Tao, Jin; Du, Lei; Sun, Hao; Sun, Qinglin; Xie, Guangming; Zhou, Quan

LADRC-based Path Following Control for Cylindrical Drilling Platform Towing System

Published in:
Proceedings of the 2020 Chinese Automation Congress, CAC 2020

DOI:
10.1109/CAC51589.2020.9327631

Published: 06/11/2020

Document Version
Peer-reviewed accepted author manuscript, also known as Final accepted manuscript or Post-print

Please cite the original version:
Tao, J., Du, L., Sun, H., Sun, Q., Xie, G., & Zhou, Q. (2020). LADRC-based Path Following Control for Cylindrical Drilling Platform Towing System. In *Proceedings of the 2020 Chinese Automation Congress, CAC 2020* (pp. 5368-5373). Article 9327631 IEEE. https://doi.org/10.1109/CAC51589.2020.9327631

LADRC-based Path Following Control for Cylindrical Drilling Platform Towing System

1st Jin Tao
College of Engineering
Peking University
Beijing, China
College of Artificial Intelligence
Nankai University
Tianjin, China
Department of Electrical Engineering and Automation
Aalto Univeristy
Espoo, Finland
jin.tao@aalto.fi

2nd Lei Du
Department of Mechanical Engineering
Aalto Univeristy
Espoo, Finland
lei.du@aalto.fi

3rd Hao Sun
College of Artificial Intelligence
Nankai University
Tianjin, China
sunh@nankai.edu.cn

4th Qinglin Sun
College of Artificial Intelligence
Nankai University
Tianjin, China
sunql@nankai.edu.cn

5th Guangming Xie
College of Engineering
Perking University
Beijing, China
xiegming@pku.edu.cn

6th Quan Zhou
Department of Electrical Engineering and Automation
Aalto Univeristy
Espoo, Finland
quan.zhou@aalto.fi

2020 Chinese Automation Congress (CAC) | 978-1-7281-7687-1/20/$31.00 ©2020 IEEE | DOI: 10.1109/CAC51589.2020.9327631

***Abstract*—The towing process is the precondition to put a cylindrical drilling platform into use, which is saturated with risk due to the complexity of the towing environment, towing maneuvering, and the sudden and severity of accidents. Therefore, to control the cylindrical drilling platform towing system safely following a predefined course to reach the target see area becomes increasingly important. For environmental disturbances caused by wind and currents changing with time, a linear adaptive-disturbance-rejection-control (LADRC) based path following control method for cylindrical drilling platform towing system is proposed. Firstly, on the basis of both the mathematical modeling group model and the catenary model, three degrees of freedom nonlinear model of the cylindrical drilling platform towing system is built to obtain its real-time motion state. Then, a LADRC controller based on a two-dimensional trajectory tracking guidance law is designed for real-time path following control. Finally, simulation experiments of the path following control for the cylindrical drilling platform towing system is conducted. The results illustrate that the LADRC can effectively resist influences of the environmental disturbances and has a better path following performances than the traditional proportional–integral–derivative (PID) controller.**

***Index Terms*—cylindrical drilling platform towing system; path following control; LADRC; environmental disturbances**

I. INTRODUCTION

There exists rich resources, such as minerals, oil, and gas in the ocean. With the effective development and utilization of these resources, the global resource and energy crisis can be effectively alleviated [1]. Therefore, a lot of countries attach great importance to the exploration and development of deep-sea oil and gas resources. Consequently, the demand for energy resource exploration impels the increase of the offshore drilling platform. Cylindrical drilling platforms are the most advanced mobile oil platform, and because of the reliability and stability performances, they can be used to deal with various harsh marine environments during operation. The towing process is the precondition to put the platform into use, which is saturated with risk caused by the complexity of the marine environment, towing maneuvering and program, and the sudden and severity of accidents. The offshore towing operation nowadays mainly relies on human command and service. Therefore, human causes are the primary reason for towing accidents [2]. Intelligent dispatching and control lead the future development trend of making the navigation safer and ocean cleaner. To improve the adaptive regulation ability

This work was sponsored by the National Natural Science Foundation of China under grant no. 62003175, the National Key Research Project under grant no. 2019YFC1510900, the China Postdoctoral Science Foundation under grant Nos.2020M670045 and 2020M670663 and the Academy of Finland under grant no.315660. Jin Tao is the corresponding author.

of the towing system, it is significant to imply advanced control algorithms in the towing process, so that intelligently and stable towing can be realized.

In practice, the towing operation of the cylindrical drilling platform is always planned in advance. Therefore, the towing operating area is usually restricted to other ships' passing, and water depth is enough. However, the towing system is vulnerable to environmental disturbances, which will increase the control difficulty and may lead to deviating from the planned route [3]. Due to most of risks come from the deviation of the planned paths, how to maintain the whole cylindrical drilling platform towing system, which contains a tugboat, towlines, and a cylindrical drilling platform, cruising on the planned course with the influences of environmental disturbances is necessary but essential to reduce potential risks.

In recent years, Much attention has been focused on intelligent control for autonomous ships. For example, by using rudder and fin actions, a proportional-derivative (PD) controller on basis of neural network was developed in order to decrease roll motions of the ship on the required trajectory [4]. For marine uncrewed surface vessels, a nonlinear trajectory tracking control method was designed using a sliding mode approach based on nonlinear robust model [5]. On the baisi of singular perturbation, a two-scale control law was proposed to stabilize rudder roll of ships [6]. A control method of adaptive neural path tracking for underpowered ships in the field of marine practice was presented [7]. [8] designed a path following nonlinear adaptive controller to take care of the drifting force generated by the vehicle's side slip. [9] designed the main control framework, which includes the use of powerful adaptive radial basis functions and auxiliary design systems for extended backstepping technology. Based on a closed-loop gain shaping method, [10] developed a linear reduction of backstepping control method for path following of ships. [11] proposed a robust adaptive control method with off-track error constraint for underactuated marine vessels.

For the cylindrical drilling platform towing, the existing researches focus on the construction of the motion model, ship maneuverability, ship structure, and dynamic of towing system [12]. Nevertheless, as far as we know, little attention has been paid on the course following control of the cylindrical drilling platform towing system under environmental disturbances. In our previous research, we had applied active-disturbance-rejection-control (ADRC) in the towing system control [13], compared with the previous studies, the main differences lie in the change of the control objects. Here, we control the cylindrical drilling platform to track the pre-planed path, which is more in line with the actual operations.

Here, we first build a three degree-of-...n our previous research, we had applied ADRC in the towing system control [13], compared with the previous studies,...freedom (DOF) mathematical model of cylindrical drilling platform towing system under the disturbances of the wind and the current. Regarding various disturbances in the marine environment, a linear adaptive-disturbance-rejection-control (LADRC) based path following controller is then proposed to guarantee the towing system following the planned route. To verify the proposed LADRC, simulation experiments are conducted to illustrate its feasibility.

The remainder of this paper is organized as follows. Section 2 describes the mathematical model of the towing system of the cylindrical drilling platform. Section 3 focuses on the design of the LADRC-based path-following controllers for the towing system. Section 4 explains the simulation results, and Section 5 gives the conclusions.

II. MATHEMATICAL MODEL OF TOWING SYSTEM

A. Coordinate system of towing system

To descirbe the ship's operating motion, earth fixed coordinate system (O-XY) and ship coordinate systems ($o_i - x_i y_i$, $i = 1, 2$) are applied, as shown in Fig. 1. The origin point o_1 of the tuboat coordinate system $o_1 - x_1 y_1$ is fixed to the center of gravity of the tugboat. Two axes x_1 and y_1 point to the heading of the tugboat and to the starboard, respectively. To be similar, the origin point o_2 of the cylindrical drilling platform coordinate system $o_2 - x_2 y_2$ is at the center of gravity of the platform. x_2 and y_2 point straight to the towing line junction point and to the starboard, respectively. The distance between the center of gravity of the cylindrical drilling platform of the tugboat is represented by half of the length of the tugboat, and the distance between two connection points is described by the radius of the platform.

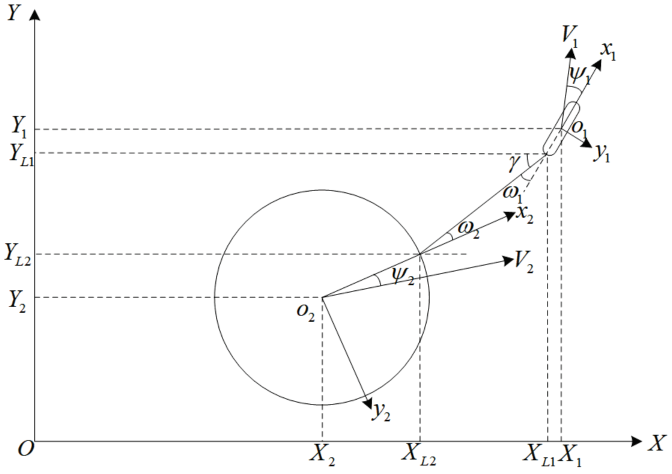

Fig. 1. Coordinate systems of the towing system.

In Fig. 1, the subscript 1 represents the tugboat and 2 denotes the towed platform. X_i, Y_i, X_{Li} and Y_{Li} denote the position of ship's center (o_i) and the towline connection points in earth fixed coordinate system $O-XY$. ψ_i denotes the ships' drift angle, V_i denotes the ships' speed, and γ is the towline direction in $O - XY$. ω_i is the angle of towing between the towline and x_i-axis in $o_i - x_i y_i$ coordinate system.

Relative positions between the cylindrical drilling platform and the tugboat can be presented as:

$$\left\{\begin{array}{l} X_{L1}=X_1-L_1\cos\psi_1 \\ Y_{L1}=Y_1-L_1\sin\psi_1 \\ X_{L2}=X_2+L_2\cos\psi_2 \\ Y_{L2}=Y_2+L_2\sin\psi_2 \\ \gamma=\arctan\left[\left(Y_{L2}-Y_{L1}\right)/\left(X_{L2}-X_{L1}\right)\right] \\ \omega_1=\gamma-\psi_1 \\ \omega_2=\gamma-\psi_2 \end{array}\right. \tag{1}$$

where L_1 denotes the tugboat length, and L_2 stands for the diameter of the platform.

B. Motion model of ships

The operation risk of the cylindrical drilling platform towing system is assessed on the two-dimensional horizontal plane. Ignoring the vertical motion, 3-DOF ship motion model is built on the basis of the mathematical modeling group (MMG) model theory as:

$$\left\{\begin{array}{l} (m_i+m_{ix})\dot{u}_i-(m_i+m_{iy})v_i r_i=\sum F_{Xi} \\ (m_i+m_{iy})\dot{v}_i-(m_i+m_{iy})u_i r_i=\sum F_{Yi} \\ (I_{izz}+J_{izz})\dot{r}_i=\sum N_i \end{array}\right. \tag{2}$$

where m, m_x and m_y denote the mass of ships (i.e., the plantform and the tugboat) and their added values in $o_i x_i$ and $o_i y_i$ directions, respectively. I_{zz} denotes the inertial moment and J_{zz} denote the added value. F represents the component force acting on ships in $O-XY$ coordinate system. N denotes the ships' corresponding moment. u and v denote the speed of ships in $o_i x_i$ axis and $o_i y_i$ axis under the ship coordinate systems, respectively. And r represents the angular velocity of ships while they are turning.

C. Towline model

Regardless of the vertical height difference between the towed points of the cylindrical drilling platform towing system and take the elasticity and resistance of the towline into consideration, the catenary model is built as:

$$\left\{\begin{array}{l} F_T=\left(H_D-2\frac{F_T}{\omega}sh^{-1}\left(\frac{\omega L_R/2}{F_T}\right)\right)\frac{EA}{L_R} \\ R_L=1.224\frac{SdV_i{}^2}{10^4}\left[1+\frac{1.122d}{10^4F_T}\left(\frac{S}{10^3}\right)^2\right] \end{array}\right. \tag{3}$$

where F_T denotes the horizontal tension component of the towline. H_D denotes the horizontal distance of the towline. ω represents the towline's weight per meter, and L_R denotes its length. E stands for the towline's Young's modulus. A denotes the cross-sectional area of the towline. R_L represents the resistance of the towline, d denotes its diameter, and S denotes the towline's length suspending in water.

The forces and moments of the towline on the tugboat and the platform in the ships' coordinate systems $o_i-x_i y_i$ are described as:

$$\left\{\begin{array}{l} X_{T1}=-F_T\cos\left(\omega_1\right) \\ Y_{T1}=-F_T\sin\left(\omega_1\right) \\ N_{T1}=Y_{1T}\cdot\frac{L_1}{2} \\ X_{T2}=F_T\cos\left(\omega_2\right) \\ Y_{T2}=F_T\sin\left(\omega_2\right) \\ N_{T2}=Y_{T2}\cdot\frac{L_2}{2} \end{array}\right. \tag{4}$$

where X_{Ti}, Y_{Ti} are the component of the cable force acting on the tugboat and cylinder drilling platform in $o_i x_i$ and $o_i y_i$ directions, respectively, and N_{Ti} is the cable moments.

III. LADRC BASED CONTROLLER DESIGN

The traditional PID control algorithm has no significant ability to suppress the disturbance that changes with time, and the intelligent algorithms are too dependent on the model. In order to conquer drawbacks of the traditional PID algorithm and the model-based control algorithms, on the basis of feedback linearizatiion, Jingqing Han first proposed the concept of ADRC [15]. Zhiqiang Gao further developed LADRC [16], which is a linearized form of ADRC. In ADRC, an extended state observer (ESO) is applied to estimate external disturbances and internal dynamics. And in each sampling period, the dynamic compensation of the state error feedback is used to simplify the whole system into an integrator chain. In recent years, ADRC or LADRC has been successfully applied to various control problems [17]–[23].

A. Principle of LADRC

Given a traditional second order system:

$$\ddot{y}=-a\dot{y}-by+\omega_{drt}+bu \tag{5}$$

where y denotes the output of the system, u represents its input, and ω_{drt} denotes the external disturbances. a and b are parameters of the system.

Furthermore, (5) can be rearranged as:

$$\begin{aligned} \ddot{y}&=-a\dot{y}-by+\omega_{drt}+\left(b-b_0\right)u+b_0u \\ &=f\left(t,y,\dot{y},\omega_{drt}\right)+b_0u \end{aligned} \tag{6}$$

where $f\left(t,y,\dot{y},\omega_{drt}\right)$ denotes the total disturbances, composed of the external disturbance ω_{drt} and the internal disturbance $-a\dot{y}-by+\left(b-b_0\right)u$. b_0 represents an estimation of b.

Define:

$$\left\{\begin{array}{l} \dot{x}_1=x_2 \\ \dot{x}_2=x_3+b_0u \\ \dot{x}_3=h \\ y=x_1 \end{array}\right. \tag{7}$$

where $x_3=f$ is regarded as an augmented state of the system, and $h=\dot{f}$ denotes unknown disturbances.

Using a state observer, f can be estimated according to a state space model as:

$$\left\{\begin{array}{l} \dot{x}=Ax+Bu+Eh \\ y=Cx \end{array}\right. \tag{8}$$

where $A=\begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{bmatrix}, B=\begin{bmatrix} 0 \\ b_0 \\ 0 \end{bmatrix}, C=\begin{bmatrix} 1 & 0 & 0 \end{bmatrix}, E=\begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$.

Then, ESO of the system is built as:

$$\left\{\begin{array}{l} \dot{z}=Az+Bu+L\left(y-\hat{y}\right) \\ \hat{y}=Cz \end{array}\right. \tag{9}$$

where $L = [\beta_1, \beta_2, \beta_3]$ denotes the observer gain vector, which is parameterized as $\beta_1 = 3\omega_o, \beta_2 = 3\omega_o^2, \beta_3 = \omega_o^3$. Here, ω_o denotes the observer bandwidth, which is the only parameter that needs to be ajusted. After well adjusting $omega_o$, the observer z can track the state x excellently. Define:

$$u = \frac{-z_3}{b_0} + u_0 \tag{10}$$

The system model is reduced by ignoring the estimation error of z_3:

$$\ddot{y} = f - z_3 + b_0 u \approx u_0 \tag{11}$$

The control law is written as:

$$u_0 = k_p(r - z_1) + k_d(\dot{r} - z_2) \tag{12}$$

To sum up, LADRC is constructed by (9), (10) and (12). The flow-chart of LADRC is shown as Fig. 2.

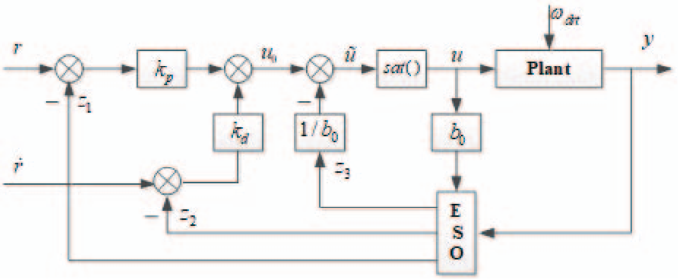

Fig. 2. Flow-chart of LADRC.

B. Design of LADRC Controller

Take into consideration the error between the sailing direction of the towed platform and the desired direction of the planned path, and the distance between the cylindrical drilling platform and the planned path, the error for path following control is constructed as follows.

Define:

$$\begin{cases} \Delta x = x_r(t) - x_r(t-1) \\ \Delta y = y_r(t) - y_r(t-1) \\ \hat{x} = x_r(t) - x(t) \\ \hat{y} = y_r(t) - y(t) \end{cases} \tag{13}$$

where Δx and Δy denotes the x and y axis distance difference of the desired path at 1 sampling time, respectively. $(x_r(t), y_r(t))$ represents the current point of the desired path at time t, and $(x_r(t-1), y_r(t-1))$ represents the former point of the desired path at time $t-1$. $\hat{x}$ and $\hat{y}$ denote the distance between the platform and the disired path at time t. And $(x(t), y(t))$ represents the current position of the cylindrical drilling platform at time t.

Furthermore, the distance error and the desired heading angle of the platform are written as:

$$\begin{cases} \Delta d = (\hat{x}\Delta y - \hat{y}\Delta x)/\sqrt{\Delta x^2 + \Delta y^2} \\ \varphi_r = tan(\hat{y}/\hat{x}) \end{cases} \tag{14}$$

where Δd denotes the distance error and φ_r represents the heading angle of the platform.

Consequently, the course following control of the cylindrical drilling platform towing system can be treated as an tracking problem of the platform heading angle. The current heading angle of the cylindrical drilling platform $\varphi(t)$ can be arranged as:

$$\varphi(t) = \varphi_r(t) + k\Delta d \tag{15}$$

where k is a weighted value.

Take a derivative of (15):

$$\dot{\varphi}(t) = w_z(t) \tag{16}$$

Moreover, a second order form of the heading angle $\ddot{\varphi}(t)$ is arranged as:

$$\begin{cases} \ddot{\varphi}(t) = f(t, \varphi(t), w_z(t), \omega_{dtr}(t)) + b_0(t)u(t) \\ y = \varphi(t) \end{cases} \tag{17}$$

The ESO of the heading angle is constructed based on (9). By properly designing the ESO, the current heading angle of the platform $\varphi(t)$, the changing rate of heading angle $\dot{\varphi}(t)$ and the total disturbance f is estimated. Therefore, the course following control of the cylindrical drilling platform towing system can be abtained via dynamic compensation of state error feedback.

IV. SIMULATION AND ANALYSIS

A. Parameter settings of the cynlindrical drilling platform towing system

In this section, we perform simulation experiments based on a certain type of the cynlindrical drilling platform towing system, the physical parameter of the towing system is shown in Table.1.

TABLE I
PHYSICAL PARAMETERS OF CYLINDRICAL DRINLLING PLATFORM TOWING SYSTEM

Tugboat				
Width	***Length***	***Displacement***	***Draught***	***Square factor***
16.4 m	63.6 m	4522 t	6.22 m	0.692
Rudder height	***Rudder area***	***Pitch***	***Aspect ratio***	***Propeller diameter***
5 m	7.5 m^2	5.2 m	1.7	5 m
Cylindrical drilling platform				
Diameter	***Tonnage***	***Draught***	***Square factor***	
86 m	33000 t	6.4 m	0.7854	
Towline				
Diameter	***Reference quality***	***Maximum load***	***Tensile compression stiffness***	
54.6 mm	12 $kg{\cdot}m^{-1}$	1800 kN	$9.2 \times 10^8 N$	

In this simulation experiments, the tugboat is powered by a propeller, and the direction of the tugboat is controlled by a rudder, presented as rudder angle δ. Additionally, there exists the limitation of the speed and rudder angle that need to be satisfied. Here, the initial heading angles of the tugboar and the platform are set to 0°, and their initial speeds are set to 2.57 m/s.

B. Towing system settings

In practical operation, the towing process of the platform is always point-to-point towing. Since these operations ar well planned in advance, the towing operation water is usually restricted by the passage of other ships and the water depth is sufficient. Consequently, the path is set as lines in th horizontal plane. The starting point of the first line is (0, 0 m and the end point is (5000, 0) m. The starting point of th second line is the end of the first line, i.e., (5000, 0) m, and the ending point is (10000, 2000) m.

In order to verify the proposed LADRC based path following control method, we applied both the designed LADRC and the traditional PID controller in the path following experiment under wind and current disturbances. The wind and curren environments are set as:

- Wind disturbances: at t = 2500 s, we add the latera constant wind into the simulated environment, and last 100 s. The wind speed is set to 20 m/s, and its direction points to the left abeam.
- Current disturbance: the current is add into the simulation environment at t = 2500 s, and lasts 100 s. The current speed is set to 2 m/s, and its direction is set to pointing to the left abeam.

The parameters of LADRC are tuned as: $\omega_0 = 3$, $b_0 = 0.015$, and $\omega_c = 0.2$. The parameters of the traditional PID controller are set as: $k_p = 5$, $k_i = 1$, and $k_d = 0.1$. The simulation results are shown in Fig. 3 - 4.

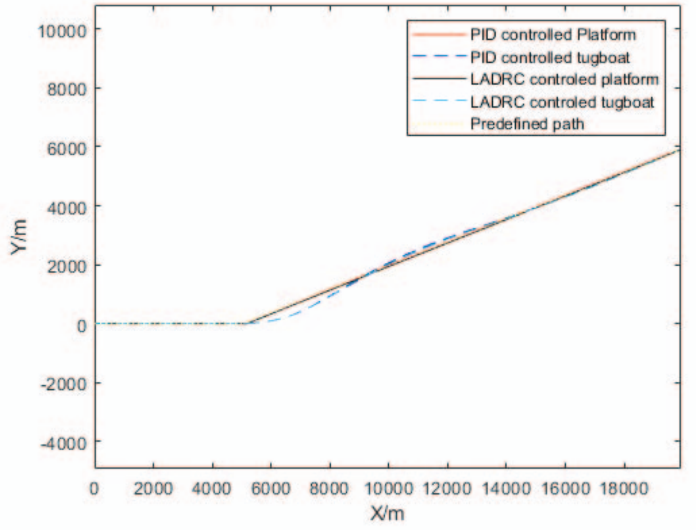

Fig. 3. Path following control of PID and LADRC.

Fig. 3 shows trajectories of the tugboat and the platform controller by LADRC and PID. And Fig. 4 shows control output of LADRC and PID controller. From simulation results, we can observe that both PID and LADRC controllers can control the cylindrical drilling platform to follow the designed path well. Since our control target is the cylindrical drilling platform, the distance between the desired path and the tugboat is always greater than the platform. As shown in Fig. 4, at the turning stage, i.e., the joint of the first line and second line, the PID controller shows a slower response and a larger overshoot, which indicates the LADRC outperforms the PID controller.

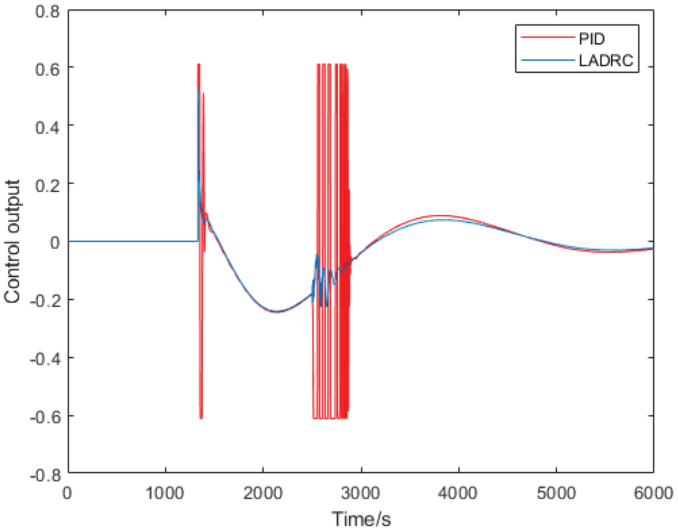

Fig. 4. Control outputs of PID and LADRC.

Under the atmospheric disturbances caused by the wind and current, which have strong influences on the course following control of the cylindrical drilling platform towing system, the output of the PID controller saturates, and meanwhile the whole system divergences. Nevertheless, the proposed LADRC achieves a more satisfactory path.

Thus, the PID controller's tracking effect is worse than the one using the ADRC. The main reason lies that the LADRC can detect disturbances in the external environment through ESO and use dynamic compensation to achieve anti-disturbance effects. Therefore, in cylindrical drilling platform towing system control, we show that the robustness and the control precision of LADRC are better than the traditional PID controller.

V. CONCLUSION

This paper first built a three DOF mathmatical model of the cylindrical drilling platform towing system according to MMG and the catenary models. Secondly, for the horizontal path following control of the towing system, a control scheme based on LADRC was proposed, which aims to use ESO for interference estimation and compensation in each sampling period to solve the control uncertainty caused by environmental disturbances. Finally, we conducted simulation experiments for a certain type of towing system. Experimental results show that the proposed LADRC path following controller can achieve better control performances compared with the traditional PID controller.

However, we realize that the towing system is a very complex nonlinear system, thus, the external and internal dynamics within the system is difficult to analyze. In addition, there exists many parameter of LADRC that need to be well tuned, which add more difficulty for the controller design. Therefore, how to achieve a more precise path following, improve control accuracy, simplify settings, and be more conducive to practical engineering applications, which need to be solved in our future work.

REFERENCES

[1] R. Nersesian, “Energy for the 21st century: a comprehensive guide to conventional and alternative sources,” Routledge. 2014.

[2] E. Akyuz, M. Celik, “Utilisation of cognitive map in modelling human error in marine accident analysis and prevention,” Saf. Sci. vol. 70, pp. 19-28, Dec. 2014.

[3] T. I. Fossen, “Handbook of marine craft hydrodynamics and motion control,” John Wiley & Sons. 2011.

[4] M. C. Fang, Y. H. Lin, B. J. Wang, “Applying the PD controller on the roll reduction and track keeping for the ship advancing in waves,” Ocean. Eng. vol. 54, pp. 13–25, Nov. 2012.

[5] F. Fahimi, C. Van Kleeck, “Alternative trajectory-tracking control approach for marine surface vessels with experimental verification,” Robotica. vol. 31, no.1, pp. 25-33, Mar. 2013.

[6] R. Ren, Z. Zou, X. Wang,“ A two-time scale control law based on singular perturbations used in rudder roll stabilization of ships,” Ocean Eng. vol. 88, pp. 488–498, Sep. 2014.

[7] G. Zhang, X. Zhang, Y. Zheng, “Adaptive neural path-following control for underactuated ships in fields of marine practice,” Ocean Eng. vol.104, pp. 558–567, Aug. 2015.

[8] T. I. Fossen, K.Y. Pettersen, R. Galeazzi, “Line-of-sight path following for dubins paths with adaptive sideslip compensation of drift forces,” IEEE Trans. Control. Syst. Technol. vol. 23, no. 2, pp. 820-827, Jul. 2014.

[9] Z. Zheng, L. Sun, “Path following control for marine surface vessel with uncertainties and input saturation,” Neurocomputing. vol. 177, pp. 158-167, Feb. 2016.

[10] X. K. Zhang, Q. Zhang, H. X. Ren, G. P. Yang, “Linear reduction of backstepping algorithm based on nonlinear decoration for ship course-keeping control system,” Ocean Eng. vol. 147, pp. 1–8, Jan. 2018.

[11] J. Ghommam, S. E. Ferik, M. Saad, “Robust adaptive path-following control of underactuated marine vessel with off-track error constraint,” Int. J. Syst. Sci. vol. 49, no. 7, pp. 1540-1558, Apr. 2018. .1-19 (2018)

[12] A. Fitriadhy, H. Yasukawa, K. K. Koh,“Course stability of a ship towing system in wind,” Ocean Eng. vol. 64, pp. 135-145, May 2013.

[13] J. Tao, L. Du, M. Dehmer, Y. Q. Wen, G. M. Xie, Q. Zhou, ”Path following control for towing system of cylindrical drilling platform in presence of disturbances and uncertainties,” ISA trans. vol. 95, pp. 185-193, Dec. 2019.

[14] Y. Yoshimura, “Mathematical model for manoeuvring ship motion (MMG Model), ” In Workshop on Mathematical Models for Operations involving Ship-Ship Interaction, pp. 1-6, 2015.

[15] J. Han, “From PID to active disturbance rejection control, ” IEEE Trans. Ind. vol. 56, no. 3, pp. 900-906, Mar. 2009.

[16] Z. Gao, “Scaling and bandwidth-parameterization based controller tuning. In Proceedings of the American control conference,” pp. 4989-4996, IEEE, Piscataway, 2006.

[17] J. Tao, Q. L. Sun, P. L. Tan, Z. Q. Chen, Y. P. He, “Autonomous homing control of a powered parafoil with insufficient altitude,” ISA trans. vol. 65, pp. 516-524, Nov. 2016.

[18] H. Sun, Q. L. Sun, S. Z. Luo, Z. Q. Chen, W. N. Wu, J. Tao, Y. P. He, Y, “In-flight compound homing methodology of parafoil delivery systems under multiple constraints,” Aerosp Sci Technol, vol. 79, pp. 85-104, Aug. 2018.

[19] J. Tao, Q. L. Sun, H. Sun, Z. Q. Chen, M. Dehmer, M. W. Sun, “Dynamic modeling and trajectory tracking control of parafoil system in wind environments,” IEEE ASME Trans. Mechatron. vol. 22, no. 6. pp. 2736-2745, Dec. 2017.

[20] J. Tao, W. Liang, Q. L. Sun, S. Z. Luo, Z. Q. Chen, P. L. Tan, Y. P. He, “Modeling and control of a powered parafoil in wind and rain environments,” IEEE T. Aero. Elec. Sys. vol. 53, no. 4, pp. 1642-1659, Feb. 2017.

[21] J. Tao, Q. L. Sun, Z. Q. Chen, Y. P. He. ”Homing control of a parafoil system in large wind environments.” Control Appl. vol. 33, no. 12, pp.1630-1638, 2016.

[22] J. Tao, Q. L. Sun, P. L. Tan, W. N. Wu, Z. Q. Chen, Y. P. He. ”Homing control of parafoil systems in unknown wind environments .” Acta Aeronautica et Astronautica Sinica. vol. 38, no. 5, pp.320523-320523, 2017.

[23] J. Tao, Q. L. Sun, P. L. Tan, W. N. Wu, Z. Q. Chen, Y. P. He. ”Linear active disturbance rejection based altitude control for an unmanned powered parafoil .” Journal of National University of Defense Technology. vol. 39, no. 6, pp.103-110, 2017.