Computers and Electronics in Agriculture 150 (2018) 52–61

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Original papers

Enhanced fish bending model for automatic tuna sizing using computer vision

P. Muñoz-Benavent[a,*], G. Andreu-García[a], José M. Valiente-González[a], V. Atienza-Vanacloig[a], V. Puig-Pons[b], V. Espinosa[b]

[a] Institute of Control Systems and Industrial Computing (AI2), Universitat Politècnica de València (UPV), Camí de Vera (s/n), 46022 València, Spain
[b] Institut d'Investigació per a la Gestió Integrada de Zones Costaneres (IGIC), Universitat Politècnica de València (UPV), Camí de Vera (s/n), 46022 València, Spain

A R T I C L E I N F O

Keywords:
Underwater stereo-vision
Computer vision
Fisheries management
Automatic fish sizing
Biomass estimation

A B S T R A C T

This paper presents a non-invasive fully automatic procedure to obtain highly accurate fish length estimation in adult Bluefin Tuna, based on a stereoscopic vision system and a deformable model of the fish ventral silhouette. The present work takes a geometric tuna model, which was previously developed by the same authors to discriminate fish in 2D images, and proposes new models to enhance the capabilities of the automatic procedure, from fish discrimination to accurate 3D length estimation. Fish length information is an important indicator of the health of wild fish stocks and for predicting biomass using length-weight relations. The proposal pays special attention to parts of the fish silhouette that have special relevance for accurate length estimation. The models have been designed to best fit the rear part of the fish, in particular the caudal peduncle, and a width parameter has been added to better fit the silhouette. Moreover, algorithms have been developed to extract snout tip and caudal peduncle features, allowing better initialization of model parameters. Snout Fork Length (SFL) measurements using the different models are extracted from images recorded with a stereoscopic vision system in a sea cage containing 312 adult Atlantic Bluefin Tuna. The automatic measurements are compared with two ground truths: one configured with semiautomatic measurements of favourable selected samples and one with real SFL measurements of the tuna stock collected at harvesting. Comparison with the semiautomatic measurements demonstrates that the combination of improved geometric models and feature extraction algorithms delivers good results in terms of fish length estimation error (up to 90% of the samples bounded in a 3% error margin) and number of automatic measurements (up to 950 samples out of 1000). When compared with real SFL measurements of the tuna stock, the system provides a high number of automatic detections (up to 6706 in a video of 135 min duration, i.e., 50 automatic measurements per minute of recording) and highly accurate length measurements, obtaining no statistically significant difference between automatic and real SFL frequency distributions. This procedure could be extended to other species to assess the size distribution of stocks, as discussed in the paper.

1. Introduction

Monitoring of wild fish stocks and inspection in aquaculture require extremely gentle handling of the target to avoid damage, but traditional sampling methods are usually invasive, expensive, time-consuming and laborious. Optical sensors and machine vision systems have proven to be very appropriate for developing faster, cheaper and non-invasive methods to work with live fish (in situ), as reported in recent years (Zion, 2012), (Shortis et al., 2016), (Mallet and Pelletier, 2014), (Boutros et al., 2015), (Hao et al., 2015), (Saberioon et al., 2017).

Automatic identification of a single fish is an essential step in achieving a fully automatic sizing process. Body bending while swimming means that the same individual is observed with very different shapes, sizes and orientations, depending on the video frame. So, robust fish detection methods dealing with these variations are required (Lines et al., 2001), (Rosen et al., 2013), (Rahim et al., 2012), (Atienza-Vanacloig et al., 2016). In (Atienza-Vanacloig et al., 2016) a deformable adaptive model based on computer vision methods that automatically fit the body ventral silhouette of adult Bluefin Tuna (*Thunnus Thynnus*) while swimming was proposed. This model achieved very high success rates (up to 90%) discriminating individuals in complex images acquired in real conditions, but it was not strong enough to estimate sizes.

* Corresponding author.
E-mail addresses: pmunyoz@upv.es (P. Muñoz-Benavent), gandreu@upv.es (G. Andreu-García), jvalient@upv.es (J.M. Valiente-González), vatienza@upv.es (V. Atienza-Vanacloig), vipuipon@upv.es (V. Puig-Pons), vespinos@upv.es (V. Espinosa).

https://doi.org/10.1016/j.compag.2018.04.005
Received 31 January 2018; Received in revised form 29 March 2018; Accepted 3 April 2018
0168-1699/

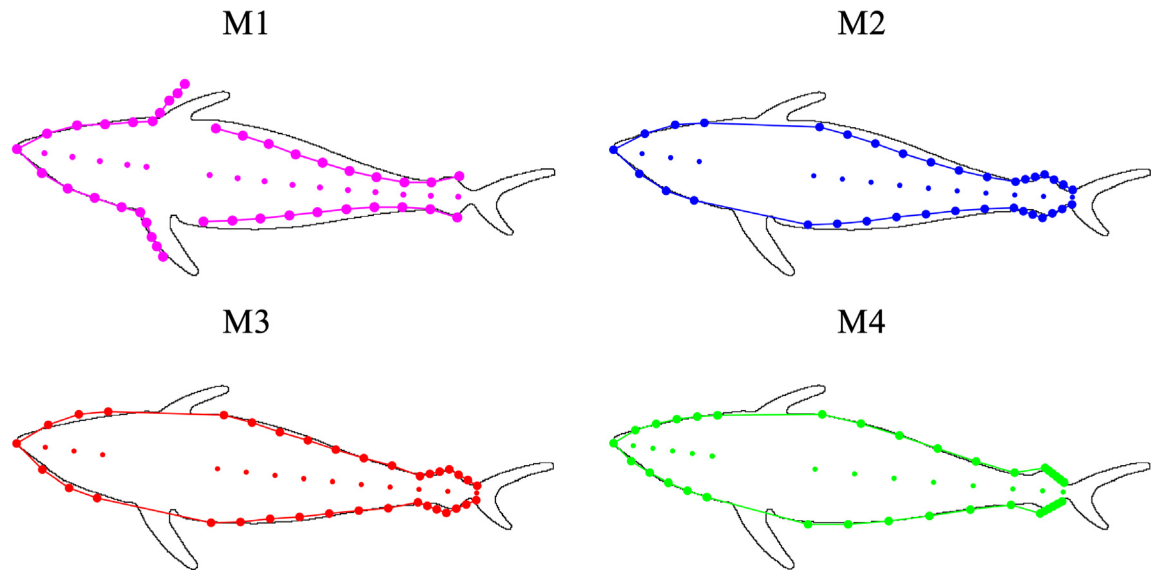

Fig. 1. Graphical representation of the four different geometric tuna models (**M1**, **M2**, **M3** and **M4**). Small dots representing model mid-body points and large dots representing model landmarks.

The purpose of this study is to define an effective geometric tuna model to automatically process the stereo videos and obtain accurate fish measurements. The present work takes the geometric model (**M1**) defined in (Atienza-Vanacloig et al., 2016) as a starting point and studies three new models (**M2**, **M3** and **M4**) to reach high similitude between models and real tuna silhouettes. Geometric models can provide a set of parameters and landmarks to capture the essential features of a tuna silhouette considering its variability. When the target has been identified and characterized in the images, 3D biometric measurements can be obtained from a calibrated stereo vision system. The models are compared from three points of view: quantity of successful fittings, computing time and accuracy of the length measurements.

To evaluate our proposals, fish length measurements using the different models are extracted from images recorded with a stereoscopic vision system under real conditions in Grup Balfegó growing farms, on the west Mediterranean coast. These measurements are compared with semiautomatic measurements of selected samples and with true data from Snout Fork Length (SFL) measurements of the tuna stock collected by Grup Balfegó at harvesting. The results confirm the potential of our fully automatic sizing method, which could be applied to monitor fish in aquaculture for growth management purposes and biomass estimation in fish transfers between cages and to monitor wild fish stocks.

1.1. State of the art

A variety of applications with optical sensors and machine vision systems have been developed to work in underwater conditions: fish sizing (Ruff et al., 1995), (Tillett et al., 2000), (Lines et al., 2001), (Harvey et al., 2003), (Costa et al., 2006), (Dunbrack, 2006), (Torisawa et al., 2011), (Letessier et al., 2015), (Williams and Lauffenburger, 2016); fish counting and sizing (Costa et al., 2009), (Rosen et al., 2013); fish sizing in combination with acoustic techniques (Sawada et al., 2009), (Espinosa et al., 2011), (Kloser et al., 2011); fish farm automation (Martinez-de Dios et al., 2003); wild fish stock assessment (Willis and Babcock, 2000), (Watson et al., 2009), (Harvey et al., 2012), (Langlois et al., 2012), (Seiler et al., 2012), (Zintzen et al., 2012), (Wakefield et al., 2013), (Santana-Garcon et al., 2014), (McLaren et al., 2015) and fish species classification (Hu et al., 2012), (Zion, 2012), (Huang et al., 2013), (Spampinato et al., 2010),(White et al., 2006).

Fish measurements, such as length, height and width, are commonly used for different purposes: as indicators of health in wild fish stocks (Dunbrack, 2006), (Shortis et al., 2016), (Rosen et al., 2013), (Shafait et al., 2017); for biomass estimation to control fishing quotas (ICCAT, 2015), to monitor growth rates in fish farms (Puig et al., 2012); and for fish sorting and grading (Hong et al., 2014), (Zion et al., 2007), (Hao et al., 2016), (Shafait et al., 2017). Measurements of live fish can be achieved with underwater stereoscopic vision systems, two cameras in a side-by-side arrangement, as recommended by the International Commission for the Conservation of Atlantic Tunas (ICCAT) in (ICCAT, 2015), to control catches for tuna farming. Nevertheless, vision sensors and image processing methods have to overcome difficulties such as limited visibility, temporal and spatial variations in lighting, varying distances and aspects between cameras and objects, motion and density of the monitored targets, and even lack of physical stability. Moreover, for the case of stereoscopic vision systems, the cameras must be synchronised to ensure temporal correspondence between both videos. In addition, underwater calibration of the system is required for accurate and reliable measurements. All these conditions represent a very demanding challenge, which have limited the development of fully automatic solutions. In fact, most of the aforementioned applications and the most widely used commercial systems for fish sizing, AQ1 AM100 (Phillips et al., 2009) and AKVAsmart, formerly VICASS (Shieh and Petrell, 1998), require human intervention in some of their stages, making the process slow and laborious, and introducing the variability of manual measuring. Some authors, such as (Lines et al., 2001), (Zion, 2012), (Shortis et al., 2016), (Atienza-Vanacloig et al., 2016), (Shafait et al., 2017), highlight the need for fully automatic methods for these tasks.

2. Geometric tuna models

Fish length and other features, such as bending angle, can be properly characterized using geometric models, since they are able to fit the tuna silhouette considering its variability due to different shapes, sizes and orientations. A geometric model for adult tunas (**M1**), formerly presented in (Atienza-Vanacloig et al., 2016) to discriminate individuals, is used in this paper to estimate fish length using a stereoscopic vision system. Based on that model (**M1**), three new models (**M2**, **M3** and **M4**) have been developed to improve the fit to the fish silhouette and the fish length estimation. Fig. 1 shows a graphical representation of these models.

The first main modification to model **M1** involves considering that areas with high variability, or with greater significance for providing accurate biometric measurements, should be represented by a greater