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Ornamental fish counting by non-imaging optical system for real-time applications

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ABSTRACT

One of the more labor-intensive operations in ornamental fish farms is fish counting. It is performed primarily when spawned fry are collected and introduced into grow-out tanks and when preparing fish for marketing. For various reasons such as cost and mode of operation of existing counting systems and inability to combine them with existing farm equipment, in many farms fish are counted manually despite time pressure and shortage of labor. An optical system for fish counting has been developed using hybrid non-imaging optics and an image-processing scheme to obtain an efficient single-detector counting system. The optical design includes a tailored field-stop aperture and a non-imaging scheme that reduces the influence of water fluctuations in a partially filled tube. The resultant increased signal-to-noise ratio enables overcoming the effects of water fluctuations. A prototype was tested with dummy and live fish. Counting errors with well-separated fish were less than 2%. Such a system can be used in similar operations with other small fish (e.g. edible fish hatcheries).

1. Introduction

Despite differences in specific practices, tropical ornamental fish farms share one specific important objective - reduction of labor to a practical minimum. This objective can be achieved by completely or partially automating operations such as quality sorting and counting. Careful quality inspection and counting fish for shipment is labor intensive and conducted under a tight time schedule. Due to space limitations and lack of simple, inexpensive and easily maneuverable sorting and counting devices, this operation is done manually in many farms.

Most of the fish counting devices currently on the market are designed for large-size edible fish and few limited solutions for small ornamental fish counting are available. Vaki Aquaculture Systems Ltd. (Vaki, 2018) offers a micro fish counter for fish fry larger than 0.2 g based on a computer vision system with a reported accuracy of 98%. Impex Agency Hoerning ApS (Impex, 2018) offers its “TPS model” fish counter for fish larger than 0.2 g, also with a reported accuracy of 98%. However, the maneuverability of these systems in the typically narrow passages between the farm’s nursery tanks is questionable, since some of them weigh more than 50 kg. This similarly hampers their integration with quality inspection and strain sorting. Older electronic methods and devices for fish (Yada and Chen, 1997; Aqua Scan Fish Counters LTD, 2018) and fish egg (Joyce and Rawson, 1988) counting have limitations that make them invalid and impractical for ornamental fish counting.

Many counting operations are based on mass evaluation, behavior evaluation, or color pattern detection by machine vision (MV) (Zion et al., 2007; Washburn et al., 2008; Hsieh et al., 2011; Loh et al., 2011; Salomonsoft, 2018). In recent years, researchers have invested much effort in tracking fish to monitor behavior and feeding (Zion, 2012; Saberioon et al., 2017; Zhou et al., 2017a; Atoum et al. (2015) used MV in the visual regime to identify feeding processes in fish tanks. The MV system was trained to identify fish eating at the water surface, and detection included matching a correlation filter and secondary filtering by SVM (support vector machine) classification (Atoum et al., 2015). Zhou et al. (2017b) introduced the MV system to monitor feeding processes by near-infrared imaging. Fukunaga et al. (2015) used MV to solve occlusions while tracking ornamental medaka (*Oryzias latipes*) fish. Individuals with occlusions were identified by means of fitting to a Gaussian mixture model. Pérez-Escudero et al. (2014) presented the IdTracker, which tackles the occlusion problem by identifying all individuals separately in every frame. Recognition of individual fish was previously shown by Matai et al. (2012), using the scale-invariant feature transform (SIFT) algorithm.

Other tasks may justify use of a relatively expensive system based on

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Abbreviations: FOV, field of view; MV, machine vision; SNR, signal-to-noise ratio; NA, numerical aperture

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camera and MV computation power, required for a real time solution. However, such an investment is considered overkill for simple counting. Hernandez-Ontiveros et al (2018) used a Raspberry Pi inexpensive computer to count batches of fish in an aquarium. It took 230 s to process an image, This is too long for counting fish as they pass quickly through a detection chamber.

Manual counting is done in many ways, one of which is placing many fish on a wet tray mounted above a water tank and pushing small groups of 3–5 fish into an outlet while adding the numbers and memorizing the count. This operation is sometimes combined with an inspection and sorting operation. Due to known manual counting errors, farmers instruct workers to count 3–5% more than the planned counts, in order to avoid marketing deficiencies. A slow water flow flows on the tray and drains through the outlet while carrying the counted fish. A tube connected to an outlet leads the counted fish to a floating basket. The water flow in the tube is shallow and does not fill the tube.

To count the fish sliding through such a tube, one may suggest a counting chamber based on a simple transmitter receiver scheme, in which a narrow optical beam source mounted on one side of the tube is directed to a detector on the other side. Each time the beam is crossed by a passing fish, the signal change is counted. This scheme works well in a homogeneous medium such as a tube completely filled with water (Mann and Jensen, 1961). However, in partially filled tubes the water fluctuates and reflects the light to random directions, away from the detector, thus, preventing proper functionality of such a simple optical detector.

The goal of the presented work was to develop a simple in-line, low-cost and real-time optical fish-counting system for integration with common ornamental fish farm practices. To meet this challenge, we present a single detector based on optical and signal-processing scheme that relaxes the influence of water fluctuations on the optical detector's reading by engineering the field of view (FOV) in a way that concentrates a wide light beam. The resulting relaxed signal is post-processed in short frames to allow quick and efficient counting of fish of various sizes.

2. Material and methods

2.1. The proposed concept

Under typical commercial conditions fish slide along a tube passing through an optical detection chamber. The optical detection chamber consists of two clear windows mounted on opposite sides of the tube, one on the light source side and the other on the detection side (Fig. 1a). Since the tube is only partially filled with water, the water surface fluctuates randomly. Light from a LED source (A) propagates towards the detector (H), either directly or reflected from a reflector (B). In the absence of fish, the light reaches the window on the detector side (F) either directly, or scattered from the chamber walls (D), or reflected from the water surface (E). It reaches the detector either as scattered light (R1) or directly (R2) into the FOV of the optical system (G). When a fish crosses the detection chamber (Fig. 1b), it block some of the rays, creates a shadow on the detection FOV and darkens the detector. Such a shadow triggers the detector's electrical gate.

2.2. The optical model

The side silhouette of the fish is modeled as an opaque rectangle $f(x,y)$ of length L (in the flow direction x) and height H (in a perpendicular direction y):

$$f(x, y) = R\left(\frac{x}{L}\right)R\left(\frac{y}{H}\right). \tag{1}$$

The water flow in the tube is assumed to be shallow. For the sake of presentation simplicity, a rectangular detection window (H) of Wx and Wy dimensions is assumed. In the absence of fish in the detection chamber, the window is fully illuminated (Fig. 1a), such that:

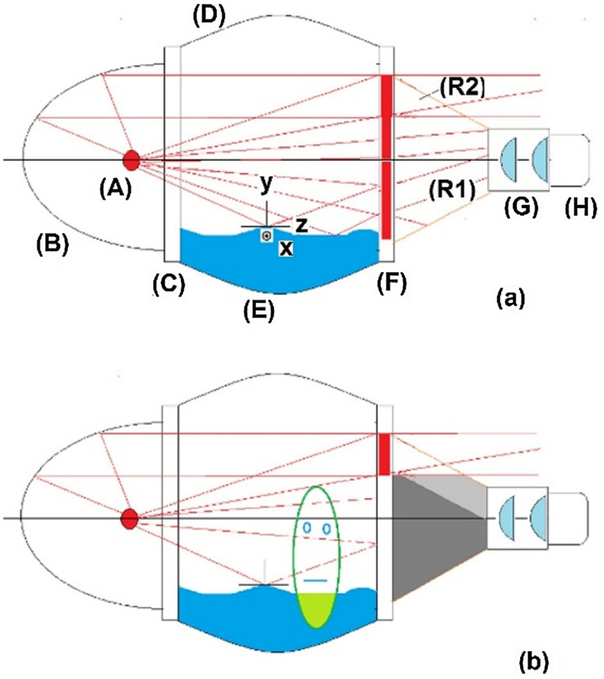

Fig. 1. A cross section of the detection chamber in absence (a) and presence (b) of fish. (A) LED; (B) Reflector; (C) window; (D) Upper tube wall; (E) Tube bottom; (F) Detection window; (G) Lens system; (H) Detector; (R1) Scattered light; (R2) Direct light.

$$W_{in}(x, y, t) = R\left(\frac{x}{Wx}\right)R\left(\frac{y}{Wy}\right)(I + N(x, y, t))\left[\frac{W}{m^2}\right] \tag{2}$$

where $R(x/W)$ is a rectangular function with width equal to W, I is the average illumination and $N(x,y,t)$ is the fluctuations due to random reflections of the reflected light (a detailed account of the contribution and nature of the reflections is elaborated further on).

The fish location (x_f) relative to the window is:

$$x_f(T) = \int_0^T v(t)dt. \tag{3}$$

where $v(t)$ is the fish sliding speed. When a fish is present in the chamber (Fig. 1b), it partially shades over the window. Neglecting detection noise, in the presence of fish, the illumination level as a function of time (t) denoted E_{fish} is:

$$E_{open} = \underbrace{\int_0^{W_x}\int_0^{Wy} R\left(\frac{x}{Wx}\right)R\left(\frac{y}{Wy}\right)(I + N(x, y, t))\, dxdy}_{\text{"“"OpenApp"”"}}$$

$$E_{shaded} = \underbrace{\int_0^{\infty}\int_0^{H} R\left(\frac{x}{Wx}\right)R\left(\frac{y}{Wy}\right)(I + N(x, y, t))\cdot f(x - x_f, y)dxdy}_{\text{"“"ShadedApp"”"}}$$

$$E_{fish}(x_f(t)) = E_{open} - E_{shaded} \tag{4}$$

The first part of this expression (E_{open}) expresses the illumination energy on the detection window when there is no fish in the chamber. The second part (E_{shaded}) expresses the shade caused by the fish as it progresses through the chamber. E_{open} is a summation of a constant term (E_I) and a temporal term (E_N):