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Ocean Dashboard

Inexpensive Smart Sensors Could Revolutionize Ocean Sensing

By Marco Flagg

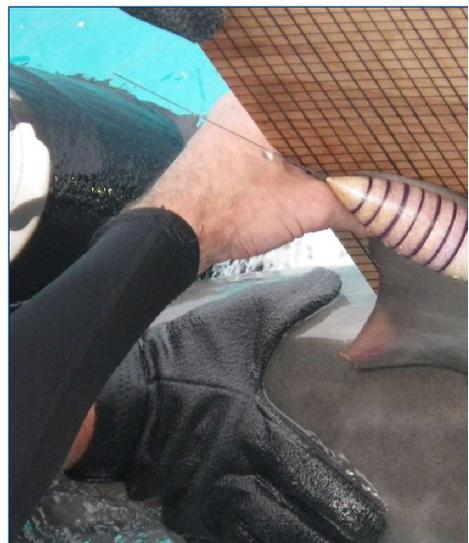
When University of Miami Professor Neil Hammerschlag tagged a tiger shark in the Bahamas with the first of a new generation of pop-up archiving satellite tags called SeaTag-MOD in late 2011, the primary purpose of the experiment was narrow: to track the migration of the shark. This would be done by tag transmissions to the Argos satellite constellation during brief opportunities when the fin-mounted tag broke the surface. In fact, only a few such opportunistic transmissions were received, but internally the tag scanned and archived sensor readings every 4 min. Timing dawn and dusk via light measurements served as the proxy of the shark's longitude, and the strengthening or weakening magnetic field would indicate transitions of latitude. Spurts of acceleration might signal hunting activity, and a pressure sensor along with a temperature sensor would reveal the vertical habitat and temperature preference of the animal.

A year onward, the tag separated from the shark, floated to the surface and, powered by its solar panels, provided a continuous stream of position fixes and basic status reports via Argos. Satellite localizing indicated a pop-up position in the northern Bahamas not far from the tagging location, with a drift north in the Gulf Stream. The following fall, as the tiny explorer drifted past Newfoundland, a growing fuzz of marine fouling dimmed the sunlight reaching its solar panel. Messages and location fixes became sparse and eventually stopped.

This would have been the end of the story, except that two years on Hammerschlag received an email from South Wales, reporting the tag had been found on the beach.

Back at the lab, the returned tag proved to be in good shape. All systems worked, and the tag resumed satellite reporting once cleaned and floated. More significantly, the tag's sensor scans had continued throughout the journey, the dimmed sunlight being sufficient for scanning the environment if not for transmission. The track estimation from the light and magnetic sensors revealed that the shark had resided in the Bahamas until spring. It then headed northeast, described by a loop north of Bermuda while probing depths to 800 m in brief dives. By summer, it took up residence at the continental shelf offshore Connecticut for the season, staying close to the surface and only once venturing deeper than 200 m. In the fall, it started its return journey south, tracing the continental shelf, again probing the depths, and ultimately returning with great site fidelity to the Bahamas, where the device popped off just tens of miles from the tagging position.

The following drift across the Atlantic was documented as well, and stormy winter seas and summer periods of glass calm were apparent in the accelerometer readings



as the tag bobbed on the waves. Fast forward in the observation record a year and a half, with the tag having completed most of its Atlantic journey and now west of Ireland, several pronounced depth spikes were apparent.

Desert Star Systems' SeaTag is equipped with a float, but sometimes an animal will ingest the floating tag and dive with it until regurgitating it some period later. This was not the case here. Upon reaching depths consistent with bathymetry at each site, the tag would remain still, at near constant or just slowly drifting depth for hours to a few days before suddenly surfacing again. Other sensor readings confirmed the validity of these square dives and ruled out causes such as heavy biofouling or float body loss until the seemingly most unlikely of explanations remained: The water encountered by the tag must have suddenly become lighter, causing it to sink to the seafloor. After some time, the tag must have returned to normal density, prompting the tag to rise from the seas again; a real-life enactment of old sailors' lore of ships suddenly and inexplicably sinking beneath the waves.

One explanation would be a methane seep, the mixture of gas and water being light enough to overcome the minimal flotation of the tag. As research showed, these

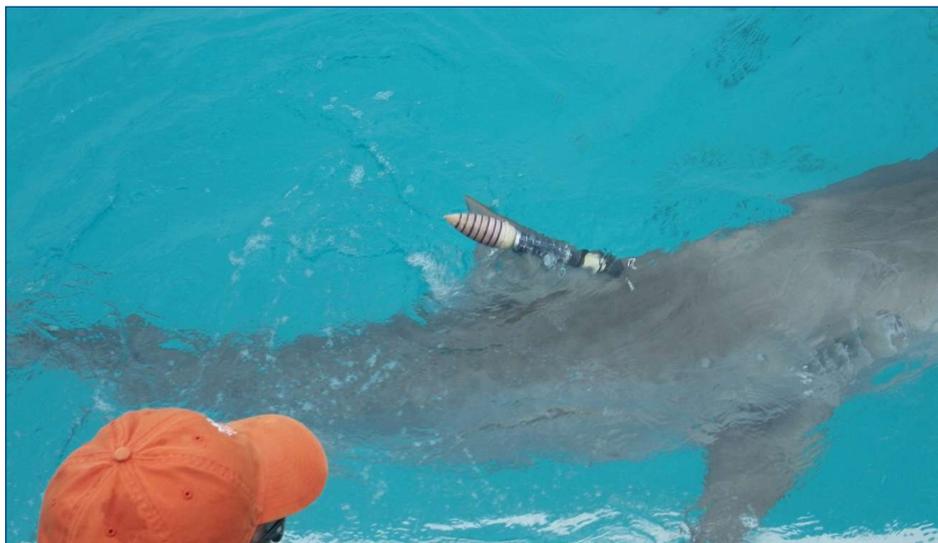
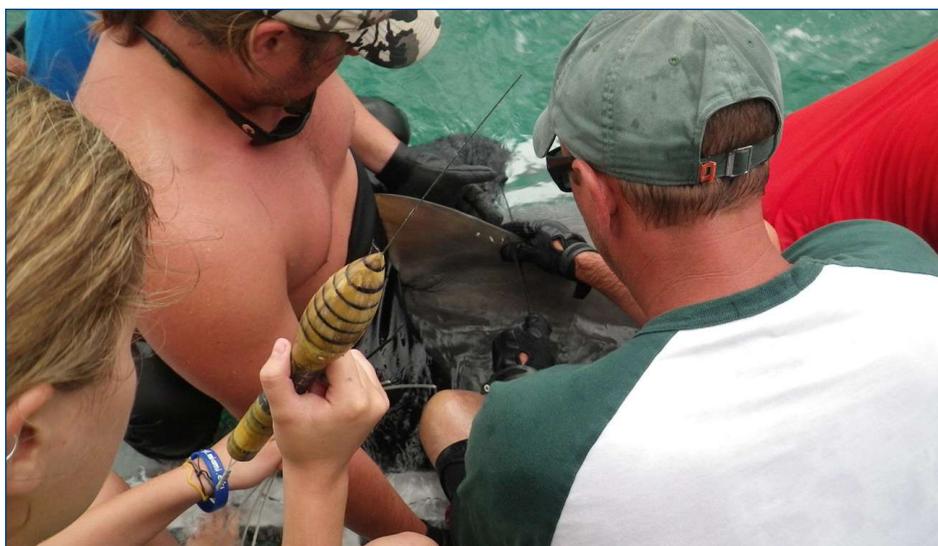
events all happened within the bounds of a recent offshore exploration. The tiny explorer, commissioned to track a shark, had inadvertently "discovered" the Porcupine Basin of Ireland, a large hydrocarbon field only recently explored. It had probed potential methane or gas seeps known in the area from the surface to the seafloor at depths up to 600 m.

A 'Smartphone' for Ocean Exploration

SeaTag-MOD somewhat resembles the fundamental design concepts of a smartphone specifically optimized for ocean exploration. At 145 g, weighing somewhat lighter than a smartphone, its cylindrical body is terminated with a syntactic float rated for service depth to 2,000 m through which runs the antenna for satellite reporting.

A thin-film solar panel covers the tag's body, and solar energy is stored in an internal ultracapacitor for use both in satellite reporting and ongoing sensor operation at night or during deep dives. A primary battery for extended operation in darkness is integrated in an exchangeable plug-in payload section. The solar and capacitor design has an unlimited recharge endurance. Thus, some users

A tiger shark is tagged with a SeaTag-MOD PSAT.



now routinely recover and reuse tags, achieving cumulative deployments of years. Solar energy collection is possible even underwater to a typical depth of twice the vertical visibility, but energy collection here becomes quite small, so the tag uses minimal power. Running the base profile of wake-up housekeeping every 16 sec. and full sensor scanning and flash memory archiving once every 4 min., averaged power consumption is only about 0.1 mW. Compare this to about 1,200 mW for a smartphone in typical use, meaning the draw of the phone in your pocket could alternatively power 12,000 tags. Thus, battery endurance in complete darkness and running the standard sampling and archiving profile is more than four years. Even a tag configured without a battery and using only its capacitor will maintain full operation for 30 hr. in darkness, plus another two weeks in standby mode. Yet, recharging requires only about 30 min. at the surface. The tag's internal sensor suite again resembles

that of a smartphone, including a three-axis accelerometer and magnetic sensor, temperature sensor and light and depth sensors. Archived data are stored on an integrated microSD flash card, its 2-GB memory enough for four years' worth of archived data at a full set of sensor scans every 2 sec.

Reporting is based on the Argos satellite constellation, far slower than any cell phone connection but with global availability from pole to pole. Argos transmissions are short bursts of 0.91 sec. during which data are transmitted at 400 bits/sec. Yet given system-enforced minimum transmit intervals and sporadic satellite availability in the sparse constellation, effective throughput of user data is on the order of 1 bit/sec, i.e., slow even by Morse code standards. Still, the solar-powered tag manages to transmit an Argos packet with 31 user bytes a little faster than once every 2 min. when floating at the surface in broad sunlight. A packet is enough to transmit, for example, a full scan of all

10 sensor channels, including a time stamp and auxiliary information.

Ocean Dashboard: Toward a Fully Instrumented Ocean

The U.S. Navy Strategic Studies Group (SSG) was a think tank charged to generate revolutionary naval warfare concepts. During the 2012 group review, Director Adm. James R. Hogg predicted that the Navy would become obsolete in its current composition within the next few decades. In the abstract, a navy might be considered a set of actuators, e.g., weapons linked to, and informed by, a sensor system. These include sonar, remote imaging, intelligence reports and the like. Hogg argued that while the Navy has very sophisticated sensors hosted on its ships, aircraft, drones, submarines, AUVs, satellites, etc., it also has very few of these platforms in relation to the size of the oceans. In fact, the detection range of underwater sounds and sonar is frequency dependent. Smaller targets such as speed boats or AUVs/UUVs tend to produce sounds at higher frequencies and lower source levels, thus limiting the detection range to a few kilometers or even into the tens or hundreds of meters. As asymmetric threats such as swarming attacks, piracy by speedboats or the use of AUVs/UUVs, etc. increases, the Navy's fleet of sensor platforms are becoming mere pixels of knowledge in the ocean. An early warning may be the maritime piracy situation in African waters. While piracy offshore Somalia declined to zero after the 2010 deployment of the international navy task force CTF-151, there was a spate of new attacks in 2017. Meanwhile, piracy incidents in West Africa increased from 54 in 2015 to 95 the following year. And, in California, cartels are using panga boats to land large quantities of drugs along the rugged Big Sur coast.

These trends indicate that instruments capable of more extensive sensing are needed for defense and law enforcement applications, such as detecting illegal fishing in remote waters. These instruments

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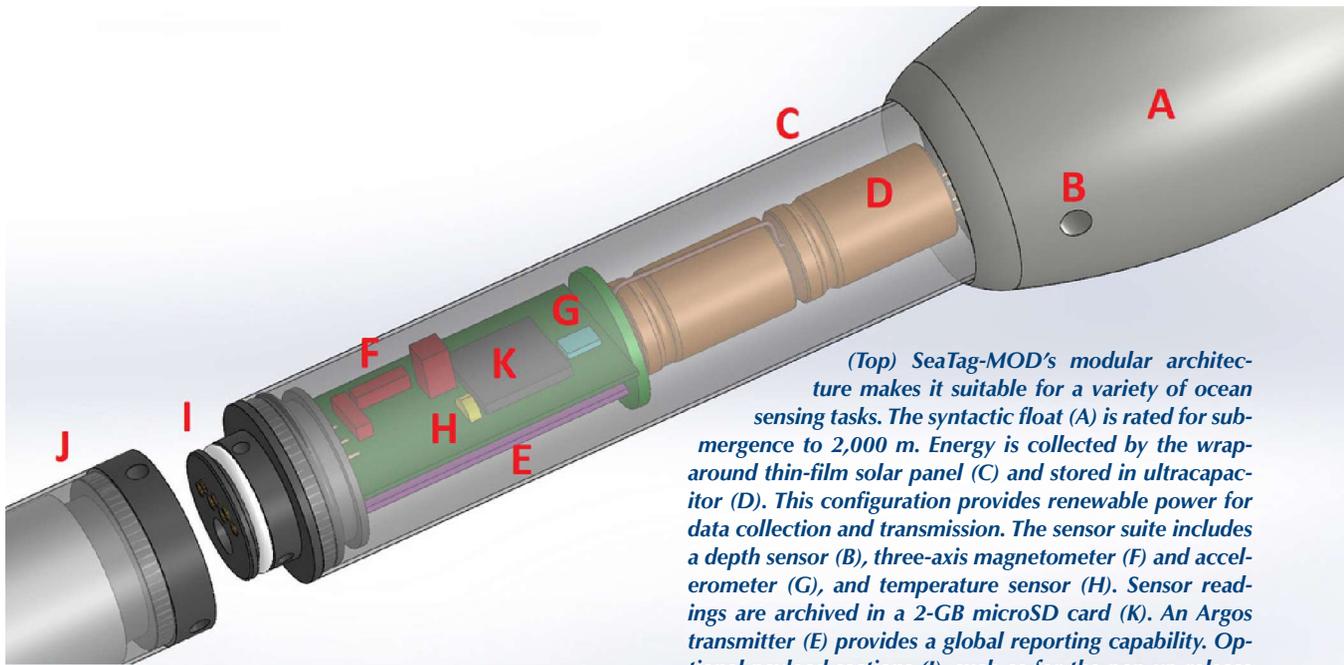
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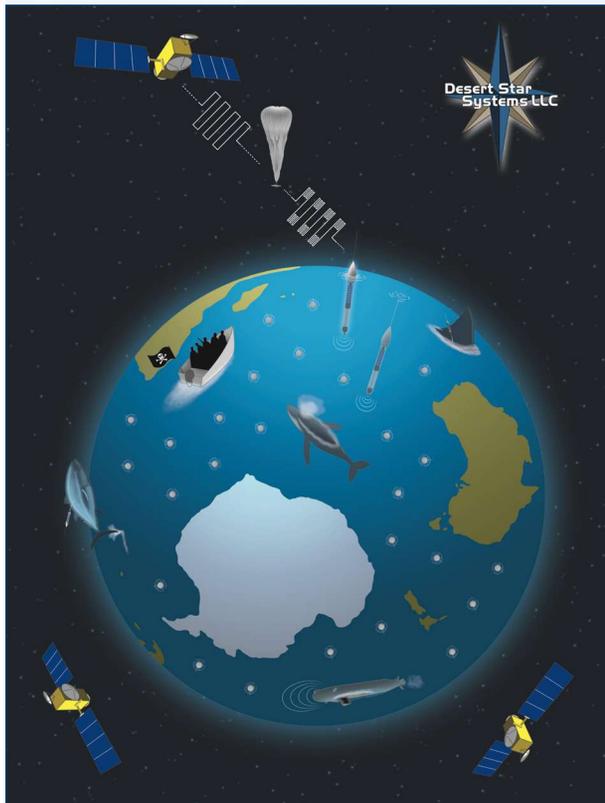
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(Top) SeaTag-MOD's modular architecture makes it suitable for a variety of ocean sensing tasks. The syntactic float (A) is rated for submergence to 2,000 m. Energy is collected by the wrap-around thin-film solar panel (C) and stored in ultracapacitor (D). This configuration provides renewable power for data collection and transmission. The sensor suite includes a depth sensor (B), three-axis magnetometer (F) and accelerometer (G), and temperature sensor (H). Sensor readings are archived in a 2-GB microSD card (K). An Argos transmitter (E) provides a global reporting capability. Optional payload sections (J), such as for the pop-up release function and a primary battery, are accepted by interface connector (I). (Copyright: Desert Star Systems)



(Left) Under the Ocean Dashboard concept, widely distributed, miniature smart ocean sensors detect and report on a variety of events as illustrated. The envisioned WD-1 smart ocean sensor will incorporate sound detection, recording and localizing capabilities. A small buoyancy engine allows the sensor to dive to listen, then surface to report and recharge. Applying Desert Star's modular design, WD-1 will incorporate acoustic design blocks from Desert Star's SonarPoint system, thereby further building economies of scale and reducing the cost of the new device. (Copyright: Desert Star Systems)

are also needed to assess stocks of commercial fish and monitor the environmental impact of industrial activities. These applications point to the need for an Ocean Dashboard—a new capability to detect, monitor, track and report events in the oceans as they occur, powered by small, inexpensive smart sensors, like the SeaTag-MOD.

Breaking the Vicious Cycle of High Cost, Small Markets In Ocean Tech

Dense smart sensor networks are now the norm for resource, process and activity management on land. But

ocean technology is often caught in a vicious cycle in which the special nature and stringent demand on equipment results in high prices. This limits the applications and market for the technology, which in turn reinforces high prices.

Given the large size of the oceans and the sensor density needed for effective detection, how could a realistic network be established even for select ocean areas? Here, the economic history of the tiny ocean explorer points to a solution. SeaTag devices are the result of a 2009 NOAA Small Business Innovative Research (SBIR) solicitation that sought innovation and cost reduction in pop-up satellite tags (PSAT) so that this capable technology, typically priced at around \$4,000 per device, might be deployed in more significant numbers than the few to low tens of a typical study. Desert Star's modular design approach managed to break the high-cost cycle. We build new products not from scratch but in a modular fashion in which a typical new product is engineered approximately 85 percent cut-and-paste style from pre-existing design blocks with about approximately 15 percent new content added. These blocks include electronic circuitry, mechanical components, firmware and software

libraries, communication protocols and even text fixtures and procedures. While the market for an individual product may be limited, the cumulative use of each design block, manufacturing technique and test procedure as employed across multiple devices is much higher. The resulting economies of scale cut device cost and build demand, allowing further price reductions. The vicious cycle leading to high costs and limited use has been replaced with a virtuous cycle of lower costs and growing demand. Today, a SeaTag-LOT PSAT for stock assessment, basic migratory tracking and mortality studies is available for \$500, only about one-eighth the price of previous options. On the high end, SeaTag-MOD's reusable design has reduced the effective price per deployment to under \$1,000 in some cases. Consequently, the devices have now been adopted for species that have not previously benefited from PSAT technology, such as lake trout. Ongoing or proposed studies based on sample size exceeding 100 are becoming more frequent.



PSAT tags are most frequently used on large pelagic species such as tuna, billfish and sharks, but technical innovations, price reduction and reusability are now enabling tagging of other species such as lake trout, pictured here. This growing demand reduces cost, which may eventually enable widespread ocean sensing and reporting applications. (Photo Credit: Rick Goetz)

Deployment, Practicality and Implications Of Ocean Dashboard

The Ocean Dashboard would be powered by a soda can-sized device building on the SeaTag-MOD design, but also incorporating a digital acoustic recorder and signal-processing capability, plus a small, solar-powered buoyancy engine for controlled diving. Numerous of these WD-1 devices could be deployed cheaply as needed; thrown off the stern of patrolling ships or dropped from airplanes. Sinking to depth to listen quietly, observe, time and fingerprint acoustic events, a WD-1 may then surface to report, recharge its batteries and sink again to ride the conveyor belt of ocean currents to a new location in a targeted fashion. As with SeaTag, WD-1 will be designed in a modular fashion. It will draw long-endurance sound recording and localization design blocks from Desert Star's microMARS and SonarPoint systems, developed in recent years through NOAA's Advanced Sensor Technology Working Group (ASTWG) and the Office of Naval Research's Marine Mammal Program (MMP).

Of course, just like our smartphones are enabled by capable cell and Wi-Fi communication infrastructures, so will an Ocean Dashboard need adequate communication channels. Argos is particularly useful for very small devices, and Iridium yields faster rates for somewhat larger devices starting around the soda can size standard. As requirements grow, faster communication solutions that can produce cell phone-like bandwidth for small devices at sea are on the horizon or at least plausible. SpaceX recently launched the first two of its Starlink low-Earth orbit internet satellites. The satellites' steerable high-gain, phased-array antennas, while normally intended to communicate with similar pizza box-sized antennas on fixed stations or ships, might still yield cell network

equivalent speed when communicating with a practical low-gain antenna on a miniature sensor at sea. Alphabet X (Google) Project Loon involving steerable internet balloons is another option. In ocean areas of particular interest, networks of these balloons may work as a stratospheric "cell tower" network. In more remote settings, steerable balloons might be commissioned to visit smart sensors for rapid data retrieval in response to visit requests logged via a slow satellite link.

Ultimately, an Ocean Dashboard as a global maritime information utility is likely to be based on a multilevel structure, with small and inexpensive drifting devices such as WD-1, animal tags, etc. most pervasive but complemented by larger and more capable platforms. Boeing's recent acquisition of the Wave Glider manufacturer Liquid Robotics to boost autonomous surveillance at sea and the companies' glider-centric vision of the Digital Ocean is a recent such indicator.

The introduction of miniature ocean smart sensors, steep price reductions for ocean technology and the potential for faster communication options for maritime devices are placing us at a revolutionary threshold in ocean sensing.

On the defense front, Adm. Hogg's prediction may be set to come true as a Navy built around a limited number of very expensive and vulnerable sensor-hosting ships and other platforms is replaced by a fleet of relatively simple weapons carriers roaming the oceans; a fleet tying into and informed by a near invisible, virtually undefeatable and always present distributed ocean sensing network capable of identifying the type of new asymmetric threats that now increasingly evade detection.

Similar to GPS, as Ocean Dashboard capabilities grow and costs decline, such a sensing network will surely grow into a ubiquitous new global utility.

The journey and accidental "discovery" of the tiny ocean explorer may be a harbinger pointing out the opportunities and implications of a revolutionized ocean sensing infrastructure.

References

For a list of references, contact Marco Flagg at marco.flagg@desertstar.com. **ST**

Marco Flagg is the CEO of Desert Star Systems LLC. For the past 25 years, he led Desert Star's design team, building a broad but modular ocean technology product line. Today, his focus is leveraging this design base to introduce affordable and scalable solutions for current problems in ocean management.

