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Human vs robot: Comparing the viability and utility of autonomous underwater vehicles for the acoustic telemetry tracking of marine organisms

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ABSTRACT

Currently, individual animal movement data can be obtained using a variety of methods, but each methodology is limited in either temporal or spatial resolution. A new method of active tracking was developed which utilizes autonomous underwater vehicles (AUV) equipped with stereo-hydrophones that can accurately estimate the position of a moving acoustic tag, while remaining at a distance. This technology was tested and compared to standard human-based active tracking technology to understand the benefits and limitations of this new technique. An AUV and a researcher independently tracked stationary and moving targets of known location in order to compare their spatial and temporal accuracy. Both methods were then used to track a leopard shark, *Triakis semifasciata*, in the field. The autonomous vehicle accurately positioned both stationary and moving tags with a positional error of <10 m. For stationary transmitters, the AUV and the researcher were comparable, but when tracking moving transmitters, the AUV had significantly better spatial accuracy. Throughout all trials, the AUV had a higher frequency of accurate location estimates than a researcher actively tracking. Based on these findings, the AUV was able to more accurately track and record the position of an acoustically tagged shark in the field. Using this new technology, researchers should be able to maintain or improve the spatial resolution of measurements when actively tracking acoustically tagged individuals and will be able to increase the temporal resolution of measurements while minimizing the potential influence of tracking on the behavior of the animal.

1. Introduction

Quantifying animal movement at fine spatio-temporal resolutions has provided insight into behaviors, such as social interactions, interspecies interactions, micro habitat selection, and activity levels (Berejikian et al., 2016; Cagnacci et al., 2010; Coulombe et al., 2006; Garcia et al., 2015; Mourier et al., 2012). Technology allowing for the coupling of spatial information to high resolution behavior information from data loggers (i.e. accelerometry, video), along with fine-scale adjacent environmental data, are providing opportunities to better understand the decision-making processes in animals (Hays et al., 2016; Hussey et al., 2015). Obtaining high resolution movement data ($\pm$ 3 m) for mobile marine animals has been challenging though due to technology limitations. While tools like satellite telemetry (e.g., GPS fastlock) have been extremely effective in quantifying fine-scale movements of terrestrial and air-breathing marine animals, this technology has not been as effective for non-air breathing marine animals, due to the limited amounts of time these animals may spend at the surface or the poor positional resolution of archiving satellite transmitters (Hussey et al., 2015). As a result, acoustic telemetry tracking has been the primary tool for gathering movement information on non-air breathing mobile marine animals. Unlike satellite telemetry, acoustic telemetry requires a more proximate (<1 km) hydrophone and receivers to detect acoustic transmissions which are used to convey positioning information. Acoustic telemetry tracking can be applied using several techniques (active tracking, passive tracking, multi-lateration arrays, acoustic surveys) designed to estimate location of individuals, yet each technique has unique limitations, including degree of labor intensity, spatio-temporal resolution or scale (Bass and Rascovich, 1965; Grothues et al., 2010; Haulsee et al., 2015; Heupel and Webber, 2012).

Historically, active tracking, following an animal fitted with an acoustic transmitter from a surface vessel, has been the primary tool used to acquire high-resolution spatial movement information for mobile marine animals (Bass and Rascovich, 1965; Nelson, 1978, 1990). By closely following the animal, the tracker is able to use the position of the vessel as an estimate of the position of the animal. Depending

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on the proximity of the animal to the surface this localization technique could influence its behavior, so often trackers try to maintain distance between the vessel and the animal being tracked. Furthermore, oceanographic conditions, the position of the animal in the water column, the speed of the animal, as well as the trackers experience and skill level can all impact the spatio-temporal resolution of location estimate. These factors combined result in active tracking producing temporal resolutions between 5 and 30 min, spatial accuracies of between 5 and 30 m, and due to the labor intensity, temporal scales ranging from hours to days. While this provides a relatively fine spatio-temporal resolution, the resolution is often insufficient to be able to identify differences between Area Restricted Search (ARS - indicative of foraging) and resting. Despite these limitations, active tracking has remained one of the most common method to track the fine spatial movements, and habitat associations of an individual.

In order to extend the temporal scale and to simultaneously track more individuals over longer periods of time (days to years), researchers have turned to autonomous "passive" tracking systems to also obtain movement information. These systems rely on stationary omni-directional underwater receivers in arrays, grids, or strategically placed locations to detect movement patterns (Heupel et al., 2006; Heupel and Webber, 2012). These receivers can only determine whether a transmitter is present within its detection radius, which can vary considerably depending on habitat, oceanographic conditions, weather, and the power output of the transmitter. Yet, these systems sacrifice spatial resolution (>100 m) and frequency of position estimates compared to active tracking; however, this varies depending on the system.

More recently, there have been a variety of multi-lateration positioning systems developed to further generate fine-scale positions from a passive acoustic array (Biesinger et al., 2013; Ehrenberg and Steig, 2002; Heupel and Webber, 2012; Klimley et al., 2001; Steig and Johnston, 2010). These systems, such as the Vemco VRAP and VPS, HTI Model 290, and the Lotek MAP600 use differences in time-of-arrival of a detection on multiple acoustic receivers to estimate the position of a transmitter. By positioning stationary receivers in high densities, these multi-lateration arrays can provide fine positional resolution (<5 m) of multiple tagged individuals simultaneously (Andrews et al., 2011; Espinoza et al., 2011). Since many marine animals are often moving through complex, heterogeneous habitats, obtaining consistent positions is difficult due to the static nature of the array, resulting in consistent or intermittent "dead spots" within the array (Biesinger et al., 2013; Binder et al., 2016). In addition, changing environmental conditions and biofouling of stationary receivers can also effect position estimate frequency and accuracy (Clements et al., 2005; Heupel et al., 2008). These systems increase the spatial resolution of passive arrays, however, they still often lack the ability to obtain positions at fine temporal resolutions, and are not effective at tracking highly mobile species that move beyond the extent of an acoustic receiver array. In addition, due to the high density of receivers and costs of post processing these systems can incur significant costs over a traditional passive array with poorer positional accuracy.

In order to survey for tagged individuals dispersed over larger areas, researchers have been equipping autonomous underwater vehicles (AUVs, e.g. gliders and propeller driven vehicles) with passive acoustic receivers (Grothues et al., 2010; Grothues and Dobarro, 2009; Haulsee et al., 2015). These AUVs use a single passive receiver and move along preprogrammed paths surveying for tagged individuals while simultaneously collecting a wide array of oceanographic data (e.g., salinity, DO, light, chlorophyll, bathymetry, and video). These systems however, cannot generate precise locations while surveying areas and are not programmed to track individuals. In order to be able to track an individual, these AUVs need to be able to generate a fine-scale location of a tag in real time. Lin et al. (2013) developed a localization algorithm that could localize a transmitter from a pair of time-synchronized hydrophones. This method uses the difference in time of arrival to calculate an angle to the transmitter and a time of flight calculation to estimate distance to the transmitter, which are then incorporated into a particle filter to refine possible position estimates in real time.

This system was designed to be integrated into an Ocean Server Iver 2 AUV (Clark et al., 2013; Forney et al., 2012; Lin et al., 2014). This relatively small AUV (25 kg, 140 cm long) was designed to incorporate the position estimate from the paired hydrophone system designed by Lin et al. (2013) and programmed to alter its path in order to follow a tagged animal. This would provide an autonomous mobile system for locating and actively tracking acoustically tagged fishes (Clark et al., 2013; Forney et al., 2012; Lin et al., 2013, 2014; Xydes et al., 2013), providing similar positional accuracy as that of a stationary multilateration array, but allow flexibility to follow highly mobile species. Furthermore, by having the system be autonomous, it would have the potential to reduce the labor-intensive aspect of active tracking, and could be a useful tool to quantify the movements of animals.

In order to determine whether the 1) paired hydrophone localization technique and 2) incorporation into an autonomous vehicle may provide an accurate, efficient, land ess labor intensive tracking tool, comparison of the performance of these integrated systems with the historically standard method of active tracking is necessary. The goal of this study was to determine if the tracking AUV can provide more accurate position estimates and at a higher temporal resolution than a skilled human tracker.

2. Methods

A series of field trials were conducted in Big Fisherman's Cove, Santa Catalina Island, California to compare the positional accuracy and tracking efficiencies between a skilled human tracker in a surface vessel, using standard active tracking equipment and techniques and with a customized autonomous underwater tracking vehicle (AUV).

2.1. Human-based active tracking

Human-based active tracking was conducted aboard a 5 m Boston Whaler outfitted with a ship-borne acoustic receiver (Vemco VR100) and custom-built gunnel mount for easy, under-way use of a directional hydrophone (Vemco VH110). The acoustic receiver was maintained at a gain of 0 during all tracking trials. Researchers obtained "ground zero" locations by orienting themselves above the tag, determined by equal signal strength from all directions. The VR100 receiver records the time of detection, signal strength, tag ID, listening channel frequency, and GPS coordinates of the receiver. The tags used during all trials were Lotek MM-M-16-50-PM acoustic tags, which transmit predominantly at the 76.8 kHz frequency. While these tags were programmed to transmit a unique ID, pressure, and motion every two seconds, the Vemco VR100 could not decode Lotek coding, so were only used for geolocation tracking. All location estimates from human-based tracking are based on the coordinates provided by the GPS onboard the VR100.

2.2. AUV

During tracking trials two OceanServer Technology Inc. (Fall River, MA) Iver2 model autonomous underwater vehicles (AUVs) were used (Fig. 1). The Iver2 AUV is a torpedo-shaped robot that has a rear propeller to provide locomotion and four aft fins to control the pitch and yaw of the vehicle. The sensor payload includes a 3-DOF compass, wireless antenna, GPS receiver, and Doppler velocity logger (DVL) with the ability to expand to carry other environmental sensors such as temperature, salinity, chlorophyll, and sidescan sonar. The AUV uses a combination of GPS surface position and DVL to estimate position while operating underwater and can estimate their position with a precision of 0.3% of the distance traveled. The AUVs are designed to stay within a designed area dictated by the operators, in order to reduce the chance of colliding with objects such as moorings, kelp beds, and running aground. The vehicles are depth rated to 100 m, maximum speeds of 4 knots, and