Ocean Systems Engineering, *Vol. 5, No. 3 (2015) 199-220*
DOI: http://dx.doi.org/10.12989/ose.2015.5.3.199

An alternative portable dynamic positioning system on a barge in short-crested waves using the fuzzy control

Ming-Chung Fang[a] and Zi-Yi Lee[*]

Department of Systems and Naval Mechatronic Engineering, National Cheng Kung University, No.1, University Road, Tainan City 701, Taiwan R.O.C.

(Received May 13, 2015, Revised August 9, 2015, Accepted September 1, 2015)

Abstract. The paper described the nonlinear dynamic motion behavior of a barge equipped with the portable outboard Dynamic Positioning (DP) control system in short-crested waves. The DP system based on the fuzzy theory is applied to control the thrusters to optimally adjust the ship position and heading in waves. In addition to the short-crested waves, the current, wind and nonlinear drifting force are also included in the calculations. The time domain simulations for the six degrees of freedom motions of the barge with the DP system are solved by the 4th order Runge-Kutta method. The results show that the position and heading deviations are limited within acceptable ranges based on the present control method. When the dynamic positioning missions are needed, the technique of the alternative portable DP system developed here can serve as a practical tool to assist those ships without equipping with the DP facility.

Keywords: fuzzy control; time domain; dynamic positioning; short-crested waves

1. Introduction

The Dynamic Positioning (DP) control system can maintain the position and heading of a ship precisely in the ocean by using thrusters, which is very important to adjust ship's position relative to a mobile object such as the remotely operated vehicle (ROV). The first DP system was designed for a plane with the horizontal motion (surge, sway and yaw) by the single-input single-output (SISO) PID controller in the 1960s (Fay 1989). Generally, most vessels with DP system adopt azimuth thrusters and propulsion propeller to generate thrust forces to maintain the desired position and heading in the horizontal plane (Morgan 1978). DP systems incorporating with different control techniques based on linear optimal and Kalman filter theories were already applied to deal with the ship dynamic positioning problems by many authors, e.g., Balchen (1980) and Sørensen, *et al.* (1996). However, the Kalman filter generally needs to be combined with the other analytical technique for further practical applications (Saelid *et al.* 1983). Besides, Stephens *et al.* (1995) also successfully applied the nonlinear fuzzy controller to handle the ship dynamic positioning system. Inoue and Du (1995) brought a concept of the self-tuning fuzzy control system on a DP system that the control strategy is improved automatically according to the sea conditions

∗Corresponding author, Ph.D., E-mail: z10301066@email.ncku.edu.tw
[a] Professor, E-mail: fangmc@mail.ncku.edu.tw

http://www.techno-press.org/?journal=ose&subpage=7 ISSN: 2093-6702 (Print), 2093-677X (Online)

practical applications.

The present study applies the fuzzy system to control the revolutions per minute (R.P.M.) of propellers i.e., two stern thrusters and one bow thruster create the forces to counteract the environmental forces. The wave forces on the barge in the real sea state are based on the short-crested waves approach. The formulas of the wave spectrum expressed by International Towing Tank Conference (ITTC) (Michel 1999 and ITTC 2005) were adopted here, which contains the two parameters, significant wave height and average period. Depending on the irregular wave method based on the wave energy spectral analysis theory was closer the accurate ship motions and forces at sea than using the regular wave method.

The nonlinear mathematical model developed in the present paper, including seakeeping and maneuvering characteristics, has a set of ordinary differential equations (O.D.E.) which are needed to solve the six degrees of freedom (6 DOF) motions of the barge with the DP system in random waves. It is seen that the time domain approach is more direct and accurate and can include nonlinear contributions which are typically neglected in the linear frequency domain approach (Kang and Kim 2014). Hence the 4th order Runge-Kutta method is then applied to solve the time domain motion simulations of the barge. The portable outboard DP system consisting of one sideward bow thruster and two forward stern thrusters, and the operations controlled by applying the fuzzy algorithm with respect to different sea states are investigated. As the original design of the ship may not have the DP system, applying portable outboard thrusters as the DP system might be a good alternative idea which is suggested in the present study. The results show that the technique developed here can serve as an effective simulation tool to improve the stability and the safety for the ship with the portable dynamic positioning requirement at random sea.

2. Mathematical formulas

2.1 Equations of motions

The extensive nonlinear equations of 6-DOF ship motions with fuzzy DP control based on the mathematical model developed by Fang and Luo (2005) are shown as below

$$m(\dot{u}-v\dot{\psi})=\left(m_y(\omega_e)-X_{v\dot{\psi}}\right)v\dot{\psi}-m_x(\omega_e)\dot{u}-m_x(\omega_e)z_G\ddot{\theta}-m_z(\omega_e)w\dot{\theta}+X_{FK}(\omega_0)+X_{WF}-R+X_D+F_{cx}+F_{Tx} \quad (1)$$

$$m(\dot{v}+u\dot{\psi})=-m_x(\omega_e)u\dot{\psi}-m_y(\omega_e)\dot{v}+m_y(\omega_e)z_G\ddot{\phi}-Y_v v-Y_{\ddot{\psi}}\ddot{\psi}+Y_{\dot{\psi}}\dot{\psi}+Y_{v|v|}v|v|+Y_{v|\dot{\psi}|}v|\dot{\psi}|+Y_{\dot{\psi}|\dot{\psi}|}\dot{\psi}|\dot{\psi}|+Y_{FK}(\omega_0)+Y_{DF}(\omega_e)+Y_{WF}+Y_D+F_{cy}+F_{Ty} \quad (2)$$

$$m\dot{w}=-m_z(\omega_e)\dot{w}-Z_w(\omega_e)w-Z_{\ddot{\theta}}(\omega_e)\ddot{\theta}-Z_{\dot{\theta}}(\omega_e)\dot{\theta}-Z_\theta(\omega_e)\theta+Z_{FK}(\omega_0)+Z_{DF}(\omega_e)+mg \quad (3)$$

$$I_{xx}(\omega_e)\ddot{\phi}-I_{xx}(\omega_e)\dot{\theta}\dot{\psi}=J_{xx}(\omega_e)\dot{\theta}\dot{\psi}-J_{xx}(\omega_e)\ddot{\phi}-K_{\dot{\phi}}\dot{\phi}+m_y z_G\dot{v}+(Y_v v-Y_{\dot{\psi}}\dot{\psi})z_G+K_{FK}(\omega_0)+K_{DF}(\omega_e)+K_{WF}+N_{Tx} \quad (4)$$