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# Fuzzy Reasoned Waypoint Controller for Automatic Ship Guidance

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**Abstract:** Guidance systems usually calculate the ship's desired course based on given waypoints or trajectory. In this paper, a fuzzy reasoned waypoint controller is discussed. The control laws considered here is similar to collision avoidance rules. However, instead of collision risk, nearness is reasoned by the fuzzy controller based on human operator's manipulating experience. Depending on the nearness of next and second next waypoint one at a time, fuzzy controller decides the desired heading. By this way, the necessity of calculating the circle of acceptance radius or path curvature separately at each turning point is eliminated. After getting the desired heading, as a course keeping controller, PD is used to correct the instantaneous heading. The proposed controller simplifies the total control design process and easily applicable to practical navigation path planning. Simulations with different sets of waypoints are carried out to justify the effectiveness of the proposed controller. Several experiment results are also included in this paper which validates the proposed control algorithm.



*Keywords:* Waypoint Control, Fuzzy Logic, PD Control, Navigation System, Guidance of Ship, Ship Control, MMG model, Free Running Experiment.

## 1. INTRODUCTION

Navigational path planning is a usual task of ship operators which is done based on the given set points called waypoints (WPs) to be passed. These waypoints are generated according to sail plan and weather data or given manually as autopilot inputs. Nowadays, the autonomous navigation of marine vehicles is gaining everybody's attention due to the inherent difficulties in manual ship navigation and control. Each ship's response is different from others and to get used to it, every ship operator needs some time. Therefore, to follow a planned path manually, i.e. proper timing of rudder angle changes as well as to take the counter rudder to overshoot the existing sway velocity and yaw rate has always been a crucial matter. As a result, in the field of ship manoeuvring, the waypoint tracking problem is an issue of high interest.

The waypoint tracking control problem is basically how making the ship follow a given set of waypoints by controlling the rudder (Fossen, 1994 and Petterson, 2001). To solve the problem, defining proper guidance algorithm is very important. There are several guidance algorithms exist (Jensen, 2011), like pure pursuit guidance algorithm, Line-of-sight (LOS) guidance algorithms, etc. Pure pursuit algorithm only considers the target i.e. waypoint and the vehicle itself. It seems like a predator use to chase a prey where the approach results in a tale chase. On the other hand, LOS guidance requires defining the enclosure radius or look ahead distance to get the LOS setpoint. However, in both cases WP switching algorithm is needed. On contradictory, this paper proposes a fuzzy controller based guidance algorithm which measures the nearness of next and second next waypoint one at a time and decides the desired course. Therefore, there is no need of additional algorithms for waypoint switching. In order to measure the nearness of WPs, distance to closest point approach (DCPA) and time to closest point approach (TCPA) are used, which are discussed in the later part of this paper.

Several researches are also done using Fuzzy logic for autonomous navigation, but in a different a way than explained in this paper. Cheng and Yi (2006) used fuzzy rules to get the rudder output directly based on the cross track error (the shortest distance between the ship and straight line joining two consecutive waypoints) and heading error. The authors also used fuzzy turning control to decide the turning starting distance at each waypoint. Lee *et al.* (2004) used fuzzy logic to decide the weight factor for goal (waypoint) that attracts the ship and obstacle that repels it. The authors' basic concept was based on Virtual Force Field (VFF) method.

In this paper, as mentioned earlier, using the value of DCPA and TCPA, the nearness of WPs is reasoned by fuzzy controller and desired course is calculated. Then, as a course keeping controller, PD is used to match the desired heading. Therefore, basically the proposed controller has two control loops. The outer loop belongs to the fuzzy controller that generates the desired course based on given waypoints for the inner control loop and the inner control loop makes the ship move towards the direction of minimising the heading error by controlling the rudder angle. The outer loop, i.e. the tracking control loop is treated as an additional feedback loop


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around the inner loop i.e. course keeping loop. For the outer control loop, the control laws similar to collision avoidance rules as mentioned by Hasegawa (1986, 1990 and 1993) are used. The author in his papers, measures the collision risk (CR) value depending on the existing marine traffic for the own ship using DCPA and TCPA. The basic control law is when the own ship approaches closer to any target ship, the value of CR will increase. Depending on such calculated CR value, necessary actions like changing of rudder, speed decreases etc. are taken. In case of waypoint controller, similar to this, as the ship is away from the second next waypoint, the command course will consider only for the next waypoint. However, with the increase of nearness to the next waypoint, the course will modify by considering both next and second next waypoint.

This paper is organised as follows. In section 2, a brief description of mathematical model used to predict the ship dynamics is presented. Section 3, describes the controller design and control scheme. Simulation results illustrating the effectives of proposed controller are presented in section 4 which is followed by some experiment results in section 5. At last, conclusions are given in section 6.

## 2. SUBJECT SHIP AND MATHEMATICAL MODEL

A considerable number of vessels travelling all over the world are only equipped with a single rudder and a single screw propeller. In this research, among those types of subject ships available, 'Esso Osaka' 3-m model is chosen which is scaled as 1:108.33. The main reason of choosing this model is the availability of large amounts of captive model test results as well as a physical model itself. Its details are given in Table 1.

**Table 1. Principal particulars and parameters of model ship**

| Hull | | Propeller | | Rudder | |
|---|---|---|---|---|---|
| $L$ (m) | 3 | $D_p$ (m) | 0.084 | $b$ (m) | 0.083 |
| $B$ (m) | 0.48 | $P$ (m) | 0.06 | $h$ (m) | 0.1279 |
| $D$ (m) | 0.2 | Pitch Ratio | 0.7151 | $A_R$ (m$^2$) | 0.0106 |
| $C_b$ | 0.831 | $Z$ | 5 | $\Lambda$ | 1.539 |

The coordinate system used to formulate the equation of motion together with the wind direction consideration is shown in Fig. 1. Here, the ship heading is assumed as clockwise and wind direction as anti-clock wise positive.

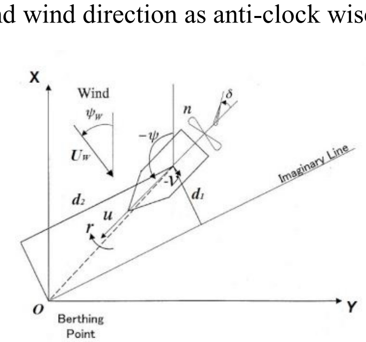


Fig. 1. Coordinate system

A modified version of mathematical model based on MMG (23rd ITTC meeting) for describing the ship hydrodynamics in three degrees of freedom is used for this model ship. In the MMG model, not only hull, propeller and rudder forces are considered separately, but their interactions are also taken into account. The corresponding equations of motions at CG (centre of gravity) of the ship are expressed in the following form:

$$\begin{aligned} (m+m_x)\dot{u}-(m+m_y)vr &= X_H+X_P+X_R+X_W \\ (m+m_y)\dot{v}+(m+m_x)ur &= Y_H+Y_P+Y_R+Y_W \\ (I_{ZZ}+J_{ZZ})\dot{r} &= N_H+N_P+N_R+N_W \end{aligned} \tag{1}$$

$X_H, Y_H, N_H$ : Hydrodynamic forces and moment acting on hull
$X_P, Y_P, N_P$ : Hydrodynamic forces and moment due to propeller
$X_R, Y_R, N_R$ : Hydrodynamic forces and moment due to rudder
$X_W, Y_W, N_W$ : Hydrodynamic forces and moment due to wind

To consider the wind disturbances, Fujiwara wind model (1998) is adopted and instead of steady wind, gust wind is considered (Davenport, 1967).

## 3. CONTROLLER DESIGN AND CONTROL SCHEME

Fuzzy control is a practical alternative solution of variety of challenging nonlinear control problems. Optimal control laws can be implemented based on ship operator's knowledge while designing the fuzzy controller. Therefore, it can behave similar to that operated by human beings. In this research, fuzzy controller is used to decide the course for navigation path planning. Based on the ship operator's manipulating experience, the control rules for desired course are developed.

As mentioned earlier, the navigational path is consists of several set points named waypoints (WPs). These waypoints are usually selected at the turning points. Then, the path is planned normally directing to the next point (WP) to be passed. However, near the turning point, the fuzzy system will decide to choose the appropriate course defined by the next two WPs as following equation:

$$\psi_I = \psi_1 + (\psi_2 - \psi_1) * CDH \tag{2}$$

where, $\psi_I$ is order of course change, $\psi_1$ is course of the shortest path to the next WP, $\psi_2$ is course of the shortest path to the second next WP and $CDH$ is the reference degree to the second next WP ( $0 \le CDH \le 1$ ), calculated by fuzzy controller.

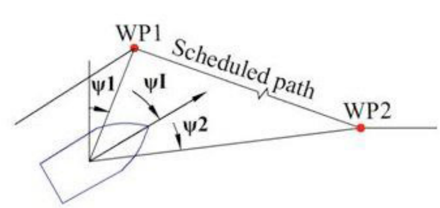


Fig. 2. Course command near a course changing point