Research on Control and Programming in the Recovery Of Autonomous Underwater Vehicle

Gao Yinghui
College of Shipping Building Eng, Harbin Engineering University, 150001
yier_wei@0451.com or angela_gao@dbtel.com.cn

Wang Fei
College of Shipping Building Eng, Harbin Engineering University, 150001
jqm0@0451.com

Xu Yuru
College of Shipping Building Eng, Harbin Engineering University, 150001

Abstract In research of Autonomous Underwater Vehicles (AUV), recovery is an unavoidable problem. Up to now, it is not satisfactorily resolved even in global range. This paper studies a new deepwater recovery plan of AUV: the embedded embarkation recovery supported by the submarine. Firstly, after the analysis of the specific hydrodynamic problem, the paper builds up a simulation system for AUV recovery. According to the specific requirements in the complex underwater surroundings and elaboration in control, we construct a fuzzy controller for the recovery mission. In addition, the paper studies the programming of recovery. Finally, In the simulation system， the control and programming is proved to be simple and reliable.

Keywords AUV Recovery，System Simulation, Fuzzy Control，Programming

1. Introduction

In research of Autonomous Underwater Vehicles (AUV), recovery is an unavoidable problem. Up to now, it is not satisfactorily resolved even in global range. Whether the problem is resolved or not will have deep effect on the practicability of AUV.

The importance of this research is obvious: On the view of objectiveness, the application of AUV has to involve the launch and recovery; AUV usually takes power with itself underwater, so its work time is limited and can not navigate too far. Thus, it is very necessary for AUV recovery to supplement energy, read information and maintain components. Moreover, the huge costs of AUV bring forward the requirement of security and reliability for AUV recovery. From subjectiveness, the problem to be resolved in the recovery consists of programming, control and hydrodynamic etc. It not only promotes the research of path plan, location and simulation of sonar, accurate control and optimization of hydrodynamic model etc, but also symbolize the strength of AUV research.

General speaking, AUV recovery is divided into two modes: water and underwater.

In the mode of water, one of the most direct ways is using the advanced mechanical crane, it is said that when AUV has completed the mission and return around the supported mother ship, it will be connected to the mother ship through crane. We can imagine that AUV will fluctuate with wave, it is very difficult to realize correct link; The other water recovery method is using a recovery mechanism, AUV entered into the mechanism, then both of them rise to the water. Shenyang automatizaion institute of CAS(Chinese Academy of Sciencer) has an beneficial attempt on this recovery method.

AUV recovery in deep water has incomparable advantage; it is not only decrease the effect of wind, wave and flow, but also has the feature of concealment. There have two modes as in the following:

One underwater recovery mode is regarding AUV as a kind of weapon, thus we can use the torpedo tube to perform launch and recovery. The torpedo tube itself is used as launch, so AUV launch is very simple, but recovery is much more complex and difficult.

The other mode is embedded embarkation recovery. That is to say we can use the submarine as embarkation platform and AUV as embarkation load, return AUV to the location of each submarine podium. This is the new project discussing in this paper, and the author has a beneficial attempt on the control and programming of AUV in the simulation environment.

2. Simulation system of AUV recovery

In order to accurately describe and research the real system in laboratory, we must build the simulation system as accurate as possible on the basis of certain reasonable simplification and hypothesis. The simulation system in this paper consists of: hydrodynamic, thrust and ocean environment simulation etc. More details for thrust and ocean environment see [1]. Here the author only introduces the special hydrodynamic of AUV recovery.

During the AUV recovery, because of the difference on hydrodynamic and added mass between the area near submarine and the infinite deep water, the motion module must be modified or rebuilt. The problem to be considered is mainly the interaction among AUV, water and submarine when AUV moves near submarine. The calculate method is:

When an object moves in a unit speed, it is possible to determine the derivational speed φ_i at certain point in the space, then the added mass can be calculated in the following formula.

$$A_{ij} = -\rho \iint_s \varphi_i l_j ds \qquad (2\text{-}1)$$

Here it is time-dependent variable, at the same time; it is a function of space position C_1、C_2、C_3 and orientation angle α、β、γ. Using the calculus way, we can gain the derivative of time-dependent added mass to the space position: $\frac{\partial A_{ij}}{\partial C}$. On this basis, the suffered force on object can be obtained according to the Lagrange equation:

$$F_m = -\sum_{i=1}^{12}\left[A_{im}\dot{U}_i + \sum_{j=1}^{12}\frac{\partial A_{im}}{\partial X_j}U_i\frac{\partial X_j}{\partial t}\right] + \frac{1}{2}\sum_{i=1}^{12}\sum_{j=1}^{12}\frac{\partial A_{ij}}{\partial Xm}U_iU_j \qquad (2\text{-}2)$$

As shown in the above formula, in order to gain the interferential force that the submarine acts on AUV, the added mass must be calculated firstly. The author replaces it with the added mass near wall surface and uses the finite cell grid to compute the added mass, and takes it into (2-2) to calculate the hydrodynamic that submarine acts on AUV.

According to the real condition of AUV embarkation, on the assumption that the submarine suspends in the water, while AUV sails to the submarine in certain speed, getting to the embarkation area near the podium of submarine. As the submarine keeps quiet and flow field is comparative immovable, the interference on AUV is very poor. When the distance between AUV and submarine is far (10m far from the submarine surface in the paper), it can be considered as in the boundless flow field; otherwise, the effect can not be ignored, AUV sail to the submarine in two modes via the programmed path:

① Recovery from double side of the podium, firstly performing the distance control from far away, it is equal to navigating. Then in the switching area, AUV switches to the accurate control in close distance and sail to submarine slowly.

② Recovery from upside of the podium, AUV gets to the switching area in arbitrary way, at the same time, we control AUV in depth to the target area.

Project ①: $u_z = -1.0\ m/s$, The result is shown in figure 1,here the abscissa is distance between AUV and the podium and the ordinate is disturb force. From the figure, the force can be ignored as the distance is more than 5m,while the distance is less than 1.5m, the force can be approximate to the computation of wall surface.

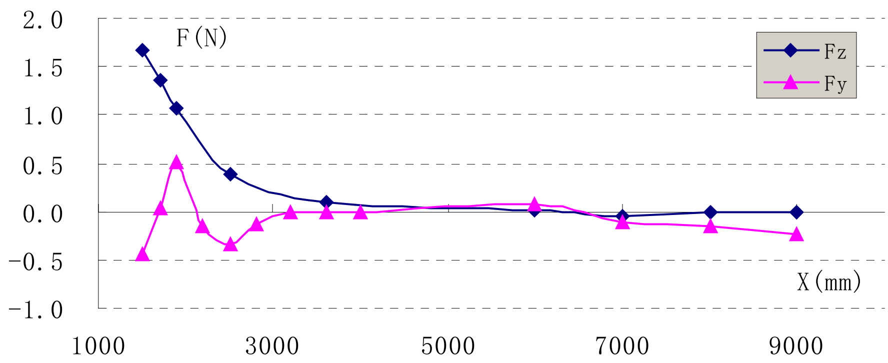

Figure 1 Force curve of project①

Project②: $u_y = -1.0\ m/s$, The result is shown in figure 2, here the abscissa is the depth distance between AUV and submarine.

Notes: It must be focus on that F_y、F_z, they have a huge break At Y=7.5m.

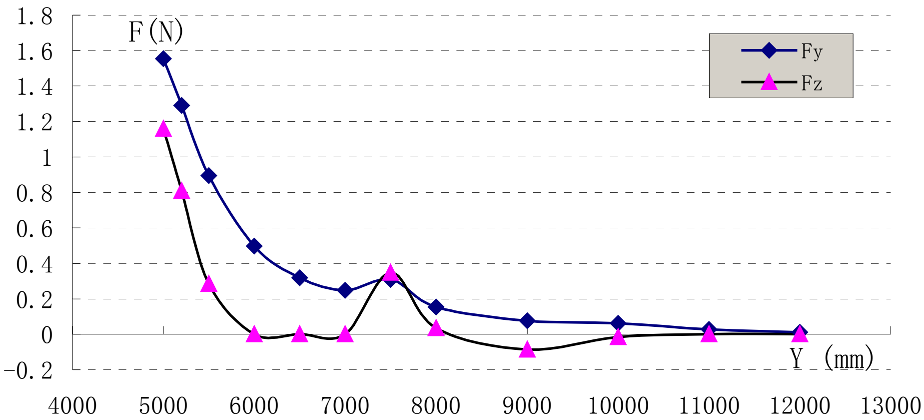

Figure 2 Force curve of project②

As shown above, the author discusses the hydrodynamic force when AUV moves to the submarine. In order to calculate the force in various speed, the result must be attributive:

$$C_f = \frac{F}{1/2 \cdot \rho v^2 L^2} \qquad (2-3)$$

3. Motion Control of AUV Recovery

Since AUV recovery involves the complex mission around the submarine, while the influence which the disturb flow field acts on the AUV can not modified via experiment data exactly, it requires high precision on the controller design. The controller based on the fuzzy logic doesn't depend on the accurate system module, but the system knowledge, so it is adaptive for such strong nonlinear system for AUV recovery.

During fuzzy controller design for AUV recovery, the author uses the fuzzy controller theory and designs the appropriate fuzzy control rules according to the speciality of AUV recovery, and acquires the satisfying result. For more detailed information of fuzzy controller design, see the author's graduate thesis for master degree. Here we only discuss the scheduled project of embedded embarkation recovery.

Considering the special requirement of AUV embarkation recovery, the hydrodynamic becomes complex and uncertain. From the computing method of hydrodynamic in 2nd section, it is known that: because of the complexity for computing, it is impossible and unpractical to get the force and moment exactly in six dimensions. At the present time, we can only get the accurate force in one dimension. Thus, it has a special requirement for recovery: only controlling AUV to anear the submarine slowly in one dimension is possible. Therefore, the paper designs two-recovery project: horizontal control recovery and deep control recovery. The whole recovery procedure is shown in the figure 3.

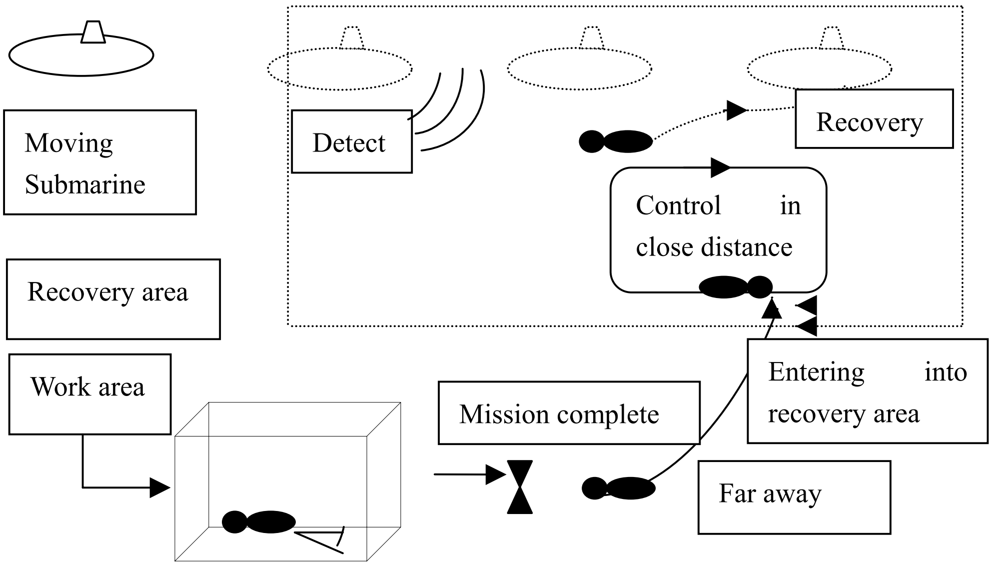

Figure3 AUV recovery procedure

On the top of the section, the called horizontal control of AUV recovery is that AUV sails to the podium from submarine side after entering into the recovery area. The detailed information is described in the following:

Firstly, performing the control from far away at the front of submarine, when the influence from submarine can be ignored and the motion can be considered as navigating to the switching area. In this phase, AUV departs from submarine side for 10m, it is said that the horizontal distance is constant, as well as the deep distance is also unchangeable with about 6m(from the submarine surface). As soon as AUV arrived the switching area, the hydrodynamic was changeable; it must start the accurate control in recovery area. Finally, AUV sails to the submarine side in horizontal distance until get to the target area. It must be paid attention to keeping AUV comparative static in certain degree before the sequential recovery work.

It must be focus on determining the recovery area, that is to say the size of switching area is very important; which will impact on whether the recovery mission successes or not. The paper determines the switching area according to the effect rang which the submarine acts on the hydrodynamic. From above we know: when the horizontal distance between AUV and submarine exceed 10m, the horizontal hydrodynamic can be completely ignored, so the switching area can be determined in rang of 10m around submarine. For the static submarine, the distance between both is absolute; otherwise, it will be relative distance. In order to simplify the system, the author supposes that the submarine is suspending in the water.

The deep control recovery is similar with horizontal control recovery, the paper will not discuss in detail.

4. Programming of AUV recovery

During the practical recovery process, there has two points must be considered. One is the switching area, which needs the programming on general geometrical path; the other is the recovery area, which belongs to the local plan, namely it must add the path plan with avoiding collision logic to avoid the potential collision between AUV and submarine.

(1) Path plan in switching area

The path plan in switching area can be described in details: the switching area is the critical area the submarine acts on AUV. Because of the complexity of hydrodynamic in recovery area, it requires that AUV can keep the appropriate pose before enter the recovery area. At the same time, for the special requirement of control precision, it must ensure that AUV's speed is about 0.

To satisfy all of these, the paper designs the following programming project:

① To ensure AUV in the status of low speed, it is necessary to set middle target point.

② To ensure AUV is parallel to the center line of submarine, it is necessary for AUV to move in certain direction. For this, the space must be divided into different area as shown in figure 4.

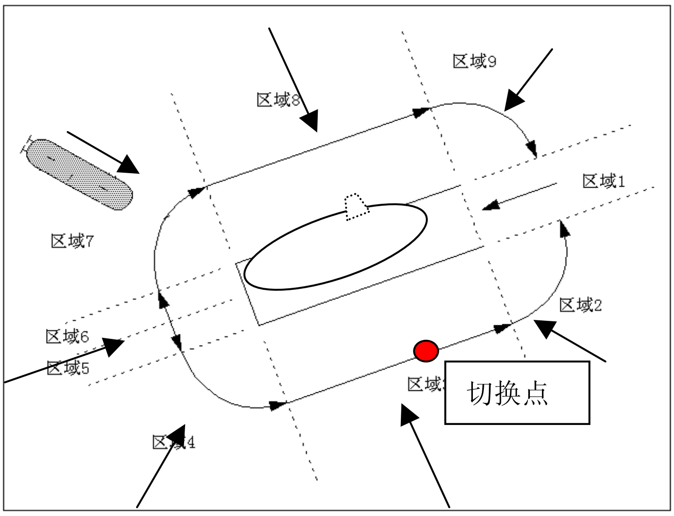

Figure 4 programming of switching area

Analysis: As shown in figure 4, the switching area can be divided into 9 regions in two-dimension space. For the symmetry, it can be only considered the case of region 1 to 3.

① To region 1，AUA is at front of the submarine. Considering the complexity of flow field on which submarine fore acts, it is difficult to recovery from fore. Thus, it must ensure that the motion of AUV is outside the critical region. When arriving at the switching area, AUV must be parallel to centerline of submarine to prepare for the recovery.

② To region 2，it is similar with region 1. The difference is the original position. In this case, the position is not at the front of the submarine, so it is much more simple.

③ To region 3，it is equal to navigating to the switching area, and control accurately after arriving at switching area.

(2) Programming in recovery area

The programming in recovery area belongs to local path plan. The short baseline sonar only gains the approximate target position, so it is necessary to perform accurate program and control to success in arriving the excepted position as well as avoiding the collision between AUV and submarine. Therefore, the programming becomes a very important problem. During the process of recognizing the target position, AUV needs to understand its own position and the environment and combine the various data information, and then it can acquire the determined information of expected position to program an appropriate path. In whole procedure, there involves two problem in the following:

① Synthetically understanding to the sensor and environment information(for recovery signal on the submarine podium etc.)

② According to acquired information, add the avoiding collision logic and program the appropriate path.

The paper integrates control and avoiding collision, and then realizes it in the simulation system. For details see [2].

5. Simulation result and analysis

After analyzing the motion control and path programming during the recovery Process, the paper makes the following simulation experimentation to prove the simpleness and availability of the proposed recovery project. The following is n recovery example. Hypothesis: Horizontal control recovery, Region 2, Original position (-10.0, -10.0), Switching point(0,0), Navigating angle 0, Target position(0,10), No current. Thus the simulation result is as shown the following.

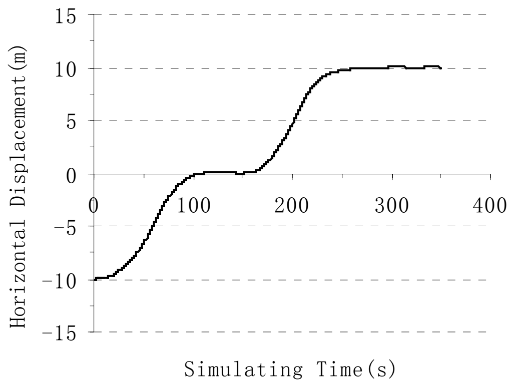

Figure 5 Curve of switching control

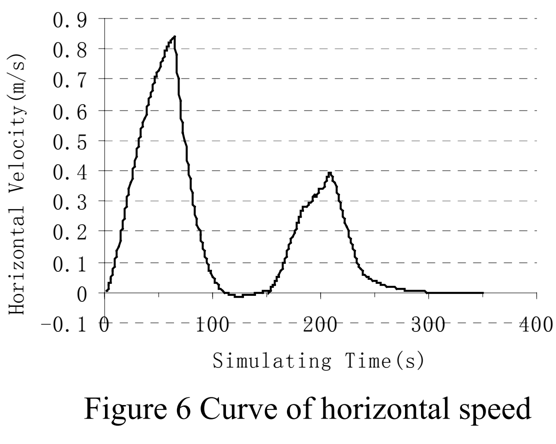

Figure 6 Curve of horizontal speed

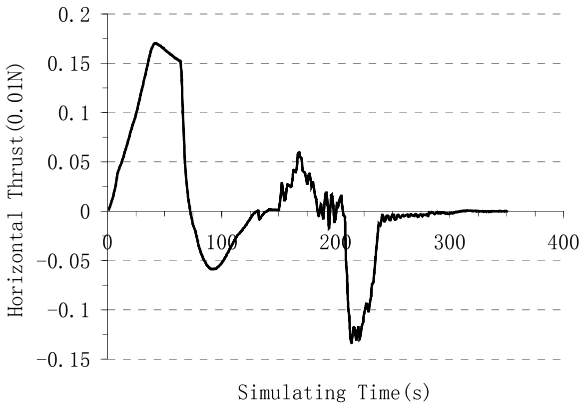

Figure 7 Curve of horizontal thrust

Analysis: as shown in above figure, using the fuzzy logic controller designed in this paper, the control effect is excellent. It has two advantages:

(1) System response time is short and excess is small while the switch is very smooth and rapid.

(2) The oscillation is very little as well as the change of speed and thrust are also slow without large break.

6. Conclusion

This paper studies a new deepwater recovery plan for AUV in details: the embedded embarkation recovery supported by the submarine. Firstly, after the analysis of the specific hydrodynamic problem, the paper builds up a simulation system of AUV recovery. Then according to the specific requirements in the complex underwater surroundings and elaboration in control, the author constructs a fuzzy controller for the recovery mission. In addition, the paper studies the programming of recovery. Finally, In the simulation system，the control and programming is proved to be simple and reliable.

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