

Orientation Control of Hovercraft Systems via an SMFLC and Image-Guided Techniques

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Abstract—This paper is concerned with the control of a hovercraft vessel using a sliding mode fuzzy logic control and image-guided techniques. Firstly, we introduce the R/C hovercraft type vessel dynamics. Secondly, the sliding mode fuzzy logic control (SMFLC) is proposed in this paper. A significant feature is that the transient response during the reaching phase has been remarkably improved by the proposed control. Finally, an image-guided technique is presented. To illustrate the effectiveness of the proposed method, we choose the R/C hovercraft vessel as the experimental system. Simulation results showed good responses via the proposed techniques.

Keywords—R/C hovercraft vessel, Sliding mode fuzzy logic control, Orientation control, Image-guided technique

I. INTRODUCTION

There was extensive research on nonlinear control in connection with the design of autopilots for high-performance aircraft in the early 1950s. In the last few years, the regulation of a ship vessel, by means of two independent thrusters located at the aft, has received sustained attention [1][2][3][4][5]. Nevertheless, position control of an underactuated vehicle is a difficult problem in general. Especially, if the friction is not existent in the environment, an underactuated vehicle often drifts in the direction without actuation. To cite an instance, it is difficult to control positions of such vehicles as a satellite, a hovercraft, and an airship unless sufficient numbers of thruster or torquer are available. Since a large motion leads to inherent nonlinear dynamics, a nonlinear control method is necessary for their position control.

Variable structure control was initiated in Russia by many researchers, like Barbashin [6], Utkin [7], Emelyanov [8]. The control scheme has successfully been applied to many engineering problems including automatic flight control, chemical processes, helicopter stability augmentation systems, electric motors, robots, etc. Variable structure control law is deliberately changed according to some defined rules which depend on the state of the system. The scheme has been mainly considered for continuous-time systems in the form of sliding mode control.

Sliding mode control is known to be very robust against parameter variations and external disturbances and has been widely accepted as an efficient method for tracking control of

uncertain nonlinear systems. It has been shown to be able to achieve ‘perfect’ performance in principle in the presence of parameter uncertainties, bounded external disturbance, etc [9]. However, in order to account for the presence of parameter uncertainties and bounded disturbances, a discontinuous switching function is inevitably incorporated into the control law to achieve so-called sliding condition [10]. Due to imperfect switching in practice it will raise the issue of chattering, which is usually undesirable. To suppress chattering, a continuous approximation of the discontinuous sliding control is usually employed in the literature. Though, the chattering can be made negligible if the width of the boundary layer is chosen large enough, the guaranteed tracking precision will deteriorate if the available control bandwidth is limited. To reach a better compromise between small chattering and good tracking precision in the presence of parameter uncertainties, various compensation strategies have been proposed. For example, integral sliding control [11], [12], [13], sliding control with time-varying boundary layers [5] etc., were presented. Alternatively, applying so-called reaching law approach, Gao et al. [14] proposed sliding controllers such that the trajectories are forced to approach the sliding surface faster when they are far away from the sliding surface. This approach seems to be an efficient method capable of increasing the approaching speed to the sliding surface. However, the behavior of the system dynamics, governed by the transformed first-order equation, can only be predicted through the measurement of the generalized error. Hence the transient response during the reaching phase may not be remarkably improved.

In this work, it is concerned with the control of a hovercraft vessel using an SMFLC and image-guided techniques. The effectiveness of the newly developed control scheme will be demonstrated through the control of the R/C hovercraft vessel. The simulation results validate the superiority and practicality of the proposed method for the orientation control of hovercraft systems.

II. HOVERCRAFT TYPE VESSEL DYNAMICS

We employ an R/C hovercraft (356 mm×212 mm×142 mm) shown in Fig. 1 on a planar ground as the system to be controlled. This model is based on that used in the recent work

of Tanaka *et al.* [4]. Fig. 2 shows the hovercraft type vehicle (HTV) model and its coordinate system, where

- α : angle of the vehicle
- d : distance between the gravity and fans
- β : angle between the gravity and fans
- m : mass of the vehicle
- I : inertia of the vehicle
- u_R : force of right side fan
- u_L : force of left side fan

Then the HTV dynamics are represented as

$$\begin{aligned}\ddot{x} &= \frac{\cos \alpha}{m} u_1 \\ \ddot{y} &= \frac{\sin \alpha}{m} u_1 \\ \ddot{\alpha} &= \frac{d \sin \beta}{I} u_2\end{aligned}\quad (1)$$

where $u_1 = u_R + u_L$ and $u_2 = u_R - u_L$. [14]

In this simulation, $\beta = \pi/4$, $m = 0.1$, $I = 0.5$ and $d = 0.1$. Since the control purpose is $\lim_{t \rightarrow \infty} y = 0$ and $\lim_{t \rightarrow \infty} \alpha = 0$, that is, x is not a controlled variable, the controlled object is described as

$$\begin{aligned}\ddot{y} &= \frac{\sin \alpha}{m} u_1 \\ \ddot{\alpha} &= \frac{d \sin \beta}{I} u_2\end{aligned}\quad (2)$$

III. FUZZY VARIABLE STRUCTURE CONTROL

Consider a simple n^{th} -order SISO nonlinear system

$$y = f^{(n)}(t, y, \dots, y^{(n-1)}) + g^{(n-1)}(t, y, \dots, y^{(n-1)})u \quad (3)$$

Assume that $f = \hat{f} + \Delta f$, where $\hat{f}$ is the known part and Δf is the uncertain part, which includes the internal noise bounded in $|\Delta f| \leq F$. The object is to find a sliding control u such that the output y of (3) will approximately track a desired signal, y_d which is assumed to be n^{th} -order continuously differentiable and all of its derivatives are uniformly bounded. Given the tracking error

$$e(t) = y(t) - y_d(t) \quad (4)$$



Figure 1. Hovercraft type vehicle

For any $q > 0$, define the following transformation

$$s(t) = \left(\frac{d}{dt} + q \right)^{n-1} e(t) \quad (5)$$

Then

$$\dot{s} = \hat{f} + \hat{w} + u \quad (6)$$

where

$$\hat{w} = \sum_{k=1}^{n-1} \binom{n-1}{k-1} e^{(k)} \lambda^{n-k} - y_d^{(n)} \quad (7)$$

An n^{th} -order tracking problem can be transformed into an equivalent 1st-order stabilization problem. It is easy to show that the control law

$$u = \frac{1}{g} (\hat{u} + u_f) \quad (8)$$

with

$$\begin{cases} \hat{u} = -\hat{f} - \hat{w} \\ u_f = -\Gamma_f \text{sat}\left(\frac{s}{\Phi}\right) \end{cases} \quad (9)$$

will result in a closed-loop system satisfying the reaching condition:

$$s\dot{s} \leq -\eta|s|, \quad \forall |s| \geq \Phi, \quad (10)$$

Provided $\Gamma_f \geq F + \eta$, for some $\eta > 0$. u_f is the output of the FLC. Each fuzzy rule of a FSMC can be expressed as

Ruleⁱ: if $s = LS^i$, then $u_f = LU^i$.

where LS^i is a linguistic value of s in the i -th fuzzy rule.

This controller ensures that starting from any initial state the error trajectory will reach the boundary layer, $|s| \leq \Phi$ in finite time.

IV. IMAGE-GUIDED TECHNIQUE [15]

To obtain the relative locations of the landmark and the hovercraft, an image-guided search algorithm is used to find the center of the landmark and the moving vector. These procedures for image processing are shown in Fig. 3.

A. Image Preprocessing

The image preprocessing includes binarization and filtering with the aim of distinguishing the object from the background. To reduce the amount of data, the three-dimensional RGB-image information is transformed into a one-dimensional colour axis. Unfortunately, the regulation of the threshold value usually produces noise.

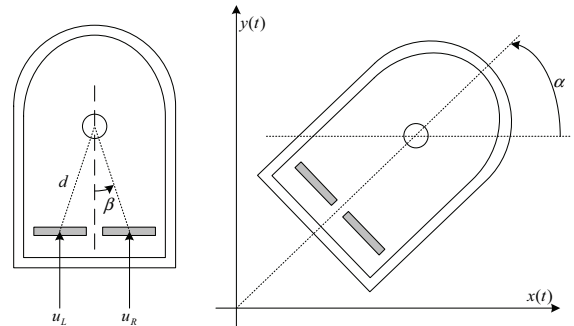


Figure 2. The HTV model and its coordinate system

To improve the image quality, the median and area filters will be used to reduce this noise.

B. Moving-Target Detection

1) Sobel filter

To detect the edge of a binarized picture, a Sobel filter is the most common tool and is very useful. The following two matrices are used as the filter operators:

$$G_x = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \quad (11)$$

$$G_y = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & 1 \end{bmatrix}, \quad (12)$$

where G_x and G_y are used for edge detection in the x -direction and the y -direction, respectively. These two 3×3 convolution masks are applied to each pixel. The result of each convolution is treated as a vector representing the edge through the current pixel. If the magnitude of the sum of these two orthogonal vectors is greater than any user-specified threshold, the pixel is marked in black as an edge. Otherwise, the pixel is set to white.

2) Moving-edge detection

To extract the background automatically, a large enough number of successive structures must be available for processing. The procedures for moving-edge detection are shown in Fig. 4. First, three successive structures (I_t , I_{t+1} , I_{t+2}) will be taken from CCD, and then the differences $D[I_{t+2} - I_{t+1}]$ and $D[I_{t+1} - I_t]$ can be calculated. The Logical AND operation can be used to evaluate the difference product. Hence, the moving vector of I_{t+1} can be obtained.

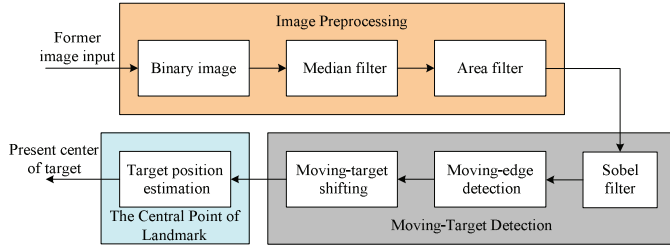


Figure 3. Procedures for image processing

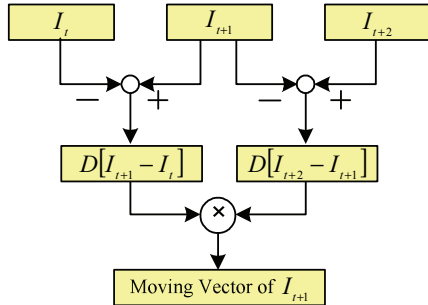


Figure 4. Moving-edge detection

3) Moving-target shifting

As shown in Fig. 5, to overcome image-delay, the moving-target shifting method will be used to get the new landmark

M2. By comparing $D[I_{t+2} - I_{t+1}]$ with $M1$, the shift values X_d and Z_d can be estimated as follows.

$$\begin{cases} X_d = (C1 - C2) + (A1 - A2) \\ Z_d = (B1 - B2) + (D1 - D2) \end{cases} \quad (13)$$

C. The Central Point of Landmark

In this article, 0 and 1 gray-level images are regarded as the background and the landmark, respectively. If the maximum and minimum values of projection are found on the x -axis and z -axis, respectively, then the center point can be obtained (see Fig. 6).

V. SIMULATION RESULTS

According to the notations given above, we take $\hat{f}_y = 0$, $\hat{w}_y = \lambda_y \dot{e}_y - \ddot{y}_d$, $\hat{f}_a = 0$, and $\hat{w}_a = \lambda_a \dot{e}_a - \ddot{\alpha}_d$. Initial values are chosen as $(x_0, y_0, \alpha_0) = (1, 1, -1.5)$. By setting the parameters as $\Phi_y = 1$, $\lambda_y = 7$, $\Phi_a = 15$, and $\lambda_a = 25$.

The input and output membership functions are shown in Figs. 7 and 8, respectively. The simulation results of [4] are shown in Fig. 9. Figs. 10 and 11 indicate the time responses of the y -axis track and the angle of the vehicle under the proposed control scheme, respectively.

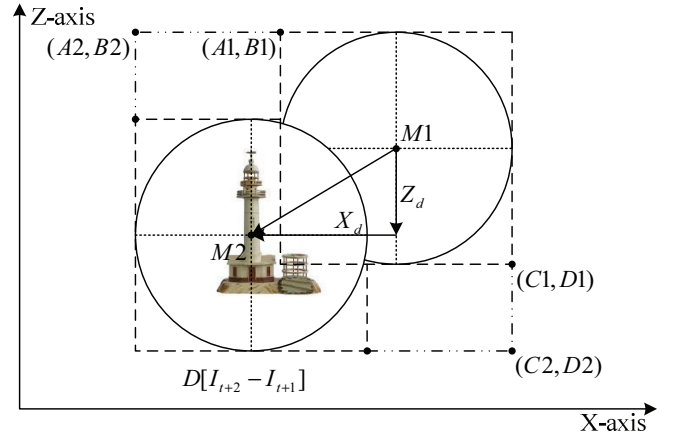


Figure 5. Moving-target shifting

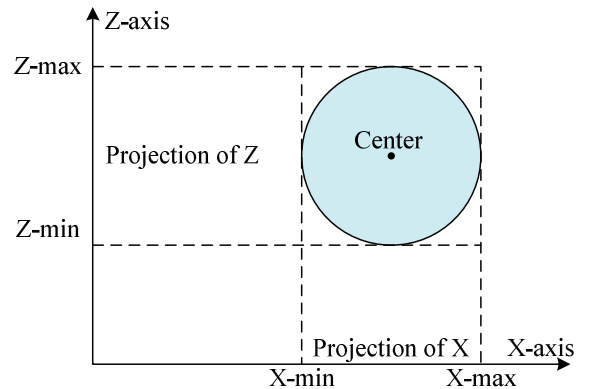


Figure 6. Central point of the landmark

The corresponding control action is shown in Fig. 12 (solid line: force of right side fan; dotted line: force of left side fan). The trajectories are evidently better than those of [3].

VI. CONCLUSION

We have presented an SMFLC scheme and image-guided techniques in this article for a hovercraft vessel. The proposed control scheme has shown to be capable of improving the transient response as well as the steady state response. To illustrate the effectiveness of the proposed method, we choose the R/C hovercraft vessel as the experimental system. The simulation results validate the superiority and practicality of the proposed method for the orientation control of hovercraft systems.

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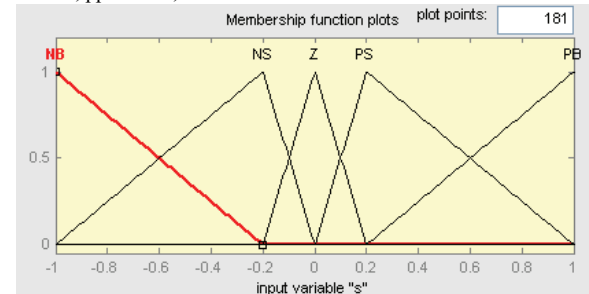


Figure 7. The input membership function

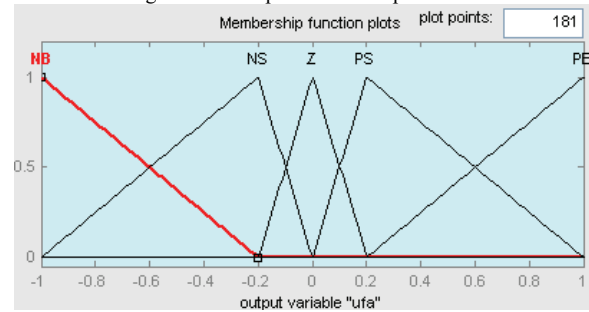


Figure 8. The output membership function

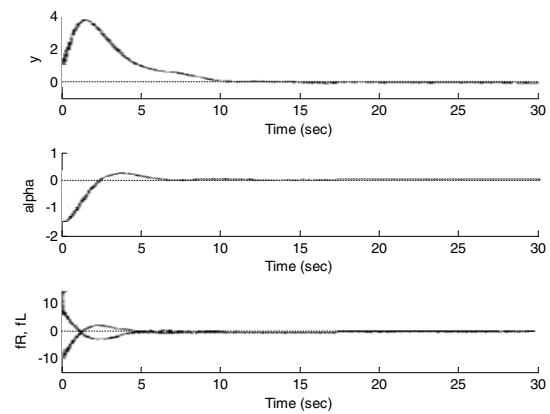


Figure 9. The simulation results of [3]

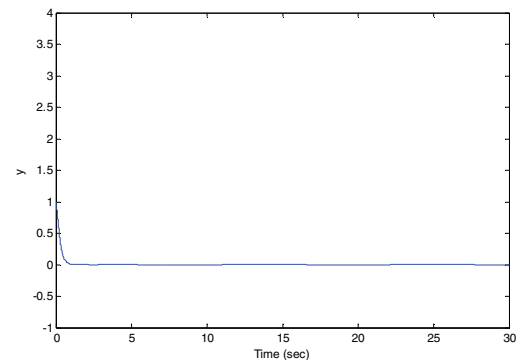


Figure 10. The response of $y(t)$ via the proposed method

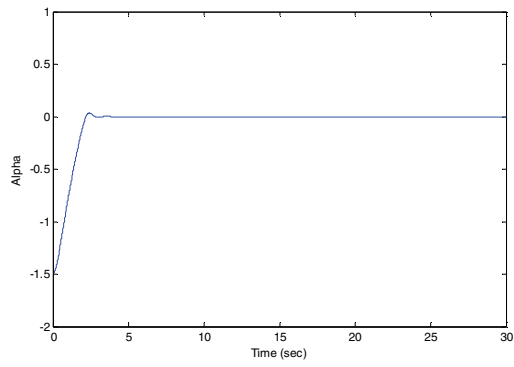


Figure 11. The response of $\alpha(t)$ via the proposed method

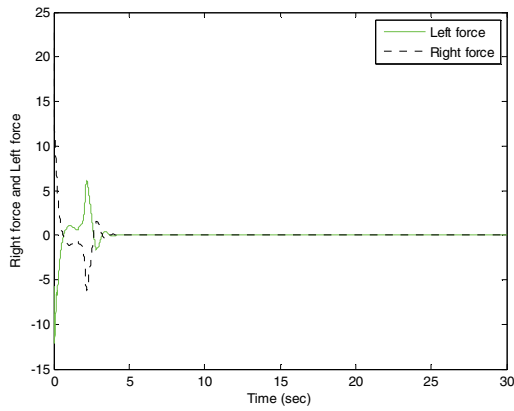


Figure 12. The forces of right and left side fans via the proposed method