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Development and Analysis of Robotic Manipulators for Manufacturing Automation: A Review of Kinematic Modelling, Dynamic Analysis, and Simulation Approaches

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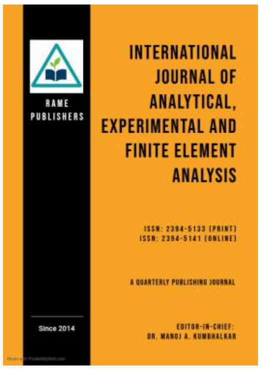

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Abstract: Robotic manipulators have become a fundamental component of modern manufacturing automation due to their ability to perform repetitive, precise, and hazardous tasks with high accuracy and reliability. The increasing demand for productivity, quality improvement, and operational flexibility has accelerated research in robotic manipulator design, kinematic modelling, dynamic analysis, control systems, and simulation-based validation. This review paper presents a comprehensive analysis of existing research related to robotic manipulators with particular emphasis on serial-link robotic arms used in manufacturing applications. The literature reveals that kinematic modelling based on the Denavit-Hartenberg (D-H) convention remains the most widely adopted approach for determining manipulator position and orientation, while dynamic analysis techniques are extensively employed for actuator selection and performance evaluation. Recent studies demonstrate the growing use of simulation platforms such as RoboDK, MATLAB, Gazebo, and MSC ADAMS for workspace analysis, trajectory planning, collision detection, and virtual commissioning. Furthermore, advancements in control strategies, machine vision integration, digital twins, and intelligent automation have significantly enhanced the capabilities of robotic systems. The review highlights that six-degree-of-freedom (6-DOF) manipulators provide superior dexterity, workspace accessibility, and end-effector orientation control compared with lower degree-of-freedom configurations. Despite significant progress, challenges remain in developing cost-effective robotic systems that combine high accuracy, structural rigidity, adaptability, and ease of implementation. The findings of this review provide valuable insights into current developments, research gaps, and future directions in robotic manipulator technology for manufacturing automation applications.

Keywords: Robotic Manipulator, Manufacturing Automation, Industrial Robotics, Kinematic Analysis, Dynamic Analysis, RoboDK, MSC ADAMS, Trajectory Planning, Workspace Analysis, 6-DOF Robot.

1. Introduction

The rapid advancement of industrial automation has significantly transformed modern manufacturing systems by improving productivity, product quality, operational safety, and process consistency [1], [3], [8], [9], [13], [15]. Among various automation technologies, robotic manipulators have emerged as one of the most versatile and widely adopted solutions for performing repetitive, hazardous, and precision-oriented tasks. Industrial robots are extensively utilized in applications such as welding, material handling, assembly, inspection, painting, machining, and surface processing [3], [8], [16–20]. Their ability to execute complex motions with high accuracy and repeatability makes them indispensable in modern manufacturing environments [9], [13], [14], [20].

A robotic manipulator is a mechanical system composed of interconnected links and joints that work together to position and orient an end-effector within a specified workspace. The performance of a robotic manipulator depends on several factors, including mechanical design, kinematic configuration, workspace characteristics, payload capacity, dynamic behaviour, actuator selection, and control strategy [1–8], [9–15]. The continuous demand for flexible manufacturing systems has encouraged researchers to develop robotic manipulators capable of achieving improved dexterity, accuracy, adaptability, and operational efficiency [3], [4], [6], [7], [13], [14], [24].

Kinematic modelling represents one of the most fundamental aspects of robotic manipulator development. It establishes the mathematical relationship between joint variables and the position and orientation of the end-effector. Forward kinematics is used to determine the end-effector pose from known joint parameters, whereas inverse kinematics calculates the joint variables required to achieve a desired end-effector position [2], [7], [9], [10], [11], [23]. Accurate kinematic modelling is essential for motion planning, trajectory generation, collision avoidance, and real-time control of robotic systems [2], [6], [9], [17–20], [23]. The Denavit-Hartenberg (D-H) convention remains one of the most widely accepted methodologies for modelling serial robotic manipulators due to its simplicity and effectiveness [2], [7], [8], [9], [10], [17].

In addition to kinematic analysis, dynamic modelling plays a crucial role in evaluating manipulator performance under operating conditions. Dynamic analysis considers the effects of inertia, joint torques, gravitational forces, and external loads acting on the robot during motion [4], [11], [12], [14], [15], [21], [22]. The results of dynamic analysis are particularly important for actuator selection, structural design validation, and controller development. Various computational approaches and simulation tools have been developed to accurately predict robotic system behaviour before physical implementation [4], [12], [14], [15], [21–24]. Recent advancements in computer-aided engineering tools have significantly enhanced the robotic design process. Software platforms such as RoboDK, MATLAB, MSC ADAMS, Gazebo, and ROS provide powerful environments for virtual modelling, simulation, trajectory planning, workspace analysis, and performance validation [3], [4], [7], [13], [19], [20], [22]. These tools enable engineers to evaluate robot behaviour, optimize design parameters, and identify potential issues before prototype fabrication, thereby reducing development cost and time. Furthermore, simulation-driven design approaches have become increasingly important in industrial robotics due to the growing complexity of automation systems [3], [14], [19], [20], [22], [24].

Among different robotic configurations, six-degree-of-freedom (6-DOF) manipulators have gained considerable attention because of their ability to independently control both the position and orientation of the end-effector [9–18], [21–24]. Compared with lower degree-of-freedom systems, 6-DOF manipulators offer superior workspace accessibility, enhanced dexterity, and greater flexibility when performing complex industrial operations [9], [10], [11], [13], [15], [16], [17]. Consequently, numerous studies have focused on the design, analysis, optimization, and implementation of 6-DOF robotic systems for manufacturing automation applications [12]–[18], [21–24].

In recent years, researchers have also explored advanced technologies such as machine vision, artificial intelligence, digital twins, collaborative robotics, and intelligent control systems to further improve robotic capabilities [13], [14], [20], [22], [24]. The integration of these technologies has expanded the scope of robotic applications beyond traditional industrial operations, enabling robots to perform increasingly sophisticated tasks with minimal human intervention [13], [14], [20], [24].

Considering the growing importance of robotic manipulators in manufacturing automation, a comprehensive review of existing research is necessary to understand current developments, identify research trends, and highlight future opportunities. This review paper presents an extensive analysis of published work related to robotic manipulator design, kinematic modelling, dynamic analysis, simulation techniques, control strategies, and industrial applications. The review aims to provide researchers and practitioners with a consolidated understanding of recent advancements while identifying key challenges and future directions in robotic manipulator development for manufacturing automation.

2. Literature Review

2.1 Overview

In recent years, substantial research has been devoted to advancing the capabilities of robotic manipulators, focusing on their kinematic modelling, control strategies, and specific applications in industrial and automation tasks. This review surveys previous work in this field, drawing from international journals, conferences, and technical reports, to provide an overview of the state-of-the-art while highlighting research gaps and areas requiring further exploration.

2.2 Design and Development of Robotic Manipulators

Jadeja and Pandya [1] conducted a comprehensive study on designing and developing a 5-DOF robotic arm manipulator, focusing on its mechanical and control aspects. The authors detailed the selection of materials and components, emphasizing the importance of structural integrity and flexibility in robotic applications. Their research involved an in-depth analysis of kinematic models to optimize the arm's range of motion and operational capabilities. They implemented various control algorithms, including PID control and adaptive techniques, to enhance the manipulator's precision and responsiveness. The study addressed challenges related to joint configurations and actuator performance, providing solutions to minimize errors during operation. The findings highlight the potential of 5-DOF robotic arms in diverse fields, particularly in automation, manufacturing, and healthcare. Furthermore, the authors discussed the practical implications of their design choices, emphasizing how effective manipulator design can significantly improve productivity and efficiency in various robotic tasks [1].

Karupusamy et al. [3] conducted an in-depth kinematic modelling and performance analysis of a 5-DOF robot specifically designed for welding applications. Their research explored various design parameters, including joint configurations, actuator types, and end-effector design, to optimize the robot's performance in terms of accuracy and welding quality. The authors utilized advanced simulation techniques to model the kinematic behaviour of the robot and conducted experiments to validate their findings in a practical setting. Their experimental validation demonstrated the effectiveness of the proposed kinematic models, revealing how precise modelling can improve the operational efficiency of robotic systems in industrial settings. Additionally, the study assessed the impact of different welding techniques and parameters on the overall performance of the robot, providing valuable insights for industry practitioners. This research underscores the growing importance of advanced robotic solutions in manufacturing processes and highlights the potential for further innovations in kinematic modelling for specialized applications, such as automated welding and assembly [3].

The functional flow chart illustrates the operational sequence for a 5-DOF robotic system. The diagram presents the essential steps and logic used in controlling the robotic manipulator, from initial position setting to motion execution and feedback loops for adjustments. This flow chart serves as a framework to understand the sequence and interaction of control components in a 5-DOF robot, which is relevant for developing a similar control flow in the current manipulator project [1], [3], [5].

Deshpande and George [7] developed a 5-DOF robotic arm for educational applications with a focus on kinematic modelling and analysis for pick-and-place operations. Using the Denavit-Hartenberg (DH) convention, the authors derived both forward and inverse kinematics and verified accuracy through MATLAB simulations. This design provides students a practical tool to explore programming, modelling, and control principles in robotics, highlighting its value in education [7].

Noor, Sabin, and Mahmod [5] developed a 5-DOF robotic arm with a smartphone-based Graphical User Interface (GUI) for educational and hobbyist purposes. Controlled via Bluetooth through an Arduino interface, the arm can perform simple drawing tasks using inverse kinematics to define the gripper's path. This design offers a user-friendly introduction to robotic control, making it accessible for students and beginners interested in learning robotic principles [5].

2.3 Kinematic Modelling and Motion Control for Manipulators

Iliukhin et al. [2] investigated the modelling of inverse kinematics for a 5-DOF manipulator, which is essential for enabling accurate positioning and movement control in robotic systems. Their study presented a systematic approach that integrates both geometric and algebraic methods to solve inverse kinematics equations, facilitating the calculation of joint angles required for a desired end-effector position. The authors emphasized the computational efficiency of their proposed techniques, which can significantly reduce processing time in real-time applications. They explored various algorithms, including numerical methods and iterative approaches, to enhance the accuracy of the results. The findings contribute to the field of robotics by providing a robust framework for enhancing the performance of manipulators in various operational scenarios. By addressing common challenges in inverse kinematics, this research lays the groundwork for future developments in robotic applications that require precise control and flexibility, such as automated assembly lines and surgical robots [2].

The kinematic scheme demonstrates the structural configuration of a 5-DOF manipulator, similar to the CAD model developed in this project. The diagram shows the arrangement of joints and links, each represented with Denavit-

Hartenberg (DH) parameters, allowing for precise end-effector positioning within the workspace. The kinematic scheme aligns with the project's manipulator design, providing a basis for developing accurate kinematic models and ensuring that the robot achieves the required workspace reach and orientation for welding operations [2], [7].

The figure below displays the outcome of forward kinematics modelling for a 5-DOF manipulator. The model visualizes the calculated end-effector positions based on different joint angle inputs, demonstrating the manipulator's reachable workspace. This result provides valuable insight into how the end-effector can achieve precise positioning within the defined space, confirming the reliability of the kinematic equations applied. This modelling result supports the development of forward kinematics in the current project, ensuring accurate end-effector control across the weld-cladding surface [2], [7].

Guo et al. [6] presented a novel method for the dexterity analysis of a 5-DOF robotic manipulator, utilizing a graphic and topological approach to evaluate dexterity characteristics and workspace performance. By introducing the spatial mapping envelope concept, the authors defined both reachable and dexterous workspaces, partitioning the workspace into regional and orientation volumes. This method offered conditions for achieving strict dexterity at any given point, making it useful for optimizing manipulator structure and motion control [6].

Bellicoso et al. [8] introduced the Prism Ultra-Lightweight 5 Arm (PUL5AR), a 5-DOF robotic arm designed for aerial manipulation on unmanned aerial vehicles (UAVs). The arm's lightweight design allows it to fold compactly during take-off and landing, minimizing destabilization effects on the UAV. Using Denavit-Hartenberg kinematics and Euler-Lagrange dynamics, the authors demonstrated high control accuracy, making PUL5AR suitable for UAV applications in challenging environments requiring precise manipulation [8].

3. Comparative Analysis of Existing Research

The reviewed literature demonstrates significant advancements in the field of robotic manipulator design, kinematic modelling, dynamic analysis, and manufacturing automation. Researchers have investigated various robotic configurations ranging from simple 3-DOF and 5-DOF manipulators to advanced 6-DOF industrial robotic systems. The comparison of existing studies reveals that each approach offers specific advantages and limitations depending on the intended application.

Several researchers have focused on the design and development of low-cost robotic manipulators for educational, research, and industrial applications. These studies primarily emphasize mechanical design optimization, actuator selection, and prototype development. While such systems provide economical solutions for automation, their workspace limitations and reduced orientation control often restrict their application in complex manufacturing environments.

Kinematic modelling has emerged as one of the most extensively investigated areas of robotic research. Most studies employ the Denavit-Hartenberg (D-H) convention to establish forward and inverse kinematic relationships. The reviewed works indicate that D-H based modelling provides reliable mathematical formulations for determining end-effector position and orientation. However, inverse kinematic solutions become increasingly complex as the number of degrees of freedom increases, particularly in redundant robotic systems.

Dynamic analysis studies have highlighted the importance of evaluating joint torque requirements, velocity profiles, acceleration characteristics, and inertial effects during manipulator operation. Researchers commonly utilize software tools such as MSC ADAMS and MATLAB to perform dynamic simulations. The findings consistently indicate that base and shoulder joints experience higher loading conditions compared to wrist joints due to the cumulative weight of subsequent links and actuators. Dynamic analysis has proven essential for proper actuator selection and structural validation.

Recent investigations have increasingly adopted simulation-driven design methodologies. Platforms such as RoboDK, MATLAB, Gazebo, and ROS are widely used for workspace analysis, trajectory planning, collision detection, and performance evaluation. Simulation-based approaches significantly reduce development time and cost by enabling virtual validation before prototype fabrication. Nevertheless, discrepancies between simulation and experimental results are frequently observed due to manufacturing tolerances, actuator nonlinearities, friction effects, and control system limitations.

The literature also indicates a clear trend toward increasing manipulator degrees of freedom. While 5-DOF manipulators provide satisfactory performance for basic positioning tasks, several studies report limitations in end-effector orientation control and workspace accessibility. In contrast, 6-DOF robotic manipulators offer improved dexterity, greater trajectory flexibility, enhanced reachability, and superior orientation control, making them more suitable for advanced manufacturing applications such as welding, inspection, and material handling.

Furthermore, recent research efforts have focused on integrating advanced technologies such as machine vision, artificial intelligence, digital twins, collaborative robotics, and intelligent control algorithms. These developments have significantly improved robotic autonomy, adaptability, and decision-making capabilities. However, the complexity and implementation cost associated with these technologies remain major challenges for widespread industrial adoption.

Overall, the comparative analysis reveals that modern robotic manipulator research is progressing toward highly flexible, intelligent, and simulation-driven systems. Although substantial progress has been achieved in manipulator design, kinematic modelling, and dynamic analysis, opportunities remain for developing cost-effective robotic platforms that combine high accuracy, structural robustness, real-time control capability, and ease of industrial implementation.

4. Research Gaps

The review of existing literature reveals that significant progress has been made in the fields of robotic manipulator design, kinematic modelling, dynamic analysis, and manufacturing automation. However, several challenges and research gaps still exist that limit the widespread adoption and effectiveness of robotic systems in industrial environments.

A large portion of the reported research focuses on either mechanical design, kinematic modelling, or control system development individually. Relatively few studies provide a comprehensive framework that integrates manipulator design, kinematic analysis, dynamic evaluation, simulation validation, and prototype implementation within a single development methodology. This lack of integration often results in discrepancies between theoretical performance and practical implementation.

Most existing studies concentrate on simulation-based validation using software tools such as MATLAB, RoboDK, Gazebo, and MSC ADAMS. While simulation provides valuable insights into manipulator behaviour, limited experimental validation has been reported in many cases. Consequently, the effects of actuator inaccuracies, joint backlash, friction, manufacturing tolerances, and real-world disturbances are often not adequately addressed.

Another significant research gap is associated with low-cost robotic manipulators intended for small and medium-scale industries. Although commercial industrial robots offer high accuracy and reliability, their acquisition and maintenance costs remain prohibitively expensive for many organizations. Existing research provides limited guidance on developing economical robotic systems capable of delivering industrial-level performance while maintaining affordability.

The literature also indicates that many robotic manipulators are designed with lower degrees of freedom, such as 3-DOF, 4-DOF, or 5-DOF configurations. While these systems are suitable for simple positioning tasks, they frequently suffer from limitations in workspace accessibility and end-effector orientation control. Further investigation is required to develop optimized 6-DOF manipulators that provide enhanced flexibility without significantly increasing system complexity and cost.

Although dynamic analysis has been widely reported, comparatively less attention has been devoted to the optimization of actuator selection, energy consumption, structural weight reduction, and overall system efficiency. Future robotic systems must achieve a balance between structural rigidity, payload capacity, precision, and energy efficiency to meet modern manufacturing requirements.

Furthermore, the integration of advanced technologies such as machine vision, artificial intelligence, digital twins, and autonomous decision-making remains in its early stages for many manufacturing applications. Existing implementations are often application-specific and require further development to achieve robust and generalized industrial deployment.

The literature review therefore highlights the need for cost-effective, experimentally validated, and highly flexible robotic manipulators that integrate accurate kinematic modelling, dynamic analysis, simulation-based validation, and intelligent control capabilities. Addressing these challenges will contribute significantly to the advancement of robotic automation systems for future manufacturing environments.

5. Future Research Directions

The rapid evolution of robotics, artificial intelligence, and industrial automation is expected to significantly influence the future development of robotic manipulators. Based on the findings of the reviewed literature, several promising research directions can be identified for enhancing the capabilities, efficiency, and industrial applicability of robotic systems.

One important area of future research is the development of advanced 6-DOF and higher-degree-of-freedom manipulators with improved dexterity, workspace accessibility, and payload capacity. Future designs should focus on achieving an optimal balance between structural rigidity, lightweight construction, energy efficiency, and manufacturing cost. The use of advanced materials and topology optimization techniques may further improve manipulator performance while reducing overall system weight.

The integration of intelligent control algorithms represents another significant research direction. Artificial Intelligence (AI), Machine Learning (ML), and Deep Learning techniques can be employed to enable adaptive motion planning, autonomous decision-making, fault detection, and predictive maintenance. Such capabilities will allow robotic systems to operate more efficiently in dynamic and uncertain manufacturing environments.

Machine vision and sensor fusion technologies are expected to play a critical role in future robotic automation systems. The integration of cameras, LiDAR, force sensors, and depth sensors can improve object recognition, localization accuracy, quality inspection, and adaptive task execution. Vision-guided robotic systems will be capable of responding to variations in workpiece geometry and environmental conditions without extensive reprogramming.

Digital twin technology has emerged as a promising tool for robotic system development and monitoring. Future research should focus on creating real-time digital replicas of robotic manipulators that continuously synchronize with physical systems. Such digital twins can facilitate predictive maintenance, performance optimization, virtual commissioning, and remote monitoring while reducing operational downtime.

Another important research direction involves the adoption of Robot Operating System (ROS) based architectures for industrial robotic applications. ROS provides a flexible and scalable framework for integrating sensors, actuators, simulation environments, and intelligent control algorithms. Future robotic systems can leverage ROS-based ecosystems to achieve greater interoperability and modularity.

Collaborative robotics (cobots) is expected to become increasingly important in modern manufacturing environments. Future studies should focus on developing safe human-robot interaction strategies, real-time obstacle avoidance systems, and adaptive control algorithms that enable robots and human operators to work together efficiently within shared workspaces.

Furthermore, research on autonomous trajectory planning and optimization can improve robot productivity and operational efficiency. Advanced algorithms capable of minimizing cycle time, reducing energy consumption, and avoiding singularities and collisions will be essential for next-generation manufacturing systems.

Finally, the integration of robotic manipulators with Industry 4.0 technologies, Industrial Internet of Things (IIoT) platforms, cloud computing, and smart manufacturing systems will create highly connected and intelligent production environments. These advancements will enable real-time data exchange, predictive analytics, and autonomous process optimization, thereby increasing manufacturing flexibility and competitiveness.

Overall, future research should focus on the development of intelligent, autonomous, cost-effective, and highly adaptable robotic systems capable of meeting the evolving requirements of modern manufacturing automation.

6. Conclusion

Robotic manipulators have become an essential component of modern manufacturing automation due to their ability to perform repetitive, precise, and hazardous operations with high accuracy and reliability. This review paper examined existing research related to robotic manipulator design, kinematic modelling, dynamic analysis, simulation techniques, control strategies, and industrial applications. The literature indicates that significant advancements have been achieved in the development of robotic systems through the integration of advanced computational tools, simulation environments, and intelligent control methodologies.

The review highlights that kinematic modelling based on the Denavit-Hartenberg (D-H) convention remains the most widely adopted approach for analysing manipulator motion and determining end-effector position and orientation. Dynamic analysis has proven to be an effective method for evaluating actuator requirements, joint loading conditions, and overall system performance. Furthermore, simulation platforms such as RoboDK, MATLAB, Gazebo, and MSC ADAMS have become indispensable tools for workspace analysis, trajectory planning, collision detection, and virtual validation of robotic systems before physical implementation.

The comparative analysis revealed that six-degree-of-freedom (6-DOF) manipulators offer superior dexterity, workspace accessibility, and orientation control compared to lower degree-of-freedom configurations. However, challenges associated with cost, system complexity, actuator selection, experimental validation, and intelligent control continue to limit the widespread adoption of robotic systems in certain manufacturing sectors.

The review also identified several research gaps, including the need for integrated design methodologies, cost-effective robotic platforms, enhanced experimental validation, and greater adoption of intelligent technologies. Emerging developments in artificial intelligence, machine vision, digital twins, collaborative robotics, and Industry 4.0 are expected to significantly enhance the capabilities of future robotic systems.

Overall, the reviewed studies demonstrate that robotic manipulators will continue to play a critical role in the advancement of manufacturing automation. Future research should focus on developing intelligent, adaptable, and economically viable robotic solutions capable of meeting the increasing demands of modern industrial environments while improving productivity, quality, safety, and operational efficiency.

References

[1] Y. Jadeja and B. Pandya, "Design and development of 5-DOF robotic arm manipulators," *International Journal of Scientific & Technology Research*, vol. 8, no. 11, pp. 2158–2167, 2019.

[2] V. N. Iliukhin, K. B. Mitkovskii, D. A. Bizyanova, and A. A. Akopyan, "The modeling of inverse kinematics for 5-DOF manipulator," *Procedia Engineering*, vol. 176, pp. 498–505, 2017.

[3] S. Karupusamy, S. Maruthachalam, and B. Veerasamy, "Kinematic modeling and performance analysis of a 5-DoF robot for welding applications," *Machines*, vol. 12, no. 6, Art. no. 378, 2024.

[4] H. Badkoobehhezaveh, R. Fotouhi, Q. Zhang, and D. Bitner, "Vibration analysis of a 5-DOF long-reach robotic arm," *Vibration*, vol. 5, no. 3, pp. 585–602, 2022.

[5] N. M. M. Noor, M. S. Sabin, and R. Mahmod, "Performance analysis of a 5-DOF robotic arm by implementing a graphical user interface," *Malaysian Journal of Science and Advanced Technology*, pp. 158–165, 2023.

[6] W. Guo, R. Li, C. Cao, and Y. Gao, "A novel method of dexterity analysis for a 5-DOF manipulator," *Journal of Robotics*, vol. 2016, no. 1, Art. no. 8901820, 2016.

[7] V. Deshpande and P. M. George, "Kinematic modelling and analysis of 5-DOF robotic arm," *International Journal of Robotics Research and Development*, vol. 4, no. 2, pp. 17–24, 2014.

[8] C. D. Bellicoso, L. R. Buonocore, V. Lippiello, and B. Siciliano, "Design, modeling and control of a 5-DoF light-weight robot arm for aerial manipulation," in *Proc. 23rd Mediterranean Conference on Control and Automation (MED)*, 2015, pp. 853–858.

[9] J. Iqbal, R. U. Islam, and H. Khan, "Modeling and analysis of a 6-DOF robotic arm manipulator," *Canadian Journal on Electrical and Electronics Engineering*, vol. 3, no. 6, pp. 300–306, Jul. 2012.

[10] A. Khatamian, "Solving kinematics problems of a 6-DOF robot manipulator," in *Proc. International Conference on Computing*, 2015.

[11] A. T. Hasan, A. M. S. Hamouda, N. Ismail, and H. M. A. A. Al-Assadi, "An adaptive-learning algorithm to solve the inverse kinematics problem of a 6-DOF serial robot manipulator," *Advances in Engineering Software*, vol. 37, no. 7, pp. 432–438, 2006.

[12] Y. Pi and X. Wang, "Trajectory tracking control of a 6-DOF hydraulic parallel robot manipulator with uncertain load disturbances," *Control Engineering Practice*, vol. 19, no. 2, pp. 185–193, 2011.

[13] A. Shahzad, X. Gao, A. Yasin, K. Javed, and S. M. Anwar, "A vision-based path planning and object tracking framework for 6-DOF robotic manipulator," *IEEE Access*, vol. 8, pp. 203158–203167, 2020.

[14] S. Wang, X. Shao, L. Yang, and N. Liu, "Deep learning aided dynamic parameter identification of 6-DOF robot manipulators," *IEEE Access*, vol. 8, pp. 138102–138116, 2020.

[15] O. Krakhmalev, N. Krakhmalev, S. Gataullin, I. Makarenko, P. Nikitin, D. Serdechnyy, K. Liang, and S. Korchagin, "Mathematics model for 6-DOF joints manipulation robots," *Mathematics*, vol. 9, no. 21, Art. no. 2828, 2021.

[16] A. G. Dharmawan, B. W. C. Sedore, G. S. Soh, S. Foong, and K. Otto, “Robot base placement and kinematic evaluation of 6R serial manipulators to achieve collision-free welding of large intersecting cylindrical pipes,” in *Proc. ASME International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, vol. 57144, Paper V05CT08A010, 2015.
[17] L. Huo and L. Baron, “Kinematic inversion of functionally-redundant serial manipulators: Application to arc-welding,” *Transactions of the Canadian Society for Mechanical Engineering*, vol. 29, no. 4, pp. 679–690, 2005.
[18] L. Huo and L. Baron, “Joint-limits and singularity avoidance in robotic welding,” *Industrial Robot: An International Journal*, vol. 35, no. 5, pp. 456–464, 2008.
[19] A. Gasparetto, P. Boscariol, A. Lanzutti, and R. Vidoni, “Path planning and trajectory planning algorithms: A general overview,” in *Motion and Operation Planning of Robotic Systems: Background and Practical Approaches*, pp. 3–27, 2015.
[20] Á. Madridano, A. Al-Kaff, D. Martín, and A. De La Escalera, “Trajectory planning for multi-robot systems: Methods and applications,” *Expert Systems with Applications*, vol. 173, Art. no. 114660, 2021.
[21] L. Zhang, J. Wang, J. Chen, K. Chen, B. Lin, and F. Xu, “Dynamic modeling for a 6-DOF robot manipulator based on a centrosymmetric static friction model and whale genetic optimization algorithm,” *Advances in Engineering Software*, vol. 135, Art. no. 102684, Sep. 2019.
[22] L. Ding, H. Wu, Y. Yao, and Y. Yang, “Dynamic model identification for 6-DOF industrial robots,” *Journal of Robotics*, vol. 2015, no. 1, Art. no. 471478, 2015.
[23] L. Li, Y. Huang, and X. Guo, “Kinematics modelling and experimental analysis of a six-joint manipulator,” *Journal Européen des Systèmes Automatisés*, vol. 52, no. 5, 2019.
[24] M. A. Mousa, A. T. Elgohr, and H. A. Khater, “Whale-based trajectory optimization algorithm for 6-DOF robotic arm,” *Annals of Emerging Technologies in Computing*, vol. 8, no. 4, pp. 99–114, Oct. 2024.