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PARAMETRIC IDENTIFICATION AND SENSITIVITY ANALYSIS FOR AUTONOMOUS UNDERWATER VEHICLES IN DIVING PLANE*

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Abstract: The inherent strongly nonlinear and coupling performance of the Autonomous Underwater Vehicles (AUV), maneuvering motion in the diving plane determines its difficulty in parametric identification. The motion parameters in diving plane are obtained by executing the Zigzag-like motion based on a mathematical model of maneuvering motion. A separate identification method is put forward for parametric identification by investigating the motion equations. Support vector machine is proposed to estimate the hydrodynamic derivatives by analyzing the data of surge, heave and pitch motions. Compared with the standard coefficients, the identified parameters show the validation of the proposed identification method. Sensitivity analysis based on numerical simulation demonstrates that poor sensitive derivative gives bad estimation results. Finally the motion simulation is implemented based on the dominant sensitive derivatives to verify the reconstructed model.

Key words: parametric identification, Autonomous Underwater Vehicles (AUVs), support vector machine, sensitivity analysis

Introduction

Autonomous Underwater Vehicles (AUVs) are intelligent robots employed to carry out predefined underwater tasks. They play an irreplaceable role in the exploitation and utilization of ocean resources due to its non-substitutable superiority for risky and tiring undersea work. In recent years, AUVs are widely used for oceanographic survey, target detection, underwater rescue, mine hunting and so on. Take REMUS for example, it has successfully collected the density, salinity, temperature, water quality and other useful information[1]. To realize energy efficient AUV with low resistance, low energy consumption and excellent maneuverability, the researchers devoted themselves to improving the performance of the AUV modular, and conventional only-propeller- driven pattern is replaced by propeller-fin-driven model[2]. Consequently, the research on maneuvering performance of AUV with horizontal fins in diving plane is more significant, because the maneuverability in the horizontal plane is more or less the same as surface craft which has been extensively developed.

In the research on AUV's maneuverability in diving plane, the pivotal problem is precisely determining the hydrodynamic coefficients. For calculation of inertia coefficients, the common methods are captive model tests by Planar Motion Mechanism (PMM), regression estimation method with empirical formula

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and calculation method using potential theory. There are four frequently-used methods for calculation of viscous coefficients, which are empirical formula method, captive model test, Computational Fluid Dynamics (CFD) method based on viscous flow and method of free-running model or full-scale tests in combination with system identification. With the development of experimental measurement techniques and system identification methods, the forth method has been more and more widely employed.

In general, there are several commonly-used methods of system identification for underwater vehicles. The traditional techniques include the Least Square (LS) method[3], Maximum Likelihood (ML) method[4], and Extended Kalman Filter (EKF)[5], while the modern ones are those using artificial intelligent algorithm including Neural Network (NN)[6] and Support Vector Machines (SVM)[7]. With regard to the traditional methods, the approximation results would be sensitive to the initial value, which is unfavorable for maneuvering prediction. Two serious defects, i.e., bad generalization and so-called curse of dimensionality, restrict the application of NN, SVM was put forward based on statistical analysis in 1990s, and originally used to deal with pattern recognition and classification problem, but it performs very well in function regression. It is based on the law of minimization of structural risk, considering both empirical risk and level of confidence, which consequently improves its generalization performance. SVM contains the LS-SVM, ε support vector machines (ε-SVM), ν support vector machines (ν-SVM) and so on. It has been successfully applied to surface vehicles and satisfactory results have been gained[8,9].

In fact, even though the identification method is commendable, it is still difficult to obtain high-precision parameters for some complicated maneuvering motion models. On one hand, the sampling information including the sample size and the input excitation will influence the results, on the other hand, the characteristic of the model will also take effect due to the sensitivity of the system parameters. Sensitivity analysis is helpful for model development, model validation and reduction of uncertainty[10]. Rhee and Kim pointed out that the accuracy of the identification results is closely related to the sensitivity of the parameters[11], that is, more sensitive derivative gives more efficient estimation result. There are many different methods of sensitivity analysis. In this paper, a simple calculation process is adopted to measure the sensitivity of the viscous hydrodynamic derivatives. After that, the mathematical model for the AUV's diving motion is reconstructed.

This paper applies the LS-SVM method to identify the viscous hydrodynamic derivatives in the mathematical model of AUV's diving motion[12]. Zigzag-like simulation is carried out based on the mathematical model. Separate identification method is proposed to identify the hydrodynamic derivatives for surge, heave and pitch motions respectively. Sensitivity analysis is implemented to explain some poor results and the numerical simulation is carried out by using dominant sensitive coefficients.

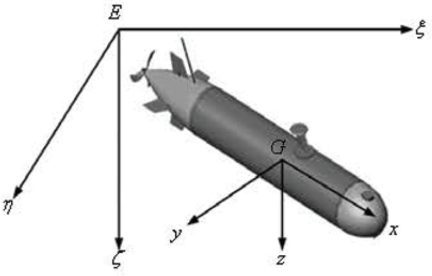

Fig.1 Global coordinates and local coordinates

1. Mathematical model for AUV's diving motion

To describe the motion characteristics for AUV, the coordinate system is established, as shown in Fig.1, where $E-\xi\eta\zeta$ denotes the global or inertial coordinate frames, while $G-xyz$ represents the local or body-fixed frames.

Generally, we should consider all the six degrees of freedom for the motion of an AUV, but only the maneuvering motion in the diving plane is considered here under the condition of weak maneuvering[13]. In addition, the environment surrounding the AUV, including ocean current, wall effect, wave interaction near the free surface and so on, is always extremely complicated[14,15]. Here, infinite deep and unbounded flow field is assumed, and the environment disturbance is ignored.

Under these assumptions, the mathematical model of the AUV maneuvering motion in the vertical plane, with the origin of the local coordinate system being located at the center of gravity, is described as follows[12]:

$$m(\dot{u}+wq)=\frac{\rho}{2}L^3\left(X'_{\dot{u}}\dot{u}+X'_{wq}wq\right)+\frac{\rho}{2}L^2$$

$$\left(X'_{u|u|}u|u|+X'_{\delta_s\delta_s}u^2\delta_s^2\right)+X_T \qquad 1(a)$$

$$m(\dot{w}-uq)=\frac{\rho}{2}L^4Z'_{\dot{q}}\dot{q}+\frac{\rho}{2}L^3\left(Z'_{\dot{w}}\dot{w}+Z'_{uq}uq\right)+\frac{\rho}{2}L^2$$

$$\left(Z'_{uu}u^2+Z'_{uw}uw+Z'_{w|w|}w|w|\right)+\frac{\rho}{2}L^2Z'_{\delta_s}\delta_s u^2 \qquad 1(b)$$

$$I_y\dot{q}=\frac{\rho}{2}L^5\left(M'_{\dot{q}}\dot{q}+M'_{q|q|}q|q|\right)+\frac{\rho}{2}L^4\left(M'_{\dot{w}}\dot{w}+M'_{uq}uq\right)+$$

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