International Journal of Mechanical Engineering and Robotics Research Vol. 11, No. 9, September 2022

Fractional Order Integral Sliding Mode Tracking Control of a Third-Order Double-Acting Electrohydraulic Actuator Model

Muhammad Fadli Ghani
Malaysian Institute of Marine Engineering Technology (MIMET), Universiti Kuala Lumpur, Lumut, Perak, Malaysia
Email: muhamadfadli@unikl.edu.my

Rozaimi Ghazali and Hazriq Izzuan Jaafar
Centre for Robotics and Industrial Automation, Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100, Durian Tunggal, Melaka, Malaysia
Email: {rozaimi.ghazali, hazriq}@utem.edu.my

Chong Chee Soon
Department of Engineering and Built Environment, Tunku Abdul Rahman University College, Penang Branch Campus
Email: chongcs@tarc.edu.my

Yahaya Md. Sam
Department of Control and Mechatronics Engineering, School of Electrical Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia
Email: yahaya@fke.utm.edu.my

Zulfatman Has
Electrical Engineering Department, University of Muhammadiyah Malang, 65144 Malang, Indonesia
Email: zulfatman@umm.ac.id

***Abstract*—This article presents a fractional order integral sliding mode control method for tracking control of sinusoidal, multi-sinusoidal, and chaotic trajectories in an Electro-Hydraulic Actuator (EHA) system. To acquire the proposed controller, the linear model of the EHA system is determined utilizing the parametric identification method, and the model's parameters are estimated utilizing the MATLAB System Identification toolbox. Incorporating a fractional order integral sliding surface into the conventional sliding mode control algorithm yields a fractional order integral sliding mode controller. Using Lyapunov's theory of stability, the closed-loop system with the proposed controller is evaluated for its stability. Through simulation, the control output of the tracking control system was acquired in order to assess the performance of the trajectory tracking control. The results demonstrate that the proposed controller outperforms the conventional sliding mode controller in trajectory tracking control.**

***Index Terms*— fractional order integral sliding mode tracking control, electrohydraulic actuator, particle swarm optimization**

I. INTRODUCTION

Electro-Hydraulic Actuator (EHA) systems are particularly practical and trustworthy owing to their small size in comparison to their power, their tremendous force-producing capabilities, and their rapid response times [1]–[3]. These properties make them particularly well-suited for use in construction equipment, which is sometimes referred to as mobile hydraulic machines [4]–[7]. The EHA system is recognized to be a nonlinear system with significant uncertainty due to the servo valve's high-frequency behaviour and external disturbances [8]–[11]. As a result, controller design for the EHA system can be difficult because of its uncertainty, nonlinearity, and disturbances.

Researchers and scientists are always on the lookout for more effective techniques to govern nonlinear complex systems. For almost seven decades, linear proportional integral and derivative controllers (PID) have been employed to regulate large plants [8], [12], but they have consistently failed to provide satisfying results for nonlinear, time-varying, uncertain, and complex systems.

Numerous classical nonlinear controllers are available, including gain scheduling [13], model reference adaptive control (MRAC) [14], self-tuning regulator (STR) [15], [16], and sliding mode controller (SMC) [17]–[23]. The sliding mode controller is one of these control systems that has gained considerable popularity among academics and

---

Manuscript received June 1, 2022; revised August 1, 2022.

doi: 10.18178/ijmerr.11.9.669-675

scientists due to its robust nature. SMCs are a subclass of variable structure controllers whose core design is based on Lyapunov stability theory, ensuring the overall system's bounded input and bounded output stability [24]. It is a high-gain controller in which the output of the system rapidly reaches the sliding surface and attempts to retain its place on it.

Despite decades of study about SMC, important technical issues such as the consequences of un-modelled dynamics, parameter uncertainty, chattering, and adaptive behaviour have attracted researchers and scientists. To address these issues, SMC included quick oscillations in the controller output, which may cause damage to the system's final control element [25]. To solve these issues, many technological systems have been devised and are included in the conventional SMC. Conventional variable order control methods and intelligent procedures are now being used together in a new trend [26].

Therefore, this paper explains the effort involved in developing a fractional order integral sliding mode controller (FOISMC) by modifying the sliding surface in the conventional SMC algorithm for a third-order double-acting EHA model. To demonstrate the proposed control method's effectiveness, its performance is simulated and compared with that of the conventional SMC controller.

The following summarizes the paper's contributions: a) FOISMC was designed and shown to be an effective controller; and b) the proposed controller's optimized variables are designed using the particle swarm optimization (PSO) approach.

The rest of this paper will be structured as follows: Section 2 discusses the theory and definition of fractional calculus. Additionally, Section 3 discusses the EHA's system identification model and the design of the associated controller utilizing the PSO technique. Section 4 discusses and evaluates the simulation's results. Section 5 presents a conclusion based on the acquired findings.

II. THEOREM AND DEFINITION OF FRACTIONAL CALCULUS

In the scientific and/or engineering community, fractional calculus has a three-century history but is largely unknown. The topic has been related to mathematicians for three centuries, but it has only recently been associated with engineering, physics, and economics. As reported in [27], the basic operator in fractional calculus is (1), where a, t, and r represent the operation's limit order and common real number, respectively. The generic fractional difference integral has three definitions: Grunwald-Letnikov (2), Riemann-Liouville (3), and Caputo (4) for $n-1<r<n$.

$$ {}_{\mathrm{a}}D_t^r = \begin{cases} \dfrac{d^r}{dt^r} & for\, r>0 \\ 1 & for\, r=0 \\ \displaystyle\int_{\mathrm{a}}^{t} (d\tau)^{-r} & for\, r<0 \end{cases} \tag{1} $$

$$ {}_{\mathrm{a}}D_t^r f(t) = \lim_{h\to 0} h^{-r} \sum_{j=0}^{\frac{t-a}{h}} (-1)^j \binom{r}{j} f(t-jh) \tag{2} $$

$$ {}_{\mathrm{a}}D_t^r f(t) = \frac{1}{\Gamma(n-r)} \frac{d^n}{dt^t} \int_a^t \frac{f(\tau)}{(t-\tau)^{r-n+1}} d\tau \tag{3} $$

$$ {}_{\mathrm{a}}D_t^r f(t) = \frac{1}{\Gamma(r-n)} \int_a^t \frac{f^n(\tau)}{(t-\tau)^{r-n+1}} d\tau \tag{4} $$

III. METHODOLOGY

A. System Identification and Experimental Setup of EHA System

System identification involves modeling of the EHA system with prior knowledge by physical-based modeling and utilizing of input and output data which obtained through open-loop real-time experiment. In 2000, Knohl and Unbehauen explained in [30] regarding physical-based modeling for the EHA system presented in Fig. 1 by ignoring nonlinearities and producing a model structure based on a continuous transfer function as shown in (5) with three parameters: a_1, a_2, and a_3, where x_p and u, are system output and input, respectively [8][28].

$$ \frac{X_p(s)}{U(s)} = \frac{a_1}{s(s^2+a_2 s+a_3)} \qquad \dddot{x}_p = a_1 u - a_2 \ddot{x}_p - a_3 \dot{x}_p \tag{5} $$

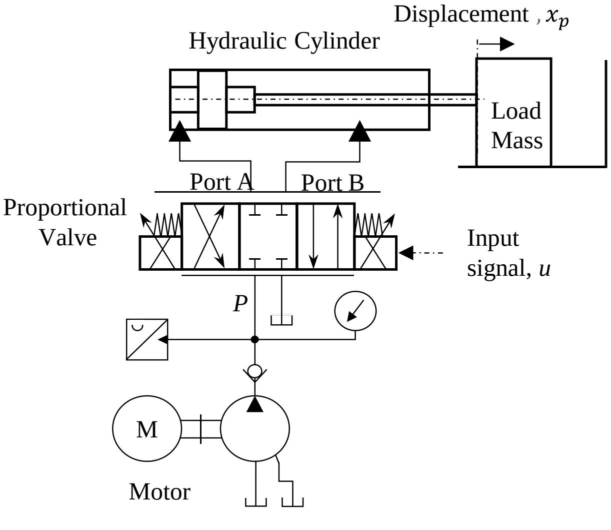

Figure 1. Schematic diagram of the EHA system.

Additionally, a linear model is adequate for tracking control with advanced control strategies to achieve high performance of an EHA system in trajectory tracking applications, and the linear model of an EHA system is frequently valid over a relatively broad range [29]. In addition, the parameters of the model in (5) were estimated using the MATLAB System Identification toolbox.

The experimental workbench for the EHA system, depicted in Fig. 2, was used to collect time domain input-output data. The EHA system workbench consists of a real-time control system based on MATLAB/Simulink and PCIe-6321, a moving cylinder, and a hydraulic power supply with an 8 MPa supply pressure and a 16.6 L/min flow capacity. The hydraulic cylinder has a bore of 40 mm and a rod of 25 mm. It is governed by a proportional directional valve that has a maximum flow rate of 80 L/min and a maximum supply pressure of 31.5 MPa. Real-time cylinder displacement is measured using a wire displacement sensor.

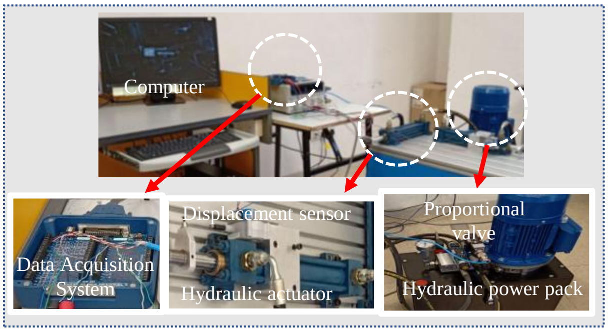

Figure 2. EHA system workbench

Fig. 3 illustrates in physical detail the EHA system's experimental mechanism.

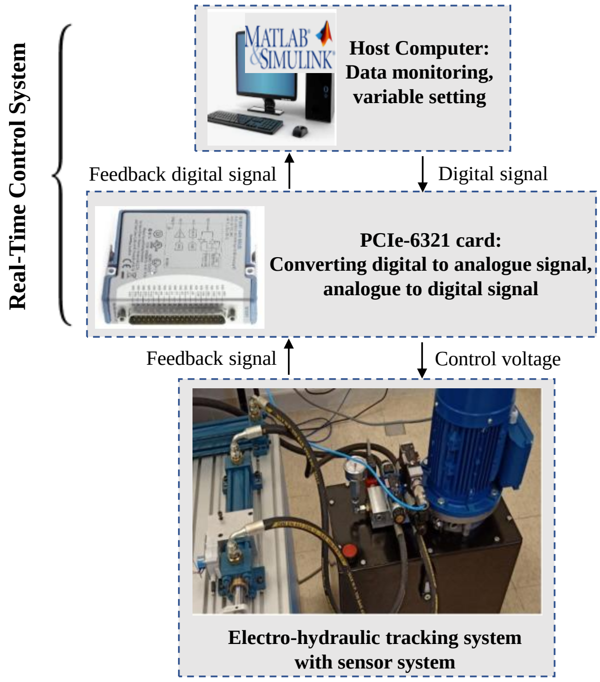

Figure 3. Experimental diagram for the EHA system workbench.

The control hardware includes a host computer, a PCIe-632116-bit A/D and D/C card for obtaining sensor signals and transferring control signals, and several other devices. The host computer connects with the PCIe-6321 card and acts as the operator interface for human-computer interaction. MATLAB/Simulink is used to program and run the open-loop experiment, and the sampling rate for the experimental system has been set to 1 kHz.

B. Controller Design

In the early 1960s, SMC was created as a variable-structure control. The most crucial step in SMC design is the construction of the sliding surface mathematical equation. The illustration of the error signal (e) is shown in Fig. 4, and the equation (6) identifies e and its third-order derivative, where r and xp are the reference input and piston displacement signals, respectively.

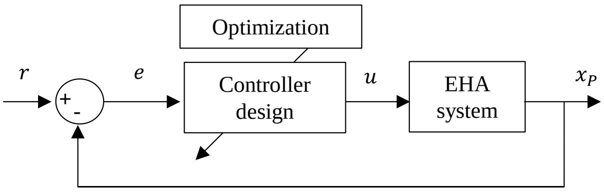

Figure 4. The controller's block diagram.

The system is established to be a third-order system for the current development effort on the proposed controller. The proposed fractional integral (I^{α}) sliding surface is defined in (7), where $D^{-\alpha}$ is a fractional integration of order α and n is the system order. The derivative of (7) is represented in (8). By letting α = 1, the sliding surface for conventional SMC can be formed. When a reaching law is implemented, the system's output is compelled to follow the surface being considered. The reaching law must be constructed in such a way that it satisfies certain requirements in order to maintain the closed loop system's stability. This study makes use of the constant rate of reaching law stated in (9). The FOISMC's output control signal is created as in (10).

$$e = r - x_p, \qquad \dddot{e} = \dddot{r} - \dddot{x}_p \tag{6}$$

$$\begin{aligned} s = \left(\lambda + \frac{d}{dt}\right)^{n-1} & e + k_i D^{-\alpha} e \\ & = \lambda^2 e + 2\lambda \dot{e} + \ddot{e} \\ & + k_i D^{-\alpha} e, 0 < \alpha \\ & < 1.4 \end{aligned} \tag{7}$$

$$\begin{aligned} \dot{s} = \lambda^2 \dot{e} + 2\lambda \ddot{e} + \dddot{r} - a_1 u + a_2 \ddot{x}_p \\ + a_3 \dot{x}_p + k_i D^{-\alpha} \dot{e} \end{aligned} \tag{8}$$

$$\begin{aligned} & \dot{s} = -\epsilon sign(s), \epsilon > 0, \\ & \qquad sign(s) = \begin{cases} 1, & s > 0 \\ 0, & s = 0 \\ -1, & s < 0 \end{cases} \end{aligned} \tag{9}$$

$$\begin{aligned} u = \frac{1}{a_1} (\lambda^2 \dot{e} + 2\lambda \ddot{e} + \dddot{r} + a_2 \ddot{x}_p + a_3 \dot{x}_p \\ + k_i D^{-\alpha} \dot{e} \\ + \epsilon sign(s)) \end{aligned} \tag{10}$$

C. Stability Analysis

The primary objective of the controller design is to guarantee that the feedback control system operates continuously in a steady manner. According to the Lyapunov stability theorem, when condition $s\dot{s} < 0$ is met, the whole system becomes stable and approaches the sliding surface. The Lyapunov function (11) is used in this paper with the constraint that $V(0) = 0$ and $V(t) > 0$ for $s \neq 0$. To ensure that the trajectory transitions smoothly from the reaching to sliding phase and maintains stability, it is required to adhere to the reaching condition marked as in (12). With reference to (13) and (14), it is evident that the criterion $s\dot{s} < 0$ has been met in this case.

$$V = \frac{1}{2}s^2 \tag{11}$$

$$\dot{V} = s\dot{s} < 0, s \neq 0 \tag{12}$$

When $s > 0, sign(s) = 1, \epsilon > 0$,

$$\dot{V} = -s\big(\epsilon sign(s)\big) = -s(\epsilon) < 0 \tag{13}$$

When $s < 0, sign(s) = -1, \epsilon > 0$,

$$\dot{V} = -s(\epsilon sign(s)) = s(\epsilon) < 0 \tag{14}$$

D. Particle Swarm Optimization

Fig. 5 depicts how the PSO algorithm is used in practice. To get the ideal values for the design gain parameters, the PSO was constructed by imitating the swarm social behaviour of birds flocking and fish schooling. Particles, or swarms of people, explore the whole population in a high-dimensional search region for the best global solution at a particular position and velocity. Every particle in the swarm has a fantastic response and follows a simple principle by replicating its previous success. Furthermore, the particle's placement in the neighbourhood is impacted by the particle's personal best position, with the global best position being the best solution among the personal best positions.

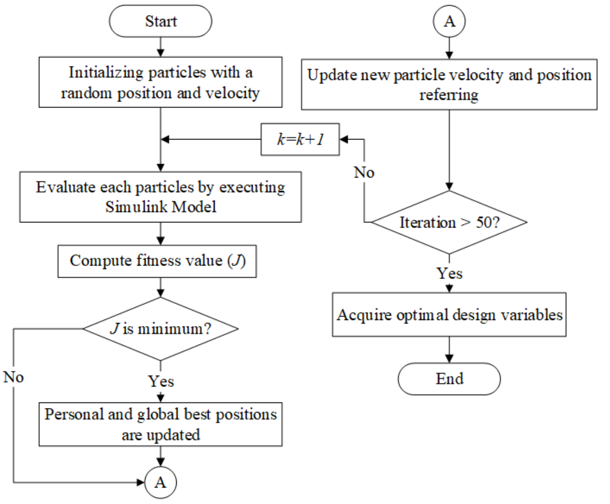

Figure 5. Common process of the optimization algorithm.

In this work, the particle population size, maximum number of iterations, and social and cognitive coefficients are all set to 20, 50, 2, and 2, respectively by using the heuristic approach. In addition, the fitness function is written in (15), where m is the total number samples.

$$J = \sqrt{\frac{1}{m}\sum (e)^2} \tag{15}$$

Furthermore, the proposed controllers' effectiveness for tracking control is defined by the MSE index in (16), where a lower value of the MSE index indicates a better capability of the controller for effective tracking control in the EHA system.

$$MSE = \frac{1}{m}\sum (e)^2 \tag{16}$$

IV. SIMULATION RESULTS AND DISCUSSION

This section shows the evaluation of tracking control performance for the FOISMC and conventional SMC controllers using MATLAB/Simulink (R2021b) with 1 ms of sample time and optimized controllers' variables using PSO algorithm. To construct the necessary trajectory, sinusoidal, multi-sinusoidal, and chaotic signals are employed. The values of a_1, a_2, and a_3 are 144400, 372.3, and 7855, respectively, which are developed by the MATLAB System Identification toolbox procedure. Furthermore, the variable values of the proposed and conventional SMC controllers, which were developed by the PSO process, are listed in Table I.

TABLE I. CONTROLLER VARIABLE DESIGN

Variable	**Value**	
	Conventional SMC	**FOISMC**
λ	395.42	399.76
ϵ	6.49	5.71
k_i	-	99.32
α	-	1.36

The trajectory profiles are illustrated in Fig. 6, which were utilized to evaluate the performance of FOISMC and conventional SMC controllers, respectively. Taking into consideration the tracking performance with associated error signals shown in Figs. 7 and 8, it can be clearly seen that these two controllers can track the three signal trajectories. However, the FOISMC's tracking performance outperformed the conventional SMC.

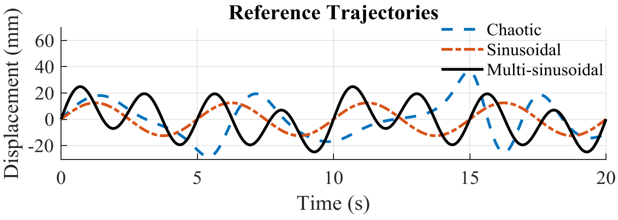

Figure 6. Trajectories signal.

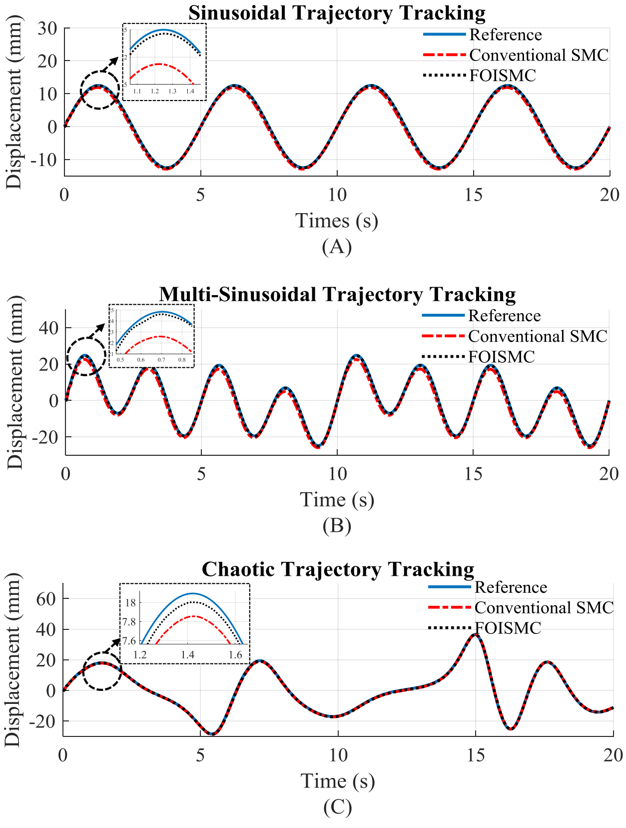

Figure 7. Tracking performance: (A) Sinusoidal (B) Multi-sinusoidal (C) Chaotic.

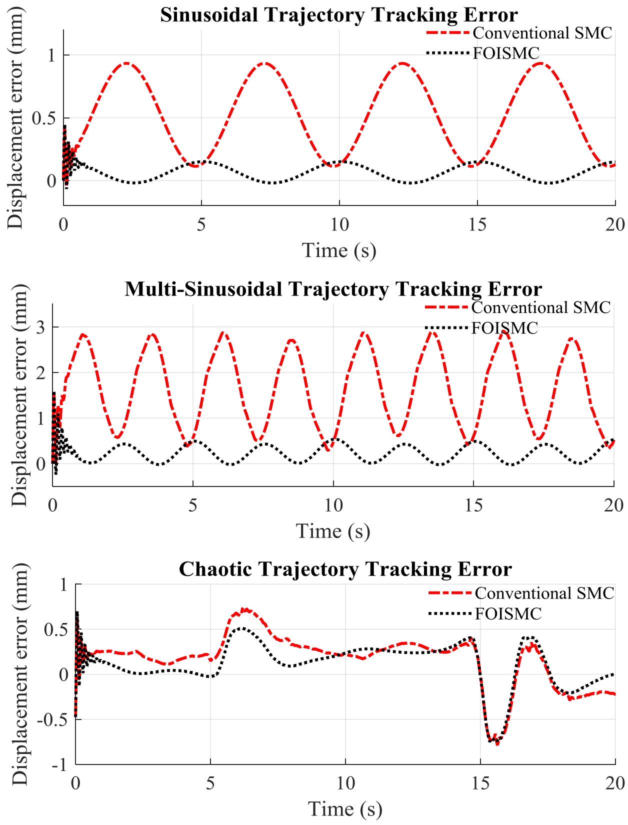

Figure 8. Error signal: (A) Sinusoidal (B) Multi-sinusoidal (C) Chaotic.

Furthermore, Table II summarizes the results of a detailed investigation relating to the mean square error (MSE) based on sinusoidal, multi-sinusoidal, and chaotic trajectory tracking control using conventional SMC and FOISMC controllers. The MSE values obtained from tracking sinusoidal, multi-sinusoidal, and chaotic trajectories using conventional SMC controller are 0.3557 mm^2, 13.8973 mm^2, and 0.2562 mm^2, respectively. Meanwhile, the MSE values acquired from the same trajectories tracking using FOISMC controller significantly decrease to around 98%, 98.1%, and 65% of the conventional SMC’s MSE value, respectively. Therefore, it is revealed that the FOISMC is the preferable controller as compared to the conventional SMC controller for the trajectory tracking control in the EHA system.

TABLE II. MSE RESULTS

Trajectory	**MSE (mm^2)**	
	Conventional SMC	**FOISMC**
Sinusoidal	0.3557	0.0071
Multi-sinusoidal	3.8973	0.0750
Chaotic	0.2562	0.0888

V. CONCLUSION

This study focuses on a fractional order integral sliding mode control method for tracking control of sinusoidal, multi-sinusoidal, and chaotic trajectories in an EHA system. To obtain the proposed controller, the linear model of the EHA system is determined using the parametric identification technique, and the model's parameters are estimated using the MATLAB System Identification toolbox. A fractional order integral sliding mode controller is then presented by integrating a fractional order integral sliding surface into the conventional sliding mode control algorithm. The stability of the closed-loop system with the proposed controller is evaluated using Lyapunov's theory of stability. Through simulation work, the tracking control system's control output was gathered in order to evaluate the trajectory tracking control's performance. Results reveal that the proposed controller for trajectory tracking control outperforms the conventional sliding mode controller. In addition, future research should assess the proposed controller's performance on a real-time hardware platform and compare it to other sliding mode control methods such as fractional order proportional-integral-derivative sliding mode and fuzzy proportional-integral-derivative controllers.

CONFLICT OF INTEREST

Authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

M. F. Ghani and R. Ghazali conducted the research, analyzed the data, and wrote the paper. H. I. Jaafar, C. C. Soon, Y. Md. Sam, and Zulfatman review the manuscript. All authors had approved the final version manuscript.

ACKNOWLEDGEMENT

The support of Universiti Teknikal Malaysia Melaka (UTeM), Universiti Kuala Lumpur (UniKL) and Ministry of Higher Education (MOHE) are greatly acknowledged. The research was funded by Fundamental Research Grant Scheme (FRGS) Grant No. FRGS/1/2021/FKE/F00468.

REFERENCES

[1] B. Song, D. Lee, S. Y. Park, and Y. S. Baek, “Design and performance of nonlinear control for an electro-hydraulic actuator considering a wearable robot,” *Processes*, vol. 7, no. 6, p. 389, June 2019.

[2] F. Kou, Z. Wang, J. Du, D. Li, and E. Fan, “Study on force tracking control of electro-hydraulic active suspension,” in *Proc. 2017 IEEE 3rd Information Technology and Mechatronics Engineering Conference (ITOEC)*, Oct. 2017, vol. 6, no. 1, pp. 1078–1082.

[3] W. Wang *et al.*, “Research on large-diameter electro-hydraulic rotary table and its control system for deep-water drilling rig,” *J. Phys. Conf. Ser.*, vol. 1601, no. 2, p. 022030, July 2020.

[4] S. Qu, D. Fassbender, A. Vacca, and E. Busquets, “A high-efficient solution for electro-hydraulic actuators with energy regeneration capability,” *Energy*, vol. 216, p. 119291, 2021.

[5] B. Xu, J. Shen, S. Liu, Q. Su, and J. Zhang, “Research and development of electro-hydraulic control valves oriented to industry 4.0: A review,” *Chinese J. Mech. Eng. (English Ed.*, vol. 33, no. 1, pp. 1-20, 2020.

[6] S. Tafazoli, C. W. De Silva, and P. D. Lawrence, “Tracking control of an electrohydraulic manipulator in the presence of friction,” *IEEE Trans. Control Syst. Technol.*, vol. 6, no. 3, pp. 401–411, 1998.

[7] K. Abuowda, I. Okhotnikov, S. Noroozi, P. Godfrey, and M. Dupac, “A review of electrohydraulic independent metering technology,” *ISA Trans.*, vol. 98, pp. 364–381, Mar. 2020.

[8] M. Jelali and K. Andreas, *Hydraulic Servo-systems: Modelling, Identification and Control*, Springer Science & Business Media, 2002.

[9] Z. Xing, Q. Gao, and Y. Wu, “Modeling and identification of electrohydraulic system and its application,” *IFAC Proc.*, vol. 17, no. 1 PART 1, pp. 6446–6451, 2008.

[10] R. Ghazali, C. C. Soon, H. I. Jaafar, Y. M. Sam, and M. F. Rahmat, “System identification of electro-hydraulic actuator system with pressure and load effects,” in *Proc. 4th IEEE Int. Conf. Control Syst. Comput. Eng. ICCSCE 2014*, no. November, pp. 256–260, 2014.

[11] R. Alfina, Nasril, D. Astharini, D. M. Gandana, and A. H. Lubis, “Modeling and analysis of servo hydraulic position control system using pi-fuzzy logic controller method,” *Int. J. Mech. Eng. Technol.*, vol. 9, no. 1022–1033, pp. 1022–1033, 2018.

[12] A. R. Plummer, “Control techniques for structural testing: A review,” vol. 221, pp. 139–169, 2007.

[13] S. Takahiro and U. Kenko, “Gain scheduling control for electro-hydraulic servo system considering time-delay modeling error,” in *Proc. the 2004 IEEE International Conference on Control Applications*, , vol. 2, 2004, pp. 1709–1716.

[14] A. Kireççi, M. Topalbekiroglu, and I. Eker, “Experimental evaluation of a model reference adaptive control for a hydraulic robot: A case study,” *Robotica*, vol. 21, pp. 71–78, 2003.

[15] A. M. P and H. Khaloozadeh, “Regulator design for an electro-hydro servo-system,” *Int. Conf. Control. Instrumentation, Autom.*, pp. 126-131, 2017.

[16] H. Behzad, S. Khorashadizadeh, and A. A. Kalat, “A robust adaptive method to control the crushing mill machine,” in *Proc. the 2nd International Conference on Control, Instrumentation and Automation*, 2011, pp. 547–551.

[17] L. Zhang, D. Cong, Z. Yang, Y. Zhang, and J. Han, “Robust tracking and synchronization of double shaking tables based on adaptive sliding mode control with novel reaching law,” *IEEE Access*, vol. 4, pp. 8686–8702, 2016.

[18] L. Cheng, Z. C. Zhu, G. Shen, S. Wang, X. Li, and Y. Tang, “Real-time force tracking control of an electro-hydraulic system using a novel robust adaptive sliding mode controller,” *IEEE Access*, vol. 8, pp. 13315–13328, 2020.

[19] C. Guan and S. Pan, “Adaptive sliding mode control of electro-hydraulic system with nonlinear unknown parameters,” *Control Eng. Pract.*, vol. 16, pp. 1275–1284, 2008.

[20] D. T. Tran, K. Jeong, G. Jun, J. S. Kiro, M. J. Kiro, and K. K. Ahn, “Adaptive gain back-stepping sliding mode control for electrohydraulic servo system with uncertainties,” in *Proc. 2017 14th Int. Conf. Ubiquitous Robot. Ambient Intell. URAI 2017*, 2017, pp. 534–539.

[21] A. S. S. Ianagui and E. A. Tannuri, “High order sliding mode control and observation for DP systems,” *IFAC-PapersOnLine*, vol. 51, no. 29, pp. 110–115, 2018.

[22] J. Feng, Q. Gao, W. Guan, and Z. He, “Mathematical modelling and backstepping adaptive sliding mode control for multi-stage hydraulic cylinder,” *Int. J. Model. Identif. Control*, vol. 30, no. 4, p. 322-332, 2018.

[23] C. C. Soon, R. Ghazali, M. F. Ghani, C. M. Shern, Y. Sam, and Z. Has, “Chattering analysis of an optimized sliding mode controller for an electro-hydraulic actuator system,” *J. Robot. Control*, vol. 2, no. 1, pp. 7–12, 2022.

[24] V. Utkin, “Variable structure systems with sliding modes,” *IEEE Trans. Automat. Contr.*, vol. 22, no. 2, pp. 212–222, 1977.

[25] V. Utkin, H. Lee, Utkin, Vadim, and H. Lee, "Chattering problem in sliding mode control systems," in *Proc. International Workshop on Variable Structure Systems, VSS'06.*, IEEE, pp. 346-350, 2006.

[26] J. Kumar, A. T. Azar, V. Kumar, and K. P. S. Rana, “Design of fractional order fuzzy sliding mode controller for nonlinear complex systems,” *Mathematical Techniques of Fractional Order Systems*, Elsevier, pp. 249–282, 2018.

[27] F. M. Zaihidee, S. Mekhilef, and M. Mubin, “Application of fractional order sliding mode control for speed control of permanent magnet synchronous motor,” *IEEE Access*, vol. 7, pp. 101765–101774, 2019.

[28] M. F. Ghani, R. Ghazali, H. I. Jaafar, C. C. Soon, Y. Sam, and Z. Has, “Improved third order PID sliding mode controller for electrohydraulic actuator tracking control,” *Journal of Robotics and Control (JRC)*, vol. 3, no. 2, pp. 219-226, 2022.

[29] E. M. Herbert, *Hydraulic Control Systems*, John Wiley & Sons, New York, 1967.

[30] T. Knohl and H. Unbehauen, “Adaptive position control of electrohydraulic servo systems using ANN,” *Mechatronics*, vol. 10, no. 1–2, pp. 127–143, 2000.

Muhamad Fadli Ghani received his Bachelor of Engineering (Electrical–Instrumentation and Control) in 2008 and Master of Engineering (Electrical) in 2015 from Universiti Teknologi Malaysia (UTM). Currently, he pursued Doctor of Philosophy (Electrical Engineering) in Universiti Teknikal Malaysia Melaka (UTeM).

Rozaimi Ghazali received his B. Eng degree in Electrical Engineering (Instrumentation and Control) in 2008 and PhD in Electrical Engineering in 2013 from Universiti Teknologi Malaysia (UTM). Currently, he is an Associate Professor at Universiti Teknikal Malaysia Melaka (UTeM) and his interests involve system identification and robust controller design.

Hazriq Izzuan Jaafar received his B. Eng degree in Electrical Engineering (Power) in 2008, Master of Engineering (Electrical - Mechatronics & Automatic Control) in 2013, and PhD in Electrical Engineering (Control System) in 2019 from Universiti Teknologi Malaysia (UTM). Currently, he is a Senior Lecturer at Universiti Teknikal Malaysia Melaka (UTeM) and his interests involve control systems engineering, cranes, system modelling, PID control and particle swarm optimization.

Chong Chee Soon received his B. Eng degree in Electronic Engineering (Mechatronics) from Universiti Tun Hussein Onn Malaysia (UTHM) in 2014 and Master of Electrical Engineering at Universiti Teknikal Malaysia Melaka (UTeM) in 2017. He has pursued Doctor of Philosophy (Electrical Engineering) in Universiti Teknikal Malaysia Melaka (UTeM) in 2018. Currently, he served as a Lecturer in Tunku Abdul Rahman University College, Penang Branch Campus (TARUC PG).

Yahaya Md. Sam received his degree in electrical engineering from Universiti Teknologi Malaysia, and the degree of Master of Science in Control System Engineering from The University of Sheffield UK, and the degree of doctor philosophy in Electrical Engineering from Universiti Teknologi Malaysia, in 1986, 1988 and 2004, respectively. Currently, he is Professor at the Universiti Teknologi Malaysia.

Zulfatman Has received his B. Eng degree in Electronic Engineering (Mechatronics) from University of Muhammadiyah Malang (UMM) in 2002, M. Eng in Electrical and Electronic Engineering from Universiti Teknologi Malaysia (UTM) in 2009, and PhD in Control and Instrumentation Engineering in 2015 from Universiti Teknologi Malaysia (UTM). Currently, he served as an Associate Professor in University of Muhammadiyah Malang (UMM).