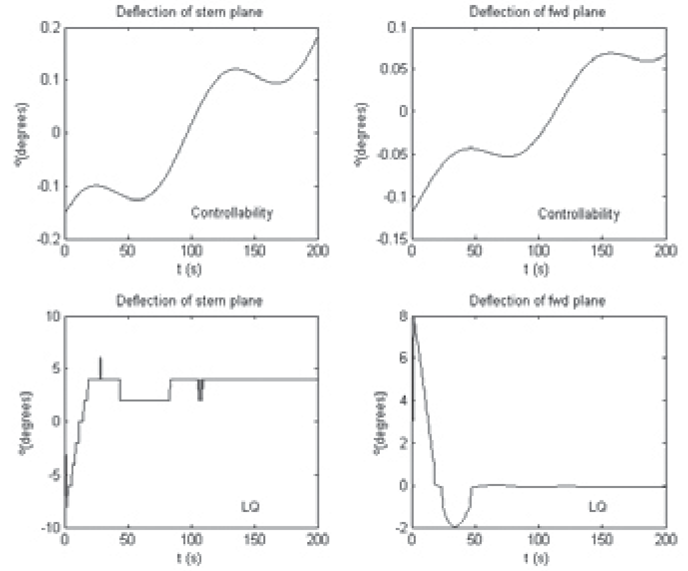

Figure 2: Controls.

3. Conclusions

In addition to the classical LQ control strategy, a new approach based on controllability theory has been implemented for the automatic simulation of a depth change manoeuverability for an SSK submarine. The main differences between both methodologies follow:

(1) The controls obtained from the LQ controller appear in a feedback form. So, from a practical point of view it is necessary to complete the control system with a suitable Kalman filter to correct the data of the state provided by the sensors of the submarine. For the contrary, the controls obtained from the controllability theory do not require the use of those.

(2) No constraints on the controls are imposed in the controllability strategy. This may lead in some cases, for instance for short times, to some unrealistic results with sharp changes of controls and states. With the LQ controller, these sharp changes may be corrected by using appropriate weights in the associated cost. This, however, requires a postprocessing work.

(3) Concerning the accuracy of reaching the final state, it is evident that the best strategy is controllability theory (see Figure 1). Nevertheless, the LQ controller can be also designed to improve this property by choosing an appropriate cost functional.

(4) As for the optimality of controls, we notice that the controls obtained from the controllability theory are optimal in the L2 (0,T;) norm (see Figure 2).

As indicated in the abstract, the present work is only a preliminary study on this topic. Many interesting open questions could be analyzed.

Acknowledgments. Work supported by Navantia S.A., Fundación Séneca (grant 00675/PI/04) and Universidad Politécnica de Cartagena (grant CA07/41).

4. References

[1] J. Felman, Revised standard submarine equations of motion. Report DTNSRDC/SPD-0393-09, David W. Taylor Naval Ship Research and Development Center, Washington D.C., 1979.

[2] E. Fernández-Cara and E. Zuazua, Control theory: History, mathematical achievements and perspectives, Bol. Soc. Esp. Mat. Apl. 26 (2003), 79-140.

[3] T. I. Fossen, Guidance and control of ocean vehicles, John Wiley and sons, 1994.

[4] J. García, J. A. Murillo, I. A. Nieto, D. Pardo and F. Periago, On a linear automatic control model for the manoeuverability of an underwater vehicle, in preparation.

[5] K. Ogata, Ingeniería de control moderna, Prentice Hall, 1998.

UNDERWATER SLAM FOR MANMADE ENVIRONMENTS

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1. Introduction

The possibility of having truly autonomous vehicles heavily depends on their ability to build accurate models or maps of the environments they traverse, and to know their location in them. This has made this problem, known as Simultaneous Localization and Mapping (SLAM), the focus of a great deal of attention in recent years [1-2]. Multiple techniques had shown promising results in a variety of different applications and scenarios. Some of them perform SLAM indoor, outdoor, on land and even on air. However, the underwater environment is still one of the most challenging scenarios for SLAM because of the reduced sensorial possibilities. Acoustic devices are the most common choice while the use of cameras and laser sensors is limited to applications where the vehicle navigates very near to the seafloor. Another important issue is the difficulty to find reliable features. There are approaches using clusters of acoustic data as features [3-4], or merging visual and acoustic information in order to improve the reliability [5], while other strategies simply introduce artificial beacons to deal with complex environments [6].

This article focuses on underwater SLAM applied to some particular manmade environments (harbours, marinas, marine platforms, dams, etc.) were structured elements are present and can be used to produce reliable features. Although most of the previous work done on this field focuses on open sea and coastal applications, obtaining an accurate positioning in such scenarios would notably increment AUVs capabilities. Monitoring, inspection and surveillance of underwater structures are some examples of applications that can benefit from such a system.

2. Feature extraction from acoustic images

The algorithm presented in this paper relays in a mechanically scanned imaging sonar (MSIS) to obtain the features that will conform the map. Although these mechanically actuated devices usually have a low scanning rate they are quite popular because of their low cost. This work propose the use of line features in underwater environment as a representation of the cross sections produced when a sonar scan intersects with existing planar structures (see Figure 1). Using this kind of sonar presents some difficulties. First, due to the low scanning rate it is necessary to merge information from dead-reckoning sensors in order to reduce the effects of movement-induced distortion in the resulting data. Second, these devices do not produce instantaneous acoustic snapshots of the surroundings but a constant continuous dataflow. Therefore, the feature extraction algorithm should be able to deal with this continuous stream of data while detecting the line features as soon as they appear. Our approach consists on an adapted version of the Hough transform [7]. This algorithm accumulates the information from the sensor data into a voting table which is a parameterized representation of all the possible feature locations. Those features that receive a great number of votes are the ones with a relevant set of compatible sensor measurements and thus the ones that most likely correspond to a real object in the environment. In our application, a data buffer storing the most recent high intensity returns from the sonar is used to vote in the Hough space whenever a new reading arrives. When a line feature receives a sufficient number of votes it is detected. Then, its uncertainty is estimated by analyzing the acoustic imprint left by the detected object.

3. SLAM algorithm

The classical stochastic map approach has been chosen to implement the SLAM algorithm [8]. An extended Kalman filter (EKF) with a constant velocity kinematics model is used to estimate the vehicle pose and retain the estimates of the previously observed features in order to build a map. The information from a Doppler velocity log (DVL) and a compass improve the estimate of the vehicle movement. The acoustic data from a MSIS together with the actual estimate of the position of the vehicle are the inputs of the feature extraction algorithm which runs simultaneously to the SLAM algorithm. When a line feature is extracted from the current acoustic data, it is initialized in the stochastic map. An individual compatibility nearest neighbour (ICNN) test is applied in order to determine possible pairings between the new feature and these previously in the map. If the compatibility test is negative, the feature is not associated and therefore, it is initialized as a new feature. If it is positive, the information from the observed feature is merged with the feature in the map and thus, the whole state is updated.

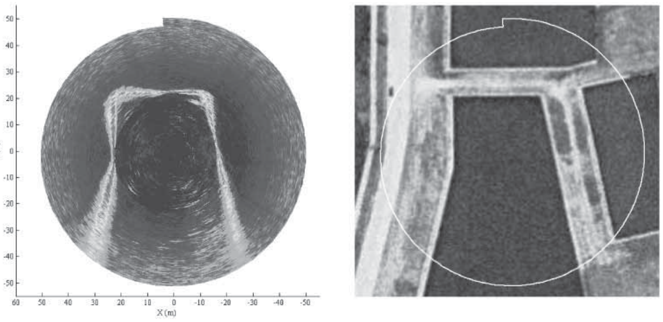

Figure 1. Acoustic Image generated from a 360º scan sector (left). Real environment where the sonar data were gathered (right).

4. Experimental results

In order to test the reliability of the proposed algorithm we carried out an extensive experiment on a abandoned marina in the Costa Brava (Spain). The ICTINEUAUV gathered a data set along a 600 m operated trajectory which included a small loop around the principal water tank and a 200 m straight path through an outgoing canal. Figure. 2 shows the resulting map and trajectories for the experiment represented layered with a satellite image for a better interpretation of the scene. As it can be seen, the dead-reckoning trajectory suffers from an appreciable drift (even causing it to go outside the canal). On the other hand, the SLAM-estimated trajectory is much better and corrects this defect. The set of line features from the obtained map matches almost perfectly with the real position of the marina boundaries. Comparing the result with the GPS track the similarity of the two trajectories is evident.

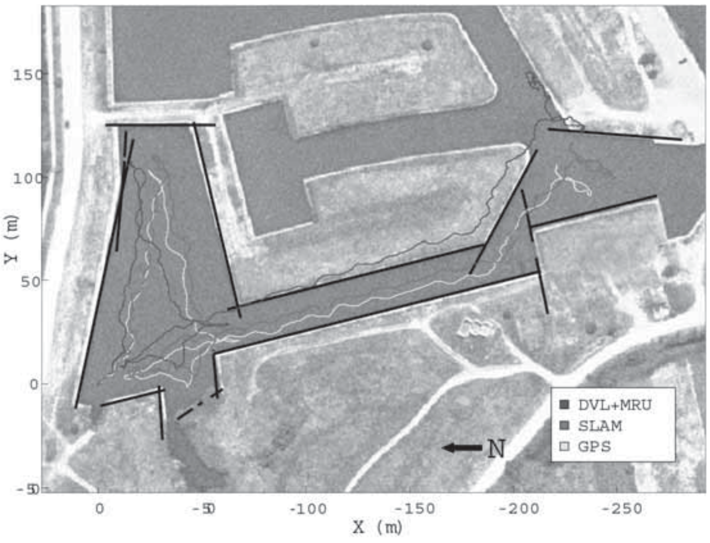

Figure 2. The resulting map

5. Conclusions

An algorithm to perform SLAM in partially structured underwater environments has been presented. The main contributions of this work include a feature extraction method capable of working with the continuous stream of data from the MSIS while dealing with the distortions induced by the vehicle movement in the acoustic images, a method for estimating their uncertainty, and the application domain. Experimental results support the viability of the proposal.

4. References

[1] H. Durrant-Whyte and T. Bailey, Simultaneous localisation and mapping (SLAM): Part I, the essential algorithms, Robotics and Automation, 2006.

[2] T. Bailey and H. Durrant-Whyte, Simultaneous localization and mapping (SLAM): Part II, state of the art, Robotics and Automation, 2006.

[3] J. Leonard, R. Carpenter, and H. Feder, Stochastic mapping using forward look Sonar, Robotica, 2001.

[4] I. Tena, Y. Petillot, D. Lane, and C. Salson, Feature extraction and data association for AUV concurrent mapping and localisation, Proc ICRA, Seoul, 2001.

[5] S. Williams and I. Mahon, Simultaneous localisation and mapping on the great barrier reef. Proc ICRA, New Orleans, 2004.

[6] P. Newman and J. Leonard, Pure range-only sub-sea SLAM, Proc ICRA, Taipei, 2003.

[7] J. Illingworth and J. Kittler, A survey of the hough transform, Computer Vision, Graphics, and Image Processing, Academic Press Professional, 1988.

[8] R. Smith, M. Self and P. Cheeseman, Estimating uncertain spatial relationships in robotics, Autonomous robot vehicles, New York, 1990.