Mapping sea ice from above and below

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Abstract

In order to improve the capabilities of AUVs when operating in the Arctic, and under sea ice in particular, there are a number of requirements that we, the authors, see as essential for a successful operation. These requirements not only deal with features of the AUV itself, but also with launch and recovery techniques, positioning under the ice, artificial intelligence for under-ice behaviour, the optimal sensor package for mapping the underside of sea ice and the operational scenario as a whole. A key new technology being presented is the **Stand-Alone USBL Positioning Buoy**, which will enable insertion, tracking and retrieval of the AUV to be more rapid and secure, and enable in-mission low bandwidth communication. For mapping the topside of the ice a UAV (Unmanned Aerial Vehicle), which fulfils a similar set of requirements, will be described in detail below.

Keywords

AUV, UAV, ice thickness, multibeam sonar, 3D ice, navigation, tracking buoy, underwater positioning.

1 Introduction

This article will explain the concept of mapping sea ice from above and below in the most effective way. We will do this through five different perspectives. They are a) positioning under ice, b) requirements for “The Arctic AUV”, c) the sensor package – of which multibeam sonar is the most effective for under-ice mapping, d) an operational scenario including how to control AUV swarms and finally d) UAV requirements. This journey through the different ways of approaching the complex task of measuring sea ice from above and below, will lead us to the conclusion that: The technology for mapping sea-ice from above and below systematically, covering large areas in one dive, exists and just needs to be to be put together.

Today, planned AUV missions often involve the use of “AUV swarms”, i.e. multiple AUVs under centralised control. This is only possible when USBL and modem are combined.

2 Positioning and Communication Under Ice

In any survey of the under-ice surface, accurate underwater positioning is essential, especially in regions of strong currents. For underwater positioning under ice, we have identified the EvoLogics USBL system 18/34 as best for AUV use**,** because of its extraordinary capabilities in such demanding conditions. With sea ice being an excellent reflector for an acoustic signal, due to the contents of air trapped inside the ice, it requires a special approach in order to achieve a reliable communications channel. EvoLogics has, for the last many years, perfected this technology.

EvoLogics writes about their technology: “Dolphins and whales have adapted to the situation under water very well, communicating over long distances. They chirp and sing across a broad frequency bandwidth. This continuous change of frequencies not only serves to transmit information, but also to compensate for sources of interference such as echoes and noise.

Building upon eight years of studies on the physics of dolphin communication, EvoLogics has developed the patented Sweep Spread Carrier (S2C) technology. To mimic dolphin sound pattern, modems built on S2C technology continuously spread the signal energy over a wide range of frequencies and adapt the signal structure so that the multipath components do not interfere with each other. At the receiver end, advanced signal processing collects the energy and converts the received signals into narrow band signals. This results in achieving significant depression of multipath disturbances and substantial system gain, enabling successful decoding of signals also in crucial environments even when they are heavily masked by noise.” [3]

In order for this kind of USBL positioning system to be used from vessels without a dedicated, hullmounted USBL system, the Stand-alone USBL Positioning Buoy was constructed by Bo Krogh. The concept was tested during our cruise with the USCGC “Healy” in 2014, and further developed with the Stand-Alone functionality for a 2017 Gavia cruise with R/V “Polarsyssel”.

3 The USBL Positioning Buoy - details.

The Stand-alone USBL (Ultra Short Baseline) Positioning Buoy system consists of:

1. An EvoLogics USBL transducer (model S2CR 18/34) with an internal AHRS (Attitude and Heading Reference System) which is a compact unit that has a horizontally omnidirectional beam pattern, optimized for medium range operations in reverberant shallow waters such as under ice. It provides 3D positioning with a slant range accuracy of 0.01m and angular accuracy of 0.1 degrees.
2. A GNSS receiver, a Hemisphere V103, which is a Professional Heading and Positioning Compass receiving signals from both GPS and GLONASS satellites.
3. A long range WiFi dataradio to ensure contact with the mother vessel. This is mounted on an easy-to-transport, easy-to-assemble spar buoy together with two boxes for batteries and equipment.

The capability of communicating with the AUV**s** is an important advantage of the combined positioning and communication system which will consist in its ability to simultaneously track the AUVs movements and transmit instant messages, enabling real-time control and navigation based on the current positioning data. This is a key to the future of a turnkey AUV system for local surveys in collaboration with other types of measurement.

4 Requirements for the Arctic AUV

Based on our experience from Arctic AUV operations since 2002, we have compiled the following list of requirements, which are designed to enhance the operational capabilities of an AUV system in Arctic or Antarctic waters.

4.1 Power to the INS.

The AUV shall preferably have the capability to keep its positioning system powered up and running during battery change or charge. This is to keep the alignment of the INS (Inertial Navigation System). The reason for this is to save operational time prior to launch.

4.2 External positioning feed.

When operating in cold and harsh environments such as Arctic waters, it is preferable to keep the AUV indoors during battery charge and maintenance. This means that the AUV must have the capability to receive a positioning feed e.g. by WiFi or ethernet from an external GNSS source such as the GNSS system of the mother vessel. The reason is**,** that the GPS satellites are quite low over the horizon in Arctic latitudes, and it will therefore take a longer time to acquire an alignment of the INS based positioning system if the AUV has to be placed out on the deck of the mother vessel. Preferably, the AUV should have a GNSS (Global Navigation Satellite System) capable of receiving signals from all available systems, i.e. GPS, GLONASS, Galileo and BeiDou.

4.3 Launch and recovery system.

The Gavia AUV, used for both the 2014 and 2017 operations, is a compact lightweight AUV designed for manual deployment from ships and boats. We had used it in earlier ice surveys in 2007 and 2008 (Wadhams and Doble, 2008; Doble et al., 2009). In both cases it was deployed through a slot cut in the floor of a heated tent and was operated with a Kevlar line attached to the vehicle. This was needed both for insurance purposes and to ensure control in the event that the vehicle ignored its programmed instructions. In 2014 and 2017 it was operated from a ship's MOB boat, again with a Kevlar line.

The experience gained from all these Arctic operations is that the Kevlar line reduces the operational capabilities of the AUV so much that it cannot even do a simple lawn-mover pattern. During all the mentioned operations, only small areas were covered. The only way forward is therefore to develop the reliability of the system so that it can carry out operations without the Kevlar line.

4.4 Survey Plan.

The obvious survey plan is simply to program the vehicle's navigation to carry out a systematic survey (often by a "mow the lawn" geometry) of the ice area or ice features that are of interest. But however, the question arises of how we can best terminate the survey and recover the vehicle. When ending or aborting a mission it seems obvious that the vehicle should just be brought to the surface for recovery. But supposing the surface is ice-covered, or the survey lines leave the vehicle at a considerable distance from the ship**,** what will happen then?

These considerations led to the concept of "go there and loiter" in which a latitude and longitude are specified to which the vehicle goes and then circles around at some depth until the operator decides upon surfacing or on some new navigational need. This can also be the default option for an aborted mission. It would be just as easy to have the AUV home to a transponder inserted into the sea at a desired spot.

The benefits of an AUV persist as long as all its systems function properly. An unexpected situation may cause the AUV to malfunction. An autonomous vehicle with no data exchange with a surface control centre can stay underwater with limited or no functionality for a long time until it is eventually recovered to the vessel. This shortcoming can be eliminated by equipping the AUV with a transponder, capable of sending and receiving acoustic signals, as well as with an additional system for full range underwater acoustic communication. The transponder provides a reference for estimating the AUV's position, while the communication system allows transmitting sensor parameters, the vehicle's status data, payload data (measurements, images, etc.). These systems change the AUV's operation from being entirely autonomous to a so-called supervised autonomy mode. Along with enabling an operator to control the AUV from a surface vessel, the supervised autonomy mode allows us to reduce the accuracy requirements for the on-board navigation system and thus reduces the AUV cost.

Other requirements relevant to survey operations would be:

1. The ability to follow a gradient such as temperature or a value from a hydrocarbon sniffer.
2. One man operation. Once the vehicle is in the water (even if its weight requires 3 people for handling in air).
3. An internal battery or external power supply to the AUV to keep the alignment of its INS during battery change or charge.
4. An external positioning feed, e.g. via WiFi, to the AUV to enable alignment of the INS while inside the Mother Vessel.
5. At least two GNSS (Global Navigation Satellite Systems): GPS and GLONASS, Galileo and BeiDou if possible.
6. A launch and recovery system that enables operation from a vessel. We have had very successful operations from a ship like "Arctic Sunrise" which has a stern compartment with a stern door and a gantry, permitting winching out the vehicle from inside the ship and placing it in the sea. On the other hand, when the vehicle is taken out in a small boat the on-board facilities are less and the possibility of the boat getting trapped in ice is very real.
7. By using the EvoLogics USBL and modem it should be possible to communicate with the AUV, including the capability to receive short status messages. Equally important is the capability to send a new mission plan to the vehicle.

5 Sensor Package

The sensor package depends on a trade-off between a desire for small size and small power requirements, and a need for a maximum outfit of useful sensors. For an under-ice mission the following should be considered:

1. Upward (and maybe downward) looking DVL/ADCP, range preferably 100m. This gives currents in the water column as well as the speed under the ice/surface.

2. Multibeam sonar (e.g. Interferometric Bathymetry system) and sidescan sonar that can be run upward-looking for under ice mapping, or downward-looking for seabed surveys.
3. Possible other AUV sensors: a) fish sonar, b) hydrocarbon/methane sniffer for detecting under-ice oil slicks, c) hydrophone to identify mammals, d) camera, preferably a video camera.
4. Surface transponder position update, i.e. the ability to update the positioning system of the AUV, when it passes in the vicinity of the USBL Buoy
5. Back calculation software for the INS/DVL positioning should be available.

6 Operational Scenario

In order to provide an easy overview of all the details, all operational systems, ie. the vessel, the USBL Positioning Buoy, the AUV(s) and the UAV(s) would benefit from being plotted on one screen. The well known software package HYPACK for Hydrographic Data Collection and plotting (approximately 14,000 users world-wide) is ideally suited for this, where the operations screen can be transmitted to several stations aboard the vessel.

In that way, the AUV supervisor is not doing the operational planning alone, as happened in 2014 and 2017; it now becomes a joint decision, where all operational conditions such as ice, current, weather etc. are considered together.

This also means that the mission planning for both the AUV(s) and the UAV(s) are done from Hypack. There is already a data exchange protocol available, which is called MavLink (Micro Air Vehicle Communications Protocol), that many drones and ASVs (Autonomous Surface Vehicles) use.

Achieving consent to perform AUV operations in ice-infested waters without the Kevlar line, is best started well in advance of mobilisation. The process should start with a risk analysis, based on the principles of the “Zero Incident Mindset” and ALARP (As Low As Reasonably Practicable), which describe in detail the risks involved and what mitigating actions can been taken.

Such mitigating actions are described in the sections above. The next step thereafter is to approach the insurance underwriters.

7 Arctic UAV requirements

When an AUV operates alone it can give detailed information about the underside of the ice, but with no accompanying information about the topside. Often we need to know the full topography of a pressure ridge (sail plus keel), the depth of the snow cover, as well as other information about the upper part of the ice cover and near-surface meteorology. The best that has been done so far has been to independently deploy a laser mapping system from the deck of the ship or by physically walking over the experimental area and setting out laser targets, as we did in 2012 with considerable success. With the rapidly improving capability of airborne drones, i.e. UAVs (unmanned aerial vehicles), it is obvious that a full ice survey system should include an AUV operating in collaboration with the AUV, with coupled navigation so as to yield upper and lower surface ice maps.

The requirements for an Arctic UAV are thus:

- UAV shall have an INS based positioning system.
- Ability to fly in fog – using two independent radio links perhaps.
- Moving Base RTK technology for positioning.
- VTOL capability, i.e. the start and land vertically from the deck of an almost stationary vessel.
- The same WiFi radio network as the Buoy and the AUV.
- Mission planning from Hypack, i.e. capability to read and execute fx MavLink files.

An example of a suitable system, scheduled for use in the next round of AUV/UAV development studies, is being supplied by the leading UAV expert, Dr Christopher Zappa of Lamont-Doherty Earth Observatory, who will deploy an HQ-90 (see Figure 1), a new concept for long endurance vertical takeoff and landing that makes use of the Piccolo autopilot from Cloud Cap Technology. Hybrid Quadrotor (HQ) technology offers an innovative and logistically simple solution to the problem of vertical takeoff and landing: it combines the vertical takeoff and landing (VTOL) capabilities of a quadrotor and the efficiency, speed, and range of a normal fixed-wing aircraft.

The HQ-90 has a cruising speed of 40 knots, with an endurance of 15 hours at a nominal 7 kg payload. It can therefore survey 900 track kilometeres per flight, which greatly exceeds the survey capacity of an AUV, so the airborne mosaic of ice surface topography covers and incorporates the submarine mosaic of a smaller area (e.g. a single pressure ridge) established by the AUV in a ship-day of operations. The HQ-90 can reach 14,000 feet, has a wingspan of 3.8 m and weighs 43 kg. The flexible payload capacity using swappable nose cones and fuselage mounting combined with HQ-90's large amount of available onboard power (250W at 24 VDC) allows deployment of an extensive sensor suite. A number of different sensor suites were tested and integrated during long-term tests from RV "Falkor" in 2016. The most useful one appears to be the Li-MET package**,** which gives us laser profiling of the ice surface. Li-Met includes a LIDAR for wave height and surface roughness with 5 cm absolute accuracy along a repeated track and ± 2.5 cm along a single scan; fast response 3D wind speed and direction (100 Hz), fast response temperature (50 Hz), fast response relative humidity (100 Hz) for estimating momentum, latent heat and sensible heat turbulent fluxes by eddy covariance techniques.

8 Conclusions

This is an exciting time for the development of ice sensing using autonomous vehicles. The advent of smaller, more efficient and reliable designs of AUV makes it easier and cheaper to deploy vehicles under ice, conduct surveys and obtain systematic results on ice draft mapping. At the same time the very rapid development of UAV technology gives a low-cost tool which can supply equivalent data on the upper surface topography of the same ice. All that remains is the perfection of the technology that will allow these two systems to be joined together and used in the field to provide 3D ice. Such surveys will help us to understand and map the rapid decline in ice thickness which is resulting from the Arctic amplification of global warming.

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Figures

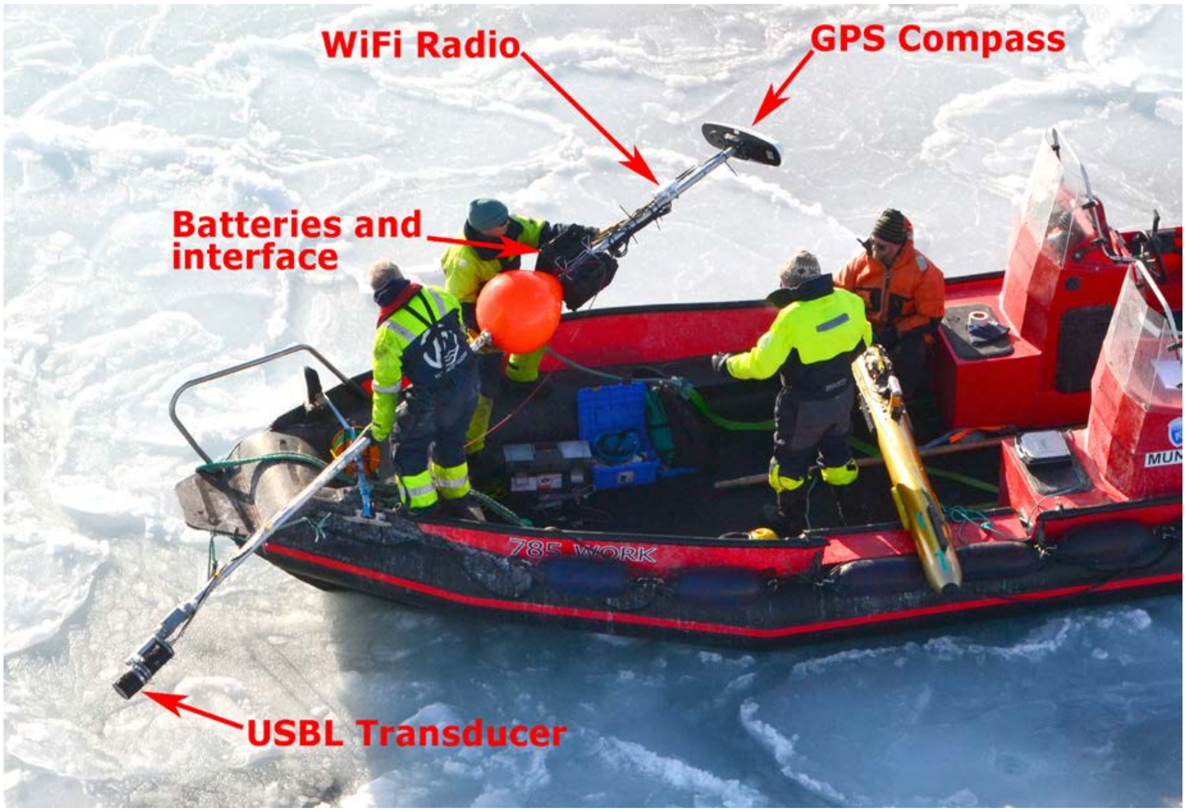

Figure 1. Stand-Alone USBL Positioning Buoy and Gavia AUV in boat.

Figure 2. Stand-Alone USBL Positioning Buoy, here seen in newly formed frazil ice in the Barents Sea 2017.

Figure 3. Latitude Engineering Hybrid Quadrotor model HQ-90 with vertical takeoff and landing (VTOL) capability.