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Research Article

Fuzzy Technique Tracking Control for Multiple Unmanned Ships

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Abstract: A Fuzzy logic control law is presented and implemented for trajectory tracking of multiple under actuated autonomous surface vessels. In this study, an individual unmanned ship is used to be the leader that tracks the desired path; other unmanned ships are used to be the followers which track the leader only by using its position. A fuzzy controller was implemented for the ship leader position with a constant velocity; however, the ship follower needed a fuzzy controller for the position and the forward velocity. Simulation results show that the fuzzy method presents an interesting robustness against the environmental disturbances and effective tracking results.

Keywords: Fuzzy logic control, multiple unmanned ships, ship path following, under actuated surface vessels

INTRODUCTION

Unmanned ship is an effective tool for human to exploit the sea. With the increasing complexity and diversity of exploiting need, only through the pursuit of some performance indexes of individual unmanned ship optimal has been far from meeting the need. Multiple unmanned ships cooperation system has spatial, function and time distribution characteristics, which could expand the perception scope of individual unmanned ship and achieve complex tasks that are difficult for individual unmanned ship to do.

Tracking path control of marine vehicles is an enabling technology with a number of interesting applications. A fleet of multiple surface vessels moving together in a prescribed pattern can form an efficient data acquisition network for environmental monitoring and oil and gas exploration. Moreover, path tracking control techniques can be used to perform underway replenishment at sea, to perform automated towing operations of surface vessels, barges or oil platforms and to coordinate the motion between untethered underwater vehicles and surface vehicles.

Many people have researched the path tracking control of unmanned ship. The path tracking control is mainly divided to three categories. The first is to describe the path tracking error in body coordinate system, describe the movement of reference point by its pose and differential coefficient; this control method is appropriate for any reference curve. The second is to describe the path tracking error in Serret-Frenet coordinate system, describe the movement of reference point by the curve's changing rate and curvature. The third is to describe the path tracking error by using distance and bearing angle which are transformed through polar coordinate (Liangsheng and Weisheng, 2011).

Do *et al*. (2004, 2005) assumed that the inertia matrix of dynamic ship model was diagonal and proposed the robust adaptive path tracking algorithm of under actuated ship based on vision method and polar coordinate transform. Do *et al*. (2006a, b) researched the path tracking control of under actuated surface ship in norm Serret-Frenet coordinate system by using Lyapunov direct method and inverse technique (Fig. 1).

At present, there are mainly three formation control methods for agents. They are leader-follower method, virtual structure method and behavior method. The basic idea of first method is to make some agents be leaders and the rest be followers, Leaders track the reference path and followers track the leaders to keep the formation. The second method is to regard the formation as a rigid body and each agent is relatively fixed in the rigid body. The last method is to divide the formation control task to a set of basic actions and synthesize the actions to achieve formation control.

Fahimi (2007) proposed a leader-follower formation control method which was based on sliding mode variable structure. By using distributed controller, Even B solved the path tracking control problem of multiple surface ships under communication limited condition. He also researched the formation control of under actuated AUVs based on cross-track method Even *et al*. (2006a, b).

Ghabcheloo (2007) researched the formation control of multiple underwater vehicles by using the information consistency of multi-agent, which included the case of losing communication data (Ghabcheloo *et al*., 2006). Fossen proposed some nonlinear formation control methods, such as Lagrange method in zero

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Fig. 1: Coordinate path folllowing of group surface vessels

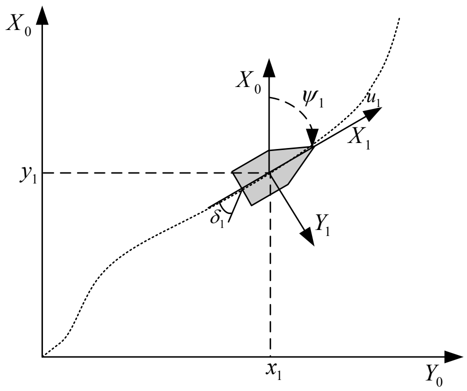

Fig. 2: Surge-sway-yaw motion coordinate system

space, non-source method, etc., (Ivar-Andr *et al*., 2005, 2006; Ivar-Andr, 2006).

In the previous studies, existing mathematical ship models were developed to incorporate the use of all kind of controllers that could be commanded in a strategic manner. The models are still complex to use in control; many studies tried some modifications and simplifications to make it useful and easy to be controlled. Adopting these models, some theoretical study results have been achieved on the ship control motion (Thor, 1994). However, the external disturbances and the system uncertainty were considered little in these recent works.

Roughly speaking, the intelligent control does not require the mathematical model of the plant. The control engineer makes use of the fact that the Human Operator (HO), the most successful 'intelligent controller' available until now, is able to control the complicated process without knowledge of the process mathematical model. Also, the human can learn to control many systems without prior knowledge of system response behavior. HO behavior is modeled mathematically instead of modeling the process itself to develop the controller directly (Enab, 1996).

In this study, we call the intelligent control theories and try to achieve better results of control; we attempt to use the fuzzy control approach to study the path tracking of multiple under actuated ships in presence of the environmental disturbances and the uncertainty of the ship model.

By applying the fuzzy control method, the leading unmanned ship uses the virtual structure method; however, the following unmanned ships track the leader only by using the leader's position.

In this study, we study coordinated path following of 3DOF marine vehicles that are independently actuated in surge and yaw, but under actuated in sway. The marine vehicles can be surface vessels or underwater vehicles moving with constant depth.

METHODOLOGY

Ship leader controller: A horizontal plane model in surge, sway and yaw is a common approximation for surface vessels (Fig. 2).

From the 6DOF model the horizontal plane model is found by isolating these components and setting heave, roll and pitch to zero.

We consider an under actuated marine vehicle described by the 3-DOF model:

$$\begin{cases} \dot{x}_1 = u_1 \cos\psi_1 \\ \dot{y}_1 = u_1 \sin\psi_1 \\ \dot{\psi}_1 = r_1 \end{cases} \tag{1}$$

The undesirable motion of a ship in a seaway is induced by the action of environmental disturbances: waves, wind and current. However, ocean waves are the dominant environmental disturbance; and hence, the type of disturbances described in this study.

Linear wave model approximations are usually preferred by ship control systems engineers, owing to their simplicity and applicability. This model is written as Graham *et al*. (2008):

$$F(s) = \frac{s}{s^2 + 2.(0.1).(0.5)s + (0.5)^2} \tag{2}$$

When the ship leader is moving at constant forward speed u_1, the environmental disturbances deflect the ship from its desired path. The role of the ship control system is to keep the ship moving as desired under these disturbances (Fig. 3).

Roughly speaking, the approach is to steer the ship such that it eliminates the distance between itself and the desired path (Fig. 4).

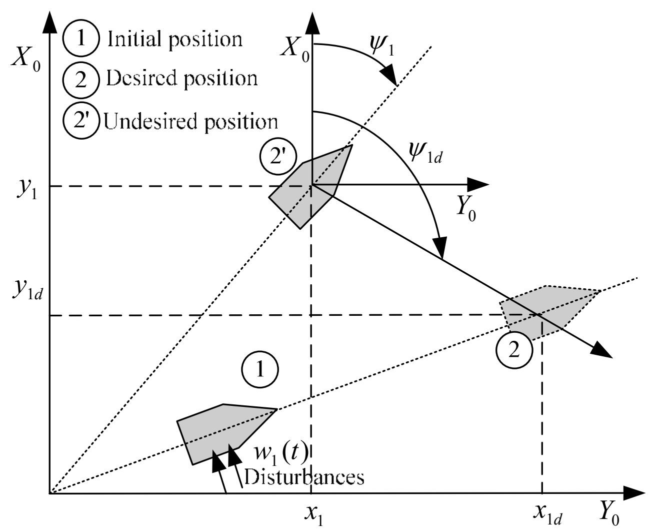

Fig. 3: General framework of ship path following

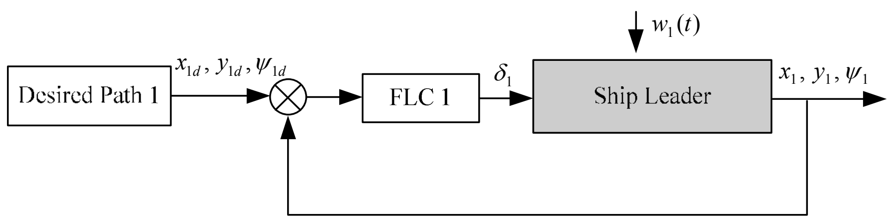

Fig. 4: Fuzzzy control scheme

We define the following variables to mathematically formulate the control objectives:

$$\begin{cases} x_{e1} = x_{d1} - x_1 \\ y_{e1} = y_{d1} - y_1 \\ \psi_{e1} = \psi_{d1} - \psi_1 \end{cases} \quad (3)$$

Note that:

$$\psi_{d1} = \arcsin\left(\frac{y_{e1}}{\sqrt{x_{e1}^2 + y_{e1}^2}}\right) \quad (4)$$

According to the desired path, the control loop gives the desired rudder angle for the rudder actuator and this last makes the ship move toward the desired position by acting on the yaw motion.

The fundamental objective is to design the fuzzy controller to force ship leader to follow a specified path as closely as possible.

The control input variables for the proposed intelligent controller are chosen as the error ψ_{e1} and the change of the error $d\psi_{e1}$ as follows:

$$\begin{cases} \psi_{e1}(k) = \psi_{d1}(k) - \psi_1(k) \\ d\psi_{e1}(k) = \psi_{e1}(k) - \psi_{e1}(k-1) \end{cases} \quad (5)$$

The variable δ_1 is defined as the outputs for the fuzzy controller. We can write:

$$\delta_1 = \text{Fuzzy}(\psi_{e1}, d\psi_{e1}) \quad (6)$$

The inputs/output linguistic variables are defined as:

$$\begin{cases} \psi_{e1}(t) \equiv \{NB, NM, NS, ZE, PS, PM, PB\} \\ d\psi_{e1}(t) \equiv \{NB, NM, NS, ZE, PS, PM, PB\} \\ \delta_1(t) \equiv \{NB, NM, NS, ZE, PS, PM, PB\} \end{cases} \quad (7)$$

Triangular distributions in [−1, 1] interval are chosen as membership functions for $\psi_{e1}(t)$, $d\psi_{e1}(t)$ and $\delta_1(1)$.

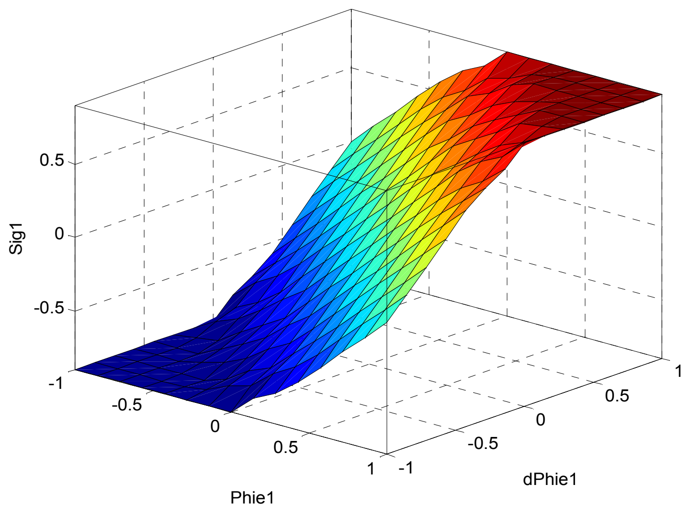

Fig. 5: Ship leader controller surface

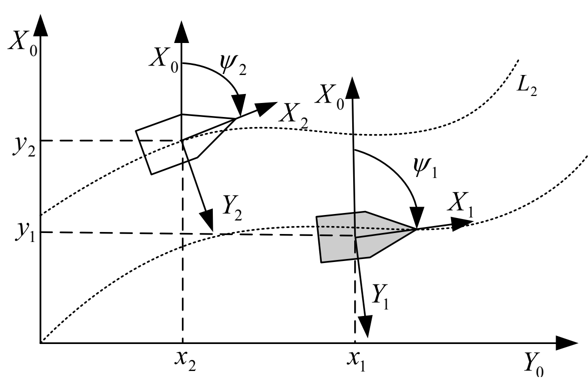

Fig. 6: Coordinate system of path tracking

Table 1: Rule base of the fuzzy controller

		Yaw error						
Rudder angle		NB	NM	NS	ZE	PS	PM	PB
Change in error	PB	ZE	PS	PM	PB	PB	PB	PB
	PM	NS	ZE	PS	PM	PB	PB	PB
	PS	NM	NS	ZE	PS	PM	PB	PB
	ZE	NB	NM	NS	ZE	PS	PM	PB
	NS	NB	NB	NM	NS	ZE	PS	PM
	NM	NB	NB	NB	NM	NS	ZE	PS
	NB	NB	NB	NB	NB	NM	NS	ZE

The defuzzification laws are chosen as shown in Table 1.

The surface control of the fuzzy controller for the ship leader is presented in Fig. 5.

Ship follower controllers: Suppose there is an arbitrary curve L_1 in the X_0Y_0 plane of ground coordinate system, which would be the target path of leading unmanned ship in the formation. A body frame coordinate system X_1Y_1 is established for ship leader moving with a constant forward speed u_1 and X_2Y_2 is established for the ship follower moving with inconstant forward speed u_2 (Fig. 6).

According to the Fig. 6, the coordinates of the vehicles in the ground coordinate system X_0Y_0 could be written as:

$$\text{Ship leader}: \begin{cases} \dot{x}_1 = u_1 \cos \psi_1 \\ \dot{y}_1 = u_1 \sin \psi_1 \\ \dot{\psi}_1 = r_1 \end{cases} \qquad \text{Ship follower}: \begin{cases} \dot{x}_2 = u_2 \cos \psi_2 \\ \dot{y}_2 = u_2 \sin \psi_2 \\ \dot{\psi}_2 = r_2 \end{cases} \tag{8}$$

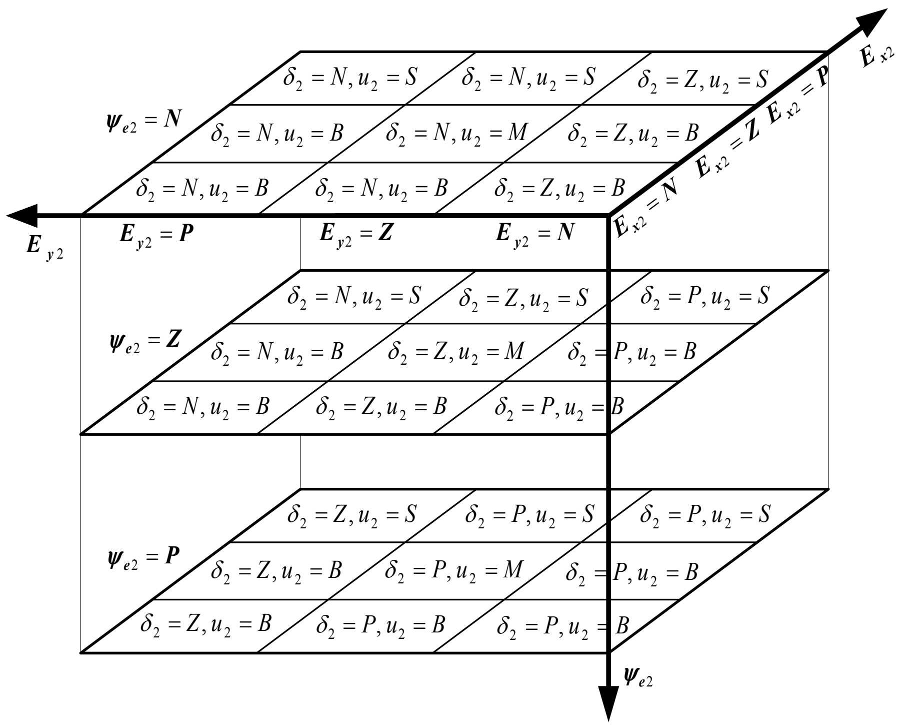

Fig. 7: Rule base of the fuzzy controller

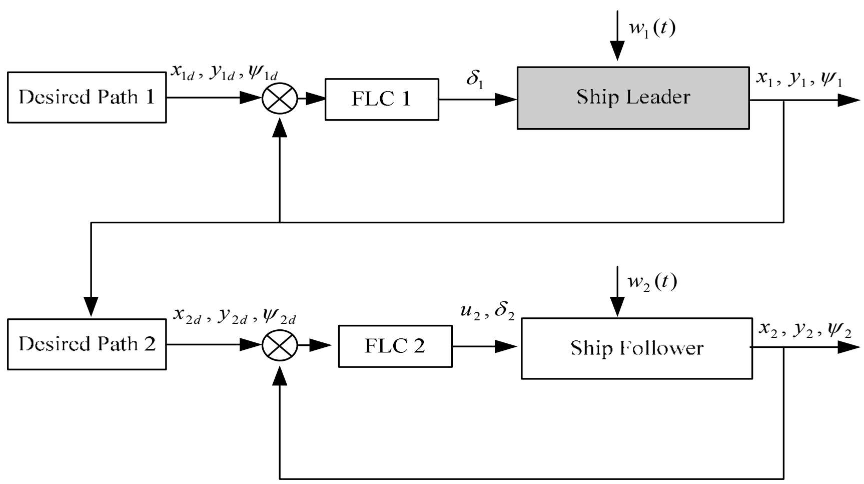

Fig. 8: Control scheme of the ship leader and the follower

In order to satisfy the remaining control goal, the vehicle follower has to adjust its forward speed and steering angle to coordinate its motion with the ship leader (according to control scheme in Fig. 7 so as to achieve the desired position and move with the desired velocity profile $u_{d2} = u_{d1} = u_d$.

The desired position of the ship follower with respect to the body frame X_1Y_1 is defined as:

$$\begin{cases} {}^1x_2 = {}^1D_x \\ {}^1y_2 = {}^1D_y \end{cases} \qquad (10)$$

The objectives of the second controller are to keep ${}^1x_2$, ${}^1y_3$ constants and equal to ${}^1D_x$, ${}^1D_y$ respectively and the yaw angle ${}^1\psi_2 = 0$ in straight motion.

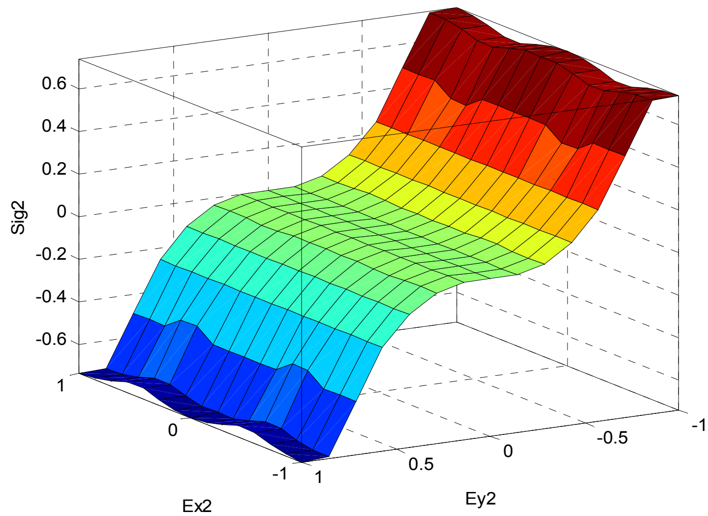

Fig. 9: Surface control of the rudder angle δ_2

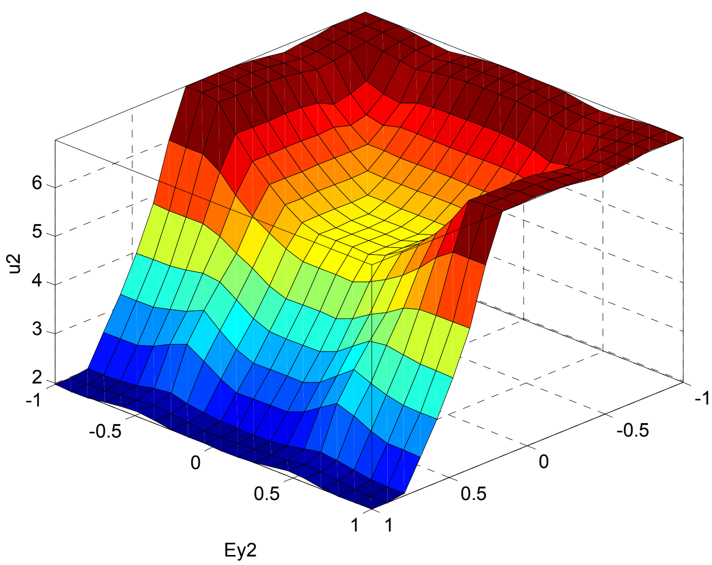

Fig. 10: Surface control of the forward velocity u_2

For the ship follower, let's define the position error with respect to X_1Y_1:

$$\begin{cases} {}^1E_{x2} = \quad (x_2 - x_1)\cos\psi_1 + (y_2 - y_1)\sin\psi_1 - {}^1D_x \\ {}^1E_{y2} = -(x_2 - x_1)\sin\psi_1 + (y_2 - y_1)\cos\psi_1 - {}^1D_y \end{cases} \quad (11)$$

The second controller is designed as followed:

$$(\delta_2, u_2) = \text{Fuzzy}({}^1E_{x2},\ {}^1E_{y2},\ {}^1\psi_2) \quad (12)$$

The inputs/outputs linguistic variables are defined as:

$$\begin{cases} {}^1E_{x2} \equiv \{N, Z, P\} \\ {}^1E_{y2} \equiv \{N, Z, P\} \\ {}^1\psi_2 \equiv \{N, Z, P\} \\ \delta_2 \equiv \{N, Z, P\} \\ u_2 \equiv \{S, M, B\} \end{cases} \quad (13)$$

The defuzzification laws are chosen as shown in Fig. 7.

The surface control of the fuzzy controller for the ship follower is presented in Fig. 9, 10 for the two outputs δ_2 and u_2, respectively.

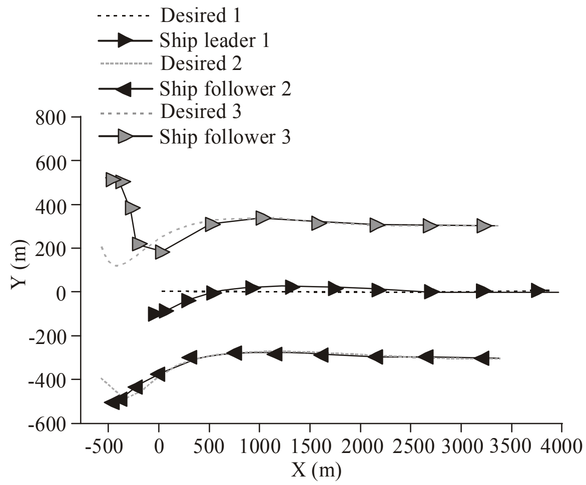

Fig. 11: Tracking paths of three unmanned ships

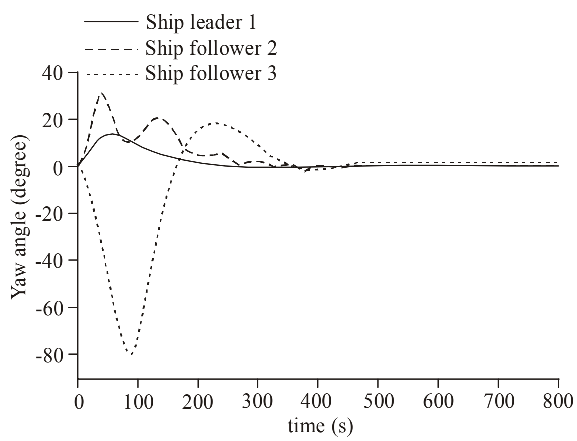

Fig. 12: Yaw angles

SIMULATION RESULTS AND DISCUSSION

The proposed formation control scheme has been implemented in Simulink^{TM} and simulated for the case of three surface vessels. The desired straight line paths and desired inter-vehicle spacing is given by, (D_{x1}, D_{y1}) = (0, 0), (D_{x2}, D_{y2}) = (-500, -300), (D_{x3}, D_{y3}) (-500, 300).

The desired velocity profile is chosen as u_d = 5m/s. The initial conditions are taken as: (D_{x10}, D_{y10}) = (-100, -100), (D_{x20}, D_{y20}) = (-500, -500), (D_{x30}, D_{y30}) = (-500, 500)

The simulation results are shown from Fig. 11 to 14. Figure 11 shows the trajectories of unmanned ships applying the proposed method of control. Figure 12 shows the variation of the yaw angles during the motion of the three vessels. Figure 13 shows the variations in

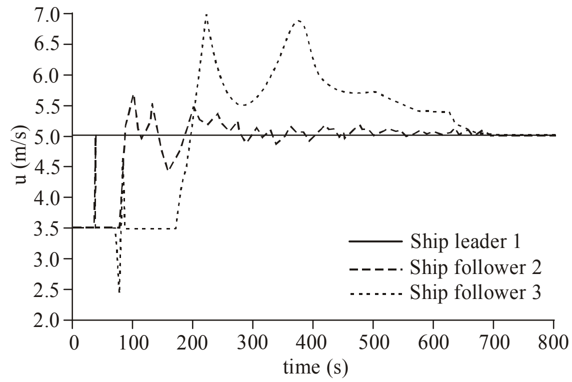

Fig. 13: Forward velocities

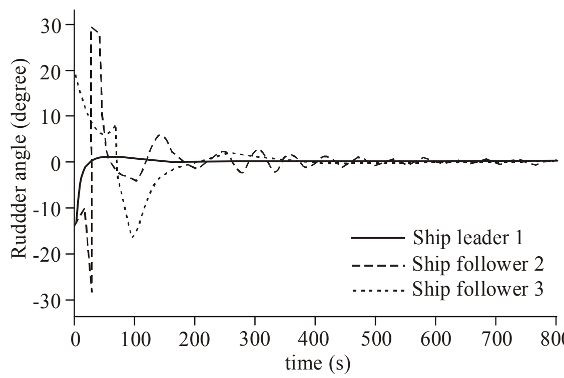

Fig. 14: Rudder angles

the forward velocities. Figure 14 presents the rudder angle change of each unmanned ship; we should note that the ship leader forward velocity is constant and u_1 = 5 m/s, which the desired profile velocity.

From the simulation results we know that the leading unmanned ship moves to the target path quickly and then tracks the target path with the forward velocity $u_1 = u_d$ = 5 m/s; the following unmanned ships track the desired path in the respect with the ship leader. During the tracking process, the route, forward velocities and yawing angle of each unmanned ship change reasonably.

CONCLUSION

The study addressed the problem of steering for a group of unmanned vehicles along given spatial paths. The proposed solution is based on fuzzy logic techniques and addresses explicitly the inter-vehicle equidistance constraints.

The principal role of the fuzzy technique is to eliminate the need of the ship model; the controller depends only on the selection of the fuzzy variables, the membership functions and the rule base. Triangular membership functions were considered and Mamdani model was adopted to fulfill the objectives. Another interest of the proposed method is the design simplicity.

We tested the effectiveness of the controllers in presence of the environmental disturbances induced by waves, wind and ocean-current. The simulation results show that the proposed method has a fast dynamic and a strong robustness under the disturbances.

In the other hand, the fuzzy controller is based specially on the inference rules. This characteristic gives a big advantage to fuzzy control methodology in such as situation of control. Furthermore, the method leads to a decentralized control law whereby the exchange of data among the vehicles is kept at a minimum.

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REFERENCES

Do, K.D., Z.P. Jiang and J. Pan, 2004. Robust and Adaptive path following for underactuated ships. Automatica, 40: 929-944.

Do, K.D., Z.P. Jiang and J. Pan, 2005. Global partial-state feedback and output-feedback tracking controllers for underactuated ships. Syst. Cont. Lett., 54: 1015-1036.

Do, K.D. and J. Pan, 2006a. Global robust adaptive path following of underactuated ships. Automatica, 42: 1713-1722.

Do, K.D. and J. Pan, 2006b. Robust path following of underactuated ships: Theory and experiments on a model ship. Ocean Eng., 33: 1354-1372.

Enab, Y.M., 1996. Intelligent controller design for the ship steering problem. IEE Proceed. Cont. Theor., 143(1): 17-24.

Even, B., P. Alexey and Y.P. Kristin, 2006a. Cross-Track Formation Control of Underactuated Autonomous Underwater Vehicles. Group Coordination and Cooperative Control, number 336 in 'Lecture Notes in Control and Information Sciences', Springer-Verlag, Berlin Heidelberg, pp: 35-54.

Even, B., P. Alexey, G. Reza, Pettersen, Y.P. Kristin, P. Antonio and S. Carlos, 2006b. Formation control of underactuated marine vehicles with communication constraints. Elsevier IFAC Publications / IFAC Proceedings series.

Fahimi, F., 2007. Sliding-mode formation control for underactuated surface vessels. IEEE Trans. Robot., 23(3): 617-622.

Ghabcheloo, R., A.P. Aguiar, A. Pascoal, C. Silvestre, I. Kaminer and J. Hespanha, 2006. Coordinated path following in the presence of communication losses and time delays. IEEE Conference on Decision and Control, San Diego, California, USA.

Ghabcheloo, R., 2007. Coordinated path following of autonomous vehicles. Ph.D. Thesis, Instituto Superior Técnico, Technical University of Libson, Portugal.

Graham, C.G., P. Tristan, S. Maria and Y.T. Ching, 2008. On Fundamental Limitations for Rudder Roll Stabilization of Ships. Department of Electrical and Computer Engineering, the University of Newcastle, Callaghan, NSW 2308, Australia.

Ivar-Andr, F.I., J. Jerome and I.F. Thor, 2005. Formation control of marine surface craft using lagrange multipliers. IEEE Conference on Decision and Control and the European Control Conference, pp: 752-758.

Ivar-Andr, F.I., 2006. Coordinated control of marine craft. Ph.D. Thesis, Norwegian University of Science and Technology.

Ivar-Andr, F.I., J. Jerome and I.F. Thor, 2006. Formation control of marine surface craft: A lagrangian approach. IEEE J. Oceanic Eng., 31(4): 922-934.

Liangsheng, X. and Y. Weisheng, 2011. Formation and path tracking control for multiple unmanned ships. The 2nd International Conference on Intelligent Control and Information Processing, China, 2: 425-428.

Thor, I.F., 1994. Guidance and Control of Ocean Vehicles. John Wiley and Sons Ltd., New York, pp: 494, ISBN: 978-0-471-94113-2.