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Optimal design of hydraulic support landing platform for a four-rotor dish-shaped UUV using particle swarm optimization

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Abstract

Four-rotor dish-shaped unmanned underwater vehicles (FRDS UUVs) are new type underwater vehicles. The main goal of this paper is to develop a quick method to optimize the design of hydraulic support landing platform for the new UUV. In this paper, the geometry configuration and instability type of the platform are defined. Computational investigations are carried out to study the hydrodynamic performance of the landing platform using the Computational Fluid Dynamics (CFD) method. Then, the response surface model of the optimization objective is established. The intelligent particle swarm optimization (PSO) is applied to finding the optimal solution. The result demonstrates that the stability of landing platform is significantly improved with the global objective index increasing from 1.045 to 1.158 (10.86% higher) after the optimization process.

Keywords: Four-rotor dish-shaped UUV; Hydraulic support; Particle swarm optimization; Response surface model; Computational fluid dynamics

1. Introduction

The wide application of Unmanned Underwater Vehicles (UUVs) affects tremendously the development of the ocean exploration. Long time reconnaissance and exploration at a certain area on the seabed have become an imperative task. So the ability of landing or mooring on the seabed is necessary for these UUVs. The application of landing on the seabed has stepped up the demands upon the optimal design of landing or mooring platform for UUVs. In recently, the research of landing or mooring mode for a UUV has become an international hot issue.

There are two main types of landing or mooring mode: mooring platform and bottom resting platform using hydraulic support. As for mooring platform, numerical differential models between mooring chain and seabed had been studied and improved for a floating platform (Huston and Kamman, 1982; Wang et al., 2010). Similarly, a finite difference method for of mooring chains had been analyzed for an underwater flight vehicle (Feng and Allen, 2004). Then, the influence of external disturbance factors on mooring system was taken into account (Cerveira et al., 2013). The landing platforms have the advantage of simple structure, but they are more easily affected by ocean currents and it is difficult for them to keep at a stable attitude. Hydrodynamic characteristics and stability of UUV parking on the seabed have been analyzed for bottom resting platform (Song et al., 2012). Disturbance factors from the seabed are stumbling block for the performance of the landing platform. So the hydraulic support is incorporated into the landing system. The advantages of bottom resting platform with hydraulic supports, such as move away from the distractions of the seabed and extended-duration deployments, rely on the shape and layout which has excellent high stability.

In this paper, the FRDS UUV is a new unmanned underwater vehicle designed in Northwestern Polytechnical

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University China (Song et al., 2016). The UUV is designed to investigate and explore a certain area on the seabed. Computational Fluid Dynamics (CFD) uses numerical analysis and algorithms to solve and analyze problems that involve fluid flows. Hydrodynamic characteristics of the landing platform were analyzed by using CFD software.

The optimal layout design of the hydraulic support will make the platform staying away from distractions. In engineering, Multi-Objective Programming (MOP) is proposed to found the best comprehensive performances (Liang et al., 2012) for particle swarm optimization. MOP is concerned with mathematical optimization problems involving more than one objective function to be optimized simultaneously. In order to obtain the objective function, correct Design of Experiments (DOE) is important.

Then it is necessary to choose a highly effective optimization method. Many optimization problems from the industrial engineering world are very complex and quite hard to solve by conventional optimization techniques. Inspired by observing the natural swarming behavior of bird flocking, Particle Swarm Optimization (PSO) was proposed (Eberhart and Kennedy, 1995). PSO algorithm is simple in concept, easy to implement and computationally inexpensive, so it attracts the attention of many scholars and researchers. Genetic Algorithm (GA) and PSO have been compared (Juang, 2004), which proved PSO is more simple and effective. PSO has been successfully applied to a wide range of application areas. PSO have been improved for different applications (Angeline, 1998; Andrews, 2006; Chen, 2015). PSO has been applied extensively in electromagnetics optimization (Jin and Rahmat-Samii, 2010), vehicle routing problem (Hu and Wu, 2010) and screening and classification in engineering applications (Chan et al., 2013; Agrawal and Bawane, 2015) etc. However, intelligent and efficient PSO has been little used in ocean engineering from being born.

In this paper, a new procedure for the optimal design of the FRDS UUV landing platform was presented, in which a complete design sequence was established. Hydrodynamic performance of the landing platform was analyzed by Ansys CFX. Multi-objective optimization model was built by response surface analysis. The global objective function was obtained according to the weight of subs. PSO algorithm was used to obtain the optimal solution. Finally, the optimal design scheme was accurately found in the feasible scheme. In conclusion, the comprehensive performances of landing platform are excellent compared with other design schemes.

2. Geometry configuration

The overall appearance of the FRDS UUV is a spheroid which is generated by revolving an ellipse about its short axis. Four propellers, which are uniformly installed on the ducts of the shell, work together as the vectored thrust unit. The manufacture and trial voyage of the FRDS UUV have been finished. Fig. 1(a) shows the four-rotor dish-shaped UUV we produced and Fig. 1(b) shows the schematic of the hydraulic support landing platform of the UUV.

Compared with the traditional underwater vehicle with slender body of revolution, the FRDS UUV has the advantages of high static stability and large bearing capacity. Due to a circular disc appearance, omnidirectional attitude motion is achieved, so the UUV is suitable for a small and complex water environment.

The hydraulic supports are designed and used to build the landing platform of the UUV. They have evident advantages to keep the stability of the FRDS UUV and avoid the interference of the uncertain factors from the seabed. Fig. 2 shows the external and internal structure view of the landing platform.

Several factors, including the shape of UUV, the hydraulic support types, fender positions, the seabed pattern and environmental conditions, should be taken into consideration in the design of a landing platform. In order to determine the system of landing platform, several main parameters are defined and listed in Table 1.

In order to optimize the design, i.e. the landing platform that lead to the minimum responses of the disturbance from ocean currents, the appearance and layout of hydraulic support should be taken into account primarily.

Based on the concept design of the hydraulic support landing platform, empirical design was completed to reduce the overturn moment as an initial design scheme. In this paper, 30 sample points (design schemes) were selected. The hydrodynamic characteristics of the landing platform were got using Ansys CFX, and the response values were obtained. Based on the important degree, the objective weights were obtained using score from experts. Then the global response surface model is established. Finally, PSO algorithm is applied to complete the optimization process. The design procedure schematic is shown in Fig. 3.

2.1. Instability type

Force analysis of landing platform is completed, as shown in Fig. 4. Instability type of the FRDS UUV landing platform is determined in this section. The equilibrium equation of the critical state is established for the two kinds of instability type.

The first kind of instability type: Side slip. When the hydrodynamic drag of the FRDS UUV and hydraulic support in the horizontal exceeds the friction between the fender and seabed, sideslip occurs. The mathematical model for the critical state can be obtained:

$$F_x + F_L - k_0 \cdot \left(G - F_y - N\right) \geq 0 \tag{1}$$

$$F_x = \int_{\Omega_t} [-p\cos(n,x) + \tau\cos(t,x)]d\Omega_t = C_x \frac{1}{2}\rho v_\infty^2 S \tag{2}$$

where F_L is the hydrodynamic drag of hydraulic support; F_x is hydrodynamic drag of the FRDS UUV; C_x is drag coefficient. Hydrodynamic drag and drag coefficient have a relationship as shown in Eq. (2); similarly, F_y is hydrodynamic lift of landing platform, and hydrodynamic forces and coefficients can be gained using Ansys CFX; k_0 represents friction coefficient.