Navigation and collision avoidance of underwater vehicles using sonar data

Ørjan Grefstad
Dept of Marine Technology
NTNU
Trondheim, Norway
orjangr@stud.ntnu.no

Ingrid Schjølberg
Dept of Marine Technology
NTNU
Trondheim, Norway
Ingrid.Schjolberg@ntnu.no

***Abstract*— Collision avoidance is one of the main challenges in the field of autonomous underwater vehicles (AUV). In this paper a method for detecting obstacles, using a single-beam mechanically scanning sonar, including planning of an optimal path around the obstacles is proposed. The obstacle detection is archived with an inverse-sonar model updating a vehicle-fixed occupancy grid. A new and obstacle-free path is planned using Voronoi diagrams and Dijkstra's algorithm. The path is smoothed using Fermat's spiral and a LOS-guidance system with a time-varying lookahead-distance as guidance. The method is implemented and a full-scale test is performed from IKM's onshore control room on a remotely operated vehicle (ROV) operating at Statoil's Snorre B oil field. The technology is applicable to ROVs and AUVs in underwater operations.**

Keywords—obstacle detection, collision avoidance, path planning, single-beam sonar

I. INTRODUCTION

Underwater vehicles and specifically remotely operated vehicles (ROVs) are commonly used for Inspection, Maintenance and Repair (IMR) missions in the oil and gas industry. This is a cost-driven industry and advances in automation is key-factor to reduce the mission expenses. One of the main difficulties during automated missions is the risk of collision. The collision avoidance challenge is often solved using multi-beam sonars, in a Simultaneous Localization And Mapping approach [1] or with the image recognition based techniques [2]. By using a single-beam sonar the costs can be significantly reduced. The object detection challenge is thougher with single-beam sonars , but can be solved with occupancy grids [3] or with a potential field method [4].

In this paper, occupancy grids are populated using the dynamic inverse-sonar model developed in [5]. The detected obstacles are then used as input to an online re-planning algorithm. This algorithm is motived by the work presented in [6]

II. SYSTEM DESCRIPTION

The system developed in this paper is tested on IKM's Merlin UCV, which is a work-class ROV permanently situated at Statoil's Snorre B oil field. The ROV is shown in Fig. 1. However, the method is applicable also to autonomous underwater vehicles (AUVs). The ROV has a Doppler-velocity log aided INS system, which together with a hydro-acoustic positioning system, situated at the rig provides accurate attitude and position information. This is a useful tool in the verification of the developed system.

The ROV is equipped with a Tritech Super SeaKing sonar. The mounting position of the sonar is highlighted in Fig. 1**Feil! Fant ikke referansekilden.**. The sonar is a single beam, mechanically scanning sonar, which utilizes CHIRP technology with frequencies centred at either 325 kHz or 675 kHz.

The ROV is operated from IKM's onshore control-room at Bryne, Norway, which makes it accessible for testing of new algorithms. The communication with the ROV's control system and the sonar is performed with UDP-messages following a binary protocol. The position updates are received as NMEA-messages.

METHODS AND IMPLEMENTATION

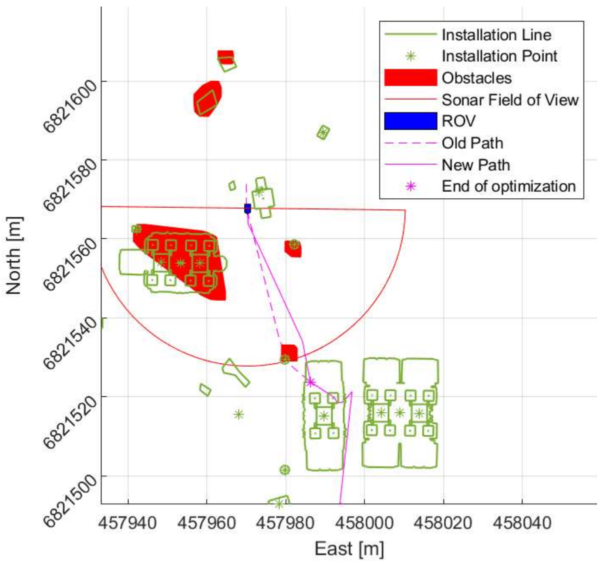

Fig. 2: Recalculation of the path during collision

The collision avoidance system is divided into three modules. First, the obstacles are detected in the object detection module. The detected obstacles are then passed on to the path planning module, which checks for potential collision threats, and calculates a new path if needed. The last module is the guidance system.

III. RESULTS

The system is first tested for object detection capabilities, then the complete system is tested with pre-planned paths, going straight through obstacles.

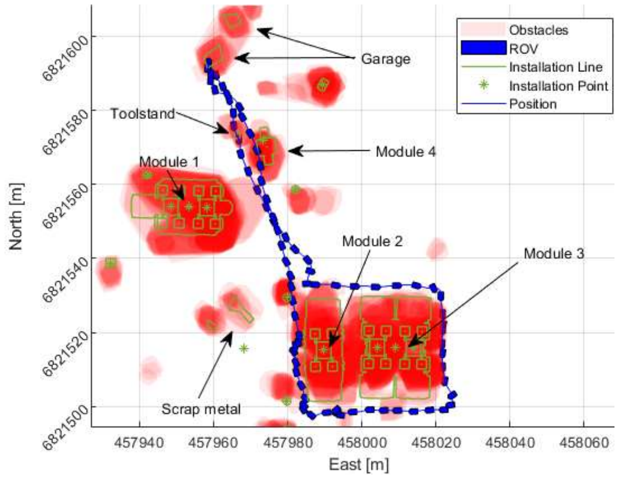

Fig. 3: Obstacle detection test. Some obstacles on the map are labeled

A. *Obstacle detection*

In the first test the ROV was flown by a pilot, from the garage, around a subsea-module and back again. The results from this test can be observed in Fig. 3. A snapshot of the detected obstacles is taken every 10 seconds and then plotted in the same figure. The altitude of the ROV is controlled by the pilot and thus it appears to be flying straight through some obstacles, such as the toolstand and Module 4. In these cases, the ROV was flying above them. The ROV is flying at a mean altitude of approximately 2 meters until it reaches Module 2, then the mean altitude is increased to 3.5 meters for the remainder of the flight. It can be observed that all obstacles are clearly detected. It should be noted that there is some drift in the position, which can be observed by looking at the tool stand, which has changed location between the beginning and the end. The detected obstacles appear larger than the obstacles on the map, and this is due to a safety-margin of two meters. It should also be noted that the algorithm has some problems accurately detecting the south-side of Module 3. This is likely due to the high altitude and proximity to the module, which causes the sonar to miss it completely.

B. *Collision Avoidance*

Several tests on collision avoidance are performed. All of the tests start close to the garage, with a preplanned path. The ROV was never able to reach the destination point due to constraints with the tether and ongoing operations.

Results from the first collision avoidance test can be observed in Fig. 2. It should be noted that most of the obstacles in the sonar's field of view are detected. The only undetected obstacle is Module 4 (see Fig. 3), which is due to proximity and altitude. The system is calculating a short deviation from the planned route, and is able to avoid the obstacle before the new path rejoins the old one. Right after the point where the optimization stops, between Module 2 and 3, there is a sharp bend in the path. This is the result of an earlier path recalculation. Since it is outside the optimized region, it is not smoothed away before it is closer to the optimized region. Fig. 5 shows a later time in the same test. The planned path on the east-side of Module 2 and 3 is longer than the one on the west-side, and thus the shorter one is selected. There is also an opening between Module 2 and 3, but due to the width of the ROV, this path is not feasible. It should be noted that the small obstacle south-east of Module 4 has disappeared from the grid, as the ROV flew at a high altitude close to it, and therefore several scans showed no obstacles.

The second test is made a few days later, with a different configuration of the sonar. The sonar configuration is decided by the pilot, and has implications for the effectiveness of the algorithm. When looking at **Feil! Fant ikke referansekilden.**Fig. 6 and Fig. 4 it can be observed that the obstacles appear smaller. This is due to the change in the sonar configuration causing less distinguishable return echoes. The system still manages to calculate a route around the obstacles.

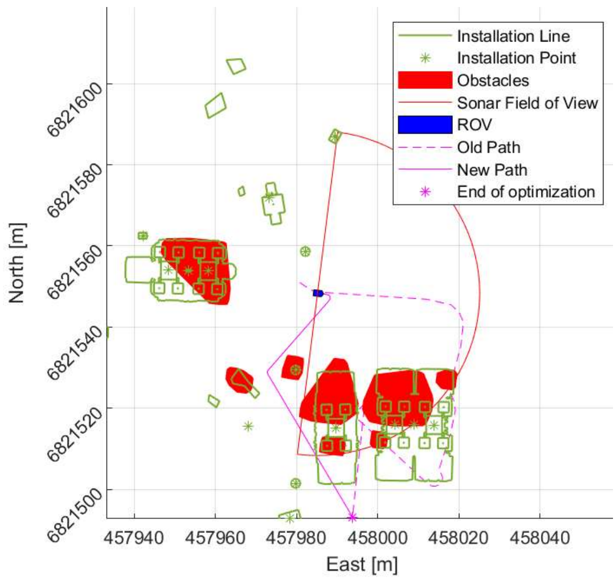

Fig. 5: Recalculation of the path during collision avoidance test 1.

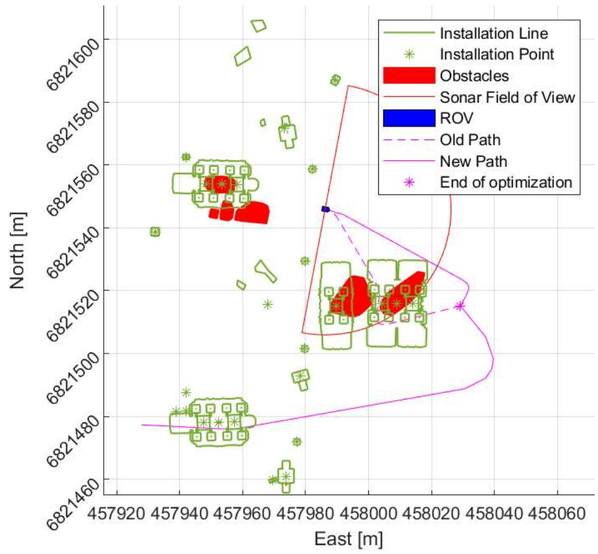

Fig. 4: Recalculation of the path during collision avoidance test 2

IV. DISCUSSION AND CONCLUSIONS

This paper has presented an effective method for detecting obstacles using a single-beam sonar, as well as an effective way of calculating a new obstacle-free path. A vehicle-fixed local occupancy grid has several advantages over a global

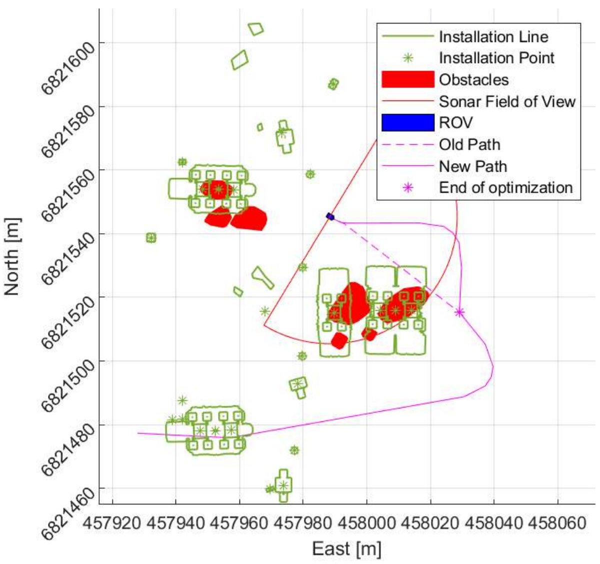

Fig. 6: Recalculation of the path during collision avoidance test 2

map. The complexity is reduced, and thus calculation time is significantly less. The major advantage is that the grid can be completely decoupled from global positions. The changes in position can then come from only a doppler-velocity log and a compass.

The full-scale test showed that the system is capable of detecting the obstacles in its path in an effective manner. A new and obstacle-free path is calculated and executed. The full-scale test showed that a mechanically-scanning single-beam sonar is adequate for detecting and avoiding obstacles.

The dependence on the sonar configuration is a problem that should be addressed, either through making the detection algorithm independent of the sonar configuration, or by making an algorithm that can automatically tune the sonar.

This system only considers paths in the two-dimensional space, but Voronoi diagrams can easily be extended to work in a 3D-space, but this will most likely not be possible without the use of extra sensors, such as a camera, an extra sonar or a 3D-sonar to extract information about the height of obstacles. Adding data from a camera will also improve the detection capabilities at a close range. The methods are applicable to any underwater vehicle equipped with a single beam sonar.

REFERENCES

[1] A. Palomer, P. Ridao, and D. Ribas, “Multibeam 3D underwater SLAM with probabilistic registration,” *Sensors (Switzerland)*, vol. 16, no. 4, 2016.

[2] B. Braginsky and H. Guterman, “Obstacle Avoidance Approaches for Autonomous Underwater Vehicle: Simulation and Experimental Results,” *IEEE J. Ocean. Eng.*, vol. 41, no. 4, pp. 882–892, 2016.

[3] V. Ganesan, M. Chitre, and E. Brekke, “Robust underwater obstacle detection and collision avoidance,” *Auton. Robots*, vol. 40, no. 7, pp. 1165–1185, 2016.

[4] F. J. Solari, A. F. Rozenfeld, V. A. Sebastian, and G. G. Acosta, “Artificial potential fields for the obstacles avoidance system of an AUV using a mechanical scanning sonar,” in *3rd IEEE/OES South American International Symposium on Oceanic Engineering, SAISOE 2016*, 2017.

[5] M. Zhou, R. Bachmayer, and B. Deyoung, “Mapping for control in an underwater environment using a dynamic inverse-sonar model,” in *2016 OCEANS MTS/IEEE Monterey, OCE 2016*, 2016, pp. 1–8.

[6] A. M. Lekkas, *Guidance and Path-Planning Systems for Autonomous Vehicles*, no. April. 2014.

[7] S. Thrun, “Learning Occupancy Grid Maps with Forward Sensor Models,” *Auton. Robots*, vol. 15, no. 2, pp. 111–127, 2003.

[8] M. Candeloro, A. M. Lekkas, A. J. Sørensen, and T. I. Fossen, “Continuous Curvature Path Planning using Voronoi diagrams and Fermat’s spirals,” *IFAC Proc. Vol.*, vol. 46, no. 33, pp. 132–137, 2013.

[9] T. I. Fossen, *Handbook of Marine Craft Hydrodynamics and Motion Control*. 2011.