A Novel Disturbances Compensating Dynamic Positioning of Dredgers Based on Adaptive Dynamic Surface Control

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Abstract:-In order to deal with the control difficulties of the dredger's dynamic positioning system under large disturbances and severe sea conditions, an adaptive dynamic surface control method is proposed to be used in the dredger's dynamic positioning system. Disturbances can be estimated and compensated by adaptive arithmetic. The addition of low pass filters in backstepping design process allows the dynamic surface control technique to be implemented without differentiating any model nonlinearities, which could simplify the design significantly. The proposed adaptive robust controller guarantees the semi-globally asymptotical stability of the closed-loop system, and output asymptotic track to desired trajectory. Besides, the final tracking accuracy could be adjusted via certain controller parameters. This scheme is verified by the comprehensive simulation results in typical operation scenarios. The simulation results show that the proposed controller has desired position tracking transient performance and robustness to the uncertain disturbances.

Key-Words:-Dynamic positioning (DP), Adaptive dynamic surface control(ADSC), Nonlinear controller design, Backstepping, Dredger, Disturbances compensating

1 Introduction

High efficiency and stable dredgers play a crucial role in port dredging industry, and large dredgers carry out dredging sand in deep-ocean constantly. So the dynamic positioning (DP) system is essentially necessary in improving the efficiency of the port dredging operation or working in harsh marine environment.

As there are large disturbances caused by dredging operation, it is difficult to maintain the stability and accuracy for dredgers' DP systems. In order to solve this problem, force-and-torque sensors are applied to measure and compensate this kind of the reaction caused by dredging operation in traditional dredgers' DP systems. But this will increase the DP system's complexity and unreliability. Based on such consideration, an ADSC technique is proposed in this paper for the dredger's DP system to solve this problem without adding extra sensors.

A dynamically positioned vessel maintains its position (fixed location or predetermined track) exclusively by means of active thrusters. Recently, DP systems have been used in many kinds of vessels and offshore oilfield. Offshore oilfield has moved to a deeper , and more severe environment for new oil sources. However, in a conventional chain and anchor mooring system, the length of lines becomes excessive, and maintaining the position of an offshore platform becomes difficult both technically and economically. Therefore, DP systems with thrusters are often used for those applications. The first DP system is introduced in the early 1960s [1]. Conventional DP systems are designed based on linearization of the kinematic equations of motions about a set of predefined constant yaw angles so that linear control theory can be applied. The kinematic equations of motion are usually linearized about 36 different yaw angles. For each of these linearized models, optimal Kalman filters and feedback control gains need to be computed. It is the most widely used in ships' DP systems currently [2][3]. Due to limitations of linear control techniques such as complexity in tuning control gains and no global stability results because of linearization, recently, several researchers applied nonlinear control theory to design various control systems for DP of surface vessels. Lyapunov technique and backstepping technique are used to design a DP controller system [4]-[8]. Tremendous strides have been made in the area of controller design for nonlinear systems. The recent book by Krstic, Kanellakopoulous, and Kokotovic[9] develops the backstepping approach to the point of a step by step design procedure. However, the computing expansion problem exists in the backstepping technique.

Dynamic surface control technique has been in continuous development ever since the late 1990s [10]-[12]. Dynamic surface control technique is an improved backstepping control technique, the design process of which design process is executed in a step-by-step way. Nevertheless, a first-order low-pass filter of the synthetic input at each step of the traditional backstepping is introduced, so repeated differentiations of the demands of the modelling nonlinearities are cancelled. Therefore the algorithm complexity caused by expansion of the differential terms could be avoided, and the controller design procedure could be simplified.

Adaptive arithmetic can estimate the value of disturbances and change the feedback to guarantee the system stability. In this paper, ADSC is used for a DP system affected by the uncertainties. And then, comparisons are studied to verify the advantages of the ADSC technique over the conventional backstepping control technique in dredgers' DP systems.

2 Problem statement

An xz-plane of symmetry is first defined for the convenience of problem statement. As shown in Fig. 1, $O_E X_E Y_E$ is the earth-fixed frame, OXY is the body-fixed frame, and O_c is the centre of gravity of the vessel.

Assume that the ship has an xz-plane of symmetry; surge is decoupled from sway and yaw, heave, pitch and roll modes are neglected; the body-fixed frame coordinate origin is on the centre-line of the ship (is shown in Fig. 1). In this figure, the mathematical model of the ship used for DP in a horizontal plane is described as [13]:

$$\begin{cases} \dot{\eta} = J(\psi) v \\ M\dot{v} = -Dv + \tau + \tau_{dis} \end{cases} \tag{1}$$

where τ_{dis} represents environmental disturbances, $\eta = [x \quad y \quad \psi]^T$ denotes the position(x, y) and heading ψ of the ship coordinated in the earth-fixed frame, $v = [u \quad v \quad r]^T$ indicates the ship's surge, sway and yaw velocities coordinated in the body-fixed frame. The other terms in (1) are defined below.

The rotation matrix $J(\psi)$, mass including added mass matrix M, and damping matrix D are given by

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

$$M = \begin{bmatrix} m - X_{\dot{u}} & 0 & 0 \\ 0 & m - Y_{\dot{v}} & mx_g - Y_{\dot{r}} \\ 0 & mx_g - N_{\dot{v}} & I_Z - N_{\dot{r}} \end{bmatrix},$$

$$D = -\begin{bmatrix} X_u & 0 & 0 \\ 0 & Y_v & Y_r \\ 0 & N_v & N_r \end{bmatrix}$$

(2)

where m is the vessel mass, I_z is the moment of inertia about the body-fixed z-axis, x_g is the distance from the origin O of the body-fixed frame to the centre of gravity of the vessel. The other symbols in (2) refer to hydrodynamic derivatives, see [14].

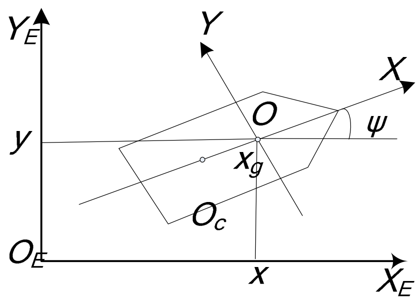


Fig.1, Definition of the earth-fixed frame $O_E X_E Y_E$ and the body-fixed frame OXY

The control input vector $\tau \in \mathbb{R}^3$ of forces and moment provided by the actuator system, and the disturbance vector τ_{dis} of forces and moment induced by waves, wind and ocean currents are given by

$$\begin{cases} \tau = Gu \\ \tau_{dis} = J^T(\psi)b \end{cases} \tag{3}$$

$u \in \mathbb{R}^n$ is the control input, where $n \geq 3$ denotes the number of independent actuators, and $G \in \mathbb{R}^{3\times n}$ is a constant matrix describing the actuator configuration. Unmolded external forces and moment due to waves, wind, ocean currents, and ship parameters perturbation are lumped together into an earth-fixed constant vector $b \in \mathbb{R}^3$.

For a real simulation of the marine environment disturbance, the following mode is adopted. Environmental forces mode in fixed coordinate system is [15]

$$\dot{b} = -T^{-1}b + E_b\omega_b \tag{4}$$

where b is a three-dimensional vector, T is a three-dimensional time-constant diagonal matrix, ω_b is zero-mean white noise, and E_b is a three-dimensional diagonal matrix which denotes the amplitude of the environmental forces.

For system (1), we define the variables as follows

$$\begin{cases} x_1 = \eta \\ x_2 = J(\psi)v \end{cases} \tag{5}$$

then the model can be rewritten as

$$\begin{cases} \dot{x}_1 = x_2 \\ \dot{x}_2 = Ax_2 + B\tau + C\tau_{dis} \end{cases} \tag{6}$$

where $A = -J(\psi)M^{-1}D$, $B = C = J(\psi)M^{-1}$

For the DP system, we suppose the control object is the position tracking problem. Then the problem involved in this paper is to design a robust adaptive dynamic surface controller τ of system (1) ,which make the output $\eta = x_1$ of the controlled system track asymptotically its reference signal $\eta_d = x_{1d} = \begin{pmatrix} x_d & y_d & \psi_d \end{pmatrix}$, i.e., the tracking error $S_1 = x_1 - x_{1d}$ tend to zero asymptotically when $t \to \infty$.

The following assumption will be introduced about system (6).

A1: x_i, (i=1,2) are all measurable and bounded.

A2: The position reference trajectory x_{1d} and its second-order derivative are known and bounded

3 Controller design

For the model of the system in equation (6), define the surface errors as follows.

$$S_1 = x_1 - x_{1d} \tag{7a}$$

$$S_2 = x_2 - x_{2d} \tag{7b}$$

where x_{1d} is the reference trajectory, x_{2d} will be given later by the first order filter. Then the design procedure for the robust adaptive dynamic surface controller is described in detail as follows.

Step1: For the model of the system in equation (6), according to (7a), the derivative of S_1 is

$$\dot{S}_1 = \dot{x}_1 - \dot{x}_{1d} = x_2 - \dot{x}_{1d} \tag{8}$$

In order to make $S_1 \to 0$, choose the virtual control $\bar{x}_2$ and filter x_2 with one order filter, then define

$$\tau_2\dot{x}_{2d} + x_{2d} = \bar{x}_2 \tag{9}$$

where $x_{2d}(0) = \bar{x}_2(0)$, τ_2 is a time constant , and $\bar{x}_2$ is a stabilizing function which will be designed later.

Defining the boundary layer errors as:

$$y_2 = x_{2d} - \bar{x}_2 \tag{10}$$

the derivative of x_{2d} is

$$\dot{x}_{2d} = \tau_2^{-1}(\bar{x}_2 - x_{2d}) = -\tau_2^{-1}y_2 \tag{11}$$

By selecting the first Lyapunov function candidate as:

$$V_1 = \frac{1}{2}S_1^TS_1 + \frac{1}{2}y_2^Ty_2 \tag{12}$$

then the time derivative of V_1 along the solution of (8) and (12) can be obtained as

$$\begin{aligned} \dot{V}_1 &= S_1^T\dot{S}_1 + y_2^T\dot{y}_2 \\ &= S_1^T(x_2 - \dot{x}_{1d}) + y_2^T\dot{y}_2 \\ &= S_1^T(S_2 + x_{2d} - \dot{x}_{1d}) + y_2^T\dot{y}_2 \\ &= S_1^T(S_2 + y_2 + \bar{x}_2 - \dot{x}_{1d}) + y_2^T\dot{y}_2 \end{aligned} \tag{13}$$

Let take the first stabilizing function as:

$$\bar{x}_2 = -k_1S_1 + \dot{x}_{1d} - S_2 \tag{14}$$

where $k_1 > 0$ is a designed constant, and according to the inequality as:

$$S_1^TS_1 + \frac{1}{4}y_2^Ty_2 \geq S_1^Ty_2 \tag{15}$$

the derivative of V_1 satisfies the following inequality :

$$\dot{V}_1 \leq S_1^TS_1 + \frac{1}{4}y_2^Ty_2 - S_1^Tk_1S_1 + y_2^T\dot{y}_2 \tag{16}$$

Now substituting (9) into (16) , results in

$$\dot{V}_1 \leq S_1^TS_1 + \frac{1}{4}y_2^Ty_2 - S_1^Tk_1S_1 + y_2^T(\dot{x}_{2d} - \dot{\bar{x}}_2) \tag{17}$$

And then substituting (11) and (14) into (17), the inequality becomes

$$\dot{V}_1 \le S_1^T S_1 + \frac{1}{4} y_2^T y_2 - S_1^T k_1 S_1 + y_2^T \left(-\tau_2^{-1} y_2 + k_1 \dot{S}_1 - \ddot{x}_{1d} \right) \quad (18)$$

Substituting (8) into inequality (18), the inequality is

$$\dot{V}_1 \le S_1^T S_1 + \frac{1}{4} y_2^T y_2 - S_1^T k_1 S_1 + y_2^T \left[-\tau_2^{-1} y_2 + k_1 \left(x_2 - \dot{x}_{1d} \right) - \ddot{x}_{1d} \right] \quad (19)$$

And then substituting (7b) into inequality (19), $\dot{V}_1$ satisfies the inequality as follows:

$$\dot{V}_1 \le S_1^T S_1 + \frac{1}{4} y_2^T y_2 - S_1^T k_1 S_1 - y_2^T \tau_2^{-1} y_2 + y_2^T \left(k_1 S_2 + k_1 x_{2d} - k_1 \dot{x}_{1d} - \ddot{x}_{1d} \right) \quad (20)$$

Defining a vector as

$$B_1 = k_1 S_2 + k_1 x_{2d} - k_1 \dot{x}_{1d} - \ddot{x}_{1d} \quad (21)$$

then the inequality (20) can be rewritten as follows:

$$\dot{V}_1 \le S_1^T S_1 + \frac{1}{4} y_2^T y_2 - S_1^T k_1 S_1 - y_2^T \tau_2^{-1} y_2 + y_2^T \left[B_1 \left(x_{2d}, S_2, \dot{x}_{1d}, \ddot{x}_{1d} \right) \right] \quad (22)$$

Assuming $x_{2d}, S_2, \dot{x}_{1d}, \ddot{x}_{1d}$ are bounded, defining

$$\left| B_1 \left(x_{2d}, S_2, \dot{x}_{1d}, \ddot{x}_{1d} \right) \right| \le H \quad (23)$$

where $H > 0$ is a constant, and supposing

$$k_1 = 1 + r \,, \; r > 0 \quad (24)$$

then the time derivative of V_1 satisfies the following inequality as:

$$\dot{V}_1 \le -r S_1^T S_1 + \frac{1}{4} y_2^T y_2 - y_2^T \tau_2^{-1} y_2 + \left| y_2^T B_1 \right| \quad (25)$$

Step2 : According to (7b), the derivative of S_2 is

$$\dot{S}_2 = \dot{x}_2 - \dot{x}_{2d} = A x_2 + B\tau + C\tau_{dis} - \dot{x}_{2d} \quad (26)$$

If select the second Lyapunov function candidate as

$$V = V_1 + \frac{1}{2} S_2^T S_2 + \frac{1}{2} \tilde{\tau}_{dis}^T \rho^{-1} \tilde{\tau}_{dis} \quad (27)$$

where $\rho = diag\{\lambda_{11}, \;\; \lambda_{22}, \;\; \lambda_{33}\}$ is the adaptive gain coefficient matrix, $\lambda_{ii} > 0$; $\hat{\tau}_{dis}$ is the estimate of τ_{dis}, and $\tilde{\tau}_{dis} = \hat{\tau}_{dis} - \tau_{dis}$ is the estimate error between $\hat{\tau}_{dis}$ and τ_{dis}, then from (27), the derivate of V is

$$\dot{V} = \dot{V}_1 + S_2^T A x_2 + S_2^T B\tau + S_2^T C\tau_{dis} - S_2^T \dot{x}_{2d} - \tilde{\tau}_{dis}^T \rho^{-1} \dot{\hat{\tau}}_{dis} \quad (28)$$

By substituting $\tilde{\tau}_{dis} = \hat{\tau}_{dis} - \tau_{dis}$ into (28), the equation (28) changes to

$$\begin{aligned} \dot{V} &= \dot{V}_1 + S_2^T A x_2 + S_2^T B\tau + S_2^T C\left(\tilde{\tau}_{dis} + \hat{\tau}_{dis} \right) - S_2^T \dot{x}_{2d} - \tilde{\tau}_{dis}^T \rho^{-1} \dot{\hat{\tau}}_{dis} \\ &= \dot{V}_1 + S_2^T A x_2 + S_2^T B\tau + S_2^T C\tilde{\tau}_{dis} + S_2^T C\hat{\tau}_{dis} - S_2^T \dot{x}_{2d} - \tilde{\tau}_{dis}^T \rho^{-1} \dot{\hat{\tau}}_{dis} \end{aligned} \quad (29)$$

As ρ is a diagonal matrix, an equation is obtained as:

$$\tilde{\tau}_{dis}^T \rho^{-1} \dot{\hat{\tau}}_{dis} = \dot{\hat{\tau}}_{dis}{}^T \rho^{-1} \tilde{\tau}_{dis} \quad (30)$$

then $\dot{V}$ changes to

$$\dot{V} = \dot{V}_1 + S_2^T(\, A x_2 + B\tau + C\hat{\tau}_{dis} - \dot{x}_{2d} \,) + (\, \tilde{\tau}_{dis}^T C^T S_2 - \tilde{\tau}_{dis}^T \rho^{-1} \dot{\hat{\tau}}_{dis} \,) \quad (31)$$

If let

$$\tilde{\tau}_{dis}^T C^T S_2 = \tilde{\tau}_{dis}^T \rho^{-1} \dot{\hat{\tau}}_{dis} \quad (32)$$

then the disturbances adaptive control updating law is obtained as

$$\dot{\hat{\tau}}_{dis} = \rho C^T S_2 = \rho \left(M^{-1} \right)^T J\left(\psi \right)^T S_2 \quad (33)$$

and the actual control τ is acquired as

$$\tau = B^{-1} x_{2d} - B^{-1} A x_2 - B^{-1} k_2 S_2 - B^{-1} C\hat{\tau}_{dis} \quad (34)$$

By substituting *A*, *B* and *C* into (34), the feedback control law is obtained as:

$$\tau = M J^{-1}\left(\psi \right) \dot{x}_{2d} + D v - \hat{\tau}_{dis} - B^{-1} k_2 S_2 \quad (35)$$

Then considering inequality (25), $\dot{V}$ satisfies the following inequality as:

$$\dot{V} \le -r S_1^T S_1 + \frac{1}{4} y_2^T y_2 - y_2^T \tau_2^{-1} y_2 - S_2^T k_2 S_2 + \left| y_2^T \right| \left| B_1 \right| \quad (36)$$

If k_2 and τ_2 are selected satisfying the following equations as

$$k_2 = 0.25 + r \,, \tau_2^{-1} = \frac{1}{4} + \frac{H^2}{2\varepsilon} + r \quad (37)$$

And there is an inequality with an arbitrary positive constant ε as follows:

$$\left((y_2^T y_2)(B_1^T B_1) \big/ 2\varepsilon \right) + \left(\varepsilon \big/ 2 \right) \ge \left| y_2^T \right| \left| B_1 \right| \quad (38)$$

So it is obvious that

$$\left((y_2^T y_2)(B_1^T B_1) \big/ 2\varepsilon \right) + \left(\varepsilon \big/ 2 \right) \ge \left| y_2^T B_1 \right| \quad (39)$$

Considering (36), (37) and (39) and assuming that

$$V\left(S_1, S_2, y_2, \tilde{\tau}_{dis} \right) = p \,, \quad p > 0 \quad (40)$$

then the derivative of V satisfies the following inequality:

$$\dot{V} \le -2rV + \varepsilon \big/ 2 \quad (41)$$

If let $r \geq \varepsilon / 4p$ and $V = p$, $\dot{V}$ will satisfy the following inequality as:

$$\dot{V} \leq 0 \tag{42}$$

So all the states of the closed loop, including $S_i(t)$, $\tilde{\tau}_{dis}$ and y_2 are uniformly bounded, and then the DP system is Semi-globally asymptotically stable.

Theorem: Consider the nonlinear DP system described by (1), then for all admissible uncertainties, a set of surface control gain k_i (i=1,2) and the time constant of filter τ_2 exist and such that the robust ADSC law (35) and the disturbance adaptive updating law (33) guarantee semi-global stability asymptotically of the closed-loop system, and the system output can track the preset reference position.

4 Simulation results

The closed-loop DP system is verified by simulations using the Matlab/Simulink toolbox. One ship with DP system as a case is studied to illustrate the performance of the proposed controller.

The main dimensions of the example ship are given in Table 1.

Table 1, The example ship's parameters

ship length	286.3m	distance from gravity center to the center	4.51m
waterline length	280.5m		
ship width	46.89m	draft	17.38m
ship height	24.5m	displacement	205326t

Based on the ship's main parameters listed in table 1, the nondimensional system matrices describing the example ship are estimated by empirical formula [16].

$$M = \begin{bmatrix} 1.1254 & 0 & 0 \\ 0 & 1.8945 & -0.0734 \\ 0 & -0.0734 & 0.1287 \end{bmatrix}$$

$$D = -\begin{bmatrix} 0.0360 & 0 & 0 \\ 0 & 0.1182 & -0.0125 \\ 0 & -0.0043 & 0.0305 \end{bmatrix} \tag{43}$$

The adaptive dynamic surface controller parameters are selected as $k_1 = 1.5$, $k_2 = 0.75$, $\tau_2 = 0.004$, $\rho = \{2, \ 2, \ 2\}$ in simulations. The ship's start position is set to $\eta_0 = [-5 \ \ -5 \ \ 20]^T$, and the desired position is set to $\eta_d = [0 \ \ 0 \ \ 0]^T$. And simulation results of the traditional backstepping technique are shown to be compared with the ADSC technique. In addition, in order to demonstrate the robust performance of the controllers, both small and large disturbances conditions are dealt with, respectively in section 4.1 and section 4.2. Small disturbances simulate ordinary sea conditions; large disturbances simulate severe sea conditions or simulate the reaction force of dredging.

4.1 Simulations under small disturbances

Referring to environmental forces mode (4), and considering the ordinary sea conditions with small disturbances, the simulations are done under the disturbances where the parameters are described as (44).

$$\mathrm{T} = \begin{bmatrix} 1000 & 0 & 0 \\ 0 & 1000 & 0 \\ 0 & 0 & 1000 \end{bmatrix}$$

$$E_V = 5 \tag{44}$$

The disturbances' waveforms are shown in Fig.2 and the corresponding maximum values are listed in Table 2. The simulation results of backstepping technique are shown in Fig.3, and the simulation results of ADSC technique are shown in Fig.4.

The DP system, using either of traditional backstepping or ADSC, can maintain stable under the disturbances where the parameters are described as (44). However, simulation results show that the system's stability and accuracy using the ADSC technique are much better than that using the traditional backstepping technique (Compared results are listed in Table3). And the DP system's transient performance using ADSC technique is superior to that using traditional backstepping technique (see Table 4 and Table 5).

Table 2, The maximum values of disturbances

	x – axis(MN)	y- axis(MN)	Yaw (MNm)
maximum value	75	77	40

Table 3, Outputs steady-state errors with backstepping and ADSC

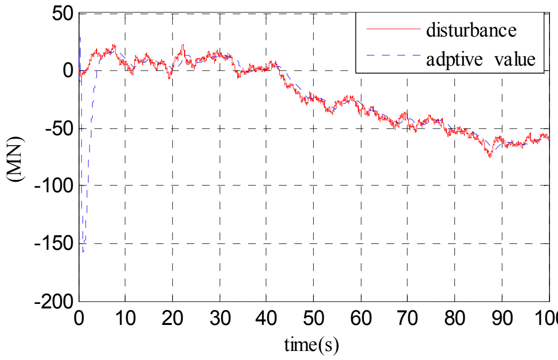
	x- error(m)	y- error(m)	yaw- error(deg)
backstepping	0.2	0.2	0.5
ADSC	0.06	0.02	0.005

Table 4, Dynamic performance with backstepping

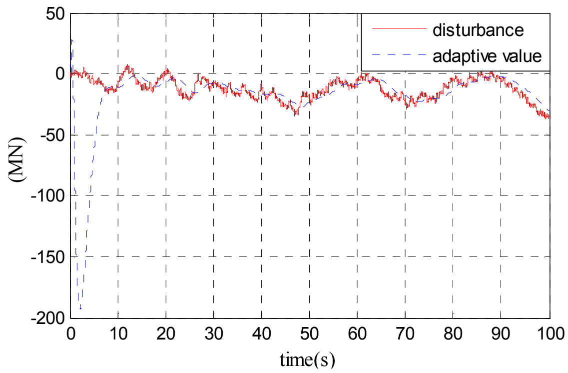
	x- axis	y- axis	yaw
settling time	10s	12s	13s
overshoot	0.37m	0.42m	1.8deg

Table 5, Dynamic performance with ADSC

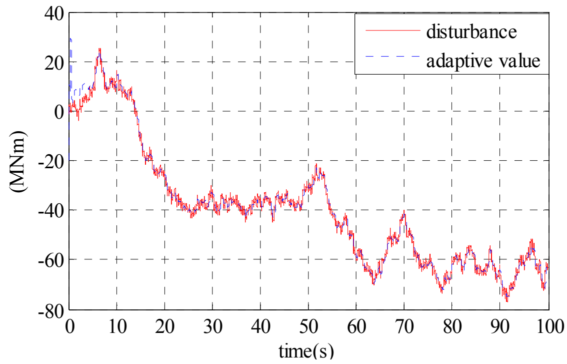
	x- axis	y- axis	yaw
settling time	3s	4s	2s
overshoot	0m	0. 2m	0m



(a) x-axis disturbance and its adaptive value

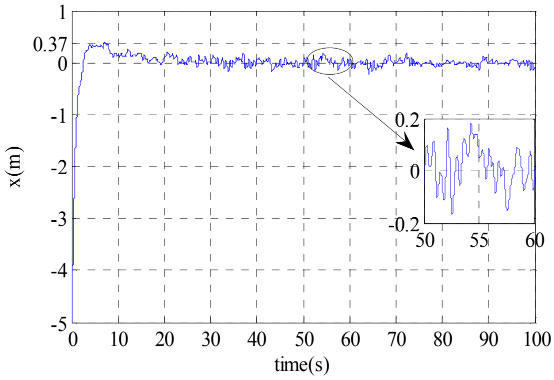


(b) y-axis disturbance and its adaptive value

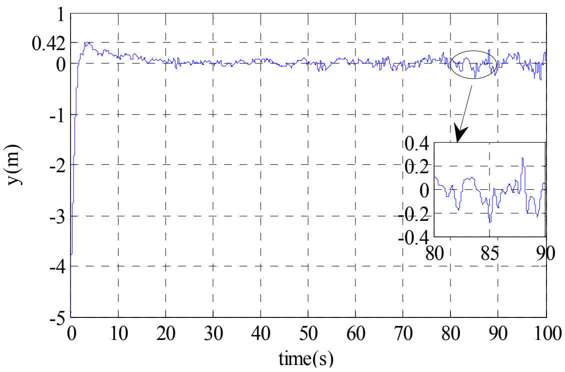


(c) yaw disturbance and its adaptive value

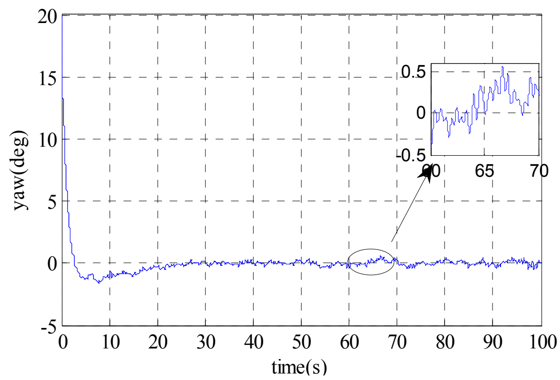
Fig.2, Disturbances waveforms in both methods and their adaptive value waveforms in ADSC



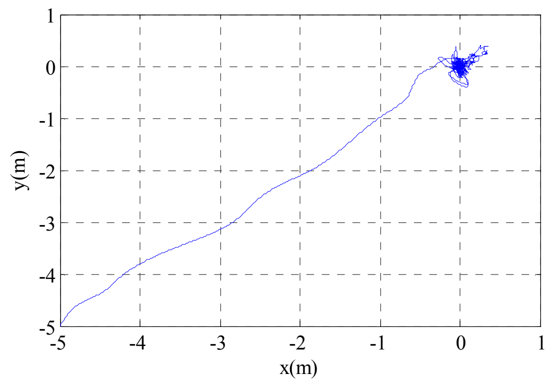
(a)x-position(m)



(b)y-position(m)

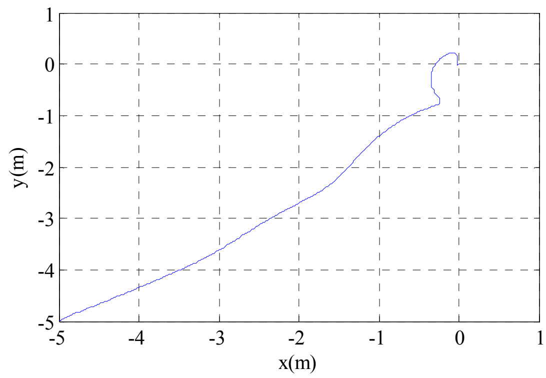


(c)yaw-angle(deg)



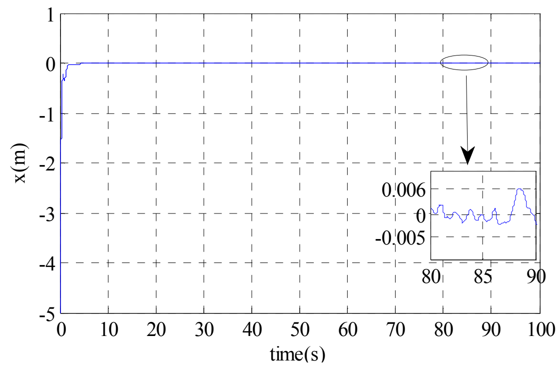
(d)xy-plot

Fig.3, Simulation results using backstepping control strategy

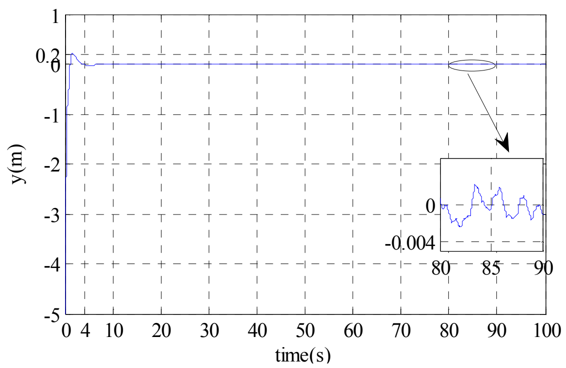


(d)xy-plot

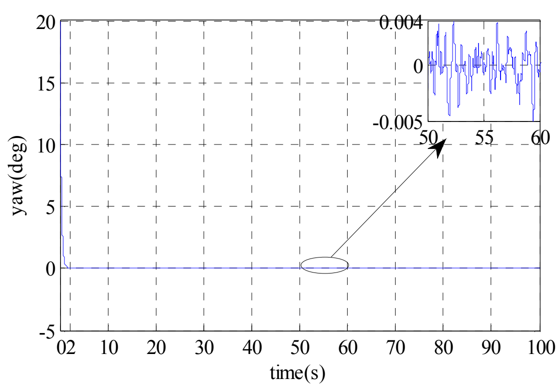
Fig.4, Simulation results using ADSC control strategy



(a)x-position(m)



(b)y-position(m)



(c)yaw–angle(deg)

4.2 Simulations under large disturbances

Referring to environmental forces mode (4), and considering the severe sea conditions with large disturbances, simulation is done under the disturbances where the parameters are described as formula (45).

$$T = \begin{bmatrix} 1000 & 0 & 0 \\ 0 & 1000 & 0 \\ 0 & 0 & 1000 \end{bmatrix}$$

$$E_V = 100 \tag{45}$$

There are two characteristics about the disturbances in this section. One is the large magnitude which simulates severe sea conditions; the other is the dramatic change which simulates the reaction of dredging operations (see Fig.5). The disturbances' waveforms are shown in Fig.5. The maximum values of disturbances are listed in Table 6.

Simulation results of the traditional backstepping technique are shown in Fig.6, and simulation results of ADSC technique are shown in Fig.7.

The DP system using traditional backstepping controller can not maintain stable under this condition, the controller can not meet the requirements of the desired performances for there are large steady-state errors (see table5 and Fig.6). However, the system with ADSC controller can still maintain stable and has good control performance under the same condition (see Fig.7 and table7). In ADSC technique, adaptive arithmetic can estimate disturbances and compensate them in time (see Fig.2 and Fig.5). The reaction of dredging operation can be compensated by adaptive values in ADSC controller. So the DP system using ADSC technique can maintain stable and has good performance even in harsh condition (See Table 7 and Table 8).

Table6, The maximum values of disturbances

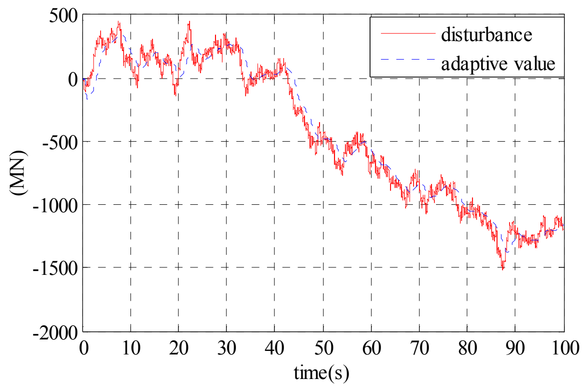
	x – axis(MN)	y-axis(MN)	Yaw (MNm)
maximum values	1500	750	1500

Table 7, Outputs steady-state errors of backstepping and ADSC

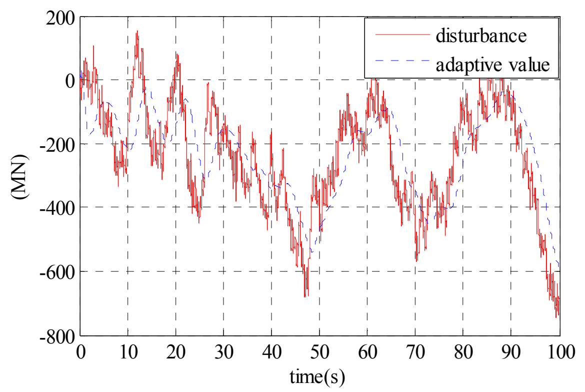
	x-error(m)	y-error(m)	yaw error(deg)
backstepping	35	25	12
ADSC	0.2	0.1	0.1

Table 8, Dynamic performance with ADSC

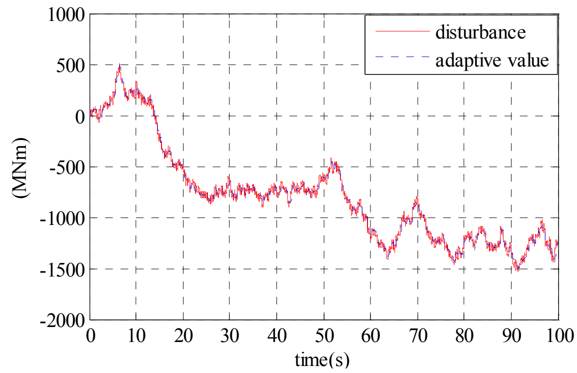
	x- axis	y- axis	yaw
settling time	3s	4s	1.5s
overshoot	0m	0. 25m	0m



(a)x-axis disturbance and its adaptive value

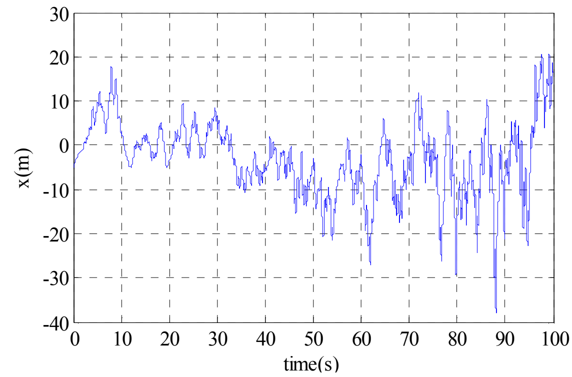


(b)y-axis disturbance and its adaptive value

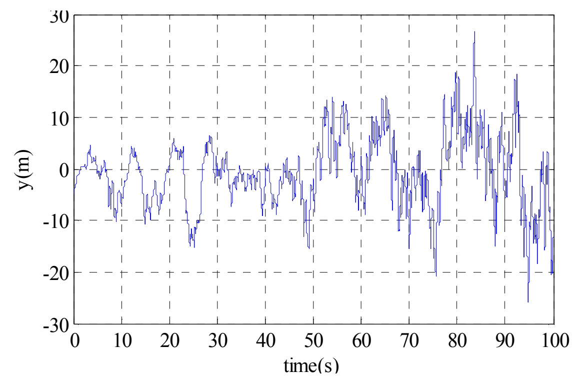


(c)yaw disturbance and its adaptive value

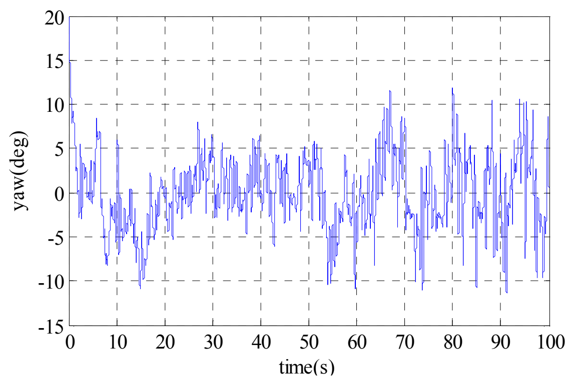
Fig.5, Disturbances waveforms in both methods and their adaptive value waveforms in ADSC



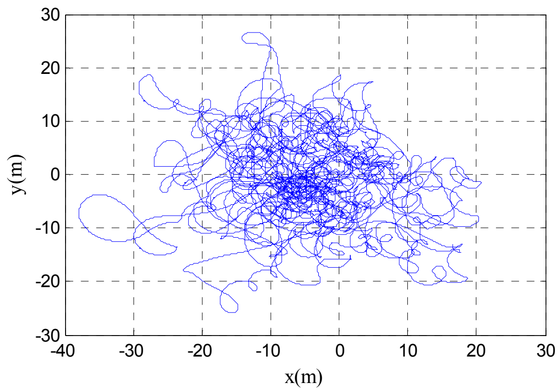
(a)x-position(m)



(b)y-position(m)

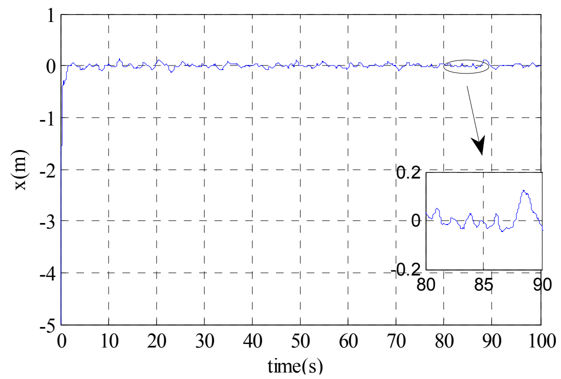


(c)yaw–angle(deg)

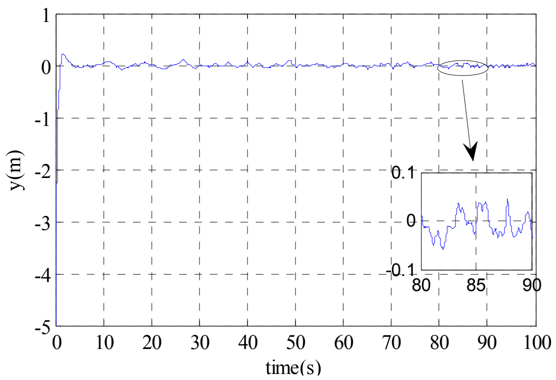


(d)xy-plot

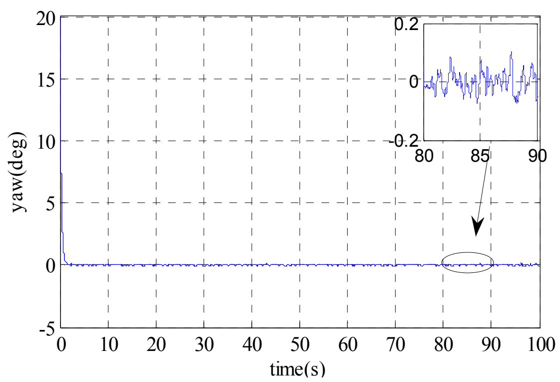
Fig.6, Simulation results using backstepping



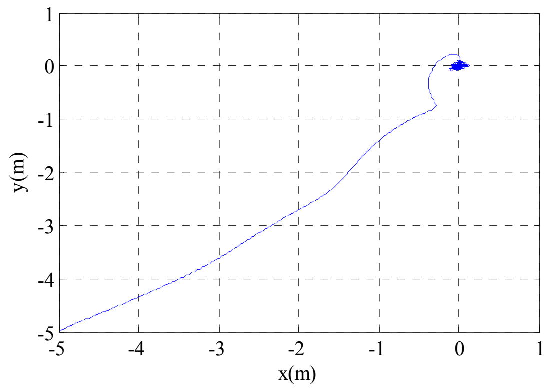
(a)x-position(m)



(b)y-position(m)



(c)yaw-angle(deg)



(d)xy-plot

Fig.7, Simulation results using ADSC

5 Discussion

Simulation results in section 4 show that ADSC has distinct advantages in DP system.

The system with ADSC controller is more stable than that with traditional backstepping tcontroller, i.e., ADSC technique has stronger robustness.

Furthermore, owing to the feed-forward compensating by adaptive arithmetic, the system with ADSC controller has excellent performance even when the ship under large disturbances or under harsh sea conditions.

6 Conclusion

A novel adaptive control strategy is presented in this paper based on the perturbed nonlinear mathematic model using dynamic surface control technique. The external disturbances are considered comprehensively in simulations, and finally the semi-global adaptive tracking is well achieved. Furthermore, the simulation results illustrate that the proposed control technique is practical, effective, as well as robust to the external disturbances.

The controller design uses first order filters to avoid differentiation, thereby the controller design procedure could be simplified.

Adaptive arithmetic is applied to compensate the external disturbances and the perturbation of the parameters, and guarantee the system's stability even under large force reaction disturbances or under harsh sea condition. So dredging reaction can be compensated without extra sensors in dredgers.

Acknowledgements

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