NONLINEAR CONTROL OF UNMANNED SURFACE VEHICLE

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Abstract

An Unmmaned Surface Vehicle is a marine vehicle which has a complicated nonlinear model and partially uncertain parameters in its model. Therefore, an USV needs an advance control technique to solve this complicated problem. Nonlinear control is the most suitable technique to control this model. Nonlinear control is less sensitive to parameter uncertainty and disturbance perturbation which is beneficial for Unmanned Surface Vehicle which has highly disturbance parameter perturbation also. In the previous work, a disturbance model has never been considered in the control process due to highly perturbation in the model. Therefore, this work take account of the disturbance factors of Unmanned Surface Vehicle model.

Keywords
Nonlinear, control, unmanned, disturbance.

INTRODUCTION

A marine vehicle such as Unmanned Surface Vehicle is an essential vessel in marine industry because it sails in the ocean, lakes, and river. Therefore, an adequate control engineering technique is needed in order to have USV sailing save on the water. There are many researches in control field have been conducted for this work, such as PID, backstepping control, sliding mode control, fuzzy control, and neural network control. However, USV is still a complex nonlinear model which is hard to control. PID performs poor control due to highly nonlinear model of USV. While fuzzy control and neural network data is cannot be reliable and also complicated, so that the intelligent control also weak for USV.

On the other hand, nonlinear control has proven itself as a powerful technique for a complex nonlinear model. Nonlinear control is the most suitable technique to be used for tracking and regulating the set point of nonlinear model, whereas backstepping approach which utilizes Lyapunov function is an excellent tool to ensure the system stable in the equilibrium point. In general, nonlinear control has been proven able to give approximately robust control performance.

In this paper, a nonlinear control approach is developed for tracking control of Unmanned Surface Vehicle. A nonlinear control is a powerful tools to control nonlinear model with uncertain parameters such as USV since the technique is less sensitive to parameter change especially disturbance perturbation.

There are many nonlinear control of unmanned surface vehicle have been conducted. However, those works were not considering the disturbance factors. Therefore, this paper describes the nonlinear control of unmanned surface vehicle considering disturbance factors.

RESEARCH METHODOLOGY

MODEL FORMULATION

Unmanned Surface Vehicle model formulation consist of kinematics formulation and dynamics formulation

a. Kinematics Model
   A ship model generally requires six coordinates which are surge, sway, heave, roll, pitch, and yaw. While, USV only needs three coordinates which are surge, sway, and yaw. USV has two fixed frames which are earth fixed frame and the body fixed frame. The earth fixed frames consist of position and heading in vector which is set as:

$$\partial = [x, y, \alpha]^3 \quad (1)$$

The body fixed frame consists of velocity vectors which are surge, sway, and yaw. However the sway velocity is neglected, so that the velocity vector is set as

$$v = [u, r]^T \quad (2)$$

Therefore, the kinematics equation of the USV is set as:

$$\dot{\partial} = D(\partial)v \quad (3)$$

Where

$$D(\partial) = \begin{bmatrix} \cos(\alpha) & 0 \\ \sin(\alpha) & 0 \\ 0 & 1 \end{bmatrix} \quad (4)$$

Then set desired path reference as:

$$\partial_{\mathrm{d}} = [x_d, y_d, \alpha_d]^T \quad (5)$$

While, the desired velocity vectors is set as;

$$v_d = [u_{d,} r_d]^T \tag{6}$$

Sway velocity is neglected for USV. In addition, the desired trajectory is set as:

$$\dot{\partial}_d = D_d(\partial) v_d \tag{7}$$

where:

$$D_d(\partial) = \begin{bmatrix} \cos(\alpha_d) & 0 \\ \sin(\alpha_d) & 0 \\ 0 & 1 \end{bmatrix} \tag{8}$$

b. Dynamic Model

The nonlinear dynamic of USV is given by (7):

$$M(\dot{v}) + C(v)v + D(v)v = f + f_d \tag{9}$$

$$f_d = [f_1 f_2 f_3]^T \tag{10}$$

where:

M = Inertia matrix
C = Carioles matrix
D = Damping matrix
f_d = Disturbance

Their structures is given by:

$$M = \begin{bmatrix} m11 & 0 & 0 \\ 0 & m_{22} & 0 \\ 0 & 0 & m_{33} \end{bmatrix}$$

$$C(v) = \begin{bmatrix} 0 & 0 & -m_{22}v \\ 0 & 0 & m_{11}u \\ m_{22}v & -m_{11}u & 0 \end{bmatrix}$$

$$D(v) = \begin{bmatrix} d11 & 0 & 0 \\ 0 & d_{22} & 0 \\ 0 & 0 & d_{33} \end{bmatrix}$$

The parameter of M, C (v), and D (v) are partially uncertain

RESULT AND DISCUSSION

NONLINEAR CONTROL FORMULA

In this section we discuss tracking of USV position on the earth fixed frame (x,y,α) . We use a feedback linearization method on the equation (2.3) to select the kinematic control law as shown below:

$$\begin{bmatrix} u_1 \\ r_1 \end{bmatrix} = \begin{bmatrix} \cos(\propto_d) & 1 \\ \sin(\propto_d) & 1 \\ 0 & 1 \end{bmatrix}^T \begin{bmatrix} R_x \\ R_y \\ R_\propto \end{bmatrix} \quad (11)$$

where:

$$R_x = \dot{x}_d - K_x(x - x_d) \quad (12)$$

$$R_y = \dot{y}_d - K_y(y - y_d) \quad (13)$$

$$R_\alpha = \dot{\alpha}_d - K_\alpha(\alpha - \alpha_d) \quad (14)$$

Then we employ input control law in the kinematic equation, as shown below:

$$\dot{\partial}_1 = D_1(\partial_1)v_1 \tag{15}$$

where:

$$\dot{\partial}_1^{\ T} = [\dot{x}_1 \ \ \dot{y}_1 \ \ \dot{\propto}_1] \tag{16}$$

$$D_1(\partial_1) = \begin{bmatrix} \cos(\alpha_1) & \sin(\alpha_1) & 0 \\ 1 & 1 & 1 \end{bmatrix} \tag{17}$$

$$v_1 = [u_1 \, r_1]^T \tag{18}$$

Similar with the kinematic equation, we also employ the control law in the dynamic equation as shown below:

$$M(\dot{v_1}) + C(v_1)v_1 + D(v_1)v_1 = f + f_d \tag{19}$$

So that, schematic control system can be shown as below:

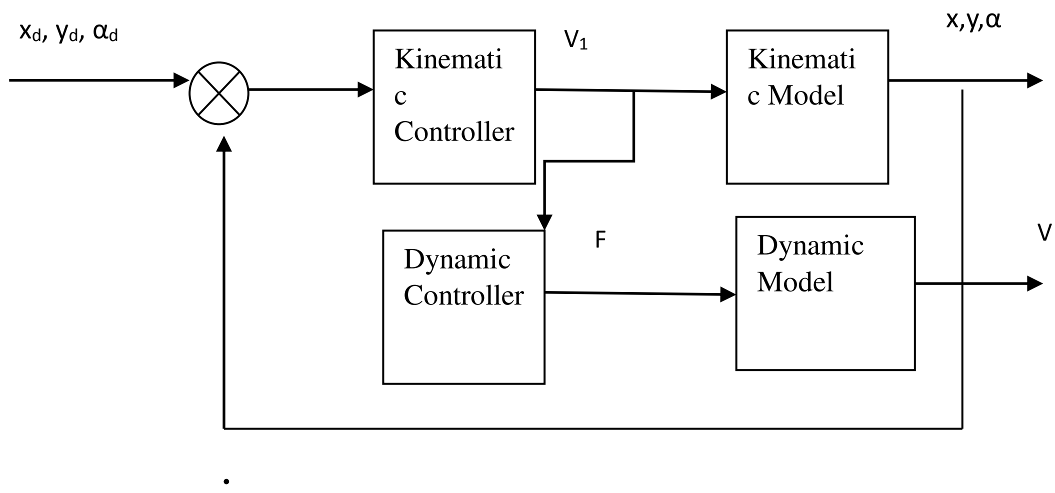

Figure 1.
USV nonlinear control block diagram.

In order to obtain the trajectory control, set USV data from [7] such as:

Table 1.
Physical data of Unmanned Surface Vehicle

$m_{11} = 2.0$
$m_{33} = 0.05$
$d_{11} = 2.45$
$d_{33} = 0.04$

We use matlab/simulink for simulation the USV model and it is examined in time domain. The nonlinear model of USV is described detail in [7].

Finally, we get the simulation result of tracking control of USV as shown bellow.

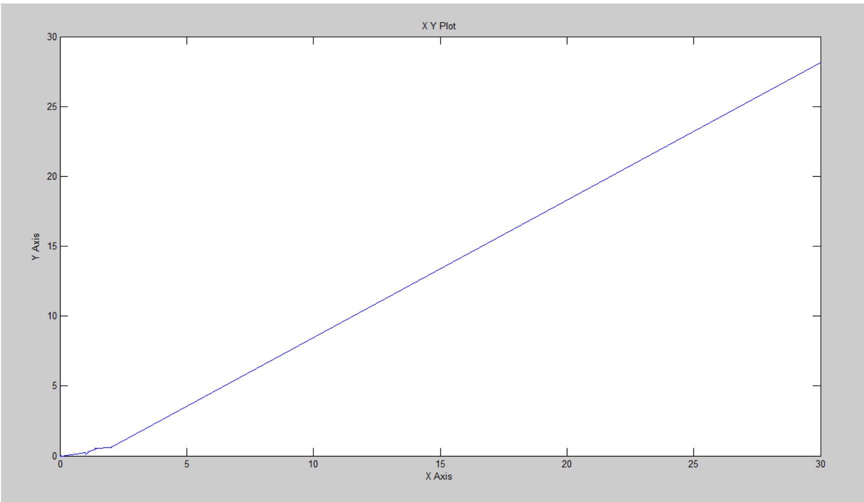

Figure 2.
Tracking control of USV linear trajectory (x, y).

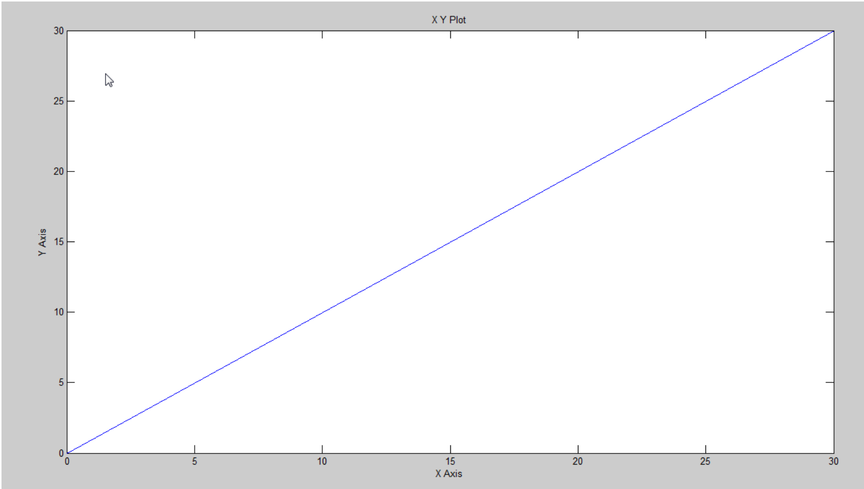

Figure 3.
Tracking control of USV desired trajectory.

Figure 2 shows that the actual USV model start unstable for a few second before it reach stability condition. The actual position control almost able to follow the desired trajectory (x,y) state feedback. So that, the nonlinear control has able to control nonlinear USV dispute its parameter uncertainities and disturbance parameter perturbation.

Eventhough, Unmanned Surface vehicle has a highly nonlinear mathematic model, the simulation result demonstrate that the vehicle still able to track the linear trajectory (x,y) satisfactory. However, we still expect a more robust output in real time experiment. Therefore, we need more advance nonlinear method or an intelligent control method to control this marine vehicle better than this nonlinear method.

CONCLUSION

This paper describe about nonlinear control of unmanned surface vehicle. Unmanned surface vehicle has a complicated nonlinear model which is difficult to control. However, this paper tries to use nonlinear control method to track the desired trajectory. Nonlinear control is recognized less sensitive to uncertain parameters and disturbance perturbation. Therefore this method is suitable with a highly nonlinear model which has partially uncertain parameters such as Unmanned Surface Vehicle. This work also emphasis on disturbance presents so that the control performing satisfies the design. In the future work, we expect the input saturation and the actuator model will also take into account of the control design.

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