Implementing parallel-paired lasers in on board camera systems for data collection in crustacean fisheries

Giulia Cambiè, Michel J. Kaiser, Graham Monkman, Jan Geert Hiddink, Ben Powell

School of Ocean Sciences, College of Natural Sciences, Bangor University

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Introduction

The introduction of the Marine Strategy Framework Directive (MSFD) and the reform of the Common Fishery Policy (CFP) are require EU member states to commence and/or improve data collection for data poor species. Even with the result of the UK referendum, there will still be a requirement to meet these reporting obligations and standards. While quota species are generally characterised by regular monitoring programs, which combine fishery dependent and independent data, however most of the commercially important non-quota species are usually data deficient. This data deficiency is particularly acute in shellfisheries such as those for brown crab, lobster, whelks and scallops. While the implementation of data collection programs is essential to provide indicators of the state of commercially exploited stocks, diminishing public resources and an increasing burden of evidence collection has highlighted to the need to consider technological solutions as an alternative to traditional methods of data collection.

Currently, for most inshore shellfish fisheries, data collection relies on self-reporting of landings, point of first sale data, port sampling, and on-board sampling by fisheries officers. On-board observers and scientific vessel surveys collect detailed data, but they are expensive and time-consuming. The use of on-board camera systems to collect data has been tested in fisheries targeting shellfish (Hold et al., 2015). Camera systems were found to be a reliable and accurate method for collecting data on the size and sex of crabs and lobsters. Future computer automation of image extraction and measurements should increase the application of video cameras for data collection and ensure a widespread adoption of such data collection systems.

Before it is possible to consider the development of automated software systems to measure animals in the field of view, a reliable mechanism is needed to eliminate errors associated with depth of field linked to the variable distance between the animal and the background reference scale included in the field of view (Hold et al., 2015). This distance is influenced by fishers, who may pass the catch across a defined area under the camera at varying heights, and by the animal's body depth. The use of parallel-paired lasers coupled to video cameras may be a simple and accurate method to obtain precise estimates of animal size from camera images (e.g. Bergeron 2007; Deakos, 2010).

The aim of the present study was to test if the use of parallel-paired lasers improved the accuracy of the measurement of crustacean size [lobster (*Homarus gammarus*) and brown crab (*Cancer pagurus*)] in inshore pot fisheries operating in Welsh waters (UK). If this is the case, parallel-paired lasers would be an important improvement in the initial data collection prior to development of software to automate image extraction and measurements.

Material and methods

Camera system, equipment and at-sea data collection

The camera system comprised a Nextbase camera model 512G with an incorporated GPS, which allowed the latitude and longitude of the fishing location and the corresponding time to be displayed in the video. The camera was set to video mode at 1280 × 720 pixel resolution at 30 frames per second. The system was encased in a waterproof box, with a window against which the camera lens rested. Two parallel-paired lasers (Odiforce, 3-5mW Green Laser Module) separated by a known distance were mounted onto the box and projected through the window. When the videos were taken, the laser projections on the target species provided a scale bar. The camera system was connected to an external portable battery and installed on board two fishing vessels, at ~80 cm distance from the measuring board. The exact configuration of the mounting system was finalized only after detailed discussion with each fisher (Figure 1) taking account of operational and safety issues relevant to normal working practices.

Three surveys were undertaken on board the two fishing vessels, two near to Hell's Mouth (Llyn Peninsula, North Wales) and one close to Cardigan (Mid Wales) (Figure 2). In two surveys the lasers projected on the animals' body appeared as green dots while in one survey they appeared as green lines. However during this last survey, a technical problem prevented the video recording. During the on board observations, fishers were asked to pass the catch across a defined area of a measuring board mounted under the camera (Figure 1). This board was characterized by a coloured background, composed of 1 x 1 cm green (RGB (0, 255, 0)) squares alternated to 1 x 1 cm magenta (RGB (255, 0, 255)) squares. These colours were chosen to maximise the contrast between the background and the animals' body, as an essential step prior to the development of automatic measurement program software (in progress).

Lobsters and crabs were measured and sexed in situ by a single scientist after being passed under the camera system. The following data were recorded: carapace length (CL) and sex of lobsters; carapace width (CW) and sex of brown crabs. Length and width measurements were taken to the nearest millimetre using Vernier callipers. Lobsters were sexed by observing the first of the sexually dimorphic pleopod pairs. Crabs were sexed by observing the abdominal flap shape and size.

Figure 1. Camera system installed on board two fishing vessels, one operating off Hell's Mouth (Llyn Peninsula, North Wales) (left) and one fishing in Cardigan Bay (Mid Wales) (right). The square pattern measuring board is shown with the camera mounted in the grey box. The 'on/off' red switch is clearly visible to allow fishers to operate the system manually.

Video analysis and statistical analysis

Videos were analysed using VLC media player version 2.1.3. From a subsample of the videos a total of 154 animals were analysed comprising 73 brown crabs and 81 lobsters. Still images were extracted from the video footage using the VLC snapshot feature. Still images were then analysed in ImageJ version 1.43. The distance between the two laser dots (10 cm and 9.3 cm for the two camera systems implemented on board the two fishing vessels) was first measured. When possible, CL (lobster) and CW (brown crabs) of each animal was calculated twice, using two different reference scales. The first reference scale was the distance between the two laser dots and the second one was the distance between 10 consecutive squares on the measuring board (10 cm). For some footage (n = 45, 18 lobsters and 27 brown crabs) only the measurement using the board as reference scale was taken, because the lasers' light was not visible, due to the brightness sunlight reflected from the animal's body (Figure 3). A comparison between the two measurements ("laser" versus "board" as reference scales) and those taken on-board by the scientific observer (named "real") was performed using linear regression. In addition the difference between the measurement obtained from the video and the measurements made using the scale on the reference board was plotted against the measurement obtained by the scientist on-board the vessel to assess the presence of any significant difference from a slope of zero. Finally a quadratic model (1, 2) was performed and compared to the corresponding linear model, to assess if the predictive model used by Hold et al (2015) was still the best option.

$$\text{Real CW} \sim \text{Video CW} + (\text{Video CW})^2 \qquad (1)$$

$$\text{Real CL} \sim \text{Video CL} + (\text{Video CL})^2 \qquad (2)$$

Figure 2. Map showing the location of the at-sea surveys conducted on board two inshore fishing vessels during May and June 2016.

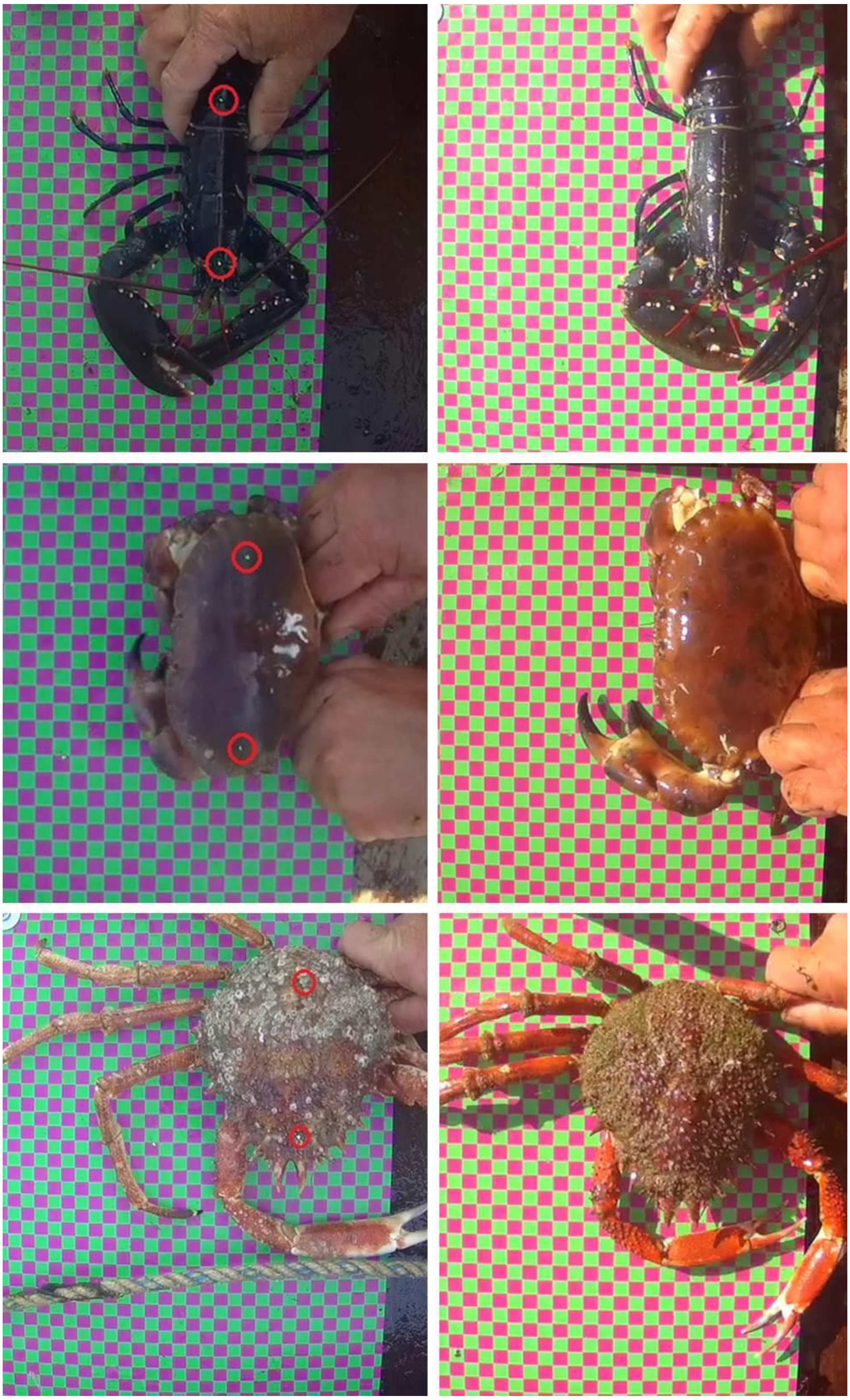

Figure 3. Pictures of lobsters (top) brown crabs (middle) and spider crabs (bottom) when the lasers dots are visible (left) and when they were not visible due to bright sunlight conditions (right). Pictures of spider crabs have been taken only to show the potential problems in identifying the green laser dots on species other than the target species (lobster and brown crab).

Results

During the three surveys a total of 808 individuals were caught. Commercial species that were encountered included brown crabs, lobsters, spider crabs and whelks, representing altogether 88% of the total catch in number (Figure 4). The sex ratio (n. of males/(n. of males + n. of females)) was estimated for the main target species, brown crab (sex ratio = 0.38) and lobster (sex ratio = 0.41). 10.1% of lobsters were ≥ the Minimum Landing Size (MLS) (90 mm CL) and 56.6% of brown crabs were ≥ MLS (140 mm CW).

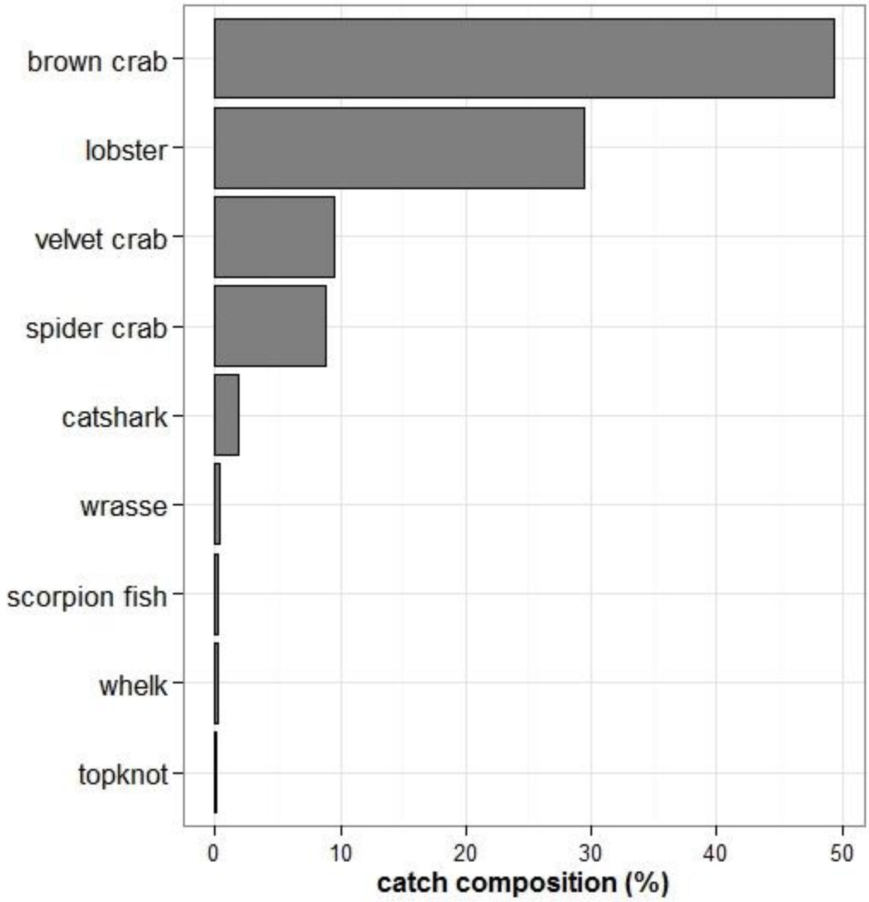

Figure 4. Catch species composition and the percentage contribution (in numbers) for the three fishing operations with pots observed during May and June 2016.

The analysis of individual organisms from the video footage (73 brown crabs and 81 lobsters) showed a difference in the size estimates depending on the reference scale that was used (lasers vs board) (Figure 5). For both species, the size of animals obtained by using the lasers as the reference scale was much more precise than the size obtained from the board. In particular, the slope of the relationship "Video size ~ Real size" was always better (closer to 1 = perfect fit) using the lasers as the reference scale (Table 1).

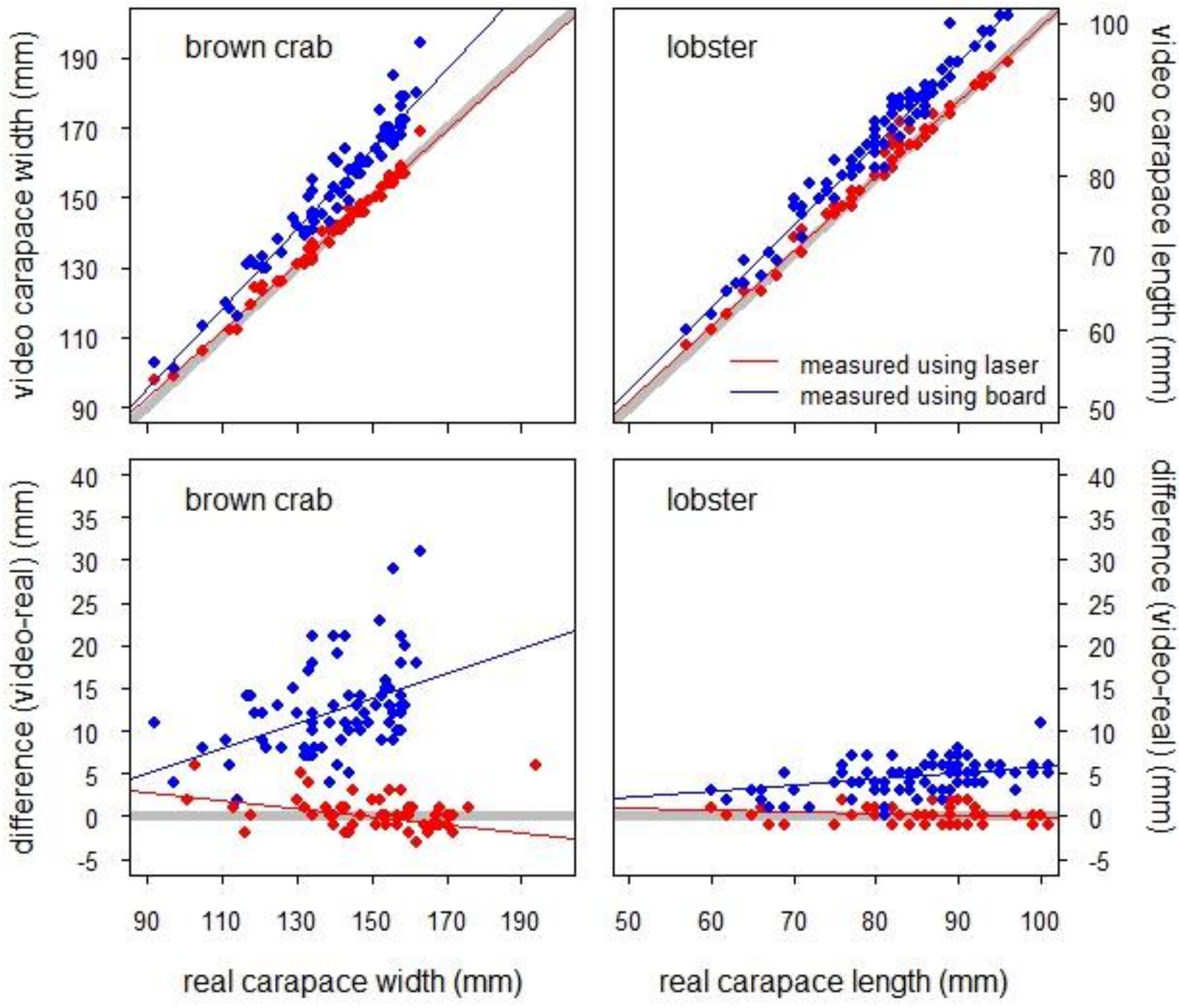

Figure 5. Top: Relationship between animal size measured from the video and those measured on board for brown crab (top left) and lobster (top right). The grey line is the diagonal of the quadrat and represents the perfect relationship (slope =1 and intercept =0). Bottom: Relationship between animal size measured on board and the difference between the animal sizes measured from the video and those measured on board for brown crab (bottom left) and lobster (bottom right). The difference between the animal sizes measured from the video and those measured on board should tend to zero (grey line). Animals measured from the video using the board as reference scale are indicated with blue points and the blue line is the corresponding linear relationship. Animals measured from the video using the laser as

reference scale are indicated with red points and the red line is the corresponding linear relationship.

This trend is also confirmed by the relationship "(Real size -Video size) ~ Real size", which showed a slope closer to zero when using the lasers as the reference scale. In particular for lobster the slope of this last relationship was not significantly different from zero, demonstrating that the measurements obtained using the lasers were not significantly different from the measurement obtained on board. For brown crab the slope of the relationship "(Real size -Video size) ~ Real size" was closer to zero when using the lasers as reference scale rather than the board. However in this case the slope was significantly different from zero, possibly due to few outliers characterised by a value "Real size -Video size" greater than 5 mm (Figure 5). These outliers were possibly caused by the error associated with the estimates from the video images for which resolution was not optimal (Figure 6) and not from the on board measurement. Our results show that an error is introduced when measuring an animal from an image but this error is small or not significant when the lasers dots represent the reference scale. By using the board as the reference scale a bigger error is introduced. This error can be corrected through specific calibrations (see Apprendix 1), but not the variation associated with the measurement, which is bigger by using the board rather than the laser, as demonstrated by the standard deviation of the model residuals (Table 1).

*Table 1. The intercept, slope, standard deviation (SD) of the model residuals of the linear relationships between the measurements derived from the video (with lasers or the board as the reference scale) and those obtained on board (real) for brown crabs and lobsters. *, p-value ≤ 0.05; **, p-value < 0.01; ***, p-value < 0.001.*

Species	**Ref. scale**	**Linear relationship**	**Intercept**	**Slope**	**SD (residuals)**
b. crab	laser	Video CW ~ Real CW	7.08**	0.95***	1.8
b. crab	board	Video CW ~ Real CW	-8.04	1.15***	4.8
b. crab	laser	(Real CL -Video CL) ~ Real CL	7.08**	-0.05**	1.8
b. crab	board	(Real CL -Video CL) ~ Real CL	-8.04	0.15***	4.8

lobster	laser	Video CL ~ Real CL	2.07	0.98***	1.2
lobster	board	Video CL ~ Real CL	-1.07	1.07***	1.8
lobster	laser	(Real CW -Video CW) ~ Real CW	2.07	-0.02	1.2
lobster	board	(Real CW -Video CW) ~ Real CW	-1.07	0.07**	1.8

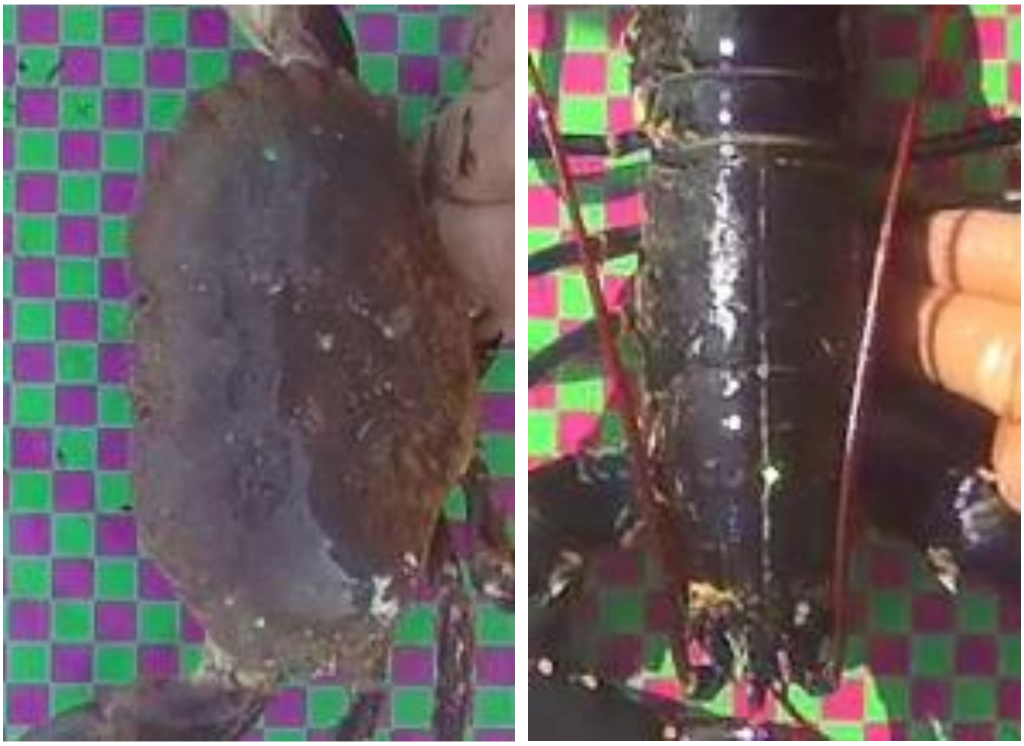

Figure 6. Example of zoomed-in snapshots showing poor definition of the carapace borders for brown crabs (left) and lobsters (right).

We then fitted a quadratic model for brown crab (Real CW ~ Video CW + $(\text{Video CW})^2$) and lobster (Real CL ~ Video CL + $(\text{Video CL})^2$) and we compared it with the corresponding linear models to assess if the quadratic term improved the estimates, as suggested by Hold et al. (2015). The AIC values showed that the linear model is always the best option, because the more complex model (the model with the quadratic term) is not associated with a strong decrease in the AIC values (Table 2).

Table 2. AIC values for the linear (Real size ~ Video size) and the quadratic models (Real size ~ Video size + (Video size)^2) to assess the best fit for the relationship between the measurement derived from the video (with laser and board as reference scale) and those obtained on board (real) for brown crabs and lobsters.

Species	**Ref. scale**	**AIC linear model**	**AIC quadratic model**
brown crab	laser	221	221
brown crab	board	435	435
lobster	laser	178	177
lobster	board	325	327

Our results show that the quadratic term does not improve the model and, for our data at the established camera distance of ~ 80 cm, the relationship "Real size ~Video size" can be approximated to a linear model. However, there is an error when estimating the animals' size from a video and this error varies depending on the camera distance and the animals' height. This effect is explained in Appendix 1 and can be represented by the equation (3):

real size = apparent size*camera distance/(camera distance + apparent size*a) (3)

where "real size" is the size of the animals measured on board by an observer and the "apparent size" is the size of the animals estimated from the video.

According to this equation, when the camera distance is much higher than the animal's height, the relationship real size ~ video size can be approximated to a linear model. In contrast, when the camera distance is small, real size ~ video size is a non linear relationship (Appendix 1).

Discussion

The present study showed that the use of paired lasers greatly improved the accuracy of the measurement of crustacean body size using on-board camera systems, thus confirming the findings of different studies on this subject (e.g. Bergeron 2007; Deakos, 2010; Rohner et al., 2011). This analysis represents a step forward in the optimisation of the camera system, its future automation and, ultimately, its widespread adoption. We demonstrated that the use of paired lasers projected on the body of crabs and lobsters minimised the error that originated from the variable distance between the animals and the reference scale included in the field of view. We demonstrated that the error associated with the size estimates obtained by using the background board (on which the crustaceans are located) as the reference scale causes a significant overestimation of the animals' size. The use of parallel-paired lasers thus represents a cost effective solution to this problem and should always be adopted when using camera systems to measure animal size. In fact our results showed that, while an error is always introduced when measuring an animal from a video snapshot, this error is small or not significant when the laser is used as a reference scale. The variation associated with the measurement was also much smaller by using the laser as demonstrated by the standard deviation of the model residuals.

Our results also showed that there is no need to use a predictive quadratic model to correct for the error generated from the height of the animals above the measuring scale, as suggested previously by Hold et al. (2015). The size estimated from a video snapshot depends on the distance between the camera and scale board. We demonstrated that, when the camera is installed at a relative high distance from the board and the animals (as in this study, where the distance camera- board was ~ 80 cm), the error generated by the animals' height is negligible (because the distance from the camera to the scale board is much bigger than the object height) and the relationship Real size ~ Video size should be fitted with a simple linear model. However, for cameras installed very close to the object, the non-linear function "real size=camera distance*apparent size/(camera distance+a*apparent size)" should be fitted to correct for the error generated by the animal's height and not a quadratic model, as suggested by Hold et al. (2015).

While the use of paired lasers improves the accuracy of the measurement of morphometric dimensions on the animal's body, some limitations need to be addressed to optimise the camera system and, possibly, its future software. We summarised the limitations in five main points.

1. *Light colour and intensity*.

The green paired lasers used in this study were clearly visible on the animals' body only during cloudy days. A possible increase in laser intensity could solve the problem as well as the potential use of different lasers' colours.

2. *Distance between lasers.*

In the two camera systems experimented the distance between the paired lasers were 10 cm and 9.3 cm. The distance between the parallel-paired lasers should be reduced and not exceed 5 cm, to ensure the projection of the lasers dots even on the smallest crustaceans (e.g. small brown crabs and velvet crabs), thus allowing for a precise size estimation for all species and all age classes.

3. *Improving video resolution.*

The resolution of the images extracted from the videos recordings is needed. In fact, a zoomed-in image is often necessary when using the program ImageJ to estimate the animal's size and hence poor resolution can be associate with error in the estimates. The increase in video resolution is particularly required when the camera distance from the board is high. Some investigation is required to establish the optimal trade-off between video resolution and camera distance to the object of measurement.

4. *GPS data.*

The camera implemented in this study had an integrated GPS logger which allowed the latitude and longitude of the fishing location and the corresponding time to be displayed in the video. The information on the fishing location displayed on the video is certainly useful to avoid confusion between multiple videos and the corresponding GPS data. However, these GPS data cannot be downloaded from the current camera system (e.g. on excel file) and therefore an improvement of the system is required to ensure a rapid, easy download of the spatial data.

5. *Video control*

The camera systems used in the present study were characterised by a waterproof box, with a window against which the camera lens rested. A single switch was used to start the recording and to turn the lasers on. This system should be improved to allow scientists to check the video recording function is working. In fact in one occasion the switch turned the lasers on but the video recording did not started due to a problem with the connections of the camera. Scientists and fishers should be able to easily check for any possible problem with the video recording without removing the camera (in the current system the checking operation requires at least three minutes).

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APPENDIX 1

Effect of the camera distance on the size estimates.

There is an error in estimating the animal size from a video and this varies depending on the camera distance and the animals' high. To explain this effect, we represented an object (e.g. crab) under a camera angle (Figure A1). The object is the blue rectangle CDEF and the camera angle is α. The real size of the object (size measured on board the vessel) is represented by the segment EF, which is equal to the segment CD. The apparent size of the object (the size estimated from the video using the background board as reference scale) is the segment BD.

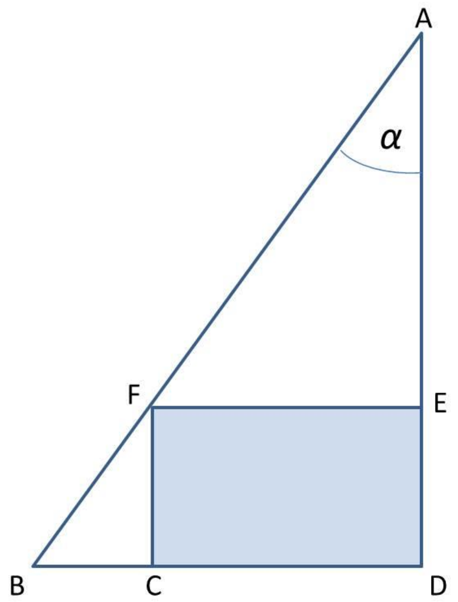

Figure A1. Schematic of an object (blue rectangle) under a camera angle α.

The triangle AFE has the same angle α than the triangle ABD. Therefore the ratio EF/AE is equal to the ratio DB/AD. The object's height DE can be considered proportional to the object's size EF (DE =

a*EF, where 0<a<1). The ratio EF/AE = real size/(camera distance-a*real size). The ratio DB/AD = apparent size/camera distance. Therefore:

real size/(camera distance-a*real size) = apparent size/camera distance

apparent size = (real size*camera distance)/(camera distance - a*real size)

apparent size*camera distance-apparent size*a*real size = real size*camera distance

apparent size*camera distance = real size(camera distance + apparent size*a)

real size = apparent size*camera distance/(camera distance + apparent size*a)

In conclusion, the relationship between the real animal size (y) and the apparent animal size (x) is defined by the following equation:

y= bx/(b+ax)

When the camera distance (b) is >> than the animal's height (as in the present study, where the camera is located at ~ 80 cm from the background board) this relationship can be approximated to a linear model, as demonstrated by our results. However when the camera distance is small the relationship y ~ x ceases to be linear (Figure A2).

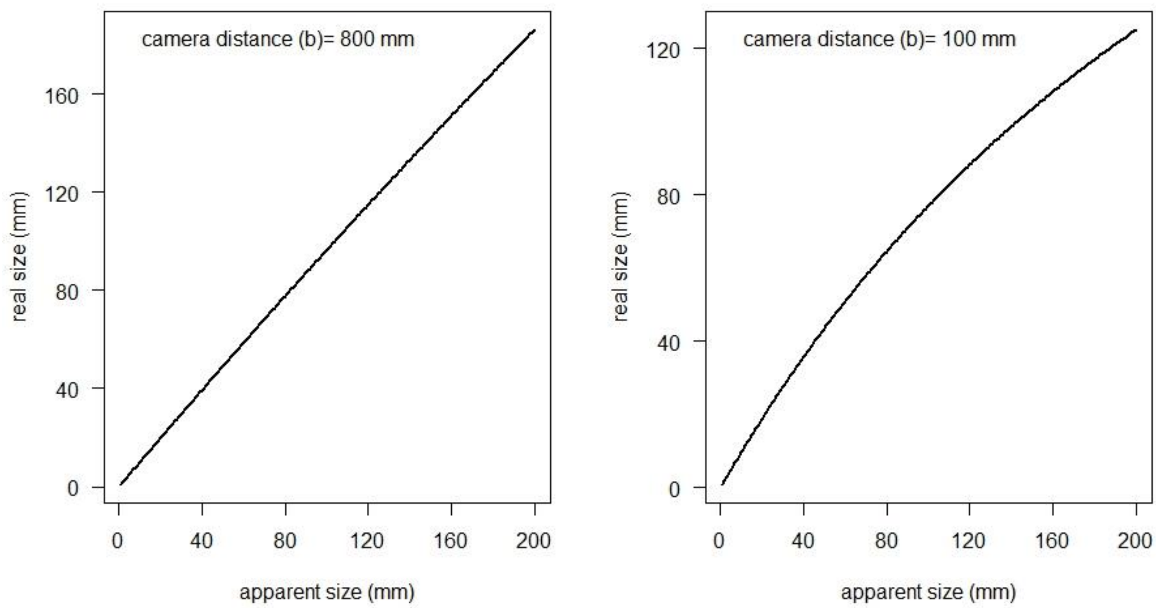

Figure A2. Simulation of the effect of the distance camera-board on the size estimates. The graphs demonstrate that, when the camera distance is much bigger than the animals' high, the relationship real size ~ video size can be approximate to a linear model (left). When the camera distance is small (e.g. 10 cm), real size ~ video size is a non linear relationship (right).