Research Article

Finite-Time Control of Dynamic Positioning Vessel Based on Disturbance Observer

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In this paper, a finite-time controller is proposed for dynamic positioning vessels with error constraints and prescribed performance. A nonlinear observer is employed to give the estimations of the unknown disturbances containing an uncertain model, and the estimation errors converge to the equilibrium point in a finite time. A finite-time controller is developed based on the nonlinear observer. Finally, the effectiveness of the proposed control strategies is demonstrated by simulation.

1. Introduction

The dynamic positioning (DP) system has become one of the key devices in ocean engineering equipment, and it is attracting a great deal of attention [1, 2]. The DP system can automatically maintain the vessel at the predefined position and heading through its actuators under environmental disturbances. The DP system is easy to operate compared with traditional mooring positioning and prevents the destruction of the seafloor [2]. Furthermore, the cost of the DP system does not increase with increasing water depth, more and more container surface vessels begin to equip the DP system, and they are applicable to a wide variety of offshore operations, such as oil and gas extraction, cabling, rescue, in offshore wind turbine service, pipeline laying [3].

In the 1960s, the first DP system was applied, and it was designed based on a single-input and single-output proportional-integral-derivative (PID) calculation method and a low-pass filter. With the development of optimal control theory, a DP system is developed combined with typical Kalman filtering in the 1970s [4]. Starting from 1990s, with the advance of nonlinear theories, many nonlinear control computation methods had been developed and adopted to DP systems, for example, nonlinear backstepping control in [5], sliding model control presented in [6, 7], and hybrid control in [8]. The availability and maneuverability of the DP system have been largely optimized with the adoption of these advantageous control strategies. However, since the DP system has notably nonlinear, heavily coupled, multi-variable, and severely disturbed characteristics, the control of DP vessels is still facing many challenges. Among these, external environmental disturbance, featuring uncertainty, full of change, hard measured, is one of the thorny problems.

The uncertain environmental disturbances cannot be measured precisely, since they are continuously changing. Hence, many adaptive control strategies had already been employed to head off the disturbances. Reference [9] advocated the adaptive fuzzy control strategy, where the fuzzy logic computation method was applied to estimate unmodeled dynamic features and time-varying disturbances. In [10, 11], the incorporation of adaptive techniques based on approximation and neural network methods based on radial basis function were used to tackle the unknown disturbances and uncertain vessel dynamic feature. These fuzzy/neural network methods have remarkable advantages in figuring out the tough dynamic feature. Reference [12] raised a robust nonactive nonlinear observer to rebuild the velocities and second-step varying disturbances. The nonlinear disturbance observer was employed to distinguish undetermined environmental disturbances in [13–15].
However, the observation errors could only constrict to an adjacent section of nominal with exponential type rather than an accurate estimate.

There are a lot of unremitting investigations and studies on uncertain environmental disturbances, and some advances have been achieved. Reference [16] presents one disturbance observer to estimate and observe external unknown disturbance and make compensation in control law to remarkably inhibit disturbance. Reference [17] puts forward one adaptive control to estimate environmental disturbance and realize inhibiting disturbance as well as enhance the robustness of the DP system. Since the accurate model of vessel is hard-gained, [18] points out neural network adaptive control, utilizing the neural network infinite approaching characteristics, to carry out online estimation and compensation, and finally to overcome the impact incurred by uncertain vessel model to inhibit external disturbances effectively. Reference [19] employed an output-feedback controller, based on a neural network observer to evaluate the velocity of vessel to finally achieve vessel heading and position keeping. In [20], one adaptive control algorithm of single-input undetermined nonlinear systems was developed combining with input saturation and unknown environmental disturbance, amid which input saturation and unknown environmental disturbance were handled by using a Nussbaum function. In [21], based on the fuzzy system with the vectorial backstepping algorithm, an adaptive control strategy applied to the DP system of vessels under unknown dynamic features and bounded environmental disturbance was developed. Reference [22] displayed a fuzzy control strategy for a DP system of vessels by applying optimal theory to compensate for the impacts of external disturbances, and the controller performance parameters could be easily solved in linear inequalities. Reference [23] advocated a distinguished cooperative surrounding control method for mobile robots with uncertainties, and aperiodic sampling is presented, one robust antdisturbance kinetic control protocol is incorporated for the overall uncertainties existing in velocity channels, and aperiodic sampling-based extended state observers are proposed to provide accurate disturbance evaluation with determining convergence. There was a high-gain observer-based control strategy designed for the DP system of vessels with uncertain dynamics and input saturation, which could safeguard the uniform ultimate boundness of all states of the system [24]. Reference [25] puts forward a coordinated control strategy which was constituted by a finite-time disturbance observer, some assistant dynamic systems, and a dynamic surface control method. One nonlinear finite-time observer is designed to forecast undetermined external disturbance, Based on observer-based with an unknown input, an appointed-time funnel control method was presented for quad-rotors in the condition of environmental disturbances and parametric uncertainties [26].

The study above either emphasizes the adverse influence of external disturbance on DP vessels or adopts compound control strategies to maintain the vessel desired position and heading. However, in some situations, such as a vessel is operated within one limited or narrow water area, and the performance constraints must also be weighted for DP vessel as well as dynamic response to prevent the collision.

Apart from the uncertainties, the deviation constraints are also considered in this paper. Position and heading deviation constraints can optimize the control outcome of transient and steady state and elevate the security of the DP vessel. Usually, the barrier Lyapunov function (tan function) is an effective approach to address the constraint problem in many researches. For example, Reference [27] developed the track tracking control algorithm applied to DP vessels with total state constraints and unknown dynamics. A tan function was utilized to realize total state constraints. In reference [28], a symmetric tan function was employed for a fully actuated surface vessel to constrain its output variables. Reference [29], based on the adaptive feedback technique, raised one leader–tracking formation control strategy for underactuated surface vessels; meanwhile, the asymmetric tan function was adopted to address the variable constraint problem. In order to reduce the chattering problem, in the designated performance boundaries, system profiles evolution was strengthened, and a tracking differentiator (TD)-based predefined performance control technique was proposed [30].

The finite-time control technique is recognized as one effective control solution because it has many advantages, such as high robustness and quick convergence. It also owns many strengths alike less convergence time, better accuracy, and strong antdisturbance capability. Thus, in this paper, we adopt the finite-time control technique for the DP vessel aiming to optimize its control performance.

In this investigation, the main tasks are showcased as follows:

1. A disturbance observer is designed to carry out an estimation of disturbances
2. A finite-time controller with performance constraints is put forward, and the stability of the formation control system is proved without the assumption that disturbance estimate error converges to zero within a finite time

In this paper, performance constraints and unknown time-varying external disturbances are considered simultaneously, one nonlinear finite-time observer is designed to estimate unknown time-varying disturbances, and a novel control method for surface vessels is proposed. It is verified that all variables in the closed-loop control system could converge to a small adjacent zone of zero. Additionally, in this research, a tan function is utilized, which can address the error constraint problem well. Compared to the sliding mode controller (SMC), this advocated tan function and controller can not only solve the problem of deviation constraints but also be applied to the case without constraint requirements.

This paper is constructed as follows. Section 2 describes some necessary preliminaries and the problem formulation. Section 3 proposes the DP observer and proves its stability. Section 4 designs the controller and carries out the stability analysis. Section 5 provides simulations and comparison results to prove the effectiveness of the proposed controller. Section 6 concludes this paper.
2. Preliminaries and Problem Formulation

2.1. Notations. The following symbols will be presented in this research. $| \cdot |$ stands for the absolute value of a scalar. $\lambda_{\min} (\cdot )$ implies minimum eigenvalue of one square matrix. $\| \cdot \|$ delegates the Euclidean norm. $\mathbb{R}^{m\times n}$ symbolizes the $n \times n$ dimensional Euclidean Space. $\text{diag}(a_i)$ indicates a block-diagonal matrix with $a_i$ being the $i$th diagonal element. $(\cdot)^T$ and $(\cdot)^{-1}$ represents the transpose and inverse of one matrix, respectively. $\text{sgn}(y)$ represents $|y|^\alpha \text{sgn}(y)$ with $\alpha > 0$ and $y \in \mathbb{R}$.

2.2. Problem Formulation. The dynamic positioning ship model with three degree of freedom can be formulated as follows [32]:

$$
\dot{\eta} = R(\psi) v,
$$

$$
M \dot{v} + Dv = \tau + d(t),
$$

(1)

where $R(\psi)$ is the rotation matrix for coordinate transformation and given by

$$
R(\psi) = \begin{bmatrix}
\cos (\psi) & -\sin (\psi) & 0 \\
\sin (\psi) & \cos (\psi) & 0 \\
0 & 0 & 1
\end{bmatrix},
$$

(2)

with the traits: $\|R(\psi)\| = 1$ and $R^T(\psi)R(\psi) = I_{3 \times 3}$. For the following easy writing, we simplify the letters as follows, such as $R = R(\psi)$ and $R^T = R^T(\psi)$. The vector $v = [u, v, r]$ denotes the velocity vector in the vessel body fixed frame $X_BOBY_B$. $\dot{\eta} = [x, y, \psi]$ represents the position and heading angle in the earth fixed coordination frame $X_EOEYE$. (see Figure 1). $M \in \mathbb{R}^{3 \times 3}$ implies the inertia matrix contained added mass, which is positive definite, invertible, and $M$. $D \in \mathbb{R}^{3 \times 3}$ denotes the damping matrix, which is positive definite. $\tau = [\tau_1, \tau_2, \tau_3]^T$ denotes the thrust input produced by thrusters. $\tau_d = [\tau_{d_1}, \tau_{d_2}, \tau_{d_3}]$ constitutes the total environmental disturbances induced by wind, waves, sea currents in surge, sway, and yaw, respectively.

$\tau_c = [\tau_c, 1; \tau_c, 2; \tau_c, 3]^T$ is computed by the DP controller. DP control objective: the control objective of this paper is to develop a DP control policy $\tau_c$ for DP ship to maintain an expected position and track a reference point $\eta_d$ with unknown time-varying external disturbances, such that

$$
\lim_{\xi \rightarrow \infty} \|\eta - \eta_d\| \leq e_1,
$$

(3)

where $e_1$ is a positive constant which could become small enough through adjusting the control parameters. For the subsequent research and analysis, the following assumptions are made.

**Assumption 1.** The time-varying external disturbances $\tau_d$ and its time derivation $\dot{\tau}_d$ are bounded, that is, there exist unknown positive constants $\overline{d}$ and $\overline{\tau}_d$ such that

$$
|\tau_d| \leq \overline{d}, \quad |\dot{\tau}_d| \leq \overline{\tau}_d.
$$

(4)

**Remark 1.** Considering the environmental disturbances are usually regarded as slowly varying and containing limited energy, the disturbances imposing on the vessel could be viewed as unknown limit update rates and bounded outputs. Hence, Assumption 1 is reasonable.

**Remark 2.** The environmental disturbances are constituted by low-frequency portion and high-frequency portion, where the low-frequency portion results in the vessel to drift off, and the high-frequency portion causes the vessel’s periodic fast motions. The maneuverability of the high-frequency portion will cause great power consumption and massive tear and wear of the thrusters. Therefore, the high-frequency portion should be screened out by a wave filter during the development of the DP controller [33]. Therefore, merely the low-frequency portion is taken into account during the DP controller development.

**Assumption 2.** The real-time position-heading and velocity signals for DP vessels are available.

**Assumption 3.** The position and related reference signals $\eta_d$, $\dot{\eta}_d$, and $\ddot{\eta}_d$ are in boundedness.

3. Finite-Time Disturbance Observer Design

In this part, an observer which is applied to estimate total disturbances including the unknown system matrix and environmental disturbances is developed.

$$
\dot{\eta} = Rv,
$$

$$
M \dot{v} = \tau - Dv + \tau_d.
$$

(5)

The dynamic positioning ship model is rewritten as

$$
\dot{\eta} = Rv,
$$

$$
M \dot{v} = \tau + \xi,
$$

(6)
where $\zeta = -Dv + \eta_d$. Assumption 4: $\|\overline{c}\| \leq q$

A finite-time disturbances observer is designed as

$$M\dot{\overline{c}} = \tau + \overline{\zeta},$$  \hspace{1cm} (7)

where $\overline{\zeta}$ is the estimated value of $\zeta$.

Define

$$\omega = M\dot{\overline{c}} - M\overline{\dot{c}}.$$  \hspace{1cm} (8)

The updated law of $\overline{\zeta}$ is chosen as

$$\overline{\dot{\zeta}} = \overline{\zeta} + L_1\text{sig} (\omega) + \frac{1}{2} \int \text{sig} (\omega) \, dt,$$

$$\text{sig}(\cdot) = | \cdot | \cdot \text{sign}(\cdot).$$  \hspace{1cm} (9)

Then,

$$\dot{\omega} = \zeta - \overline{\zeta}$$

$$= -L_1\text{sig}(\omega) - \frac{1}{2} \int \text{sig}(\omega) \, dt + \dot{\zeta}.$$  \hspace{1cm} (10)

Define a new variable $x = [x_1^T, x_2^T]^T = [\omega^T, \chi^T]^T$ with $\chi^T = -L_2\int \text{sig}(\omega) \, dt + \dot{\zeta}$, then

$$\dot{x}_1 = -L_1\text{sig}(\omega) + x_2,$$

$$\dot{x}_2 = -L_1\text{sig}(\omega) + \overline{\zeta}.$$  \hspace{1cm} (11)

Choose the Lyapunov function candidate as

$$V_o = \frac{1}{2} x^T P \varphi,$$  \hspace{1cm} (12)

where

$$\varphi = \begin{bmatrix} \text{sig}(x_1) \\ x_2 \end{bmatrix},$$

$$P = \begin{bmatrix} 2L_2 & -L_1 \\ -L_1 & 2I_{3\times3} \end{bmatrix}.$$  \hspace{1cm} (13)

Notice that the Lyapunov function $V_o$ has continuous and differentiable property anywhere excluding $x = \{ (x_1, x_2)| x_1 = 0_{3\times1} \}$ and features positive definite and unbounded. So, the following inequality holds

$$\frac{1}{2} \lambda_{\text{min}} (P) \|c\|^2 \leq V_o \leq \frac{1}{2} \lambda_{\text{max}} (P) \|c\|^2.$$  \hspace{1cm} (14)

Carry out the time derivative of the Lyapunov function $V_o$ and get:

$$\dot{V}_o = -\zeta^T H_o \zeta + \zeta^T h_0 \dot{\zeta}$$

$$\leq -\lambda_{\text{min}}(H_o) \|c\|^2 + q\|c\|\|h_0\|,$$  \hspace{1cm} (15)

where

$$H_o = L_1 \begin{bmatrix} L_2 + L_1^2 & -L_1 \\ -L_1 & I_{3\times3} \end{bmatrix},$$

$$h_0 = \begin{bmatrix} -L_1 \\ 2I_{3\times3} \end{bmatrix}.$$  \hspace{1cm} (16)

Then, $\dot{V}_o \leq -k_0 \|c\|^2$, where

$$k_0 = \lambda_{\text{min}} (H_o) - q\|h_0\| \|c\|.$$  \hspace{1cm} (17)

To safeguard $k_0 > 0$, the following inequality holds

$$\|c\| \geq \left( \frac{q\|h_0\|}{\lambda_{\text{min}} (H_o)} \right).$$  \hspace{1cm} (18)

The expression of $\dot{V}_o$ will be bounded as

$$\dot{V}_o \leq -\beta V_o,$$  \hspace{1cm} (19)

where $\beta = 2k_0/\lambda_{\text{max}} (P)$.

This is the end of proof.

ESO is cited from the article in [34], and comparison is made between ESO and observer devised in this paper.

As shown in Figure 2, in the longitudinal direction, at an initial stage, the observer cannot perform as well as ESO that at the beginning, the gain of the observer is greater which results in estimator oscillatory, afterward, the gain of estimator reduces and guarantees estimation of disturbances with designed accuracy. The remaining two directions correspond to each other very well, which confirms the effectiveness of the proposed controller.

4. Control Law Design

Within this part, a BLF is applied to realize the deviation constraints; furthermore, the proposed controller is also employed in the DP vessel control. First, a control strategy featuring semiglobal uniform boundness stability is provided. Second, a finite-time controller is developed, and its stability is proved.Hereinafter, a semiglobally uniformly bounded control approach is designed for DP vessel.

Step 1. The DP vessel’s position and heading errors are described as $e_1 = \eta - \eta_d$, $e_2 = v - \alpha$, $\alpha$ is a virtual control function. Replace the positioning errors with Eq. (3) and (4), and the vessel motion equalities are converted as

$$\dot{e}_1 = R(e_1 + \alpha) - \dot{x}_d,$$

$$\dot{e}_2 = M^{-1}[-Dv + \tau + \tau_d] - \dot{\alpha}.$$  \hspace{1cm} (20)

In this paper, one of the main purposes is to ensure the error $\dot{e}_1$ remain in the predefined boundness. Therefore, the problem could be transformed into the constraint of $\|e_1\|$. Furthermore, one tan function is introduced as follows.

Define

$$V_{e_1} = K_{p_1} \tan \left( \frac{\pi e_1 T_{e_1}}{2k_{p_1}} \right),$$  \hspace{1cm} (21)

where $K_{p_1}$ is the time-varying boundness of $\|e_1\|$ and satisfies $\|e_1(0)\| \leq K_{p_1}(0)$.

Remark 3. Suppose the starting value of $\|e_1\|$ meets $\|e_1\| \leq k_{p_1}(0)$ and $V_{e_1}$ is bounded, and combining the condition of $\lim_{e_1 \rightarrow k_{p_1}(0) (k_{p_1}^2/\pi \tan(\pi e_1 T_{e_1} / 2k_{p_1})) = \infty}$, it can be deemed that $\|e_1\|$ will not exceed $k_{p_1}$.
Remark 4. Suppose $e_1$ is not needed to be constrained, then \[ \tan \text{ function (17)} \text{ holds} \lim_{k_b \to \infty} (k_2^2 / \pi \tan (\pi e_1^T e_1 / 2k_2^2)) = 1/2e_1^T e_1 \text{ with } k_b \to \infty, \] which is the commonly used quadratic form. So, the designed control law in this paper is also suitable for the one without constraint requirement.

Define $\Delta = \pi e_1^T e_1 / 2k_b^2$, then carry out differentiating $V_{e_1}$ to time, we can obtain

\[
V_{\dot{e}_1} = \frac{e_1^T \dot{e}_1}{\cos^2 (\Delta)} + \frac{2k_b \dot{e}_1}{\pi} \tan (\Delta) - \left( \frac{k_b}{k_b^2} \right) \frac{e_1^T \dot{e}_1}{\cos^2 (\Delta)}.
\]  

where $\dot{e}_1 = R\dot{v} - \dot{\eta}_d$.

Define $e_2 = \nu - \alpha$, $\nu = e_2 + \alpha$.

The virtual control function $\alpha$ is proposed as

\[ \alpha = R^T \left( \dot{\eta}_d - \frac{k_b}{e_1^T} \sin (\Delta) \cos (\Delta) - K_1 \frac{1}{e_1^T} \left( \frac{k_b^2}{\pi} \right)^{3/4} \cos^2 (\Delta) \right) \]  

where $K_1$ is a positive constant.

**Figure 2:** The comparison between ESO and observer.
Figure 3: Comparison of trajectory under proposed controller and SMC controller.

Figure 4: Comparison between desired vessel position and proposed position.
\[
V_{\varepsilon_1} = \frac{e_1^T R_2}{\cos^2(\Delta)} - \lambda_{\text{min}} (K_1 - 2K_3) \frac{k_{b_1}^2}{\pi} \tan(\Delta) - K_2 \left( \frac{k_{b_1}^2}{\pi} \right)^{3/4} \tan(\Delta)^{3/4} - \left( K_3 - \frac{k_{b_1}}{k_{b_2}} \right) \frac{e_1^T e_1}{\cos^2(\Delta)} + \epsilon \left( \frac{k_{b_2}}{k_{b_1}} \right)^{3/4} \tan(\Delta)^{3/4},
\]

Choose \( K_3 = \sup \left( \sqrt{\frac{k_{b_2}}{k_{b_1}} (\epsilon + \epsilon)} \right) \), \( \epsilon \) is a positive constant.

\[
\dot{V}_{\varepsilon_1} \leq \frac{e_1^T R_2}{\cos^2(\Delta)} - \lambda_{\text{min}} (K_1 - 2K_3) \frac{k_{b_1}^2}{\pi} \tan(\Delta) - K_2 \left( \frac{k_{b_1}^2}{\pi} \right)^{3/4} \tan(\Delta)^{3/4},
\]

where \( K_2 \) is a positive constant.

**Step 2.** Set up the Lyapunov function candidate as

\[
V_2 = V_{\varepsilon_1} + \frac{1}{2} e_2^T M e_2,
\]

\[
\dot{V}_2 \leq \frac{e_2^T R_2}{\cos^2(\Delta)} - \lambda_{\text{min}} (K_1 - 2K_3) \frac{k_{b_1}^2}{\pi} \tan(\Delta) - K_2 \left( \frac{k_{b_1}^2}{\pi} \right)^{3/4} \tan(\Delta)^{3/4} + e_2^T (\tau + \zeta - \bar{M} \dot{\alpha}).
\]

Then, the control law could be chosen as follows

\[
\tau = -K_4 e_2 - K_5 e_2 \left( e_2^T e_2 \right)^{-1/4} + \bar{M} \dot{\alpha} - \bar{\zeta} - \frac{R e_2}{\cos(\Delta)},
\]

so

\[
\dot{V}_2 \leq -\lambda_{\text{min}} (K_1 - 2K_3) \frac{k_{b_1}^2}{\pi} \tan(\Delta) - K_2 \left( \frac{k_{b_1}^2}{\pi} \right)^{3/4} \tan(\Delta)^{3/4} - e_2^T K_4 e_2 - \lambda_{\text{min}} (K_2) \left( e_2 e_2 \right)^{3/4} + e_2 (\bar{\zeta} - \bar{\zeta}).
\]
where $K_4$ and $K_5$ are positive constants.

\[
e_2(\xi - \xi) \leq \frac{1}{2}e_2^T e_2 + \frac{1}{2}(L_1 \text{sign}(\omega) + x_2)^2
\]

\[
\leq \frac{1}{2} \left( e_2^T e_2 + \xi^T L_1 \xi - L_1 \text{sign}(\omega) x_2 \right)
\]

\[
\leq \frac{1}{2} \left( e_2^T e_2 + \xi^T L_1 \xi + \frac{1}{2} \lambda_{\text{min}}\|L_1\|\|\xi\|\right).
\]

Step 3. Choose a Lyapunov function as follows:

\[
V_3 = V_2 + V_o
\]

\[
\dot{V}_3 \leq -\lambda_{\text{min}}(K_1 - 2K_3) \frac{k_0^2}{\pi} \tan(\Delta)
\]

\[
- k_2 \left( \frac{k_0^2}{\pi} \right)^{3/4} \tan(\Delta)^{3/4}
\]

\[
- \left( \frac{1}{2} e_2^T e_2 - \lambda_{\text{min}}(K_3) e_2^T e_2 \right)^{3/4}
\]

\[
- (k_0 - \frac{3}{2})_{\text{min}}\|\xi\|\|\xi\|
\]

Then,

\[
\dot{V}_3 \leq -c_1 V_3 - c_2 V_3^{1/4},
\]

where $c_1 = \min\{\lambda_{\text{min}}(K_1 - 2K_3), 2\lambda_{\text{min}}(K_4) - 1/\lambda_{\text{max}}(M), 2k_0 - 3L_1 / \lambda_{\text{max}}(P)\}$, $c_2 = \min\{\lambda_{\text{min}}(K_2), 2\lambda_{\text{min}}(K_3)/\lambda_{\text{max}}(M)\}$.

5. Numerical Simulations

In this part, digital simulation and comparison results are provided to verify the effectiveness of the proposed control method with tan function.

5.1. Performance of Proposed Controller. Within this subpart, the simulation outcomes are displayed to exhibit the property of the proposed controller.

The finite-time disturbances observer for the DP ship is designed according to (5) and (7), and the reference data of the proposed observer are chosen $M = \begin{bmatrix} 23.8 & 0 & 0; & 0.8 & 0 & 0.264 \end{bmatrix}$, $D = \begin{bmatrix} 2 & 0 & 0 & 0 & 0 & 0.1; & 0 & 0 & 0.5 \end{bmatrix}$, $L_1 = 0.1 \times \text{diag}[1;1;1], L_2 = 1 \times \text{diag}[1;1;1]$. The proposed controller for DP vessel is designed as (26) and (27). The parameters are selected as $k_1 = 0.5$, $k_2 = 0.5$, $k_3 = 0.5$, $k_4 = 51 \times \text{diag}[1;1;1]$, $k_5 = \begin{bmatrix} 5 & 0 & 0; & 5 & 0 & 0 \end{bmatrix}$.
The simulation outcomes are illustrated in Figures 3–7. Figure 3 shows the trajectory of the vessel. The positions and headings of the vessel approach to the desired point, so that the desired maneuvering of the vessel is finally realized, and the performance under the proposed controller is better than the sliding mode controller (SMC). Figure 4 shows the tracking errors of the DP vessel. They converge to the desired track rapidly and coincide with desired one very well. Figure 5 indicates a comparison of vessel position error under the proposed controller and SMC. It can be found that under the SMC controller, error response curves of the DP vessel cannot abide by performance constraints, and under the proposed controller, the tracking errors are smaller than the SMC controller obviously. Figure 6 shows the comparison between desired vessel velocity and proposed velocity and also shows that the tracking velocity errors are near to zero. Figure 7 indicates the external disturbances and the estimated disturbances acting on the DP vessel by the proposed controller. In the longitudinal direction, at the initial stage, the observer cannot converge well due to that at the beginning the gain of the observer is greater which results in estimator oscillatory and fast convergency; afterward, the gain of estimator reduces and guarantees estimation of disturbances with designed accuracy. The remaining two directions coincide with each other nicely, which verifies the effectiveness of the proposed controller.

5.2. Comparison Study. A comparison simulation is implemented using the SMC DP (SDP) proposed in [7]. The SDP considered the time-varying external disturbances, but the property constraint was not taken into account. The estimator parameters of SDP are selected as the same in [7], and the vessel model of SDP is selected as the same as Section 5. The simulation outcomes are illustrated in Figures 3–7. Figure 3 shows that the trajectory of the DP vessel under the proposed controller is more excellent than the one under the SMC controller; Figure 5 demonstrates that the position errors under the proposed controller converge to the neighborhood of zero much faster than the one under the SMC controller; Figure 7 shows that the estimated disturbances of the DP vessel arrive at the actual value very quickly.

6. Conclusion
In this research, a fresh control method is presented for DP vessels under the condition of unknown time-varying disturbances. To improve the property of the proposed controller, the designed observer is adopted to estimate environmental disturbances. To optimize the performance, the position deviation constraint function is constructed, and the proposed controller is developed. It is shown that the proposed controller can let errors converge to a small neighborhood of zero more quickly. Simulation results
display the validity of the proposed controller. But this paper does not consider thruster output constraints and signal transmission delay, and these concerns will be investigated in the future.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References


