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Inspection of Submerged Structures

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***Abstract* – Very common motivation for the inspection of underwater infrastructures is to measure and estimate their degradation status. Measurements required for this estimation could vary for different inspections but often include the size of the gap between the underwater structure and the seabed, between two structures or openings or cracks on the structure itself. Marine environment is very challenging for accurate spatial measurements because it is GPS-denied environment due to very high attenuation of the radio waves and because of very limited penetration of visual and laser signals, methods that are commonly used in terrestrial applications. Alternatives generally applied underwater are acoustic instruments for range measurement. The most appropriate instrument for multiple simultaneous range measurement is multi-beam profiling sonar. In this paper, we describe the use case related to the inspection and monitoring of the degradation status of the steel hull of the ship that sunk one hundred years ago. The profiling multi-beam sonar attached to an Autonomous Surface Vehicle was used to inspect the degradation status i.e. to measure the gap along the ship side. These sea trials have showed that reliable estimation of submerged gaps/cracks and openings could be obtained utilizing this methodology.**

Keywords – inspection; submerged structures; multi-beam sonar.

I. INTRODUCTION

Inspection of submerged structures is becoming the common task today as the number of oil & gas offshore installations, bridges and harbours is constantly increasing. Furthermore, the ageing of these infrastructure presents a growing safety challenge that requires frequent inspections. Common requirement during inspections of underwater structures is to measure the gap between the underwater structure and the seabed, between two structures or openings or cracks on the structure itself. Marine environment is very challenging for accurate spatial measurements because it is GPS-denied environment due to very high attenuation of the radio waves and very limited penetration of visual and laser signals. These methods that are commonly used in terrestrial applications, are not applicable underwater. Alternatives generally applied underwater are acoustic instruments for range measurement. Comparing to their terrestrial counterparts, acoustic instrument use lower frequencies and therefore they are characterized with lower resolution and higher uncertainties. The most appropriate instrument for multiple simultaneous range measurement is multi-beam profiling sonar.

An overview of some of the techniques for sonar-based underwater mapping is presented in [1]. The work aims on improving map accuracy through improved segmentation performance. The work elaborated in [2] compares the imaging capabilities of the different sonar systems for underwater inspection tasks. The paper presents the specific advantages and disadvantages of the short-range acoustic systems for different visualization tasks.

In order to achieve high-quality results, the multibeam sonar needs to move around the site in such a way as to provide the best possible viewpoint for the measurement. Most commonly a sonar is attached to the boat, but recently both in research and commercial studies, an unmanned vehicle/robot is used. The paper [3] elaborates the requirements and techniques exploited in on-water bridge inspection, design and control of Unmanned Surface Vehicles for inspection and acoustic remote sensing techniques for imaging underwater bridge structures and bottom features. The study [4] describes the robot that needs to adapt online its trajectory for inspection of underwater structures. Set of planning algorithms generate trajectories under motion constraints, which can be followed without deviations.

In this paper, we will describe the inspection study that is not the most common one, but still fully relevant. It is related to the inspection and monitoring of the degradation status of the steel hull of the ship that sunk one hundred years ago. The shipwreck lays upside down on the seabed, inclined on its superstructure. The south side of the hull is slightly lifted from the seabed creating the gap. The degradation status is evaluated by the extent of that gap. Degradation of the steel hull would eventually result in closing that gap until the hull completely collapses under its own weight. This study was performed as part of the work with much broader scope of mapping the shipwreck and its surrounding using different unmanned vehicles, tools and techniques [5].

A. Equipment

The equipment used for this inspection was Autonomous surface vehicle (ASV) and Norbit WBMS 400/700KHz multibeam sonar as a remote sensing payload.

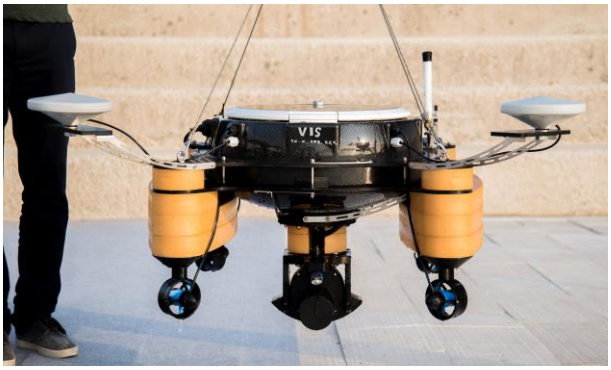

Fig. 1 System used for inspection. It consists of Acoustic Multibeam Sonar (in the middle below the vehicle) and Autonomous Surface Vehicle with its navigation, communication and propulsion payload.

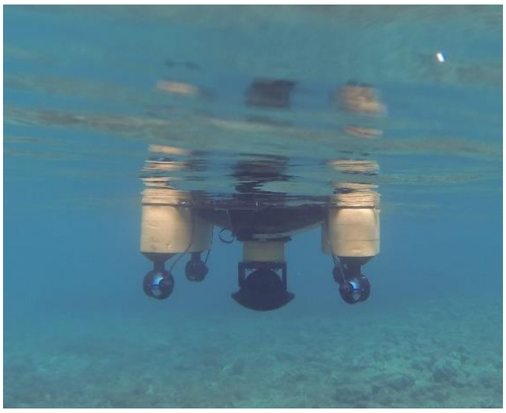

Fig. 2 The system in the water with sonar attached

The ASV has catamaran hull geometry to achieve improved sea-keeping and hydrodynamic performances. Vehicle was developed at the Laboratory for Underwater Systems and Technologies (LABUST), Faculty of Electrical Engineering and Computing, University of Zagreb (UNIZG-FER), Croatia. The ASV is fully actuated with four thrusters that make up the X configuration. This configuration allows it to move horizontally under any orientation [6]. The ASV has a diagonal length of 1m and weighs about 30 kg with payload configuration used in these trails. The maximum speed in ideal conditions is 1 m/s. Navigation payload consists of Inertial navigation System (INS) and high-precision Trimble GPS (two antennas shown left and right in Fig. 1). For communication with the control station, WiFi was used (WiFi antenna in the background on the right in Fig. 1). Vehicle control was achieved using Robot Operating System[1] (ROS), mission planning and analysis using open-source software Neptus[2], while Norbit WBMS GUI[3] was used to monitor the quality of the acquired acoustic data. The ASV was previously used by LABUST for variety of different applications [7-8].

The Norbit iWBMSe multibeam sonar was the main remote sensing payload for the ASV data collection. The sonar was mounted below the ASV as shown in Fig. 1 and Fig. 2., taking care of precise alignment between the them. Sonar is integrated with the GNSS-assisted inertial navigation system, sound speed measurement, roll stabilization and Ethernet interface. The sonar has a swath of up to 210 degrees, range 0.2-275m 10mm range resolution, 0.9x1.9degrees longitudinal resolution, 256-512 beams, and 200kHz-700kHz frequency.

II. DESCRIPTION OF THE METHOD

As mentioned earlier, to inspect the degradation status of the shipwreck, the size of the gap between the ship hull and the seabed needs to be measured. Graphical representation of the methodology is given in Fig. 3. Red line represents the area ensonified by the sonar. The image is conceptual, it does not respect the real proportions e.g. depth vs. hull size, nor sonar beam width and tilt angles. To achieve the best possible view of the gap the ASV sailed parallel to the side of the wreck with the multibeam sonar swath of 60° tilted 15° towards the wreck.

To accurately calculate the depth from sonar range measurements, first the sonar position and swath launch angle needs to be estimated. For that we need to know position of the ASV i.e. sonar as they a rigidly connected, alignment angles between the ASV and sonar, in case that they are not perfectly aligned, and sonar attitude represented by yaw, pitch and roll angles. Merging information of sonar position, the swath launch angle and beam range and angle yield geo-referenced depth measurement for every single beam. It is well-known methodology and therefore we will not provide more details here. More details could be found by interested

[1] https://www.ros.org/
[2] https://lsts.fe.up.pt/toolchain/neptus
[3] https://norbit.com/subsea/

readers in [9-10].

ASV position and yaw are provided by the GNSS system with two antennas set 1 m apart, while pitch and roll are provided by inertial navigation system integrated into the sonar.

Sonar ping rate for the expected depth of 70 m was set to 3-4 Hz while ASV velocity was set to 0.6-0.7 m/s. This setup ensured along-track resolution of 20-25 cm. Similar resolution was achieved across-track.

Total uncertainty of the gap measurement is the result of superimposed uncertainties of the ASV navigation i.e. estimation of the ASV position, and uncertainties related to sonar attitude and range measurements.

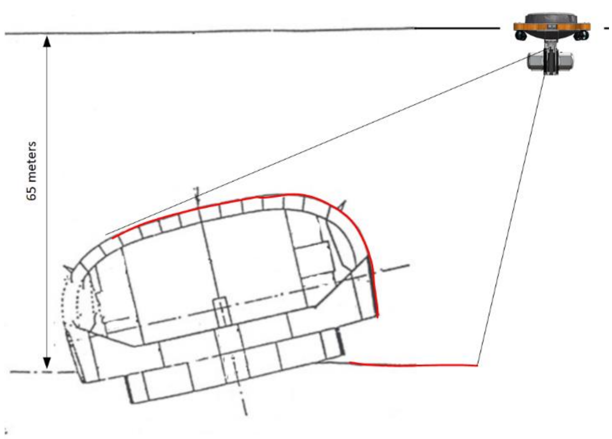

Fig. 3 Methodology applied for inspection of the Submerged Structure

III. RESULTS AND DISCUSSIONS

As it was described in the methodology section, the inspection area is scanned with the multibeam sonar while ASV was moving along the shipwreck side on the sea surface. Obtained result is a set of lateral profiles of the shipwreck. Multibeam systems use beamforming (512 beams) and beam travel time to extract directional information and range information from the returning soundwaves. It generates a swath of depth readings from a single ping. Each and every of these swaths is georeferenced based on ASV position and sonar attitude at the time of ping and represents a single lateral profile of the shipwreck. Fusing all lateral profiles in space, the point cloud of the one side of the shipwreck can be reconstructed allowing us to measure the gap.

Fig. 4 presents one lateral profile of the shipwreck where the gap between the seabed and hull exist. Seabed is relatively flat on the depth of approximately 65 m while hull is clearly lifted up. The point cloud of this lateral profile allows us to measure the gap pretty accurately. In this particular case, we estimated the gap width to be 4 m.

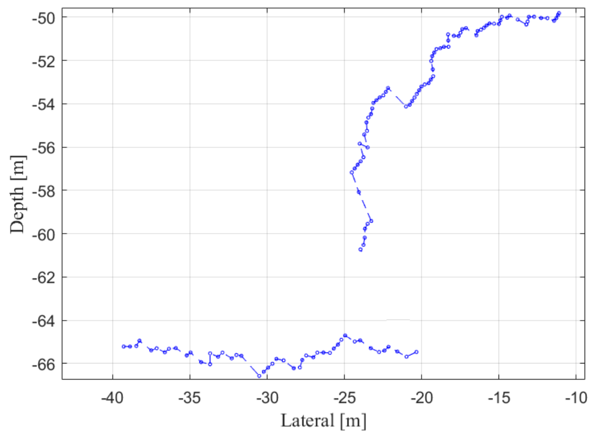

Fig. 4 One multibeam profile over the part of the wreck where the gap between the hull and seabed exist

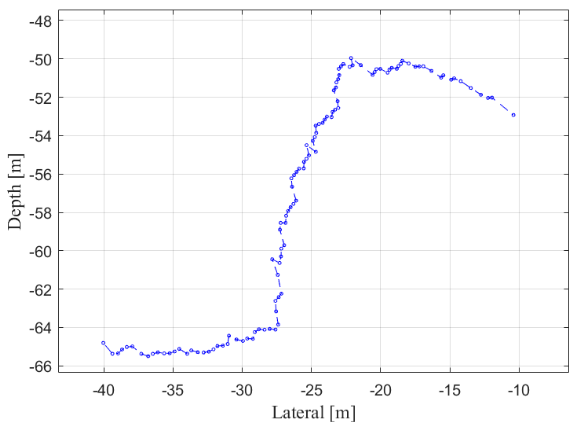

Fig. 5 One multibeam profile over the part of the wreck where gap is closed

At contrary, *Fig. 5* presents the lateral profile where the gap does not exist. Analysing the point cloud, we can see that measurements form the continuous line i.e. there is no interruption at the transition between the seabed and the hull, meaning that there is no gap.

Fusion of all profiles gives us complete picture of the inspection site. The result is shown in Fig. 6 and presents the side view of the complete shipwreck side. Here we can see that gap exist all the way from the stern end of the ship (5 m in local reference frame) to the position of 105 m in a local reference frame i.e. the gap is approximately 100 m long. What we can also notice is that gap has different width along the wreck side. Analysing and measuring the gap profile by profile we concluded that gap varies is size from as less as 2 m to up to 4.5 m. Average gap width is close to 4 m i.e. it is 3.8 m. Fig. 7 shows zoom-in on the one part of the inspection area where gap is clearly distinguishable and easy to measure.

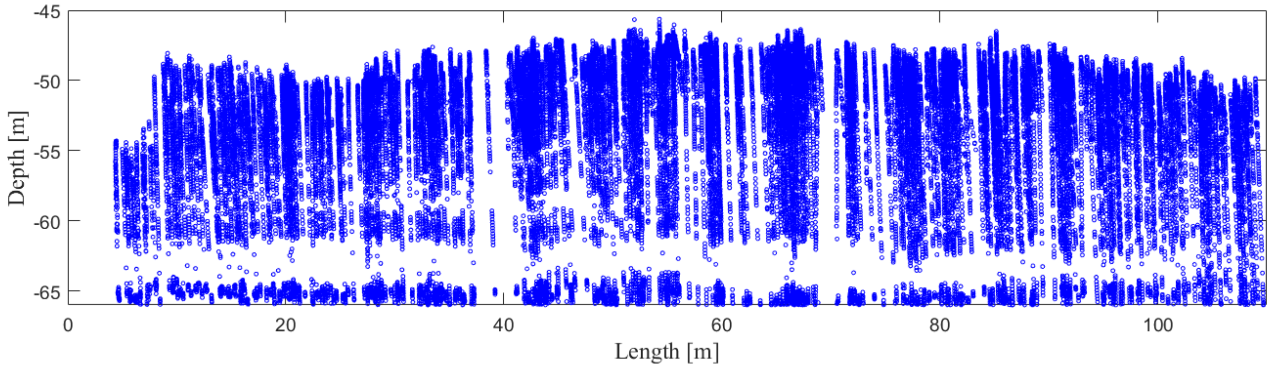

Fig. 6 The result of the multibeam sonar scanning of the inspection area. Image represents 2D side view of the shipwreck. Y-axis represent the depth while x-axis represent the distance in meters from the local origin.

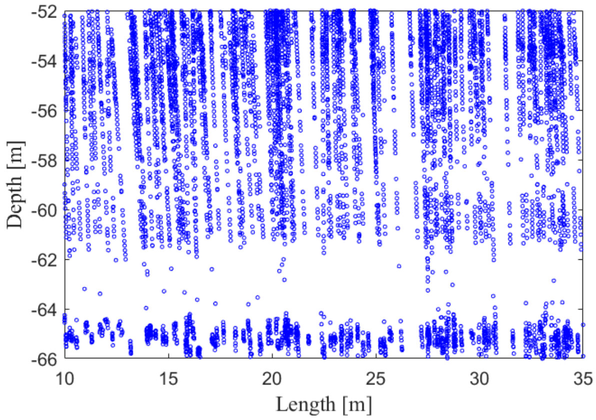

Fig. 7 Selected part of the shipwreck where gap exist. Outliers in the gap area are clearly noticeable.

There are two interesting points to mention here. First, it is evident that lateral profiles are not distributed evenly along the shipwreck. It can be easily explained by the fact that ASV caring the sonar was rolling slightly on the waves which in result affected the directional stability of the sonar and acoustic beams. However, it did not compromise the reliability of measurements because the lateral profiles are geo-referenced based on both ASV GNSS position and sonar attitude measurements, but it still caused an uneven distribution of lateral profiles. The second is the fact that some points/measurements are visible on the area where the gap exists, both on Fig. 6 and Fig. 7. Our first thought was that these are measurement outliers, but the fact that there were substantial number of them forced us to perform deeper analysis taking into account all data collected in the scope of the survey. What has been noticed from the video footage of the wreck was that shipwreck was completely covered by ghost fishing nets that were stuck there over the years (Fig. 8). Furthermore, nets mesh was often clogged by biofouling which could easily reflect the acoustic signal and cause the sonar echo. We believe that this is the reason for the significant number of outliers in the gap area where we do not expect them to be.

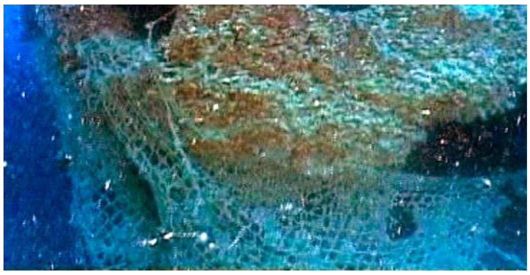

Fig. 8 Image captured from the video footage shows some of the ghost fishing nets covering the shipwreck

IV. CONCLUSIONS AND OUTLOOK

This paper investigates the use of a multibeam sonar carried by ASV for inspections of submerged structures. Very often inspection tasks include the measurement of the gap between the underwater structure and the seabed, between two structures or openings or cracks on the structure itself. In this paper, we described the study related to the inspection of the degradation status of the shipwreck by measuring the gap between the seabed and the ship hull. The inspection system consisted of the profiling multi-beam sonar attached to an Autonomous Surface Vehicle. During the inspection, the gap of 2-4 m wide was identified on the shipwreck side and geo-referenced. Gap was approximately 100 m long. In the generated point cloud, a number of outliers were present in the zone where gap was detected. Our conclusion is that these outliers are related to the backscatter coming from the ghost fishing nets that cover most of the shipwreck including gaps, often in multiple layers. The sea trials elaborated in this paper have showed that reliable estimation of the gaps/cracks and openings on the submerged structures could be obtained utilizing proposed system and methodology. Through this study we also identified the referent degradation status of the shipwreck which will be used for the future monitoring.

V. ACKNOWLEDGMENTS

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