**SMarT Series Concept of Operations (CONOPS)**

October 2018

Team 6

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SMarT

SDR Marine wildlife Tracking

# **CHANGE RECORD PAGE**

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| --- | --- | --- | --- |
| **Revision** | **Comments** | **Pages Affected** | **Date** |
| HW 1 | Initial CONOPS Draft | All | 10/8/2018 |
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# **1 INTRODUCTION**

The Bureau of Ocean Management (BOEM) actively tracks the paths of migratory marine wildlife to enhance scientific understanding of the marine environment and gain insight into possible strategies for conservation efforts. Many species of marine wildlife rarely surface and can move great distances between surfacing events, making accurate tracking and data acquisition a difficult task [1].

Current satellite-based tracking systems primarily consist of the Argos satellite constellation [2]. However, Argos has a number of drawbacks which limits its utility, including location inaccuracies and low bandwidth. The goal of the SMarT (Software-defined radio Marine wildlife Tracking) mission is to implement an improved system for tracking marine wildlife over currently available systems.

## **1.1 Mission Overview**

The SMarT mission aims to replace the current Argos-based wildlife tracking system with a significantly more accurate platform that can also capture more information that Argos is currently capable of. The SMarT mission space segment will consist of a constellation of 40polar-orbiting 3U CubeSats equipped with software-defined radios (SDRs) to acquire data transmitted via radio from tags attached to marine wildlife while seeking to improve upon the gaps left by the Argos system.

The SMarT constellation will be placed in an orbit with an altitude of 750 km to provide the satellite with 26.5 degrees of coverage [3]. 40 satellites optimally phased in five orbital planes will provide continuous coverage and an improvement over the existing Argos system [4]. The SMarT mission will use polar orbits to ensure the entire globe including the poles are covered by the satellites ground track. In addition, the polar orbit will ensure that the entire surface will have an overhead flyby without requiring the entire constellation to be established first.

## **1.2 High-Level Objectives**

NASA and The Bureau of Ocean Energy Management (BOEM) are interested in procuring an improved animal telemetry data collection system to improve on the existing Argos tracking technology. The primary goals of the SMarT mission are:

* Provide high-reliability tracking for marine wildlife
* Significantly improved location accuracy versus current Argos doppler tracking
* Improve understanding of marine wildlife migration patterns and overall ocean environment health
* Increased data bandwidth to enable collection of multiple types of data
* Support for two-way communication between transmitters and satellite
* Enable receiving on multiple frequencies through software-defined radio
* Relay data to ground stations

The current Argos-based satellite tracking technology was first launched in 1978 and consists of a constellation of 6 satellites that orbit the earth in a polar orbit at an altitude of 850 km. When an overhead flyby coincides with the surfacing of an animal with a transmitting tag, the satellites use the Doppler shift of the data transmitted from the transmitter (at least 4 transmissions are required for a complete estimate) to deduce a possible location. However, the Doppler method of determining location can be highly inaccurate. Depending on the measurement, location can be ascertained to less than 250m or only to as much as 1500m. [4] While it is possible to equip Argos transmitter tags with GPS, GPS requires a relatively long time to get a location measurement, and marine animals do not always surface for long enough to get a complete measurement. [2] Second, Argos relies on a satellite flying overhead at the same time than an animal holding a transmitter surfaces in order to ascertain a position and collect information. [5] Allowing for collection of information during surface events where a satellite is not overhead would increase the amount of available location data.

Some of the limitations of Doppler-based tracking can be mitigated by using tags equipped with a GPS system to calculate location more accurately. [2,6] However, migratory marine animals spend short intervals of time at the surface where an adequate skyview is available. Due to the long time between surfacing events, traditional GPS may be forced to revert to cold starting, in which time to first fix can take up to 15 minutes [7]. The short amount of time spent on the surface prevents traditional GPS systems from successfully acquiring a location before the animal dives again.

In addition to the location accuracy challenges, modern tags often collect far more data than just location. This additional data can help shed light on a variety of behavioral characteristics, such as diving and feeding behavior, which are not well-reflected in location information and are otherwise difficult to acquire [5]. However, the limited bandwidth of the Argos system means that only some of this data can be wirelessly transmitted, and the rest must be manually collected by physically retrieving the tag, which may not always be possible.

The SMarT mission will achieve better location accuracy and data collection over Argos by using a variety of techniques. First, SMarT will take advantage of newer GPS processing technologies in wildlife tags through the use of Fastloc GPS tags. Unlike traditional GPS, Fastloc GPS can estimate location within milliseconds and is therefore much more suitable for marine animal tracking applications. It can also continue processing after the animal has dived, enabling it to compute a location even if a sky view is no longer visible. While not as accurate as traditional GPS, studies comparing Fastloc and typical Argos Doppler measurements have shown that Fastloc allows for far more accurate monitoring of animal movements. [5, 6]

In addition to improving location accuracy, the wildlife tags will also enable the collection of greater volumes of data over Argos. Argos requires that a transmitter be at the surface while a satellite is flying overhead in order to acquire transmitted information and acquire position via Doppler positioning. [8] However, the SMarT mission will allow location and other non-position information such as diving and feeding behavior to be stored on-board so that it can be transmitted to the satellite when a surfacing and satellite overhead flyby coincide.

The greater data collection capacity will also require greater bandwidth capability. While Fastloc has been used with Argos before, due to the limited bandwidth of the Argos system, only a subset of all of the Fastloc measurements can be transmitted to a satellite at any given time. The remaining measurements are be stored on-board the tag and must be physically retrieved. [9] Argos-based tracking is limited to a 60 kHz bandwidth with some additional higher data-rate capabilities. The SMarT mission will take advantage of bandwidth enhancements available through Software-Defined Radios (SDRs) and data compression to increase the effective bit rate of tag-to-satellite information transfer.

An added benefit of using a software-defined radio (SDR) to receive tag signals is the greater flexibility in the collection and processing of transmitted information. Unlike legacy tracking systems, using software-defined radio enables the satellite uplink to be reconfigured at will, enabling flexible mission accommodation.

## **1.3 System-Level Performance Requirements**

* Location Accuracy. The location information provided by Fastloc GPS will have a 50% resolution of within 36 m or less. [10]
* Data Speeds. Information can be transmitted from tag to satellite at a speed exceeding 4.8 kbit/s. This is the maximum available transmit speed on the Argos high-speed channel. The regular channel on Argos-3 is similar to that available on Argos-1 and Argos-2 and achieves a lower maximum bit rate. [11]
* Global Coverage. 40 satellites will enable complete global coverage.
* Orbit. Polar and sun-synchronized orbits are standard for Earth observation. The orbit altitude will be 750 km, and an orbit angular separation of 38.58 degrees will ensure optimal phasing. [12]
* Attitude Determination and Control. A robust and precise attitude control subsystem is required for pointing of RF antennas in nadir direction for tracking and transmission. The SMarT mission constellation will have three-axis attitude control capability. The attitude control system shall maintain pointing accuracy of 3° (3-sigma) from target. This high precision allows for the use of directive antenna. The GOMX-3 mission has demonstrated that a 3U CubeSat can achieve 1° pointing (1-sigma) accuracy under nominal conditions [13] and simulation results for ExoplanetSat has shown less than 0.001° can be achieved [14]. Furthermore, The attitude determination system shall estimate the satellite’s attitude within 1° accuracy.
* Fault Tolerance and Safe Mode.

## **1.4 Mission Timeline**

### **1.4.1 Launch**

A near-polar, sun synchronous orbit suggests Vandenberg AFB in Southern California as a primary launch location. The SMarT mission would require a minority share in a launch to LEO, making SpaceX, Orbital, or ULA likely candidates for the launch provider. If these providers are unable to place the SMarT constellation into the desired altitude as a minority party in a reasonable launch time frame, alternative small satellite-specialist launchers such as Virgin Orbit can be considered. Other alternatives include international space companies, such as Arianespace.

### **1.4.2 Checkout**

After the SMarT mission space segment reaches the desired altitude, positive communication will be established with each satellite. Since the entire SMarT constellation is located in LEO, a relatively low cost ground station antenna can be used. In addition, with a sun-synchronous orbit command and telemetry can be accomplished in regular intervals. SMarT will not use deployable solar panels. Once communications is established, system monitoring and operations can begin.

### **1.4.3 Operations and Disposal**

Using the ARGOS satellite constellation as a model, the SMarT constellation satellites will remain in orbit for many years. The small (1-3 U) SMarT CubeSats will last between 2-5 years based on historical data [15]. There will exist a tradeoff with altitude selection, as a lower altitude allows for improved signal acquisition, but also a more rapid orbital decay due to increased atmospheric drag. Once we’ve selected an altitude that balances lifespan with signal quality, we can design the CubeSat itself to have a lifespan appropriate for expected rate of orbital decay.

Due to the constellation’s LEO orbit, the satellites will experience an increasing amount of atmospheric drag as its orbit decays over time. As a CubeSat, no propulsion systems will be carried onboard to correct or alter the orbit after insertion. The satellite orbits will eventually decay until the satellite is destroyed during atmospheric re-entry.

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