McFarlane et al., 2004; Saberioon et al., 2016; M. Sun et al., 2016; Xu et al., 2006; Zion, 2012).

Many attempts have been made to monitor and analysis the process of fish behavior. Human observers can develop a capacity for evaluating the behavior of fish, but visual observation is often impeded by several factors such as the observer's experience. And so, for a commercial scale fish farm, raises labor and time costs, leading to the issue of how to quantify feeding behavior by a objective and automatic method (Liu et al., 2014; Mallekh et al., 2003). A high-frequency imaging sonar (DIDSON) and some acoustic tags were applied to directly observe and quantify fish behavior (Føre et al., 2011; Kolarevic et al., 2016; Rakowitz et al., 2012). Moreover, although acoustic techniques can be used without light, the application of these techniques is limited by the high cost and difficulty of implementation (Belcher et al., 2002; Saberioon et al., 2016; Zion and Barki, 2012).

Computer vision technology provides an automated, non-invasive and cost-effective method of recording behavioral parameters (Xu et al., 2006). In order to quantify the behavior, a behavior detection method based on computer vision and Delaunay Triangulation was developed by Nasirahmadi et al. (2017, 2015). And the classification of animal behavior was studied using machine vision and Support Vector Machine (SVM) (Martiskainen et al., 2009; Smith et al., 2016). Single camera or multi-camera 3D

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machine vision has been used in behavior analysis or trail tracking (Saberioon and Cisar, 2016; Sadoul et al., 2014). Furthermore, a series of swimming, grouping behaviors monitoring and analyzing systems have been developed (Papadakis et al., 2012; Pinkiewicz et al., 2011). For feeding and related studies, machine imaging had been used previously to detect the feed residue in fish shoal feeding (Atoum et al., 2015; Foster et al., 1995; Parsonage and Petrell, 2003), quantify fish activity (Duarte et al., 2009), quantify feeding activity and behavior (Liu et al., 2014; Pinkiewicz et al., 2011), and estimate feeding intensity (Zhao et al., 2016). Practice has proven that machine vision is a highly cost-effective method and more suitable for an environment with sufficient lighting such as in a laboratory, cages, and pools (Dios et al., 2003; Kane et al., 2004; Saberioon et al., 2016; Xiao et al., 2015). While in some aquaculture facilities have poor lighting, the near-infrared computer vision technology is not affected by visible light intensity and can yield good imaging results in an environment with relatively dim light (Farokhi et al., 2016; Hung et al., 2016). Furthermore, the cost of this technique is also very low and the development is easy. Therefore, due to the low cost and low need of visible light intensity, it is suitable for used for motoring fish behaviors in aquaculture which have poor lighting. In fact, a near-infrared (NIR) system has already been deployed and achieved very good results for 3D fish movement trail tracking (Pautsina et al., 2015). In this study, according to the study of Pautsina et al. (2015), a 850 nm wavelength near-infrared was used, and this wavelength has not been shown to affect normal fish growth or result in a stress response.

On the basis of simulating the commercial scale fish farm environment, the current study proposed a near infrared computer vision-based method for quantify the feeding behavior of fish. Feeding behavior was described by the flocking level based on a Delaunay Triangulation method due to the motions of feeding fish. Meanwhile, possible factors that might influence the analysis results were both taken into account, including water surface reflections were classified by the SVM. To assess the reliability of our method, it was also compared with the results of human exports method. The purpose of this study was to build a potential method to quantify the feeding behavior of swimming fishes. It aims to provide information for real time feedback and automatically control of feeding process in fish feeding procedures.

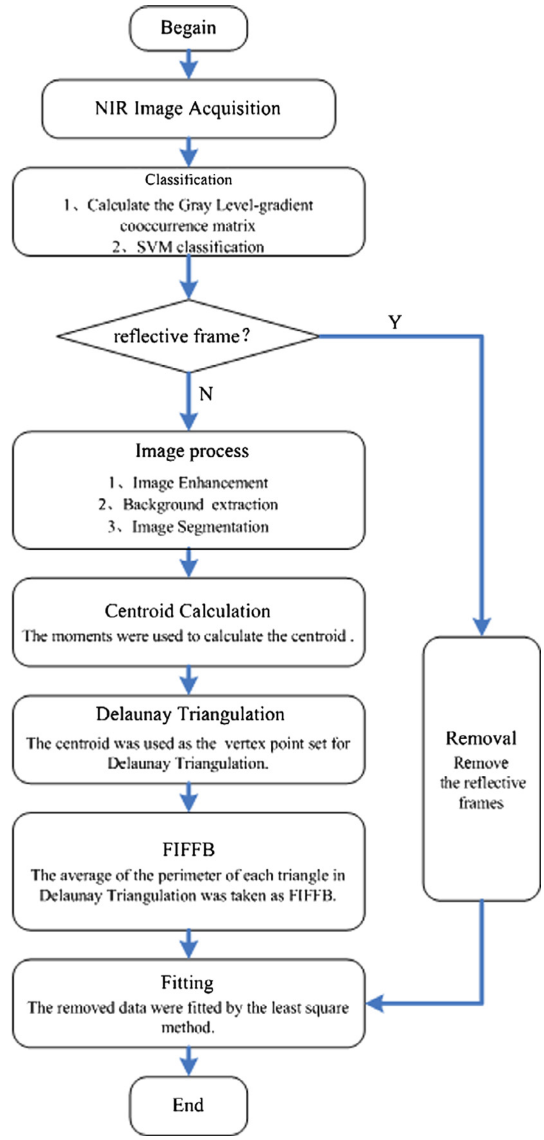

Fig. 1. Schematic of the near-infrared imaging method.

2. Materials and methods

In this study, the method is not suitable for all fish species or culture methods, the preconditions for the method proposed in this paper are indicated as follows:

(1) Species. By default, this method is applicable to swimming fish species such as carp, salmon, and tilapia, which feed actively and have significantly different feeding behaviors at different life stages.
(2) Feeding mode. The suitable fish feeding methods include manual feeding or fixed-point feeding from a feeder; floating and sinking types of feed are acceptable.
(3) Culture pattern. This method is suitable for cages, ponds, and RAS, and it is highly recommended for use in environments with poor light conditions.

A schematic of the system is shown in Fig. 1.

2.1. Experimental materials

For this experiment, adult *Cyprinus carpio var. specularis* fish of 15–25 cm in length were selected as the subjects. Before being used in the experiment, the fish were raised for several months and were allowed to adapt to the experimental culture environment. During acclimation, the oxygen level was maintained within the range of 5–7 mg/L, water temperature was maintained at 15–27 °C, and the fish were fed a commercial diet of 3% of the body weight per day.

2.2. Experimental system

The experiment was performed in the aquaculture laboratory at the Xiaotangshan National Experiment Station for Precision Agriculture, Beijing, China. The system includes six tanks, each with a diameter of 1.5 m and a water depth of 1 m. A Mako G-223B NIR industrial camera (Germany AVT, Allied Vision Technologies) was used for image collection; the camera had a bit depth of 8\12, a pixel dimension of 5.5 μm, and a resolution of $2048 * 1088$. It was used in conjunction with a near-infrared light source of 850 nm and an industrial camera lens with a focal length of 8 mm (KOWA LM8HC, Japan). The total photon flux at the water surface was 57.8 μmol m^{-2} s^{-1}. The camera and the near-infrared light source were attached to the top of the tank. Since the distance