Journal of Experimental Marine Biology and Ecology 466 (2015) 120–126

Contents lists available at ScienceDirect

Journal of Experimental Marine Biology and Ecology

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

Low-cost small action cameras in stereo generates accurate underwater measurements of fish

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ARTICLE INFO

Article history:
Received 28 August 2014
Received in revised form 14 February 2015
Accepted 19 February 2015
Available online 7 March 2015

Keywords:
Body size
Length
Monitoring
Stereo-photogrammetry
Videography

ABSTRACT

Small action cameras have received interest for use in underwater videography because of their low-cost, standardised housing, widespread availability and small size. Here, we assess the capacity of GoPro action cameras to provide accurate stereo-measurements of fish in comparison to the Sony handheld cameras that have traditionally been used for this purpose. Standardised stereo-GoPro and Sony systems were employed to capture measurements of known-length targets in a pool to explore the influence of the type of camera, distance to camera rig, angle to the optical axis and target speed on measurement accuracy. The capacity to estimate fish length *in situ* was also compared by measuring the same fish on a coral reef with two baited remote underwater video systems, each fitted with both a GoPro and a Sony camera system. Pool trials indicated that the GoPros were generally less accurate than the Sonys. Accuracy decreased with increased angles and distance for both systems but remained reasonably low (<7.5%) at 5 m distance and 25° angle for GoPros. Speed of target movement did not result in any consistent decrease in accuracy. *In situ* measurements revealed a strong correlation ($R^2 = 0.94$) between Sony and GoPro length measurements of the same individual fish, with a slope not different from 1 and an intercept not different from 0, suggesting that GoPro measurement errors do not result in a consistent bias at the level of individual fish. Moreover, the investigation of kernel density functions of the length distribution of the entire fish assemblage indicated that difference in measurement accuracy becomes negligible for purposes of comparing population size structure. We suggest a measurement protocol for the use of GoPro stereo-camera systems that improves accuracy, where distance to target is limited to 5 m and angle to optical axis is restricted to 25°. For distances up to 7 m, angles should be restricted to 15°. This protocol supports the use of small action cameras such as the GoPro system, providing reductions in cost and increases in effective sampling efforts, compared with traditional rigs based on relatively expensive handheld cameras.

1. Introduction

Accurately measuring change in diversity, relative abundance and population characteristics is a key component of successful marine ecology and conservation. Body size is a particularly important phenotypic metric with a fundamental role in population ecology, providing insights to condition, physiology and behaviour (Peters 1986) and reflecting variability in age structure (Olsen et al., 2004), genetic variability (Olsen et al., 2009) and environmental conditions (Sarma et al., 2008). In marine fishes, size is also closely related to reproductive output and recruitment (Beldade et al., 2012). Moreover, size is a sensitive response to anthropogenic influences such as fishing (Olsen and Moland, 2010), climate change (Genner et al., 2010) and pollution (Farkas et al., 2003).

Low-cost, non-destructive methodologies that enable accurate size estimates of the individual animals that comprise marine communities are increasingly sought. Lethal sampling can be inappropriate if sampling: (1) inside no-take marine protected areas (MPAs); (2) rare or red listed species; (3) species that are restricted by quotas; or (4) in circumstances where the killing of animals to study them raises ethical questions. Traditional underwater visual census (UVC) has provided a wealth of coverage on shallow reef communities but is limited due to depth restrictions imposed by safe SCUBA practices and the need for highly specialised skills for *in situ* species identification and length estimation. In temperate and tropical reefs, stereo baited remote underwater video systems (BRUVS) are increasingly utilised to assess the diversity and abundance of fish over time and space (Harvey et al., 2007) and to assess impact of anthropogenic activity and management and conservation strategies (Mclean et al., 2011). Stereo-camera systems also provide relatively accurate estimates of individual body lengths (Harvey and Shortis, 1998) and thus

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http://dx.doi.org/10.1016/j.jembe.2015.02.013
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provide information related to fish population structure. Customised software (www.seagis.com) applies trigonometric principles and generates estimates of horizontal and vertical orientation (Letessier et al., 2013a), lengths of target (mm), 3-dimensional positioning (x, y, z coordinates) and angle to the optical axis. Estimates of lengths using stereo-BRUVS are demonstrably more accurate and precise than those derived using single cameras (Harvey et al., 2002b) and those estimated during UVC (Harvey et al., 2004).

A great strength of stereo-BRUVS is their ability to generate large data sets with extensive spatial coverage in relatively short time periods across a wide range of depths. For instance, up to 45 one-hour samples can be generated per day with the deployment of 15 individual rigs (Meeuwig, unpublished data), with typical surveys collecting on the order of >200 samples over a week of vessel time. Stereo-BRUVS do have a number of limitations including (1) the length of time potentially required to process video (Holmes et al., 2013); (2) undersampling of small (e.g., Pomacentridae), relatively cryptic (e.g., Apogonidae, Holocentridae) or similar (e.g., *Ctenochaetus striatus* vs *Ctenochaetus binotatus*) species (Mallet, 2014); and (3) general uncertainty surrounding the area of the bait odour plume, such that fish abundance is recorded as a proxy (MaxN) rather than as densities or biomass per square meter (but see Priede and Merrett, 1996). Nevertheless, stereo-BRUVS can cover large areas at a high temporal frequency and are very efficient at surveying highly mobile species such as large predators that are attracted by the bait. Such properties are particularly critical where animals are rare and patchily distributed as is the case for pelagic ecosystems (Letessier et al., 2013b) and/or where top-order predators are of interest. Sampling in these cases can require a high number of replicates for elucidation of spatial and/or temporal patterns. However, potential for broader adoption of stereo-BRUVS has been limited, in part, by costs associated with the acquisition of stereo-camera rigs (approx US$ 4500 per rig; www.seagis.com; accessed August 2014). This cost is primarily linked to the cost of purchasing customised housing and mid- to high range handheld video cameras.

Small action cameras such as GoPros are a relatively novel range of cameras that are receiving interest in their capacity to be used in underwater videography studies because they are of relatively low cost and because they are supplied with a standard underwater housing rated to 60 m. Housings rated to greater depth are also available commercially (see for example http://www.cam-do.com/GoProUnderwaterSolutions.html) such that the total cost of a stereo-camera rig based on GoPros is approximately $1300. Moreover, their shape and size make them well suited for use in stereo (Schmidt, 2012). As they are small and lightweight, they can also be easily and cheaply mobilised to remote field sites in large numbers, as well as fit to lightweight rigs (Letessier et al., 2013a). Moreover, GoPros in particular are widely available, which makes their adoption attractive. However, concerns have been raised with respect to their capacity to generate robust lengths estimate (Letessier et al., 2013a, 2013b), in part because they utilise rolling shutters and because they have curved 'fish-eye' lenses. Rolling shutters can distort the image during moments of rapid motion (Liang et al., 2005), and fish-eye lenses result in greater field of view than flat lenses, but with a barrel distortion, where magnification decreases with distance to the optical axis (Shah and Aggarwal, 1994).

Here we assess the capacity of stereo-GoPros to accurately measure lengths compared with a traditional Sony-based stereo rig using two experimental approaches:

1. Standardised stereo-GoPro and Sony systems were employed to capture measurements on targets of known lengths in a pool to explore the influence of camera system, distance to camera system, angle to the optical axis and target movement speed on accuracy of length measurements. This experiment was aimed at determining the technical limits of both camera systems to measure size underwater.
2. Two BRUVS rigs, each fitted with a GoPro and Sony camera system, were deployed on a coral reef, in order to estimate the lengths of fish appearing simultaneously in the sampling fields of both camera systems. This experiment aimed at determining the capacity of both systems to measure fish size in real conditions of use at sea based on a standard BRUVS protocol.

2. Methods

2.1. Camera systems

Our assessment of stereo-measurements accuracy were conducted using Sony HDR-CX12 and GoPro Hero 2 cameras, both in pool and on a coral reef. Cameras on each stereo pair system were situated 800 mm apart, with an inward convergent angle of 8°. GoPros were set to record at medium field of view (127°), 1080p and 30 FPS. The vertical field of view is set at 93°. Sonys were recording at 1080p, set at 30 FPS, with a horizontal field of view of 68.8° and a vertical field of view of 46°. Both systems were calibrated prior to the experiment using a standard calibration cube (SeaGIS, 2008). Images between each stereo-camera pair were synchronised by reference to a clapperboard clapping three times. Measurements were conducted using the EventMeasure software (SeaGIS, 2008) following the protocol outlined in Mclean et al. (2011).

2.2. Pool trial

A series of measurements was conducted inside a freshwater pool at the University of Western Australia using a Sony and a GoPro camera system. Our pool-based trial was specifically designed to determine whether GoPros can be used for stereo-measurements and to identify conditions in which accuracy could be improved. Measurement accuracy—how close the measurement is to the actual value —was reported as the ratio of the measured length over the known length of the target (St. John et al., 1990). The error was derived by subtracting the accuracy from 1. Since we were interested in the magnitude of the error, the absolute value reported and used hereafter.

A series of measurements was conducted using fixed target lengths of 50, 100, 200, 300, 400, 500, 600, 700, 800 and 900 mm and were taken at 1, 2, 3, 4, 5 and 7 m distance. The targets were always presented perpendicular to the optical axis. The lengths of the targets were chosen as representative of typical body lengths of fish observed on reefs. The cutoff of 7 m was chosen because measurements of fish further away are already conventionally discarded as part of the EventMeasure BRUVS stereo-measurement standard protocol due to water visibility, fish detectability and camera accuracy issues in real conditions of use at sea (http://www.seagis.com.au/event.html). Each fixed length target was composed of several lengths of black masking tape upon a white board. Measurements of fixed targets were also conducted at different angles from the optical axis (from 0° to 40°, Fig. 1), which varied with distance to the camera systems (Table 1). Half the measurements were conducted to the left, and half to the right from the optical axis.

To explore the effect of target movement speed on the accuracy of camera measurements, a series of measurements were conducted while moving the targets at speeds of 0.4 m/s (slow), 0.9 m/s (medium) and 1.4 m/s (fast), speeds that are typical of fish observed on stereo-BRUVS in the field. Measurements were conducted at 3 and 5 m distance, between a 0° and 40° angle. The target speeds were achieved by manually increasing the speed at which the target was moved. Attempts were made to keep the speeds consistent. Replicated movements ($n = 9$) showed relatively high accuracy was achieved (coefficient of variation = 0.16, 0.25 and 0.21 for 0.4, 0.9 and 1.4 m/s respectively) by the operators.

Measurements of each target were taken at each distance and angle (Fig. 1) for each camera system, by two different video-analysts in order to assess inter-observer error. EventMeasure provides an internal measure of accuracy, in the form of residual mean square (RMS, Letessier et al., 2013b), which calculates the difference between the predicted