Earth Magnetic Field Augmented Position Estimation for Marine Animal Tags

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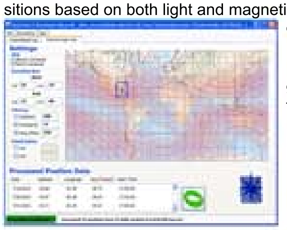
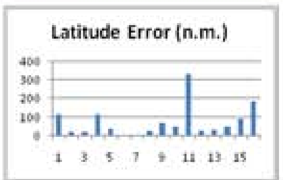
The Position Estimation Method

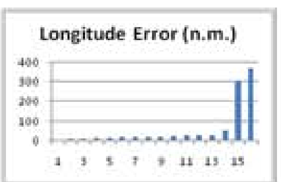
Natural-signal geolocation tags have traditionally relied just on light signals to obtain longitude and latitude. But, light based estimations can be quite uncertain. Length of day may vary only slightly with latitude, and the exact moment of the sun crossing the horizon is difficult to determine for an underwater tag with much confidence. For this reason, SeaTag devices estimate positions based on both light and magnetic field intensity readings. The fundamental method proposed by Dr. Peter Klimley in the 1990s is straightforward. First, longitude is determined by light measurements. Next, the software (left image) runs along that line of longitude until a match with the measured total magnetic field intensity is found. The cross-hair of the light based longitude and the magnetic based latitude defines the position of the tagged animal.



Latitude & Longitude Estimation Methods



SeaTag takes magnetic readings every four minutes with the daily average used to estimate the latitude. The median latitude error of the 16 data sets (left) we used was 44 nautical miles. The outliers point to the limits of the method. #11 was an observation in a small backyard in Germany with metal lawn furniture in close proximity. #1 & #4 were two tags in the Sierra Nevada in winter which put the temperature below the bounds of the compensation curve used by the software.



SeaTag determines noon time by finding the half-way point between first and last light, not the moments of sunrise/sunset. This method has the advantage of being independent of light attenuating factors such as tag fouling, cloud cover, water clarity, or depth. It also makes use of the steep rise and fall of light intensity before sunrise and sunset which lessens the impact of any asym metries. The observed median longtiude error was 20 nautical miles, with results generally robust.

Data courtesy of Mote Marine Lab, Dr. Tony Tucker

Position Estimation Confidence Error Upper Bounds

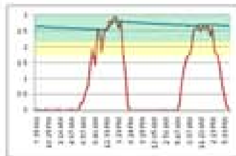
On a smaller scale, the method is subject to errors of a magnitude as shown. On a larger scale, the speed of the day/night transition puts a bound on longitude errors, while errors in magnetic observations bound latitude errors. The maximum magnetic measurement error across the 16 data sets (referenced above) plus another 30 magnetic-only sets was 1700nT. With gradients around 3-10 nT/nm in much of the oceans, upper error bounds are on the order of hundreds of miles.

Data from a sea turtle off Casey Key, Florida (average position error was around 40-45nm)

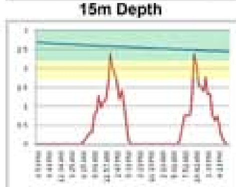
Sun in a Can... Unlimited Endurance

SeaTag devices incorporate a stored solar power system that equips them with a remarkable advantage: 'Unlimited' endurance! There is no battery to wear out and the tags can continue collecting data or even transmitting satellite data without a limit - for weeks, months or years, perhaps even decades. Tags that are returned or found, such as archival -GEO tags, can be re-programmed and put back into service as if new. Of course nothing in this world is truly 'unlimited' nor will work under all circumstances...the data below details our tests/observations.

How Energy is Collected at Depth



15m Depth



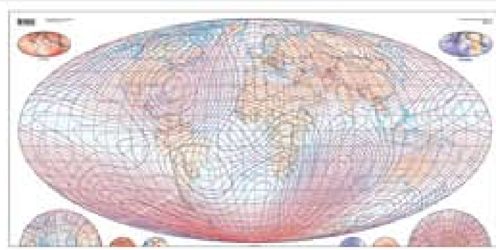
28m Depth

The solar power system requires about 2-3% of full surface sunlight (2000-3000 Lux) to still harvest useful energy. As a rule of thumb, tags can collect energy down to a depth equivalent to about two times the vertical water visibility. The figures, to the left, show two tags at 15m depth and 28m depth at Wolf Island, Galapagos. The vertical visibility was about 15m. The red lines are the solar panel voltage and the blue lines are the capacitor voltage (the "stand-in battery"). Notice the rapid charge action of the 15m tag on the first day. The bottom tag does not show charging as light is more subdued. The green band represents the capacitor voltage range required for full operation, while yellow is the energy conservation range in which data acquisition stops but clock is still maintained. The curve of the capacitor's voltage loss is much less dramatic while in the yellow band because there is no data acquisition. The 28m tag would be sufficient to retain the real-time clock indefinitely.

Limits of Endurance

SeaTag's stored solar power system is made possible by the use of thin film solar panels and ultra capacitors. The result? A half hour of full sun exposure near the surface collects enough energy to operate the tag for around two weeks of darkness! A battery-assisted version is available for animals that may experience extended periods of darkness.

In the absence of the hard lifetime limit normally imposed on tags by battery life the question becomes, what limits SeaTag? Biofouling potential and the reliability of the attachment method and release mechanism are possible life-time or performance limiters. While relevant factors will be situation specific, we will continue to collect data and develop solutions. Current work includes evaluation of a clear, nontoxic anti-fouling paint and the development of a very high reliability propellant based release mechanism.



The International Geomagnetic Reference Field (IGRF) as published in a USGS chart. Red lines of equal intensity running approx. east-west establish a north-source gradient in many parts of the world. Magnetic field intensity measurement can readily determine latitude within tens of miles.

The First Four Tags

SeaTag™ devices incorporate the light-magnetic position estimation and stored solar power as base technologies. Individual tags are then optimized for specific functions. In addition to these standard tags, the modularity of the SeaTag™ architecture also lends itself in particular well to the implementation of custom tags.

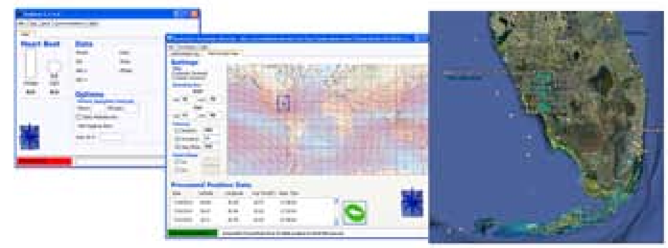
SeaTag-GEO is a small archival geolocation tag intended for the effective management of endangered marine animals and large scale tagging programs. The streamlined device combines precision position estimates with indefinite endurance in a small package and at a low cost. Attachments will be manufactured by Hallprint (Australia).

SeaTag-SOL is optimized primarily for amphibious animals such as pinnipeds and turtles. Combining advanced sensing and an integrated 'ZigBee' short-range radio modem, it supports remote and autonomous high-speed data recovery without entering a colony and can use the modem to study animal interactions or social behavior (proximity).

SeaTag-MOD is a pop-up ARGOS satellite tag with a modular 'plug and play' design. In addition to numerous standard sensors, specialized capabilities such as a dissolved O2 sensor or acoustic transducers can be integrated in a 'payload module' to support a specific research interests. Solar powered 'unlimited endurance' data transmission also supports higher volume data recovery than is normally possible with battery limited pop-up tags.

The tags are available with two different float designs. The low-drag float is slightly longer (+45mm); however offers about 50% less drag.

SeaTag-CAM is an example of a static environmental observation station. It supports long-term visual observations in remote areas by transmitting static images via ARGOS satellite at a slow rate (approx. one 640x480 image per week). Applications may include surveillance of animal colonies, streams, or glaciers. An underwater version for tasks such animal abundance counts through silhouette images is planned, with experiments in progress.



(left to right) SeaDock software is used to configure and download data to/from the tags. SeaTrack software (middle) is used to process the data from the tag. Several processing filters are included such as averaging over days, maximum distance traveled per day, and a magnetic offset. The data is then exported into a standard txt file or a Google Earth file for immediate viewing.

[1] NOAA SBIR Program Solicitation FY2007, Topic 8.1.3 "Archival Tag for a Wide Range of Migratory Marine Animal Sizes" **[2]** Optimizing Positional Accuracy of Archival Tags with Irradiance and Magnetic Sensors. A. Peter Klimley, William J. Mangan, Proceedings of 45th Annual Tuna Conference, 1994