Underwater Recovery Realization for an AUV Using Positioning-to-Line Strategy

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Abstract **- The underwater recovery problem of an autonomous underwater vehicle (AUV) was addressed in this paper. In order to realize the recovery task, a docking station, which is an open-shelf structure with guiding lights and transponder hydrophones, was designed to recover the vehicle. Based on the positioning-to-line (PTL) strategy, three subsystems, including steering, diving and speed controllers, were designed to guarantee the position and attitude of the vehicle move to expected ones. In addition, acoustic and optical guiding methods were adopted to provide position information as the vehicle approached to the docking station. A water tank experiment was designed to evaluate the performance of the proposed strategy. Experimental results demonstrated that the proposed PTL strategy was effective to autonomously realize underwater recovery by an open-shelf docking station for the AUV.**

Index Terms - autonomous underwater vehicle; PTL; underwater recovery; underwater guiding

I. INTRODUCTION

The research of AUV has been a hot topic in recent year with the development of the marine robotics. The applications in the area of AUV include discovering offshore oil fields, scientific of deep sea, exploitation of underwater resources, long range survey, oceanographic mapping and underwater pipelines tracking. Voluminous literatures have been presented on the subject of underwater recovery for AUVs [1-8]. Statistics have showed that the docking success rate is about 5%, far away from the expectation of reliable autonomous manipulation [9].

In [6], ALIVE made use of LBL sonar and SBL sonar as distant guiding equipments. On the other hand, imaging sonar and monocular camera were adopted as nearby guiding sensors. And accurate self-position estimation was obtained by fusing the two sensors' information. In August, 2003, sea trials had demonstrated that the ALIVE could dock into underwater fixed structure by its manipulating arm to complete detection or maintenance tasks.

It is believed that the guiding system ALIVE adopted would be reasonable for underwater recovery of AUV. As far as we know, there are few documents that describe in detail the design course of an AUV docking system. In this paper, a swimming-into-platform docking method was designed and a control approach based on the philosophy of positioning to line strategy was proposed. The paper is organized as follows. Section II introduces the AUV platform and the docking station. Section III addresses the proposed PTL strategy, which makes the vehicle automatically swim into the docking station. The performance of the proposed strategy is illustrated in section IV. Finally, section V contains the main conclusions and describes some problems that warrant further research.

II. UNDERWATER RECOVERY SYSTEM

A. AUV Platform

The recovery system can be divided into two parts, the AUV platform and the docking station. The outline of the AUV platform is shown in Figure 1 with related instrumentations, including: (1) one stern elevator; (2) two stern rudders; (3) four main thrusters; (4) four auxiliary thrusters; (5) four short base-line sonar (SBL) transducers; (6) an optical sensor. The vehicle measures 5.82 x 1.95 x 1.05 m. The four main thrusters are used to perform forward speed control mounted symmetrically about its longitudinal axis in the horizontal plane and in the vertical plane. The forward speed of the vehicle with respect to the water is approximately between 0 to 4 knots. And the heave speed is between 0 to 2 knots using the four auxiliary thrusters, which are also utilized to realize heading control. The optical sensor is set at the centre of SBL transducers' array.

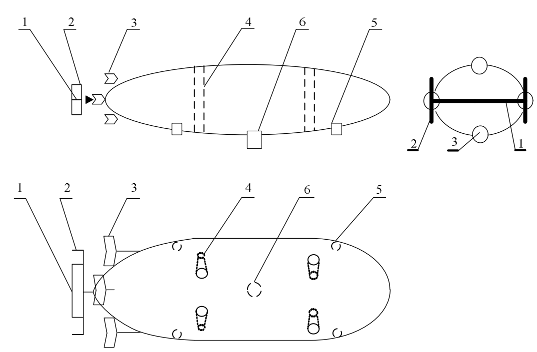

Fig.1 A detailed outline of the AUV platform

B. Docking Station

Figure 2 is a picture of the docking station, which was ready to launch into a water tank. This station is adopted with an open-shelf structure, which is helpful to release the water pressure when the vehicle launch into it. It's resting on the bottom of the water tank. The guiding lights used as visual targets are set on the bottom of the docking station (see figure

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3). These nine upward-facing lights are in the longitudinal midline. The referenced light is a heart-shaped one whose orientation indicated by its vertex is an expected heading which the AUV is going to follow.

Fig.2 The launch of docking station

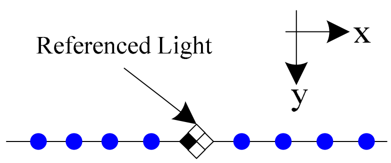

Fig.3 A structure of the guiding lights

In addition, the transponder hydrophones worked with SBL system are installed on the topside of the station; and these two hydrophones are set on one of the rectangle's long side. In order to avoid collision between the vehicle and the station, some rubber tires are tied to the bottom crossbeams. Figure 4 is one of the two hydrophones

Fig.4 Hydrophone installed on the station

III. PTL STRATEGY

The underwater recovery for the AUV addressed in this paper is based on the PTL strategy. It means that the distance between the centre of SBL transducers' array and the centre of docking station should be controlled in a small neighbourhood; and the angle error between vehicle's longitudinal line and docking station's longitudinal midline should be controlled in a small neighbourhood as well. Figure 5 is a sketch of the vehicle's recovery process. This water tank measures 50 x 30 x 10 m, which is located in Harbin Engineering University, Heilongjiang Province, China.

According to figure 5, this process can be divided into five steps as follows.

Step 1:

As the AUV is not far away from the docking station in the horizontal plane with a random heading angle, the first action in this step is to adjust its orientation to align the centre of docking station. Since the area of the water tank is not very large and the vehicle is nearby, the auxiliary thrusters are used to change its heading angle under low sailing speed (less than 2 knots). The main thrusters are then activated to propel the vehicle towards the projection of the station's centre in the horizontal plane while the heading angle is controlled. According to the strategy of PTL, the distance between the centre of SBL transducers' array and the centre of docking station should be as small as possible. The SBL system is adopted to provide the vehicle's position and attitude relative to docking station.

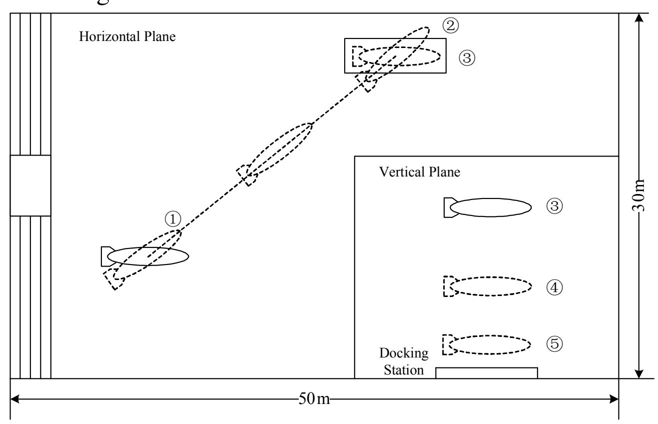

Fig.5 The schematic diagram of docking

Step 2:

The auxiliary thrusters are used to change its heading angle when the vehicle approaches the set target range about the station's centre in the horizontal plane. According to the strategy of PTL, the angle error between vehicle's longitudinal line and docking station's longitudinal midline should be as small as possible. The vehicle's position and attitude are calculated by the SBL system.

Step 3:

Once the angle error between vehicle's longitudinal line and docking station's longitudinal midline are satisfied with the set value, the vehicle is going to descend by the auxiliary thrusters in the vertical plane. As the accuracy of the position information provided by the SBL system is substantially decreased at close proximity to the docking station, the guiding systems will be changed to visual guiding system when the vertical distance between the vehicle and docking station is less than 3m.

Step 4:

This step is called re-regulation, which is a mixture of step 1 and step 2. When the vehicle is 2 m away from the top of the docking station, step 3 will be suspended. During this process, the distance between the centre of SBL transducers' array and the centre of docking station and the angle error between vehicle's longitudinal line and docking station's longitudinal midline will be re-regulated. The vehicle's position and attitude are calculated by the visual guiding system.

Step 5:

When the vehicle's position and heading angle are satisfied with requirements proposed by the PTL strategy, step 3 will be continued. The vehicle will descend using the auxiliary thrusters until it is 0.6 m away from the bottom of the docking station. If this distance is less than 0.6 m, the thrusters will be shutdown, allowing the vehicle drop to the bottom depending on inertia.

IV. EXPERIMENTAL RESULTS

In order to validate the proposed strategy, it is assessed in a water tank using the AUV addressed in section II. At the beginning of experiment, the vehicle was kept still on the surface about 23 m away from the dock station in the horizontal plane and 8.6 m away in the vertical plane. The recovery station was lying on the tank's bottom and would not move during underwater recovery.

Figure 6-8 showed three coordinate components relative to the station-fixed frame during the recovery experiment. It was programmed that the states of the control system were updated with a period of 0.5 sec.

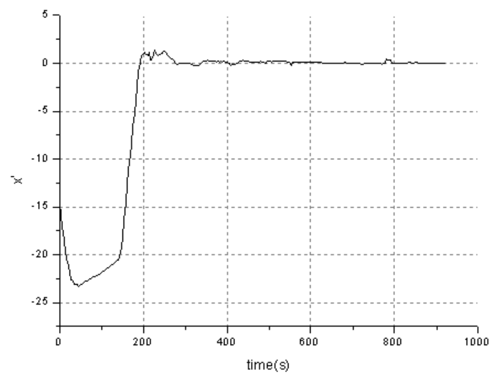

Fig.6 Longitudinal coordinate in the station-fixed frame

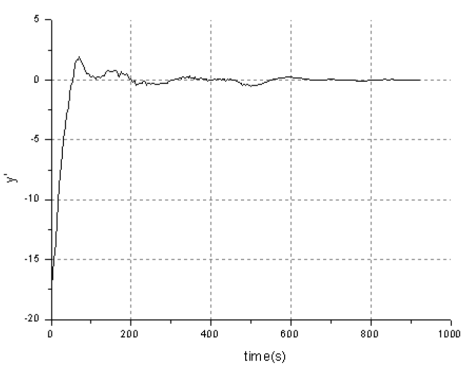

Fig.7 Transversal coordinate in the station-fixed frame

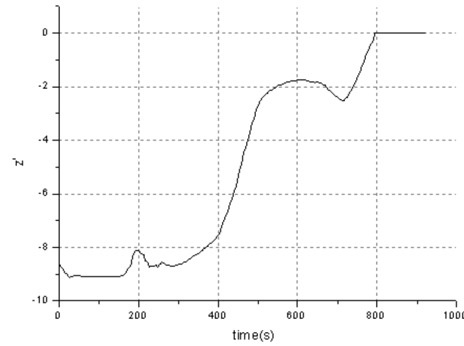

Fig.8 Vertical coordinate in the station-fixed frame

It was shown that the recovery mission lasted about 13 minutes. In figure 7, the transversal position error in the station-fixed frame was decreased to zero gradually for the vehicle's heading was controlled to towards the centre of docking station. At the same time, the longitudinal coordinate was increased due to the rotation of the station-fixed frame in the horizontal plane. While the heading error in step one was satisfied with the threshold (5 degrees), the speed controller was activated to propel the vehicle towards the projection of the station's centre in the horizontal plane.

In figure 8, there are two sections where depth was changed unexpected. Around 200 seconds, the speed of the vehicle was declined because the distance between the centre of SBL transducers' array and the centre of docking station was small enough. The increased pitch which was caused by hydrodynamics would induce a variation in depth for the position of the depth meter is not at the centre of AUV. Around 600 seconds, the up movement of the vehicle was caused by interference between heading control and depth control in step four.

The same process has been carried out for many times. And the results have showed that the docking success rate was about 50% which meant that there were still many details need to be considered to increase the successful probability.

V. CONCLUSION

The objective of this paper is to realize the underwater recovery for an existed AUV. Firstly, a docking station system was designed according to the AUV platform. Then, the PTL strategy was proposed to make all the error states in the recovery system gradually decrease to near zero. Although two different guiding systems should be considered for the recovery task, the experimental results obtained illustrated that the proposed methodology was effectiveness and the recovery mission was completed satisfying design requirements.

In future work, we are planning to carry out some trials on underwater recovery with moving docking station in the water tank based on the PTL strategy.

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