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NOTE

Photogrammetry of killer whales using a small hexacopter launched at sea[1]

J.W. Durban, H. Fearnbach, L.G. Barrett-Lennard, W.L. Perryman, and D.J. Leroi

Abstract: Conventional aircraft have been used for photogrammetry studies of free-ranging whales, but are often not practical in remote regions or not affordable. Here we report on the use of a small, unmanned hexacopter (APH-22; Aerial Imaging Solutions) as an alternative method for collecting photographs to measure killer whales (*Orcinus orca*) at sea. We deployed and retrieved the hexacopter by hand during 60 flights (average duration 13.2 min, max 15.7 min) from the upper deck of an 8.2 m boat, utilizing the aircraft's vertical takeoff and landing (VTOL) capability. The hexacopter was quiet and stable in flight, and therefore could be flown at relatively low altitudes without disturbing whales. The payload was a Micro Four-Thirds system camera that was used to obtain 18920 still images from an altitude of 35–40 m above the whales. Tests indicated a ground-resolved distance of <1.4 cm across the full extent of a flat and undistorted field of view, and an onboard pressure altimeter enabled measurements in pixels to be scaled to true size with an average accuracy of 5 cm. As a result, the images were sharp enough to differentiate individual whales using natural markings (77 whales in total) and preliminary estimates resolved differences in whale lengths ranging from 2.6 to 5.8 m. This first application at sea demonstrated the APH-22 hexacopter to be a safe and cost-effective platform for collecting photogrammetry images to fill key scientific data gaps about whales, and we anticipate this utility will extend to studies of other wildlife species.

Key words: UAS, hexacopter, wildlife VTOL, whales.

Résumé : Les aéronefs classiques ont été utilisés pour des études de photogrammétrie de baleines en liberté, mais souvent ils ne sont ni pratiques, ni abordables dans les régions éloignées. Ici, nous présentons un rapport sur l'utilisation d'un petit hexacoptère sans pilote (APH-22; Aerial Imaging Solutions) en tant que méthode alternative pour recueillir des photographies afin de mesurer les épaulards (*Orcinus orca*) en mer. Nous avons déployé et récupéré l'hexacoptère manuellement au cours de 60 vols (durée moyenne de 13,2 min, maximum de 15,7 min) à partir du pont supérieur d'un bateau de 8,2 m, grâce à la capacité de décollage et d'atterrissage verticaux (VTOL) de l'aéronef. L'hexacoptère était silencieux et stable en vol, et ainsi on pouvait le faire voler à des altitudes relativement basses sans perturber les baleines. La charge utile était un système photographique Micro Four-Thirds qu'on a utilisé pour obtenir 18920 images fixes d'une altitude de 35 à 40 m au-dessus des baleines. Les essais ont indiqué une limite de résolution au sol de <1,4 cm sur l'étendue complète d'un champ de vision plan sans distorsion, et un altimètre pression embarqué a permis de changer l'échelle des mesures en pixels à des dimensions réelles avec une précision moyenne de 5 cm. Par conséquent, les images étaient suffisamment nettes pour pouvoir distinguer certaines baleines par leurs marques corporelles (77 baleines au total)

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[1]This note is one of a special series of invited papers on the use of unmanned vehicle systems in wildlife studies.

et les estimations préliminaires distinguent des différences de longueur de baleine variant de 2,6 à 5,8 m. Dès la première utilisation en mer, l'hexacoptère APH-22 s'est avéré une plateforme sécuritaire et économique pour collecter des images photogrammétriques afin de combler des données scientifiques de base manquantes concernant les baleines, et nous prévoyons que cette utilisation s'étendra à des études d'autres espèces fauniques.

Mots-clés : système d'aéronef sans pilote (UAS), hexacoptère, faune, décollage et atterrissage verticaux (VTOL), baleines.

Introduction

Conventional aircraft have been successfully used for photogrammetry studies of free-ranging whales. Fixed-wing planes and helicopters have been used to obtain vertical photographs from directly above whales, from which shape profiles can be measured to assess body condition to infer nutritional status and pregnancy (e.g., Perryman and Lynn 2002). When combined with information on scale (= altitude/focal length), these images can also be used to estimate absolute length (e.g., Pitman et al. 2007) and monitor growth trends (e.g., Fearnbach et al. 2011). However, aircraft operations are often not practical in remote regions, and not affordable under typical research budgets, and therefore this technique has not been widely used.

Here we report on a recent project using a small unmanned aerial system (UAS) as an alternative method for successfully obtaining photogrammetry images of killer whales (*Orcinus orca*) at sea. Our study area was around Vancouver Island, off the British Columbia coastline of western Canada. Previously, we used a helicopter to measure "Southern Resident" killer whales in the more accessible waters off Southern Vancouver Island (Fearnbach et al. 2011), but required an alternative approach to obtain comparative measurements from the "Northern Resident" population in the more remote area at the north of the island. We chose to use a small multi-rotor UAS because vertical takeoff and landing (VTOL) capability was required to operate from a small boat, and we required stability in flight for photographic operations. We chose a small (1.2 kg dry weight without payload; 82 cm wingspan) hexacopter that was recently used in Antarctica to obtain photographs for counting seals and penguins, and to estimate the size of leopard seals onshore (Goebel et al. 2015). This UAS platform has been proven to have the endurance and performance characteristics to conduct successful photographic missions in a windy environment, and to create a limited sound footprint that does not disturb wildlife.

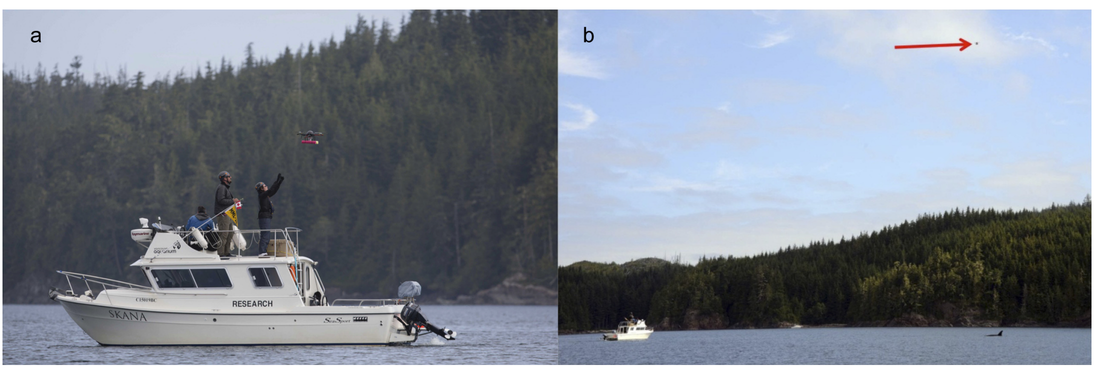
Materials and methods

The APH-22 hexacopter (Aerial Imaging Solutions, Old Lyme, CT; Fig. 1) is described in Goebel et al. (2015); however, one key modification to firmware was required for operating from a boat, namely, the ability to store a motionless calibration of the gyro sensors made on land and recall these gyro offsets from non-volatile memory when on the boat. This enabled the hexacopter to maintain stable flight attitude, even when launched from a moving platform at sea. We successfully deployed and retrieved the hexacopter by hand during 60 flight missions launched from the upper deck of an 8.2 m SeaSport boat (Fig. 2). This procedure proved to be safe and repeatable, because of the stable flight and low weight of the hexacopter; the only payload was a camera (Olympus E-PM2, 0.23 kg; Olympus M.Zuiko 25 mm F1.8 lens, 0.13 kg) and hexacopter battery (QuadroPower 6200 mAh Lipo Flat; 0.58 kg). Wind speeds were less than 5 m/s (10 knots) during all flights, as we chose to only fly when a smooth sea state would enable detailed images of whales beneath the surface.

The average duration of the 60 flights was 13.2 min (max = 15.7 min). These marine flights were conservatively ended well in advance of battery limitations — the APH-22 has been flown for >25 min during test flights with the same battery. The total distance covered during a flight averaged 1350 m (max = 2480 m), but the distance to the pilot was smaller (typically <200 m) as the boat was continuously maneuvered to enable line-of-sight piloting of the hexacopter and facilitate positioning over whales. The hexacopter was controlled by the pilot using a radio link (2.4 GHz), and we did not experience any loss of link during the 13.25 h of total flying. Finer-scale positioning of the hexacopter above whales was accomplished through guidance from a ground station operator who viewed live analog video captured by the onboard camera and transmitted to a portable monitor on the boat using a 5.8 GHz link. When whales were in the frame, the pilot used a remote link to trigger the capture of high-resolution (12.3 MP) still images on the camera's flash memory. The ground station also displayed telemetry information (910 MHz link), which enabled monitoring of altitude, flight time, and battery levels for flight management.

Fig. 1. The APH-22 hexacopter (Aerial Imaging Solutions, Old Lyme, CT) that was used to fly 60 successful missions to collect vertical photogrammetry images of killer whales at sea. Here shown with the Olympus E-PM2 camera and interchangeable lens system; the camera mounts on the underside of the hexacopter to be downward-facing.

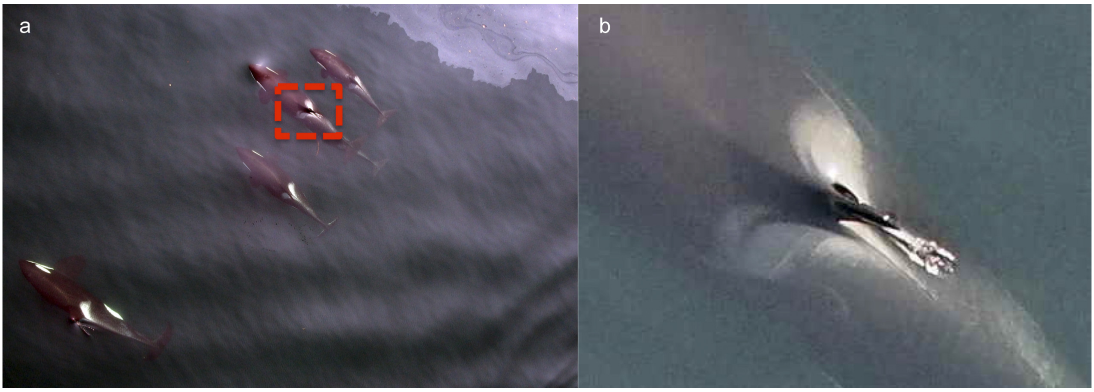
Fig. 2. (*a*) Boat-based operations using the APH-22 hexacopter, which was hand-deployed and retrieved (photo by Bruce Paterson) from the upper deck of an 8.2 m boat, and (*b*) used to obtain overhead images of killer whales from altitudes of 35–40 m (photo by Suzanne Burns; red arrow indicates the hexacopter above a killer whale).



Results and disscusion

We were successful at positioning the hexacopter directly above groups of killer whales, and obtained a total of 18920 still images from an altitude of 35–40 m. We did not observe any behavioral responses from the whales during any of the flights, and they likely were not aware of the small hexacopter at these altitudes. The 25 mm lens we used is considered "normal" for the Micro Four-Thirds sensor of the E-PM2 camera, in that the focal length is equal to the diagonal of a square formed by the long dimension of the sensor, and therefore photogrammetry measurements were possible across the full extent of a flat and undistorted field of view. Previous resolution tests over a standard medium

Fig. 3. (*a*) Overhead image of a killer whale group taken using an Olympus E-PM2 camera mounted on the APH-22 hexacopter, with (*b*) a magnified inset showing the distinct pigmentation pattern of a whale's saddle patch that can be used to identify distinct individuals (e.g., Fearnbach et al. 2011). This example displays the distinctive saddle patch of an adult female from the Northern Resident killer whale population, identification number A42 with a known age of 34 years in 2014 (see Ellis et al. 2011).



contrast (8:1) resolution target (RST-704, series C) showed that we had a ground-resolved distance of <1.8 cm using the 25 mm lens at an altitude of 50 m, which improved further to <1.4 cm at our standard altitude of 35 m. Our images of the whales clearly showed that this expected resolution was realized in photographs at sea: notably, we could resolve differences in natural markings to identify individual whales using images of their saddle patch pigmentation (Fig. 3), which allowed us to link measurements to whales of known age and sex (e.g., Fearnbach et al. 2011).

One of the key requirements of our photogrammetry system is the ability to obtain whale length and width profiles on a real scale. Measurements from the images in pixels can be converted to a true measurement using the known longitudinal dimension of the camera sensor and the number of pixels comprising this known width, and these can then be scaled to true lengths using the measured altitude and the focal length of the lens (e.g., Fearnbach et al. 2011). The flight controllers on the hexacopter used a Freescale MPX4115A absolute air pressure sensor, which has on-chip temperature compensation, for altitude measurements. We calculated the altitude of the hexacopter at 1 s intervals by applying the standard altitude equation to the difference between the pressure while flying and the pressure at takeoff, with a known takeoff height above sea level.

Onboard measures of altitude were validated by scale calculations of the distance between points of known separation (6.4 m = approximate whale length) on the deck of our research vessel, measured from photographs taken at our standard photogrammetry altitudes. Using 16 different calibration photographs from calculated altitudes of 35–38 m, the average bias was −0.05 m (standard deviation = 0.29 m), representing <1% of the total length of the boat. This indicated the ability to monitor absolute size and growth of whales with precision, which is demonstrated in Fig. 4 by estimated length differences among seven whales of varying ages within the "I16 matriline" (family group) of killer whales. These whales ranged in ages between a first year calf and a 45 year old adult female at the time of the photograph in 2014, with estimated lengths ranging from 2.6 to 5.8 m from this particular image. At the time of writing, work is underway to identify and measure all the whales in this large photographic sample, and further data collection is planned to quantitatively monitor individual whale growth and body condition into the future.

Conclusion

This first, and very successful, field effort at sea has demonstrated the APH-22 hexacopter to have great utility for collecting photogrammetry images to fill key scientific data gaps about free ranging whales. It is a small and portable aircraft with VTOL capability that enables safe deployment and retrieval from even small boat platforms, and therefore enables aerial photogrammetry in remote locations where conventional aircraft are impractical. It is quiet and stable in flight, and can therefore be flown at relatively low altitudes without disturbing whales. As a result, we can obtain high-resolution images that are sharp enough to differentiate individual whales using natural markings, with precise altitude to enable quantitative measurements. We anticipate that these advantageous features will provide a cost-effective option for studies of wildlife populations in general, not just whales.

Fig. 4. Overhead image of the "I16 matriline" of Northern Resident killer whales, taken using an Olympus E-PM2 camera mounted on the APH-22 hexacopter. Whales of different ages can be differentiated visually and using quantitative length estimates. From top to bottom, whale identifications, ages and length estimates are: I106, 10 yr, 4.8 m; I129, 5 yr, 3.4 m; I051, 28 yr, 5.4 m; I144, 0–1 yr, 2.6 m; I1098, 12 yr, 5.1 m; I016, 45 yr, 5.8 m; I128, 5 yr, 3.9 m. Age data from Ellis et al. (2011) and J. Towers (personal communication). Note that the best length estimates for these individual whales may change as more images are examined.

Acknowledgements

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