FIELD ROBOTS

AI-driven aerial robots advance whale research

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Aerial robots assisted with artificial intelligence improve real-time wildlife monitoring of sperm whales.

Since the outset of the Industrial Revolution, there has been an uninterrupted and ever-increasing rate of technological advancement and socioeconomic change that has resulted in detrimental long-term consequences for our planet's ecosystems and species. To identify and mitigate these negative influences, it is essential to understand the current status of ecosystems, explain how they are affected by these changes, and determine effective strategies to facilitate species conservation. A key to this understanding is the monitoring of wildlife and ecosystems in terrestrial and marine environments. Given the aims of the United Nations Decade of Ocean Science for Sustainable Development (2021–2030) (also known as the Ocean Decade), wildlife and ecosystem monitoring is especially important for deepening our knowledge of marine ecosystems (*1*, *2*).

Wildlife tracking traditionally involves two approaches (*3*). The first, direct human observation, is time-consuming, labor-intensive, and potentially dangerous. The second approach is tagging animals with tracking devices like radio transmitters or global positioning systems (GPSs), which offers efficiency but faces challenges, such as device size, weight, battery life, and communication range. The choice between these approaches depends on the animal's size, habitat, and monitoring duration.

Rapid advances in robotic systems are transforming environmental monitoring and wildlife observation, making both processes faster and more reliable. Innovative systems that have emerged from these technological developments include robotic buoys, uncrewed surface vehicles (USVs), autonomous underwater vehicles (AUVs), and uncrewed aerial vehicles (UAVs). Among these robotic systems, aerial vehicles are a good candidate for monitoring tasks because of their speed and high maneuverability. Aerial robots have been widely used to track very high frequency (VHF)–collared animals (*4*, *5*) and small animals such as birds (*6*). Furthermore, multiple aerial robots can be deployed to expedite monitoring and tracking over larger areas (*7*).

Monitoring the marine environment is challenging because of its vastness, harsh conditions, and limited transmission of signals in water, which makes real-time sensing more difficult. However, aerial robots have begun to be used for monitoring marine wildlife, particularly whales, which are an integral part of a healthy marine ecosystem. For instance, in (*8*), aerial robots were used to collect respiratory blow samples from large whales. Another work (*9*) made use of aerial photogrammetry to measure the body length of tagged whales.

Recent research by Jadhav *et al.* (*10*) addresses an important problem of gathering in situ visual observations of sperm whales, a time-consuming process despite advances in animal-worn sensor tags. Given that sperm whales spend less than 25% of their time on the surface, rendezvous opportunities are often missed, thereby making biological observations difficult. To improve the rendezvous performance, this recent research made use of two tracking methods depending on whether the whales were surfaced or underwater. When the whales were surfaced, angle-of-arrival (AoA) tracking was used by measuring the AoA to whales tagged with a VHF beacon. While the whales were underwater, AoA to the whales was obtained using acoustic tracking of their vocalizations. However, VHF tracking methods traditionally require manual operation using directional antennas.

Jadhav *et al.* developed a framework that combines a multiagent rollout–based reinforcement learning (RL) algorithm (autonomy module) and VHF signal–based sensing (sensing module) to maximize rendezvous opportunities of autonomous aerial robots with sperm whales (Fig. 1). The acronym for the framework is AVATARS—Autonomous Vehicles for whAle Tracking And Rendezvous by remote Sensing. The framework was developed to overcome several challenges, including sparsity and uncertainty of in situ AoA measurements, variability in whale positions and surfacing schedules, quality of AoA measurements to VHF tags, and the mathematical formulation between discrete whale surface events and continuous whale locations of the rendezvous problem.

The autonomy module was responsible for planning an online policy to determine the speed and heading of the robots to rendezvous with multiple whale locations using partial and noisy acoustic and VHF AoA measurements. This planning process was formulated as a finite horizon partially observable Markov decision process. Rollout-based RL methods are effective in routing problems by combining online replanning to adapt to environmental uncertainties with offline learned models for better future cost estimation, making them well suited for whale rendezvous challenges.

Approaches developed for robotic systems are initially tested in simulation. However, to ensure the performance and effectiveness of the system, it must also be verified in controlled field experiments. For wildlife tracking studies, this can be accomplished using "engineered animals" that have, at least, some of the critical characteristics of the target species. One exciting aspect of this research was the use of "engineered whales" to conduct controlled field experiments. These engineered whales, designed using speedboats, emulated various sperm whale behaviors with a VHF tag. Data collected from the engineered whales were then used as an input to evaluate the performance of the entire AVATARS system. Moreover, in the field tests on real whales, acoustic AOA measurements were collected from three untagged sperm whales during their dives to validate the autonomous routing algorithm.

The field experiments revealed open challenges in real-time deployment of the autonomy module for a robot team to

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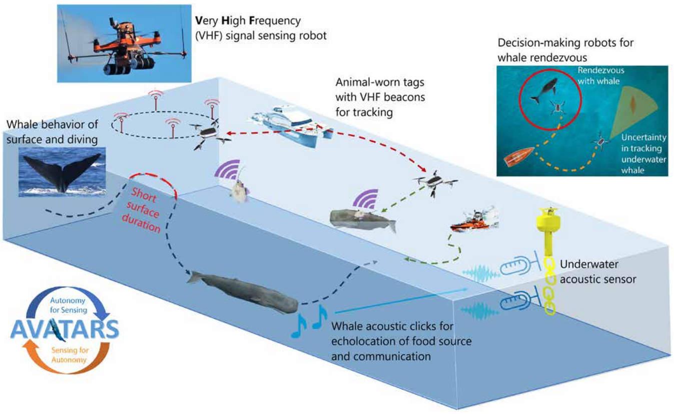

Fig. 1. Overview of AVATARS framework for sperm whale rendezvous. A UAV with the sensing module obtains AoA to whale tags emitting VHF signals, while acoustic sensors provide acoustic AoA as whales dive underwater. Robots with the autonomy module use AoA from multiple sensors, accounting for uncertainty in whale positions because of sensor noise and unpredictable surfacing, to localize and rendezvous with whales when they surface.

rendezvous with whales. These challenges stem primarily from the limitations of sensing, computation, and communication systems. As a result, substantial infrastructure is required, including whale tagging, real-time AoA computation and streaming from underwater sensors to the robots, a mesh communication network for coordination, and certification for long-duration marine operations.

This research is an important step toward long-duration autonomous marine operations with a team of aerial robots. In addition to aerial robots, heterogeneous systems consisting of aerial and surface robots can achieve long endurance in terms of energy. The robotics community can leverage the challenges posed by harsh marine environments to advance existing theoretical studies or develop new approaches for such autonomous systems. Moreover, marine biology would also benefit enormously from such systems, given that they improve the monitoring and tracking of marine animals and ecosystems in terms of speed and quality.

REFERENCES

1. UNESCO, "United Nations Decade of Ocean Science for Sustainable Development (2021-2030)" (UNESCO, 2024); www.unesco.org/en/decades/ocean-decade.
2. V. Ryabinin, J. Barbière, P. Haugan, G. Kullenberg, N. Smith, C. McLean, A. Troisi, A. Fischer, S. Aricò, T. Aarup, P. Pissierssens, The UN decade of ocean science for sustainable development. *Front. Mar. Sci.* **6**, 470 (2019).
3. D. S. Morrant, J. M. Turner, M. A. Jensen, N. A. Hansen, D. S. Bower, G. Körtner, P. D. Meek, A. J. L. Pestell, P. D. Rismiller, H. P. Waudby, C. Amos, "Wildlife tracking methods" in *Wildlife Research in Australia: Practical and Applied Methods*, B. P. Smith, J. O. Hampton, H. P. Waudby, C. Alberthsen, Eds. (CSIRO Publishing, 2022), pp. 180–200.
4. H. Bayram, K. Doddapaneni, N. Stefas, V. Isler, "Active localization of VHF collared animals with aerial robots" in *2016 IEEE International Conference on Automation Science and Engineering* (IEEE, 2016), pp. 934–939.
5. M. K. Yılmaz, H. Bayram, Particle filter-based aerial tracking for moving targets. *J. Field Robot.* **40**, 368–392 (2023).
6. O. M. Cliff, D. L. Saunders, R. Fitch, Robotic ecology: Tracking small dynamic animals with an autonomous aerial vehicle. *Sci. Robot.* **3**, eaat8409 (2018).
7. H. Bayram, N. Stefas, K. S. Engin, V. Isler, "Tracking wildlife with multiple UAVs: System design, safety and field experiments" in *2017 International Symposium on Multi-Robot and Multi-Agent Systems (MRS)* (IEEE, 2017), pp. 97–103.
8. S. Atkinson, A. Rogan, C. S. Baker, R. Ragdag, M. Redlinger, J. Polinski, J. Urban, A. Sremba, M. Branson, K. Mashburn, L. Pallin, A. Klink, D. Steel, E. Bortz, I. Kerr, Genetic, endocrine, and microbiological assessments of blue, humpback and killer whale health using unoccupied aerial systems. *Wildl. Soc. Bull.* **45**, 654–669 (2021).
9. M. S. Savoca, M. F. Czapanskiy, S. R. Kahane-Rapport, W. T. Gough, J. A. Fahlbusch, K. C. Bierlich, P. S. Segre, J. Di Clemente, G. S. Penry, D. N. Wiley, J. Calambokidis, D. P. Nowacek, D. W. Johnston, N. D. Pyenson, A. S. Friedlaender, E. L. Hazen, J. A. Goldbogen, Baleen whale prey consumption based on high-resolution foraging measurements. *Nature* **599**, 85–90 (2021).
10. N. Jadhav, S. Bhattacharya, D. Vogt, S. Gero, P. Tonessen, Y. Aluma, R. J. Wood, S. Gil, Reinforcement learning–based framework for whale rendezvous via autonomous sensing robots. *Sci. Robot.* **9**, eadn7299 (2024).

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