# Dynamic Modeling and Computer Simulation for Autonomous Underwater Vehicles with Fins

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***Abstract*—The application of autonomous underwater vehicles (AUV) is widespread with the development of the activities in deep sea. For low energy consumption, low resistance and excellent maneuverability, fins are usually used to modify AUV hydrodynamic forces. The AUV with fins can do gyratory motion by vertical fins and do diving and rising motion by horizontal fins. However, the modeling and motion control of the AUV with fins have not been solved well, which this paper concentrates on. Firstly, we build the motion equation in six degree of freedom and analyze the forces and hydrodynamic coefficients in detail, especially the fin effect. The feasibility and accuracy are verified by comparing the results between ocean experiments and simulation on WL-II mini-AUV.**

***Index Terms*—autonomous underwater vehicle, dynamic modeling, fins, simulation**

## I. INTRODUCTION

With the development of the activities in deep sea, application of the AUV is widespread, and there is a very prominent prospect. The research on the AUV includes many areas, such as vehicle (carrier/platform) design, architecture, motion control, intelligent planning and decision making, etc [1-3]. Researchers dedicate themselves to improving the performance on modularization, low-cost AUV in such applications as long-range oceanographic survey, autonomous docking, and shallow-water mine countermeasures. These goals can be achieved through the improvement of maneuvering precision and motion control capability with energy constraints. For low energy consumption, low resistance, and excellent maneuverability, fins are usually used to modify AUV hydrodynamic force. The AUV with fins can do gyratory motion by vertical fins and do diving and rising motion by horizontal fins. Therefore, the control system of the propeller-fin-drived AUV is very different to the conventional only-propeller-drived AUV.

A dynamic mathematic model for the AUV with fins based on a combination of theory and empirical data would provide an efficient platform for control system development, and an alternative to the typical trial-and-error method of control system tuning. Although some modeling and simulation methods have been proposed and applied [4, 5, 8-11], there is no standard procedure for modeling the AUV with fins in industry. Therefore, the modeling and simulation of the AUV with fins is a challenge.

This paper describes the development and verification of a six degree of freedom (DOF), non-linear model for the AUV with fins. In the model, the external force and moment resulting from hydrostatics, hydrodynamic lift and drag, added mass, and the thrusters and fins are all analyzed and expressed in matrix form. The equations describing the rigid-body dynamics are left in non-linear form to better simulate the AUV inherently non-linear behavior. Motion simulation is achieved through numeric integration of the motion equations. The simulation output is then checked with the AUV dynamics data collected in experiments at sea. The comparison results show that the non-linear model gives an accurate estimation to the actual motion of the AUV. The research object is WL-II mini-AUV, which is a small, low-cost platform serving in a range of oceanographic applications [12].

## II. MATHEMATIC MODELLING OF AUV MOTION

### A. Coordinate System and Motion Parameters Definition

It is convenient to analyze the equations of the rigid-body motion respecting to a body-fixed reference frame which keep the body geometry invariant all the time. Basing on the recommendation of International Towing Tank Conference (ITTC) and the Society of Naval Architects and Marine Engineers (SNAME), we build two reference coordinates. Start with the application of Newton II law to the AUV motion by a fixed inertial frame of reference $E-\xi\eta\varsigma$ (global coordinates), and then transfer the equations to the body-fixed coordinates (local


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coordinates) $o-xyz$ through coordinate transformation relation. We can obtain 6-DOF equations of the rigid-body motion referred to as surge, sway, heave, roll, pitch and yaw. The global coordinates and local coordinates are illustrated in figure 1.

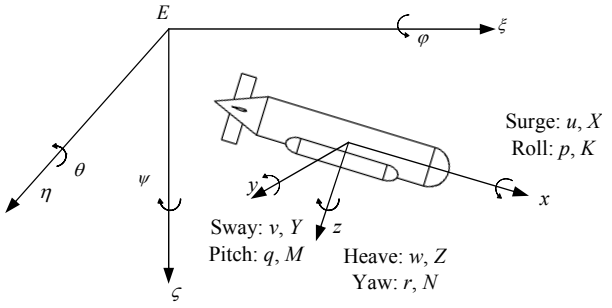



Figure 1. Body-fixed and inertial coordinate system.

Considering shape characteristics for most AUVs, the mathematic model is basing on the hypothesis that the AUV is symmetric on the *xoz* plane.

Defining generalized position vector $\mathbf{R}$, generalized velocity vector $\mathbf{V}$ and generalized force vector $\boldsymbol{\tau}$, the motion vector include

(1) Position and attitude (in *E-ξηζ*)

$$\mathbf{R}=[\mathbf{r}^T,\boldsymbol{\Lambda}^T]^T,\ \mathbf{r}=[\xi,\eta,\zeta]^T,\ \boldsymbol{\Lambda}=[\varphi,\theta,\psi]^T$$

(2) Linear and angular velocities (in *o-xyz*)

$$\mathbf{V}=[\mathbf{U}^T,\boldsymbol{\Omega}^T]^T,\ \mathbf{U}=[u,v,w]^T,\ \boldsymbol{\Omega}=[p,q,r]^T$$

(3) Force and moment parameters (in *o-xyz*)

$$\boldsymbol{\tau}=[\mathbf{F}^T,\mathbf{M}^T]^T,\ \mathbf{F}=[X,Y,Z]^T,\ \mathbf{M}=[K,M,N]^T$$

*B. Dynamics Model*

Basing on momentum theorem, the AUV dynamic equation is

$$\mathbf{M}_{RB}\dot{\mathbf{V}}+\mathbf{C}_{RB}(\mathbf{V})\mathbf{V}=\boldsymbol{\tau} \tag{1}$$

Where $\mathbf{M}_{RB}$ is the generalized mass matrix of the vehicle body, and $\mathbf{C}_{RB}(\mathbf{V})$ is the Coriolis and centripetal force matrix. $\mathbf{M}_{RB}$ is given by

$$\mathbf{M}_{RB}=\begin{bmatrix} m & 0 & 0 & 0 & mz_G & -my_G \\ 0 & m & 0 & -mz_G & 0 & mx_G \\ 0 & 0 & m & my_G & -mx_G & 0 \\ 0 & -mz_G & my_G & J_x & J_{xy} & J_{xz} \\ mz_G & 0 & -mx_G & J_{yx} & J_y & J_{yz} \\ -my_G & mx_G & 0 & J_{zx} & J_{zy} & J_z \end{bmatrix} \tag{2}$$

Where $m$ is the AUV mass, $J$ terms represent the inertial tensors, and $x_G$, $y_G$, $z_G$ represent the AUV position barycenter in local coordinates. $\mathbf{C}_{RB}(\mathbf{V})$ is given by

$$\mathbf{C}_{RB}(\mathbf{V})=\begin{bmatrix} 0 & -mr & mq & m(y_Gq+z_Gr) & -mx_Gq & -mx_Gr \\ mr & 0 & -mp & -my_Gp & m(z_Gr+x_Gp) & -my_Gr \\ -mq & mp & 0 & -mz_Gp & -mz_Gq & m(x_Gp+y_Gq) \\ -m(y_Gq+z_Gr) & my_Gp & mz_Gp & 0 & J_{zx}p+J_{zy}q+J_zr & -J_{yx}p-J_yq-J_{yz}r \\ mx_Gu & -m(z_Gr+x_Gp) & mz_Gq & -J_{zx}p-J_{zy}q-J_zr & 0 & J_xp+J_{xy}q+J_{xz}r \\ mx_Gr & my_Gr & -m(x_Gp+y_Gq) & J_{yx}p+J_yq+J_{yz}r & -J_xp-J_{xy}q-J_{xz}r & 0 \end{bmatrix} \tag{3}$$

Generalized force vector $\boldsymbol{\tau}$ at the right of (1) is outside force (or moment) acting on the AUV, including static force vector $\boldsymbol{\tau}_G$ (gravity and buoyancy), hydrodynamics force vector of the vehicle body (include $\boldsymbol{\tau}_A$ which is caused by added mass and viscous damping force $\boldsymbol{\tau}_V$), and the controlled force vector (include the thruster force $\boldsymbol{\tau}_{prop}$ and the fin force $\boldsymbol{\tau}_R$). The static force vector $\boldsymbol{\tau}_G$ reflects the effect of the vehicle weight and buoyancy. The vehicle weight is $W=mg$ and the buoyancy is $B=\rho\nabla g$, where $\rho$ is the density of the surrounding fluid, and $\nabla$ is the total volume displaced by the AUV. Therefore, $\boldsymbol{\tau}_G$ is given by

$$\boldsymbol{\tau}_G=\begin{bmatrix} X_G \\ Y_G \\ Z_G \\ K_G \\ M_G \\ N_G \end{bmatrix}=\begin{bmatrix} -(W-B)\cdot\sin\theta \\ (W-B)\cdot\sin j\cos\theta \\ (W-B)\cdot\cos j\cos\theta \\ (y_GW-y_BB)\cdot\cos j\cos\theta-(z_GW-z_BB)\cdot\sin j\cos\theta \\ -(x_GW-x_BB)\cdot\cos j\cos\theta-(z_GW-z_BB)\cdot\sin\theta \\ (x_GW-x_BB)\cdot\sin j\cos\theta-(y_GW-y_BB)\cdot\sin\theta \end{bmatrix} \tag{4}$$

Where $x_B$, $y_B$, $z_B$ are the vehicle coordinates in body-fixed coordinate system.

$\boldsymbol{\tau}_A$ which is related with added mass is given by

$$\boldsymbol{\tau}_A=-(\mathbf{M}_A\dot{\mathbf{V}}+\mathbf{C}_A(\mathbf{V})\mathbf{V}) \tag{5}$$

Where $\mathbf{M}_A$ is the added mass matrix, which is given by

$$\mathbf{M}_A = \begin{bmatrix} \lambda_{11} & 0 & \lambda_{13} & 0 & \lambda_{15} & 0 \\ 0 & \lambda_{22} & 0 & \lambda_{24} & 0 & \lambda_{26} \\ \lambda_{31} & 0 & \lambda_{33} & 0 & \lambda_{35} & 0 \\ 0 & \lambda_{42} & 0 & \lambda_{44} & 0 & \lambda_{46} \\ \lambda_{51} & 0 & \lambda_{53} & 0 & \lambda_{55} & 0 \\ 0 & \lambda_{62} & 0 & \lambda_{64} & 0 & \lambda_{66} \end{bmatrix} \tag{6}$$

Where $\lambda$ terms represent the vehicle added mass.

$\mathbf{M}_A$ can be also denoted as hydrodynamic coefficients expression:

$$\mathbf{M}_A = -\begin{bmatrix} X_{\dot{u}} & 0 & X_{\dot{w}} & 0 & X_{\dot{q}} & 0 \\ 0 & Y_{\dot{v}} & 0 & Y_{\dot{p}} & 0 & Y_{\dot{r}} \\ Z_{\dot{u}} & 0 & Z_{\dot{w}} & 0 & Z_{\dot{q}} & 0 \\ 0 & K_{\dot{v}} & 0 & K_{\dot{p}} & 0 & K_{\dot{r}} \\ M_{\dot{u}} & 0 & M_{\dot{w}} & 0 & M_{\dot{q}} & 0 \\ 0 & N_{\dot{v}} & 0 & N_{\dot{p}} & 0 & N_{\dot{r}} \end{bmatrix} \tag{7}$$

$\mathbf{C}_A(\mathbf{V})$ is a Coriolis-like matrix induced by $\mathbf{M}_A$,

$$\mathbf{C}_A(\mathbf{V}) = \begin{bmatrix} 0 & 0 & 0 & 0 & a_3 & -a_2 \\ 0 & 0 & 0 & -a_3 & 0 & a_1 \\ 0 & 0 & 0 & a_2 & -a_1 & 0 \\ 0 & a_3 & -a_2 & 0 & b_3 & -b_2 \\ -a_3 & 0 & a_1 & -b_3 & 0 & b_1 \\ a_2 & -a_1 & 0 & b_2 & -b_1 & 0 \end{bmatrix} \tag{8}$$

Where

$$\begin{cases} a_1 = \lambda_{11}u + \lambda_{13}w + \lambda_{15}q \\ a_2 = \lambda_{22}v + \lambda_{24}p + \lambda_{26}r \\ a_3 = \lambda_{31}u + \lambda_{33}w + \lambda_{35}q \\ b_1 = \lambda_{42}v + \lambda_{44}p + \lambda_{46}r \\ b_2 = \lambda_{51}u + \lambda_{53}w + \lambda_{55}q \\ b_3 = \lambda_{62}v + \lambda_{64}p + \lambda_{66}r \end{cases}$$

The viscous damping force $\boldsymbol{\tau}_V$ is given by

$$\boldsymbol{\tau}_V = \mathbf{D}(\mathbf{V})\mathbf{V} \tag{9}$$

The damping matrix $\mathbf{D}(\mathbf{V})$ is given by

$$\mathbf{D}(\mathbf{V}) = \begin{bmatrix} X_u + X_{u|u|}|u| & 0 & 0 & 0 & 0 & 0 \\ 0 & Y_v + Y_{v|v|}|v| & 0 & 0 & 0 & 0 \\ Z_0|u| & 0 & Z_w + Z_{w|w|}|w| & 0 & 0 & 0 \\ 0 & 0 & 0 & K_p + K_{p|p|}|p| & 0 & 0 \\ M_0|u| & 0 & 0 & 0 & M_q + M_{q|q|}|q| & 0 \\ 0 & 0 & 0 & 0 & 0 & N_r + N_{r|r|}|r| \end{bmatrix} \tag{10}$$

Where $X_u$, $Y_v$, $Z_w$, $K_p$, $M_q$, and $N_r$ are the linear damping coefficients. $Y_{v|v|}$, $Z_{w|w|}$, $K_{p|p|}$, $M_{q|q|}$, $X_{u|u|}$, and $N_{r|r|}$ are the quadratic damping coefficients. $M_0$ and $Z_0$ are the effect caused by the dissymmetry on *xoy* plane.

The external force and moment vector produced by thrusters $\boldsymbol{\tau}_{prop}$ is defined as

$$\boldsymbol{\tau}_{prop} = \mathbf{L}\mathbf{T}_{prop} \tag{11}$$

Where $\mathbf{L}$ is a mapping matrix, and $\mathbf{T}_{prop}$ is the thrust vector produced by thrusters given by

$$\mathbf{T}_{prop} = \begin{bmatrix} T_1 \\ T_2 \\ \vdots \\ T_n \end{bmatrix} \tag{12}$$

The number $n$ in $\mathbf{T}_{prop}$ depends on the number of thrusters. The mapping matrix $\mathbf{L}$ is a 6×n matrix that uses $\mathbf{T}_{prop}$ to find the overall force and moment acting on the vehicle.

Hydrodynamics of a single thruster is usually obtained through the in water test. A series of advance coefficient $J$ corresponding to the thrust coefficient $K_T$ data can be obtained from the in water test. Data from an in water test are shown in Fig.2. We fit the curve by the method of least squares and then obtain the fitted $J-K_T$ curve. In practical applications, we get advance coefficient $J$ and substitute it into fitted $J-K_T$ curve to get $K_T$. Finally, the thrust can be obtained. Detailed process is as follows:

(1) We get the advance coefficient $J$ from fluid velocity cross the propeller $V_{prop}$, the propeller diameter $D$, and the screw propeller rotate speed $n$ ($n$ is determined by controller): $J = \frac{V_{prop}}{nD}$.

(2) We put $J$ into fitted $J-K_T$ curve to get force coefficient $K_T$.

(3) We get the thrust forces by $\mathbf{T} = K_T n^2 D^4$.

The overall external force and moment vector produced by fins $\boldsymbol{\tau}_R$ is given by

$$\boldsymbol{\tau}_R = \begin{bmatrix} X_R \\ Y_R \\ Z_R \\ K_R \\ M_R \\ N_R \end{bmatrix} \tag{13}$$

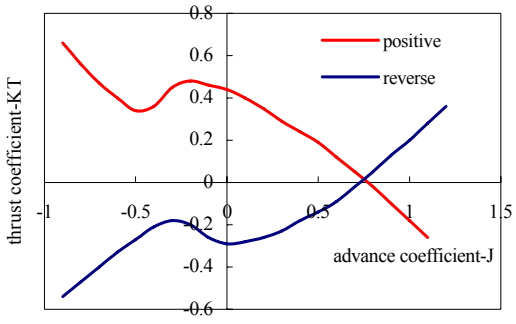



Figure 2. Capability curves of thrusters.

According to every single fin force and the installation position, $\boldsymbol{\tau}_R$ can be obtained.

As to a control fin on the vehicle, the hydrodynamic force can be decomposed into two directions: lift force **L**—vertical to stream current and drag force **D**—along stream current. Lift force and drag force can be calculated by the following equations:

$$\begin{cases} \mathbf{L} = \frac{1}{2} C_L \rho A_R v_e^2 \\ \mathbf{D} = \frac{1}{2} C_D \rho A_R v_e^2 \end{cases} \tag{14}$$

Where $C_L$ is the fin lift coefficient, $C_D$ is the fin drag coefficient, $A_R$ is the fin platform area, and $v_e$ is the effective fin velocity. The values of lift coefficient $C_L$ and drag coefficient $C_D$ are related with effective fin angle of attack $\alpha$.

We can adopt experiment, theory computation, or empirical formula to get $C_L$ and $C_D$. Experiment and empirical formula method will be introduced below.

(1) Actual measurement from experiment

A series of data of angles of attack $\alpha$ vs. lift coefficient $C_L$ and drag coefficient $C_D$ can be obtained from hydrodynamic experiment, and then fitted curves of $C_L$ and $C_D$ can be generated through least squares fit. For example, the fitted curves of a fin is shown in Fig.3.

When we know the current angle of attack of fin on the AUV, the values of $C_L$ and $C_D$ under this angle can be obtained by curves interpolation.

(2) Method of empirical equation

The empirical equations to calculate $C_L$ and $C_D$ are given by

$$C_L = \frac{\partial C_L}{\partial \alpha} \times \alpha + \frac{C_{DC}}{\lambda} (\frac{\alpha}{57.3})^2 \tag{15}$$

$$\frac{\partial C_L}{\partial \alpha} = \frac{0.9(2\pi)\lambda}{57.3[\cos \Lambda \sqrt{\frac{\lambda^2}{\cos^4 \Lambda} + 4} + 1.8]} \tag{16}$$

$$C_D = C_{d0} + \frac{C_L^{\,2}}{e\pi\lambda} \tag{17}$$

Where $\frac{\partial C_L}{\partial \alpha}$ is the slope at $\alpha$=0 in lift coefficient curves, and $C_{DC}$ is the drag coefficient of cross current which depends on tip shape and rake ratio (e.g. Quadrate tip: $C_{DC}$ =0.8. Smooth tip: $C_{DC}$ =0.4). $C_{d0}$ is the airfoil profile drag coefficient (viscous drag). For the profile section NACA0015, $C_{d0}$ =0.0065. $\Lambda$ is the sweptback angle at 1/4 chord of the fin. $\lambda$ is the aspect ratio. $\alpha$ is the angle of attack (degree).

In order to get $C_L$ and $C_D$, we should know the real effective angle of attack. As the fin located at some offset from the origin of the AUV coordinate system, it experiences the following effective velocities

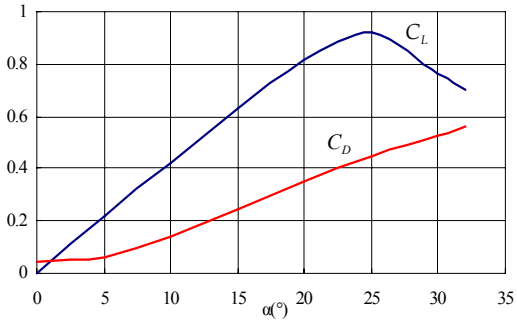



Figure 3. Lift and drag coefficient curves.

$$\begin{cases} u_{fin} = u + z_{fin} - y_{fin} r \\ v_{fin} = v + x_{fin} r - z_{fin} p \\ w_{fin} = w + y_{fin} - x_{fin} q \end{cases} \tag{18}$$

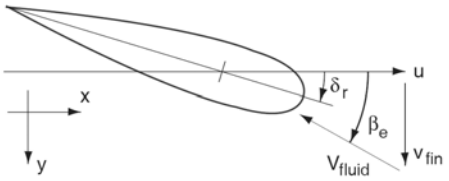
Where $x_{fin}$, $y_{fin}$ and $z_{fin}$ are the body-fixed coordinates of the fin posts.

The effective fin angles of attack $\delta_{se}$ and $\delta_{re}$ are given by

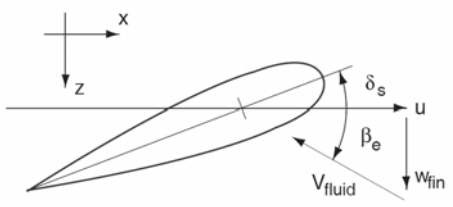
$$\begin{cases} \delta_{se} = \delta_s + \beta_{se} \\ \delta_{re} = \delta_r + \beta_{re} \end{cases} \tag{19}$$

Where $\delta_r$ and $\delta_s$ are the fin angles referenced to the vehicle hull, $\beta_{re}$ and $\beta_{se}$ are the effective angles of attack of the fin zero plane, as shown in Fig.4. $\beta_{re}$ and $\beta_{se}$ are given by

$$\begin{cases} \beta_{re} = \frac{v_{fin}}{u_{fin}} = \frac{v + x_{fin} r - z_{fin} p}{u + z_{fin} - y_{fin} r} \\ \beta_{se} = \frac{w_{fin}}{u_{fin}} = \frac{w + y_{fin} - x_{fin} q}{u + z_{fin} - y_{fin} r} \end{cases} \tag{20}$$




(a) Effective rudder angle of attack




(b) Effective stern plane angle of attack

Figure 4. Effective angle of attack scheme.

Basing on the above analysis, (1) could be rewritten into more detailed form.

$$(\mathbf{M}_{RB}+\mathbf{M}_{A})\dot{\mathbf{V}} = \boldsymbol{\tau}_{G}+\boldsymbol{\tau}_{prop}+\boldsymbol{\tau}_{R}+\mathbf{D}(\mathbf{V})\mathbf{V}-(\mathbf{C}_{RB}(\mathbf{V})+\mathbf{C}_{A}(\mathbf{V}))\mathbf{V} \quad (21)$$

### C. Kinematics Model

The coordinate transformation between body-fixed coordinate system and inertial coordinate system can is given by

$$\begin{bmatrix}\dot{\xi}_G\\ \dot{\eta}_G\\ \dot{\zeta}_G\\ \dot{\varphi}\\ \dot{\theta}\\ \dot{\psi}\end{bmatrix}=\begin{bmatrix}T_1 & 0_{3\times3}\\ 0_{3\times3} & T_2\end{bmatrix}\begin{bmatrix}u\\ v\\ w\\ p\\ q\\ r\end{bmatrix} \quad (22)$$

Where $\xi_G$, $\eta_G$ and $\zeta_G$ are the barycentre coordinates in inertial coordinate system, $\mathbf{T}_1$ and $\mathbf{T}_2$ are coordinate transform matrix given by

$$\mathbf{T}_1=\begin{bmatrix}\cos\psi\cos\theta & \cos\psi\sin\theta\sin\varphi-\sin\psi\cos\varphi & \cos\psi\sin\theta\cos\varphi+\sin\psi\sin\varphi\\ \sin\psi\cos\theta & \sin\psi\sin\theta\sin\varphi+\cos\psi\cos\varphi & \sin\psi\sin\theta\cos\varphi-\cos\psi\sin\varphi\\ -\sin\theta & \cos\theta\sin\varphi & \cos\theta\cos\varphi\end{bmatrix} \quad (23)$$

$$\mathbf{T}_2=\begin{bmatrix}1 & \tan\theta\sin\varphi & \tan\theta\cos\varphi\\ 0 & \cos\varphi & -\sin\varphi\\ 0 & \sin\varphi\sec\theta & \cos\varphi\sec\theta\end{bmatrix} \quad (24)$$

### D. Numerical Integration

Given the complex and highly nonlinear nature of (21) and (22), we will use numerical integration to solve these equations and get the vehicle speed, position, and attitude vs time.

The non-linear state equation of the AUV is given by

$$\dot{\mathbf{x}}_n=\mathrm{f}(\mathbf{x}_n,\mathbf{u}_n) \quad (25)$$

Where $\mathbf{x}_n$ is the state vector, and $\mathbf{u}_n$ is the input vector:

$$\mathbf{x}_n=[u\quad v\quad w\quad p\quad q\quad r\quad \xi\quad \eta\quad \zeta\quad \varphi\quad \theta\quad \psi]^T \quad (26)$$

$$\mathbf{u}_n=[\boldsymbol{\tau}_{prop}\quad \boldsymbol{\tau}_R] \quad (27)$$

Here, Runge-Kutta of numerical integration is usually used to solve the equations. Firstly, we calculate the following equations

$$\begin{aligned}k_1&=\boldsymbol{x}_n+\mathrm{f}(\mathbf{x}_n,\mathbf{u}_n)\\ k_2&=\mathrm{f}(\mathbf{x}+\frac{\Delta t}{2}k_1,\mathbf{u}_{n+\frac{1}{2}})\\ k_3&=\mathrm{f}(\mathbf{x}+\frac{\Delta t}{2}k_2,\mathbf{u}_{n+\frac{1}{2}})\\ k_4&=\mathrm{f}(\mathbf{x}+\Delta t k_4,\mathbf{u}_{n+1})\end{aligned} \quad (28)$$

Where the interpolated input vector is

$$\mathbf{u}_{n+\frac{1}{2}}=\frac{1}{2}(\mathbf{u}_n+\mathbf{u}_{n+1}) \quad (29)$$

Then, we combine the above equations

$$\mathbf{x}_{n+1}=\mathbf{x}_n+\frac{\Delta t}{6}(k_1+2k_2+2k_3+k_4) \quad (30)$$

### E. Simulation and Comparison

Basing on the above mathematic modelling and analysis, we build the simulation system of WL-II mini-AUV [12]. We can obtain the present relative acceleration of the AUV in the global coordinates, and the velocity of the next moment through Runge-Kutta numerical integral, and the displacement of the next moment further. The operating flowchart is shown in figure 5. The visual simulation system is shown in figure 6.

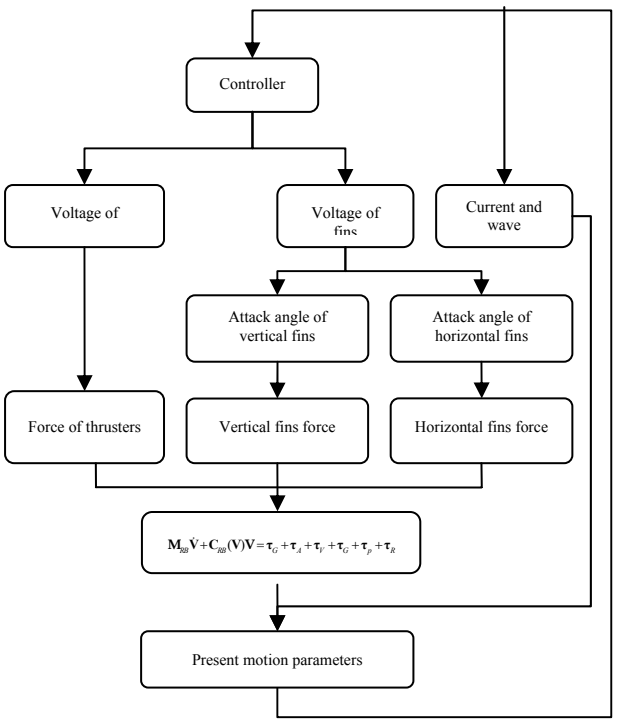
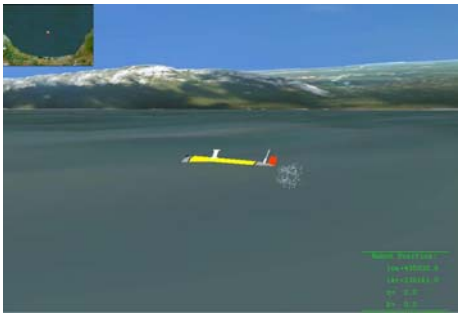



Figure 5. Operating flowchart of the simulation system.

The simulation results are compared with the results of at-sea experiments. The zigzag-like motions in horizontal plane and vertical plane are simulated and the Comparisons are shown in figure 7.

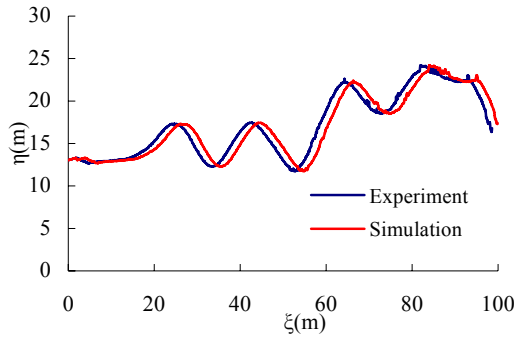


(a) Waterborne navigation

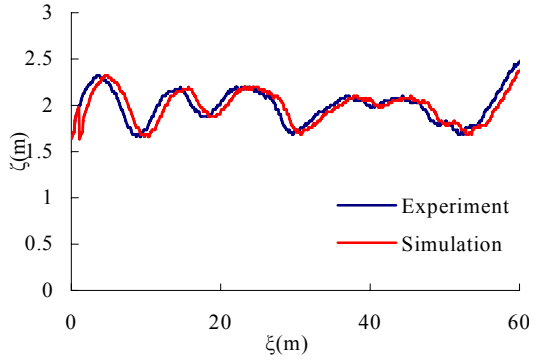
(b) Underwater navigation

Figure 6. Visual simulation system of WL-II mini-AUV.

From the comparison between simulation results and experiment results, we can conclude that the mathematic model of the AUV motion and the numerical integration method are accurate and feasible.




(a) Zigzag-like motion in horizontal plane




(b) Zigzag-like motion in horizontal plane

Figure 7. Comparison of simulation results.

## CONCLUSION

This paper concentrates on the problem of dynamic modeling for the AUV with fins. Firstly, we build motion equation in 6-DOF and analyze the force and hydrodynamic coefficients in detail, especially the fin effect. We build the simulation system according to deduction of the proposed mathematical model. The feasibility and accuracy are verified by comparing the results between at-sea experiments and simulation for WL-II mini-AUV. The results verify the feasibility and the superiority of the mathematical modeling. Moreover, the model and simulation system can be used universally to most AUVs with fins.

## ACKNOWLEDGMENT

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