



MODELING, POSITION TRACKING AND ANTI-SWAY CONTROL OF A 3D OVERHEAD CRANE USING INTELLIGENT CONTROL STRATEGIES

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ABSTRACT

This study presents the modeling and intelligent control of a 3D industrial crane, an academic prototype that closely replicates the dynamics of real-world gantry cranes used in industrial and port operations. The main objective is to minimize load sway and achieve precise positioning along the three spatial axes, thereby enhancing safety and operational efficiency. The theoretical framework is based on advanced intelligent control techniques, specifically Fuzzy Logic Control (FLC) and Adaptive Neuro-Fuzzy Inference System (ANFIS), which combine heuristic knowledge and adaptive learning to address the nonlinear, multi-input multi-output nature of the crane system. The crane dynamics were modeled using Newtonian mechanics, with system equations implemented in MATLAB/Simulink. Separate controllers for each axis were designed, tested, and compared through simulations. The results show that FLC delivers effective disturbance rejection and stable recovery, while ANFIS achieves faster transient responses and superior vertical-axis performance, albeit with limitations in horizontal motion control due to training data quality. Robustness tests confirmed the superior disturbance tolerance of FLC.



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1. INTRODUCTION

Industrial lifting is a handling activity that consists of lifting, moving, or handling heavy loads, primarily using mobile cranes, but also crane arms, forklifts, aerial work platforms, winches, or even helicopters. Equipment such as cranes, overhead cranes, gantries, winches, hoists, jib cranes, forklifts, aerial work platforms, lifting platforms, jacks, and lifting jacks are considered as lifting devices. Overhead cranes are an essential tool in many industries, allowing for the efficient movement of heavy loads. However, their use may potentially pose a risk if the necessary precautions are not taken. One of the most significant dangers with overhead cranes is swinging. Uncontrolled oscillations endanger nearby operators and can damage both the loads and their environment. Additionally, they lead to increased downtime, impacting overall productivity. To improve safety and efficiency, active control systems have been designed specifically to dampen these oscillations on overhead crane. Automated overhead cranes can help reduce labor costs, optimize operational accuracy, eliminate damage, reduce production costs, and improve the safety of operators and machines.

The studied 3 D Crane is a complicated system with several variables and non-linear behaviour. Managing it is challenging due to its non-linearity. The "3D Crane" is an academic version of an industrial crane, and its behavior closely resembles that of a real industry crane. Researchers have developed multiple control to minimize load sway for overhead crane system during transfers; for Classical Control Methods we find in [1] the Danica and Alena's work where they develop robust decentralized proportional-integral-derivative (PID) controllers for the 3D crane to ensure stability of the cart's movement, also in [2] the authors show comparative analysis of modified PID controllers versus classical PID controllers and pole-placement control compared to Model Predictive Control (MPC), applied to a complex 3D overhead is shown in [3]. Optimal control strategies aim to minimize objectives like transportation time or payload sway. The authors of [4] applied linear quadratic regulator (LQR) techniques to design an anti-sway controller for an overhead crane. They employed a parametric formula-based method to solve the LQR inverse problem and determine the weighting matrix Q.

In [5], we find also the Nazemizadeh's work which presents a developed tracking formulation of LQR that is applied to the system. An LQR controller is developed in [6] To achieve optimal position control and swing suppression, a trial-and-error approach was initially used to tune the LQR controller. Subsequently, genetic algorithms were employed to further refine the LQR controller parameters, resulting in enhanced performance. Many nonlinear controls are applied to 3D crane. partial and full feedback linearization method [7],[8], sliding mode control [9],[10], second order sliding mode control [11],[12], Fractional-Order sliding mode control [13], backstepping control strategy [14-17] and Active Disturbance Rejection Control [17]. Several adaptive control methods have been proposed for 3D overhead cranes: adaptive output-based command shaping [18], neural network-based adaptive control [19],[20], model-free adaptive control with time-delay estimation [21], adaptive sliding mode control [22], and adaptive fractional-order backstepping [23]. Fuzzy logic [24],[25], neural networks [26],[27] and neuro-fuzzy controls [28],[29] have gained prominence in recent crane control applications. In this work, we utilize the research model "3D Crane" of an industrial crane produced by Inteco Co. Ltd [30]. The 3D Crane, seen in Figure 1, is a MIMO nonlinear system with intricate dynamics that give rise to control challenges.

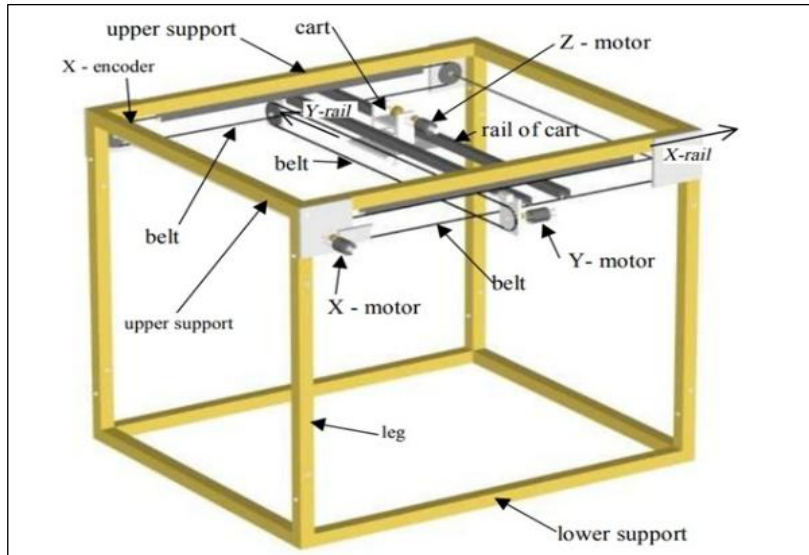


Figure 1: the model of 3D Crane.

Source: Authors, (2026).

The system configuration (Figure 2) Consists of a payload that extends from a lift-line like a swinging pendulum, which is wound by a motor connected to a cart. The contents of the payload is vertically elevated and descended in the z axis. Both the rail and the trailer have the ability to travel horizontally in the x direction. The cart may move horizontally across the rail in the y-axis direction. The load attached to the end of the lift-line can be moved freely in three dimensions. The 3DCrane is driven by a trio of DC motors. The system is operated from a personal computer. The mechanical unit is powered and connected to a PC. The software functions on the MS Windows® NT platform and utilizes MATLAB/Simulink for the purpose of developing real-time control algorithms. The control impulses produced in MATLAB/Simulink are transmitted to the motors through a data acquisition card and power amplifier. The encoder feedback supplies instantaneous position information, thereby finalising the closed-loop control system.

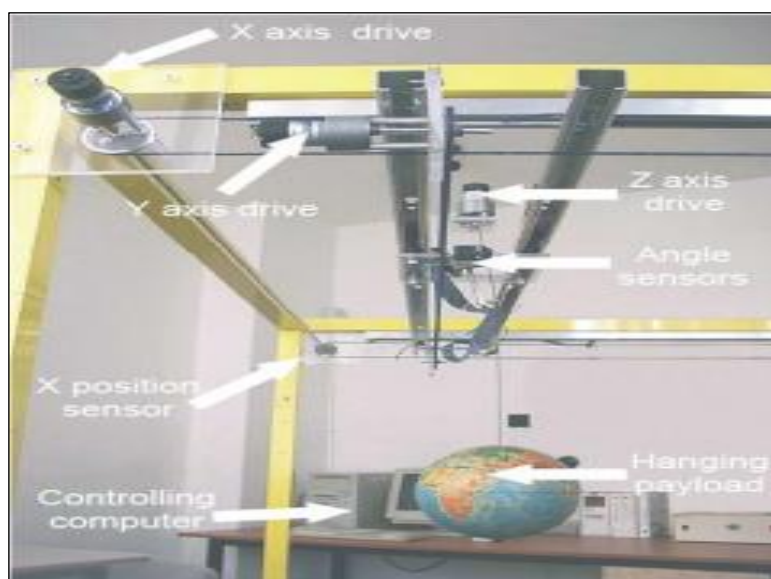


Figure 2: The 3D Crane setup.

Source: Authors, (2026).

This paper is organized as follows. The intelligent controllers are subsequently explained and synthesised. The following portions of this article are organised in the following manner. The second half of the document focusses on the representation of the 3D Crane. The controllers for anti-swing and position in the third part are synthesised. The fourth section presents the numerical simulation results of the controllers and includes a test to assess their resilience. Section 5 provides a concise overview of the entire text.

II. THE 3D CRANE MODEL

As be can seen in figure 3 wich represent the 3D Crane Dynamics; the payload's position is defined by these equations:

$$\begin{cases} x_c = x_w + R \sin \alpha \sin \beta \\ y_c = y_w + R \cos \alpha \\ z_c = -R \sin \alpha \cos \beta \end{cases} \quad (1)$$

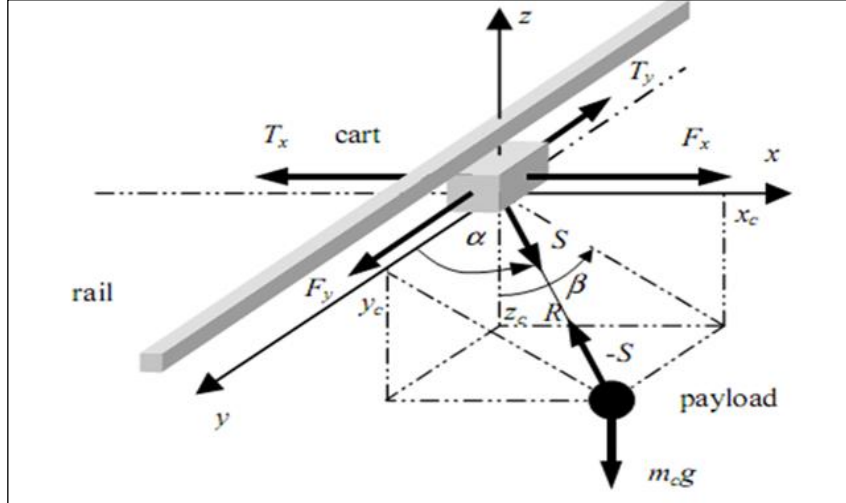


Figure 3: 3D Crane Dynamics.
Source: Authors, (2026).

Table 1: System inputs and outputs.

Symbolic representation	explanation
x_w	X-coordinate [m].
y_w	Y- coordinate [m].
R	Cable length [m].
α	The angle formed between the Y-coordinate and the wire, measured in radians.
$(x_c; y_c; z_c)$	Payload coordinates
S	Lift-line tension [N].
F_x	Horizontal rail force [N].
F_y	Longitudinal cart force [N].
FR	Lifting cable force [N];
T_x, T_y, TR	Frictional forces [N].

Source: Authors, (2026).

Applying Newton's rules to analyse the forces acting on a 3D crane $\sum F_{ext}$, we have:

$$\begin{cases} m_c \ddot{x}_c = -s_x \\ m_c \ddot{y}_c = -s_y \\ m_c \ddot{z}_c = -s_z - m_c g \end{cases} \quad (2)$$

$$\begin{cases} (m_w + m_s) \ddot{x}_w = F_x - T_x + s_x \\ m_w \ddot{y}_w = F_y - T_y + s_y \end{cases} \quad (3)$$

where:

$$\begin{cases} S_x = S \sin \alpha \sin \beta \\ S_y = S \cos \alpha \\ S_z = -S \sin \alpha \cos \beta \end{cases} \quad (4)$$

The subsequent state variables are taken into account:

$$\begin{aligned}x_1 &= y_w, x_2 = \dot{x}_1 = \dot{y}_w \\x_3 &= x_w, x_4 = \dot{x}_3 = \dot{x}_w \\x_5 &= \alpha, x_6 = \dot{x}_5 = \dot{\alpha} \\x_7 &= \beta, x_8 = \dot{x}_7 = \dot{\beta} \\x_9 &= R, x_{10} = \dot{x}_9 = \dot{R}\end{aligned}\quad (5)$$

The system yields the subsequent nonlinear state-space:

$$\left\{ \begin{aligned}\dot{x}_1 &= x_2 \\ \dot{x}_2 &= N_1 + \mu_1 c_5 N_3 \\ \dot{x}_3 &= x_4 \\ \dot{x}_4 &= N_2 + \mu_2 s_5 s_7 N_3 \\ \dot{x}_5 &= x_6 \\ \dot{x}_6 &= \frac{(s_5 N_1 - c_5 s_7 N_2 + (\mu_1 - \mu_2 s_5^2) c_5 s_5 N_3 + V_5)}{x_9} \\ \dot{x}_7 &= x_8 \\ \dot{x}_8 &= \frac{-(c_7 N_2 + c_5 s_7 N_2 + \mu_2 s_5 c_7 s_7 N_3 + V_6)}{s_5 x_9} \\ \dot{x}_9 &= x_{10} \\ \dot{x}_{10} &= -c_5 N_1 - s_5 s_7 N_2 - (1 + \mu_1 c_5^2 + \mu_2 s_7^2 s_5^2) N_3 + V_7\end{aligned}\right.\quad (6)$$

With:

$$\begin{aligned}s_n &\equiv \sin x_n, \quad c_n \equiv \cos x_n, \\ V_5 &= c_5 s_5 x_8^2 x_9 - 2x_{10} x_6 + g c_5 c_7 \\ V_6 &= 2x_8 (c_5 x_6 x_9 + s_5 x_{10}) + g s_7 \\ V_7 &= s_5^2 x_8^2 x_9 + g s_5 c_7 + x_6^2 x_9\end{aligned}\quad (7)$$

III. THE APPLIED CONTROLLERS

III.1 FUZZY LOGIC CONTROLLER:

Fuzzy Logic was introduced in 1965 by [31]. The FUZZY LOGIC CONTROL (FLC) provides an algorithm which can convert the linguistic control strategy based on expert knowledge into an automatic control strategy. Fuzzy logic controllers utilize a set of linguistic rules, based on expert knowledge, to define their dynamic behavior. These rules typically follow an 'IF-THEN' structure, where specific conditions trigger corresponding actions [32]; Figure 4 illustrates the fundamental framework of fuzzy logic control.

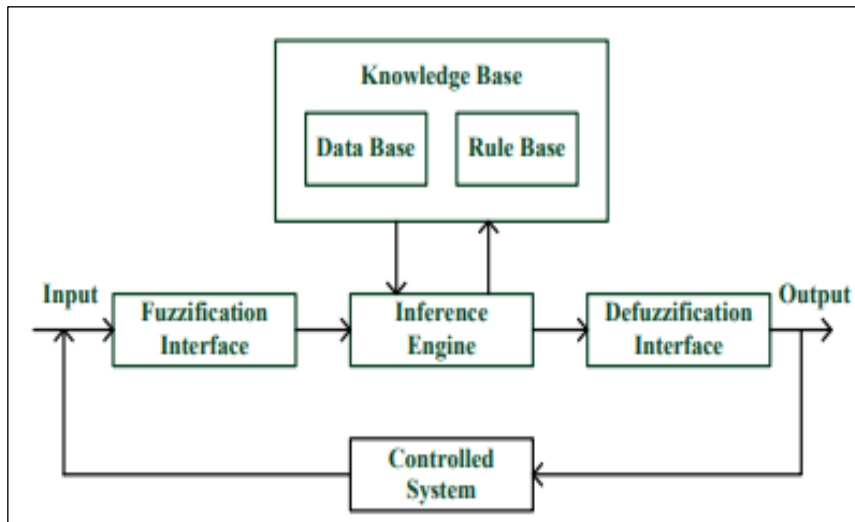


Figure 4: Fundamental architecture of FLC.

Source: Authors, (2026).

The majority of FLCs have been developed using the expertise of human operators and/or the understanding of control engineers. In this scenario, our task is to design a fuzzy logic controller using the Fuzzy Logic Toolbox of MATLAB. This will be done once we have identified the precise inputs. To simplify the process, we will divide the control into three Fuzzy Logic Controllers (FLCs) for the x, y, and z axes. The inputs for the Fuzzy Logic Controller (FLC) of the x-axis and y-axis controllers are angles alpha and beta, respectively.

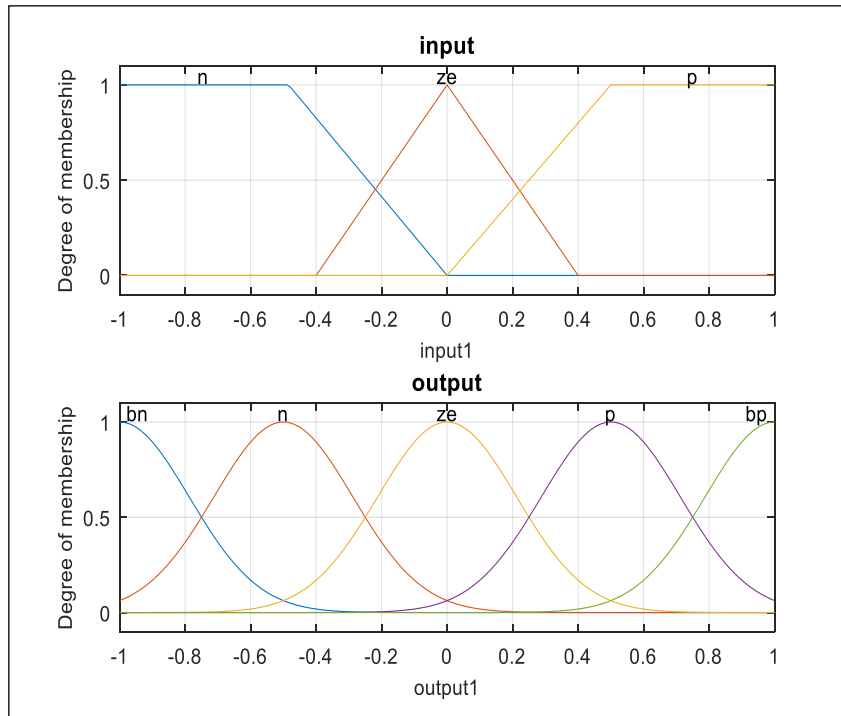


Figure 5: Membership Functions.
Source: Authors, (2026).

The fuzzy sets of input with a cardinality of 3 and the fuzzy sets of input with a cardinality of 5 are represented as follows: Figure 5 illustrates the input membership functions used in the fuzzy logic controller. BN represents a significant negative, N represents a negative, Z represents zero, P represents positive, and BP represents a significant positive. The purpose of the fuzzy logic controller rules on the X and Y axes is to generate a corrective force that opposes the direction of the swing. There are a total of 27 rules (If-Then) in this controller.

III.2 ANFIS CONTROLLER:

A fuzzy inference system implemented in the framework of adaptive networks[33], it was created by Jang in 1993[34]. Researchers from several disciplines have recently shown significant interest in utilising a combined neur-fuzzy method[33]. The ANFIS architecture consists of multiple layers of NN, as shown in Figure 6. The first layer executes a fuzzification process, the second layer executes the fuzzy AND of the antecedent part of the fuzzy rules, the third layer normalizes the MFs, the fourth layer executes the conclusion part of fuzzy rules, and the last layer computes the output of the fuzzy system by summing up the outputs of layer four [35].

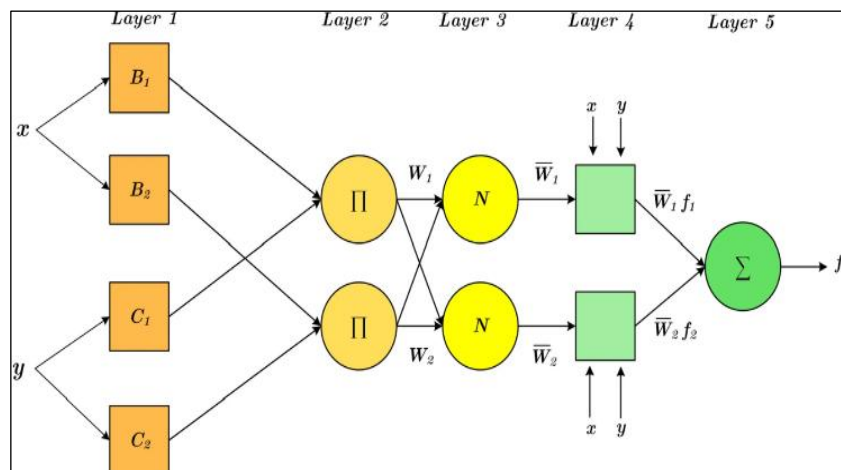


Figure 6: ANFIS structure.
Source: Authors, (2026).

The methodology employs a hybrid learning approach, utilizing backpropagation to optimize the premise parameters. Additionally, it utilises the "least squares" method for resolving the parameters. The implementation of this model may be found in the "Neuro-Fuzzy" toolbox of MATLAB. It has been observed to yield favourable outcomes when used to approximate nonlinear functions. For our study, The PID controller's inputs and outputs for the same system were used as training data for the ANFIS. The angles were considered the ANFIS inputs. The acquisition of knowledge occurs through the utilization of a table in the following manner:

Table 2: Learning parameters.

AXIS	X	Y	Z
Number of rules	27	27	9
The function of output	linear	linear	linear
Learning algorithm	hybrid	hybrid	hybrid
number of Epochs	90	90	90

Source: Authors, (2026).

IV. RESULTS AND DISCUSSIONS

IV.1 SIMULATION RESULTS: REFERENCE TRACKING

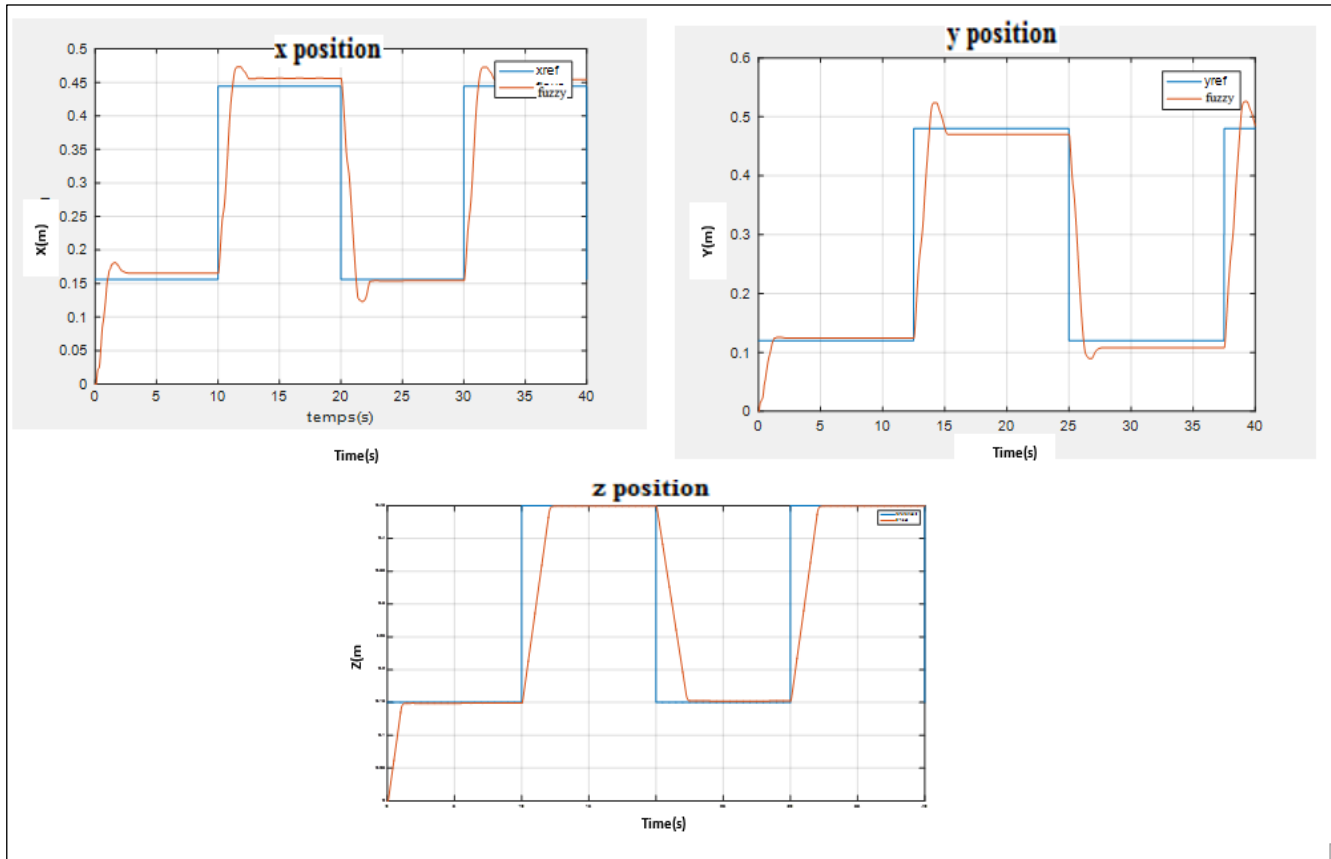


Figure 7: Reference tracking with FLC.

Source: Authors, (2026).

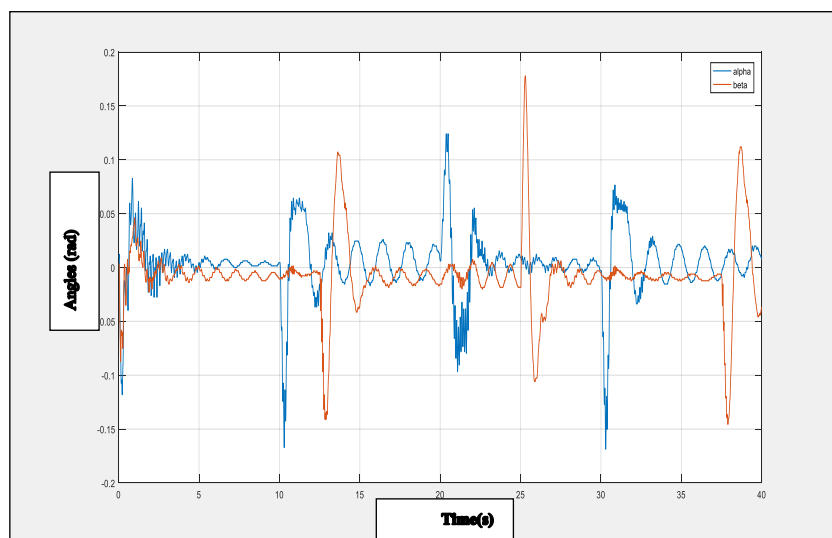


Figure 8: The swing Angle with FLC.

Source: Authors, (2026).

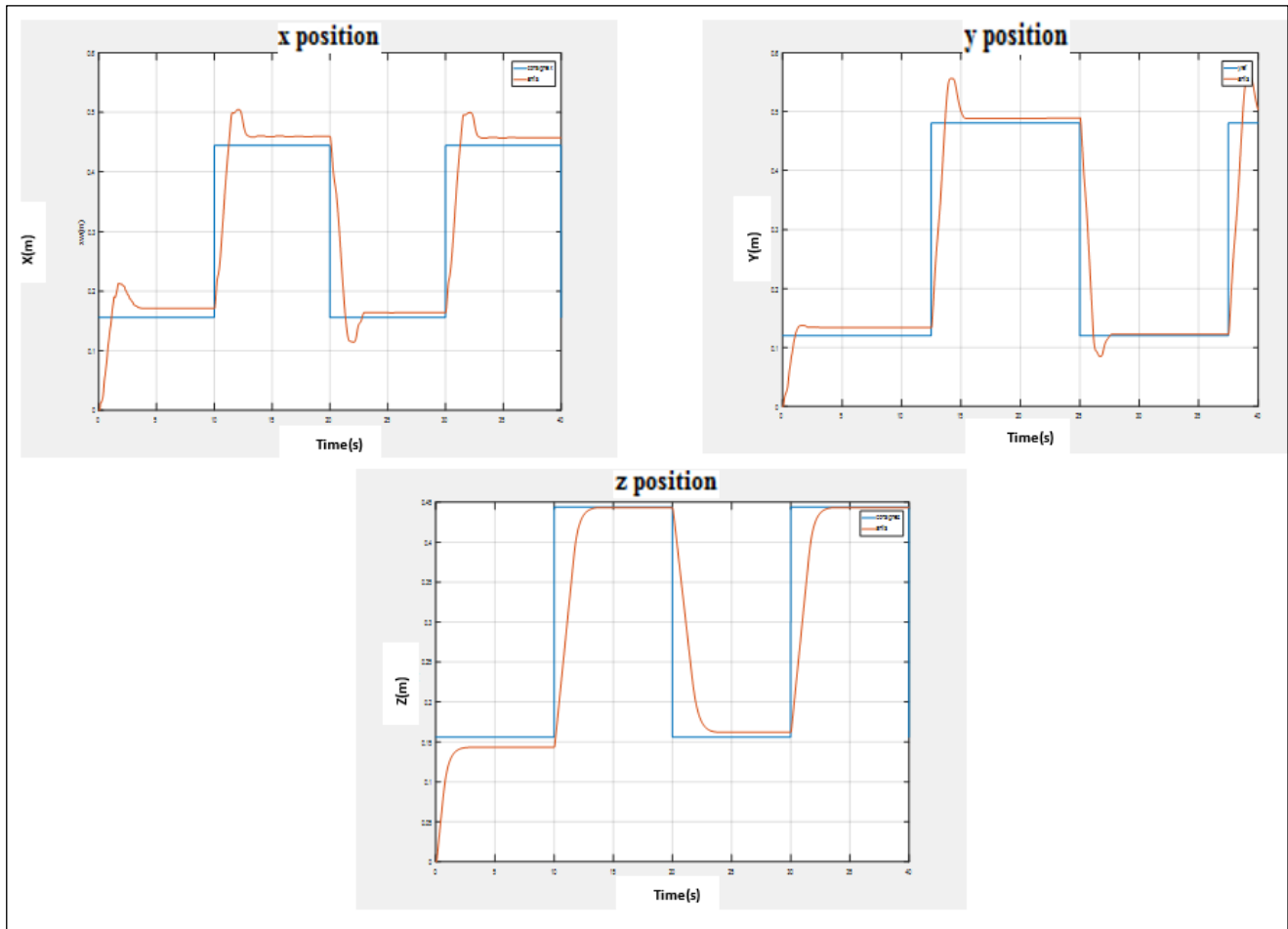


Figure 9: Reference tracking with ANFIS.
Source: Authors, (2026).

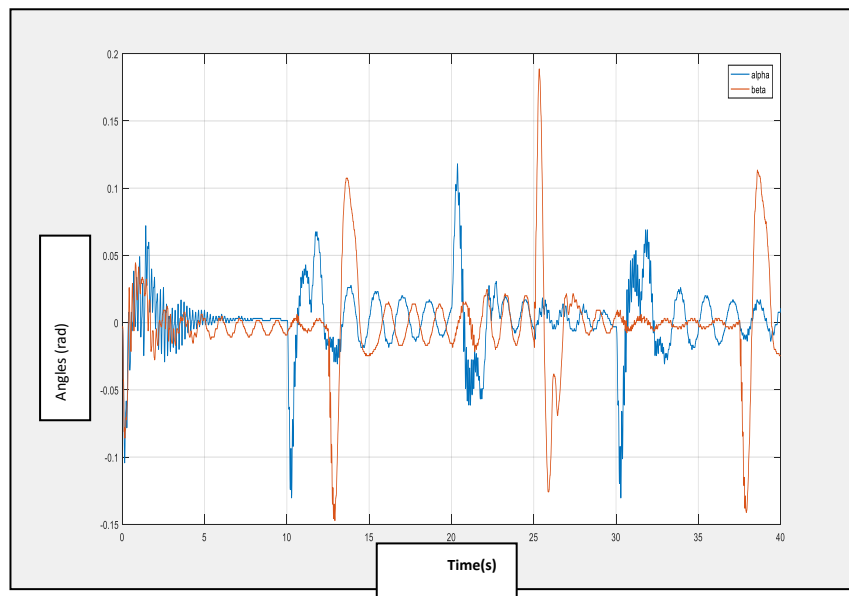


Figure 10: Angle response with ANFIS.
Source: Authors, (2026).

The results above demonstrate that both controllers, The Fuzzy controller, depicted in Figure 7 and Figure 8, is capable of attaining the desired trajectory within a specific time frame. In addition, Both controllers show significant reductions in fluctuations, especially in angles α and β , with limited overshoot (4% in x, 8% in y). Based on the analysis of Figure 9 and Figure 10, it can be inferred that the ANFIS regulator exhibits a rapid response and effectively reduces oscillations in angles α and β . Based on our findings, it can be concluded that ANFIS produces a robust outcome, particularly in relation to the z axis, and a satisfactory outcome for the X and Y axes. However, we have exceeded the target by 10% and 12% respectively. The observed performance limitations in the x and y axes are attributed to deficiencies in both optimal learning and structural complexity.

IV.2 SIMULATION RESULTS: TEST OF ROBUSTNESS

To assess controller robustness, we introduced random disturbances at $t=5$ and $t=20$ seconds.

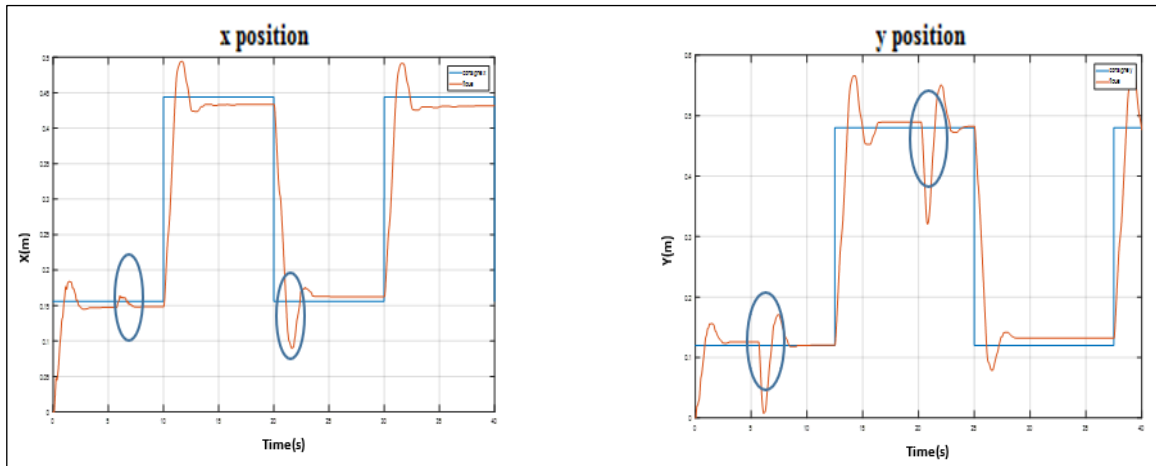


Figure 11: Reference tracking with disturbance (FLC).

Source: Authors, (2026).

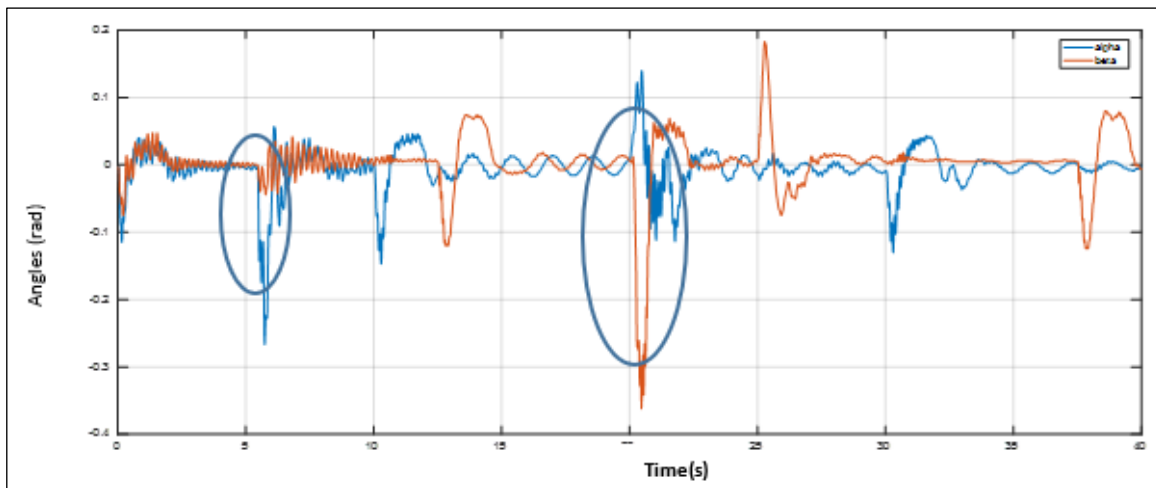


Figure 12: the angular response under disturbance conditions (FLC).

Source: Authors, (2026).

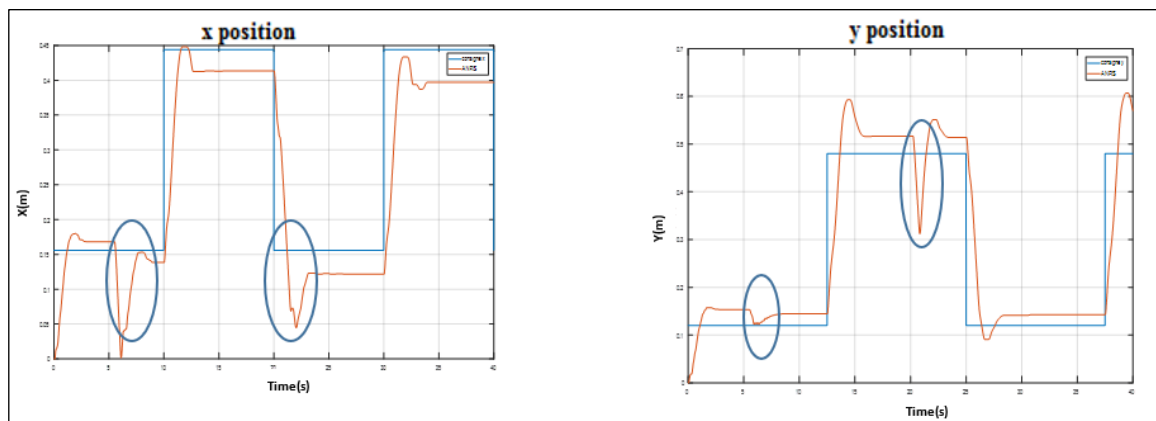


Figure 13: Reference tracking with disturbance (ANFIS).

Source: Authors, (2026).

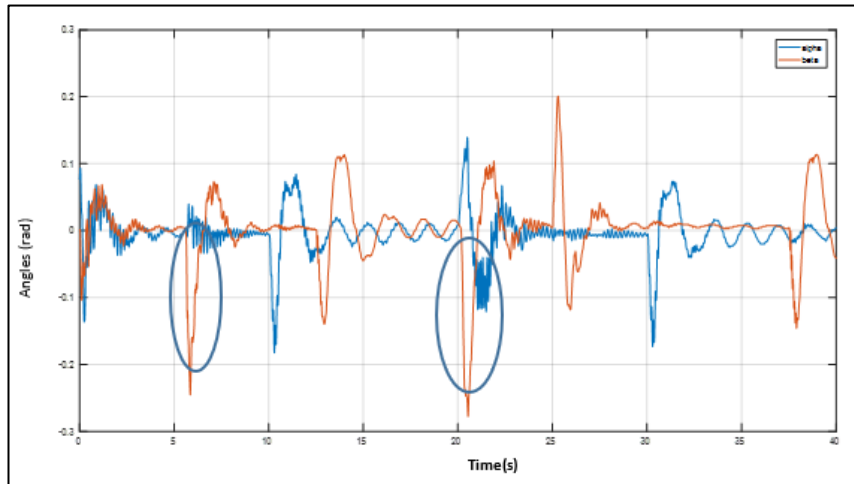


Figure 14: the angular response under disturbance conditions (ANFIS).

Source: Authors, (2026).

Robustness tests on both Fuzzy Logic and ANFIS controllers revealed significant differences in their ability to handle external disturbances. When a manual disturbance was introduced (simulating a swinging load), the Fuzzy Logic controller demonstrated superior performance. It effectively eliminated the disturbance, stabilized the load, and returned the system to its desired position with minimal oscillation. In contrast, the ANFIS controller struggled to track the desired trajectory and required a longer recovery time. These results suggest that ANFIS control may not be sufficiently robust against external disturbances.

V. CONCLUSIONS

This work introduces the modeling of a "3D Crane," a model for real-world gantry cranes. The crane is controlled using artificial intelligence techniques such as FL and ANFIS controllers. The objective of the control system is to minimize move angles and maintain a consistent the desired path in all three axes. The system's complexity and high order posed a challenge in selecting the most suitable framework for the fuzzy regulator, highlighting its main drawback of lacking clear guidance for rule design. However, both controllers offer the significant advantage of not requiring a complex system model (as demonstrated in second section) for processing. The utilization of a neuro-fuzzy control system, known as ANFIS, yields favorable outcomes when applied to specific learning conditions and databases. However, a notable disadvantage arises from the necessity of a training database for an existing control, which may not readily available. We utilized a PID controller for the learning process in our scenario. Therefore, using an irrelevant database and selecting an ideal strategy during the learning phase reduces the usefulness of ANFIS as a control alternative.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Amine Mehdi Fihakhir.

Methodology: Amine Mehdi Fihakhir and Abdesselam Guerbouz.

Investigation: Amine Mehdi Fihakhir and Abdesselam Guerbouz.

Discussion of results: Amine Mehdi Fihakhir and Abdesselam Guerbouz.

Writing – Original Draft: A Amine Mehdi Fihakhir.

Writing – Review and Editing: Amine Mehdi Fihakhir and Abdesselam Guerbouz.

Resources: Amine Mehdi Fihakhir.

Supervision: Amine Mehdi Fihakhir.

Approval of the final text: Amine Mehdi Fihakhir and Abdesselam Guerbouz.

VII. REFERENCES

- [1] R. Danica and K. Alena, "Robust Decentralized PID Controller Design," in Introduction to PID Controllers, C. P. Rames, Ed. Rijeka: IntechOpen, 2012, p. Ch. 6.
- [2] A. Cellmer, B. Banach, and R. Piotrowski, Design of modified PID controllers for 3D crane control. 2017, pp. 77-86.
- [3] M. J. Hatami and H. Moradi, "Multivariable control of 3D movement of an overhead crane with non-linear dynamics: Comparison between Pole-placement & MPC approaches," (in en), Scientia Iranica, 2024.doi:10.24200/sci.2024.62463.7853.
- [4] B. Yang and B. Xiong, "Application of LQR Techniques to the Anti-Sway Controller of Overhead Crane," Advanced Materials Research, vol. 139-141, 2010, pp. 1933-1936.doi:10.4028/www.scientific.net/AMR.139-141.1933.
- [5] M. Nazemizadeh, "A LQR Optimal Method to Control the Position of an Overhead Crane," IAES International Journal of Robotics and Automation (IJRA), vol. 3,05/28 2014.doi:10.11591/ijra.v3i4.6107.
- [6] Ü. Önen and A. Çakan, "Anti-Swing Control of an Overhead Crane by Using Genetic Algorithm Based LQR," International Journal Of Engineering And Computer Science,06/09 2017.doi:10.18535/ijecs/v6i6.12.
- [7] A. A. M. Fadlalla and M. Hassan, "Dynamic Modeling and Feedback Linearization Control of a 3-D Overhead Gantry Crane System," in 2021 IEEE International IOT, Electronics and Mechatronics Conference (IEMTRONICS), 2021, pp. 1-6.doi:10.1109/IEMTRONICS52119.2021.9422566.

- [8] P. Ospina-Henao, A. Carrillo-Suárez, L. Guarán-Martínez, A. Ortiz-Blanco, and J. Peñaranda-Vega, "Partial feedback linearization for a path control in a gantry crane used in lifting machinery in civil engineering," *Journal of Physics: Conference Series*, vol. 1723, no. 1, 2021/01/01 2021, p. 012049. doi:10.1088/1742-6596/1723/1/012049.
- [9] Q. Guo, L. Chai, and H. Liu, "Anti-swing sliding mode control of three-dimensional double pendulum overhead cranes based on extended state observer," *Nonlinear Dynamics*, vol. 111, no. 1, 2023/01/01 2023, pp. 391-410. doi:10.1007/s11071-022-07859-9.
- [10] X. Huan et al., "Sliding Mode Observation and Control for Overhead Cranes with Varying Rope Length," in 2021 China Automation Congress (CAC), 2021, pp. 4578-4583. doi:10.1109/CAC53003.2021.9727319.
- [11] L. Tuan, H. Cuong, and S.-G. Lee, Second-order sliding mode control of 3D overhead cranes. 2013, pp. 341-346.
- [12] S.-G. Lee, L. Tuan, J.-J. Kim, T.-G. Lim, and N. Cong, "Second-Order Sliding Mode Control of a 3D Overhead Crane with Uncertain System Parameters," *International Journal of Precision Engineering and Manufacturing*, vol. 15, 05/01 2014, pp. 811-819. doi:10.1007/s12541-014-0404-z.
- [13] F. Zhang, J. Geng, Z. Chen, L. Zhou, X. Shao, and J. Zhang, "Fractional-Order Sliding Mode Control for a Container Crane System," in 2024 14th Asian Control Conference (ASCC), 2024, pp. 1-6.
- [14] M. Khudhair, M. Hassan, and S. Kadhim, "Backstepping Control Strategy for Overhead Crane System," *Engineering and Technology Journal*, vol. 39, 03/25 2021, pp. 370-381. doi:10.30684/etj.v39i3A.1738.
- [15] Y. Wen, X. Lou, W. Wu, and B. Cui, "Backstepping Boundary Control for a Class of Gantry Crane Systems," *IEEE Transactions on Cybernetics*, vol. 53, no. 9 2023, pp. 5802-5814. doi:10.1109/TCYB.2022.3188494.
- [16] Z. Yu and W. Niu, "Flatness-Based Backstepping Antisway Control of Underactuated Crane Systems under Wind Disturbance," *Electronics*, vol. 12, no. 1. doi:10.3390/electronics12010244
- [17] R.-C. Roman, R.-E. Precup, and E. M. Petriu, "Active Disturbance Rejection Control for 3D Crane Systems," *Procedia Computer Science*, vol. 242, 2024/01/01/ 2024, pp. 976-983. doi:https://doi.org/10.1016/j.procs.2024.08.267.
- [18] Z. Mohamed, H. Selamat, H. Pota, M. S. Zainal Abidin, F. S. Ismail, and A. Haruna, "Adaptive output-based command shaping for sway control of a 3D overhead crane with payload hoisting and wind disturbance," *Mechanical Systems and Signal Processing*, vol. 98, 01/01 2018, pp. 157-172. doi:10.1016/j.ymssp.2017.04.034.
- [19] L. Anh and V. Linh, "Position Control and Anti-Sway of Overhead Crane System with Uncertain Nonlinear Model," *Journal Européen des Systèmes Automatisés*, vol. 57, 04/28 2024, pp. 425-431. doi:10.18280/jesa.570212.
- [20] G.-H. Kim, M. Yoon, J. Y. Jeon, and K.-S. Hong, "Data-driven Modeling and Adaptive Predictive Anti-swing Control of Overhead Cranes," *International Journal of Control, Automation and Systems*, vol. 20, no. 8, 2022/08/01 2022, pp. 2712-2723. doi:10.1007/s12555-022-0025-8.
- [21] X. Jin, W. Xu, and Z. Zheng, Model-free robust adaptive super-twisting control of multi-lift overhead cranes with finite-time convergence based on Iterative learning. 2023.
- [22] S. Bozhan, Q. Yuzhe, H. Die, and C. Yuzhu, "Nonlinear Adaptive Sliding Mode Control for Underactuated Three Dimensional Tower Crane Systems," in 2021 China Automation Congress (CAC), 2021, pp. 1256-1261. doi:10.1109/CAC53003.2021.9727331.
- [23] L. A. Tuan, "Neural Observer and Adaptive Fractional-Order Backstepping Fast-Terminal Sliding-Mode Control of RTG Cranes," *IEEE Transactions on Industrial Electronics*, vol. 68, no. 1 2021, pp. 434-442. doi:10.1109/TIE.2019.2962450.
- [24] A. Deka and S. R. Basireddy, "A Fuzzy Controller for the Emergency Braking Problem in Overhead Cranes," in 2022 IEEE Delhi Section Conference (DELCON), 2022, pp. 1-6. doi:10.1109/DELCON54057.2022.9753630.
- [25] H. P. Nguyen, N. T. Bui, and T. v.-A. Nguyen, "Tracking Control Based on Takagi-Sugeno Fuzzy Descriptor Model for Overhead Crane Combined With Input Shaping," *IEEE Access*, vol. 12, 2024, pp. 127507-127521. doi:10.1109/ACCESS.2024.3456815.
- [26] M. U. Hassan and J. Miura, "Neural Network-Based Real-Time Odometry Using IMU for Crane System and Its Application to Large-Scale 3D Mapping," in 2022 IEEE International Conference on Mechatronics and Automation (ICMA), 2022, pp. 1062-1068. doi:10.1109/ICMA54519.2022.9856381.
- [27] Q. Chen, W. Cheng, L. Gao, and J. Fottner, "A pure neural network controller for double-pendulum crane anti-sway control: Based on Lyapunov stability theory," *Asian Journal of Control*, vol. 23, no. 1, 2021/01/01 2021, pp. 387-398. doi:https://doi.org/10.1002/asjc.2226.
- [28] S. Al-Tuhaifi and K. Al-Aubidy, "Neuro-fuzzy-based anti-swing control of automatic tower crane," *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, vol. 21, 08/01 2023, p. 891. doi:10.12928/telkomnika.v21i4.24044.
- [29] D. D. Van, "Adaptive Neural-Fuzzy controller design combined with LQR to control the position of gantry crane," (in en), *International Journal of Applied Mathematics Electronics and Computers*, vol. 11, no. 2, June 2023, pp. 94-100. doi:10.18100/ijamec.1217697.
- [30] I. Ltd, "3D Crane User's Manual," Krakow-Poland 2019.
- [31] L. A. Zadeh, "Fuzzy sets," *Information and Control*, vol. 8, no. 3, 1965/06/01/ 1965, pp. 338-353. doi:https://doi.org/10.1016/S0019-9958(65)90241-X.
- [32] C. C. Lee, "Fuzzy logic in control systems: fuzzy logic controller. I," *IEEE Transactions on Systems, Man, and Cybernetics*, vol. 20, no. 2 1990, pp. 404-418. doi:10.1109/21.52551.
- [33] N. Walia, H. Singh, and A. Sharma, "ANFIS: Adaptive Neuro-Fuzzy Inference System- A Survey," *International Journal of Computer Applications*, vol. 123, 08/18 2015, pp. 32-38. doi:10.5120/ijca2015905635.
- [34] J. S. R. Jang, "ANFIS: adaptive-network-based fuzzy inference system," *IEEE Transactions on Systems, Man, and Cybernetics*, vol. 23, no. 3 1993, pp. 665-685. doi:10.1109/21.256541.
- [35] M. Turki, S. Bouzaida, A. Sakly, and M. S. Faouzi, Adaptive Control of Nonlinear System Using Neuro-Fuzzy Learning by PSO Algorithm. 2012.