Numerical Simulation on the Deploying and Recovering Process for a node of Underwater Wireless Sensor Network

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***Abstract*—An underwater wireless sensor network (UWSN) has multiple functions in ocean survey. A kind of UWSN has been proposed by Zhejiang University. In this paper the CFD method is utilized to verify the ability of a node to adjust its posture in deploying and recovering process. The minimum depth and the minimum time for a node to adjust itself to vertical were obtained in different initial inclined angles and different ocean current velocities. The different initial inclined angles were chosen as 45 degree, 60 degree and 90 degree. The different ocean current velocities were chosen as 0.5m/s and 1m/s according to the actual sea conditions around the Zhoushan Island. The minimum rising height and the minimum time for the retrievable cabin to turn 180 degree were obtained in still water. The purpose of the retrievable cabin to turn 180 degree is to keep antenna upright on the ocean surface. Because the antenna was installed on the bottom of the retrievable cabin. These results show that the design of the UWSN node is reliable as to the scheme of the node to deployment and recovery.**

Keywords*—*underwater wireless sensor network; deploying and recovering process; CFD simulation;

I. Introduction

The underwater wireless sensor network (UWSN) has been utilized in various scenarios including oceanic ecosystem preservation, petroleum exploration, fresh water quality monitoring, and others [1]. The underwater wireless sensor network consists of several UWSN nodes with many functions including data collecting, data memorizing, and acoustical communication. For each UWSN node, it has to be deployed before working underwater and recovered after completing its mission. University of Pennsylvania designed a kind of UWSN node and verified its feasibility by experiment [2]. But there are no guarantees for this node to be deployed stably on the seabed and no scheme to retrieve. University of Buffalo proposed a sort of UWSN node which is linked with a floating ball [3]. This node takes advantage of itself structure and mass distribution to make the deployment process easy and stable. The retrieve process is triggered by an electromagnetic detacher. However, there is no assessment for the deployment and retrieve process. The commercial product SM-75 [4] of Teledyne Benthos company used some weight to fix a node of UWSN on seabed and the node has positive buoyancy. After its mission has been finished, the node would detach from the weight and come up to ocean surface. This product has been used by Taiwan University to perform scientific research under hundreds meters of water. In actual use, SM-75 has a high performance [5]. However, this design has some drawbacks on fixing a node. When ocean current velocity becomes large, the distance between the node and weight which is used to fix the node would change with time. Then Doppler Effect would appear and the stability of underwater acoustic communication would be affected. In China, Northwestern Polytechnical University designed a kind of UWSN. It has a compact structure and lower energy consumption [6]. However, this UWNS system didn't have a scheme to deploy and retrieve. Also, there is a concept of Autonomous Underwater Explorer. It has powerplant and propeller is usually the general. Though the AUE is flexible in monitoring ocean environment, collecting data and communicating through acoustics, its short endurance is not suitable for a long time to work underwater [7]. A new design of UWSN node, which is used to monitor flow field around Zhoushan island, has been designed by Zhejiang University [8]. The deployment and recovery for a single node have been considered in design stage and it could be deployed at big initial inclined angle and adjust itself to vertical. And, the recovery process is reliable. When the command for recovery has been sent to a node, electric explosive bolt would be triggered and the underwater retrievable cabin would detach from triangle bracing frame. In the recovery process, the underwater retrievable cabin would turn 180 degree in order to keep antenna upright on the ocean surface. Because the antenna was installed on the bottom of the retrievable cabin. The performance of the underwater retrievable cabin has been studied. The results showed that the GRP retrievable cabin manufactured by hand layup process can stably work under ocean water of 200 meters [8].

This paper is an extended research for the UWSN node proposed by Zhejiang University. In order to ensure the reliability of the deployment and retrieve process of a node, a numerical simulation has been implemented to check the ability of a node adjusts its posture in deploying and recovering process. These simulation data are shown in following graphs.

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II. STRUCTURE OF THE UWSN NODE

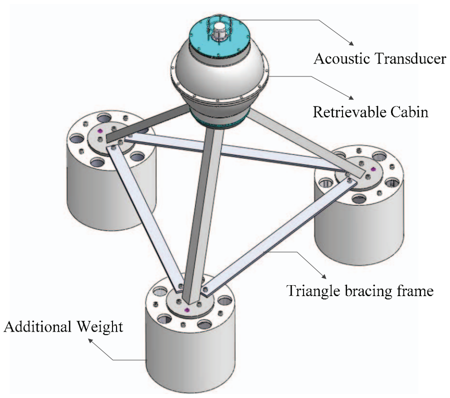

Fig 1 The Structure of UWSN node [8]

Figure 1 shows the structure of the UWSN node. A design concept of modularization which is more reliable has been used in each UWSN node. This would ensure that every module works independently and reduce the failure rate. Also, modularization design offers convenience to maintenance and repair. This single node mainly consists of two parts. One part is triangle bracing frame with additional weight in the lower place. The triangle bracing frame are made of steel and painted anti-corrosion lacquer. And the other is retrievable cabin fixed on top of the bracing frame. The retrievable cabin are made from glass reinforced plastic material (GRP). In the retrievable cabin, there are 6 function modules. Namely, master control module, acoustics module, battery manager module, retrieve manager module, Beidou orientation module and sensors manager module. In principle, the retrievable cabin should be recovered at intervals. Because this kind of node is supplied by lithium battery and the data collected is stored in storage card which is internally mounted. So the followings would mainly study the deployment and recovery process through CFD simulations.

III. NUMERICAL SIMULATION

Generally, prediction is more important than post-prediction for CFD simulation. Though, this kind of UWSN node has not been deployed and retrieved in actual use. CFD simulation has a significant meaning to predict the deployment and recovery process and help us to optimize its structure design which would enhance the stability and reliability. A CFD software namely STAR-CCM+ has been used to simulate the deployment and retrieve process.

We assume that the water is incompressible, viscous and Newtonian fluid. The flow is isothermal regardless of heat transfer. Fluid in motion must satisfy the mass and momentum conservation equations, in which the instantaneous values of various parameters are replaced by the time-averaged ones. So transient Navier-Stokes equations used in engineering are usually time-averaged. The differential forms of the continuity equation and momentum equations, the Reynolds-averaged Navier-Stokes (RANS) equations, in Cartesian coordinate system are as follows.

Continuity equation:

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho u_i}{\partial x_i} = 0 \tag{1}$$

Momentum equation:

$$\frac{\partial}{\partial t}(\rho u_i) + \rho \frac{\partial}{\partial x_j}(u_i u_j) = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j} - \rho\overline{u_i' u_j'}\right)\right] \tag{2}$$

The problem we researched related to the motions of 6 DOF. The governing equations of free motion are as follows. The equation for the translation of the center of mass of the body is noted in the global inertial coordinate system:

$$m\frac{dv}{dt} = \boldsymbol{f} \tag{3}$$

The rotation equation of the body is formulated in the body local coordinate system with the origin in the center of mass of the body:

$$\boldsymbol{M}\frac{d\vec{\omega}}{dt} + \vec{\omega} \times \boldsymbol{M}\omega = \boldsymbol{n} \tag{4}$$

Where M is the tensor of the moments of inertia, $\vec{\omega}$ is the angular velocity of the rigid body and **n** is the resultant moment acting on the body.

Though the designed working depth for this kind of node is about 200 meters, there is no necessary to simulate its deployment and recovery process using such large computational domain. The computational domain is 28m×16m×70m. And this is enough for simulating both processes due to the actual size of the height of this node is about 1.8m. And more, the simplified numerical simulation model as shown in Figure 2. The total mass of this node is 1067.9kg and the principal moment of inertia relative to the center of mass Mxx, Myy and Mzz which are used in equation (4) are 456.43kg▪m^2, 456.43kg▪m^2 and 686.63kg▪m^2 respectively. And the total mass of the retrievable cabin is 51.1kg and the principal moment of inertia relative to the center of mass Mxx, Myy and Mzz which are used in equation (4) are 1.42kg▪m^2, 1.42kg▪m^2 and 1.17kg▪m^2 respectively. For both processes, the flow state is turbulent and K-Epsilon turbulence model was used in this simulation. An unstructured polyhedral grid with 1250071 cells were chosen for this detailed studies and overset mesh technique was used to simulate the 6 DOF motions. Of course, the results were checked for grid independence.

For the deployment process, in the cube computational domain, the left side was defined as velocity inlet and right side was defined as split outlet. The bottom, top, front and back sides were treated as symmetric. Because the main purpose for this simulation is studying the motions after this node has been plunged into water and the computational domain is large enough to eliminate the boundary effect. For the recovery process, ocean current condition has not been considered. Because Beidou orientation system is applied to this node and there is no necessary to estimate how far the retrievable cabin would drift. So only the top side of the tube computational domain was defined as pressure outlet which pressure was set as 1 atm. All of the other were set as symmetric. And at initial stage about 0.05s, a linear force acted on the retrievable cabin to simulate the spring to launch it. After 0.05s, the linear force was decreasing to zero and the retrievable cabin would rise and turn 180 degree to let antenna upright on the ocean surface.

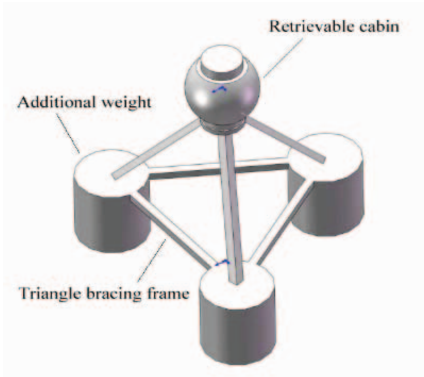

Fig 2 The Simplified Numerical Simulation Model

IV. RESULTS AND DISCUSSIONS

CFD simulations have been implemented to verify the ability that a node adjusts its posture in deploying and recovering process. The following figures show these results.

For the deployment process, the minimum depth about 20m and the minimum time about 7 seconds for a node to adjust itself to vertical are obtained despite of the different initial inclined angles. The ocean current has little influence on the deployment process. Figure 3 and Figure 4 show the time of the node to adjust itself to vertical in different initial inclined angles which are 45 degree, 60 degree and 90 degree. We can conclude that the current and the initial inclined angles almost have no influence on the time that the node would adjust itself to vertical. It means that the node needs about 7 seconds to adjust itself to vertical despite of the ocean current and initial inclined angles. Then, from Figure 5 to Figure 7, we can conclude that current has an influence on the process of adjustment. When the ocean current velocity increases, the angular velocity of the node also increases at initial time especially for the conditions of 45 degree and 60 degree initial inclined angles. But there is little influence on the condition of 90 degree initial inclined angle. It can be inferred that the horizontal momentum of the current has a positive effect on rotating this node for the conditions of 45 degree and 60 degree initial inclined angles. However, this positive effect is so small for the condition of 90 degree initial inclined angle. So when the node has been plunged into water horizontally, the current which velocity is below 1.0m/s don't have a remarkable effect on helping this node rotate to vertical. The ocean current has more effect on leading the node to drift horizontally which is shown in Figure 8. Obviously, when the ocean current velocity increases, the displacement in current direction also becomes large. There is an interesting phenomenon which is that the more the initial inclined angle is, the less displacement in current direction. It can be explained as that when the initial inclined angle is 90 degree, the projected area causes less resistance. The projected area changes with time and the total time for this node to adjust itself to vertical is almost the same. So, when the initial inclined angle is big, the time experiencing the less resistance is more and the horizontal drift is less.

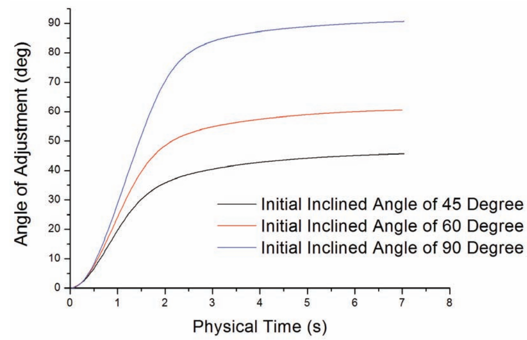

Fig 3 Adjustment of a node in 0.5m/s Ocean Current

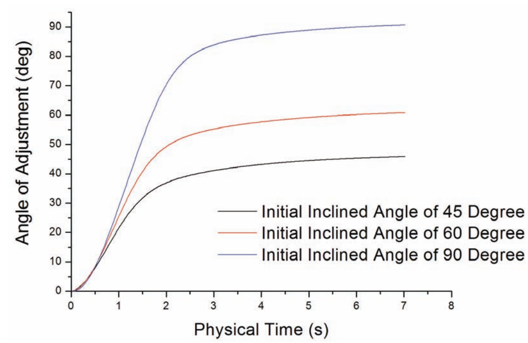

Fig 4 Adjustment of a node in 1.0m/s Ocean Current

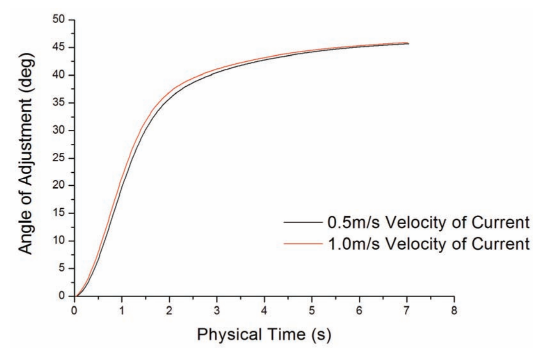

Fig 5 Adjustment of a node in Initial Inclined Angle of 45 Degree

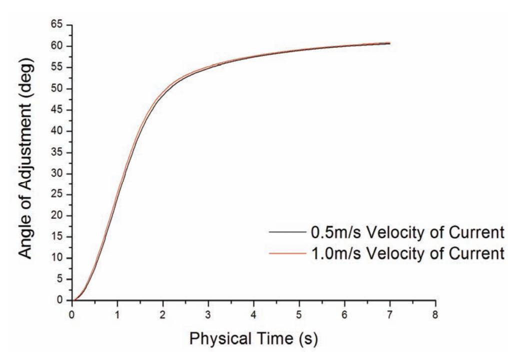

Fig 6 Adjustment of a node in Initial Inclined Angle of 60 Degree

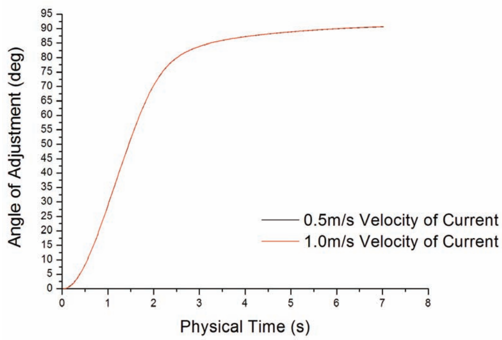

Fig 7 Adjustment of a node in Initial Inclined Angle of 90 Degree

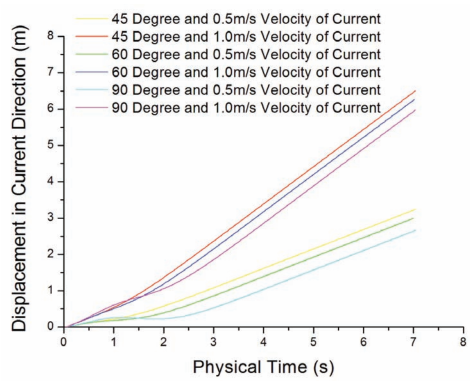

Fig 8 Displacement in Current Direction for Different Ocean Current Velocities and Initial Inclined Angles

Also, the simulation of recovering process shows that the retrievable cabin would stably come up to ocean surface and its antenna wouldn't submerge into water. Figure 9 shows the process of the retrievable cabin coming up to ocean surface. There is a triggered linear force to launch the retrievable cabin and this force leads it to turn 180 degree much more. But the retrievable cabin would adjust itself to vertical slowly in about 16 seconds. And the rising height is about 23.2m. Because we only consider the still water condition, there is little drift in horizontal direction.

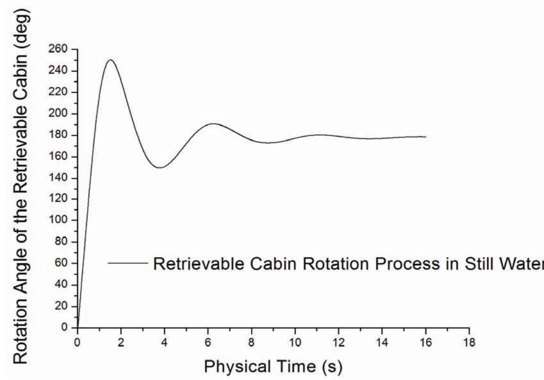

Fig 9 The Recovery Process of Rotation for the Retrievable Cabin

We can conclude from our CFD simulations that the design of UWSN node is dependable. Its ability to adjust its posture in deploying and recovering process is practicable. The scheme for this node to deploy and recover is reliable. The prediction purpose through using CFD method was obtained. Our future work is to optimize the structural design of this node according to the present study results.

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