An Analysis of Iceberg Profiling Strategies using Unmanned Ocean Systems

Mingxi Zhou
IEEE Student Member
Autonomous Ocean Systems Laboratory
Faculty of Engineering and Applied Science
Memorial University of Newfoundland
mz6580@mun.ca

Ralf Bachmayer
IEEE Member
Autonomous Ocean Systems Laboratory
Faculty of Engineering and Applied Science
Memorial University of Newfoundland
bachmayer@mun.ca

***Abstract*— With the offshore development off the Newfoundland and Labrador coast, the environment becomes the key factor to the production. Each year hundreds of icebergs depart from the Greenland and drift towards the Newfoundland and Labrador. Icebergs in the vicinity of the offshore structure have a potential of causing production downtime, scouring the pipeline on the sea floor, and destroy the infrastructures. In the iceberg management, the underside morphology of the target iceberg significantly affects decision of towing operation, ice berg drift and stability analysis. In this paper we present an overview of iceberg profiling techniques using acoustic systems, such as Multi-beam Sonar, Scanning Sonar, and Side Scan Sonars. Furthermore, three different types unmanned marine systems (underwater glider, unmanned surface craft and remotely operated vehicle) are investigated as potential carriers of the acoustic profiling system. By comparing different profiling system and its carrier, a detail mission planning scheme is presented as a reference for iceberg profiling missions. With various demands and objectives the scheme will help the operators to select a suitable mission plan.**

***Index Terms*— Iceberg, AUV, ROV, ASC, Sonar**

I. Introduction and Motivation

Each year from February to August, an ice reconnaissance is conducted by the International Ice Patrol (IIP), Canadian Ice Service (CIS) and North American Ice Service (NAIS) to monitor the iceberg danger. According to the Report of IIP in the North Atlantic [1], almost 500 icebergs appeared near the 48^oN where the Hibernia oil plantform on the Grand Banks of Newfoundland located. Responding to the appearance of icebergs, the ice management is conducted to avoid potential damage posed by icebergs to the offshore production.

In [3], the ice management on the Grand Banks is introduced and summarized. In the ice report process, all relevant ice observation, reconnaissance, monitoring information are collected. However, the underwater information is hard to obtained from above water instruments. To avoid the towrope slipping under an iceberg and iceberg rolling over, an accurate estimation of the underside ice geometry is significantly necessary.

Although the underside profile of an iceberg can be estimated from empirical equation [3] and iceberg model based on the above-water geometry, the true profile is needed to be measured and archived. The study of below-water profile of iceberg starts in 1980s. From 1984 to 1985 28 underwater profiles were collected by Oceas Ltd. [5]. Starting in 2001 Oceans Ltd. conducted a three year program for below-water iceberg profiling and obtained 46 profiles. However, the methods, such as deploying sonar probe and airborne device, discussed in [2] are costly and inconvenient. As a discussion in [2], unmanned underwater vehicle (UUV) is recommended for future works.

In considering the operation with unmanned ocean systems, the efficiency and budget of ice profiling strategy are based on the multiple factors such as the iceberg dimension, profiling device, vehicle selection and environment situation. Therefore, a comprehensive guide of iceberg profiling strategy is demanded in helping operation planning.

II. Icebergs of Newfoundland and Labrador

As discussed by S. E. Bruneau [4], the iceberg size distribution is summarized according to the IIP report from 1994 to 2004. Among reported icebergs, 60 % of the icebergs are with a diameter over 50 meters which is equivalent to the length of support vessels. According the website of Environment Canada [6], seven categories of iceberg are described. The features of different icebergs summarized from [3] to [6] are presented in Table I, and the photos of different icebergs are available on Environment Canada. The above-water categories distribution in Table I is based on 74 icebergs Oceans Ltd. have measured with bottom profile and text description of the tops in 2003.

In [5], the underside categories of icebergs are derived based on the below-water profile databased created by Oceans Ltd.. Six classifications (pinnacle, blocky, dome, wedge, ram and tabular) are described and shown in Figure 1. In [5], the researchers analysed 26 icebergs with 3D profiles of tops and bottoms to search for a relationship between the above-water profile and below-water profile. Presented in the appendix of [5], six complete iceberg profiles are shown. The tops and bottoms iceberg shape is categorized in Table II. Due to the size of the database and available information, the relationship of top-bottom geometry is undefined. However, with the increasing database, a statistical relationship is able to be detected.

TABLE I
ICEBERG CATEGORIES AND FEATURES

Categories	IIP Code	Description	Height to Draft Ratio	Distribution
Tabular	TAB	horizontal flat-topped	1:5	16%
Blocky	BLK	flat-topped steep sides	1:5	0%
Domed	DOM	smooth, rounded top	1:4	8%
Dry Dock	DDK	u-shaped slot eroded	1:1	28%
Pinnacled	PNC	central spire pyramid	1:2	26%
Wedge	WDG	tilted tabular slope sides	1:5	18%
Non Tabular	BLK	other icebergs not included	1:5	4%

TABLE II
NRC ICEBERG BREAKDOWN

Iceberg	NRC1	NRC2	NRC3
Tops	Tabular	Pinnacle	Pinnacle
Bottoms	Blocky	Pinnacle	Pinnacle
Iceberg	NRC4	NRC5	NRC6
Tops	Dry Dock	Wedge	Pinnacle
Bottoms	Dome	Blocky	Pinnacle

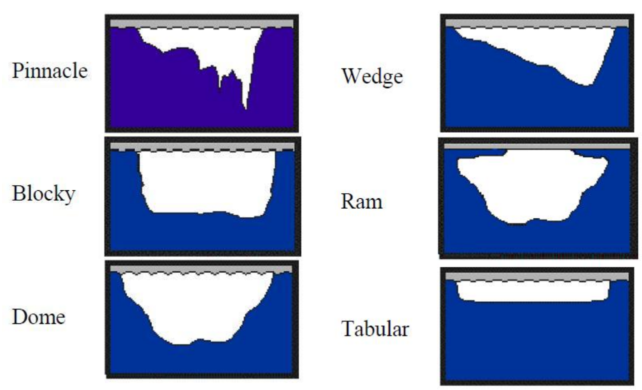

Fig. 1. Derived Iceberg Underside Categories (obtained from [5])

From the literature review of icebergs in Newfoundland and Labrador, we found 1) pinnacle icebergs have the highest distribution; 2) the database of below-water profile is needed to be expand; 3) the relationship of top-bottom profiles needs to be stated.

III. INSTRUMENTATIONS AND FACILITIES

A. Unmanned Ocean Systems

Compared to the manned ocean systems such as support vessel and submarine, unmanned ocean systems is less risky, less cost and more efficient. Remotely Operated Vehicle (ROV), Autonomous Underwater Vehicle (AUV) and Autonomous Surface Craft (ASC) are considered as potential candidates for underwater iceberg profiling.

In simplicity, ROV is a tethered waterproof enclosure with inspection instruments [7]. In 1953, the POODLE developed by Dimitri Rebikoff for archeological research is credited the first ROV. After eight years, Cable-controlled Underwater Research Vehicle (CURV) made a significant impact to the world technology with taking national headline twice. It is developed by the US Navy to retrieve the torpedoes under the water. On the CURV, a camera system is equipped for visualization, and a manipulator is installed for torpedo recovery. With the successes of CURV, ROV building projects starts all over the world. A comprehensive introduction of ROV is presented in [7]. For the situation of iceberg profiling, a mid-size observation class is preferred. It has a lower cost compared to the large-size ROV, higher efficiency and more stable compared to the small-size ROV.

Autonomous Underwater Vehicle (AUV) is a underwater robot operates autonomously with a pre-programmed system. Compared to the ROV, AUVs has more freedom without the tether. Consequently, the risks and the power limitation appear. In [8], the author included a chronological history of AUV development. The investigation of AUV began in 1960s. In the initial state, the researchers started with a investigation of the application of AUV, and testbeds building. After successful experiments with prototypes in 1980s, the investment in the AUV industry is significantly increased worldwide. Among the various selections of AUV, Autonomous Underwater Gliders (AUGs) which has a long duration are considered a cost-effective candidate for iceberg profiling mission.

Another potential candidate for iceberg profiling mission is Autonomous Surface Craft (ASC). As its name shows, ASC works on the surface and follows the commands sent from the operators onshore. In today's oceanographic operations, ASC are enrolled for bathymetric mapping, ocean environment monitoring and multi-vehicle network operations [9]. Currently, two ASCs, SeaCat [10] and Sea Dragon, are under development at Autonomous Ocean Systems Laboratory (AOSL), Memorial University of Newfoundland. These two platforms are designed to survive in the harsh environment, and regarded as important roles in ice related operations.

At current stage, Slocum underwater glider, Seaeye Falcon ROV, and SeaCat ASC, which are available at AOSL, are qualified for the iceberg profiling. Table III concluded the advantages/disadvantages of the three candidates. Falcon ROV operates under a regular AC power input which minimized the power resource problem. Furthermore, it is equipped with a camera system and a Imagenex 881A scanning sonar which scans underwater condition and visualizes it to the operator in real-time via fibre optics cable. By showing the environment around the vehicle, the operator is able to help the vehicle to avoid potential dangers. However, the drawbacks make it less competitive. The operating space is restricted by the attached tether, meanwhile an extra operator is required for tether management which increase the operation cost. More importantly, the low autonomy and lack of underwater position system reduce the capability of Falcon ROV in ice profiling operation.

Superior to the Falcon ROV, high controllability is available on the SeaCat ASC. The operators can switch between the autonomous mode and manual mode easily. Moreover, the real-time data is available to the operator for monitoring the state of ASC and sequent mission plan. Nevertheless, the "surface" limits the potential of ASC in ice profiling tasks. As described in [12], the problem, such as sonar beam passing under icebergs, exceeding sonar range, surface influence, appears and contaminates the measurements.

TABLE III
ADVANTAGES AND DISADVANTAGES OF THE UNMANNED OCEAN SYSTEMS

Vehicle	Advantages	Disadvantages
Falcon	unlimited power, low risk real-time stream data	limited range, low autonomy, high operation cost, no underwater positioning
SeaCat	high controllability, real-time data high instrument compatibility	limited depth, unstable on surface, surface effects
Slocum	low power, stable, low operation cost, high autonomy	complicated control high risk, narrow choice of sensors

Compared the the previous systems, Slocum glider has high autonomy, low operation cost, and wide operating space. But like other systems, disadvantages still exists. Originally, Slocum glider is designed for gathering ocean science information such as water temperature and conductivity. To integrate the ice profiling functionality into the Slocum glider without disturbing the original architecture is complicated. In the instrument aspect, the allowance of additional instruments are limited. The physical specification (weight and dimensions) becomes the primary criteria in selecting the profiling instruments which narrows the options. Consequently, a appropriate profiling device is required to be integrated, and a comprehensive control algorithm is need to be attached to the software.

By analysing the merits and drawbacks of the systems, none of the systems is ready-to-use for ice profiling tasks. Additional capabilities are required to be integrated which is discussed in Section IV.

B. Sonar

The acoustic methods, sonar systems, are extensively used in the underwater applications such as sea floor mapping and Object detection in the water column. Various types of sonar systems were used for iceberg detection and profiling.

Side scan sonars were the one of the first system used for underwater iceberg mapping [2]. It provides a wide beamwidth in the transverse direction and narrow sector along the track. However, in the iceberg mapping, side scan sonar is rotated for a wide horizontal projection then it is lowered vertically from a support vessel near an iceberg. For example, [11] introduced an successful iceberg underside mapping operation conducted in 1971 by the researchers in Memorial University of Newfoundland. By lowering and raising the rotated side scan sonar in four different directions with a 200 meter long cable, the underside topography of the iceberg is obtained in 30 minutes. In the statistical study described in [12], the drafts of 35 icebergs were measured with a fan-shaped transducer with 52 degree vertically and 1.5 degree horizontally. The transducer was mounted on a 7meters long pipe manhandled from the deck of the supporting vessel. The operators rotated the transducer with a 26 degree and submerged it to a depth of 1meter. Iceberg draft was profiled with travelling a circular path around the iceberg.

TABLE IV
COMPARISON OF SONAR CANDIDATES

Product	Imagenex Delta T	Tritech Micron	Imagenex Sidescan
Category	MBES	Scanning	Side scan
Beam Angle	$120^o \times 3^o$	$360^o \times 35^o$	$60^o \times 1.8^o$
Power	12 W	4 W	5 W
Dimension	5.6" $\times$ 7.7" $\times$4"	2.2" $\times$ 2.6" $\times$3.1"	7.3" $\times$ 1" $\times$1.25"
Weight air(g) water	2.49 0.7	0.32 0.18	0.3 N/A
Interface	Ethernet	RS485	RS485
Resoultion	%0.2	%0.25	%0.2
Range(max)	300m	75m	120m

Compared to side scan sonars, Multibeam echo sounders (MBES) has a wider angle span. Unlike the single transducer packaged in a side scan sonar, a transducer array is contained. Consequently, advance hardware and software is required to process and display large volumes of data for each profile. Although MBES are usually used with ships, the author in [13] successfully integrated a MBES on an AUV. The ice draft in [13] is obtained by post-process the MBES data with image mosaic.

The last potential device for iceberg profiling is scanning sonars. Similar to the radar attenna, the sonar head is continuous rotatable. The scanning sonar is widely used on ROVs. It provides the operators a 360 degree view around the vehicle to avoid the obstacles. However, a zig-zag coverage is obtained along path from scanning sonar due to the time delay for rotating transducer. As a consequence, blank area will appear in the profiling data.

Three sonar systems are selected and compared in Table IV. Shown in the chart, Imagenex Delta T MBES has the largest size and profiling range, while Tritech Micron and Imagnex side scan are relatively smaller and lower power consumption. As a result of the comparison, Delta T MBES is suitable for ASC and ROV which are not strict with power. While side scan sonar is not considered on the ASC since the surface effects. Tritech Micron scanning sonar which collect a zig-zag profile is treated as a secondary sonar to compensate and validate the primary profiling sonar such as MBES and side scan sonars. At the same time scanning sonar can be used for collision avoidance.

IV. Iceberg Profiling Strategy

According to review of iceberg off Newfoundland coast, the iceberg can be separated into 8 classifications by its draft, diameter and underside complicity (Table V), where complicated shape includes wedge and pinnacle which are not symmetric, and simple shape includes ram, blocky, dome, and tabular. On the other side, as described in Section III, each unmanned ocean systems requires a hardware upgrade to improve their ability. For the ROV and Slocum underwater glider a underwater position system is needed, while a submerged payload is needed on the SeaCat to install the profiling device. In respect to the sonar systems, due to the high power consumption, Imagenex Delta T is not suitable to be integrated on a Slocum glider. Moreover the side scan sonar is not compatible to the SeaCat, due to the surface effect of the environment which affect the side scan measurement. The Falcon ROV, who already has a Imagenex scanning sonar, is able to carry the MBES and Side scan sonar. Furthermore, each plan needs a scanning sonar which can be used for navigation and collision avoidance purpose. It is also installed as a secondary profiling device.

TABLE V
New Iceberg Classifications

Type No.	Draft (D)	Diameter (R)	Underside shape
A	100m<D <200m	100m<R <200m	Complicated
B	100m<D <200m	100m<R <200m	Simple
C	100m<D <200m	R<100 m	Complicated
D	100m<D <200m	R<100 m	Simple
E	D<100 m	100m<R <200m	Complicated
F	D<100 m	100m<R <200m	Simple
G	D<100 m	R<100 m	Complicated
H	D<100 m	R<100 m	Simple

The three potential profiling plans was summarized in Table VI and illustrated in Figure 2. In the Table VI, at least two sonars are installed on each vehicle. The primary sonar is image sonar, while the secondary sonar is installed for avoidance collision. In the post-process, the measurements of profiling sonar and secondary sonar are combined to construct an accurate topography of submerged portion of icebergs.

TABLE VI
Iceberg Profiling Strategies

Plan	I	II	III
Vehicle	SeaCat ASC	Slocum glider	Falcon ROV
Primary Sonar	Delta T	side scan	Delta T side scan
Secondary Sonar	Tritech Micron	Tritech Micron	Imag. 881A
Profiling Path	circle around iceberg	criss-cross underneath	descend/ascend in four directions

Shown in Figure 2, the ASC equipped with Tritech Micron scanning sonar and Delta T MBES is planned to circling around icebergs. The MBES will be submerged underwater and rotated 30 degree about the surge direction. In order to minimize the sea floor contamination, the sector size is set to 60 degree instead of 120 degree or 90 degree.

In the operation with Falcon ROV, a side scan sonar and MBES will be installed on ROV. The sidescan and MBES will provide a wide bathymetric iceberg profile on the descend/ascend course. Imagenex 881A is a pre-installed scanning sonar which displays the information around the ROV. The iceberg profile will be constructed with multiple data packages in different directions.

To protect Slocum glider with the appearance of iceberg, a Tritech Micron scanning sonar will be integrated in a forward scanning configuration. Meanwhile, a side scan sonar will be installed to obtain the iceberg image. In a single cross, Slocum glider will firstly dive to a depth under the iceberg, then yos in a small depth span underneath the iceberg. The iceberg profile can be constructed with multiple crosses from different directions.

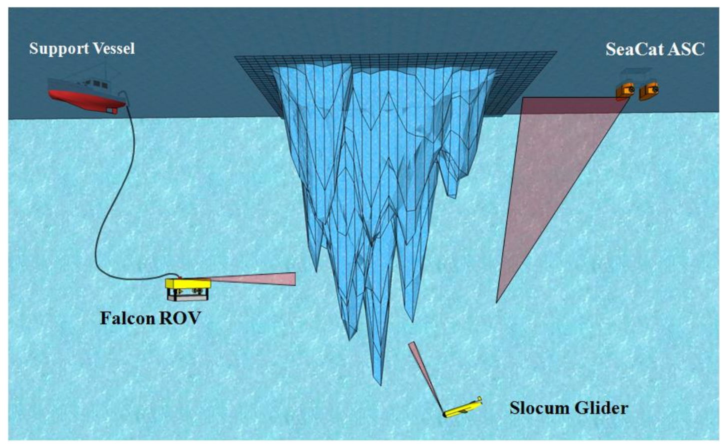

Fig. 2. Iceberg Profiling Strategies

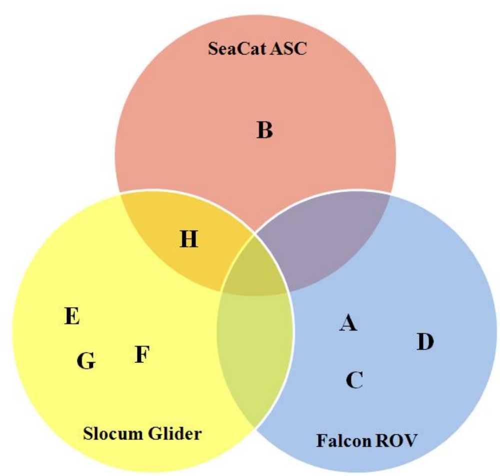

Fig. 3. Venn Diagram of Iceberg Profiling Plans

As shown in the Venn Diagram (Figure 3), at least one of the proposed plan is able to accomplish the iceberg profiling. The chart is created with several criteria is listed as follows,

1) In safety aspect, Slocum glider (200m version) is not suitable for the icebergs with draft over 100m. In order to keep away from the iceberg, a distance clearance is set between the draft and the path of glider.

2) Due to the potential of sonar beam passing under the iceberg which contaminate the result, SeaCat ASC is not preferable for icebergs with shallow draft.

3) In the scenario of high draft to diameter ratio, false measurements may obtained with SeaCat ASC. With the small diameter, the circling radius of SeaCat is intended to be reduce to achieve higher efficiency. With the increasing depth, the grazing angle increases. With a large grazing angle, the echoes strength decreases dramatically. Consequently, the draft obtained may be smaller than the actual draft.

4) SeaCat ASC is not suitable for the icebergs with complicated underside. The ASC need to adjust the distance away from the iceberg to maintain a constant coverage.

5) For large diameter icebergs, Falcon ROV is not preferable if other option is available due to the high operation cost.

In consideration of the uncertainty in shape and draft which dramatically increases the risk, a preliminary trial is recommended. The purpose of it is to obtain sufficient information for selecting the appropriate plans. preliminary trials can be completed with a MBES extended from the boat or a ASC.

V. Conclusion and Future Works

In this paper, a strategy guide with unmanned ocean vehicles is summarized by evaluating the capability of three different vehicles. Also, three candidates of sonar systems is intended to be installed to the vehicles.

As a result of the discussion, the icebergs are separated into eight categories depending on the draft, diameter and underside complicity. With the criteria and limitations setting for the vehicles, a Venn Diagram is created for strategy selection. Due to the uncertainty of draft and underside complicity, a preliminary trial is necessary to reduce the risk of vehicle collision and failure.

In the future, Tritech Micron scanning sonar will be integrated on to a Slocum glider in AOSL. Meanwhile, the ice profiling capability of the sonar systems will be tested in the Tow Tank at Memorial University of Newfoundland. An iceberg profiling field trial will be conducted in 2014.

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