Nonlinear Modeling, Simulating and Experiment of an Autonomous Surface Vehicle Driven by Twin Electric Thrusters

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***Abstract-* This paper presents a nonlinear model of a catamaran-style Autonomous Surface Vehicle (ASV) thrust with twin fixed propellers, which are driven by DC electric motors. A total model including resistance of boat body, propulsion force and driving characteristics of motor is established. Response for a full range of the ASV motion is simulated according to the model, based on which the performance of the ASV is discussed. Experiment results from sea test are in accord with the ones from simulating, which validate the nonlinear model. Compared with the classical linearized models, the advantage of the nonlinear model lies in convenience for dealing with system response for the full range of ASV motion.**

I. INTRODUCTION

Being able to carry out some dangerous missions on water surface, Autonomous Surface Vehicle (ASV) has attracts many researchers. With compact and effective GPS as well as long range and higher bandwidth wireless data systems becoming affordable, researches and applications proliferated in last decade [1-2]. So far, a variety of ASVs have been developed by some academic labs, corporations and government users [3-8]. Inspired by these projects and required by development of Shanghai International Maritime Center, we developed an ASV, which is aimed at multi-mission applications, including harbor surveillance, water quality sampling, hydrologic survey, maritime search and rescue, and so on.

Modeling and identification is a basic issue for control of ASV [9], and some models and approaches have been proposed. Reference [10] presents modeling, simulating and control of the autonomous surface marine vehicle Measuring Dolphin. Reference [11] proposes a practical approach to modeling and identification of small autonomous surface craft. Reference [12] presents identification of a control oriented nonlinear dynamic USV model. In order to make our ASV have satisfying control performance, it is necessary to model the control object properly. Based on the above references, we established a complete dynamic model of the ASV. Because the body resistance, propeller and electric motor characteristics are nonlinear, the model is nonlinear. With classical linearized model, one can only analyze the control performance in the vicinity of the linearization state. For investigating dynamic performance of the ASV motion in a full range, the nonlinear model proved to be convenient.

II. MODELING AND SIMULATING

A. Modeling

The ASV can be idealized as the motion model shown in Figure 1, where F1 and F2 are thrust force from the twin propellers fixed on the left and right side of the stern, and *f* is the resistance of the boat body. The linear speed of the ASV is denoted as V, while angular speed on the water surface is ω. Motion of the ASV can be expressed with the following equations.

$$m \cdot \dot{V} + f = F_1 + F_2 \tag{1}$$

$$J \cdot \dot{\omega} + k_{\omega} \cdot \omega = \frac{d}{2}(F_2 - F_1) \tag{2}$$

$$J_i \cdot (\frac{\pi}{30}) \cdot \dot{n}_i + T_i = M_i \qquad (i=1,2) \tag{3}$$

$$L_i \cdot \dot{I}_i + k_{ni} \cdot n_i + R_i \cdot I_i = U_i \tag{4}$$

$$F_i = K_{Fi} \cdot \rho \cdot n_i^2 \cdot D_i^4 \tag{5}$$

$$f = f(V) \tag{6}$$

$$T_i = K_{Ti} \cdot \rho \cdot n_i^2 \cdot D_i^5 \tag{7}$$

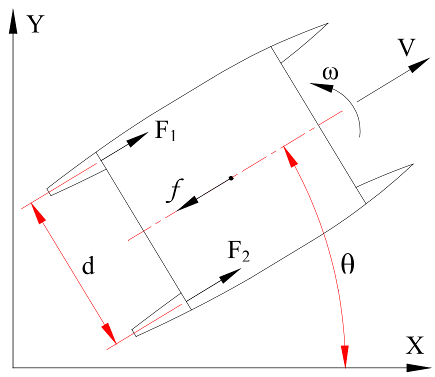

Figure 1. motion model of the ASV

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$$M_i = k_{Mi} \cdot I_i \qquad (8)$$

$$\theta = \int_0^t \omega \cdot dt \qquad (9)$$

The equation (1) expresses translation motion of the ASV, where m is the mass of the ASV. The equation (2) describes its rotation, where J is ASV's rotational inertia, and k_ω is its damp coefficient of rotation. The equations (3), (5) and (7) express characteristics of the left or right propeller, where J_i, n_i and T_i is their rotational inertia, rotational speed and torque required respectively, and K_{Fi}, K_{Ti}, ρ and D_i is their thrust coefficient, torque coefficient, dense of water around and diameter. The equations (4) and (8) describe characteristics of the left or right electric-motor, where L_i, k_{ni}, R_i, and U_i is their self-inductance coefficient of the armature, back EMF constant, armature resistance and control voltage input respectively, and M_i, K_{Mi}, I_i is their torque output, torque coefficient and current flowing through armature. The resistance f is a function of the ASV speed V, obtained through curve fitting with data of resistance test. Due to nonlinearity of (5), (6) and (7), the system is nonlinear.

B. *Simulating*

To verify the model, different control voltage is input to the left and right electric motor, as shown in the plot (1,1) and (2,1) of Figure 2. Current response flowing though the corresponding armature is shown in plot (1,2) and (2,2). Rotational speed of the propeller is shown in plot (1,3) and (2,3) respectively. Plot (3,1) shows the linear speed of ASV, and plot (3,2) describes rotational speed of the ASV around its center of mass in the horizontal plane, i.e. the change of its heading direction. The last plot (3,3) shows the trajectory of the ASV motion.

It can be seen that when both of the electric motors are input rated voltage of 24V, the ASV runs along a straight line and reaches its rated speed of about 3.8m/s. If one of the motors stops and the other operates under the rated voltage, the ASV runs along a circle, whose diameter is about 20m as shown in plot (3,3), when the change of its heading direction is constant as shown in plot (3,2). The simulating result accords with our design specification.

It also can be seen that when one of the motors stops and the other operates under the rated voltage, the propeller whose driving motor has been cut off power is still rotating with a low speed as shown in plot (3,1) and (3,2). This is because the ASV is moving, with the water flow actuating the propeller. The propeller drives the motor, making it a electric generator, resulting the negative current as shown in plot (1,2) and (2,2).

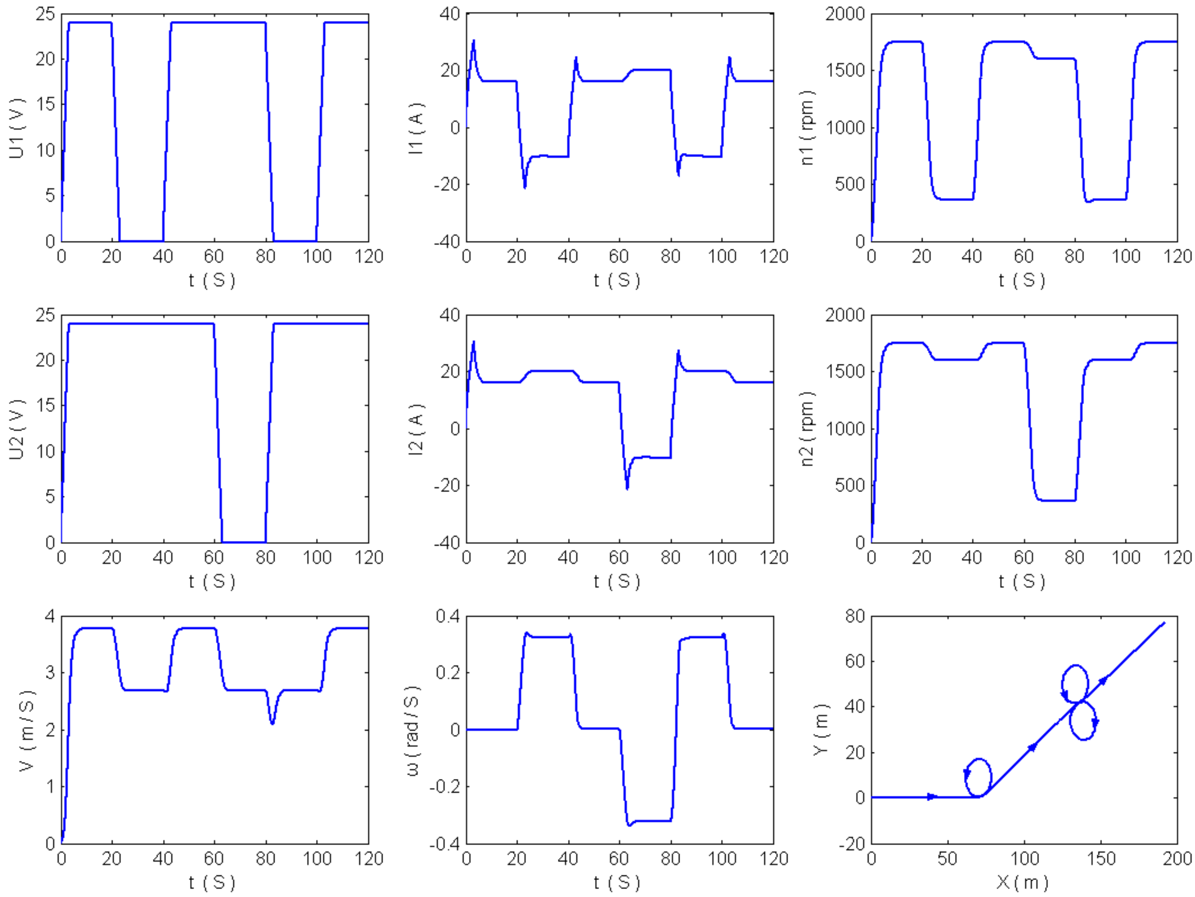

Figure 2. A simulating result

III. EXPERIMENT RESULTS

The ASV was tested at Fengxian bay of Shanghai in August 2008, as shown in Figure 2, when the sea state is level 2~3.

When both of the electric motors are input rated voltage of 24V, the ASV reached its rated speed of 3.1m/s. The trajectory of the ASV is a bit curve, not a straight line. This may be caused by the wave, or because the difference between the two motors and propellers.

When one of the motors stops and the other operates under the rated voltage, the ASV indeed runs along a circle. The diameter of the circular trajectory is about 20m, which accords with the simulating result.

As the rated speed and the diameter of the circular trajectory can describe the performance of an ASV, and both parameters from sea trial accord with the simulating results, the model proposed is effective.

IV. CONCLUSION

The nonlinear model of the catamaran-style ASV with twin fixed propellers driven by DC electric motors can describe its motion in a full range. Experiment results from sea test are in accord with the ones from simulating. Compared with the classical linearized models, the advantage of the nonlinear model lies in convenience for dealing with system response for the full range motion.

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Figure 3. The ASV on sea trial

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