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A preliminary application and its error estimates of a simple stereo-camera measure system for the far-sea fishery of Pacific saury

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Pacific saury is one of the most economically important species in the northwestern Pacific Ocean. The management of this resource relies on precise input of biological data such as body length and is often hindered by a lack of such data on captured fish. This study explores the potential of electronic monitoring (EM) using off-the-shelf stereo cameras to overcome the challenges of collecting and measuring saury body length from the Pacific saury fishery. Using a calibrated WEEVIEW SID WV3000 3D camera, a total of 252 paired images with different shooting angles and distances were obtained for further measurement using Sebastes Stereo Image Analysis Software (SSIAS). The treatments for the measurement distance (MD) were 30 cm, 60 cm, and 100 cm, for the depression angle (DA) were 30°, 60°, and 90°, and for the position angle (PA) were 0°, 45°, and 315° (− 45°). An assistant calibration (AC) in the form of a 16 cm black ruler was also added used. The SSIAS measurement results indicated that the best measurement was obtained with 0° position angle, 90° depression angle, and 30 cm distance from the target fish. The use of AC in the SSIAS + AC measurement was proven to reduce the measurement error from 2.45 to 8.64% to − 1.86 to 0.01%. This study set the baseline for the application of EM on collecting saury body length and the use of AC has been proven to increase the measurement accuracy.

Keywords Pacific saury, Body length, Electronic monitoring, Measurement

Stock assessment plays a vital role in the sustainable management of fisheries resources. Most modern stock assessments use the body length of harvested fish as a key data stream to estimate the biomass of the fish population and sustainable levels of harvest[1]. For economically important fish, the fish body length data from the harvested portion of the population is derived directly from commercial fishing activities[2]. Conventionally, the information about fish body length is provided by an onboard observer, who measures the fish manually[3,4]. However, fully implemented observer programs are not possible in many fisheries where vessels are small, range over vast stretches of the ocean, and spend months at sea targeting multiple species with various gear types[5]. Furthermore, manual measurement of fish length is a time-intensive process and can disrupt fishing operations. Consequently, gathering fish length data manually may prove challenging or constrained in quantity, especially if the vessel crew is the sole source for data collection. Moreover, a lack of scientific training and subjectively measuring methods may lead to inaccurate or misleading information[6].

Recently, many Regional Fisheries Management Organisations (RFMOs) have suggested Member fishery authorities develop Regional Observer Programs (ROP) and/or electronic monitoring programs (EM) to increase data collection, sample sizes, and information to improve stock assessment accuracy[7]. However, the absence of sufficient financial support for implementing ROP has posed challenges in attaining this objective. The COVID-19 pandemic has further hindered the progress of ROP development in numerous RFMOs. For some RFMOs EM methods may be a more practical approach, considering that the work onboard vessels are fast-paced and intensive, with fishers having insufficient time and barriers due to vessel size and configuration to measuring and collecting accurate fish body length data. Thus, EM technologies to collect fish body length onboard would be an efficient option that could reduce the pressure for data collection by fishermen who work under many additional constraints. Stereo cameras are one of the tools that could be used for EM and has been implemented in several studies related to fisheries. For example, recording fish species and abundance

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and observing fish behaviour using stereo cameras[8,9], and measuring the body length of tuna[10–12]. In addition, stereo cameras have been successfully used to measure fish body length in controlled aquaculture settings[13,14] and open water[15,16]. In general, stereo methods provide exact measurements compared to single-camera–based photogrammetric methods[17].

Pacific saury (*Cololabis saira*) is a commercially important fish in the Western North Pacific Ocean[18]. This fish is captured mostly with stick-held dipnet operations carried out from July to December across a wide area of the North Pacific from the Japanese EEZ to 170° E longitude. North Pacific Fisheries Commission (NPFC) has adopted Pacific saury as one of the priority species for sustainable management in the North Pacific Ocean. However, it is difficult to collect biological samples and information for the Pacific saury catch from the far-seas fishing fleets of Taiwan, China, and Vanuatu, as the saury is divided into several commercial size categories and then frozen in a catch box immediately after being caught[18]. One of the key information gaps for Pacific saury stock assessment is the size of the catch for each fishing fleet over time and space that will allow the application of age or stage structured assessment models. The sampling of the saury can be made more efficient using EM, as it can be conducted prior to the size categorization process. In addition, because of the non-invasive nature of image collection, the sampled fish can be returned to the catch incurring no cost to the fishing operation. This can be especially important if large sample sizes are needed. In addition, EM can collect large amounts of data in a short time without interfering with ongoing fishing operations, making EM an efficient way to collect length information on this fishery.

To date, there has been no research regarding the utilization of EM to obtain fish length data in the Pacific saury fishery. There are two objectives in this preliminary study: firstly, we aimed to apply a basic stereo camera system for estimating the body length of Pacific saury; secondly, we assessed the accuracy of this system across various shooting positions to determine the most intuitive and optimal angle with its error estimates for capturing saury images. This research will be useful in developing guidelines for image acquisition for EM in the Pacific saury fishery and potentially other fisheries on the high seas. Through this study, we hope that obtaining information on saury body length will be more efficient and precise so that the NPFC can implement sustainable fisheries management for Pacific saury.

Materials and methods

Stereo camera calibration

SEBASTES stereo image analysis software (SSIAS) is a free, open-source software package developed by the Alaska Fisheries Science Center in the Python programming language for the explicit purpose of fish length measurement with calibrated stereo-cameras[19]. It was designed for processing stereo images to determine the epipolar geometry that describes the relationship between the coordinate systems of the two cameras[20] and thus calculating the position of target points viewed in both cameras using triangulation. SSIAS has been widely used in several types of research related to digital imaging for fish length measurements[8,9]. SSIAS is based on several open-source projects, including the MATLAB camera calibration toolbox[21] and OpenCV and is available at https://github.com/noaa-afsc-mace/SEBASTES.

The stereo-camera system used in this study was a WEEVIEW SID WV3000 3D camera. It consists of two camera sensors mounted 4.5 cm apart. When triggered each sensor captures a single still image (4032 × 4032 pixels) that is stitched together to form a single image with the two views in a side-by-side orientation. These images were then split into paired stereo images and formatted for use in the SSIAS using the "SebastesImageFormat" package developed in R statistical analysis software[22] and available at https://github.com/rooperc4/SebastesImageFormat. It should be noted that although a WEEVIEW stereo camera was used in this study, other off-the-shelf stereo cameras could be used (e.g., the StereoPiV2 is currently being used for a similar application).

The calibration procedure for the WEEVIEW camera was conducted in the lab following Bouguet[21]. First, a black-white checkerboard pattern with known dimensions (50 mm by 50 mm squares in 7 rows by 8 columns) was printed and mounted on a rigid plastic sheet. Dimensions were double-checked, as distortions induced by the printer may affect the size of each of the black and white squares. Images were acquired ($n = 70$) at different distances from ~ 0.5 m to ~ 1.75 m and various angles. These images were then analysed using a MATLAB calibration toolbox, a freely available software analysis toolbox built with MATLAB computing language[21]. The basic principle of the calibration is that the MATLAB calibration tool recognizes the corners for each black and white box on the checkboard in each of the cameras and then solves for calibration parameters that determine the geometry of the relative camera positions and distortion. Thus, the position of points on each image can be known relative to one another and measurements such as fish length can be estimated.

Sample collection and design for image acquisition

Twelve saury samples were collected from Kaohsiung Fishing Port, Taiwan in 2019, and sent to the lab for body length measurement. Image acquisitions were conducted in the lab, using the calibrated WEEVIEW SID WV3000 3D camera. We hypothesized that different measurement distances, depression angles, and position angles would affect the accuracy of the digital image measurement. To test these hypotheses, we obtained the sample images from different distances and angles to determine the most suitable distance and angle to provide the best image for the digital image measurement. 252 images with different shooting angles and distances were obtained. The design for the image acquisition was set up as shown in Fig. 1. The treatments for the measurement distance (MD) were 30 cm, 60 cm, and 100 cm, for the depression angle (DA) were 30°, 60°, and 90°, and for the position angle (PA) were 0°, 45°, and 315° (− 45°). Based on the given treatments, there should be 27 unique shooting positions. However, in total there were only 21 shooting positions were examined since the combinations at the position angle of 90° with the depression angles of 45° and 315° were duplicated with the depression angle of 0° on each of the measurement distances.

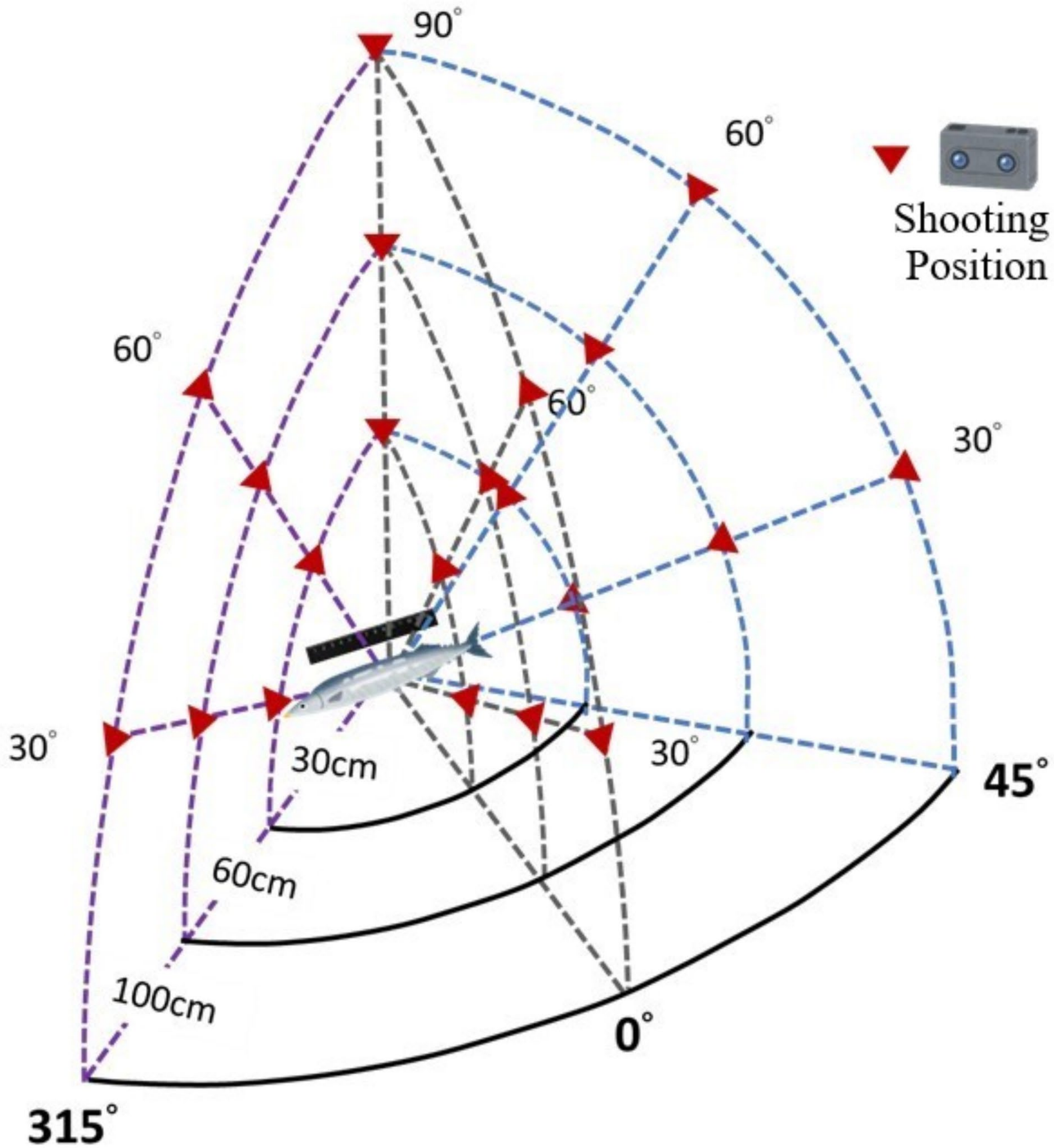

Fig. 1. A schematic diagram of the experiments on acquiring the fish images on various depression angles (30°, 60°, and 90°), position angles (0°, 45°, and 315°), and measurement distances (30 cm, 60 cm, and 100 cm).

Length measurement in SSIAS

To estimate the distance from the fish snout to its tail, SSIAS employs a stereo-triangulation method[19]. This involves identifying the coordinates of the snout (LXs, LYs, RXs, RYs) and tail (LXt, LYt, RXt, RYt) in paired images, from which their respective positions (Xs, Ys, Zs for the snout and Xt, Yt, Zt for the tail) in three-dimensional space are derived through triangulation. Once these spatial coordinates are determined for both the snout and tail, the direct linear distance between them in three-dimensional space (Xs, Ys, Zs - Xt, Yt, Zt) represents the length of the fish (Fig. 2).

To operate the SSIAS to measure individual fish from paired images collected with the stereo camera, we followed the operation manual written by Williams et al.[19]. When images are loaded into the SSIAS, it displays the paired images side by side each showing the saury (Fig. 3a). The analyst then marks the knob of the fish on both the left and right images to identify the target and get the estimated distance of the fish from the camera.

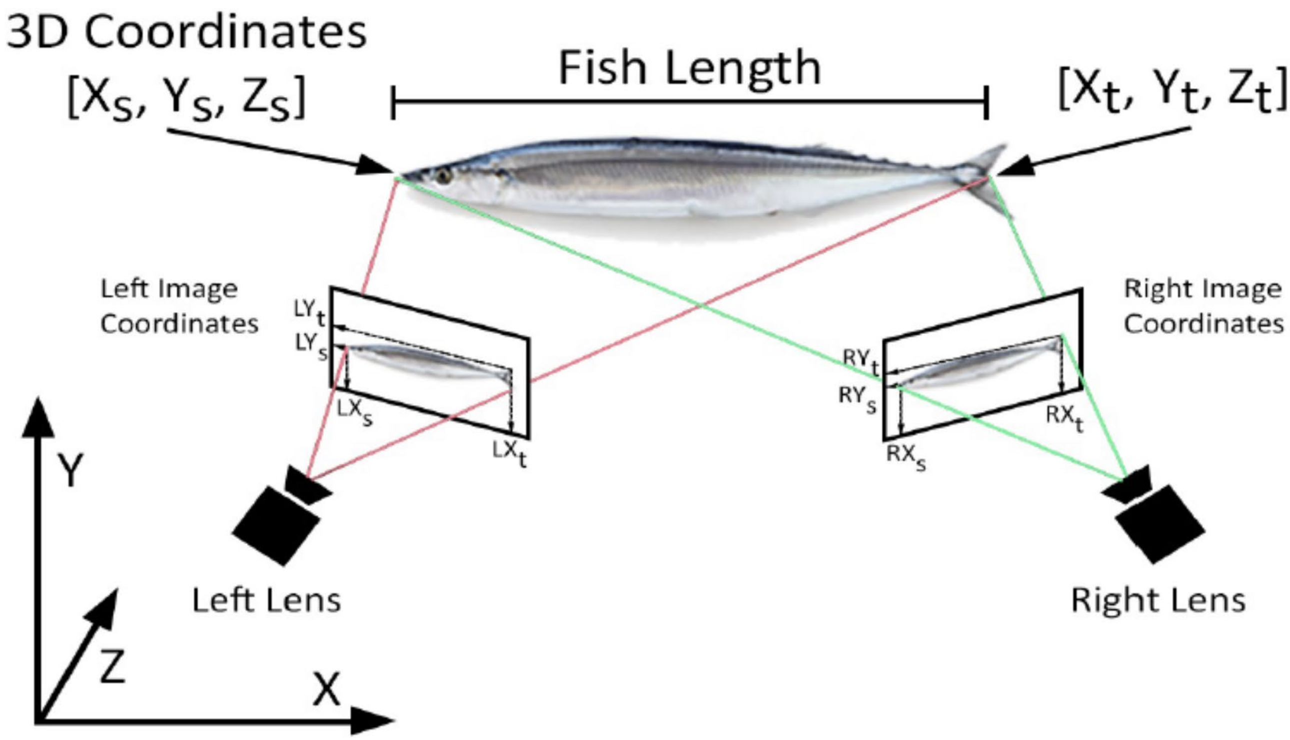

Fig. 2. Pacific saury length estimation using stereo-triangulation method (modified from Williams et al.[19]).

Next, the fish length is measured by clicking on the end of the snout and the knob (on the caudal peduncle) of the saury in each image to obtain the estimated knob length from SSIAS (L_{seb}) (Fig. 3b).

Assistant calibration

Several factors can affect the accuracy of the digital image measurement, such as the camera lens distortion, the shooting position, angle, distance, and the accuracy of the calibration. We examined the impact of these factors on precision and bias of Pacific saury length measurements by implementing an assistant calibration (AC) protocol. The AC utilized an object of known size (a 16 cm ruler) that was placed in the image with each Pacific saury (Fig. 3d). As can be seen in Fig. 3c, there are two red lines on the ruler (line number 2 and 3), for simplicity, we use line number 3 as it is easier to point the edge of the ruler directly instead of pointing the white marker inside the ruler. For each image, the length of the ruler was measured (L_{rl}) using SSIAS. A Magnifying Power (L_{MP}) coefficient (or correction) could then be estimated using Eq. (1).

$$L_{MP} = \frac{16}{L_{rl}} \tag{1}$$

The AC length (L_{ac}) of the Pacific saury was then estimated using Eq. (2).

$$L_{ac} = L_{seb} \times L_{MP} \tag{2}$$

where the AC length was the calibrated estimated length (L_{ac}) which is the proportional relationship between L_{seb} and L_{MP}. The error rate was then calculated to examine the estimation error (ε) between the actual length (L_a) (measured by the analyst using a ruler) and each estimated length (L_{ac}) using Eq. (3).

$$\mathcal{E} = \left(\frac{L_{ac} - L_a}{L_a}\right) \times 100\% \tag{3}$$

The accuracy and precision of the length measurement were expressed by the mean and standard deviation of the estimation error (error mean and SD). In addition, a coefficient of variation (CV, standard deviation/mean × 100%) was calculated for each shooting distance to compare the results between measurements with and without AC.

To test the hypotheses regarding the effect of camera position relative to the target fish we tested for significant differences in the magnifying power coefficient among treatments. The magnifying power coefficient was compared using analysis of covariance with distance to the target fish, position angle and depression angle as factors and fish length as a covariate. Significance was determined at $p < 0.05$.

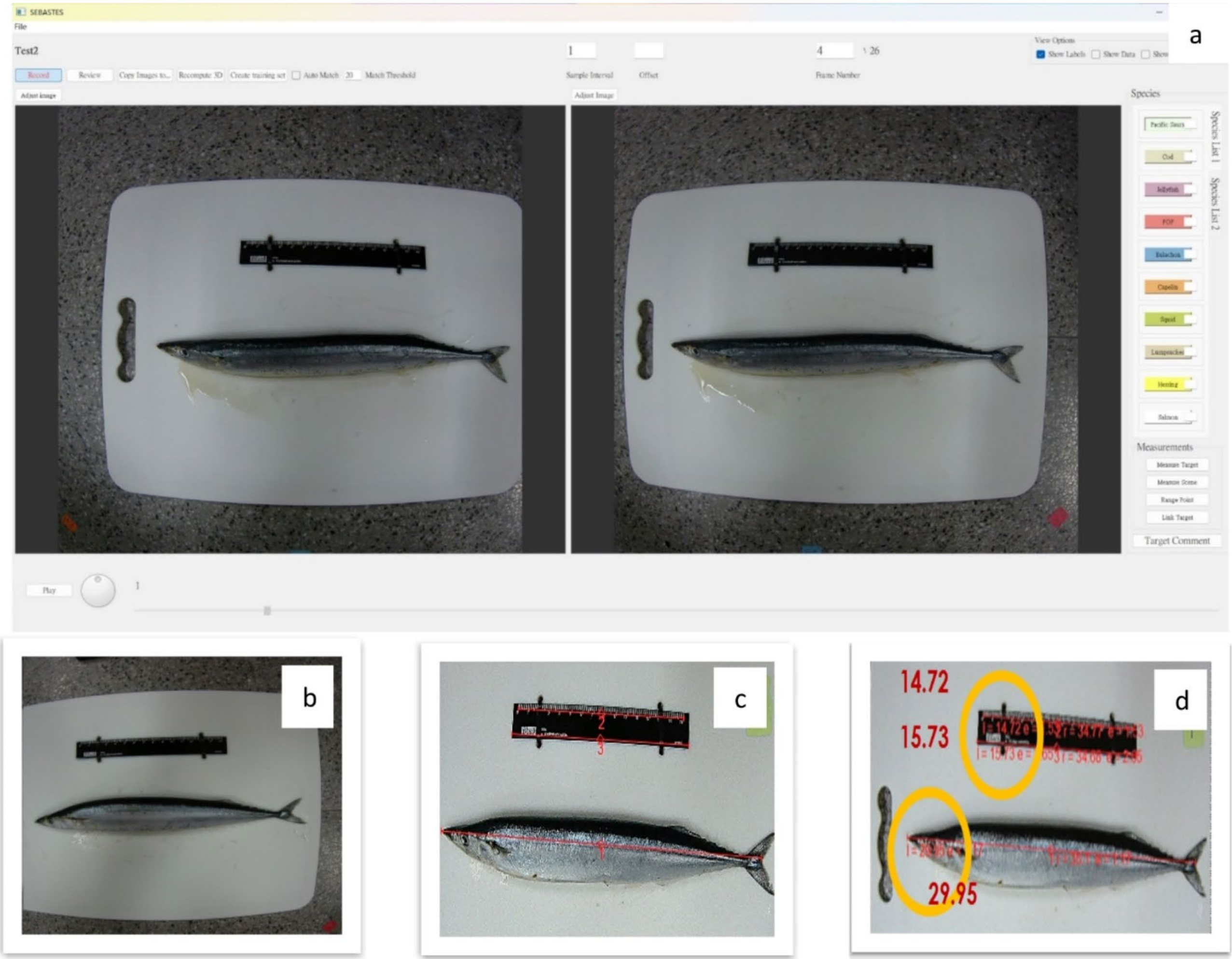

Fig. 3. SSIAS length measurement. (**a**) SSIAS interface after the image successfully loaded, (**b**) Saury position on the white board, (**c**) Different lengths measured on SSIAS, and (**d**) Length measurement results.

Results

Length measurement on SSIAS and SSIAS + AC

The result shows that there was an improvement in measurement accuracy for measurement with AC (SSIAS + AC) versus SSIAS alone (Fig. 4). Length estimation without AC (SSIAS) shows a trend to underestimate the true fish body length across the range of sizes observed. SSIAS + AC length estimation is more accurate since the regression line between the true body length and estimated body length with SSIAS + AC was not different than a 1:1 reference line (Fig. 4). The estimation error means (ε) (Eq. 2) for SSIAS measurement ranged between 2.45 ~ 8.64%, meanwhile for SSIAS + AC measurement, the error mean was decreased to -1.86 ~ 0.01% (Fig. 5). In other words, for the average 30.3 cm knob length, the estimation error was between − 0.74~-2.62 cm by SSIAS measurement, while if SSIAS + AC was used, the estimation error decreased to -0.56 ~ 0.003 cm.

Shooting position

Image samples were tested under 30 cm, 60 cm, and 100 cm measurement distances, with various depression angles and position angles. In total, 21 positions and 252 samples were examined. The result shows a positive relationship between error mean, error SD, and measurement distance in the SSIAS estimate, which means the error rate will increase with an increase in distance from the target (Fig. 5). At the measurement distance of 30 cm, the SSIAS estimation error ranged from (-3.38%) to (-2.45%) and increased to (-6.28%) – (-3.93%) at 60 cm and (-8.83%) – (-5.56%) at 100 cm. After including AC when acquiring the images, the error mean in each shooting position was decreased and unrelated to the measurement distance (Fig. 5). At 60 cm measurement distance, SSIAS + AC decreased the estimation error to (-0.53%) – (0.63%). These results indicated that SSIAS + AC could eliminate the effect of measurement distance and reduce the estimation error rate.

At the measurement distances of 30, 60, and 100 cm, SSIAS estimation resulting in the error SD ranges from 0.40 ~ 4.96% (Fig. 5), which means the estimation result in actual length error value was 0.12 ~ 1.50 cm. The error SD has a positive relationship with distance. The error mean was significantly reduced after applying the AC correction. Although the built-in calibration program can eliminate some image distortion, utilizing an

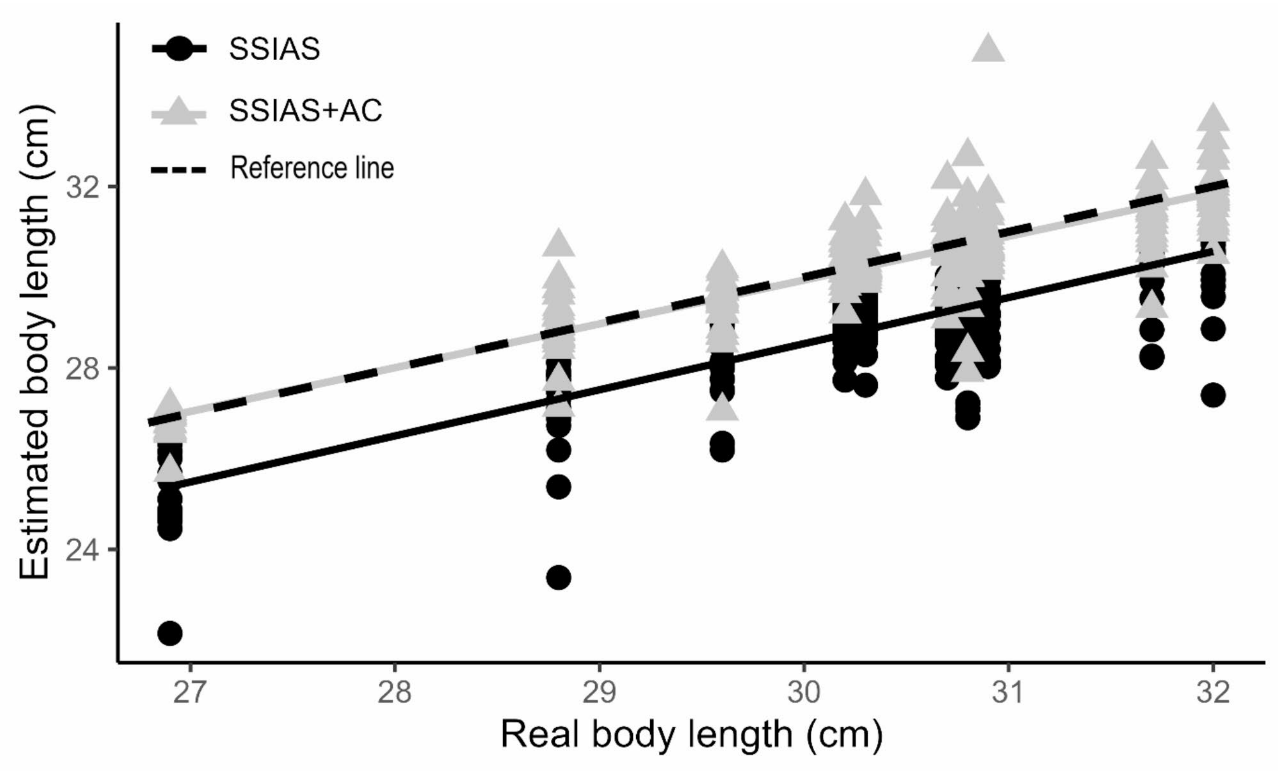

Fig. 4. A comparison between measured (true) lengths and estimated lengths. Grey and black lines indicate the regression lines between the real body lengths and the estimated body lengths with SSIAS + AC and SSIAS, respectively. The dashed black line represents a reference line indicating a 1:1 relationship between the true body length and the estimated body length.

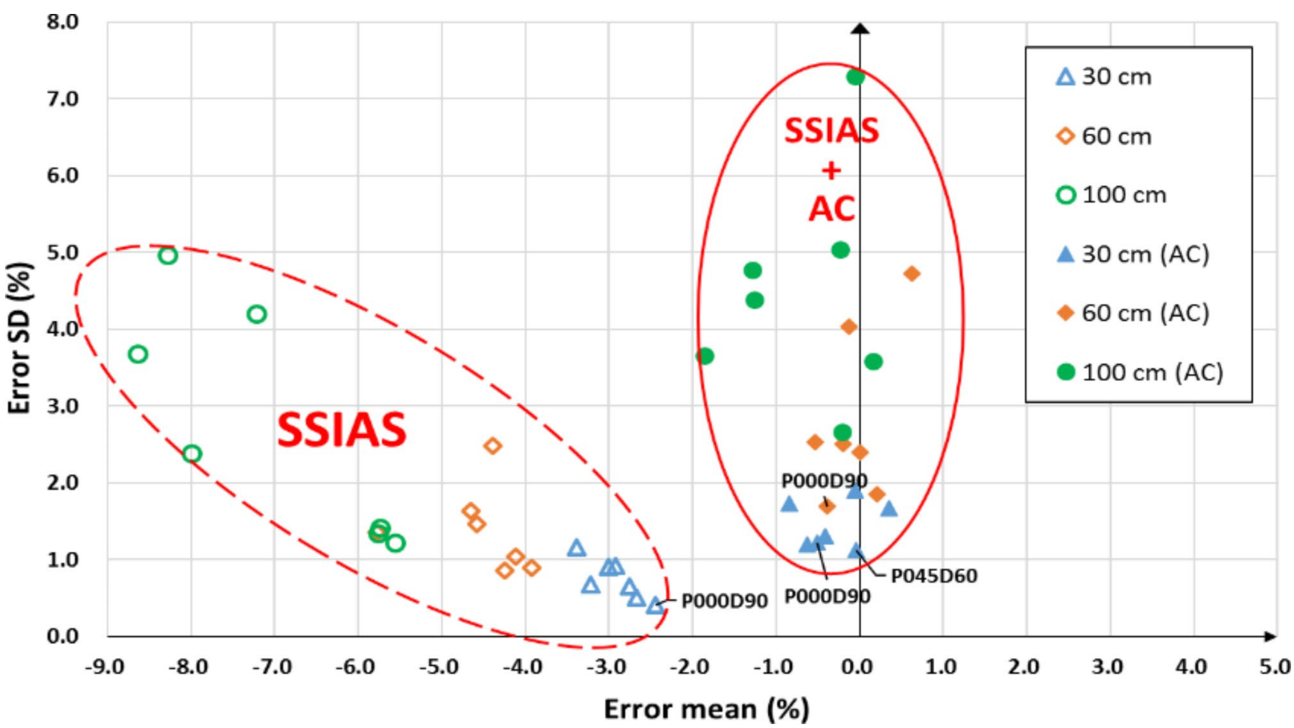

Fig. 5. Error means and error standard deviations on different shooting positions. The dashed red ellipse indicates the error mean and error SD for measurement without AC (SSIAS) while the solid red ellipse indicates the error mean and error SD for measurement with AC (SSIAS + AC).

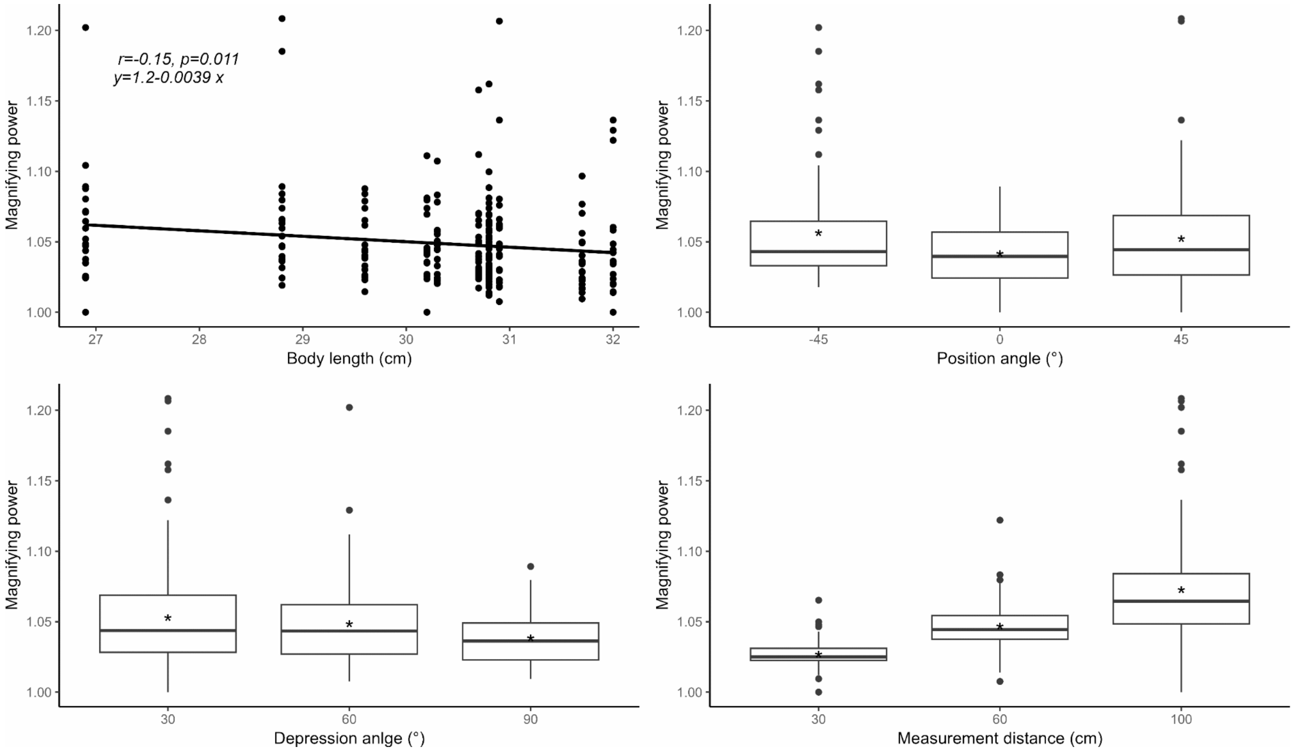

Fig. 6. Effects of fish body length, position angle, depression angle, and measurement distance on magnifying power. The solid black line in the top-left panel indicates a regression line between body length and magnifying power. Black dots represent each observation. The solid black line and star inside the box indicates the median and the mean for each group, respectively.

assistant calibration with a known size could provide a more accurate estimation result. SSIAS + AC successfully reduced the estimation error; however, it is contrary to the error SD because it was increased from 0.40 ~ 4.96% to 1.12 ~ 7.29% in SSIAS + AC measurement.

The difference in error SD indicates that the SSIAS + AC was less precise than the SSIAS measurement. However, both methods showed a similar trend in that the error SD increased at larger measurement distances. For example, the measurement using only SSIAS at 100 cm distance resulted in a higher error rate but a lower error SD (-7.24% ± 2.78%) compared to the measurement using SSIAS + AC at the same distance (0.04% ± 4.55%). This result was because the SSIAS + AC error SD includes contributions from both the precision of the measurement of the fish and the precision of the measurement of the AC. The combination of these two sources of random error increased the error SD.

The magnifying power coefficient shows a negative correlation with body length (r = -0.15, $p = 0.011$, Fig. 6), which means the length estimation using SSIAS only is more accurate for larger fish. Analysis of covariance results on the effect of different shooting positions with body length as covariate shows that position angle ($p < 0.001$), measurement distance ($p < 0.001$), and body length ($p = 0.001$) give a significant effect on the magnifying power, while depression angle ($p = 0.305$) doesn't have a significant effect on the magnifying power.

The coefficient of variation (CV) measured for different shooting positions showed that the CV increased with increasing distance from the target fish. The lowest CV was found at a 30 cm shooting distance with 4.47% and 4.46% for both SSIAS and SSIAS + AC, respectively. The shooting distance of 60 cm was associated with an increase in CV to 5.08% and 4.80% for both SSIAS and SSIAS + AC. The largest CV was found at the 100 cm shooting distance with 5.95% and 11.76% for both SSIAS and SSIAS + AC, respectively.

Discussion

The results of this study showed that the images captured using the WeeView camera and analysed with SSIAS tend to underestimate the size of fish, but with the inclusion of AC, it successfully reduced the size underestimation. This study shows that the digital image measurement is feasible and easy to operate and the proposed stereo camera system could be applied on deck during fishing operations to gather more Pacific saury length data. The use of AC in this study improved estimation accuracy by 4.47%. Estimations using SSIAS + AC had a mean error of -4.82 ± 1.92%, compared to -0.35 ± 0.59% without AC. This improvement aligns with a previous study by Hsieh et al.[11], which used an assistant calibration in the form of a color palette with a known size, improving tuna body length estimation accuracy from 11.7 ± 6.4% to 4.2 ± 3.3%. In addition, Chang et al.[23] also reported that performing a correction based on a known size calibration board can reduce big eye tuna length estimation error from 14.16% ± 2.27% for uncorrected cases to 4.80% ± 2.27% for the corrected cases. The difference in the size of the improvement is mainly due to the size differences of the fish that were measured (saury: 28–30 cm; tuna: 100–200 cm) and the best measurement distance (saury: 30 cm; tuna: 250 cm).

The distance between the two cameras on the WeeView system is 4.5 cm which is quite small. This may be partly the reason for inaccuracy increasing at larger distances, as has been found by other studies with short-baseline stereo camera systems[24]. Increasing stereo camera separation can increase both the accuracy and precision of measurements[25–27]. The effect is amplified as the distance to the target increases[27]. To obtain the most accurate length estimation result with a narrow camera separation, maintaining a good shooting position is important. Since distance significantly impacts the error mean and error SD, the operator needs to ensure that the stereo camera is operated between 30 and 60 cm. It has been shown that the most unbiased estimates of length can be obtained with camera baseline distances of > 6 cm[27,28]. However, the rule of thumb for the ratio between target distance and camera baseline was proposed as 3.6[29], which would imply an ideal baseline for a camera taking images of Pacific saury at 60 cm of 17 cm. It is important to note that cameras having shorter baselines than the 3.6 rule have been found to exhibit acceptable accuracy[8,28].

The angles of the camera relative to the fish were found to be less important in this study to determine bias in length measurement. Differences in magnifying power were not significant among depression or position angles. A good depression angle to photograph Pacific saury using the camera was between 60–90° because, at this point, both the fish body parts, and the assistant calibration can be seen clearly. The position angle of 45° relative to the fish (Fig. 1) resulted in a clearer image of the fish's tail, which allowed for better distinction by SSIAS of the fish snout and fork. Still, when considering the collections of images during fishing operations, correctly identifying the 45° angle when operating the camera may be difficult. Thus, it is recommended to use the 90° depression angle instead. The result showed that the best shooting position to obtain the most accurate body length estimation consists of a 60° depression angle, 30 cm distance, and 45° position angle, if this shooting position turns out too difficult to apply due to the actual situation on board, it is suggested that the shooting position with a 90°depression angle, 30 ~ 60 cm distance, and 0° position angle would also give an accurate body length estimation.

Based on the result, it is known that the best shooting position ranged from 30 to 60 cm since, at that distance, the fish image was still clear enough to identify the snout and tail fork. 100 cm distance should not be considered because as the measurement distance increases, the image's object (fish and assistant calibration) is smaller in the images. This is another potential reason for the positive relationship between distance and estimation error. Since the operator needs to pinpoint each object's corner in the image (fish and assistant calibration) to conduct the estimation, smaller objects could decrease the precision. It is also important to provide a clear image where the fish snout and tail could be seen clearly, which is not possible from the shooting distance of 100 cm, considering the size of Pacific saury was only around 20–30 cm. The positive relationship shooting distance and estimation error in this study is in line with a report from Harvey and Shortis[30] where there was a trade-off in accuracy when the shooting distance was increased.

According to the projection theory, images taken from the top right angle (a depression angle of 90°) can achieve the best estimation accuracy. However, this scenario cannot consistently be met onboard active fishing vessels because of the limitations of the shooting environment, the various devices, and the operators' skills when fish photos are taken. The lowest estimation error was from the depression angle of 60° with a 45° position angle (-0.62% ± 2.81%), meanwhile, the 90° depression angle with a 45° position angle resulted in 0.42% ± 1.78% estimation error (Fig. 5). Both of these combinations were reliable to apply and provided a low estimation error compared with other depression angle and position angle combinations. By considering the change in magnifying power, the combination of a 0° position angle, 90° depression angle, and 30 cm measurement distance is the best shooting position since this combination resulted in the lowest magnifying power.

The recommended shooting position found in this study are similar to Hsieh et al.[11], who found optimal position angles between 315–0° and 135–225°, with a depression angle greater than 45°. In addition, Chang et al.[23] found that the optimal shooting position to capture tuna picture for accuracy in measuring fish length is by placing the assistant calibration parallel to the fish, with the camera positioned at a depression angle of 90°, and with a position angle between 45° and 90°. Such a position resulted in an improvement from 7.22% ± 0.31–0.17% ± 0.14%. The primary goal of identifying the most ideal shooting position is to ensure that the captured image includes the critical features of the fish—specifically, the snout and tail, which are essential for length estimation. However, considering the practical situations onboard fishing vessels, the best shooting position must be easy to apply. Thus, a more realistic shooting position that balances the need for accuracy and flexibility onboard fishing vessels is the combination of a 30° depression angle, 45° position angle, and 60 cm measurement distance.

The CV calculated in this study is comparable to other studies using stereo cameras (e.g. 0.56-5%[8,17,28,31], and the < 1% CV's obtained by hand measuring fishes[32,33]. However, the largest CV calculated in this study was 11.76% which was found on the measurement using AC on 100 cm shooting distance. This occurrence could be attributed to the fish tail being hard to identify for the observer making the error accumulated not only for the black ruler (L_{rl}), but also the saury itself (L_{seb}) since the final measurement result (L_{ac}) would multiply L_{seb} with the magnifying power which was calculated from L_{rl}.

Error in measurements can be overcome to some degree with larger sample sizes. Most studies have shown that 100–1200 individual fish should be measured to describe the length-frequency distribution for a population depending on the size resolution needed[34–36]. Gerritsen and McGrath[37] multinomial sampling method found that as a rule of thumb, sampling 10 individuals per length bins would result in a reasonable CV for length distribution. For the Pacific saury fishery, where lengths range from ~ 25–35 cm, a sample of about 110 individuals would be suitable for determining the length distribution of the commercial catch. However, the issue of bias in the measurements is more important than the issue of error in measurements, so using the AC method or increasing the separation distance between the stereo cameras would be ideal.

Following the establishment of an optimal imaging position for capturing saury, subsequent research should focus on advancing the automation of length measurement from stereo imagery. Recent literature highlighted the potential of employing artificial intelligence, notably convolutional neural networks, to identify specific parts of tuna and several fish species[10]. However, currently, such technology is not implemented for the tuna fishery since the observers on board prefer using a measurement pole due to its simplicity. Our study provides a simple stereo-camera system that is easy to operate and the only requirement to generate useable data is to obtain saury images using the recommended shooting position.

Our study also provides an applicable approach with an estimable uncertainty to enhance its accuracy using software that is open for the public to access. Notably, this simple stereo camera system can still be relied upon even without integrating AC during the image acquisition process. If the circumstances on board a fishing vessel prevent the use of AC during image capture, the estimation method from the stereo image can still be conducted using solely SSIAS, yielding an underestimation result with a mean error of -0.74 cm.

In regards to the type of stereo camera used to obtain the images, it is worth noting that while this study employed a WEEVIEW stereo camera, other types of stereo cameras can also be effective for measuring fish length from stereo images using SSIAS. For instance, Boldt et al.[38]. utilized a PointGrey Chameleon 3 2.8 MP Mono USB3 Vision camera to measure the body length of pelagic fish in the Strait of Georgia. Similarly, Rooper et al.[39]. employed a Sony TRD-900 camera to measure the length of rockfishes (*Sebastes* spp.) on the Zhemchug ridges. Additionally, Baker et al.[40]. successfully used a Chameleon 3 camera to measure the length of Pacific sand lance.

Recommendations for future camera systems

The first recommendation is to use a camera system with a baseline separation greater than 6 cm. This suggestion is based on the findings of Rosen et al.[28], who observed little impact on measured length at camera baselines exceeding this value. It is also recommended that the calibration be performed at the distance from the object and the angle that is most common for the images that will be collected in the field. Finally, it is recommended that, if possible, an AC should be placed in each image to assist and check the estimated lengths of fish. For the Pacific saury fishery, in each commercial size box, the length difference among the saury individuals was not larger than 6 cm[41]. Thus, a minimum sample size of 60 is needed to estimate the length distribution of boxed Pacific saury to reproduce the complete length distribution of the commercial catch based on the rule of thumb from Gerritsen and McGrath[37].

The innovation of a simple stereo camera system brings up the prospect of its integration aboard vessels, enabling the acquisition of stereo images from the catch of commercial fisheries. This advancement is expected to enhance the management of pelagic species, such as Pacific saury. Moreover, it promises to foster comprehensive engagement and endorsement of the monitoring and data collection processes, which are deemed essential for the success of electronic monitoring[42]. This study represents a novel first step in implementing protocols for fish length collection on the high seas and implementing the recommended improvements would benefit management and assessment of Pacific saury and other exploited high seas fish stocks.

Data availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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K.P.G. was involved in the conceptualization, methodology, and writing-original draft, C.N.R. helped with conceptualization, methodology, operating the software, writing review, and editing, K.W. participated in methodology, operating the software, writing review, and editing, and W.B.H. was involved in the conceptualization, methodology, supervision, writing review, and editing. All authors participated in the discussion to finalize the manuscript.

Declarations

Competing interests
The authors declare no competing interests.

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