Quantifying photogrammetric accuracy for measuring humpback whales using Unmanned Aerial Systems

By

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Executive Summary

Photogrammetry is the practice of obtaining accurate and valid measurements from 2D images. This practice can be useful in applications where it is dangerous or difficult to reach the target. In recent years, this practice is becoming more common in the marine science field to measure large and potentially dangerous marine mammals. Even more recently, Unmanned Aerial Systems (UAS) technology is being utilized to further minimize the dangers to humans, as well as to decrease the disturbance to animals

To establish the accuracy of measurements taken from aerial imagery with UAS technology, this study calculates the distortion values from 3 different cameras, on three different UAS platforms. Lens correction values were calculated for images taken with the three cameras, a GoPro 4 Black, an Olympus E-pm2, and a Sony a5100. These lens correction values were then applied to images taken on the ground of a wooden board approximately 99.9cm long. The static ground images were taken every 10 meters up to 50 meters, to calculate the impact that distance and distortion has on the accuracy of photogrammetric measurements. Finally, each camera was attached to a different UAS platform, GoPro 4 Black with a 3D Robotics Iris+, Olympus E-pm2 with a Microcomputer HexaXL, and the Sony a5100 with a LemHex44. Images were taken at varying altitudes and were then able to be compared to the static ground images to quantify the impact that UAS has on the accuracy. The 3D Robotics Iris+ altitude measurements needed for photogrammetric calculations were derived solely from the onboard barometric sensor, while the MikroKopter and the LemHex44, altitude data were collected by an onboard barometric sensor as well as a Lightware SF11 pulse laser altimeter, thus allowing a comparison of the improved measurements obtained by using a more accurate reading of altitude.

These methods were then applied to images of humpback whales (*Megaptera novaeangliae)* collected in the Antarctic Peninsula in January and February of 2017 with the Sony a5100. A total of 48 individuals were measured for total length, and due to the UAS testing it is known that these measurements are within 1.664 cm of the true length of the whales. Additionally, width measurements of mother calf pairs were compared allowing for an important first step in establishing important time periods of growth and size differences in genders.

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Introduction

Photogrammetry is a technique that allows for the measuring and analyzing of two-dimensional images, to determine the three-dimensional location, size, and/or shape of physical objects within those images (Guo *et al*., 2010) This practice has been utilized in many fields, from the creation of three dimensional geologic maps, to aero-space engineering to test aircraft flight, to quantifying population size-structure of corals (Drap *et al.*, 2007, Jaing *et al.*, 2008). Photogrammetry is becoming increasingly useful in marine mammal research due to the difficult nature (size, temperament, location) of some many species (Bell *et al*., 1997). This technique is less invasive for target species and is additionally safer and faster for researchers (Waite, 2007). Recently, photogrammetric surveys have also been used to capture images that can be used to calculate body size of many species, providing a better understanding of the health of that individual, and if multiple individuals are measured, the population health (Durban *et al*., 2009).

Aerial surveys are used frequently to collect image data to study the distribution (Scheidat *et al*., 2012; Marsh and Saalfald, 1989), abundance (Pollock *et al*, 2004) and habitat usage (Gottsachalk *et al*, 2003) of many different species of marine mammals. Traditionally, these aerial surveys involve manned aerial flights that are often rather costly and potentially dangerous (Sasse, 2003). In Durban *et al* (2009) the risks associated with aerial photogrammetry were described with a compelling example: “Wearing a seat harness, the photographer then leaned out of the open passenger door to shoot photographs vertically down on the target whale”. This dangerous activity could be minimized through the use of robotic technology that could collect the same data. Advances in the use of Unmanned Aerial Systems (UAS) technology are now prevalent in civil and research fields, and with improvements in the design and functionality these systems have become “research grade tools”. (Hugenholt, 2012).

Recently studies have used UAS-based photogrammetry to assess the size of marine mammals (Christiansen *et al*, 2016; McFadden *et al*, 2006.), however at present there are scant data on humpback body condition. Measuring the width and length of an individual in nadir imagery can be utilized to infer much about the individual's health, and when applied across individuals, the health of that population. While this approach is innovative, some photogrammetric studies do not report the extent of distortion (e.g. pincushion or barrel) from camera lenses used for photogrammetric sampling. As such, there may be important but unreported error in photogrammetric measurements that could affect the accuracy of measurements and any inferences that are made from them. To ensure the most accurate measurements possible for future photogrammetric measurements from UAS technology, as well as assessing the platforms and technology necessary for particular projects, it is imperative to assess the distortion of images from different cameras and to quantify the error associated with this distortion.

The purpose of this study was to assess the distortion of three different cameras, a GoPro4 Black, an Olympus E-pm2, and a Sony a5100. Utilizing these three cameras will allow for the visualization and quantification of the varying types of distortion. The distortion of each individual camera can be corrected, allowing for the comparison of corrected and uncorrected images, both from static ground tests as well as UAS images to assess the impact that UAS technology has on the accuracy of photogrammetric results. Furthermore, these methods, distortion correction and the effects of UAS, will be applied to a case study of humpback whale images collected in the Antarctic Peninsula, allowing assessment of body condition of the population, as well as size comparisons of mother/calf pairs.

Materials and Methods

Overall Approach

I chose to assess multiple UAS and cameras to evaluate the results that are obtained with different platforms and camera combinations. Specifically, I assessed three different UAS platforms with three different sensors: a 3D Robotics Iris+ with a GoPro4 Black; the MikroKopter HexaXL with an Olympus E-pm2 mirrorless camera, and LemHex44 using a Sony a5100. For the 3D Robotics Iris+ altitude measurements needed for photogrammetric calculations were derived solely from the onboard barometric sensor. For both the MikroKopter and the LemHex44, altitude data were collected by an onboard barometric sensor as well as a Lightware SF11 pulse laser altimeter. This study was completed in three different steps. First, the distortion of each camera was visualized and corrected with a standard software workflow, then a static ground study was completed by taking pictures of an object, in this case wooden board, with each of the different cameras at different distances. Finally, images were taken with the cameras on UAS technology to calculate the impact that UAS have on the accuracy of the measurements. The results of the Sony a5100 were then used to correct for error and assess standard deviation of the measurement of humpback whales from the Antarctic Peninsula.

Distortion Calibration

To correct for the distortion from each type of camera, pictures were taken of a camera calibration matrix to allow for the visualization of the different types of distortion for each camera that would then allow for correction. Calibration images were imported to Adobe Photoshop and the lens correction tool was used to characterize the distortion for each image. The calculated lens correction profile was saved and applied to each image that was taken with the corresponding camera for the remainder of this study.

Static Ground Study:

A wooden board, approximately 99.9 cm long, was placed upright against a wall. Each camera was used to take pictures of the wooden board, from varying distances 10m, 20m, 30m, 40m, and 50m, to observe the effect that distance has on the accuracy the measurements obtained from images taken with each camera (Figure 1). The distance was recorded with a laser range finder and then averaged over the time that the pictures were taken.

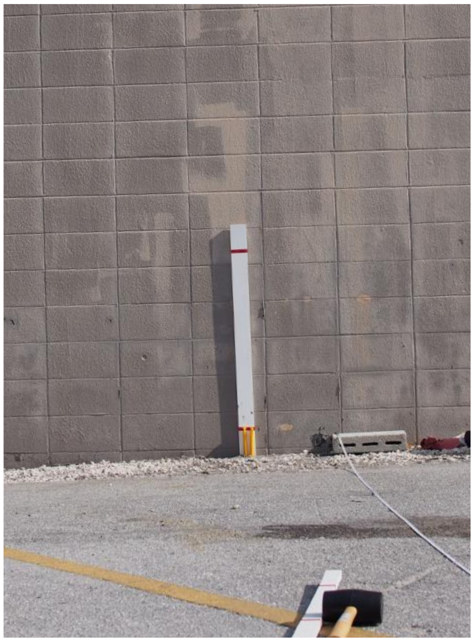


Figure 1: picture of the wooden board during the static ground test at 10m away

Measurement from UAS:

Images were taken of the wooden board from 10m, 20m, 30m, and 50m with the GoPro4 on 3D Robotics Iris+, and with the Olympus on the MikroKopter HexaXL and the Sony a5100 on LemHex44 (Figure 2). To look at the impacts of the laser altimeter compared to the UAS barometric pressure altitude recordings, pictures taken with the Olympus and the Sony were compared using altitude readings from both the respective drones as well as from the laser altimeter.

Figure 2: picture of the wooden board during the UAS test at 10m away

Photogrammetric Measurements:

Previously studies have shown that, “the relationship between the size of an object and its image on the film is determined by the ratio of the focal length of the lens and the distance from the camera to the object” (Perryman and Lynn, 1993). This information informed our calculations where our formula was as follows:

image measurement = (Altitude /focal length) * (number of pixels * pixel dimension)

Each of these four variables was necessary to obtain a measurement for each individual image, however both focal length and pixel dimension are uniform for each camera across images (Table 1 and 2).

Table 1: Focal length for each camera that remains the same for each image

Focal Length (cm)	
GoPro	1.72
Olympus	2.5
Sony	5

Table 2: Pixel dimension for each camera remaining the same across images

Pixel Dimension (mm)	
GoPro	0.000960681
Olympus	0.000375434
Sony	0.000391667

The time stamp from the picture was used to select the corresponding altitude/distance measurement from either the barometric pressure or the laser altimeter. For all pictures that were taken, each picture was corrected with the corresponding lens correction profile created from the distortion correction. Once the pictures for each type of camera were corrected for distortion and time differences, the distance in pixels of each of the targets objects was calculated. The program ImageJ was used to import pictures to allow a manually drawn line for different to assess total length.

The photogrammetric measurements from the static ground tests and the UAS tests were compared to the actual measurements of the wooden post and statistics for variance and standard deviation, which here represents error, were calculated.

Antarctic Case Study

During January-early February of 2017 the Sony a5100 was used on a Freefly Alta with the laser altimeter to capture aerial images of humpback whales off the Antarctic Peninsula. The three study locations were Wilhelmina Bay, Andvord Bay, and channel?? The platform was hand launched from a boat and flights lasted 20-30 minutes with an average altitude between 50-60m above the water. Both raw images and JPGs were taken. Images used for measuring whales were selected based on their clarity, the whale's positioning in the water, (ideally near the surface, flat, with both the rostrum and the fluke notch visible in addition to minimal rotation). This allowed for the measurement of total length of the individual.

Additionally, mom-calf pairs were measured to look at different morphological regions that are characteristically different between moms and calves. An R code (Christensen *et al*, 2016) was used to create 5% intervals of total length (Figure 5) for 10 individuals, 5 moms and 5 calves and the average difference between each measurement for each mom and calf was calculated.

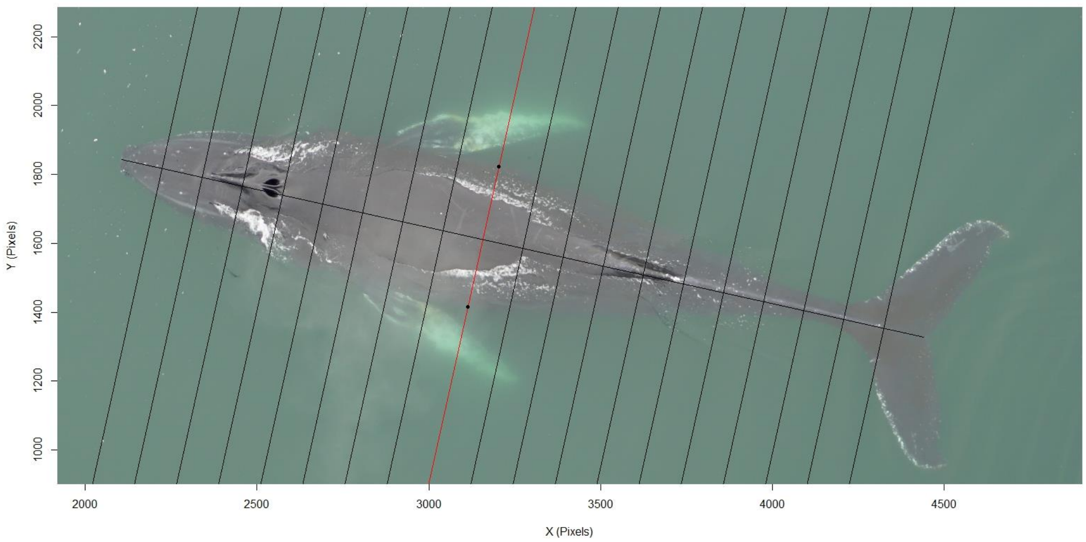


Figure 3: The outputs of the adapted R code, showing 5% width intervals across total body lengths of a calf from a mom-calf pair

Results

Distortion Calibration:

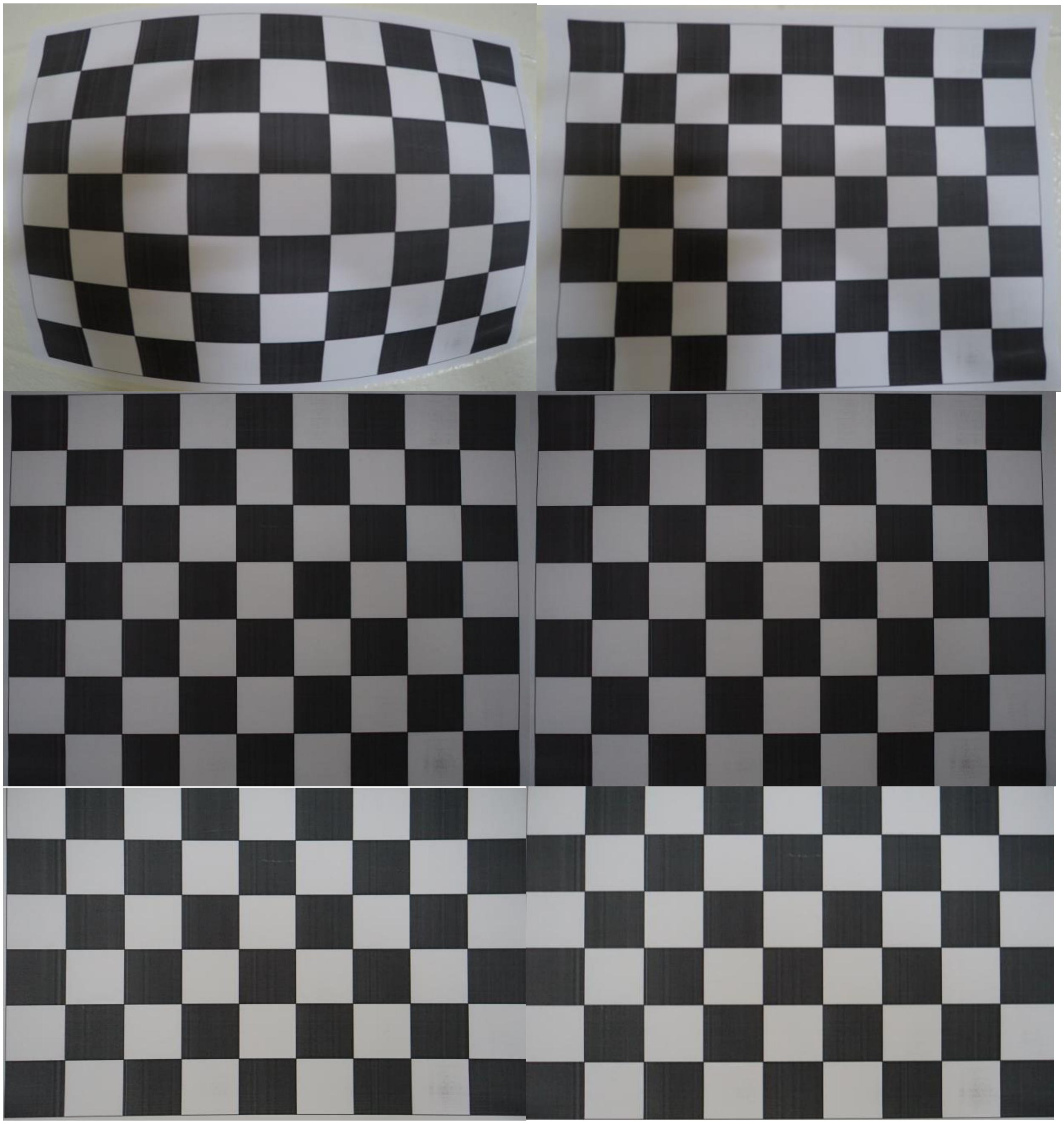


Figure 4: on the left are uncorrected images taken with the GoPro4, Olympus e-PM2, and the Sony a5100 (from top to bottom respectively). The right-side are the same images as the left, corrected for pincushion and barrel distortion using Adobe Photoshop.

Static Ground Tests

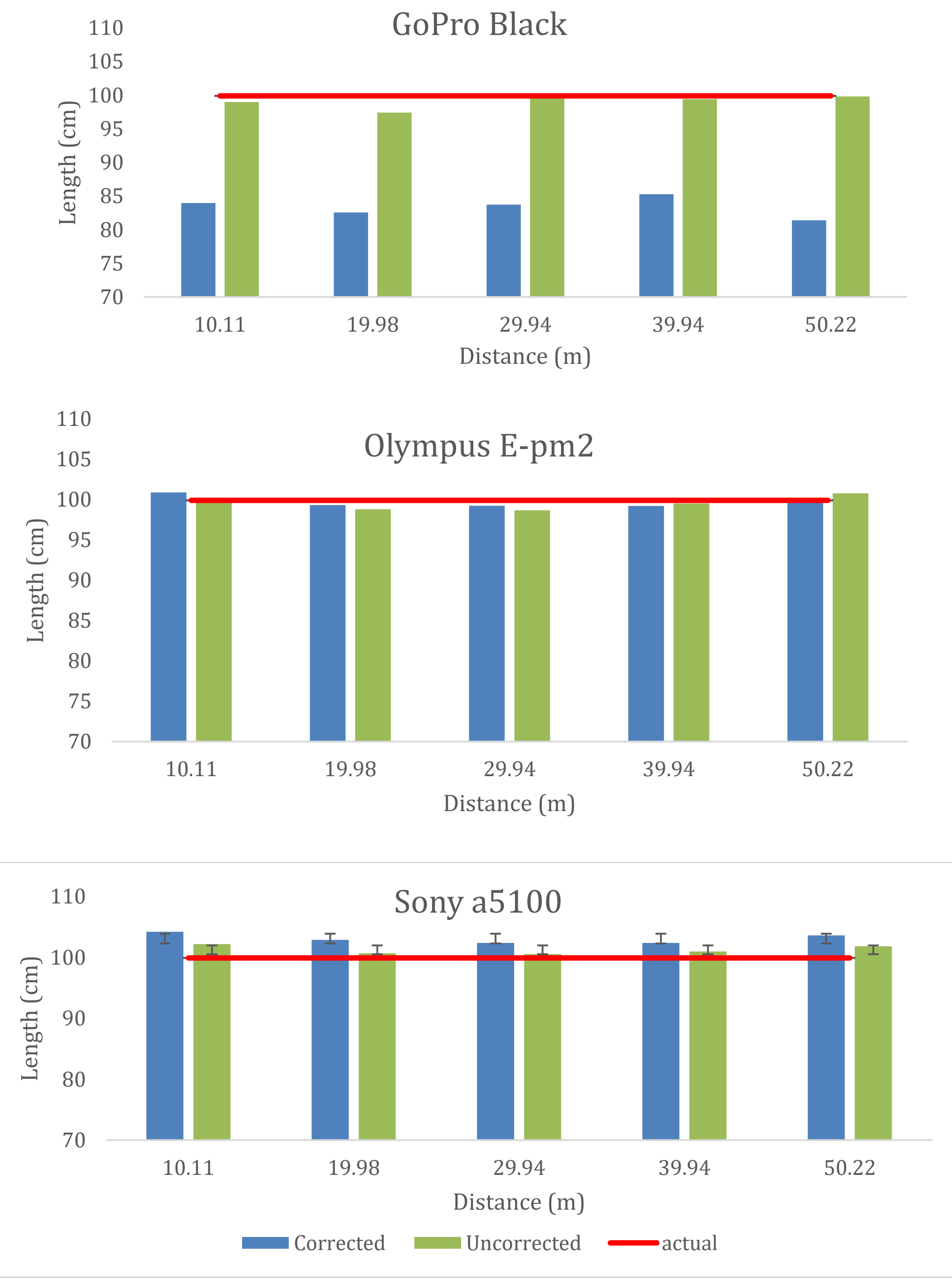


Figure 5: Blue lines show the photogrammetric measurements with the corrected images at varying distances and the green lines show the measurements of the uncorrected images. The red line shows the actual measurement of the wooden post. The top graph is the GoPro, the middle is the Olympus and the bottom is the Sony.

UAS Tests:

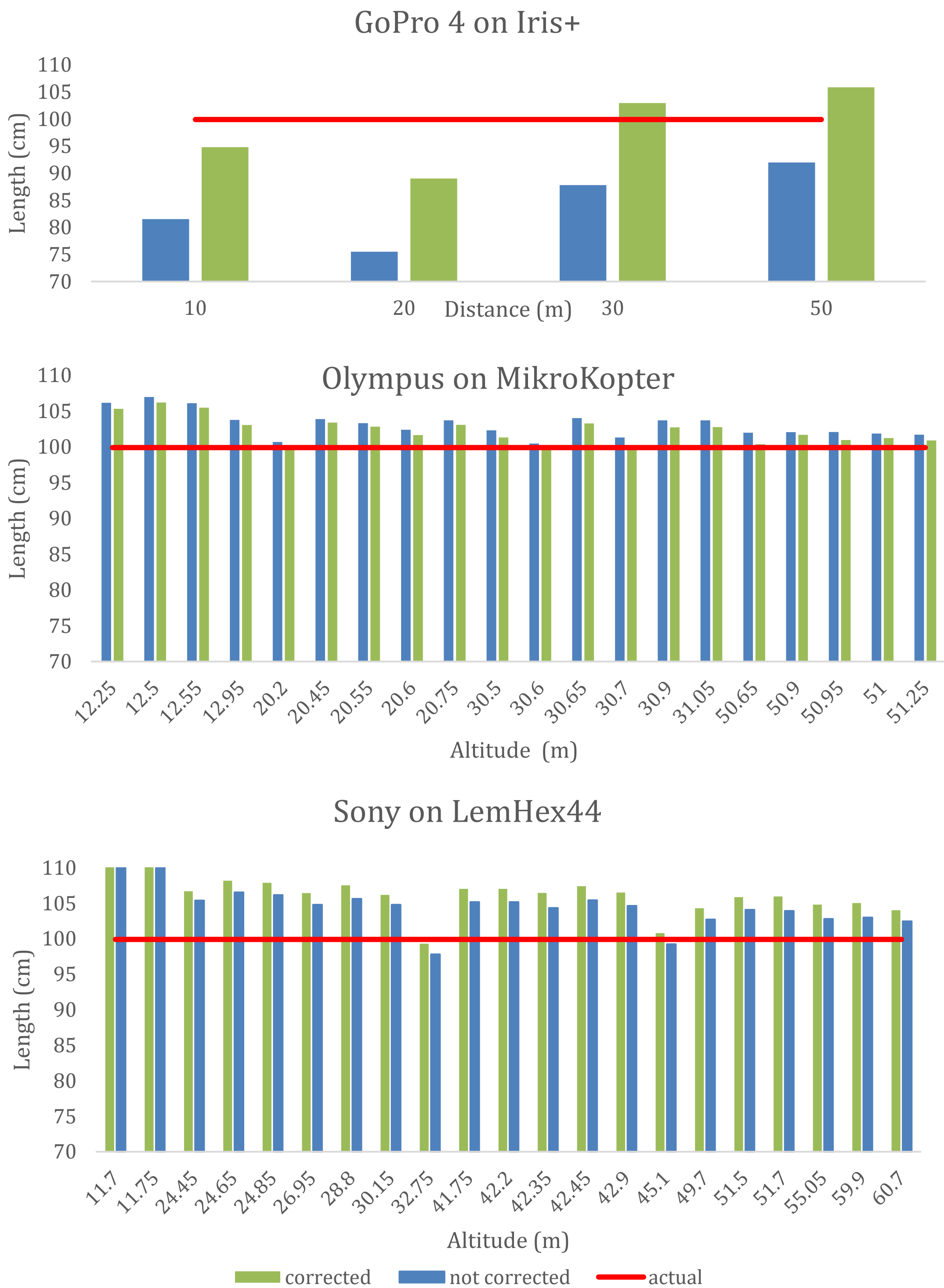
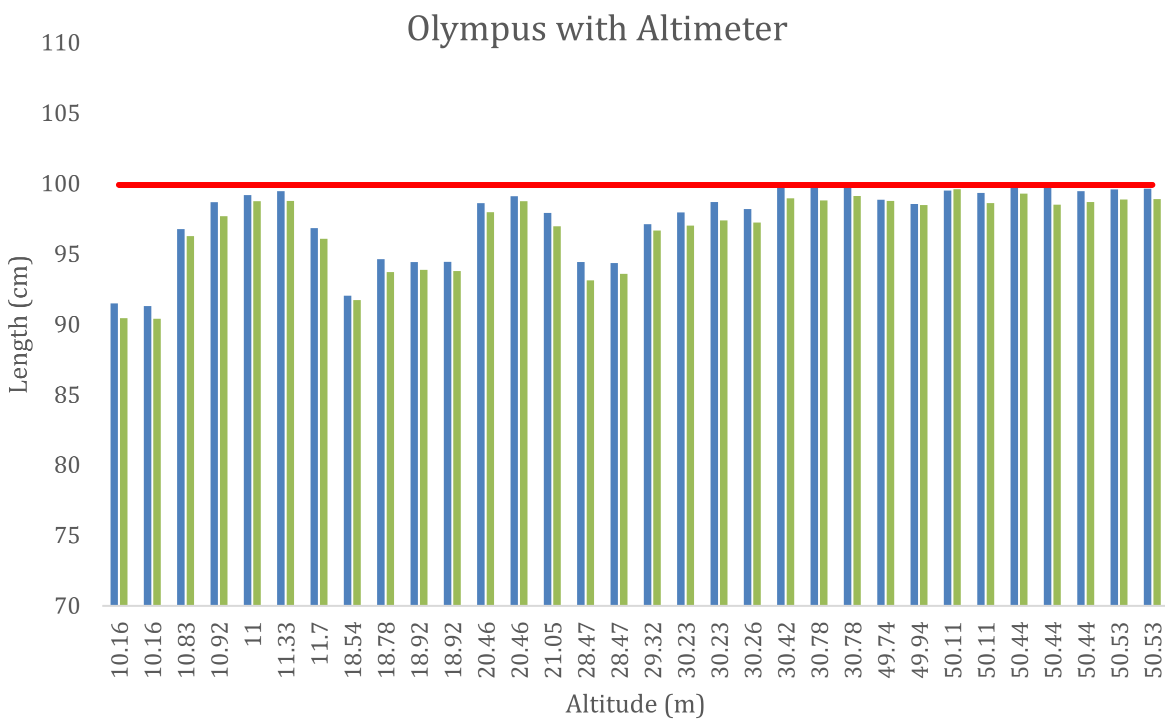


Figure 6: Blue lines show the photogrammetric measurement calculated at varying distances from the target of corrected images taken of the wooden post, the green lines show the measurements of the wooden post of the uncorrected images. The red line shows the actual measurement of the wooden post.

UAS with Altimeter:



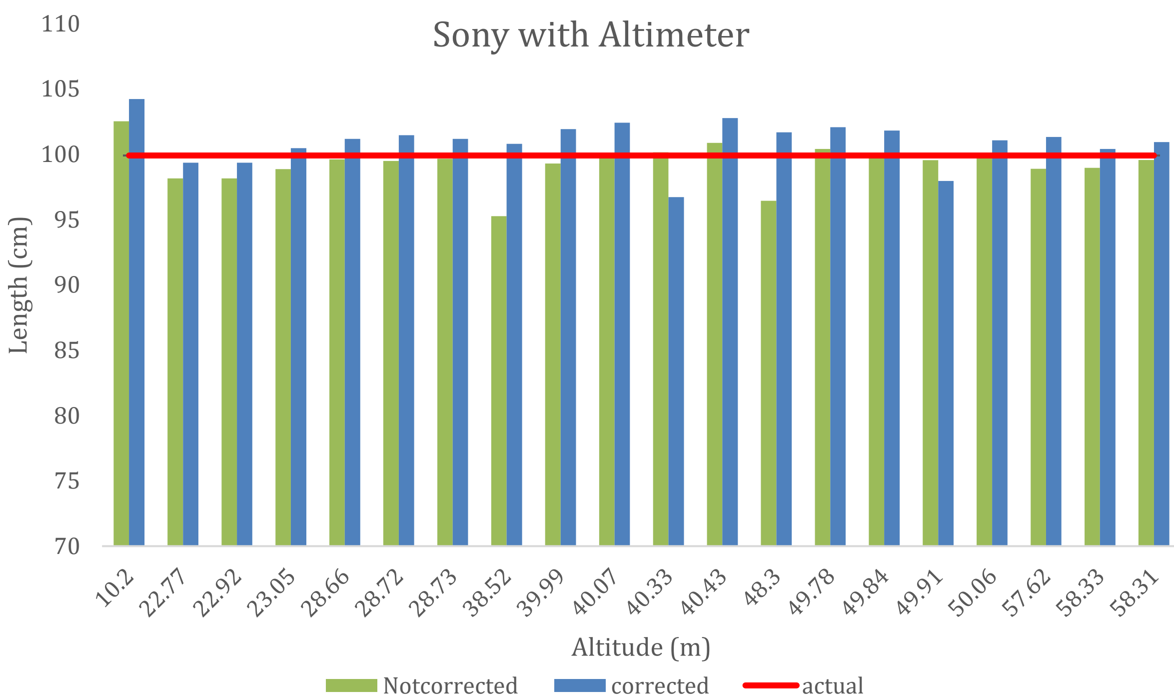


Figure 7: Blue lines show the photogrammetric measurement calculated from corrected images with the altitude measurements obtained from the laser altimeter. The green lines show the measurements of the wooden post of the not corrected images and the red line is the actual measurement of the wooden post.

Statistical Results:

Table 3: The statistical information of the fit line to the comparison of the corrected images to the uncorrected images

GoPro 4 Black	
R^2	0.026545
RSquare Adj	-0.04834
Root Mean Square Error	1.487926
Mean of Response	83.38861

Olympus E-pm2	
R^2	0.512591
RSquare Adj	0.475098
Root Mean Square Error	0.507132
Mean of Response	99.75422

Sony a5100	
R^2	0.811587
RSquare Adj	0.797094
Root Mean Square Error	0.342218
Mean of Response	103.0752

Table 4: mean and standard deviation of static ground tests of both corrected and uncorrected images

Static Ground Distribution		**Mean**	**Standard Deviation**
GoPro4			
	uncorrected	99.161	1.289
	corrected	83.388	1.453
Olympus			
	uncorrected	99.589	0.860
	corrected	99.754	0.699
Sony			
	uncorrected	99.704	0.663
	corrected	101.519	0.748

Table 5: mean and standard deviation of UAS tests from barometric altitude readings of both corrected and uncorrected images

UAS Distribution		**Mean**	**Standard Deviation**
GoPro4			
	uncorrected	98.158	8.358
	corrected	84.195	7.335
Olympus			
	uncorrected	102.248	1.829
	corrected	103.032	1.763
Sony			
	uncorrected	105.129	4.342
	corrected	106.900	4.417

Table 6: mean and standard deviation of UAS tests from laser altimeter of both corrected and uncorrected images

Altimeter Distribution			
Olympus		**Mean**	**Standard Deviation**
	uncorrected	96.765	2.702
	corrected	97.496	2.653
Sony			
	uncorrected	99.510	1.664
	corrected	101.187	1.758

Antarctic Whale Case Study

When looking at the error associated with different measurements at varying heights, the average error associated with images taken with the Sony above 50m altitude, where all of the whale images were taken, shows 0.52 cm error reducing our proposed error to sub-centimeter accuracy. Thus we can safely assume that all measurments of where whales are within 0.52 centimeters accuracy. A total of 48 whales were measured from images taken in the 2017 field season. The average total length of all individuals was 11.42 m. For the mom-calf pairs a comparison the difference between each mom and her corresponding calf was calculated at each width interval. Then the average differences were calculated at each width to look at the greatest difference between individual moms and calves. However to look at the average difference between moms and calves the difference at each total length interval were summed for all 5 pairs and compared (Table 7).

Table 7: The average difference mom-calf pairs at 5% total length width intervals.

Percentage of total body length (%)	average difference (m)
25	0.841
45	0.826
40	0.824
35	0.820
30	0.789
50	0.788
55	0.722
20	0.708
15	0.686
60	0.675
10	0.581
65	0.516
70	0.385
5	0.364
95	0.359
75	0.323
80	0.248
85	0.151
90	0.054

Discussion

The GoPro correction was calculated by Adobe Photoshop, the Sony was +1.67 and the Olympus was -1.02. This shows that the Sony had pincushion distortion and the Olympus has barrel distortion (Figure 4). These results for the camera distortion correction allowed us to explore the differences between barrel and pincushion distortion and how that impacts photogrammetric measurements.

From the camera correction comparison (Table 3), we observed that the correction of the GoPro was the least accurate correction when a line was fit to the data (R^2 =0.02). The most accurate correction comparison was of the Sony (R^2 = 0.81). This suggests that the corrected images of the Sony produce more accurate measurement results than corrected images from the GoPro and the Olympus falls between. However, based on Figures 5, 6, and 7 it is evident that for each of the cameras, the corrected images were less accurate than the uncorrected images.

In looking at the distribution of the measurements of each camera during the static ground test, the GoPro corrected images had the least accuracy and greatest standard deviation (Figure 5). The most accurate was the corrected Olympus images which were both closest to the actual measurements of the wooden post, and had the lowest standard deviation (Figure 5). The Sony was very precise, with both the corrected and uncorrected images having the lowest standard deviation, however both corrected and uncorrected images overestimated the length of the wooden post (Table 4).

Interestingly, when looking at the accuracy of the measurements of the wooden post from the varying UAS the results were similar to the patterns observed in the static ground tests. The GoPro on the Iris+ produced more accurate results with the uncorrected images, however, the standard deviation was higher at 8.358 (Table 4). The Olympus with altitude measurements from the MikroKopter overestimated the length for both the corrected and uncorrected images (Figure 6, Table 5). The Sony UAS test show that the accuracy of the Sony decreased to approximately 4.5 cm for both the uncorrected and corrected images when altitude was obtained from the barometric pressure, as well as overestimating the length. This suggests that the altitude readings from the UAS are higher than the actual altitude thus skewing the results higher than other results.

To increase the accuracy of the measurements, altitude readings from the laser altimeter were used instead of the barometric pressure from UAS flight logs. Due to environmental variables, the barometric pressure readings from flight logs are extremely inconstant, and less accurate. When using the laser altimeter altitude readings for the Olympus the accuracy of the measurements was closer to the actual measurement, however the variability increase for both the uncorrected and corrected images (Figure 7, Table 6). However, when using the laser altimeter for the Sony images, the accuracy and standard deviation increased for both the corrected and uncorrected images. Thus, for the Antarctic humpback whale case study we recommended that the Sony a5100 be used with altitude readings from the laser altimeter and the images remain uncorrected.

Case Study

A total of 48 whales were measured from images taken in the 2017 field season. Based on the UAS tests completed in the first part of this study, it is known that the results of these are within 0.52 cm of the true length of the individual. Several whales from consecutive images were selected to look at the variation between measurements taken of the same individual and the greatest difference between measurements was no greater than 4.4mm. Additionally, non-consecutive images of the same whale were examined to observe the difference between different body positions and other changes in environmental variables could have on the accuracy. From this analysis, it was observed that non-consecutive images of the same individual increased the variability of the measurement, however even with a time difference of 1 hour and 19 minutes between pictures of the same individual being taken, the difference was no greater than 4.8mm.

Additionally, from the 5 mom-calf pairs that were analyzed it can be determined that the greatest average width difference was at the 25% region of the body (Table 7). However, it is important to note that the largest differences are between 25-45%, or typically in the middle half of the individuals. While these results are not surprising, this is an important first step in identifying morphological differences in adults and calves and potentially identifying critically important stages of development for growth.

Conclusion

Based on the static measurements, as well as those done aerially, it appears that the Sony a5100 is the most accurate and precise camera. From static ground tests and UAS with altimeter the Sony a5100 measurements were the most accurate results with the lowest error. For future studies using these cameras, it is now possible for standard deviations to be applied, and for average error to be calculated for measurements of objects of unknown size. Furthermore, it was discovered that barometric pressure from UAS readings over estimates altitude and increases the magnitude of the measurements. Altitude readings from the laser altimeter increased the accuracy of the measurements and produced results closer to the expected. From these results we recommend that when possible laser altimeters be used for photogrammetric measurements, however if this isn't possible, at the very least when altitude readings from UAS are utilized, the increase in average measurements should be acknowledged.

Limitations

It should be noted that for an even more precise assessment of the accuracy of these measurements, more than one researcher would have measured each picture, thus allowing comparisons of the difference between measurement of the same object or individual whale with the exact same variable conditions. Additionally, selection of the "best" image to measure is subjective and should be verified by more than one individual. Furthermore, the ability to distinguish between whale and water in some selected images is difficult and could result in the over estimation of some individuals.

Future Studies

Due to the above limitations, in future studies, it would be ideal to utilize at least three individuals calculating the number of pixels in ImageJ to improve the validity of the results. It would also be important to look at the distortion of the cameras in different quadrants of the image, as it is very rare that the target is situated directly in the middle of the image where the least distortion is occurring. Finally, it would be important to look at the impacts of different UAS platforms on one individual camera and how that can impact the accuracy of the measurement.

Additionally, looking at the width of individuals is important to establish body condition assessments, as well as the cost of pregnancy, which is something to be explored further, however looking at these parameters across a feeding season will provide for more important input to important ecologically significant time periods and locations for humpback whales. Moreover, looking at these measurements over multiple years over feeding seasons will allow for a better understanding of not only the important ecological implications, but how climate change or other environmental impacts are potentially impacting the success of this population.

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