International Journal of Engineering

Journal Homepage: www.ije.ir

RESEARCH NOTE

Development and Control of an upper Limb Rehabilitation Robot via Ant Colony Optimization -PID and Fuzzy-PID Controllers

N. Mirrashid[a], E. Alibeiki*[a], S. M. Rakhtala[b]

[a] *Department of Electrical Engineering, Aliabad Katoul Branch, Islamic Azad University, Aliabad Katoul, Iran*
[b] *Faculty of Engineering, Department of Electrical Engineering, Golestan University, Gorgan, Iran*

P A P E R I N F O

Paper history:
Received 17 August 2021
Received in revised form 11 March 2022
Accepted 15 March 2022

Keywords:
Rehabilitation Robot
Ant Colony Optimization Algorithm
Fuzzy-PID Controller
Ziegler-Nichols Method
PID Tuning

A B S T R A C T

The control of movement rehabilitation robots is necessary for the recovery of physically disabled patients and is an interesting open problem. This paper presents a mathematical model of the upper limb rehabilitation robot using Euler-Lagrange approach. Since the PID controller is one of the most popular feedback controllers in the control strategy due to its simplicity, we proposed an ACO-PID controller for an upper limb rehabilitation robot. The main part of designing the PID controller is determining the gains of the controller. For this purpose, we used Ant Colony Optimization Algorithm (ACO) to tune the coefficients. To evaluate the validity of the proposed controller, we have compared it to Fuzzy-PID controller and the PID controller adjusted with the Ziegler-Nichols method (ZN-PID). The results showed that the performance of the ACO-PID controller is better than the others. Also, the adaptive PID controllers (ACO-PID and Fuzzy-PID) ensure accurate tracking, finite-time convergence, and stability. The results showed that the mean absolute error and normalized root mean square (NRMS) of tracking error using the ACO-PID are less than that using the Fuzzy-PID and ZN-PID controller.

***doi**: 10.5829/ije.2022.35.08b.04*

1. INTRODUCTION

Today, the increasing number of stroke patients has increased the need for rehabilitation. A simple definition of rehabilitation is an increase in the ability of human muscles by doing certain movements frequently [1]. The traditional rehabilitation method is not effective due to the lack of hospital resources and trained therapist. Robots, as a new method, are useful tools to help patients in need of rehabilitation. Accurate tracking of desired motion by the robot requires a good control strategy [2]. One of the most popular controllers is the PID controller, which is used widely in various applications due to its simplicity and convenient operation. Piltan et al. [3] have used a feedback linearization compensator (FLC) to assist the PID controller performance in the presence of system uncertainty and concluded that the above compensator improves the performance of the classic PID controller. Widhiada et al. [4] have designed an advanced PID control with automatic adjustment for the multi-fingered robot hand. The purpose of the design was to achieve a fast steady-state response and reduce convergence time. They also showed that the system has a stable response under different inputs using a designed controller. A PID controller, using the PSO algorithm and the cuckoo search algorithm, has been tuned by Ayas et al. [5]. The proposed controller has been used to control the performance of the ankle rehabilitation robot with 2-degree of freedom. The results showed that the adjusted PID controller by intelligent algorithms has lesser tracking error than the classical PID. Ayas et al. [6] have compared a fuzzy logic controller with a PID controller to control the movement of an ankle rehabilitation robot. The boundary scales of the fuzzy controller membership functions are adjusted using the cuckoo search algorithm. Experimental results showed that the proposed fuzzy controller has about 50% less tracking error than the PID controller. A PID controller

*Corresponding Author Institutional Email: esmail_alibeiki@aliabadiau.ac.ir. (E. Alibeiki)

Please cite this article as: N. Mirrashid, E. Alibeikia, S. M. Rakhtala, Development and Control of an upper Limb Rehabilitation Robot via Ant Colony Optimization -PID and Fuzzy-PID Controllers, ***International Journal of Engineering, Transactions B: Applications***, Vol. 35, No. 07, (2022) 1488-1493

has been proposed to control the performance of the lower limb rehabilitation robot by Mohanta et al. [7], which have showed good accuracy in tracking the desired path. Cheng et al. [8] have developed a rehabilitation robot to perform flexion exercises of fingers with nine degrees of freedom. They have evaluated the performance of their rehabilitation robot with a PID controller and a combined controller of the active disturbance rejection control (ADRC) and the iterative learning control (ILC) and have achieved satisfactory results. Due to the highly nonlinear nature of the walking robot, Aldair et al. [9] have proposed a robust adaptive Fuzzy-ACO controller. Also, the stability of the proposed controller has been examined by the Lyapunov algorithm. Jiang et al. [10] have provided a Fuzzy-PID controller for precise tracking by the lower limb rehabilitation robot. The suggested controller test has shown high accuracy, smooth operation, and limited-time convergence. To some applications of the PID controller to control the rehabilitation robots, interested readers may refer to literature [11-16], to name a few. Other applications of fuzzy logic and optimization algorithms can be found in literature [17-21].

Dorigo et al. [22], using the behavior of ants to find food, have introduced the ant algorithm. For a comprehensive study about the ACO algorithm, we refer to literature [23, 24]. Now, by considering the non-linear nature of the upper limb rehabilitation robot system and the conditions of uncertainty and disturbances, the coefficients of the classic PID controller should be adjusted to ensure system stability and high tracking accuracy. In this paper, we use the ACO algorithm and fuzzy logic to adjust the coefficients of the adaptive PID controller. The organization of the paper is as follows. Section 2 is devoted to the dynamic modeling of a rehabilitation robot. In section 3, the controller is designed. Section 4 explains the ACO algorithm. The simulation results are given in Section 5. Finally, section 6 concludes the paper.

2. SYSTEM MODELING

By considering the Euler-Lagrange method [25], we know:

$$\frac{d}{dt}\left(\frac{\partial L(\delta,\dot{\delta})}{\partial \dot{\delta}}\right) - \frac{\partial L(\delta,\dot{\delta})}{\partial \delta} = \tau \,, \tag{1}$$

where δ is a joint position, $\dot{\delta}$ is time derivative of the position, τ is the driving torque from the servo motor, L represents lagrangian, and:

$$L(\delta(t),\dot{\delta}(t)) = K(\delta(t),\dot{\delta}(t)) - U(\delta(t)) \tag{2}$$

where K is kinetic energy and equal to $\frac{1}{2}m||v||^2 + \frac{1}{2}I\dot{\delta}^2$, $U = mgh$ is potential energy, m is the mass, ν is the angular velocity vector, and I is the inertia. The structure of an upper limb robot is shown in Figure . For the upper limb rehabilitation robot, we have:

$$X = \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} l_1\sin(\vartheta) + l_2\sin(\vartheta+\delta) \\ -\,l_1\cos(\vartheta) - l_2\cos(\vartheta+\delta) \end{bmatrix},$$

where X is a position vector, ϑ is a constant angle and $\delta \in \mathbb{R}$ is the position angle for the vertical axis, l_1 and l_2 are the lengths of link 1 and link 2, respectively. According to Equation (1), we developed the following expression:

$$(m_2 l_2^2)\ddot{\delta} + m_2 l_2 g \sin(\vartheta+\delta) = \tau - F_{ext}, \tag{3}$$

where $F_{ext}(\delta,\dot{\delta},t) \in \mathbb{R}$ is external forces as friction or disturbances:and considered as follow

$$\mathrm{F_{ext}}(\delta,\dot{\delta},\mathrm{t}) = \mathrm{f_c}\,\mathrm{sign}(\dot{\delta}) + \mathrm{f_v}\dot{\delta}\,, \tag{4}$$

where f_c is the coulomb-friction constant and f_v is the viscous friction coefficient. On the other hand, the actuator dynamics are equal to:

$$J_m\ddot{\delta} + \frac{1}{r}f_m(r\dot{\delta}) + \frac{K_aK_b}{R_a}\dot{\delta} + \frac{\tau}{r^2} = \frac{K_a}{rR_a}v\,, \tag{5}$$

where $J_m, f_m(r\dot{\delta}), K_a, K_b, R_a, r$ and$v(t)$ are, the inertia of the rotor, the friction between the rotor and its bearing, the motor-torque constant, the back emf constant, the armature resistance, the gears reduction ratio, the armature voltage and control input, respectively. Thus, the dynamic model of rehabilitation upper limb robot will be equal to [26]:

$$\left[\frac{1}{r^2}(m_2 l_2^2 + I_2) + J_m\right]\ddot{\delta} + \frac{1}{r}f_m(r\dot{\delta}) + \frac{m_2 l_2 g}{r^2}\sin(\vartheta + \delta) + \left[\frac{K_aK_b}{R_a} + \frac{F_v}{r^2}\right]\dot{\delta} + \frac{F_c}{r^2}sign(\dot{\delta}) = \frac{K_a}{rR_a}v\,. \tag{6}$$

3. TRAJECTORY TRACKING CONTROL FOR THE UPPER LIMB REHABILITATION ROBOT

3. 1. The ZN-PID Controller Design

The block diagram of the PID controller is shown in Figure 2 and it presents the following equation:

$$U(t) = K_p e(t) + K_i \int_0^t e(\tau)\partial\tau + K_d \frac{de(\tau)}{d\tau} \tag{7}$$

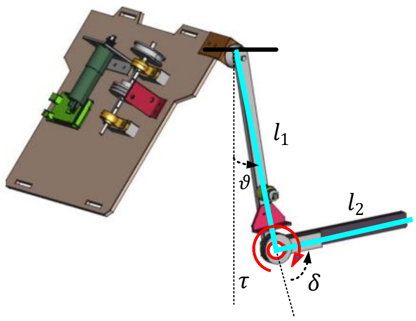

Figure 1. Structure of an upper limb robot

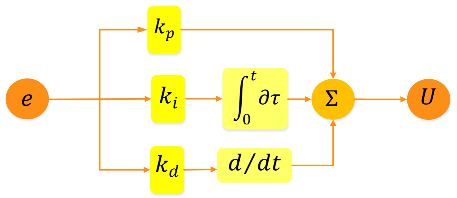

Figure 2. Structure of PID controller

where $U(t)$ is control input, K_p is proportional parameter, K_i delegates integral gain, K_d is derivative constant, and e(t) is the tracking error as $e = \delta_d - \delta$. To tune the coefficients of ZN-PID, one can use the Ziegler-Nichols formula as follows [27]:

$$K_p = 0.6K_u \,,\; K_i = \frac{2K_p}{T_u} \,,\; K_d = \frac{K_pT_u}{8} \tag{8}$$

where K_u and T_u are the Critical gain and the oscillation period, respectively.

3. 2. The Fuzzy-PID Controller Design

In this section, the gains of the Fuzzy-PID controller are adapted based on the fuzzy rules. Figure 1 depicts the block diagram of the Fuzzy-PID controller.

Suppose $[K_{p,min}, K_{p,max}]$ and $[K_{d,min}, K_{d,max}]$ are the bounds of $K_p$and K_d, respectively [27]; and

$$K_{p,min} = 0.32K_u, \quad K_{p,max} = 0.6K_u, \quad K_{d,min} = 0.08K_uT_u, \; K_{d,max} = 0.15K_uT_u$$

The coefficients of Fuzzy-PID controller are

$$K_p = K_{p,min} + K'_p(K_{p,max} - K_{p,min}) \tag{9}$$

$$K_d = K_{d,min} + K'_d(K_{d,max} - K_{d,min}) \tag{10}$$

$$K_i = {K_p}^2/\alpha K_d, \tag{11}$$

where $K'_p, K'_d \in [0,1]$, and $\alpha \in [2,5]$ are obtained outputs from fuzzy logic controller by the fuzzy rules with following form [27]:

if $e(k)$ is A_i and $\Delta e(k)$ is B_i, then K'_p is C_i, K'_p is D_i , and $\alpha = \alpha_i$, where $i = 1, 2, \dots, m$.

The fuzzy sets A_i and B_i are depicted in Figure 2 (a), and the fuzzy sets C_i and D_i are shown in Figure 2 (b) and α_i is constant (Figure 2 (c)). Where ZO, S, M, B, N, and P are zero, small, medium, big, and negative, positive, respectively.

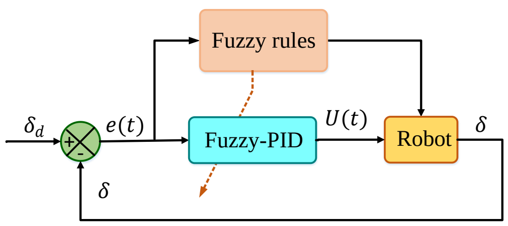

Figure 1. Block diagram of the closed-loop system for Fuzzy-PID

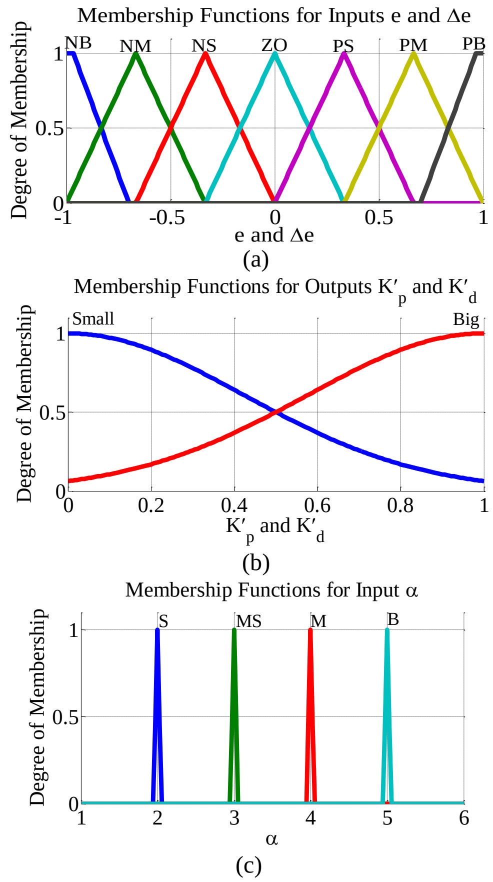

Figure 2. Membership functions of: (a) Inputs (e and Δe), (b) Outputs (K'_p and K'_d), (c) output (α)

3. 3. The ACO-PID Controller Design

We use the ACO algorithm to find the optimal values of the PID controller gains. Figure shows the block diagram of the closed-loop system for the ACO-PID.

The flow chart of the ACO algorithm follows from Figure . The ant algorithm optimization method is as follows:

1. First, we consider some ants. Then for each ant, a path that lacks a pheromone is randomly assigned to look for food. The intersections of the trajectories are also determined.
2. Ants mark the path to food by pheromone on the way back to the nest. Each intersection that has more pheromones (more ants have passed through it) attracts more ants.
3. The shortest path to food has more pheromones due to the faster return of ants to the nest and movement in the previous path. At the same time, the pheromones of the other pathways evaporate over time, and eventually, large numbers of ants converge toward the shorter pathway.
4. One can calculate the concentration of pheromone at time t by $\emptyset(t) = \emptyset_0 e^{-\gamma t}$, where $\emptyset_0$ and γ are the initial

focus of the pheromone and constant rate of pheromone evaporation. This amount is updated in the next iterations as $\emptyset_{ij}^{t+1} = (1-\gamma)\emptyset_{ij}^{t} + \alpha\emptyset_{ij}^{t}$ (if there is no ant left in the path, the amount of pheromone will be zero), where $\alpha\emptyset_{ij}^{t}$ is the amount of pheromone stored in time t for the i to j path.

The cost function (C_F) is defined as integral time absolute error (ITAE):

C_F=$\int_0^\infty$ t|e(t)|dt,

where $e(t) = \delta_d - \delta$.

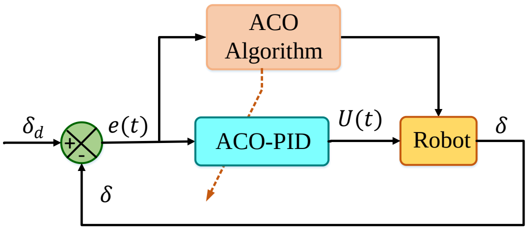

Figure 5. Block diagram of the closed-loop system for ACO-PID

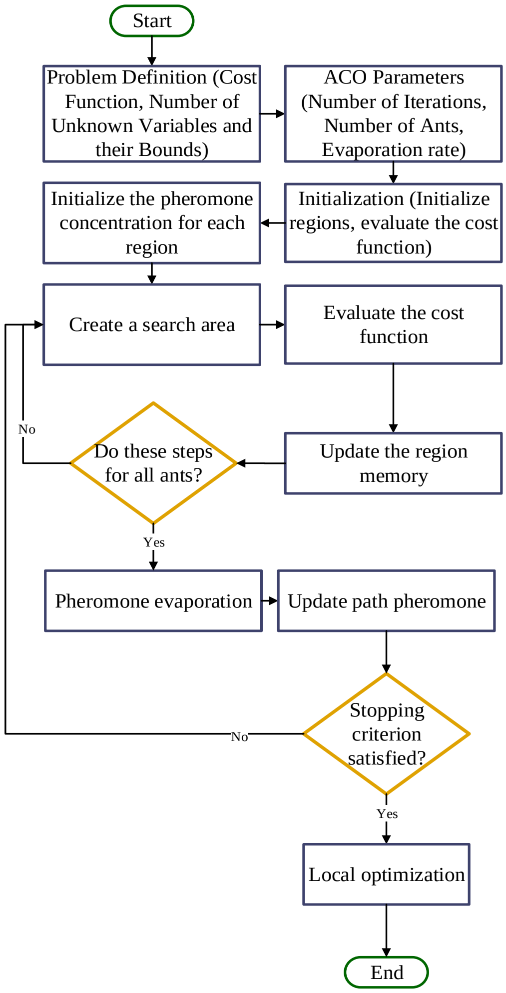

Figure 6. The flow chart of the ACO algorithm

4. RESULT AND DISCUSSION

The relationship for the desired path and velocity of tracking are given as follows.

$$\delta_d = sin(2\pi ft) + 1 \tag{12}$$

$$\dot{\delta}_d = 2\pi f cos(2\pi ft) \tag{13}$$

System velocity and acceleration ranges are [28]:

$-2\frac{rad}{s} < \dot{\delta}_d < 2\frac{rad}{s}$, $-10\frac{rad}{s^2} < \ddot{\delta}_d < 10\frac{rad}{s^2}$

Figures 7 and 8 show the desired and measured position (δ) trajectories and the measured velocity ($\dot{\delta}$) by applying the controllers, respectively. One can see from Figures 7 and 8, the adjusted gains using the fuzzy logic cause a good performance for the PID controller. The tracking is accurate, and the tracking error is small. Also, the convergence time for the Fuzzy-PID controller is shorter than the others. The position error in radians is illustrated in Figure 9.The convergence rate for the ACO-PID cost function shows in Figure 10. It is clear from the figure the best value of the cost function is 1.78 which is happened in iteration 47.

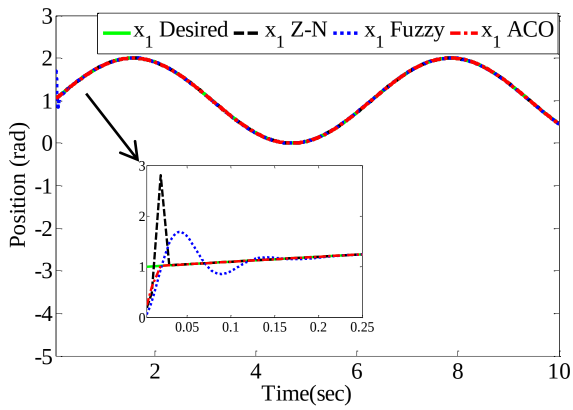

Figure 3. The measured and the desired elbow position trajectories

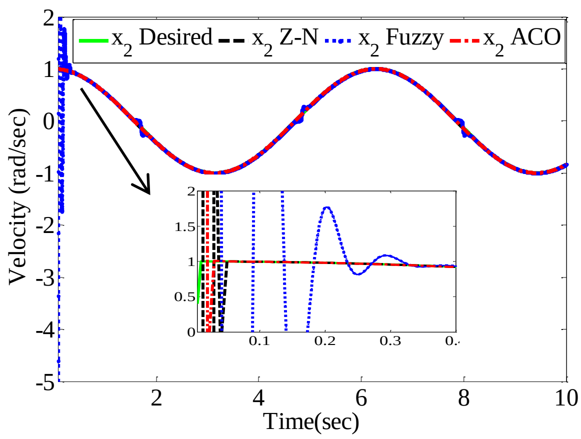

Figure 4. The measured and the desired elbow velocity trajectories

Some statistical indices corresponding to the error, such as mean absolute error (MAE), root mean square error (RMS), and normalized root mean square error (NRMS), are summarized in TABLE as follows:

$$\mathrm{MAE(rad)} = \frac{\sum_{i=1}^{n}|e_i|}{n} \tag{14}$$

$$\mathrm{RMS(rad)} = \sqrt{\frac{\sum_{i=1}^{n}|e_i|}{n}} \tag{15}$$

$$\mathrm{NRMS(\%)} = \frac{RMS}{\max(\delta_d)-\min(\delta_d)} \tag{16}$$

In the case of uncertainty, we change the system parameters values between 5 and 10%.

TABLE 1. RMS, NRMS, and MAE of controllers

	ZN-PID	Fuzzy-PID	ACO-PID
Nominal conditions			
MAE(rad)	0.0033	0.0021	0.0014
RMS(rad)	0.0668	0.0447	0.0341
NRMS(%)	3.3387	2.2366	1.7036
Uncertainties			
	ZN-PID	**Fuzzy-PID**	**ACO-PID**
MAE(rad)	0.0034	0.0023	0.0015
RMS(rad)	0.0687	0.0452	0.0357
NRMS(%)	3.4259	2.2604	1.7847

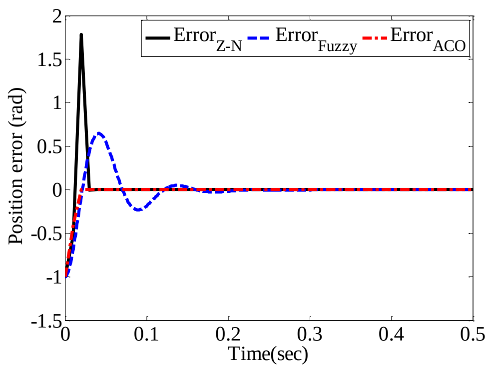

Figure 5. The position error

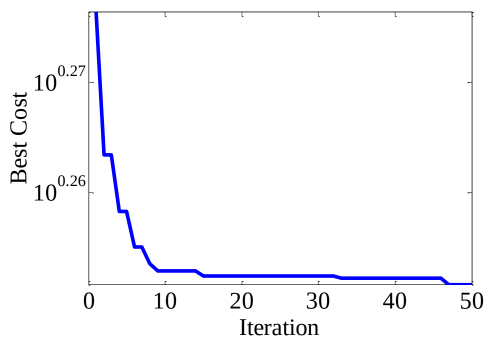

Figure 10. The convergence rate for ACO-PID cost function

5. CONCLUSION

In this paper, three controllers, ACO-PID, Fuzzy-PID, and ZN-PID, were designed to control the movement of the arm rehabilitation robot. The simulation results showed that the PID controller adjusted by the Ziegler-Nichols method, in addition to slowing down the convergence, has lower detection accuracy than the adaptive controllers (ACO-PID and Fuzzy-PID). Also, the ACO-PID controller converged to the desired path earlier than the other controllers and had higher tracking accuracy. To better evaluate the proposed controllers, the statistical comparison indices such as MAE, RMS, and NRMS reported. By analyzing the results, one can conclude that an adaptive PID controller (ACO-PID and Fuzzy-PID), while simple, can accurately track the movement of the upper limb rehabilitation robot.

6. REFERENCES

1. Zhang, K., "The design and realization of a gait rehabilitation training robot with body supporting mechanism", ***International Journal of Engineering, Transactions C: Aspects***, Vol. 29, No. 9, (2016), 1314-1318, doi: 10.5829/idosi.ije.2016.29.09c.18.
2. Zawawi, M.Z.F.B.M., Elamvazuthi, I., Aziz, A.B.A. and Daud, S.A., "Comparison of pid and fuzzy logic controller for dc servo motor in the development of lower extremity exoskeleton for rehabilitation", in 2017 IEEE 3rd International Symposium in Robotics and Manufacturing Automation (ROMA), IEEE. (2017), 1-6, doi: 10.1109/ROMA.2017.8231822.
3. Piltan, F., Emamzadeh, S., Heidari, S., Zahmatkesh, S. and Heidari, K., "Design artificial intelligent parallel feedback linearization of pid control with application to continuum robot", ***International Journal of Engineering and Manufacturing***, Vol. 3, No. 2, (2013), 51-72, doi: 10.5815/ijem.2013.02.04.
4. Widhiada, W., Nindhia, T. and Budiarsa, N., "Robust control for the motion five fingered robot gripper", ***International Journal of Mechanical Engineering and Robotics Research***, Vol. 4, No. 3, (2015), 226, doi: 10.18178/ijmerr.4.3.226-232.
5. Ayas, M.S., Altas, I.H. and Sahin, E., "Fractional order based trajectory tracking control of an ankle rehabilitation robot", ***Transactions of the Institute of Measurement and Control***, Vol. 40, No. 2, (2018), 550-564, doi: 10.1177/0142331216667810.
6. Ayas, M.S. and Altas, I.H., "Fuzzy logic based adaptive admittance control of a redundantly actuated ankle rehabilitation robot", ***Control Engineering Practice***, Vol. 59, (2017), 44-54, doi: 10.1016/j.conengprac.2016.11.015.
7. Mohanta, J.K., Mohan, S., Deepasundar, P. and Kiruba-Shankar, R., "Development and control of a new sitting-type lower limb rehabilitation robot", ***Computers & Electrical Engineering***, Vol. 67, (2018), 330-347, doi: 10.1016/j.compeleceng.2017.09.015.
8. Cheng, L., Chen, M. and Li, Z., "Design and control of a wearable hand rehabilitation robot", ***IEEE Access***, Vol. 6, (2018), 74039-74050, doi: 10.1109/ACCESS.2018.2884451.
9. Aldair, A.A., Rashid, A.T., Rashid, M.T. and Alsaedee, E.B., "Adaptive fuzzy control applied to seven-link biped robot using ant colony optimization algorithm", ***Iranian Journal of Science and Technology, Transactions of Electrical Engineering***, Vol. 43, No. 4, (2019), 797-811, doi: 10.1007/s40998-019-00201-x.
10. Jiang, D., Shi, G., Pang, Z., Li, S. and Tian, Y., "Control of a new cycling rehabilitation robot based on fuzzy pid", in Journal of

Physics: Conference Series, IOP Publishing. Vol. 1622, (2020), 012119, doi:10.1088/1742-6596/1622/1/012119.

11. Awouda, A. and Mamat, R., "New pid tuning rule using itae criteria", ***International Journal of Engineering***, Vol. 3, No. 6, (2008), 597-608, doi: 10.1109/ICCAE.2010.5451484.
12. Kang, H.-B. and Wang, J.-H., "Adaptive robust control of 5 dof upper-limb exoskeleton robot", ***International Journal of Control, Automation and Systems***, Vol. 13, No. 3, (2015), 733-741, doi: 10.1007/s12555-013-0389-x.
13. Pastor, S., Rivera, C., Avilés, O. and Mauledoux, M., "A real-time motion tracking wireless system for upper limb exosuit based on inertial measurement units and flex sensors", ***International Journal of Engineering, Transactions C: Aspects***, Vol. 32, No. 6, (2019), 820-827, doi: 10.5829/ije.2019.32.06c.04.
14. Saadat, M. and Garmsiri, N., "A new intelligent approach to patient-cooperative control of rehabilitation robots", ***International Journal of Engineering, Transactions C: Aspects***, Vol. 27, No. 3, (2014), 467-474, doi: 10.5829/idosi.ije.2014.27.03c.15.
15. Shen, Z., Zhuang, Y., Zhou, J., Gao, J. and Song, R., "Design and test of admittance control with inner adaptive robust position control for a lower limb rehabilitation robot", ***International Journal of Control, Automation and Systems***, Vol. 18, No. 1, (2020), 134-142, doi: 10.1007/s12555-018-0477-z.
16. Wang, S., Yin, X., Li, P., Zhang, M. and Wang, X., "Trajectory tracking control for mobile robots using reinforcement learning and pid", ***Iranian Journal of Science and Technology, Transactions of Electrical Engineering***, Vol. 44, No. 3, (2020), 1059-1068, doi: 10.1007/s40998-019-00286-4.
17. Maurya, R.K. and Bhowmick, B., "Review of finfet devices and perspective on circuit design challenges", ***Silicon***, (2021), 1-9, doi: 10.1007/s12633-021-01366-z.
18. Qazani, M.R.C., Asadi, H., Khoo, S. and Nahavandi, S., "A linear time-varying model predictive control-based motion cueing algorithm for hexapod simulation-based motion platform", ***IEEE Transactions on Systems, Man, and Cybernetics: Systems***, Vol. 51, No. 10, (2019), 6096-6110, doi: 10.1109/TSMC.2019.2958062.
19. Qazani, M.R.C., Asadi, H., Mohamed, S., Lim, C.P. and Nahavandi, S., "An optimal washout filter for motion platform using neural network and fuzzy logic", ***Engineering Applications of Artificial Intelligence***, Vol. 108, No., (2022), doi: 104564, 10.1016/j.engappai.2021.104564.
20. Shaik, S., "A coplanar wave guide fed compact antenna for navigational applications", ***National Journal Of Antennas and Propagation***, Vol. 2, No. 1, (2020), 7-12, doi: 10.31838/NJAP/02.01.02.
21. Srinivasareddy, D.S., Narayana, D.Y. And Krishna, D.D., "Sector beam synthesis in linear antenna arrays using social group optimization algorithm", ***National Journal of Antennas And Propagation***, Vol. 3, No. 2, (2021), 6-9, doi: 10.31838/NJAP/03.02.02.
22. Colorni, A., Dorigo, M. and Maniezzo, V., "An investigation of some properties of an" ant algorithm"", in Ppsn. Vol. 92, (1992), doi: 10.1109/3477.484436.
23. De Oliveira, S.M., Bezerra, L.C., Stützle, T., Dorigo, M., Wanner, E.F. and de Souza, S.R., "A computational study on ant colony optimization for the traveling salesman problem with dynamic demands", ***Computers & Operations Research***, (2021), 105359, doi: 10.1016/j.cor.2021.105359.
24. Fidanova, S. and Fidanova, S., "Ant colony optimization", ***Ant Colony Optimization and Applications***, (2021), 3-8, doi: 10.1007/978-3-030-67380-2_2.
25. Rosales, Y., Lopez, R., Rosales, I., Salazar, S. and Lozano, R., "Design and modeling of an upper limb exoskeleton", in 2015 19th International Conference on System Theory, Control and Computing (ICSTCC), IEEE. (2015), 266-272, doi: 10.1109/ICSTCC.2015.7321304.
26. Mirrashid, N., Alibeiki, E. and Rakhtala, S.M., "Nonlinear robust controller design for an upper limb rehabilitation robot via variable gain super twisting sliding mode", ***International Journal of Dynamics and Control***, (2022), doi: 10.1007/s40435-021-00902-4.
27. Hang, C.C., Åström, K.J. and Ho, W.K., "Refinements of the ziegler–nichols tuning formula", in IEE Proceedings D (Control Theory and Applications), IET. Vol. 138, (1991), 111-118, doi: 10.1049/ip-d.1991.0015.
28. Mefoued, S., "A second order sliding mode control and a neural network to drive a knee joint actuated orthosis", ***Neurocomputing***, Vol. 155, (2015), 71-79, doi: 10.1016/j.neucom.2014.12.047.

Persian Abstract

چکیده

کنترل حرکت ربات‌های توانبخشی برای بهبود بیماران ناتوان جسمی ضروری و یک مسئله مورد علاقه است. در این مقاله یک مدل ریاضی از ربات توانبخشی اندام فوقانی با استفاده از رویکرد اویلر-لاگرانژ ارائه شده است. از آنجا که کنترل‌کننده PID به دلیل سادگی یکی از محبوب‌ترین کنترل‌کننده‌های بازخورد در استراتژی کنترل است، یک کنترل‌کننده ACO-PID برای کنترل ربات توانبخشی اندام فوقانی پیشنهاد می‌کنیم. بخش اصلی طراحی کنترل‌کننده PID تعیین بهره‌های کنترل‌کننده است. برای این منظور، از الگوریتم بهینه سازی کلونی مورچه‌ها (ACO) برای تنظیم ضرایب استفاده می‌کنیم. اعتبار کنترل‌کننده پیشنهادی با مقایسه آن با کنترل‌کننده ACO-PID و کنترل‌کننده PID تنظیم شده با روش زیگلر-نیکولز (ZN-PID) ارزیابی می‌شود. نتایج نشان می‌دهد که عملکرد کنترل‌کننده ACO-PID بهتر از کنترل‌کننده Fuzzy-PID و کنترل‌کننده ZN-PID است. همچنین، کنترل‌کننده‌های تطبیقی PID (Fuzzy-PID و ACO-PID) ردیابی دقیق، همگرایی زمان محدود و ثبات را تضمین می‌کنند. نتایج نشان می‌دهد که میانگین مربع نرمال خطای ردیابی (NRMS) با استفاده از ACO-PID کمتر از حالتی است که از کنترل‌کننده Fuzzy-PID و ZN-PID استفاده می‌شود.