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A Method of Above-water Iceberg 3D Modelling Using Surface Imaging

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ABSTRACT

This paper reports on an algorithm to build a 3-D model of the above-water portion of icebergs using surface imaging. The goal is to work towards the automation of iceberg surveys allowing Unmanned Surface Craft to acquire shape and size information to fulfill the iceberg database. The presented methodology is made up of 3 parts: volume intersection, occluding contour finding, data collection, and integration. This method is investigated in field trials conducted through the summer of 2014 by surveying 8 icebergs during 3 expeditions.

KEY WORDS: Iceberg; surface imaging; 3-D model

INTRODUCTION

Icebergs along the Newfoundland and Labrador coast threaten offshore facilities and activities, including oil and gas production platforms, collection and offloading systems, exploration schedules and marine transportation. Iceberg management systems have been developed, implemented, and refined by research activities over the past 30 years to improve marine safety and protect offshore installations and marine transportation from iceberg threats. A survey of iceberg deflection techniques and capabilities was presented by National Research Council (NRC) Canada to develop a strategy to perform iceberg management (Crocker Wright, Thistle, & Bureau, 1988). East Coast Ice Engineering Issues studies sponsored by Program of Energy Research and Development (PERD) administered by NRC Canada give practical solutions to ice problems and excellent data resources (NRC-CHC, 2007). The aims of iceberg management could be summarized into: (1) ensuring the safety of platform operation in the environment for which it was designed; (2) reducing risk to personnel and assets over and above design requirements; (3) minimizing disruptions to drilling or production operations (Garry, 2007). Effective ice management should fulfill the tasks of iceberg detection, decision making, and altering the iceberg's path by towing or other means if necessary. Iceberg detection is generally undertaken by satellite radar or marine radar, and the measurements of the size of the above-water icebergs mostly relies on these two methods, even though the resolution is not high enough. However, high resolution models of icebergs are required since they contain significant factors which influence decision making. We can see this from the C-CORE Iceberg Decision Making Toolbox, where the independent variables influence the decisions of when, where and which icebergs to tow are iceberg location, features of the iceberg. These variables are size, mass and shape, and the structure operation and corresponding T-time (total time required to complete operation), ice load capacity of the structure, tow resource locations and environmental conditions (C-CORE, 2005). Dunderdale Iceberg Management Planning Aid (IMPA), a tool developed by Peter Dunderdale, is designed to improve iceberg towing effectiveness through prediction of expected drift outcomes for a given input of iceberg size, shape, drift velocity and direction (Brown, Dunderdale, & Mills, 2003).

For above-water iceberg observation, traditional techniques include photography, radar or other surveying techniques, and ground penetrating radar. Although it can give some information about draft and mass, shape is hard to obtain by using these methods (Comfort, 1998). Canatec (1999) produced a comprehensive database that integrated the three-dimensional shape and geometry of icebergs with records that contain 3-D data observed on the Grand Banks of Canada. (Baker, Skabova, & Timco, 1999) Fugro (www.fugro.com) announced at 2014 Arctic Technology Conference that above-water imaging techniques (3-D photogrammetry) are acquired to generate 3-D models of icebergs, but no further report could be found. In this paper, we report a technique of constructing 3-D iceberg models by using 2-D photographs in addition to some calibration measurements. This work is one part of the Ice Ocean Sentinel System (IOSS), which is endeavoring to provide critical ocean information and data products for decision-making needs in frontier, harsh and ice-prone environments.

In this paper, an algorithm to generate 3-D information about shape, size and mass is presented. In section 2 we will introduce the main methodology, including the algorithm for extrusion and intersection to build the 3-D model, and the algorithm to extract occluding contours. Section 3 and section 4 will then analyze how we designed the experiments to get the data needed to perform the algorithm, and how we processed the data to produce 3-D models of icebergs. To test this methodology, we have conducted field trials to collect field iceberg images, GPS positions, laser range information and the orientation of vehicles. The results will be posted in section 5. Section 6 summarizes the algorithm for building a 3-D model, explaining how the study could be improved.

METHODOLOGY

Volume Intersection Algorithm

Understanding the 3-D content of an object based on 2-D images is a central problem in computer vision, and many approaches have been proposed for reconstructing 3-D model when 2-D images are available. Some approaches can be used to reconstruct the 3-D shape of an iceberg from its 2-D images. Martin (1983) firstly presented a method to get volumetric description from multiple views. Many other researchers reconstructed surface volume by performing planer motion under orthographic projection on solid objects (Kim & Aggarwal, 1986; Chien & Aggarwal, 1989; Pujari, 1989; Srinivasan, 1990), and the method is referred as *volume intersection* algorithm, which could be described as follows:

"The word silhouette indicates the region of a 2-D image of an object **O** which contains the projections of the visible points of **O**. If no a priori knowledge about **O** is available, all the information provided by a silhouette $\mathbf{S_i}$ is that **O** must lie in the solid region of space $\mathbf{C_i}$ obtained by back-projecting $\mathbf{S_i}$ from the corresponding viewpoints $\mathbf{V_i}$. If n silhouettes are available, they constrain **O** within the volume $\mathbf{R_n}$:

$$R_n = \bigcap_{i=1}^{n} C_i \qquad (1)\text{"}$$

(Laurentini, 1995)

From this statement, the most critical information we need here is the silhouette extracted from the 2-D images since it has been recognized as the most effective clue to shape understanding. These silhouettes are extruded by sweeping the silhouette along either a line parallel to the viewing direction (Fig. 1) or a cone obtained by back projection from a viewpoint. The volume intersection algorithm can be realized from all different directions for solid objects. However, in this project we initially constrain ourselves to the viewpoint paralleled to the sea-surface since we are using a vehicle on the sea-surface to collect images of icebergs.

Fig 1. Simplified volume intersection algorithm. The left image is the extrusion of two different silhouettes (the front view is an irregular shape, and the left view is a square). The right image shows the isometric view of the object after intersection.

By using OPENSCAD (http://www.openscad.org/), the occluding contours can be easily extruded along the parallel projection lines and the resulting volumes can be intersected and extracted. Therefore, we can generate a 3-D object that gives the same silhouette of the captured iceberg from the specific viewpoint. With more intersections, the precision can be improved. The resulting object is called a visual hull. This is the idea behind constructing a 3-D model of an iceberg from its 2-D images. However, we note that the visual hull is not an exact reconstruction of the original iceberg, even when performing infinite number of intersections. This is because silhouettes are not sufficient to determine 3-D shape when the object is non-convex (Aloimonos, 1988). To overcome this obstacle, Laurentini (1994) defined the external visual hull and internal visual hull. Generally speaking, the external visual hull is the maximum volume, while internal visual hull is the minimum volume of an object. For the specific characteristics of icebergs, the concave can only be seen in the top view, as other views could be shown in the occluding contours. In this case we use an additional sensor, a laser range finder, in order to improve the representation of the object.

After the introduction of our choice of methodology for iceberg shape reconstruction, we are addressing the issues of algorithm to extract the silhouette, data collection, and data processing.

Finding the Occluding Contours

In the first step, we extracted occluding contours, which form a partial representation of the true iceberg shape, from the images of the icebergs. However, contour extracting is significantly different from other standard computer vision algorithms since the icebergs' shapes and shadings are irregular and random. In addition, the iceberg color is usually a gradient that might be very similar to the color of the clouds or the sea itself.

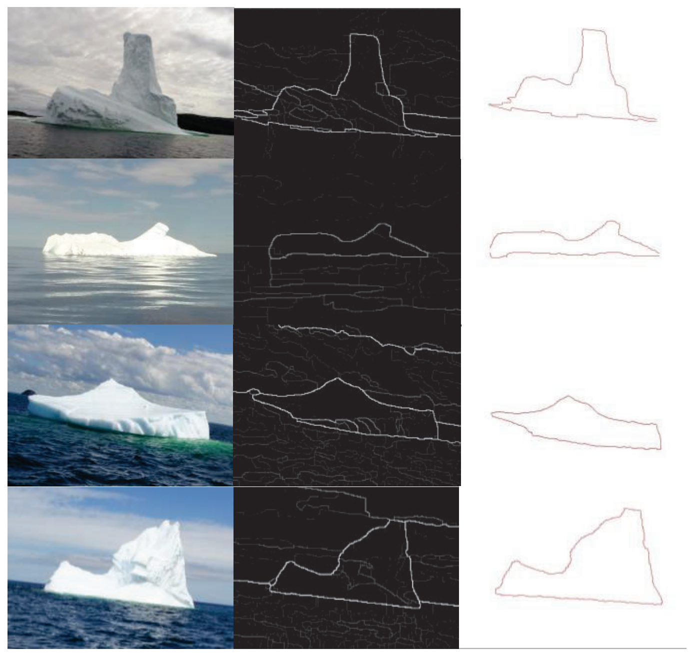

Fig 2. Occluding contour finding. Images in the left column are original images, images in the middle column are the result produced by hierarchical segmentation (Arbelaez, 2011), and images in the right column are the final contours of the surface images.

Roberts (Roberts, 1963), Sobel (Duda et al, 1973) and Prewitt (Prewitt, 1970) are proposed to perform edge detection by convoluting differential operators with grayscale images. In order to improve the performance, more recent approaches take color and texture information into account, and learning techniques are used for cue combination (Martin, Fowlkes, & Malik, 2004; Mairal, Leordeanu, Bach, Hebert, & Ponce, 2008). However, these methods are not suitable for natural images with large gradients, such as iceberg images. Ren (2008) found that combining global cues can benefit the task by reducing clutter and completing contours. Based on this previous work, we use a state-of-art algorithm for contour finding and image segmentation (Arbelaez, 2011; Maire, 2009). The algorithm couples multi-scale local brightness, color and texture cues to build a powerful globalization framework using spectral clustering. The result can be shown in a hierarchical segmentation tree in different intensities of boundary contours by using Oriented Watershed Transform (Dougherty, 1992; Najman & Schmitt, 1996) and Ultrametric Contour Map (Arbelaez, 2006) as generic machinery. For a given threshold, the output is a group of closed contours, which can be seen as either segmentation or closed boundaries. We then binarized the image of hierarchical segmentation to delete the unnecessary contours. We assumed that the whole iceberg was always inside an image otherwise the image was not be considered. We generated the single closed iceberg contour by extracting all regions that cannot be reached by filling in the background from the edge of the image. (Fig. 2)

Iceberg Information Generation

In addition to shape, iceberg mass, size and location are important factors. (C-CORE, 2005) After reconstructing the shape of the iceberg, the next step is to combine all significant data, including GPS location of camera, height of the iceberg, and distance between the camera and the iceberg, to generate the size and location information of the iceberg, which will be explained in detail in the following two sections.

ICEBERG DATA COLLECTION

Field trials were carried out in Holyrood Arm on May 16th, 2014; Conception Bay South on June 4th, 2014; Twillingate from July 28th to August 1st. All three locations are in Newfoundland and Labrador, Canada. During the expeditions, the underwater portion was also measured with a mechanical scanning sonar attached to an Autonomous Surface Craft (ASC) and a Slocum underwater glider (Zhou, Bachmayer, & deYoung, 2014). For the above-water portion of the iceberg, we collect data using a compatible collection procedure, which is presented in the following sections.

Image & Data Collection

Automated Data Collection

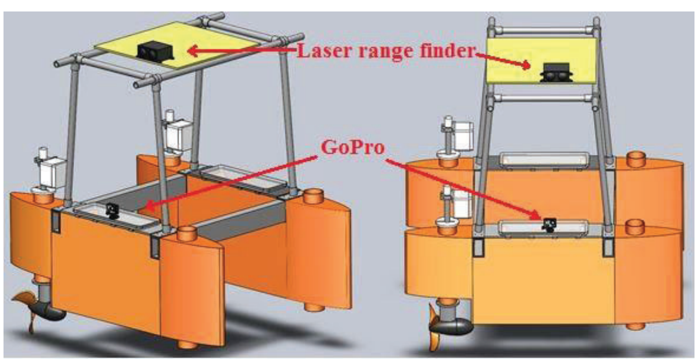

Fig. 3 The placement of GoPro and Laser range finder on ASC.

We made use of an ASC (Fig. 3) designed by Li and Bachmayer (2012) with multiple sensors to measure vehicle information, including GPS location, orientation, heading, and environmental information, such as temperature, wind speed, and humidity. On this platform, we attached a GoPro HERO 3+ Black edition camera to capture the 2-D images of the icebergs. To solve the shortcomings of the visual hull, a 1Hz sampling laser range finder (Lightware SF03/XLR) was also placed on the vehicle to measure the real time distance away from the iceberg. The camera and laser range finder were placed on the ASC as shown in Fig. 3. GPS synchronized UTC time (coordinated universal time) was used to record all data for later data integration. Since the laser range finder wasn't fully integrated into the ASC data collection system, a time-synchronized field computer was used for data collection.

Manual Data Collection

The manual data collection method was the first step to test the algorithm, which is the basis of automatic method. The manual method also serves as a backup for the automated data collection method which might present discrepancies during expeditions. Data collection via an arbitrary circle around an iceberg is sufficient for our data requirements. The choice of locations on this circle should be distributed around the iceberg, but those location points can also be arbitrary as we have recorded the GPS location of the points. The number of locations depends on the size and shape of the iceberg. If we only take a few locations, the resolution could be very low. However, having too many locations is also not desirable because the errors from the measurements will add up. Generally, we take 8~15 locations for a medium size iceberg, with a height between 18m~25m. For each location, a complete data point will consist of an image, its GPS location, and camera orientation for redundancy purposes manually or automatically measured. (Fig. 4)

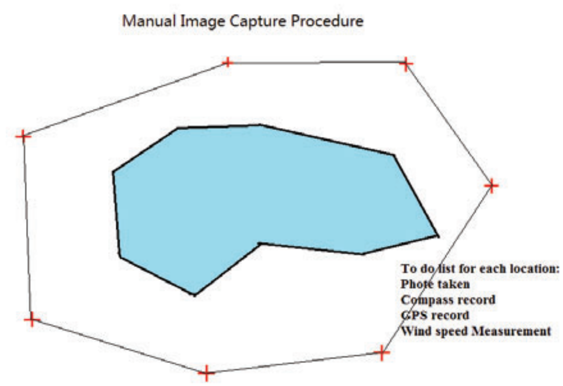

Fig. 4 Arbitrary waypoints for data collection, and the "to-do list" for each location.

Size Calibration

Using the infinite focus cameral mode and the known distance between the lens and object, we can use the pixel count in the image frame to determine the size of the iceberg. However, since icebergs are not flat, the lens-iceberg distance is not well defined.

Therefore, we need to figure out a new way to calibrate the size of icebergs. Regardless of shape, all icebergs have a peak. We assumed that the peak can be seen from all angle, and it does not change significantly with the shifting motion of the iceberg, which means the height remains almost unchanged. Compared with the base of the above water iceberg, the peak has almost no thickness so the distance is more uniquely defined. With an extra angle measured by sextant (Fig. 5) the height of the iceberg was easily computed, height accuracy was enhanced by measuring from different view-angles and using the average height. To this extent, the pixel of original image and the focal length was not critical, so that we used a fixed height pixel for all silhouette for the convenience to performing the volume intersection algorithm, while changing the whole silhouette proportionally. The resulting 3-D shape was calibrated with the real world size (or height).

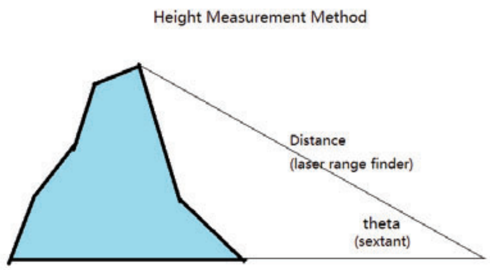

Fig. 5 Height measurement method. For size calibration, we need to measure the height of the iceberg using triangulation with range and elevation angle.

Iceberg GPS Location

The ASC can record its real time GPS position and orientation using its GPS and attitude heading reference system (AHRS). We also use laser range finder to measure the real time distance away from the iceberg. This is done on the assumption that the iceberg doesn't shift fast as the data collection process could be done in ten minutes. To combine all those information, we using equations:

$$I\_lat = V\_lat + D_x * 360 / (2*\pi*R) \quad (2)$$
$$I\_lon = V\_lon + D_y * 360 / (2*\pi*R*\cos(I\_lat)) \quad (3)$$

to calculate the GPS location of the iceberg.

In those equations, R denotes the radius of the earth when we assume the earth to be a sphere. V_lat, V_lon denote the real-time latitude and longitude of the vehicle. D_x and D_y are the east and north components of the distance measured by the laser range finder. I_lat and I_lon denote the latitude and longitude of points on the surface of that iceberg.

Fig. 6 shows the results of one iceberg collected on Jul 30th, 2014. Its shape is calculated from the GPS and heading of the vehicle, and distance between iceberg and vehicle. The laser range finder is only one dimensional but with comparable high sampling frequency (1Hz), so we can get the two dimensional top view shape of the iceberg when we point to the bottom of the iceberg. This shape can later be used to partially resolve the visual hull shortcoming of the 3-D shape estimation process discussed earlier.

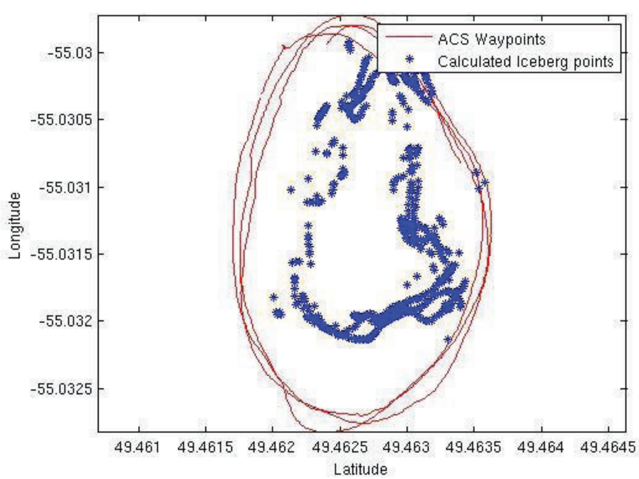

Fig. 6 GPS information. The red line is the route of ACS, while the blue stars are the points on the surface of iceberg.

The iceberg size derived from GPS laser range data can be used to get a first size estimation of an iceberg. By overlaying the computed iceberg outline and the ship position information we can provide a first reality check on the raw data.

The GPS information can be converted into earth coordinates (Fig. 11), making the combination of the result of above water and underwater portion (Zhou et al, 2014) of iceberg theoretically available, and thereby enabling determination of the whole shape of the iceberg.

DATA PROCESSING

After the data collection, the data needs to get processed in order to generate a 3-D model. Fig. 7 shows a flow chart of the data processing.

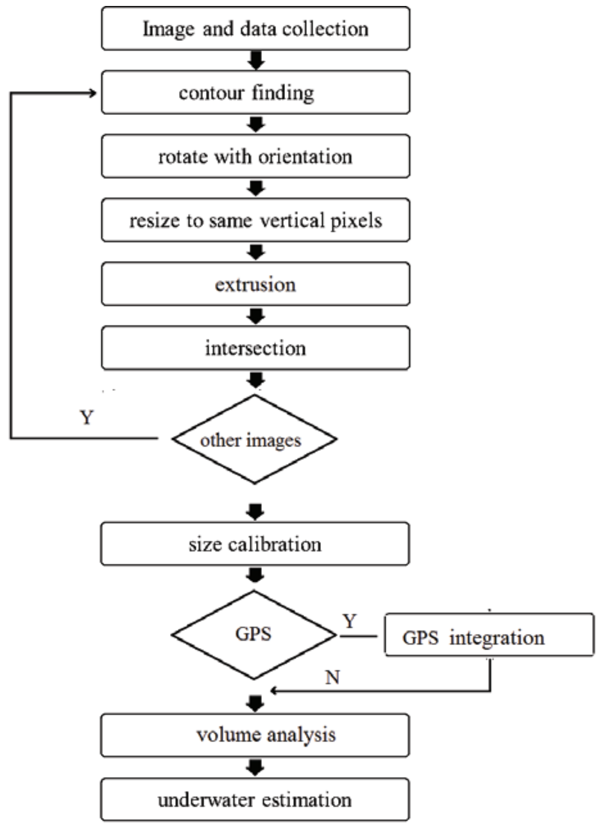

Fig. 7 Flow chart of 3-D Modelling of Above-water Iceberg

The first step is the image and data collection. After that, we need to extract the occluding contour using the algorithm mentioned before. As Fig. 2 shows, most of the time the water surface is not horizontal because of the motion of the vehicle and the GoPro camera. Therefore we need to rotate the images or contours on the basis of orientation (roll, pitch, and yaw) of the vehicle to make sure the water surface on the image to be horizontal.

Now we have contours of icebergs with their bottoms horizontal, but we still cannot perform the volume intersection algorithm. Because for each image, the iceberg's size (or pixels) on one image is different as the focal length and the distance towards the iceberg can change significantly. We make use of the characteristic that the absolute height of the iceberg does not change, and we can resize all the contours to have the same vertical pixels using Matlab or Octave, while the horizontal pixels are resized proportionally.

Then we can import the contours into OPENSCAD, a programing solid 3D modeler, to place them at the appropriate viewpoints. The viewpoints of different images can be computed by using the measured and recorded heading of the vehicle, with the known, fixed orientation of the camera on the craft. After the extrusion and intersection of silhouettes (Fig. 1), we can get a first 3D model of the iceberg. The resolution of the iceberg model can be enhanced if we choose appropriate number of intersections.

In order to provide quantitative measurements of the iceberg, we need to calibrate the size of the iceberg with the additional height information (Fig. 5).

If we have GPS information for the iceberg calculated using the GPS data and distance data collected by the laser range finder, we can transfer the top view shape of the iceberg from earth coordinates to length coordinates, and then verify if the 3-D model is correct.

Having the 3-D model of an iceberg, we can attain the volume of it using the disc integration method. The model is constructed from many polygons of different thickness. We can choose a small thickness, then we cut the 3-D shape into layers. For each layer, we already know the points inside the layer, so we can combine these points to form a polygon. As the thickness of layers approaches 0, the sum of the layers is approaching to the volume of the iceberg. With the results of the 3-D shape and the volume of the above water portion of the iceberg, we are able to estimate the underwater volume and an approximate keel depth of the iceberg derived from the empirical shape information.

RESULTS

We have collected data from 8 different icebergs with different dataset. The earlier ones are technically immature compared with the others and for some iceberg we only get part of data due to time limitation. The minimum data requirement for 3-D shape rendering is either manual or automatic data. Size calibration (height measurement) is a must if the volume are calculated. Laser information is supplement for better result by checking if there’s significant unseen concave on the sea surface.

Table. 1 Icebergs with different data sets

	Date	GPS	Manual	Automatic	Size Calibration	Laser distance
1	May 16th	N47°27’ W53°09’	√			
2	May 16th	N47°27’ W53°09’	√			
3	Jun 4th	N47°32’ W53°09’	√	√	√	
4	Jun 4th	N47°33’ W53°01’	√		√	
5	Jul 30th	N49°38’ W54°56’	√		√	√
6	Jul 30th	N49°28’ W55°02’	√	√	√	√
7	Jul 30th	N49°29’ W54°59’	√		√	
8	Jul 31st	N49°40’ W55°01’	√	√	√	

Since the data sets recorded from Iceberg No. 6 (Fig. 8) has the most dataset, we are going to use this iceberg and its dataset for the remainder of the paper.

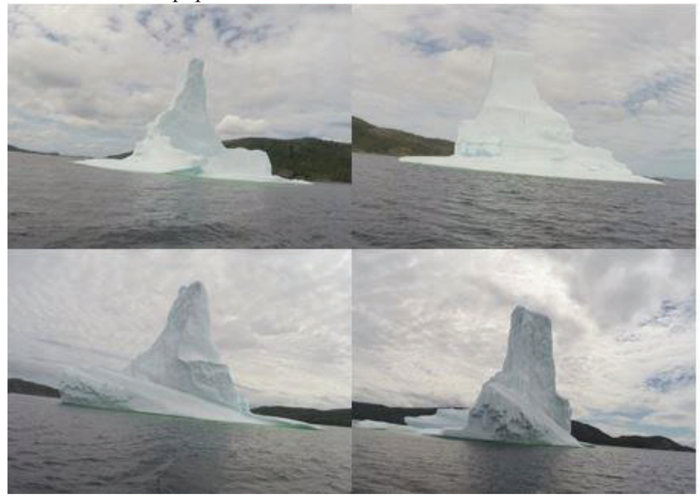

Fig. 8 Surface images from different angles towards No. 6 Iceberg.

After conducting all data processing steps as shown in Fig. 7, we get the 3-D model as following (Fig. 9)

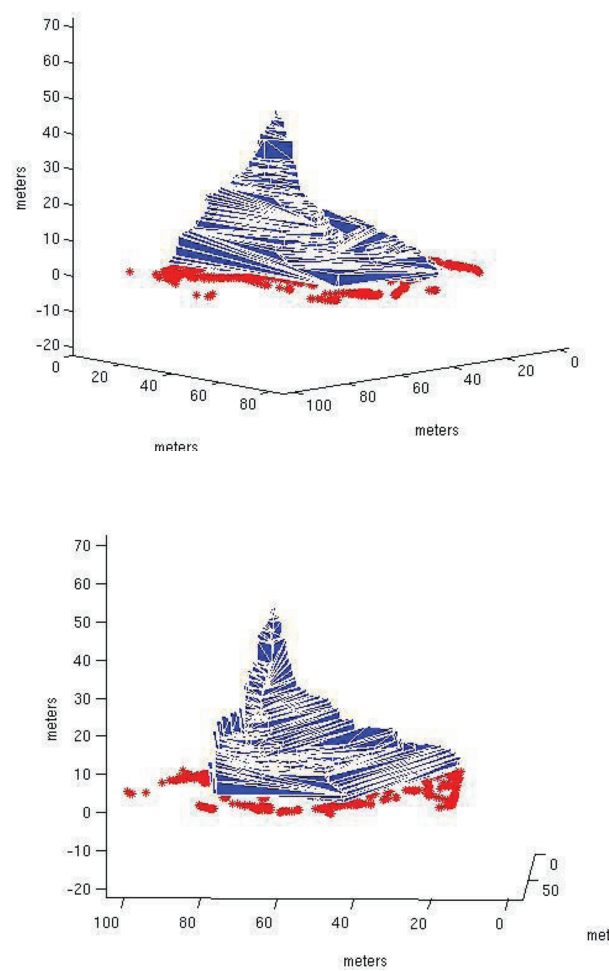

Fig. 9 The 3-D model No. 6 of iceberg showing the 3-D shape

information and the iceberg cross-section derived from the laser range measurements (red stars).

Fig. 10 shows the 3-D model of iceberg (units in meters). The red stars near the bottom is the GPS dots transferred to meters. From the top view of the iceberg, we can see that those two results are in the same length scale.

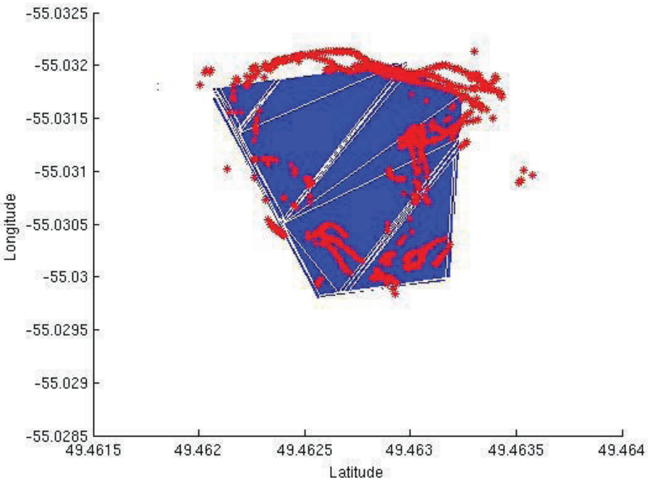

Fig. 10 Top view of the 3-D model of No. 6 iceberg.

Using the disc integration method to calculate the volume of this iceberg, the result is 81255.714229 m^3.

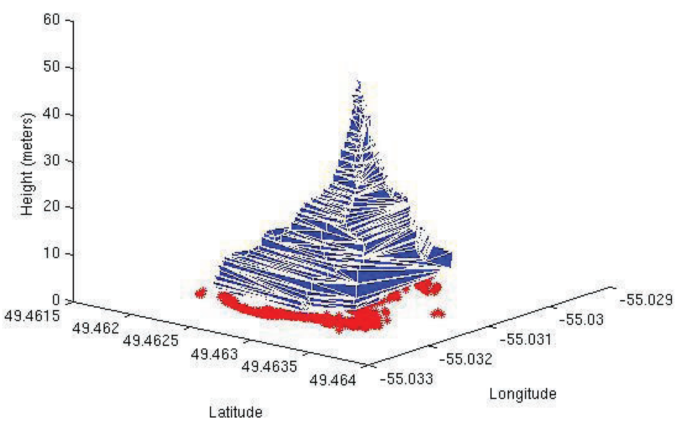

Fig. 11 The 3-D model of iceberg in earth coordinates.

CONCLUSIONS AND FUTUREWORKS

An economic, convenient, fast processing method, suitable for unmanned operations for building 3-D models of the above water portion of icebergs is established. The working principle has been established by using surface optical images taken from different directions around an iceberg, co-registered with location, orientation of the camera as well as the sampling platform.

In the future, we will integrate the camera and laser range finder into the vehicle data acquisition system in order to simplify co-registration and processing. More coding is needed to make sure the data processing to be completely automatic. Results from this process will be compared and combined with ongoing work on the shape and size estimation of the underside of iceberg (Zhou et al, 2014). In the iceberg quantitative measurements scenario, the uncertainty of the iceberg volume should be calculated by considering the external and internal visual hull. Besides, simulation on previous iceberg database provided by PERD-NRC can be used to test the resolution of the algorithm by using different number of intersections, and provide an optimal solution of the number of intersections.

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