Title

Extending an Aerial Remote Sensing Platform Using Three Digital Sensors—
Summary Report to MASTS TPS

PIs

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Goals and Objectives

Prior to this grant application we had built a low cost UAV and had successfully recorded images and initial morphometric measurements from hauled-out harbour seals in Loch Fleet NNR, Scotland. The goals of this grant were to examine the utility and relevance of new sensors. Specifically, we wished to test three different sensors: 1) a thermal imaging camera; 2) a laser rangefinder; and 3) a lightweight first person video setup. The goal of these sensors were to see if it was possible to get a different metric of body condition from thermal imaging, to more precisely measure the altitude of the UAV, and lastly to better position the UAV over the seals. We did not hire a thermal imaging camera due to logistical constraints and limitations from the manufacture. We did, however, accomplish the last two of these three objectives, and report our findings herein. We include our perspective on this platform for long-term research going forward, and conclude with specific recommendations.

Aerial photogrammetry is an old technique, and images taken from such a platform can be used to make accurate and reliable measurements of objects recorded in the picture. With the rapid rise and uptake of UAVs as a research platform, this has proven its worth in marine mammal ecology. However, as it is with most research tools, the higher the quality of the equipment, the better the results. Accordingly, we wished to determine altitude with higher precision and accuracy using a high performance laser rangefinder instead of the two internal altimeters (GPS-based, and barometric).

Laser Rangefinder

We purchased a Lightware SF02/F laser rangefinder from Lightware Optoelctronics in October of 2014. Shane Rodwell of SAMS installed the rangefinder and connected it to the Pixhawk (the avionics or flight controller for the UAV). We calibrated this at SAMS, and our first flights over ground proved remarkably successful and accurate. However, our first flights over water proved to be disappointing; the results indicated we were unable to get a reliable data stream from the sensor (Figure 1a). Subsequent discussions with the manufacturer indicated that their algorithm was insufficient to record bounce-back over water.

Lightware Optoelctronics were kind enough to send a replacement upgrade rangefinder—an SF10/C. Rodwell did the assembly, calibration and integration of the sensor into the Pixhawk to ensure a reliable data capture workflow (Figure 1b). Again, initial results over ground proved very accurate and precise (Figure 1b, and 2). We conducted more field trials in Loch Fleet in May of 2016, with uneven results. Specifically, we had intermittent signals reporting back from the sensor to the Pixhawk (not shown). Prior to the May field trials we had added a 3-axis gimbal to the UAV. This was done to increase the number of photos taken where the camera was pointing straight down, i.e. to avoid or minimise the number of times the camera's focal plane would move off parallel as a function of pitch and roll of the copter. We will return to the impact of this upgrade in the conclusion section, but here we will note that by adding in the gimbal, the extra wiring required interfered with the signal coming from the rangefinder to the Pixhawk. The end result was a broken data stream comprised of intermittent altitude measurements alternating with lost signal indications. This was remedied towards the end of the field season by fixing the wiring and re-soldering the relevant connections. These fixes resulted in a smooth unbroken data stream of precise altitude measurements. The data stream from the laser rangefinder is much smoother and more consistent than the barometric altimeter (Figures 1b, and 2).

In terms of the improvement and reliability of the measurements of the animals, we had a Master's student (Marie Kearns) work on this as part of the MRes program in Marine Mammal Science at University of St Andrews. To test the impact of the sensor on the final measurements, we flew the UAV over a Styrofoam seal of known length (Figures 3, and 4). Length measurements of the seal as determined using the rangefinder-derived altitude readings were both more precise and more accurate than either of the two onboard methods (Figure 5). Going forward then, we have every confidence that this sensor is an important part of a UAV platform, and should be included when altitude measurements are critical.

First Person View Camera
One of the things we discovered during early flights over seals at Loch Fleet, was that without an onboard downward-facing video camera, it was difficult to determine where the UAV was in relation to the seals. This was because the UAV was up to 240 meters away from the flight crew. Despite this impediment, there were two factors that enabled successful capture of images. First, we were using a relatively wide-angle lens on the camera, which ensured a wide field of view through the lens. Second, because the seals haul out relatively close to the waters' edge and because the sand banks at Loch Fleet are relatively stable, we were able to use the location of these features in satellite imagery to precisely maneuver the UAV along the water's edge. We did this by calculating way points and loading a pre-determined flight plan into the UAV.

While these two factors allowed us to capture seals in the field of view, Kearn's research had shown that the relative placement of the seal in the photograph impacts the precision of the measurements (Figures 4, and 5). Therefore, we wished to determine if an onboard video feed would allow us to better position the UAV over the top of individual seals. This would mean a greater number of pictures would be taken of individual seals when they were directly below the camera.

We purchased an FPV kit from 3D Robotics and upgraded antennas from an online reseller; the kit was mounted onto the airframe by Rodwell. The FPV kit included a small (5" x 7") handheld video monitor that is held and viewed by the Mission Commander of the flight crew. The MC communicates directly to the UAV pilot and provides commands to more precisely locate the UAV over the top of the seal(s). Because of this communication loop, the UAV can be maneuvered directly over the seal. Becky Hewitt, from University of Aberdeen, served as the MC and came down to Fife in March, 2016 to practice maneuvering flights over static objects on the ground with Schick (UAV pilot). This experience proved critical once we were in the field in May, 2016, as it allowed for rapid and easy repositioning during flights.

There are at least two ways to relay the video feed back to the handheld monitor on the ground. One is for the feed to come from the camera itself, i.e. the camera that takes the pictures (in our case this was a Sony NEX-6). The other way is to have it come from the FPV camera. The benefit of the first set up is that the image the MC sees is the same as the one being recorded by the camera. The disadvantage is that each time a still picture is taken by the camera, the video feed goes black. The second method allows for a continuous feed from the FPV camera. However, the field of view of the FPV camera is much wider than the still camera. We opted for the latter setup, and put calibration tape on the handheld monitor to provide a more accurate match between what was seen in the FPV camera and what was captured by the still camera. This worked reasonably well, however we found that the FPV camera was subject to vibrations from the UAV itself. This meant that the lenses of the two cameras would become out of sync; regular adjustments were necessary to re-calibrate the lenses.

Despite these issues, the inclusion of the FPV on the UAV allowed for very accurate and precise placement of the UAV over the seal (Figures 7 & 8). Because of this, we are able to get more seals in the centre of each picture, thereby increasing precision and accuracy of the morphometric measurements.

Conclusions

We have now conducted several field trials as part of this project. As part of these, we have many successful flights, over land, water, and over seals. From this experience, we have learned a lot about what works and what does not.

First, we believe it is critical to have dedicated engineering support for the UAV. Our project has benefited greatly from the support of the UAV team at SAMS in Oban, and could be strengthened further still by having an engineer with UAV experience *in situ* in Cromarty. Because the copter we used was a bespoke unit, this need is critical going forward.

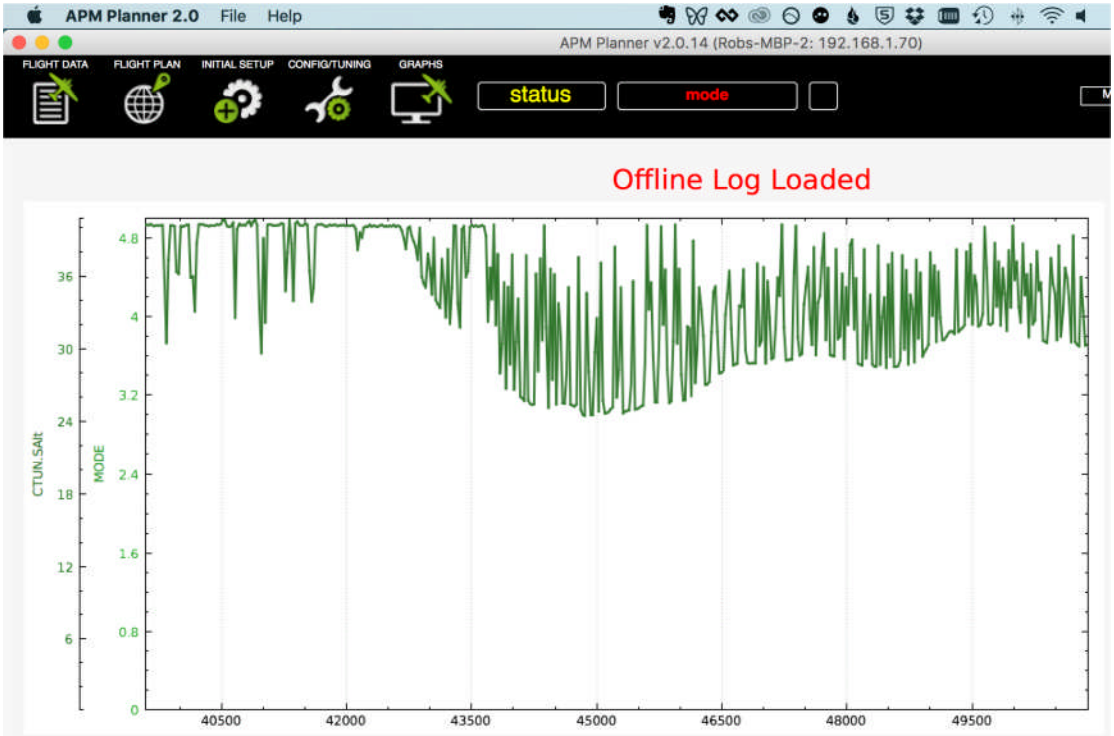
Second, with respect to image capture, we feel that a higher focal length lens is necessary. We chose the focal length of our lens based on guidance and input from researchers at NOAA in the US. However, they are primarily photographing whales; since seals are much smaller, they take up less room in the image (Figure 7). This image was taken at 30 meters, and field experience has shown that we can fly no lower than 25 meters without disturbing the seals. Therefore a higher magnification lens is a good next step. Unfortunately, the heavier the lens, the more restrictions on the UAV platform, e.g. shorter flying times, less margin for error. Since the UAV in its current state is already close to safe weight limits, a newer larger UAV may be a better next step as well.

Third, an upgrade to the FPV is recommended. While it has been very helpful to have it on board the UAV, the limitations mentioned above—differing field of view, and out of alignment lenses—are problematic. Getting a higher quality set up would alleviate this. Alternatively, feeding the video through the main camera would minimise these problems, at the expense of the blinking on/off of the feed. We could set up the FPV to send two feeds, one from the main camera in addition to the one from the FPV camera. This adds expense and gives the MC two things to have to focus on, which may be a limiting factor.

Finally, our last field trial in May highlighted how useful the 3-axis gimbal is—in fact about as critical as the FPV and the rangefinder. With the gimbal, the focal plane of the camera was almost always flat and therefore parallel to the ground/seals. In addition, the gimbal isolated the camera from a lot of the vibrations and motion of the UAV. The end result was a higher percentage of usable pictures.

There is a big step up in price between the bespoke UAV we have built and refined, and the larger more off-the-shelf UAVs. We chose to start with a smaller less expensive UAV as this was a proof-of-concept trial. In particular, since we were flying over water, we wanted to keep potential financial losses to a minimum if the copter failed, i.e. it is easier to have a £1k copter crash and sink than an £8k one. Results have shown conclusively that using UAVs to derive measurements is feasible, but not without its limitations. One straightforward way to address some of these limitations is to simply purchase a bigger, more robust platform. Another possible approach might be to hire a third party company to do the flying and picture recording. This shunts much of the financial and logistical risk off the researcher. Since our experience has shown that the actual flying is fairly straightforward, this may represent a more optimal route going forward.

Figures



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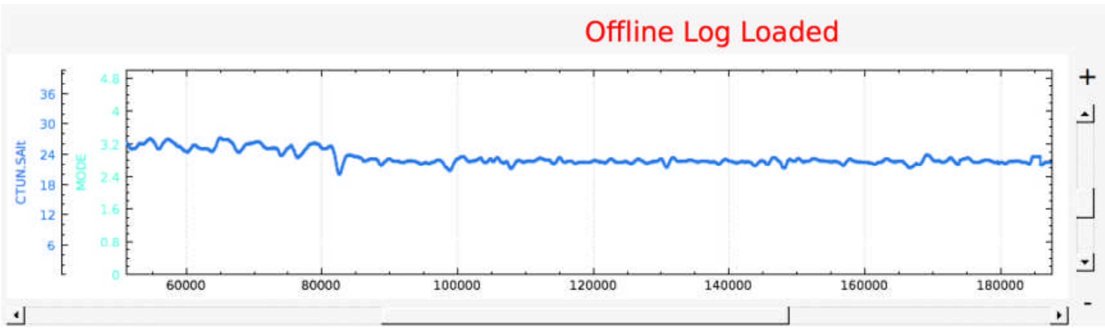

Figure 1. Top panel: Example data stream of UAV altitude (m) as recorded from the first Lightware rangefinder. Each "spike" in the measurement indicates when the rangefinder failed to receive the proper signal back from the ground. Bottom panel: data stream from second Lightware rangefinder. Note the smooth and uninterrupted data record. In each panel, x-axis represents time in milliseconds; left-most y-axis represents altitude in meters.

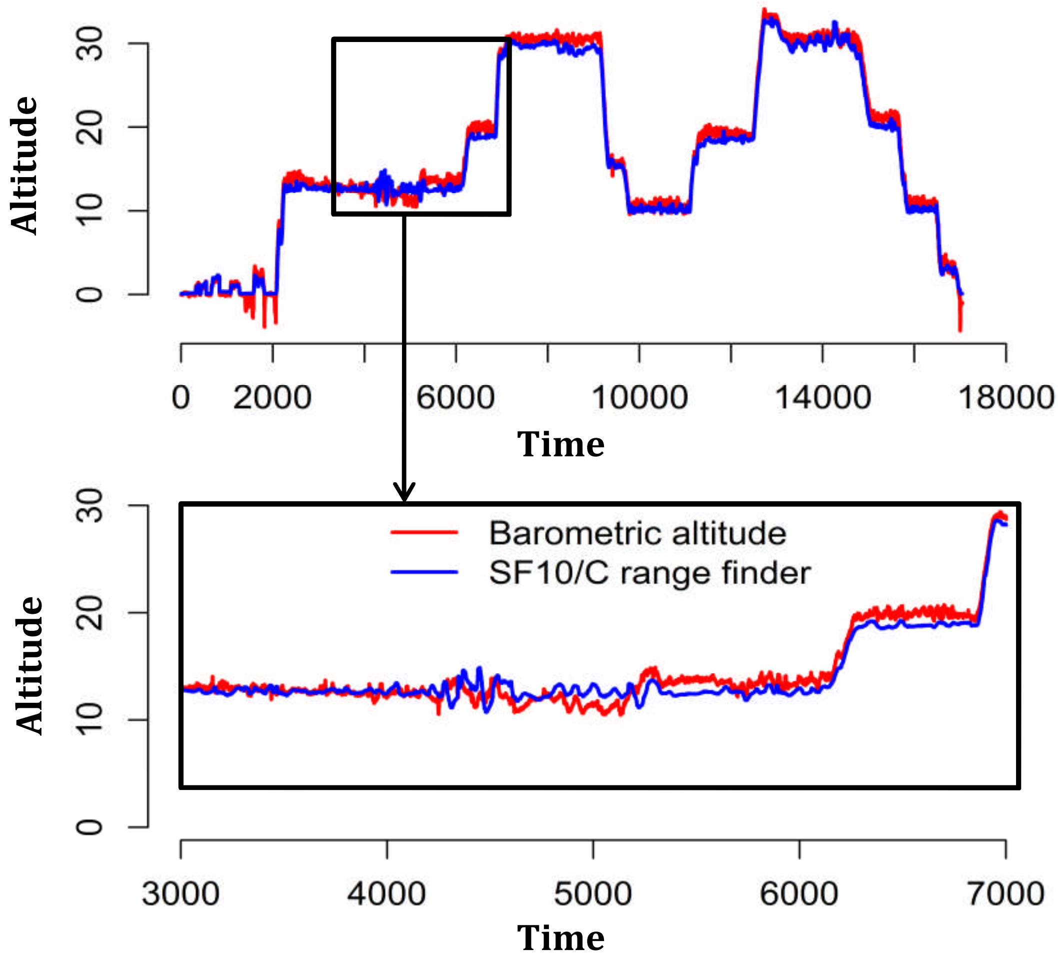

Figure 2. Comparison of altitude as recorded by the range finder (blue) and the onboard barometric altimeter (red). While the values recorded by each altimeter are close, those of the range finder are smoother and less susceptible to UAV-induced pressure changes.

Figure 3. Bespoke UAV with Styrofoam seal in background.

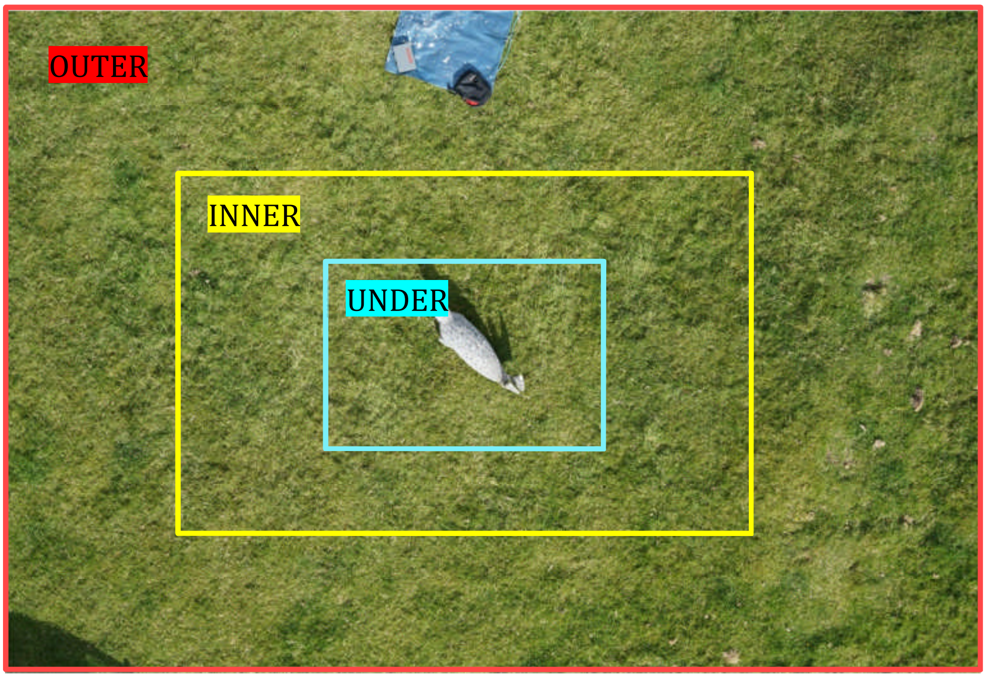

Figure 4. Aerial photograph of Styrofoam seal. Coloured rectangles indicate custom grading system to assess placement of seal within the image.

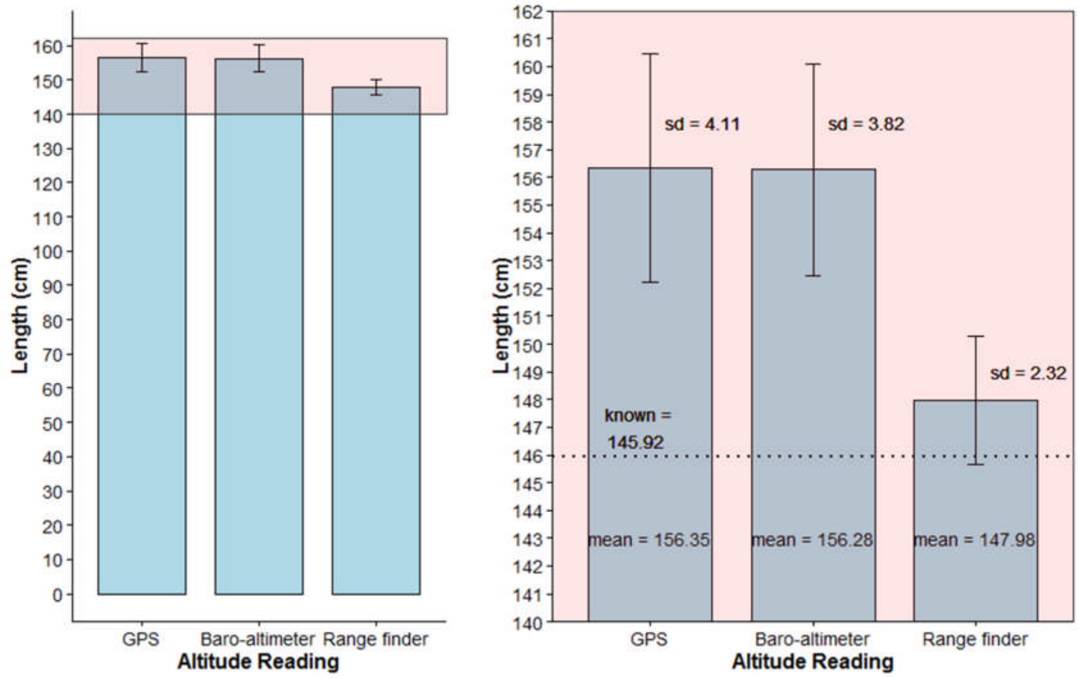

Figure 5. Length measurements of a Styrofoam seal of known length as derived from a photographic image (left panel); detailed view in relation to actual length of the seal (right panel). From the same image, we derived lengths using three different altitude measurements: 1) The GPS-based altimeter; 2) the barometric altimeter; and 3) the laser rangefinder. The length measurements derived from the rangefinder were more precise (standard deviation of 2.32 cm), and more accurate (mean length of 147.98 cm versus a known length of 145.92 cm).

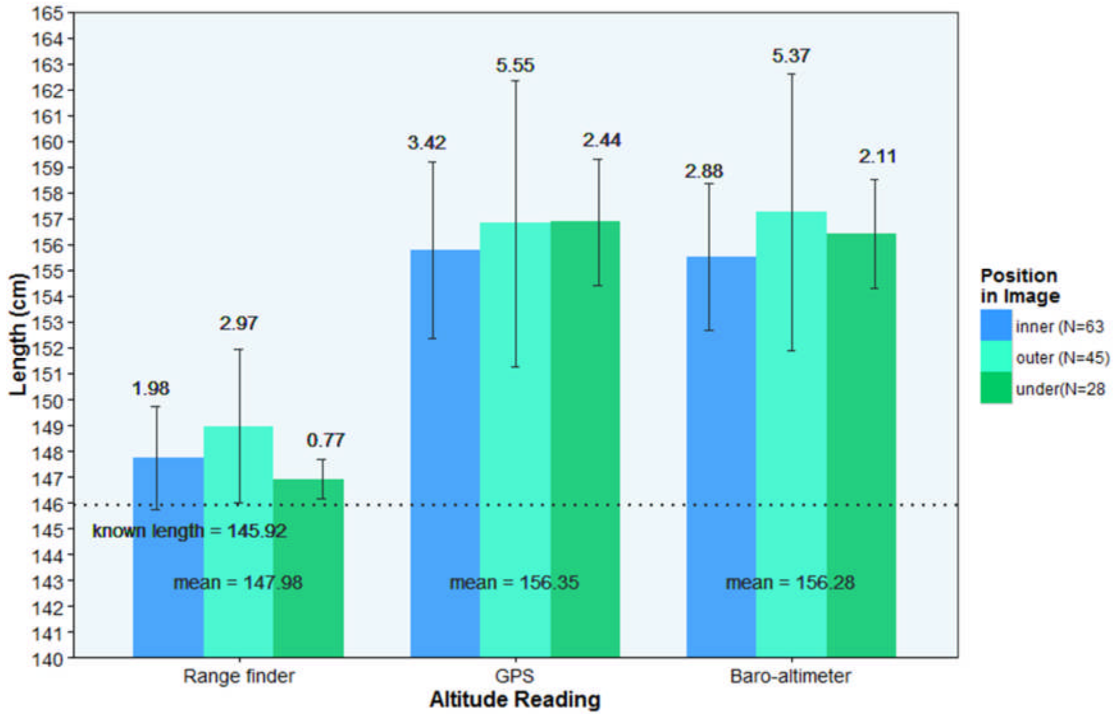

Figure 6. Length measurements as a function of a) the altitude sensor, and b) the position of the seal in the image in relation to the camera. Results indicate that the best measurements were taken using the altitude derived from the laser rangefinder and when the seal was directly under the camera.

Figure 7. Example picture taken at Loch Fleet on May 26, 2016. The UAV was equipped with the FPV setup, the laser rangefinder, and the 3-axis gimbal. Note how the FPV camera allows for near perfect placement of the seal in the image.

Figure 8. 100% zoom of the seal in the centre of the image of Figure 7. Because of the placement of the UAV with respect to the seal, the sharpness of the image, and the precision of the altitude measurements, this represents and ideal image capture. With this image we can not only measure the animal, but also can match it to the photographic catalog maintained by University of Aberdeen's Lighthouse Field Station.