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Research Article

Study on Application of T-S Fuzzy Observer in Speed Switching Control of AUVs Driven by States

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Considering the inherent strongly nonlinear and coupling performance of autonomous underwater vehicles (AUVs), the speed switching control method for AUV driven by states is presented. By using T-S fuzzy observer to estimate the states of AUV, the speed control strategies in lever plane, vertical plane, and speed kept are established, respectively. Then the adaptive switching law is introduced to switch the speed control strategies designed in real time. In the simulation, acoustic Doppler current profile/side scan sonar (ADCP/SSS) observation case is employed to demonstrate the effectiveness of the proposed method. The results show that the efficiency of AUV was improved, the trajectory tracking error was reduced, and the steady-state ability was enhanced.

1. Introduction

Many typical tasks of AUV require accurate speed control, such as path tracking and attitude control [1]. Hence, the suitable speed control strategies are important to the whole control system of AUV. However, the highly nonlinear, highly coupling, and underactuated characteristics of the dynamic model of AUV make it difficult to design the speed controller. Considering that the complex task of AUV usually is divided into lever plane task and vertical plane task and executed independently, the conventional dynamic model of AUV can be decoupled into control of speed, yaw, and depth independently [2]. Based on the linearization or decoupling of usual dynamic model of AUV, a large class of methods have been introduced to the speed control of AUV.

As the AUV dynamic model can be linearized at the domain of the working point, the PID speed controller is designed to keep the speed of AUV at a given value [3]. However, the general PID controller's parameters are fixed and difficult to set; then the adaptive PID control method is introduced in [4]; the parameters of the controller will be updated according to the speed error. Due to the uncertain disturbance of AUVs dynamic model, such as the current disturbance [5], unmodeled dynamics [6, 7], and measurement noise [8], we cannot get the precise dynamic model of AUV. Then, the control methods which do not rely on the exact model are introduced in [9]; in this paper, wave disturbances in both vertical and horizontal planes were considered. A nonlinear, Lyapunov-based, adaptive output feedback control law is designed to depth tracking and attitude control of AUV. In [10], the robust adaptive speed controller is designed for a flexible hypersonic vehicle model which is nonlinear and multivariable and includes uncertain parameters. With a view to the unknown current and unmodeled dynamics, the radial basis function (RBF) neural net is concerned to estimate the uncertain parameters of the vehicle's model [11], and then the speed controller is designed. However, the vehicle dynamics change by different scientific missions and the acoustic motion estimation and control method are researched in [12]. In order to estimate the states of the unknown inputs, the observer was designed for T-S fuzzy models in [13]. The stability of speed controller is also important to the whole control system. Reference [14] analyse the stability of PD speed controller and S-surface speed controller, which were designed based on the Lyapunov's direct.

The methods mentioned above all depend on the decoupling dynamic model of AUV. Through the analysis of AUV dynamic model, it is concluded that when AUV is sailing in lever plane or diving in vertical plane, the coupling torque developed by vertical steering rudder or lever steering rudder can be approximately ignored, but the coupling force or torque developed by speed still exits, and with the increase of the AUV speed, the coupling will be higher [15]. In this paper, considering the coupling between speed and states, a speed switching control method driven by AUV states is proposed. Through the estimation of AUV states by T-S fuzzy observer, the speed control strategy is designed in lever plane, vertical plane, and speed kept, respectively. Then the adaptive switching law is given to switch the speed control strategies established in real time.

The structure of the paper is as follows. Section 2 introduces the nonlinear dynamic model of AUV, and the nonlinear coefficient matrix is stressed. In Section 3, the T-S fuzzy observer is designed, which is based on the dynamical model of AUV. By the estimation of AUV states, Section 4 establishes the speed control strategies of AUV. ADCP/SSS observation case is considered in Section 5 to evaluate the efficiency of the speed control method proposed in this paper. Finally, we draw conclusion in Section 6.

2. AUV Model

The vehicle we studied in this paper is equipped with three actuators: a main thruster for propulsion, a vertical steering rudder, and a lever steering rudder. Since the controllable dimensions are less than model dimensions, the controller designed for such AUV is underactuated. According to [16], the 6-DOF dynamical model of AUV described by matrix and vector is put forward as follows:

$$T\dot{x} = A(x)x + M\tau_d + D(x)\tau + \alpha,$$
$$y = Cx, \tag{1}$$

where $x = [u, v, w, q, r]^T$ is the linear velocity and angular velocity of AUV in the body-fixed reference frame; $\tau = [X_{\text{prop}}, \delta_r, \delta_s]^T$ is the actuator output, which includes propeller thrust, rudder angle, and stern angle, respectively; $A \in R^{5\times5}$ is coefficient matrix; $D \in R^{5\times3}$ is control matrix; are nonlinear matrix; $M \in R^{5\times5}$ is the interference gain matrix; $a \in R^{5\times1}$ and $C \in R^{5\times5}$ are constant matrices. $y = [\theta, \psi, X, Y, Z]$ is the pitch, yaw, and generalized position of the AUV in the earth-fixed reference frame.

According to the standard motion equation of AUV, the nonlinear matrix $A(x)$ and $D(x)$ in (1) can be described as

$$A(x) = \begin{bmatrix} X_{uu}u & X_w v & X_{ww}w & (-m + X_{wq})w + X_{qq}q & (m + X_{vr})v + X_{rr}r \\ 0 & Y_v & Y_{vw}v & Y_{vq}v & -mu + Y_r + Y_{wr}w + Y_{qr}q \\ 0 & Z_w v & Z_w & mu + Z_q & Z_{vr}v + Z_{rr}r \\ 0 & M_v v & M_w + M_{w|w|}(v^2 + w^2)^{1/2} & M_{q|q|}q + M_{wq}(v^2 + w^2)^{1/2} & (J_{y-}J_z)q + J_{xy}q + J_{zx}r + M_{rr}r + M_{vr}v \\ 0 & N_v & N_{vw}v + N_{v|v|}(v^2 + w^2)^{1/2} & -J_{xy}q - J_{zx}r + N_{vq}v & N_r + N_{wr}w + N_q q + N_{r|r|}|r| + N_{|v|r}(v^2 + w^2)^{1/2} \end{bmatrix},$$

$$D(x) = \begin{bmatrix} a_T & X_{\delta_r\delta_r}\delta_r & X_{\delta_s\delta_s}\delta_r \\ 0 & Y_{\delta_r}Y_{|r|\delta_r}|r| & 0 \\ 0 & 0 & Z_{\delta_s} + Z_{|q|\delta_s}|q| \\ 0 & K_{\delta_r} & 0 \\ 0 & N_{\delta_r} + N_{|r|\delta_r}|r| & 0 \end{bmatrix}, \tag{2}$$

where $X_{[\cdot]}, Y_{[\cdot]}, Z_{[\cdot]}, M_{[\cdot]}, N_{[\cdot]}, J_{[\cdot]}$, are dimensional hydrodynamic coefficients of AUV dynamical model.

3. AUV State Estimation Based on T-S Fuzzy Observer

The nonlinear parts in (2) can be described by set as follows:

$$S = \left\{u, v, w, q, r, \left(v^2 + w^2\right)^{1/2}, \delta_r, \delta_s\right\}. \tag{3}$$

To construct the T-S fuzzy observer based on AUV's dynamical model, (1) must be rewritten as T-S fuzzy form. So, the neighborhood nonlinear approximation principle of fuzzy inference system [17] is introduced; then (1) can be rewritten as

R_i: If u is N_i^u … and $(v^2 + w^2)^{1/2}$ is N_i^{vw}; then

$$\dot{x} = A_i x + M_i\tau_d + D_i\tau + a,$$
$$y = Cx, \tag{4}$$

where $i = 1, 2, \ldots, r$, r is the number of rules; N is the fuzzy set; $A_i \in R^{5\times5}$, $M_i \in R^{5\times5}$, $D_i \in R^{5\times5}$, and $C = I$ are the constant matrices which were linearized by (2). Then, the approximate T-S fuzzy model based on (4) can be designed as follows:

$$\dot{x} = \sum_{i=1}^{n} w_i(z)\left(A_i x + M_i \tau_d + D_i \tau + a\right), \quad y = Cx, \tag{5}$$

where $z = [u, v, w, q, r, (v^2 + w^2)^{1/2}, \delta_r, \delta_s]^T$, and $w(z)$ is the weight unitary function; according to [13, 18], it can be calculated as

$$w_i(z) = \frac{h_i(z)}{\sum_{i=1}^{n} h_i(z)}, \quad i = 1, \ldots, n, \tag{6}$$

$$h_i(z) = h_{m1}(u)\, h_{m2}(v)\, h_{m3}(w)\, h_{m4}(q)\, h_{m5}(r) \times h_{m6}\left(\left(v^2 + w^2\right)^{1/2}\right) h_{m7}(\delta_r)\, h_{m8}(\delta_s), \tag{7}$$

where $m_1, m_2, m_3, m_4, m_5, m_6 \in \{1, 2\}$; $h_m(x)$ can be calculated as

$$h_1(x) = \frac{x_{\max} - x}{x_{\max} - u_{\min}}, \quad h_2(x) = \frac{x - x_{\min}}{x_{\max} - u_{\min}}. \tag{8}$$

Together with (6), we can get that the total number of rule is $n = 2^8 = 256$.

Considering the external disturbances of AUV which mainly come from sea currents and the unmodeled dynamics of model, we can define sea currents disturbance as a and unmodeled dynamics of AUV as A_δ and B_δ. Then, the uncertain input of AUV can be described as

$$\tau_d = A_\delta x + B_\delta u + a, \tag{9}$$

where $A_\delta \in R^{5\times5}$, $B_\delta \in R^{5\times3}$, and $a \in R^{5\times1}$ are unknown. Then (4) can be rewritten as

$$\dot{x} = T^{-1} \sum_{i=1}^{n} w_i(z)\left(A_i x + M_i\left(A_{\delta i} x + B_{\delta i} u + a\right) + D_i \tau\right), \quad y = Cx. \tag{10}$$

Then, we can design T-S fuzzy observer based on AUV T-S fuzzy model (10) as follows:

$$\begin{aligned}\dot{\hat{x}} &= \sum_{i=1}^{m} w_i(z)\left(A_i \hat{x} + D_i \tau + L_i(y - \hat{y}) + M_i\left(\hat{A}_{\delta i}\hat{x} + \hat{B}_{\delta i} u + \hat{a}_i\right)\right), \\ \hat{y} &= C\hat{x}, \\ \dot{\hat{A}}_{\delta i} &= w_i(z)\, M_i^T P C' e_y \hat{x}^T, \\ \dot{\hat{B}}_{\delta i} &= w_i(z)\, M_i^T P C' e_y u^T, \\ \dot{\hat{a}}_i &= w_i(z)\, M_i^T P C' e_y,\end{aligned} \tag{11}$$

where C' donates the Moore-Penrose pseudoinverse of output matrix C; L_i, $i = 1, 2, \ldots, n$ are gain matrices for each rule; $P = P^T > 0$, L_i, Λ_i^k, $i = 1, 2, \ldots, m$, $j = 1, 2, \ldots, n$, $k = 1, 2, \ldots, p$ can be calculated by LMI as

$$H\left(P\begin{pmatrix} A_i - L_i C_j + A_j - L_j C_i & M_i + M_j & 0 & \cdots & 0 \\ -\Lambda_i^1 C_j - \Lambda_j^1 C_i & 0 & 2I & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ -\Lambda_i^{p-1} C_j - \Lambda_j^{p-1} C_i & 0 & 0 & \cdots & 2I \\ -\Lambda_i^{p} C_j - \Lambda_j^{p} C_i & 0 & 0 & \cdots & 0 \end{pmatrix}\right) < 0, \quad \forall j \ge i : \exists z : w_i(z)\, w_j(z) \ne 0. \tag{12}$$

The basic sufficient stability conditions for this observer were derived in [19].

4. Speed Control Strategies Driven by States

According to the 6-DOF dynamic model of AUV, we know that the speed of AUV is strong coupling with the states of AUV. So if the AUV speed is static, then the coupling force and moment will be different depending on the difference of AUV states, which can influence the precision of actual operation of AUV [20]. Our objective is to design a strategy of AUV speed, which is driven by AUV states, so as to decrease or eliminate the influence derived by the changing of AUV states.

4.1. Lever Variable Speed Control Strategy. When AUV is sailing in the horizontal plane, the states involved are AUV speed, sway velocity, and yaw velocity. According to the experiments, we know that when AUV yaws in the horizontal plane, the sway velocity should be as small as possible and the lateral error will be close to zero. In order to reduce the lateral displacement and heeling angle, the speed of AUV should be decreased. On the other hand, if AUV is sailing direct or the velocity of yaw is small, we should consider accelerating the AUV speed so as to work more efficiently.

Assume that at any time t the speed of AUV is $\hat{u}(t)$ which is estimated by T-S fuzzy observer; then AUV speed at time $t + 1$ can be defined as

$$u_{\text{com}}(t + 1) = u_{\text{com}}(t) + k_1 f_1(\hat{v}, \hat{r}), \tag{13}$$

where $\hat{v}$, $\hat{r}$ are estimated sway velocity and yaw velocity; k_1 is the gain of speed control; f_1 is a function which is driven by AUV states. It is assumed that $|r| \le m$, and the index of yaw is defined as $k = m/2$. Namely, when $|r| < k$, the AUV speed should be accelerated. And f_1 is designed as follows:

$$f_1 = \frac{\tan\left[\left(-|\hat{r}| + k\right) * n\right]}{14.26}, \quad n = \frac{3}{m}. \tag{14}$$

And Figure 1 described the physical meanings of function f_1.

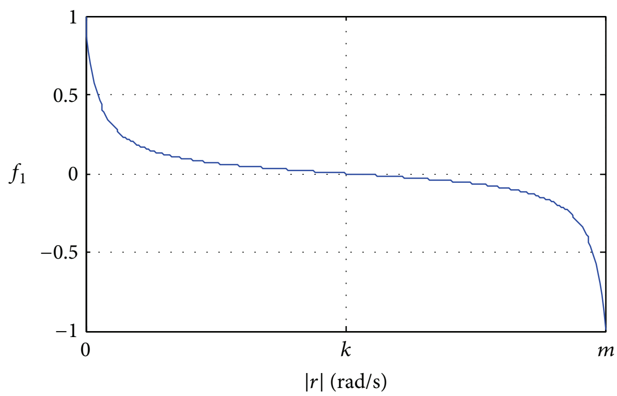

FIGURE 1: Physical meanings of f_1.

Figure 1 illustrates that when $|r|$ is approaching k, f_1 will tend to 0; then the speed acceleration or deceleration is nearly 0; when $|r|$ is approaching 0, it means that AUV is sailing almost directly, then f_1 should quickly rise to 1 so that the speed of AUV can be kept in a high value; when $|r|$ is approaching m, it means that AUV is surging; then f_1 should decrease to −1 quickly so that AUV speed can be kept in a low value.

Combined with (13) and (14), the speed error system in lever plane can be calculated as

$$\begin{aligned} e(t) &= u_{\text{com}}(t+1) - \hat{u}(t) \\ &= u_{\text{com}}(t) + k_1 f_1(\hat{v}, \hat{r}) - \hat{u}(t). \end{aligned} \tag{15}$$

To follow the speed desired, PID controller is introduced, and the instruction of thruster can be described as

$$T_{\text{com}}(t+1) = k_P e(t) + k_I \int e(t)\,dt + k_D \frac{de(t)}{dt}. \tag{16}$$

4.2. Vertical Variable Speed Control Strategy. When AUV is diving in the vertical plane, the states involved are AUV speed u, heave velocity w, and pitch velocity q. The most important indexes when AUV is diving are heaving time and overshoot. To ensure the stability of heave, the range of pitch is set to $|\theta| \le 25^\circ$. According to the 6-DOF model of AUV, we know that when the lever rudder δ_s is fixed, the pitch will be controlled only by AUV speed; therefore, we should control the range of AUV speed so that the pitch can be kept in the allowed range. Hence, at the beginning of the diving stage, u should be kept at a high value so that it can reach maximum pitch with little time; when the desired pitch or deep has been reached, the low speed is designed so that it can decrease the overshoot and keep the pitch stability.

To judge whether the current pitch has reached the bound, the estimation pitch $\hat{\theta}$ is introduced as one of the speed control system states. According to the analysis above, the vertical variable speed control strategy which is driven by AUV states is designed as follows:

$$u_{\text{com}}(t+1) = u_{\text{com}}(t) + k_2 f_2\left(\hat{w}, \hat{q}, \hat{\theta}\right), \tag{17}$$

where f_2 can be expressed as

$$f_2 = \begin{cases} \dfrac{1}{1 + \left|(\hat{q} - c)/4\right|^{2\,\text{sign}(\hat{w} - \varepsilon_2)}}, & |\Delta\theta| > \varepsilon_1, \\ 0, & |\Delta\theta| \le \varepsilon_1, \end{cases}$$
$$\Delta\theta = \begin{cases} \hat{\theta} - \theta_{\min}, & \hat{w} < -\varepsilon_2, \\ \theta_{\max} - \hat{\theta}, & \hat{w} > \varepsilon_2, \\ 0, & \text{otherwise}, \end{cases} \tag{18}$$

where $\theta_{\min}$ and $\theta_{\max}$, respectively, represent the minimum and maximum value of pitch when AUV is diving in vertical plane; c, ε_1, and ε_2 are constants. Generally, $\theta_{\min} = -25^\circ$ and $\theta_{\max} = 25^\circ$.

Combined with (17)-(18), the speed error in vertical plane can be calculated as

$$\begin{aligned} e(t) &= u_{\text{com}}(t+1) - \hat{u}(t) \\ &= u_{\text{com}}(t) + k_2 f_2\left(\hat{w}, \hat{q}, \hat{\theta}\right) - \hat{u}(t). \end{aligned} \tag{19}$$

Similarly, the instruction of thruster when AUV is diving can be calculated by (16).

4.3. Speed Kept Control Strategy. Considering the bound of the thruster, the task needs, and the security restricts of AUV, the maximum and minimum value of AUV speed should be set. When the speed of AUV accelerates to the maximum value or decreases to the minimum value, the speed should be kept at this value. It is assumed that

$$u_{\text{com}}(t+1) = u_0, \tag{20}$$

where $u_0 = u_{\max}$ and $u_0 = u_{\min}$ are constants. Then the error of AUV speed can be calculated as

$$e(t) = u_{\text{com}}(t+1) - \hat{u}(t) = u_0 - \hat{u}(t). \tag{21}$$

The calculation of thruster instruction is similar to (16).

4.4. Switching Law Design. To realize the stability switching of the speed control strategies designed at a previous section, in this section, our objective is to design a suitable switching law. The switching signal value can be calculated according to the states of AUV, and then the instruction of thruster can be calculated based on the current speed error. Assume that the expression of switching system is as follows:

$$u_{\text{com}}(t+1) = A_{\sigma(t)} \chi(t), \tag{22}$$

where $\chi(t) = [\hat{u}(t), \hat{w}(t), \hat{q}(t), \hat{r}(t), \hat{\theta}(t)]^T$ are the states of switching system; $\sigma(t) \in M$ is switching signal; $M = \{1, \ldots, n\}$ is the set of switching signal; $A_i \in R^{n\times n}$, $i \in M$ is coefficient matrix. We can know from the previous section that $M = \{1, 2, 3\}$.

Assume that w_i is the weight of subsystem A_i in the whole system. According to [21], we can know that if each subsystem A_i $(i = 1, 2, 3)$ is Hurwitz matrix and average matrix A_0 is

$$A_0 = \sum_{i=1}^{3} w_i A_i, \tag{23}$$

then A_0 is Hurwitz matrix too. Solve the Lyapunov function as follows:

$$A_0^T P + P A_0 = -I_n, \quad (24)$$

where $P = P^T > 0$. Define

$$Q_i = A_i^T P + P A_i, \quad i = 1, \dots, n; \quad (25)$$

then, for any initial state $x(t_0) = x_0$, the first switching sequence can be defined as

$$\sigma(t_0) = \arg\min \left\{ x_0^T Q_1 x_0, \dots, x_0^T Q_n x_0 \right\}, \quad (26)$$

where arg min represents the minimum order value of indicators; if there are multiple minimum indicators, then it is the minimum number of subsystem. By recursion, we can define other switching sequences as

$$t_{k+1} = \inf \left\{ t > t_k : x^T(t) Q_{\sigma(t_k)} x(t) > 0 \right\},$$
$$\sigma(t_{k+1}) = \arg\min_{i=1,\dots,n} \left\{ x^T(t_{k+1}) Q_i x(t_{k+1}) \right\}, \quad (27)$$
$$k = 0, 1, \dots.$$

From (27), we obtain that the switching law designed calculated switching signal based on the variable system states $x(t)$, and the minimum value of $x^T(t_{k+1}) Q_i x(t_{k+1})$, $i = 1, \dots, 6$ represents the maximum weight of speed control subsystem.

5. Simulation Results

In this section, the proposed speed control method designed on a simulation case was illustrated. The case under consideration is ADCP/SSS observation, which is one of the typical tasks of AUV. The simulation environment is MATLAB and with a full nonlinear model of AUV. Set the initial states and position in fixed frames as zero; the maximum of propulsion thrust is 2000 N; the largest rudder angle is 30°; $u_{\max} = 2.5$ m/s; and $u_{\min} = 1.8$ m/s. To prevent the heave angle which is too large and affect the ability of AUV, the maximum pitch is set to be 25°. The unvarying current is set to be heading x-axis with 0.25 m/s.

Conventional control system of AUV contains three forward channels, namely, the control of AUV speed, the control of AUV heading, and the control of AUV diving. The actuators are propeller, horizontal rudder, and vertical rudder, respectively. Combined with the T-S fuzzy observer designed, the AUV speed control system is constructed as in Figure 2, where $\hat{x}'$ is the vector of AUV states estimated by T-S observer; u_d is the desired value which is calculated by the speed switching control strategies designed; u_w is the current speed, which is set to be heading east and with 0.25 m/s.

Assume that the depth of sea area is 200 m. Consider that the best range of ADCP is 30–40 m, so the desired depth of observation is 170 m. After diving to the specified depth, the AUV is ordered to keep this depth and sail along comb-shaped track. Considering the range of SSS, the comb interval is set to be 150 m, and y-axis distance is 1 km. The programming points coordinates are shown in Table 1.

Table 1: Programming points coordinates (m).

X	0	100	300	300	450	450	600	600
Y	0	0	0	1000	1000	0	0	1000
Z	0	0	170	170	170	170	170	170
X	750	750	900	900	1050	1050	1150	1350
Y	1000	0	0	1000	1000	0	0	0
Z	170	170	170	170	170	170	170	0

Table 2: Comparison of overlength (m).

Overshoot term	Speed kept by PID controller	Thrust kept	Speed switching control driven by AUV states
Diving overlength	12.33	10.73	0
Surging overlength	1.50	1.50	0.72
The maximum overlength along x- axis	34.96	20.31	10.28
The maximum overlength along y- axis	20.02	12.86	7.71

Three speed control methods are considered in the simulation, which are speed kept by PID controller, propulsion thrust kept, and speed switching control driven by AUV states, respectively. The simulation results are shown in Figures 3–10. Figure 3 shows the spatial trajectory tracking response under three speed control methods, where S is the start point and E is the end of the mission. Table 2 presents the overlength valve under different speed control methods. Combining Figure 3 and Table 2, we can see that compared with other two speed control strategies, under the method proposed in this paper, the trajectory tracking overshoot is decreased; the tracking error is smaller, and the diving angle is kept at the maximum value.

The real AUV speed response is presented in Figure 4. As can be seen, when AUV is diving or surging, under the proposed speed control method, the AUV speed will decrease quickly as the feedback of AUV states. However, under the other two speed control methods, the AUV speed is kept at a stable value. Especially, under the speed kept by PID controller, as the feedback of the speed error, at the beginning of diving or surging, the propulsion thrust will increase. Combined with Figures 5, 6, and 7, we can clearly see that under the proposed method the swaying velocity and heel angle are smaller and under the speed kept by PID controller, swaying velocity and heel angle are higher.

From Figures 8 and 9, we can see that the yaw angle changes smoothly and with no overshoot, it can also be seen from Figure 1. The pitch response can be seen from Figure 10 that under the proposed method the pitch reaches maximum value quickly so as to dive more efficiently. Otherwise, From Figures 4–10, we can see that using the approach proposed in this paper can make AUV work more efficiently.

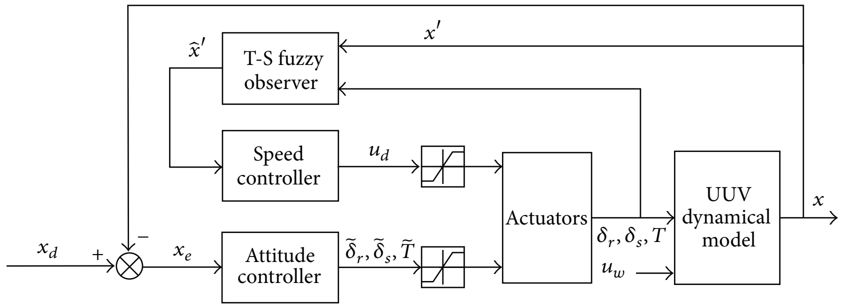

FIGURE 2: Structure of control system.

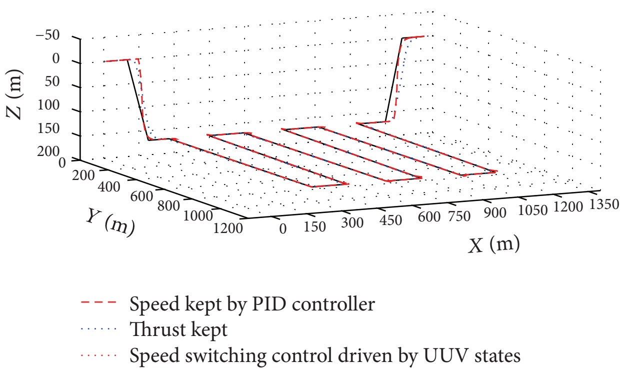

FIGURE 3: Spatial trajectory tracking response.

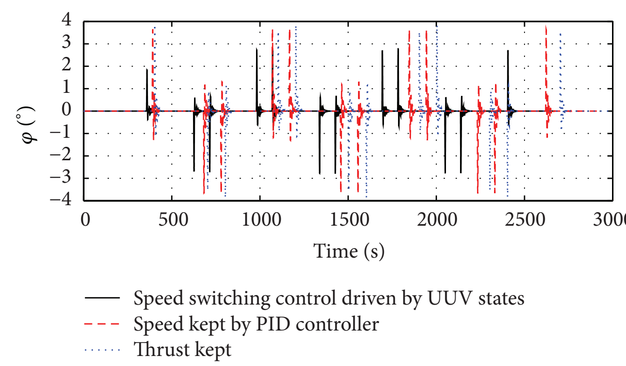

FIGURE 6: Heel response of AUV.

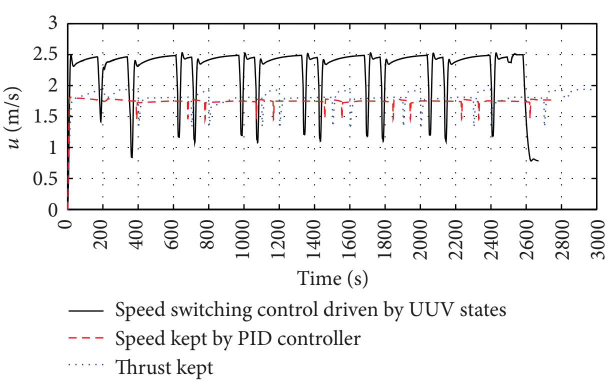

FIGURE 4: AUV speed response.

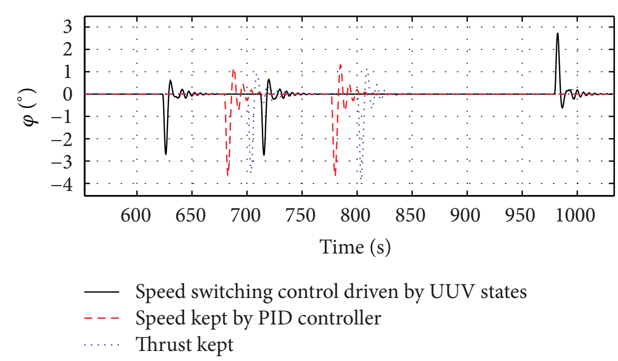

FIGURE 7: Zoomout of heel.

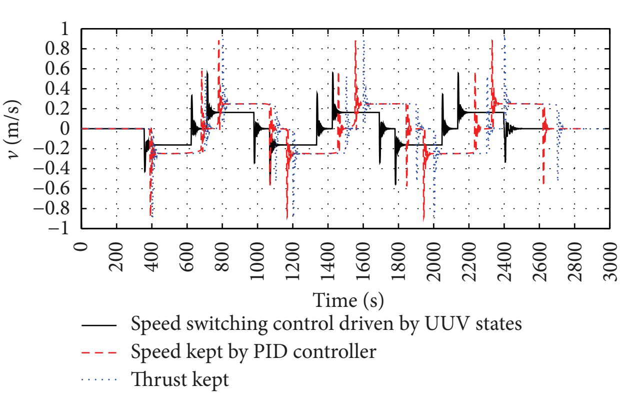

FIGURE 5: Swaying velocity response.

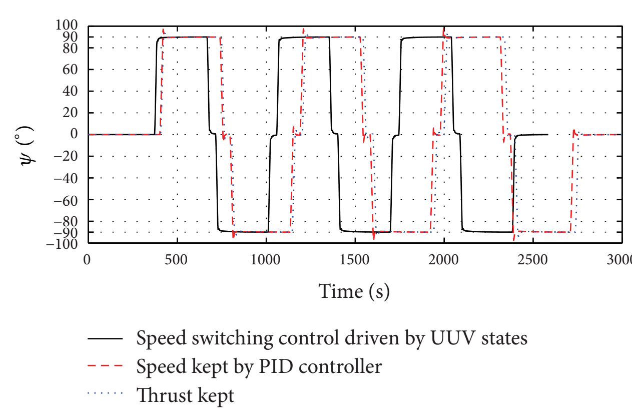

FIGURE 8: Yaw response of AUV.

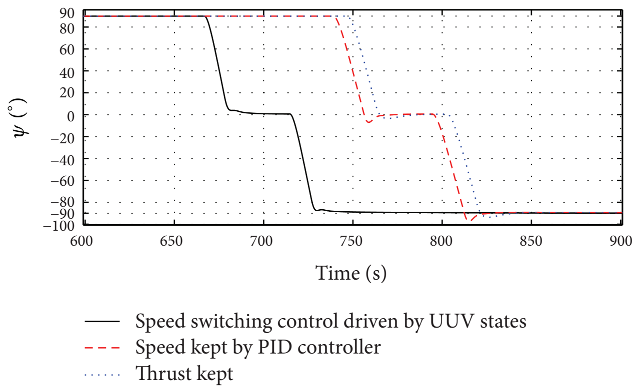

Figure 9: Zoomout of yaw.

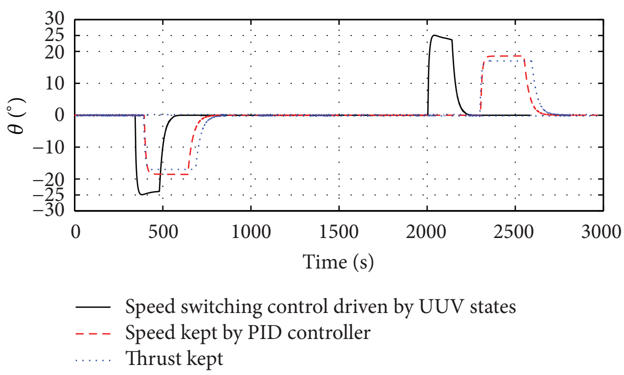

Figure 10: Trim response of AUV.

6. Conclusion

In this paper, a speed switching control method for AUV has been proposed, which is driven by AUV's states. Through designed T-S fuzzy observer to estimate the states of AUV, several speed control strategies were put forward, and an appropriate switching law is given to switch the speed control strategies designed in real time according to the states estimated. Finally, ADCP/SSS observation case was introduced to illustrate the effectiveness of the proposed speed control method. The varying currents and other unmodeled dynamics of AUV will be considered in future work.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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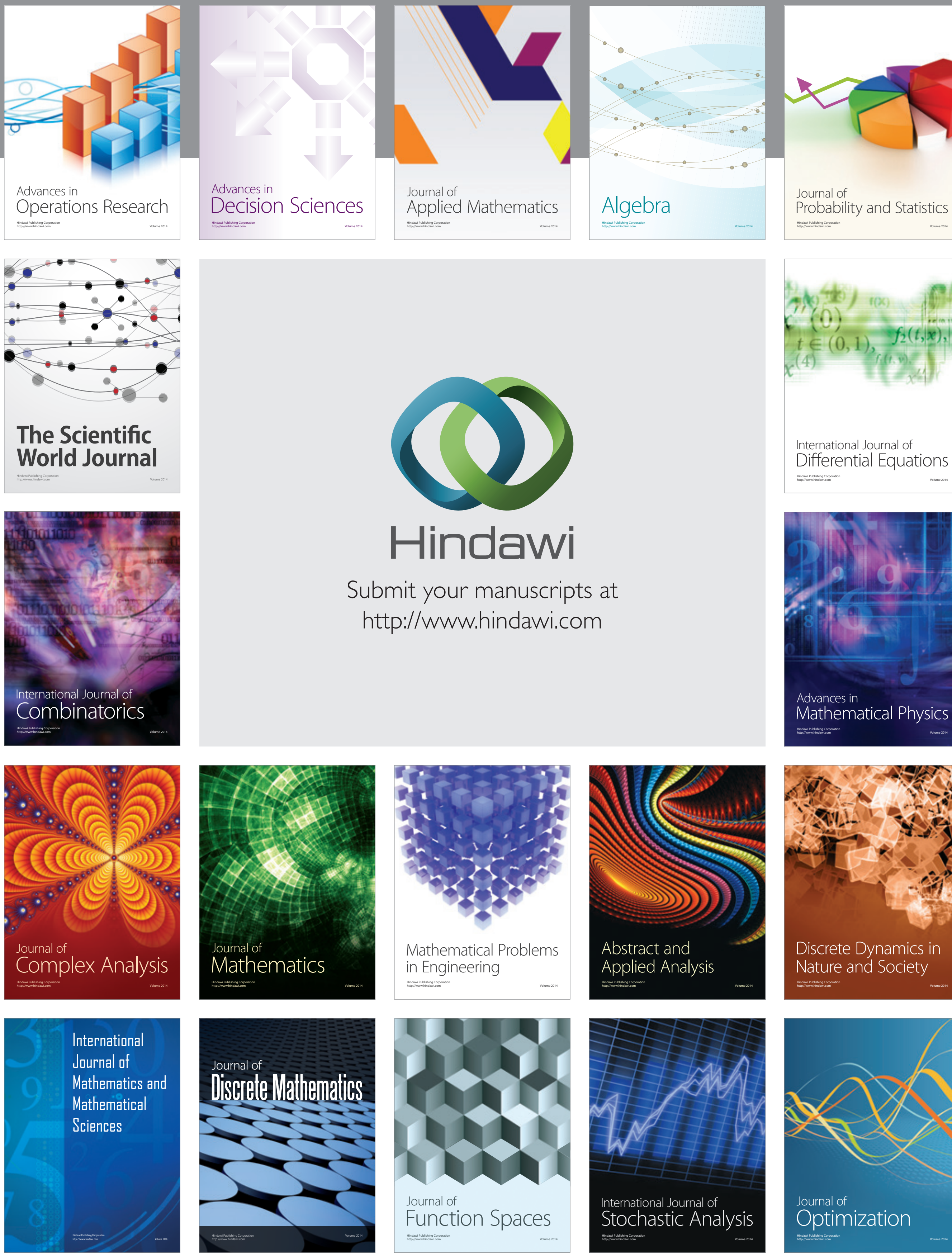
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