# Integration of a miniaturized conductivity sensor into an animal-borne instrument

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## LONG-TERM GOALS

Habitat changes affecting marine mammals can range from small scale cyclic changes (e.g. tides) and natural physical processes (e.g. fronts and eddies) to changes on an ecological scale that range from years to decades and from tens to thousands of kilometers. These habitat changes can be natural or anthropogenic (e.g. pollution, sound). For example, short-term changes of the physical environment can cause changes in marine mammal populations by affecting pup survival, while long-term unidirectional changes can result in permanent habitat change or even habitat loss that may have a significant impact on entire populations. Population consequences of the foraging behavior of marine mammals depend on the availability of prey, which in turn is in part driven by the way animals react to the quality and dynamics of their immediate environment at the scale they are able to sample it. Predicting how marine mammal populations respond to habitat changes is also essential for developing conservation management strategies. To investigate such links, we need the appropriate environmental information at the relevant scales and, while large scale monitoring of environmental change can be accomplished cost-effectively by approaches such as remote sensing, getting fine scale information from the marine mammal's immediate environment requires local in-situ monitoring.

The availability of information about the marine environment has rapidly improved over the last two decades. The Global Ocean Observing System (GOOS) is now providing a range of observations measured from space, ships, moored instruments, free floating buoys and profilers to accurately describe the present state of the oceans. Compared to twenty years ago, this relative abundance of data is providing a global view of the ocean system that can support operational ocean services worldwide. However, it is still struggling to provide data at the appropriate scales to link oceanographic observations to animal movements, especially in the high latitude seas. One rapidly developing approach has been information using the animals themselves to carry the required instruments to collect in-situ environmental data (e.g. Fedak 2013). Such data is necessarily at an appropriate scale to link changes in animal behavior to changes in their environment. However, existing instruments capable of providing data at the necessary accuracy are limited in available attachment methodologies and the size of instruments can render other approaches difficult.

## OBJECTIVES

This project aims to be a stepping stone in developing an instrument enabling accurate measurements, while the instrument is rotating around a barb attachment as it is used to tag large cetaceans. Such methodology would provide for ecosystem studies of large cetaceans that are not currently feasible. The objective of this program is to design an instrument that can provide quality data from an non-rigid attachment (e.g. barb and wire) and to successfully demonstrate that this instrument can record long-term time series within the marine environment.

## APPROACH

The only existing marine mammal tag capable of recording and transmitting vertical temperature and salinity profiles from remote locations is the Conductivity, Temperature and Depth - Satellite Relay Data Logger (CTD-SRDL) designed and built by the Sea Mammal Research Unit Instrumentation Group (SMRU Instrumentation Group), St Andrews, UK. While this instrument works well when glued to the fur of pinnipeds, it showed to be sensitive to the attachment method and orientation (e.g. Boehme et al. 2009). Errors in the order of 0.10 in salinity can occur and are caused by disturbing the external field of the inductive cell by the attachment. The use of electrodes instead of an inductive cell to measure the conductivity of the water would limit the size of the measured field (Huang et al. 2011) and would enable conductivity measurements which are not influenced by the attachment method. The University of Southampton together with the Sensors Development Group at the National Oceanographic Centre Southampton (NOCS), UK, developed a miniature conductivity and temperature sensor system (CT sensor) in recent years (Huang et al. 2011). This CT sensor consists of a multi electrode conductivity cell with a platinum resistor bridge to produce an integrated CT sensor and is combined with an impedance measurement circuit to support the sensors and to create a CT sensor system. Within this project, we want to adapt the hardware and software of this existing NOCS sensor package for easy integration into the SRDL design, so that the data can be relayed via telemetry and that the sensor is suitable for long term deployments on marine mammals.

Our approach was therefore as follows.

1. Modify an existing miniature conductivity-temperature (CT) sensor, which can deliver oceanographic information and incorporate this sensor into the proven design of a Satellite Relay Data Logger.

2. Test and evaluate the communication between CT sensor and a Satellite Relay Data Logger including logging of measurements for subsequent trasmission using a telemetry system.

3. Laboratory tests and calibration of CT sensor data to demonstrate it can obtain data of sufficient quality to investigate the links between animal behavior and local physical conditions.

4. Test of the waterproofed instrument in the marine environment including long-term stability of measurements to demonstrate it can obtain data of sufficient quality to investigate the links between animal behavior and local physical conditions.

5. A design study for a behavioural and environmental tag to be deployed on large cetaceans.

## WORK COMPLETED

The project started in August 2013. One post-doctoral researcher was hired and started to work on this project. Two requirements were defined for the CT-sensor for integration into the existing SRDL concept. The first requirement was an interface system provided with the CT-sensors to create a CT-package that can exchange information with the SRDL. While the size of the CT-package was not a driving factor at this early stage, loose size restrictions had to be adhered to for it to be fitted at the side of the existing SRDL. It was also decided that the complete potted CT-package needed to fit initially into a cuboid with sides of 60 by 25 by 20mm. Cummunication and data logging were tested and evaluated after the CT package was modified and a common interface protocol established. One CT-SRDL is currently tested under laboratory conditions and calibrated against a Valeport miniCTD probe. Another CT-SRDL unit is currently build and waterproofed for deployment in the marine environment. We are also in the early stage of the design study.

## RESULTS

The interface for easy communication between the CT-package and SRDL was determined to be an $I_2C$ interface with a Serial Data Line (SDA) and a Serial Clock (SCL). In addition three more connections were deemed to be necessary: a connection for the supply voltage (Vbat) of 100mA peak current and a voltage between 3.4V and 3.7V; a common ground (GND) and an ENABLE connection, which can be used to power on or off the CT-sensor completely (0V=off, Vbat=on) to conserve energy. The communication between the SRDL and the CT-sensor is implementing three $I_2C$ slave commands.

- Read conductivity in low power, low resolution mode to determine if the instrument in the water or not (WET-DRY mode)
- Read conductivity and temperature at high precision (near) simultaneously and filtered to match time-constants if necessary to avoid salinity artefacts. The resolution should be 16 bits distributed over the ranges of -10C to 55C for temperature (resolution 1mK) and 0-80mS/cm in conductivity (resolution 1.25 μS/cm)
- Write command(s) to store calibration data.

This interface is simplifying the integration process into the existing SRDL system, but will also enable others to integrate the CT-package easily (Figure 1).


***Figure 1: Two CT sensors (left),a single CT sensor including interface board (middle)and a CT package integrated into a SRDL (right) are shown.***

After a common interface was found, the CT-package was interfaced with an SRDL instrument (Figure 1). Then, communication and logging of data was successfully tested in the lab by putting the whole package into an environmental chamber and changing the air temperature. We found a quadratic relationship between the impedance of the platinum resistor bridge and the air temperature over the full range (0-35°C). A linear effect of the environmental temperature on the electrodes was found and described, so that the conductivity measurements by these electrodes can be compensated. The whole package is currently waterproofed to start a calibration procedure in the lab, before the instrument is tested in the marine environment.

A design study process was started to develop an instrument enabling accurate measurements from non-rigid attachments. To minimize drag the body of the tag will have a low drag shape and near neutral buoyancy in sea water. The center of gravity will also be placed in such a way that the tag is self-righting even when on the back of an animal when dry. This will keep the antenna away from the animal's body improving the chances to transmit data successfully (Figure 2).

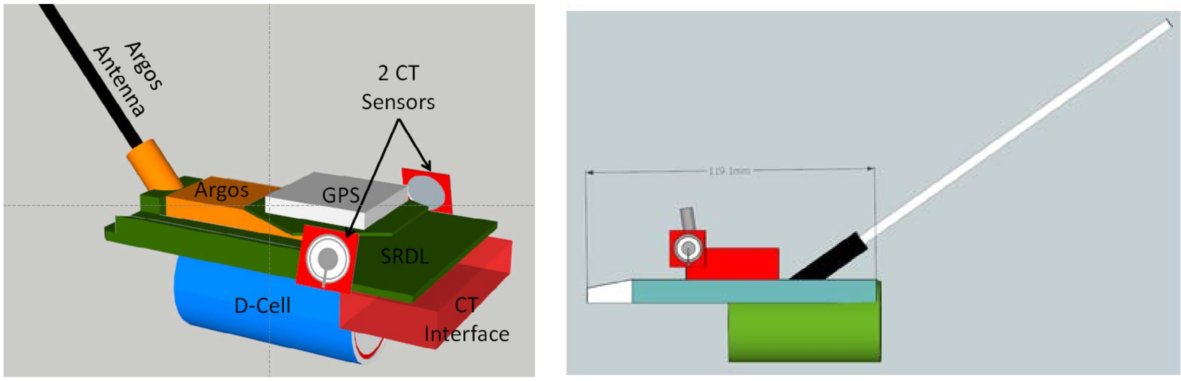


***Figure 2: Two design studies for electrode based CTD tags for non-rigid attachment. Instrument on the left has two CT sensors and a GPS receiver, while the right one has one CT sensor. The epoxy body is not shown.***

**IMPACT/APPLICATIONS**

Other research groups already registered interest in the final product to be used with rotating barb attachments to tag large cetaceans to support ecosystem studies of large cetaceans in the Arctic.

Reducing the size of the CTD sensor would allow a smaller instrument to be deployed on a much wider range of species, including many other smaller ones. However, minimizing size would also be advantageous in other important ways. It would make available space on the instruments for more complex sensor packages and geo-location approaches (Figure 2 left). It would also allow compatibility with other data relay modalities, mounting and attachment configurations or additional energy supplies while maintaining the current size and weight.

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