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Automated sorting for size, sex and skeletal anomalies of cultured seabass using external shape analysis

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ABSTRACT

In aquaculture, automation of fish processing by computer vision could reduce operating costs, improving product quality and profit. Currently fish are mechanically sorted by size, but market constraints require that externally malformed fish be removed as well. Additionally fish farmers screen for sex, in order to exploit the higher growth potential of females. The aim of this study was the development of methodological tools applicable to the on-line sorting of farmed seabass (*Dicentrarchus labrax*, L.) for size, sex and presence of abnormalities. These tools are based on image analysis and utilizing outline morphometry (Elliptic Fourier analysis) combined with multivariate techniques (based on partial least squares modelling). Moreover, the integration of these techniques produce size estimation (in weight) with a better regression efficiency ($r = 0.9772$) than the commonly used log of the measured body length ($r = 0.9443$). The two partial least squares discriminant analysis models used to select sex and malformed fish also returned high discrimination efficiencies (82.05% and 88.21%, respectively). The implementation of a similar approach within an on-line sorting machine would allow for real-time live fish processing.

1. Introduction

In aquaculture, fish grading is an important and frequent operation. The most frequent grading is size grading, which is often performed repeatedly during the rearing cycle. This ensures homogenous sized batches of fish, as even fish of the same age typically have a high variability in body weight (15–40% coefficient of variation, vs 7–10% in poultry or pigs; Gjedrem and Olesen, 2005). More homogeneous groups simplify feed management (e.g., similar pellet size) and reduce risks for cannibalism (Kubitza and Lovshin, 1999). Also for marketing, it is necessary to sort fish according to size, not only because "standard" sizes are requested by the market, but because size uniformity is essential for efficient automated processing (Biyowski and Dutkiewicz, 1996).

Morphological, and in particular skeletal anomalies, represent one of the main bottlenecks in aquaculture: they affect production with frequencies of deformed fishes ranging between 30% and 100%, according to the species, rearing system and life stages considered (see review in Boglione and Costa, 2011). Fish affected by severe skeletal anomalies cannot be marketed whole, as they may harm the consumer's image of aquaculture products, and often must be downgraded to filets or fish meal with loss of profit (Le Vay et al., 2007; Lijalad and Powell, 2009). Moreover, automated filleting is hampered in fish with severe vertebral anomalies (Branson and Turnbull, 2008). Skeletal anomalies are usually detected by external observation in the farm, but using this approach only fish with severe anomalies (affecting the external shape of fish) could be detected and removed. Removing anomalies early in a growth cycle could increase production efficiency. Thus, cost-efficient methods for automated sorting of living deformed fish need to be developed.

In addition to these routine management practices (size grading to standardize the product and culling anomalous fish), the recent development of selective breeding raises new sorting issues. Selective breeding in fish can lead to important gains in growth (5–25% *per* generation; Gjedrem and Thodesen, 2005; Vandeputte et al., 2009b) but a large part of this efficiency is linked to the ability to carry out early intense selection for fast growing individuals (Vandeputte et al., 2009a). This means that selective breeding procedures will often implement repeated sorting of thousands or even tens of thousands of fish. This sorting has to be accurate in order to get the full benefit of the high selection pressure.

Abbreviations: CS, Centroid size; EFA, Elliptic Fourier analysis; G, Gray scale channel; HSV, Hue, Saturation, Value colour space; LV, Latent vectors; PLS, Partial least squares modelling; PLSDA, Partial least squares discriminant analysis; RPD, Ratio of percentage deviation; RMSE, Root mean square error; SEP, Standard error of prevision; V, Value channel in the HSV colour space.

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Separating males from females is important for selective breeding in the seabass (*Dicentrarchus labrax*), a species without a clear morphological sex dimorphism. In this species, females are 20–30% larger than males (Saillant et al., 2001) but cannot be externally recognised. In selective breeding, selection has to be applied to both males and females to realize maximal efficiency, and rapid sorting of males from females would therefore be very important to optimize breeding schemes in the sea bass. Today, selection for body size is performed without knowledge of the phenotypic sex of the individuals, and males and females can only be separated when they are all sexually mature at 2–3 years of age, with potential problems due to the rather biased (often >75% males) and unpredictable sex-ratio of farmed sea bass batches, a consequence of a complex sex determination system with both environmental (Piferrer et al., 2005) and genetic (Vandeputte et al., 2007) influences. Therefore, the automation of fish processing by computer vision, could contribute to improve the final product quality (Arnarson et al., 1988), the sale gains (Pau and Olafsson, 1991) and the ability to conduct efficient selective breeding programs. Although a huge variety of examples using computer vision in food industry have been reported (Panigrahi and Gunasekaran, 2001), the use of computer vision in automation of the fish farming industry is still limited but increasing (reviewed by Mathiassen et al., 2011). Sizing fish is often conducted by sieving-based machinery (SDK Poland; AquaMaof Technologies, Israel) (Booman et al., 1997), and only a few systems are integrated with a computer vision approach (McCarthy, 1988). For sizing operations Strachan and Nesvadba (1990) estimated fish weight with an accuracy of at least 95%. 2D-imaging using area and other 2D-geometrical measurement features has been used to estimate the weight of several species of fish, including different species of Pacific salmon (genus *Oncorhynchus*; Balaban et al., 2010a), Alaskan pollock (*Theragra chalcogramma*; Balaban et al., 2010b), and rainbow trout (*Oncorhynchus mykiss*; Gümüş and Balaban, 2010). High-speed estimation of volume and size of whole fish and processed fish can be made using 3D-imaging Marelec Vision Graders (Marelec Food Technologies, Nieuwpoort, Belgium). Grading fish quality with machine videos is based, for example, on fish fillet colour (Misimi et al., 2006; Quevedo and Aguilera, 2010). Large defects, such as damaged fish, different fish species and/or positioning, may be detected and controlled by the filleting machine, thus allowing for diversion of defective or incorrectly oriented fishes in order not to fillet them. Similar solutions are delivered by Cabinplant (Cabinplant A/S, Haarby, Denmark), Baader (Nordischer Maschinenbau Rud.Baader GmbH, Lubeck, Germany) and Avanti Engineering (Avanti Engineering AS, Mo i Rana, Norway) (reviewed by Mathiassen et al., 2011). Otherwise, fish grading for skeletal anomalies (at market size) and sex are not available at all.

The aim of this study was the development of methodological tools applicable to the on-line sorting of farmed seabass for size, sex and presence of anomalies. These tools are based on image analysis and utilize outline morphometry (Elliptic Fourier analysis, EFA) combined with multivariate modelling techniques (partial least squares modelling, PLS). The implementation of a similar approach within an on-line sorting machine should allow real-time fish processing.

2. Materials and methods

2.1. Fish sampling

European seabass utilized in this study came from a batch comprised of crosses of 5 different wild populations, as described in details by Costa et al., 2010. Fish were reared in sea cages in tropical sea waters (20–28 °C) off Israel (ARDAG Fish farm, Eilat). When an estimated 250 g mean weight was reached, a random sample of 259 fish was individually photographed live, weighed to the nearest 0.1 g (mean sample weight ± standard deviation was 253.73 ± 79.17 g) and dissected. Spine anomalies were assessed by visual inspection of the vertebral column after removal of the left fillet. A further characterization of anomalies was done by manually measuring the angle between the antero-posterior axis (the axis passing through the mouth and the middle fish height) and the axis of the caudal peduncle (traced following the posterior part of the lateral line) on the photographs (see below), as shown in Fig. 1. Sex was determined by visual inspection of the dissected gonads, resulting in 179 males and 80 females.

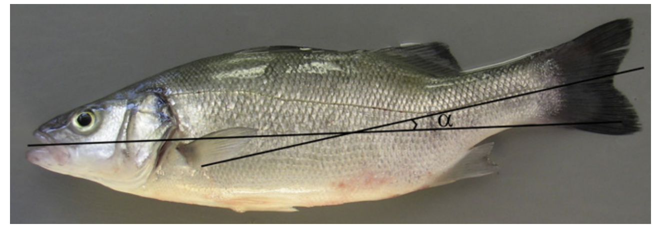

Fig. 1. Angle α characterizing the severity of axis anomalies (mainly lordosis), defined as the angle between the antero-posterior axis evaluated on the first half of the fish and the axis of the caudal peduncle.

2.2. Image processing

For each fish, a digital image (JPG format, 24-bit) was acquired at high resolution (180 d.p.i.; 6 Mpixel) using a Canon PowerShot S50 digital camera. Each fish was placed in the left side position on a white dashboard for greater contrast (Antonucci et al., 2012), with a metric reference. Each image was converted to a binary image using Matlab (Fig. 2). The images were transformed utilizing two channels: gray scale (G) and the V (Value channel in the HSV colour space). These two parameters are the most informative channels for these specific photographic conditions. A background reference value was sampled averaging the G and V channels for the pixel group having the mean value between G and V less or equal (darker pixels) to the 5th minimum percentile (>0). The Euclidean distance of each pixel from the background reference was calculated. The first and last percentile values were discarded. The entire matrix was thus rescaled from 0 to 255. An edging 'canny' (Canny, 1986) Matlab operator was adopted to binarize the image. The Canny operator works in a multi-stage process, smoothing the image by Gaussian convolution and applying a simple 2D first derivative operator to highlight regions with high first spatial derivatives. Finally one 'dilate' (size 3) and one 'fill' morphological filters were applied.

A total of 200 equally spaced points (x, y) were digitized along the outline with the software TPSdig2 (Rohlf, 2006) computed by linear interpolation along the curve. Coordinates were aligned by generalized Procrustes analysis, a procedure that consists of three steps: the translation of point coordinates to a common centroid located at the origin (0, 0) of a reference system of coordinates, the scaling of each outline with the unitary centroid size; the rotation of coordinates to minimize the sum of square distances between correspondent landmarks (Bookstein, 1991; Antonucci et al., 2012). The 200 aligned coordinates were treated as the outline (Menesatti et al., 2008).

The overall shape of each fish was analyzed by Elliptic Fourier Analysis (EFA) on the outline coordinates (Rohlf and Archie, 1984) (Fig. 3). The outline can be approximated by a polygon of x–y coordinates. EFA is based on the separate Fourier decompositions of the incremental changes of the x and y coordinates as functions of the cumulative chordal length of the outline polygon (Costa et al., 2011a). The Fourier series was truncated at the value of k at which