Control of an Unmanned Surface Vehicle with Rudderless Double Thrusters

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Abstract: USVs is very important in sailing performance and navigation costs. Usually USVs have combination of thrusters and rudder. In this paper, USV with rudderless double thrusters is used. Three degrees of freedom (DOFs) dynamic model and propeller thrust model of USV are derived and combined.
The propulsion of the USV force generated by double thrusters and the rotational moment was related to the differential thrust. The feedback control system is realized using A proportional derivative +line of sight (PD+LOS) control algorithm to achieve , the path-following control of the USV. Simulations for different scenarios are developed using MATLAB and LABVIEW toolboxes. Simulation results are reconnoitered to verify the validity of the proposed model and the efficiency of the designed controller algorithm.

Key words: USV; DC motor, LOS, LABVIEW, MATLAB, PD controller.

I. Introduction

Unmanned surface vehicles (USVs) played an important role in the field of intelligent ships. By using a many kind of sensors, it can continuously monitor various marine phenomena such as ocean waves. USV has small size, intelligence, and unmanned nature to avoid casualties, which use in anti-mine warfare, maritime security protection, and other military fields. In recent years, there are development of environmental sensing, wireless communication, positioning and navigation for USVs which use it in autonomous navigation and path-following control [1-3]. It plays necessary role in some marine application. it is necessary to establish a mathematical model about the kinematics and kinetics performance for effective motion control of USVs. Based on Three-(DOFs) model, it can get a trajectory and tracking path to follow a trajectory of target vehicle [4].
In recent years, the technological development of environmental sensing, wireless communication, positioning and navigation for USVs has made significant progress [5-7] the motion control aspect of USVs has lagged, such as in autonomous navigation and path-following control. It plays an essential role in some marine applications, such as seawater monitoring for fixed points, water sampling for fixed paths and even tracking control of the ordinary merchant ship [8].

I. Propulsion system

The propulsion system used to generate the continuous o/p of USV power and is a necessary part of the USV. It contains two direct-current (DC) thrusters powered by a 12 V. The thrusters are equipped with two three-blade propellers which are contain two rotary speed controllers, respectively. The USV requires two inputs, n1 and n2, where n1 and n2 are the two propeller speeds in Revolutions Per Second (RPS). Its use for control the USV velocity and to calculate the heading angle.

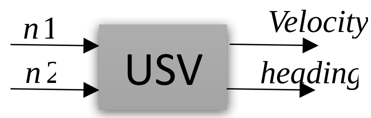

Fig 1. Block diagram of the propulsion system

n_c and n_d represent the common mode and differential mode propeller speeds

$$n_c=(n_1+n_2)/2$$

$$n_d=(n_1-n_2)/2$$

The USV needs to generate momentum by the deferential thrust between the port and starboard propellers to change the heading. During this process, the velocity also changes, so there is a coupling between the velocity and the yaw rate.
we use the rudderless double thrusters because of:

- double thrusters produce the steering moment.
- simplifies the mechanical structure of the USV.
- makes the steering of the USV more flexible.
- greatly improves the reliability and energy conversion rate of the USV.

II. Three-DOF Dynamic Model and Propeller Thrust Model

The accurate USV model is depend on design of control methodology design and simulation process. This requires both mathematical model and suitable system parameters. Generally, USV dynamic model can be divided into two parts: kinematics and kinetics, use for analysis of the forces causing the motion controller and generate feedback control loop which using in control systems.

i. Kinematic

The vessel moves in six DOFs, defined by: surge, sway, heave, roll, pitch, and yaw. but, we will simplify to 3 DOF Because some DOFs in the USV model have inherent stability, the buoyancy of the USV stabilizes can be ignored. Because of the sufficient longitudinal and lateral metacentric height of the USV, the motion of roll and pitch can also be ignored. three-DOF model of USV is surge, sway and yaw, as shown in fig 3:

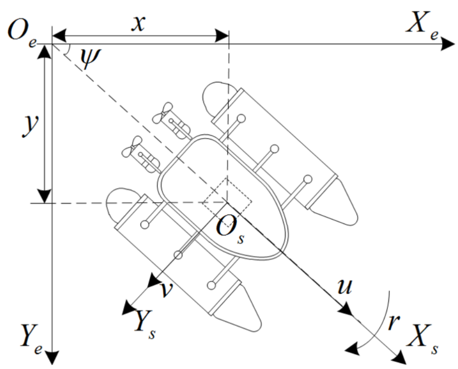

fig2 . three DOF of the USV diagram.

Which treats only geometrical aspects of motion.

$$\dot{\eta}=J(\eta)v \quad \dot{\eta}=[\dot{x}\,\dot{y}\,\dot{\psi}]^T$$

describes the vehicle linear North($\dot{x}$x), East($\dot{y}$),and Z-axis angular velocities($\dot{\psi}$) in the earth-fixed frame.

$\eta¿[x\, y\, \psi]^T$ is the position (x, y) and yaw (ψ) of the USV in the earth-fixed frame.

$v=[u\, v\, r]^T$ is the vehicle surge velocity (u), sway velocity (v) and yaw rate (r).

ii. Kinetic

We use for designing the control system of the USV Taylor-series expansions, it has advantages to make 6 DOF convert to 3DOF which use this way to identification the system model and use it for simulation to estimate the motion of vessel in water before make hard ware in the loop.

$$M\dot{v}+C(v)v+D(v)v=\tau+\tau_E \quad \text{(6 DOF equation)}$$

By reduces the analysis of the force generated by the rudder. but the direction create by the propeller is always consistent with the heading of the USV.

$$M\dot{v}+C(v)v+D(v)v=\tau$$

This is dynamic equation the simplification of 6 DOF to 3 DOF which 6 DOF make system more complex

There is the three-DOF model identification:

$$\dot{X}=u*\cos(s1)-v*\sin(s1)$$
$$\dot{Y}=u*\sin(s1)+v*\cos(s1)$$
$$\dot{\psi}=r$$

$$\dot{u}=\left(\frac{1}{50.05}\right)*¿¿$$
$$¿$$

$$\dot{v}=\left(\frac{1}{84.36}\right)*(-50.05*u*r-132.25*v)$$

$$\dot{r}=\left(\frac{1}{17.21}\right)*((50.05-84.36)*u*v-34.56*r+¿(-1.60E\text{-}4*$$

II. PD+LOS Control Algorithm

the design of the path-following controller is an important part. Because we need to make autonomous navigation of the ship. Based on the USV model, the USV motion control. the control on system by using PD+LOS guidance:

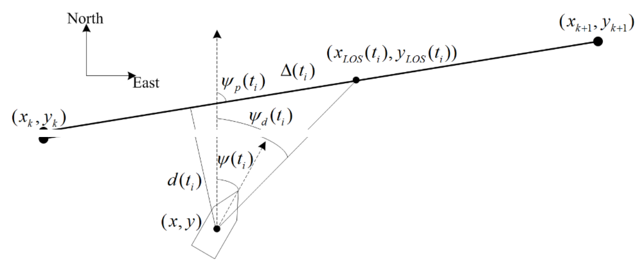

fig 3. The principle of the LOS guidance algorithm.

In the PD controller, used to improves the dynamic characteristics of the system, but is sensitive to noise. The output of the PD controller is the differential speed of the port (n_1) and starboard (n_2) thrusters. PD controller is found in simulation is used. According to USV model and the PD+LOS control, we select the PD parameters in simulation to achieve the optimal solution to control on USV motion. Based on the Ziegler-Nichols rules, we calculated the gains K_p and K_d, then set PD parameters on the system response.

III. Rustle of Simulation Using MAT LAB and LabVIEW

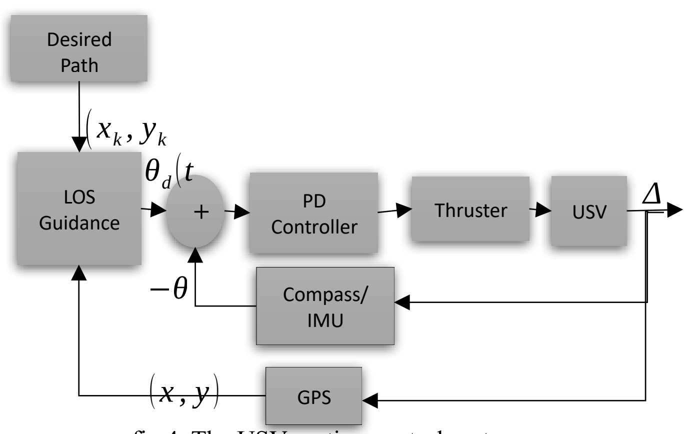

fig 4. The USV motion control system

We can see that all states in the first have a huge change to track the target which this target draw street point as example. In mat lab can show how we make control on the USV to track target. We use the look ahead distance control with this equation:

$$\gamma_p = atan2(y_{k+1} - y_k, x_{k+1} - x_k)$$

$$R(\gamma_p) = \begin{bmatrix} \cos(\gamma_p) & -\sin(\gamma_p) & ¿ \\ \sin(\gamma_p) & \cos(\gamma_p) & \end{bmatrix}$$

$$¿ = R^T(\gamma_p)\begin{bmatrix} x & -x_k \\ y & -y_k \end{bmatrix}$$

$$\Delta(\gamma_p) = ¿ - \Delta_{min})* e^{-¿_\gamma |y_k| ¿} + \Delta_{min},$$

which need two distance called Δ are the Δ minimum and Δ maximum allowed values for Δ respectively and, along with the convergence rate Υ**>0**.

The problem of designing controllers to control a surface ship which effect with dynamics of water to track a reference path, can solve it by take in consider Both full-state feedback and output feedback.

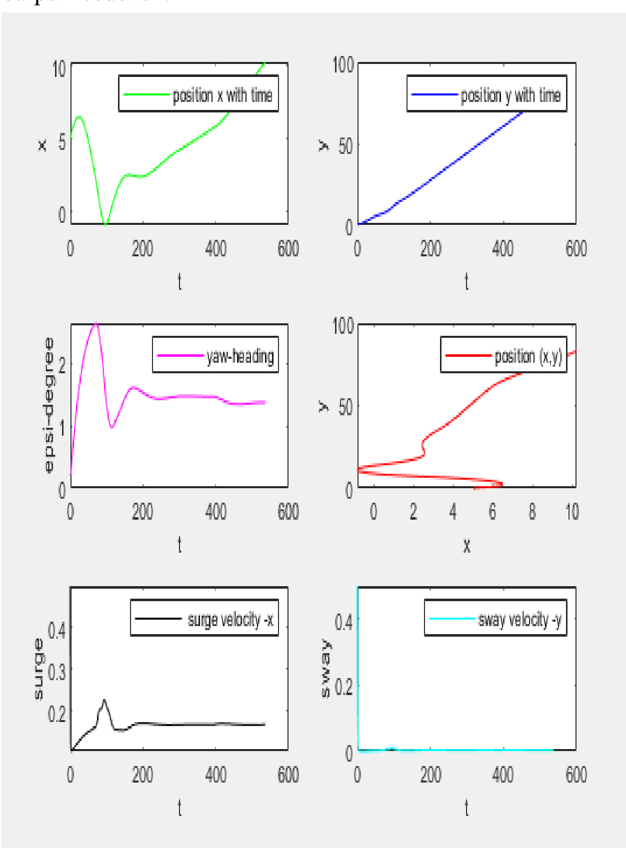

fig 4. Solution of states of model with ODE45

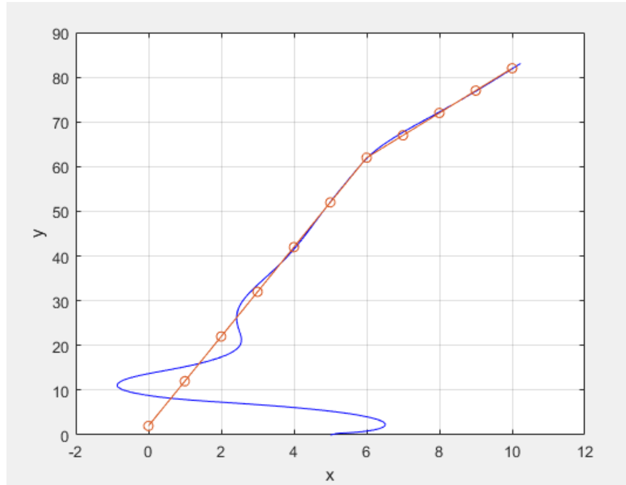

fig 5. Solution of model with ODE45

We get this result because we achieve real time in system to update the system measurement about target and USV by using the LOS Guidance, in practical, we will use the IMU/Compass to update the information and achieve the Guidance command converge to actual motion of USV. We use LabVIEW to make hard ware in the loop to achieve the mat lab result.

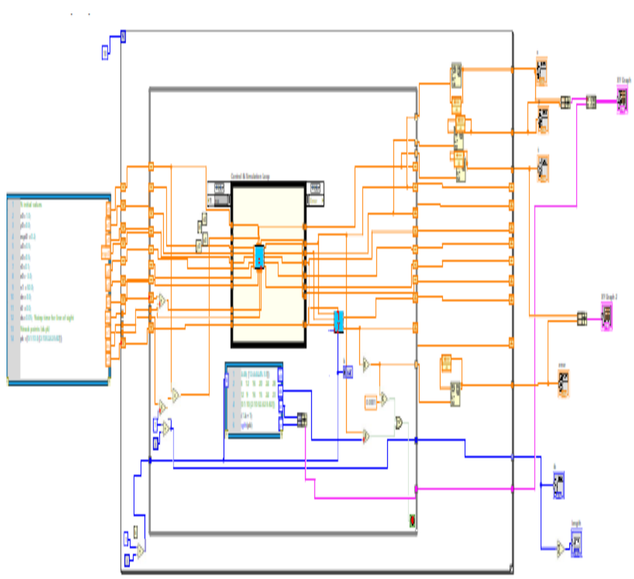

fig 6. Closed loop model using LabVIEW

The result of LabVIEW is similar to Mat Lab, then we will use Hardware to achieve my simulating with actual measurement.

IV. Conclusion

The problem control for USVs motion has been solve it by using rudderless double thrusters to simplify mechanical structure. The 3-DOF dynamic model was established combined with the propeller thrust model. The rotational moment is related to the differential thrust and the distance of two thrusters. Simulations for different scenarios are developed using MATLAB and LABVIEW toolboxes. Simulation results reflect efficiency and the validity of the proposed model and the effectiveness of the proposed designed controller algorithm.

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