

Working Towards Seafloor and Underwater Iceberg Mapping with a Slocum Glider

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Abstract—This paper reports on the integration and evaluation of a Tritech Micron mechanical scanning sonar into a Slocum underwater glider. The intent is to use the Slocum glider with the scanning sonar, to conduct seafloor and iceberg mapping tasks. The mechanical scanning sonar is installed in the extended, free flooded area of nose of the glider. After the successful integration, initial field trials were conducted in order to evaluate the performance in both seafloor surveying, and iceberg mapping modes. To achieve optimal performance, tuning of sonar parameters and vehicle trajectory control becomes significant. The performance of the vehicle and sonar are investigated in the field. Due to the transmission power absorbed by the extended nose cone, backscatter intensity is reduced, and receiver gain had to be increased, when compared to uncovered operations. With the experience gained from the initial field trial, areal surveys and autonomous iceberg mapping missions will be conducted in the future.

Keywords: Slocum glider, Seafloor surveying, Iceberg mapping, Sonar.

I. INTRODUCTION

Autonomous Underwater Vehicles (AUVs) are developed as tools to enhance our understanding of the ocean environment. As a fundamental strongpoint of AUVs usage, seafloor mapping is listed on many brochures of AUVs. On large size AUVs sidescan sonars are often integrated as a standard survey instrument. However, the endurance of the AUVs is mostly restricted to days, and often require a surface vessel to accompany the operations. On the other hand, there is a potential capability for large scale coarse ocean mapping or selective mapping with Autonomous Underwater Gliders (AUGs), such as the Slocum underwater glider, Spray glider, or Seaglider [1]. Compared to other AUVs, AUGs have longer endurance and lower operation cost. Considering the power restriction on AUGs, a forward looking altimeter (single beam sonar) is installed on a typical AUG for collision avoidance purpose. To improve the capability for mapping, a mechanically scanning sonar (Tritech International Ltd.) is selected. It consumes lower power than the sidescan sonar [2], and offers a broader coverage than the single beam sonar. Although it has less coverage than a sidescan sonar or multibeam sonar, a topography extraction algorithm can be applied to compensate the sparse data [3]. Because the sonar is able to scan any sector in 360° without mechanical modification, adaptive sampling is also applicable to a mechanical scanning sonar [4] a consideration for the energy budget.

Beyond seafloor surveying, iceberg mapping is also an interesting new operation for Slocum underwater gliders in

the North Atlantic Ocean. Icebergs originate in Greenland and drift southward following the Labrador current [5]. Off the Newfoundland coast, offshore platforms are threatened by icebergs. In order to execute appropriate ice management [5] the size, shape and overall geometry of an iceberg is required to be accurately assessed for determining the next steps. Also the drift trajectory of an iceberg is greatly influenced by its underwater geometry [6]. Therefore, an accurately measured iceberg can improve the iceberg drift prediction [7].

Previously a Slocum glider with an upward-looking single beam sonar was deployed in Western Greenland [8] to cross underneath an iceberg. Due to the modified upward-looking altimeter not being fully integrated into the glider control system, it attempted to surface underneath the iceberg. In order to identify potential issues with such high risk deployments, we constructed a simulation environment using MATLAB [9]. This allows for the simulation of iceberg mapping missions with a scanning sonar integrated into an AUV. In this paper, a mechanical scanning sonar is integrated into a Slocum glider. It provides a higher coverage and more flexibility than the single beam sonar. The performance of the sonar and vehicle are investigated by seafloor surveying and iceberg mapping field trials.

II. INTEGRATION OF TRITECH MICRON MECHANICAL SCANNING SONAR

Mechanical Integration

Figure 1 shows the mechanical scanning sonar mounted in the nose of Slocum glider. Three screws used to mount the altimeter are replaced with threaded rods. The scanning sonar plate is off-set by spacers and secured on the threaded rods. The nose extension cone is manufactured by a rapid-prototype machine in Acrylonitrile Butadiene Styrene (ABS) plastic. A pressure test was conducted to examine density fluctuations of the nose cone at 200m depth. Under high pressure air gaps trapped in the material might collapse or get filled with water. We found a weight increase of approximately 4% in our sample material.

Two Impulse IE55 Subminiature connectors are installed on the science payload section of the glider. The sonar cable is attached outside the hull of glider, and connected to the controller board inside with an Impulse connector on the rear port. To secure the cable, two aluminum brackets are installed at the pick points on the science payload. The front port is used

to download the sonar measurements stored on the controller board without opening the hull.

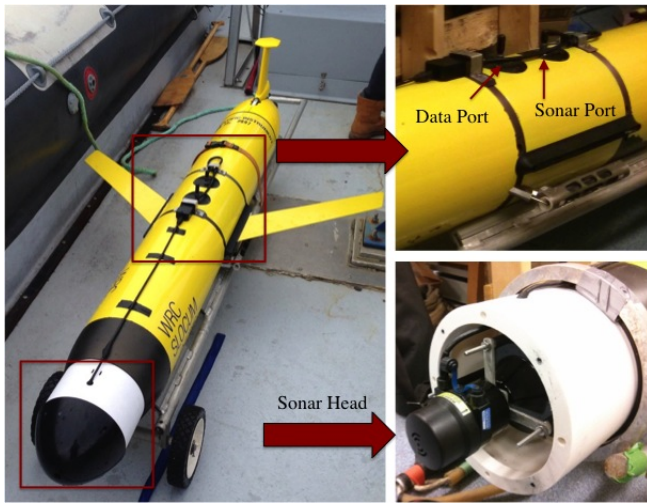


Fig. 1: Mechanical Configuration of the Slocum Glider with Scanning Sonar.

Electrical Integration

A schematic of the sonar controller board is shown in Figure 2. A Mbed micro-controller [10] is used to control the sonar with peripheral breakout boards. The Mbed controls the scanning sonar via RS485 communication with a UART to RS485 convertor. The micro-controller sends sampling commands to the sonar at a predefined frequency. The replied message from the sonar, including current beam angle and intensity-at-range measurements, are stored on a micro SD card on the sonar controller. The controller communicates with Slocum glider science bay with RS232 communication using a UART to RS232 convertor. The board and sonar is powered by the Slocum glider with an average power consumption of 4.5 Watts operating at 12 volts.

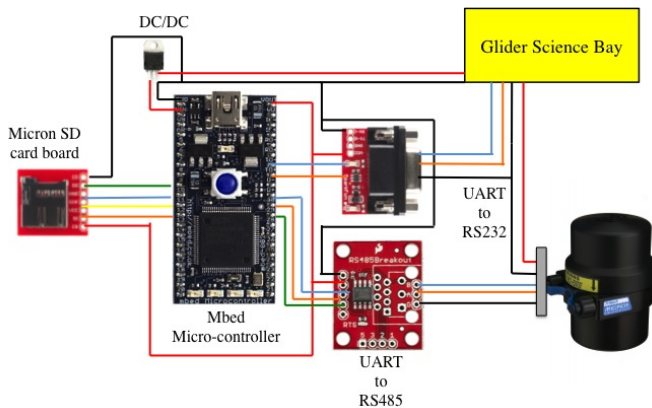


Fig. 2: Schematic of the Sonar Controller.

Software Integration

Two-way communication is available between the glider and sonar controller. The sonar controller acquires the sonar

parameters, such as sampling frequency, range and sector angle, from the glider defined by the mission file for the vehicle. During the mission, the controller processes the intensity-at-range information, and extracts ranges to objects. The current beam angle and extracted range are transmitted to the glider science computer and saved in a sonar log file.

The flow chart of the controller is shown in Figure 3. After the controller is powered on, it waits for the sonar configuration parameters (range, frequency and sector) from the glider. Then a log file will be created in the micro SD card tagged with sonar parameters. After initialization of the sonar, sampling starts during which UTC times obtained from the glider and corresponding sonar samples are written to the log file. Meanwhile, the current beam angle and extracted range are transmitted to the glider. A log file is created on the CF card of science computer which records the range and current beam angle received from the sonar controller registered with the glider UTC time.

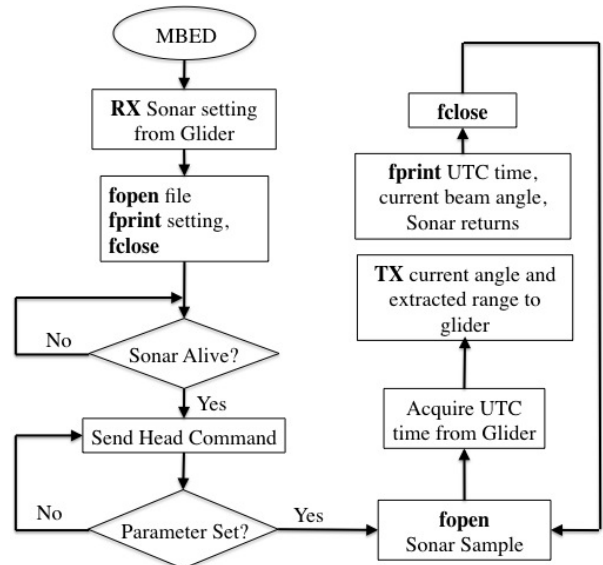


Fig. 3: Sonar Controller Program Flow Chart.

After the glider is recovered, information stored on the micro SD card is downloaded via cable to an external computer. The sonar measurement then is imported into MATLAB and post-processed. In the post-processing mode, an dynamic Otsu threshold [11] is applied to the scanning sonar scanline (intensity-at-range) data. The threshold uses the information of previous 100 samples to calculate the minimum intensity threshold for the current sample. Detailed information about Otsu threshold is available in [11]. After that, a normal distribution fit is applied through each scanline measurement with a moving window. The standard deviation and mean value is obtained for each move. The range is first restricted in the window which has the highest mean over standard deviation value. By doing this, high intensity spikes are removed. Then the location of highest intensity in the selected window is extracted as the detected range for the current sample. Finally, the detected ranges are converted into vehicle coordinates with current beam angle, and corrected into earth coordinate (longitude, latitude, and depth) using the glider's position and orientation information.

III. SEAFLOOR MAPPING TRIAL

On July 15 2014, a short seafloor mapping mission was conducted in Holyrood Marine Base. During the mission the Slocum glider travels through five defined waypoints, with roughly 200 meters between two sequential waypoints. The sonar is looking downward with a ± 60 degrees sector transverse to the surging direction. The vehicle depth, altimeter measured depth and scanning sonar measured depth are compared in Figure 4. There is a consistent trend between the scanning sonar and altimeter measured seafloor depth.

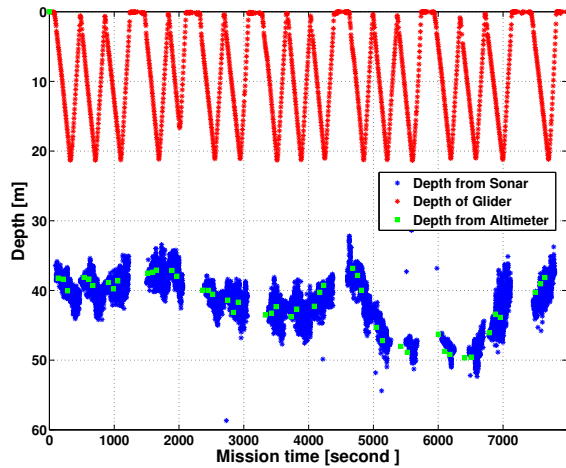


Fig. 4: Comparison of altimeter measured seafloor and sonar measured seafloor along the glider's path.

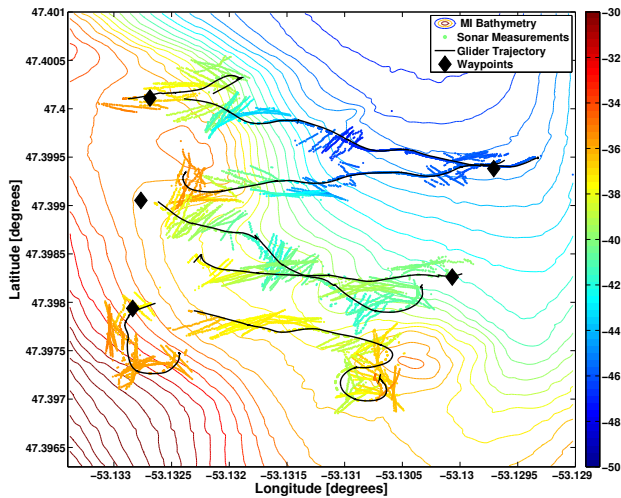


Fig. 5: Seafloor bathymetry (contour) provided by Marine Institute overlay with the scanning sonar measured seafloor depth (color lines) and glider trajectory (black lines). Colorbar displays the water depth of the measurements and bathymetry map.

Observed sonar samples are also compared with the Holyrood Bathymetry map provided by Marine Institute, Memorial University of Newfoundland. Sonar measured depth is firstly corrected with sound speed from 1500 m/s (assumed

in sonar) to 1465.7 m/s calculated from the measurement of Conductivity-Temperature-Depth (CTD) sensor. Then, the measurements are smoothed with a moving average filter, and corrected with the tide level when the mission was conducting. Bathymetry map overlay with the processed measurements from scanning sonar is shown in Figure 5. In the figure, the black lines display the glider trajectories during the mission and the colored scatter line shows the sonar measured depth registered with longitude and latitude; the waypoints assigned to the mission file are also displayed with black diamonds.

Furthermore, scanning sonar detected depth is compared with the depth from the bathymetry map at the same location in Figure 6. An average error of 4.16% is found, and a relative large error can be observed at the location where depth varies fast, due to the large beamwidth (35°) of the scanning sonar along the longitudinal direction of the glider.

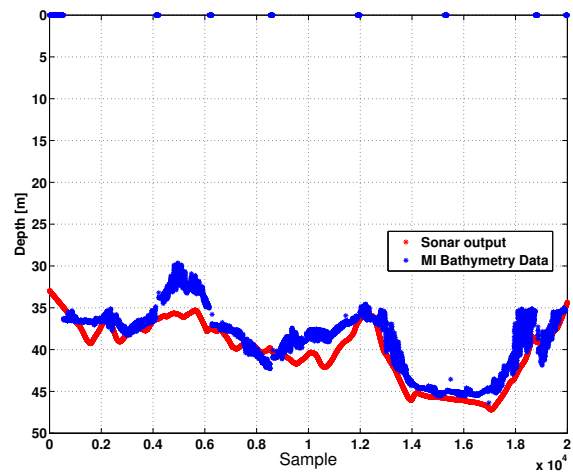


Fig. 6: Comparison of Bathymetry and Scanning Sonar Measurement at the Same Longitude Latitude location.

IV. ICEBERG MAPPING TRIAL



Fig. 7: Target Iceberg for Unmanned Surface Craft (USC) and Slocum Underwater Glider Survey (Photo by Armin Strobel).

An iceberg expedition was conducted from July 28 to August 1, 2014 at Twillingate, Newfoundland, Canada. During the expedition, the above water iceberg shape was captured photographically while the underwater portion was measured

with a mechanical scanning sonar attached to a Unmanned Surface Craft [12] and a Slocum underwater glider.

On July 31 2014, the glider was deployed near a small size iceberg (Figure 7) to travel around the iceberg in a clockwise direction. The sonar scans the starboard side of the glider vertically with a sector of ± 60 degrees. A total of four legs were conducted, and the glider was deployed from a wooden skiff. For each leg, the Local Mission Coordinate (LMC) based X and Y distance were calculated from the heading and estimated range provided by the operators in the skiff near the iceberg. Figure 8 shows a schematic of the measuring process. The skiff was kept a constant distance of 50 meters (R1) away from the iceberg corner. The heading of the mission was determined by pointing a magnetic compass to the left side of the iceberg over a clear path. To ensure the glider has a clear path in the next leg, the traveling distance for each leg was calculated by adding additional distance (30 meters in our case) to R2 shown in Figure 8.

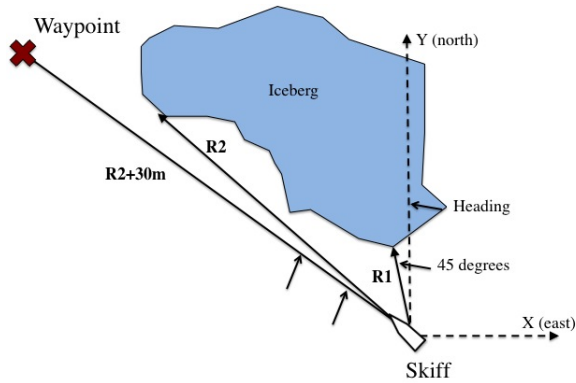


Fig. 8: Schematic of measuring the heading and distance on the skiff for glider missions. Heading is measured with a hand-hold compass, and distance is measured with hand-hold laser range finder.

During the first and second missions, the distance between the glider and the iceberg exceeded the sonar range. In the third mission glider was traveling towards a wrong direction, which might caused by a false reading on the compass. In the last leg, glider was traveling in the downwind leg, due to the iceberg drifting glider surfaced right beside the iceberg. After investigating the sonar measurements, iceberg echoes were found in the fourth missions.

In post-processing, we converted the sonar detected range into earth coordinates, and corrected the iceberg echoes with surface deflection. As a result, the glider trajectory of the fourth mission and iceberg surface scatters in earth coordinates are shown in Figure 9. The green star and black start indicate the start and end of the 4th mission, while the red start indicates the point where continuous iceberg returns are observed.

Investigating the echoes from the iceberg, the continuous intensity-at-range measurements starting from the red start in Figure 9 are shown in Figure 10. The range is converted to horizontal range away from the glider using current beam angles. Surface returns, direct iceberg returns, and iceberg returns with water-surface deflection measured by the scanning sonar are indicated. Figure 11 shows different sound propagating paths near the iceberg. Surface returns are detected as a thin curves

in Figure 10. Compare to the surface returns, echoes from the iceberg have a wider span. Due to the multipath caused by the air bubbles inside the iceberg [6], echoes from the iceberg start with a high intensity echo and followed by slowly decreasing echoes over the range. However, iceberg returns with surface deflection are also found. They occur when sonar is scanning above the horizontal plane. After the correction of the vehicle position and orientation, the location where the sound scattered is above the water surface. Thus, they are corrected by reversing the signs. No returns are received when sound arrived at the iceberg with a low grazing angle.

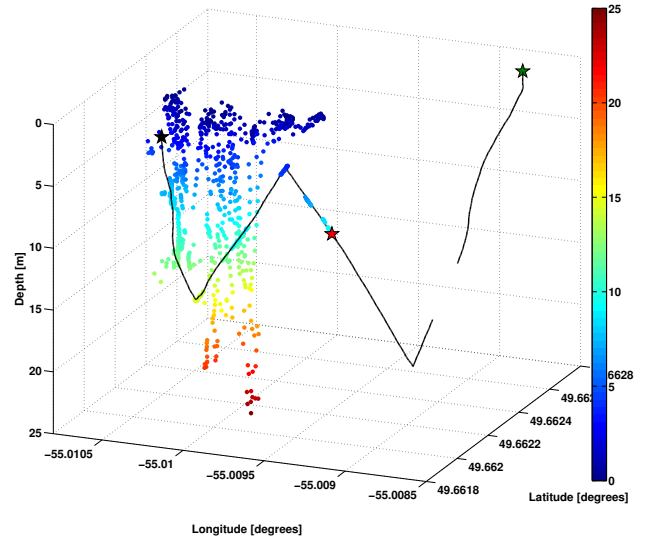


Fig. 9: Sonar measurements obtained from the fourth mission displays with glider trajectory with longitude, latitude and depth. Starting from the red start, continuous iceberg returns are observed in the intensity-at-range measurements. Colorbar displays the depth of the scatter.

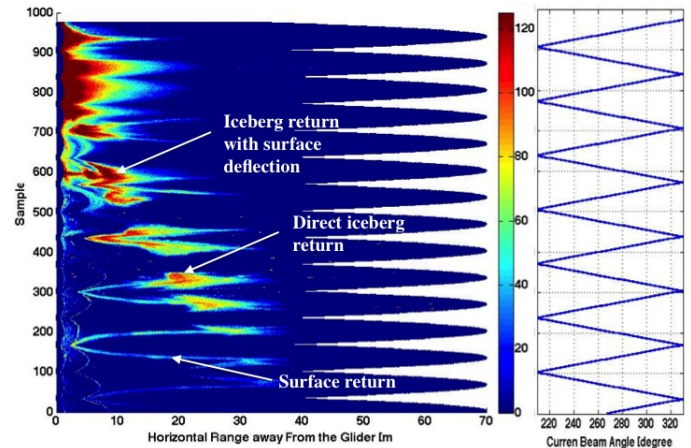


Fig. 10: Continuous intensity-at-range measurements are corrected into the horizontal plane with current beam angles starting at the red point in Figure 9. Surface returns, direct iceberg returns and iceberg returns with surface deflection are identified. Colorbar shows the scaled intensity level that 0 to 120 represents 0 to 20 dB.

Shown in Figure 10, the glider was approaching the iceberg, and the glider surfaced right beside the iceberg at the end

of the mission. Although insufficient samples for constructing a closed iceberg shape were collected in this trial, the trials confirmed the potential for the glider system to detect the iceberg surface.

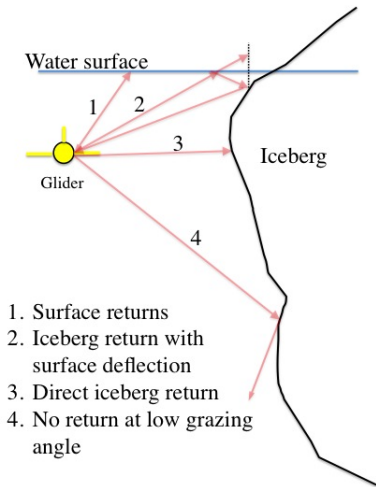


Fig. 11: A sketch of sound propagating paths in different situations. Four scenarios were observed from the collected measurements.

V. CONCLUSION AND FUTUREWORKS

A low-power mechanical scanning sonar is integrated into a Slocum underwater glider to improve its environmental mapping capability. The sonar is installed in the front of the glider with a nose extension. The sonar parameters (range, sampling frequency, and sector) are designed to be modified in the glider mission file without reprogramming the sonar controller. An additional data port is available on the science payload to download the sonar data without opening the vehicle. During the mission, full-size raw data is stored on a micro SD card on the sonar controller while the current angle and processed detected range are saved on the glider's science computer. Both seafloor surveying and iceberg mapping trials were conducted to verify the integration of the sonar.

In the future, a dynamic Otsu threshold [11] will be applied by the sonar controller and sonar range will be corrected into earth coordinate in the science computer of glider during the mission. Consequently, an autonomous waypoint update algorithm will be implemented for the Slocum glider based on the sonar measurements during the mission. Manual and autonomous waypoints mission will be conducted in Holyrood area. In the iceberg mapping scenario, the autonomous waypoint update algorithm will be modified according to the simulation environment discussed in [9]. Furthermore, the adaptive sampling algorithm will be developed to control the sonar scanning sector. In the summer of 2015, the iceberg mapping mission will be conducted with both manual and autonomous waypoint control on the Slocum glider.

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