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
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:

\[
\begin{align*}
\dot{x}_1 &= u_t \cos \psi_1 \\
\dot{y}_1 &= u_t \sin \psi_1 \\
\dot{\psi}_1 &= r_1
\end{align*}
\]  

(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):

\[
F(s) = \frac{s}{s^2 + 2(0.1)(0.5)s + (0.5)^2}
\]  

(2)

When the ship leader is moving at constant forward speed \( u_t \), 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).
We define the following variables to mathematically formulate the control objectives:

\[
\begin{align*}
  x_{e1} &= x_{d1} - x_i \\
  y_{e1} &= y_{d1} - y_i \\
  \psi_{e1} &= \psi_{d1} - \psi_i
\end{align*}
\]  

(3)

Note that:

\[
\psi_{d1} = \arcsin \left( \frac{y_{e1}}{\sqrt{x_{e1}^2 + y_{e1}^2}} \right)
\]

(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 \( \psi_{e1} \) and the change of the error \( d\psi_{e1} \) as follows:

\[
\begin{align*}
  \psi_{e1}(k) &= \psi_{d1}(k) - \psi_i(k) \\
  d\psi_{e1}(k) &= \psi_{e1}(k) - \psi_{e1}(k-1)
\end{align*}
\]

(5)

The variable \( \delta_1 \) is defined as the outputs for the fuzzy controller. We can write:

\[
\delta_1 = \text{Fuzzy} (\psi_{e1}, d\psi_{e1})
\]

(6)

The inputs/output linguistic variables are defined as:

\[
\begin{align*}
  \psi_{e1}(t) &= \{NB, NM, NS, ZE, PS, PM, PB\} \\
  d\psi_{e1}(t) &= \{NB, NM, NS, ZE, PS, PM, PB\} \\
  \delta_1(t) &= \{NB, NM, NS, ZE, PS, PM, PB\}
\end{align*}
\]

(7)

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

\[
\begin{align*}
\dot{x}_1 &= u_1 \cos \psi_1 \\
\dot{y}_1 &= u_1 \sin \psi_1 \\
\dot{\psi}_1 &= r_1 \\
\dot{x}_2 &= u_2 \cos \psi_2 \\
\dot{y}_2 &= u_2 \sin \psi_2 \\
\dot{\psi}_2 &= r_2
\end{align*}
\]

(S8)
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:

\[
\begin{align*}
\dot{x}_2 &= D_x \\
\dot{y}_2 &= D_y
\end{align*}
\]  

(10)

The objectives of the second controller are to keep \( \dot{x}_2, \dot{y}_2 \) constants and equal to \( \dot{D}_x, \dot{D}_y \) respectively and the yaw angle \( \psi_2 = 0 \) in straight motion.
For the ship follower, let’s define the position error with respect to $X_1 Y_1$:

$$
\begin{align*}
^{1}E_{x_2} &= (x_2 - x_1) \cos \psi_1 + (y_2 - y_1) \sin \psi_1 - ^{1}D_x, \\
^{1}E_{y_2} &= -(x_2 - x_1) \sin \psi_1 + (y_2 - y_1) \cos \psi_1 - ^{1}D_y.
\end{align*}
$$

(11)

The second controller is designed as followed:

$$
(\delta_2, u_2) = \text{Fuzzy}(^{1}E_{x_2}, ^{1}E_{y_2}, ^{1}\psi_2) 
$$

(12)

The inputs/outputs linguistic variables are defined as:

$$
\begin{align*}
^{1}E_{x_2} &= \{N, Z, P\} \\
^{1}E_{y_2} &= \{N, Z, P\} \\
^{1}\psi_2 &= \{N, Z, P\} \\
\delta_2 &= \{N, Z, P\} \\
u_2 &= \{S, M, B\}
\end{align*}
$$

(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 $\delta_2$ and $u_2$, respectively.
The proposed formation control scheme has been implemented in Simulink™ 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 = 5 m/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 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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