A Novel Robust Adaptive Control for PMDC Servo Motor Incorporating Recursive Least Square and Particle Swarm Optimization

Sarucha Yanyong and Somyot Kaitwanidvilai

Abstract— **Position control is a crucial control system used extensively in various industrial applications. In many of these applications, system parameters, such as the mass of an object can change unpredictably. Non-adaptive position control proves inadequate in successfully managing these fluctuations. Thus, an online adaptive control system plays a vital role in maintaining high performance despite changing parameters. This paper proposes a novel online adaptive fixed-structure robust controller for a PMDC (Permanent Magnet Direct Current) servo motor. This controller employs Recursive Least-square and Particle Swarm Optimization techniques to form the adaptive system. Simulation results demonstrate the effectiveness of our proposed technique and its potential application.**

Index Terms—Robust Adaptive Control, Recursive Least-square, Fixed-Structure H-infinity, Particle Swarm Optimization

I. INTRODUCTION

ADAPTING to changes in industrial operations such as shifts in weight on a conveyor can be a challenge when utilizing a non-adaptive controller. To address this issue, adaptive controllers, capable of adjusting their behavior according to changes within the system, have been proposed to provide improved responses. An integral part of these adaptive controllers is the system identification method. Although a variety of methods have been used by many researchers [1-3] for identifying system parameters, they often require a substantial amount of data. This significant data requirement can make real-time or online adaptation challenging.

A potential solution to this is the Recursive Least Squares (RLS) system identification method. This method employs only upcoming data for parameter identification, thereby making it more suitable for online adaptation. Hence, online system identification [4] is proposed, applying the recursive least squares method for the identification of plant parameters.

In the realm of controller adaptation, H_∞ control is a prominent technique typically employed for designing robust controllers. Robust controllers find extensive application across various fields. For instance, Xiangyu Gao et al. [5] implemented H_∞ control to handle uncertain systems. The H_∞ controller can be utilized to design a 2DOF robust control for Hard Disk Drive servo controllers [6]. Moreover, Songlin et al. [7] leveraged robust H∞ control for controlling network systems.

While H_∞ optimal control can regulate systems under conditions of disturbance and parameter changes, the resulting controller often has a complex structure and high order, rendering it less practical for real-world applications. Moreover, the majority of industrial controllers typically use lead-lag or PID controllers to control systems. Hence, designing a simpler robust controller, such as a fixed-structure H_∞ robust controller, for plant control is a logical step.

Certain researchers [8] have proposed the use of fixed-structure robust controllers to regulate plants. In terms of global optimization, S. Kaitwanidvilai et al. [9] and Jonglak Pahasa et al. [10] utilized Particle Swarm Optimization (PSO) to determine unknown controller parameters in their studies. As their results demonstrated, PSO [11] is an intelligent global optimization technique well-suited to addressing non-linear optimization problems.

The proposed solution is a PSO-based fixed-structure H∞ control system that synthesizes the optimal fixed-structure H∞ controller to maximize the stability margin (ε) of the entire system. This paper introduces a novel online adaptive fixed-structure robust controller. The proposed technique merges recursive least squares for online system identification with a PSO-based fixed-structure H_∞ controller for controller adaptation.

The recursive least squares method utilizes four steps ahead data for parameter identification, while the fixed-structure H_∞ controller is synthesized on a multicore processor at every sampling. This study focuses on the permanent-magnet DC motor [12] as the plant of interest.

The benefits of the proposed controller include its adaptability when the plant or environment changes, and the robustness of the PSO-based fixed-structure H_∞ controller's resistance to disturbance torque. The simulation results demonstrate the response of the proposed technique compared to those of the non-adaptive controller.

II. DYNAMIC MODEL OF PERMANENT-MAGNET DC MOTOR

The typical dynamic model of a permanent-magnet DC motor is depicted in Fig. 1.

Manuscript received May 23, 2023; revised June 06, 2023.

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ISBN: 978-988-14049-4-7
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

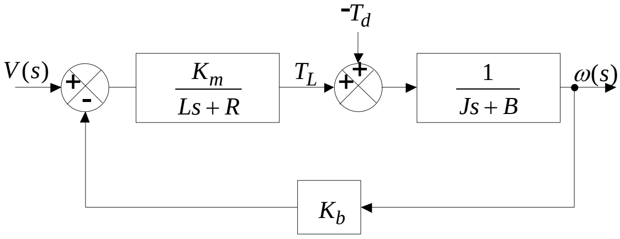


Fig. 1. Permanent-Magnet DC Motor

The transfer function for speed control of a permanent-magnet DC motor can be expressed as follows:

$$G_\omega(s) = \frac{\omega(s)}{V(s)} = \frac{K_m}{JLs^2+(JR+BL)s+BR+K_b} \quad (1)$$

Therefore, the dynamic of the plant for position control is as follows:

$$\theta(s) = \frac{1}{s}\omega(s) \quad (2)$$

Given equations (1) and (2), the transfer function for the PMDC motor, from input voltage to position, can be expressed as follows:

$$G(s) = \frac{\theta(s)}{V(s)} = \frac{K_m}{s(JLs^2+(\ JR+BL\ )s+BR+K_b)} \quad (3)$$

Where V is apply voltage; ω is Angular velocity; θ is Angular position; K_m is Torque constant; L is Motor inductance; R is Motor resistance; J is Motor inertia; B is Viscous friction and K_b is Back EMF constant. Block diagram of the proposed on-line Adaptive Robust Controller is shown in Fig. 2.

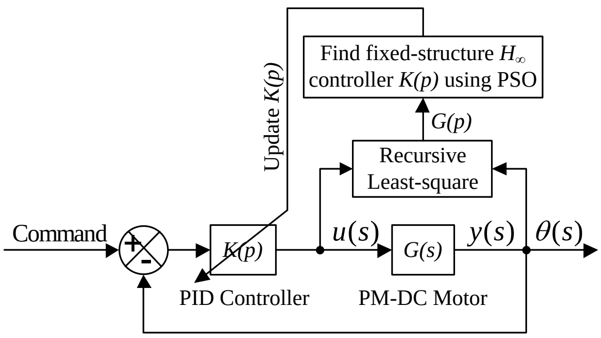


Fig. 2. On-line adaptive robust controller

III. RECURSIVE LEAST-SQUARE (RLS)

The Recursive Least Squares (RLS) method is utilized for parameter estimation, providing the ability to estimate models in real-time via recursive calculations. In this algorithm, previously estimated parameters are used to calculate current parameters, denoted as θ *(n)*. This estimator has the capability to estimate parameters at each sampling time. The equation for the Recursive Least Squares method can be written as follows:

$$\hat{\theta}(n) = \hat{\theta}(n-1) + K(n)\,\varepsilon(n) \quad (4)$$

$$\varepsilon(n) = y(n) + \varphi(n)^T\hat{\theta}(n-1) \quad (5)$$

$$K(n) = \lambda^{-1}P(n-1)\varphi(n) \cdot [I+\lambda^{-1}\varphi(n)^T P(n-1)\varphi(n)]^{-1} \quad (6)$$

$$P(n) = [I + K(n)\varphi(n)^T]\lambda^{-1}P(n-1) \quad (7)$$

Where $\hat{\theta}(n)$ is estimated parameter; $\varphi(n)$ is the set of measured input and output and λ is forgetting factor.

IV. PSO BASED FIXED-STRUCTURE H_∞ CONTROLLER

This paper proposes the fixed-structure H_∞ controller to design the robust controller based on the multiplicative perturbation. Transfer function from output disturbance to controller output is shown in (8).

$$T_{zw} = \frac{GK}{1-GK} \quad (8)$$

In this paper, the H_∞ norm is utilized to identify the optimal fixed-structure robust controller *K(p)*, which is fixed as a PID controller. The optimal *K(p)* is achieved by minimizing $\|T_{zw}\|_\infty$.

$$\varepsilon^{-1} = \|T_{zw}\|_\infty = \left\|\frac{GK}{1-GK}\right\|_\infty \quad (9)$$

In this context, ε represents the stability margin, which is used to measure the robustness of the entire system.

To address the problem indicated in equation (9), this paper utilizes Particle Swarm Optimization to find the optimal *K(p)* by minimizing the cost function. The cost function (J_{cost}) used in this optimization problem is presented in equation (10).

$$J_{cost} = \varepsilon^{-1} = \|T_{zw}\|_\infty = \left\|\frac{GK}{1-GK}\right\|_\infty \quad (10)$$

The maximum stability margin (ε) is obtained by minimizing the cost function (J_{cost}). The procedure of the proposed technique is depicted in Fig. 3.

Particle Swarm Optimization is a global optimization method wherein particles traverse the solution space to search for the optimal solution. Each particle acts as a potential optimal solution, with subsequent particles generated based on the concept of swarm movement and fitness value. In this paper, the PSO technique is employed to search for the optimal *K(p)* parameters, namely K_p, K_i, and K_d, with the goal of maximizing the fitness value. Further details about PSO can be found in references [7-8].

ISBN: 978-988-14049-4-7
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

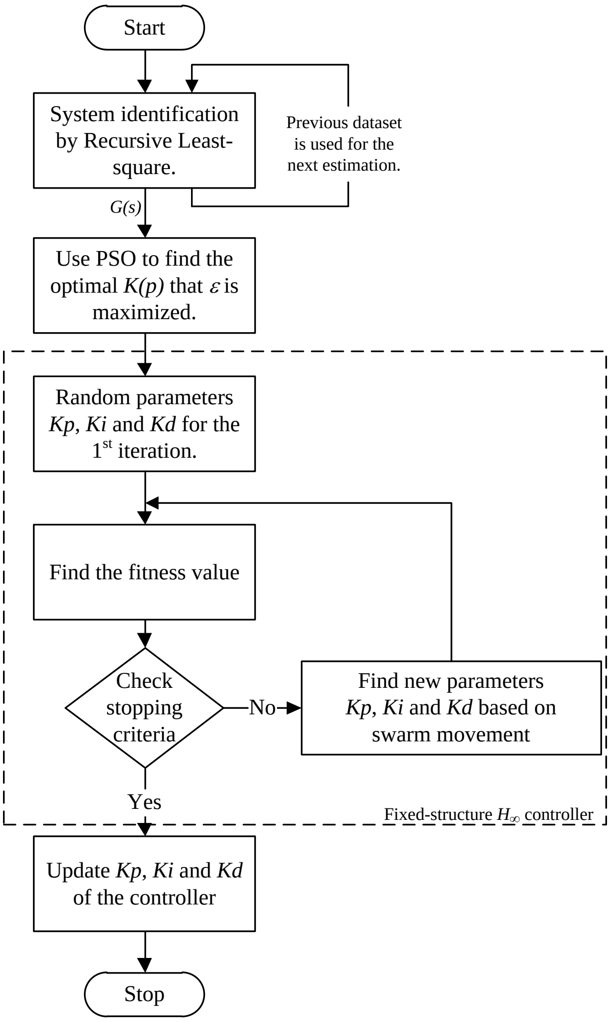


Fig. 3. Flow chart of the proposed technique

V. SIMULATION RESULTS

The proposed technique is implemented to control a permanent-magnet DC motor, which is widely used in numerous industrial applications. The parameters of the motor utilized in this study are presented in Table 1.

TABLE I
PERMANENT-MAGNET DC MOTOR PARAMETERS

Parameters	Values
Resistance (R)	2.00 Ω
Inductance (L)	5 mH
Torque constant (K_m)	0.1 N.m/A
Back emf constant (K_b)	0.1 V.sec/rad
Viscous friction (B)	0.2 N.m.sec/rad
Inertia (J)	0.00002 kg.m^2

Therefore, the transfer function of the Permanent Magnet Direct Current (PMDC) Motor studied in this research is as follows:

$$G(s) = \frac{0.1}{1\times 10^{-7} s^3 + 1.04\times 10^{-3} s^2 + 0.41 s} \quad (11)$$

The simulation results of the system identification using the proposed Recursive Least Squares (RLS) method are presented in Fig. 4. As depicted in the figure, the proposed RLS technique effectively estimates the dynamics of the plant.

The result of output response versus command of the proposed adaptive robust controller is shown in Fig. 5. As seen in this figure, the on-line adaptive controller can perform a good response to control the plant. To verify the robustness of the proposed technique, torque disturbance is applied to the plant at times 4, 7, and 12 seconds. The responses of the proposed adaptive robust controller and non-adaptive robust controller are shown in Fig. 6(a) and Fig. 6(b), respectively. As seen in these figures, the proposed controller performs better in terms of lower error.

Additionally, Fig. 7 depicts the response of the adaptive controllers tuned using different methods, namely ISE and the proposed cost function. As observed in this figure, the proposed controller exhibits durability against disturbance torque and delivers a superior response compared to the adaptive controller tuned using the ISE method.

VI. CONCLUSION

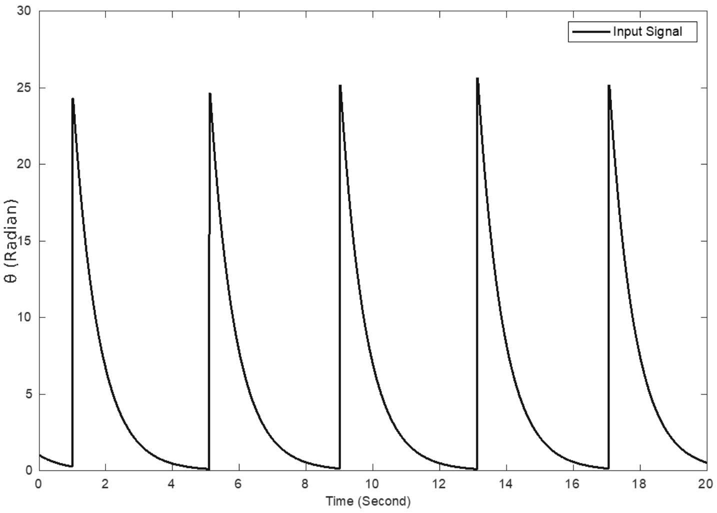
The proposed online adaptive controller can effectively control the plant even when parameters change. The designed H∞ controller demonstrates resilience against input torque disturbances and effectively reduces output errors when the system is disturbed. The results indicate that the combination of the H∞ controller and Recursive-Least Square (RLS) enhances robustness and enables online adaptability of the controller.

REFERENCES

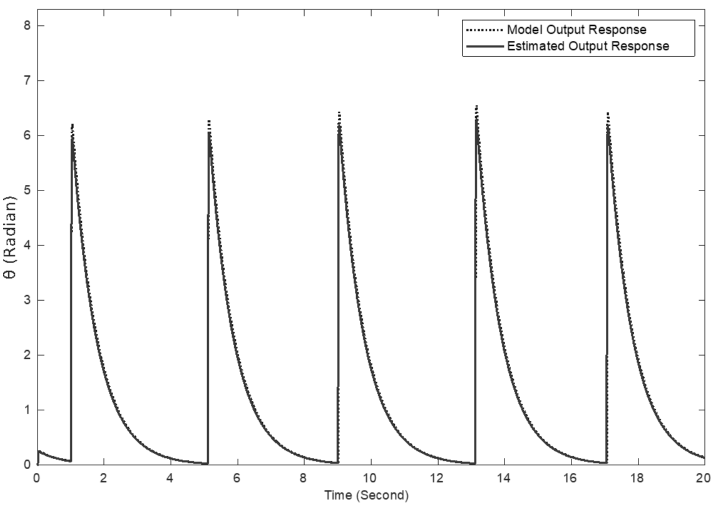
[1] H. Yousefi, H. Handroos, and A. Soleymani, "Application of differential evolution in system identification of a servo-hydraulic system with a flexible load," Mechatronics, Vol. 18, 2008, pp. 513-528.
[2] T. G. Ling, M. F. Rahmat, A. R. Husain, and R. Ghazali, "System identification of electro-hydraulic actuator Servo System," 4th International Conference on Mechatronics (ICOM), Malaysia, 2011.
[3] Y. Chen, P. Huang, and J. Yen, "Frequency-domain identification algorithms for servo systems with friction," IEEE Transactions on Control Systems Technology, Vol. 10, 2002.
[4] I. Eker, "Open-loop and closed-loop experimental on-line identification of a three-mass electromechanical system," Mechatronics, Vol. 14, 2004, pp. 549-565.
[5] X. Gao, K. L. Teo, G. Duan, and N. Wang, "Robust reliable H∞ control for uncertain systems with pole constraints," International Journal of Innovative Computing, Information and Control, Volume 8, Number 5(A), May 2012.
[6] S. Kaitwanidvilai and A. Nath, "Design and implementation of a high-performance Hard Disk Drive servo controller using GA-based 2DOF robust controller," International Journal of Innovative Computing, Information and Control, Volume 8, Number 2, February 2012.
[7] S. Hu, D. Yue, J. Liu, and Z. Du, "Robust H∞ control for networked systems with parameter uncertainties and multiple stochastic sensors and actuators faults," International Journal of Innovative Computing, Information and Control, Volume 8, Number 4, April 2012.
[8] A. H. El-Shaer, S. Sugita and M. Tomizuka, "Robust fixed-structure controller design of electric power steering systems," American Control Conference, Hyatt Regency Riverfront, MO, USA, 2009, pp. 445-450.
[9] S. Kaitwanidvilai and P. Olranthichachat, "Robust loop shaping-fuzzy gain scheduling control of a servo-pneumatic system using particle swarm optimization approach," Mechatronics, Vol. 21, 2011, pp. 11-21.
[10] J. Pahasa and I. Ngamroo, "PSO-based kernel principal component analysis and multi-class support vector machine for power quality problem classification," International Journal of Innovative Computing, Information and Control, Volume 8, Number 3(A), March 2012.

ISBN: 978-988-14049-4-7
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

[11] J. Kennedy and R. Eberhart, "Particle Swarm Optimization," In IEEE Int. Conf. Neural Networks, Vol. 4, 1995.
[12] C. Lin, A. Ting, C. Hsu, and C. Chung, "FPGA-based robust adaptive control of BLDC motors using fuzzy cerebellar modal articulation controller," International Journal of Innovative Computing, Information and Control, Volume 8, Number 5(A), May 2012.



(a)



(b)

Fig. 4. (a) Input signal, (b) Comparison between output response and estimated output response.

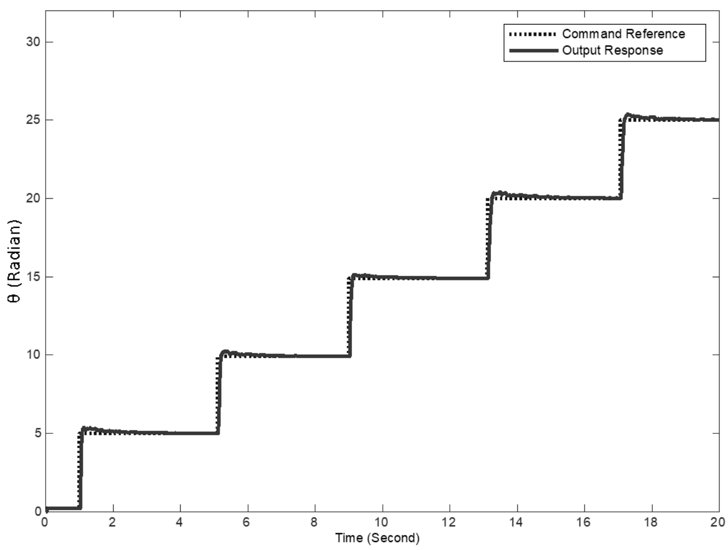
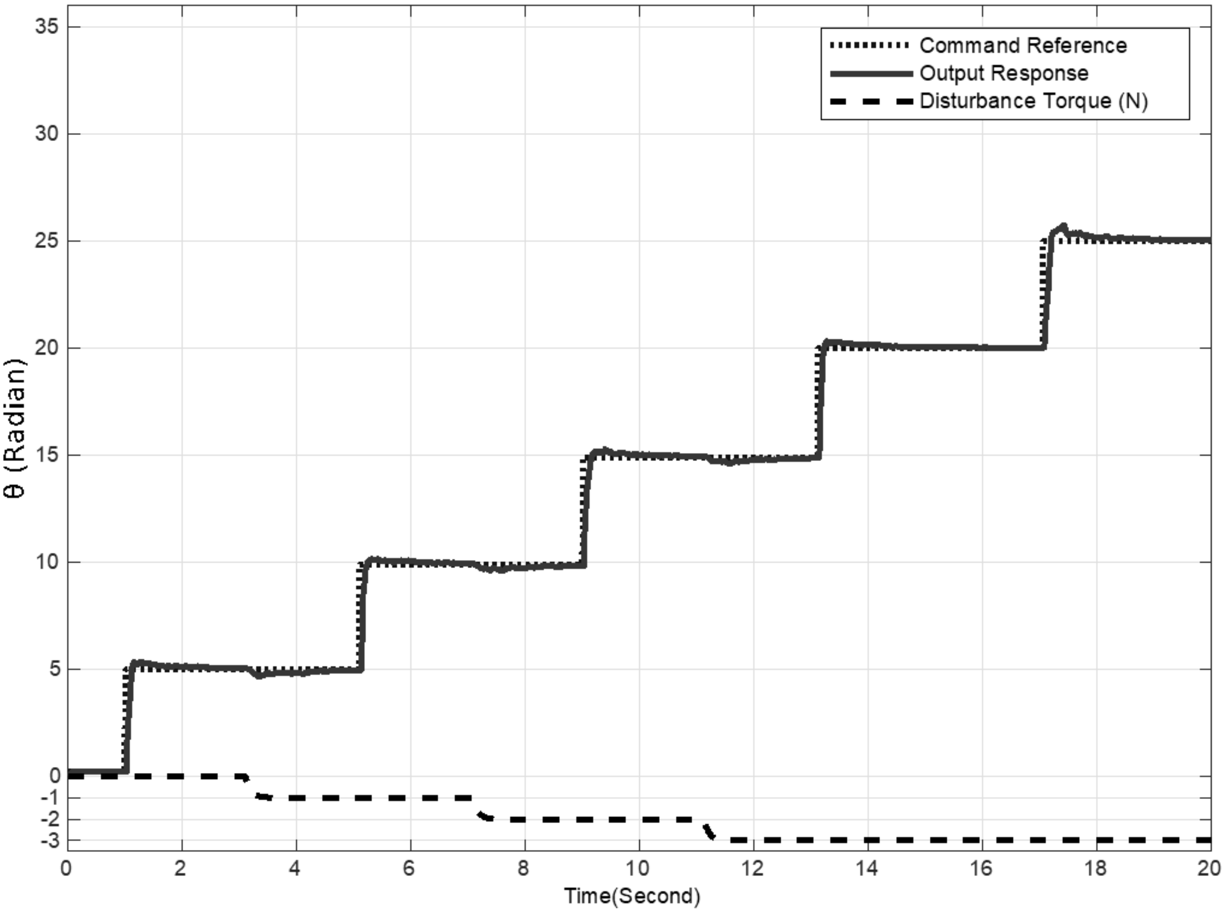
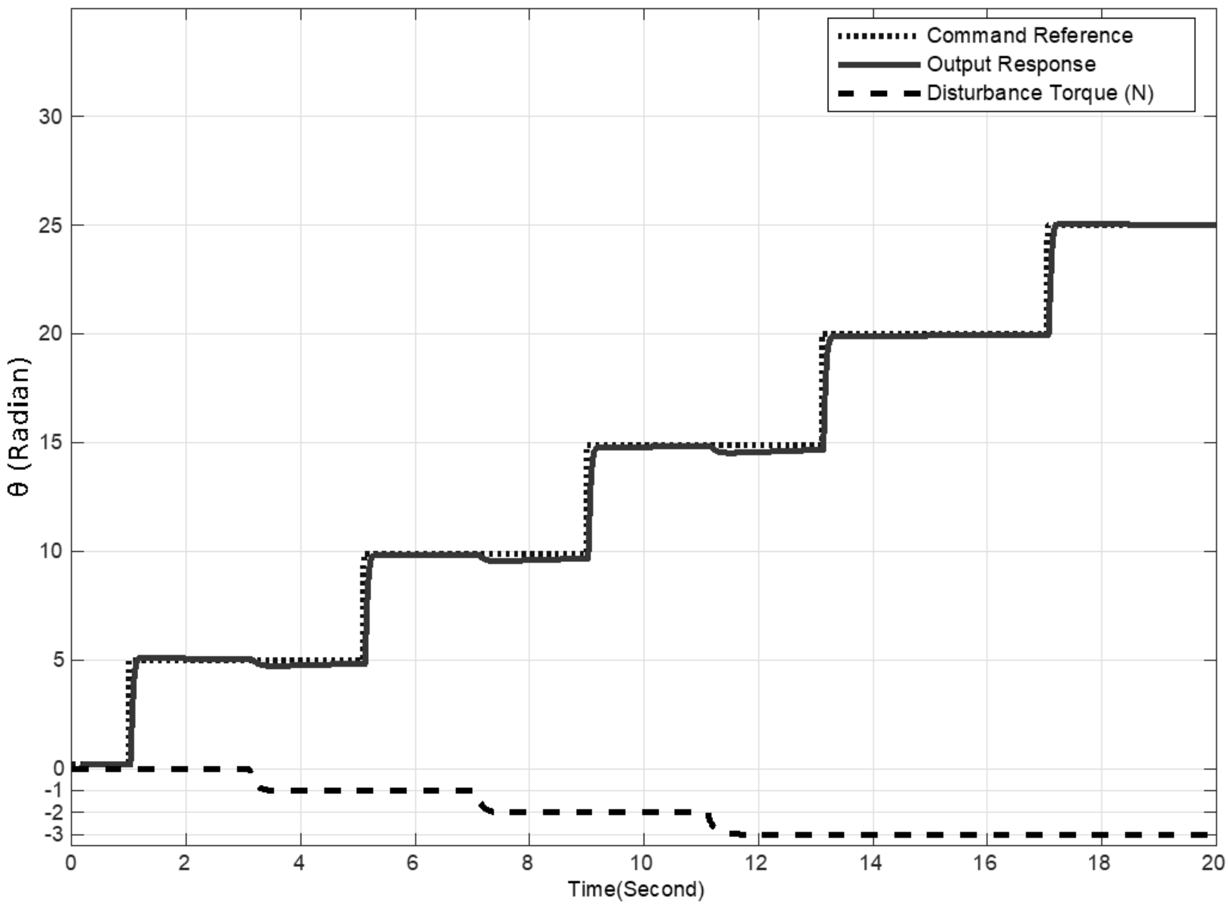


Fig. 5: Output response of the proposed online adaptive robust controller.

ISBN: 978-988-14049-4-7
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)



(a)



(b)

Fig. 6 Illustrates the output responses when applying the input torque disturbance, comparing (a) the proposed adaptive robust controller and (b) the non-adaptive robust controller.

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ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

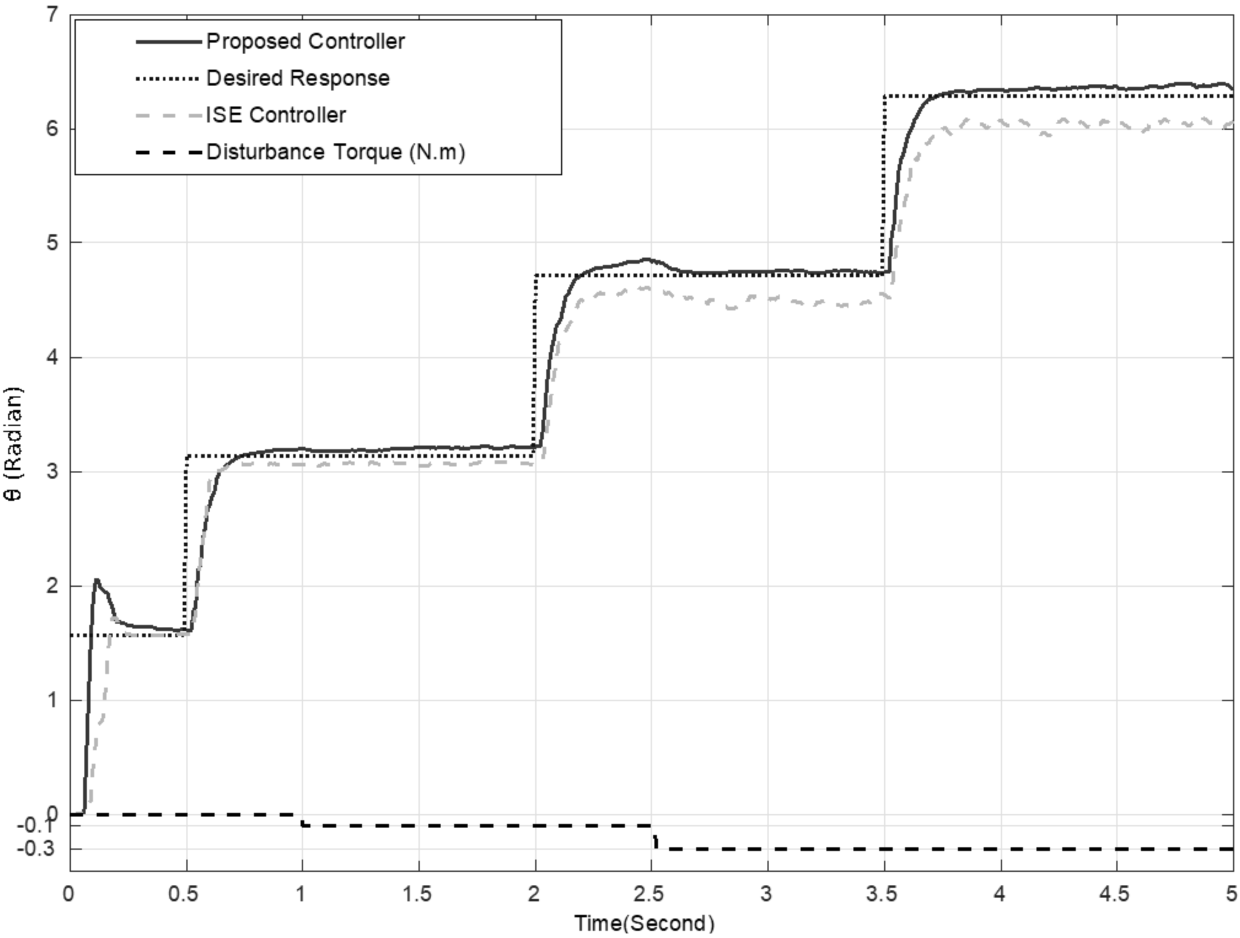

Fig. 7. A comparison between the adaptive controller based on the Integral of Square Error (ISE) method and the proposed controller.

ISBN: 978-988-14049-4-7
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)