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Simulation and Motion Analysis of a Planar Robotic Manipulator Using MATLAB Toolboxes

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Abstract: This study presents the modeling, simulation, and motion control of a two-degree-of-freedom (DOF) planar robotic manipulator using MATLAB's Simscape and Robotic System Toolbox. The research focuses on designing a simulated robotic arm capable of executing controlled movements using forward kinematics. The proposed approach involves mechanical model, creation, motion analysis, and control kinematics. The proposed approach involves a creation of a model using simscape multibody blocks, motion analysis, and control execution through Simulink. Furthermore, the study explores future advancements and the potential industrial applications of the robotic system.
Keywords: Robotics, Kinematic Analysis, MATLAB, Simscape, Simulink

I. INTRODUCTION

A. Background

Robotic manipulators are widely used in automation, manufacturing, and research due to their ability to perform precise and repetitive tasks efficiently. The increasing reliance on robotic systems has led to the development of advanced simulation tools that allow engineers to design, analyze and refine mechanisms before physical implementation. MATLAB provides an effective platform for simulating robotic movements, reducing the need for costly prototypes while ensuring accuracy in system design.

B. Problem Definition

Robotic manipulators are essential for precision tasks in automation and manufacturing. However, developing and testing them through physical prototypes is costly and time-consuming. Simulating a white-box model using MATLAB's Simscape allows accurate motion analysis without requiring real-world testing. This study focuses on creating a two-degree-of-freedom (DOF) robotic manipulator model, ensuring efficient motion control and scalability for industrial applications.

C. Research Objective

The primary objective of this study is to design and simulate the two DOF robotic manipulator utilizing MATLAB's Simscape and Robotic System Toolbox. The research aims to implement forward kinematics to validate the manipulator's motion control and ensure that the system functions effectively within its designated workspace.
A conceptual illustration of the robotic manipulator is presented in Figure 1, providing an overview of the system's design and join configuration.

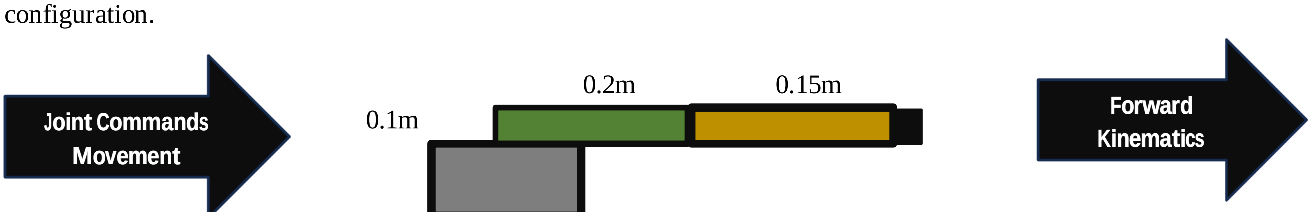

Fig. 1. Proposed plan

II. DEVELOPMENT FRAMEWORK

The development of the robotic system is structured to achieve functionally, efficiency, and ease of the implementation. The manipulator consists of essential mechanical components, including a base, rotational joints, links, and an end effector shown in **figure 2**. The system is designed in a simulated environment to optimize movements, testing kinematic accuracy, and provide a foundation for future improvements, such as trajectory planning and determining some parameters for the motor to be used in the robotic arm.

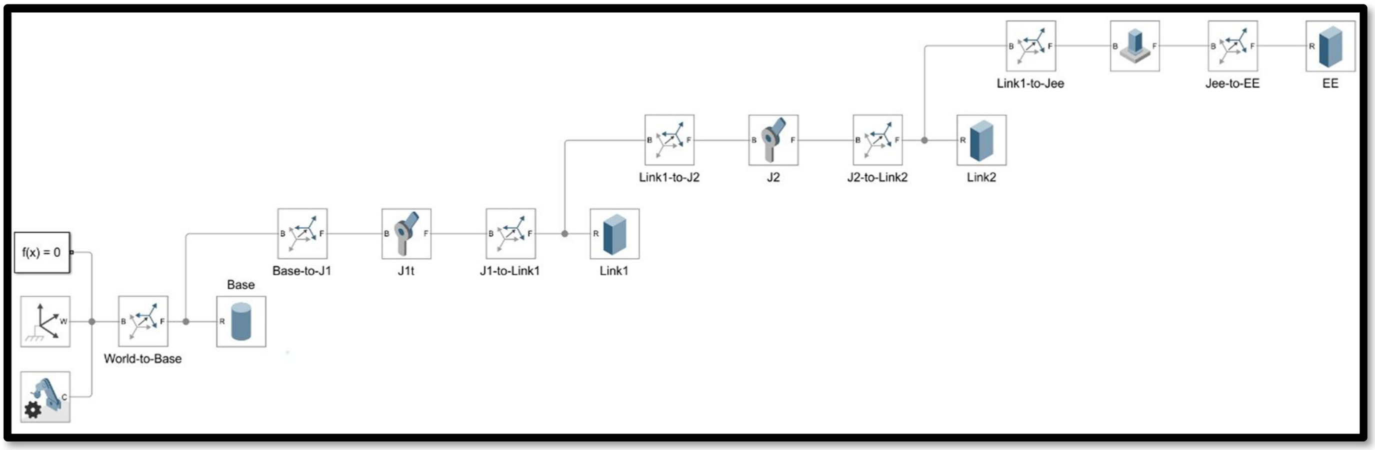

Fig. 2. Initial mechanical blocks for a model

III. DESIGN AND CONFIGURATION

The manipulator is constructed with fundamental mechanical elements, including a cylindrical base for stability, revolute joints enabling rotational motion, and links of predefined lengths. The end-effector is represented as a simple block structure which is used for picking and placing goods in industries, facilitating task execution within the workspace.

Accurate mechanical modeling is crucial for ensuring realistic simulation results. The design phase involves specifying mechanical constraints and defining reference frames. The finalized representation of manipulator is shown illustrating the positioning of links and joints within the system.

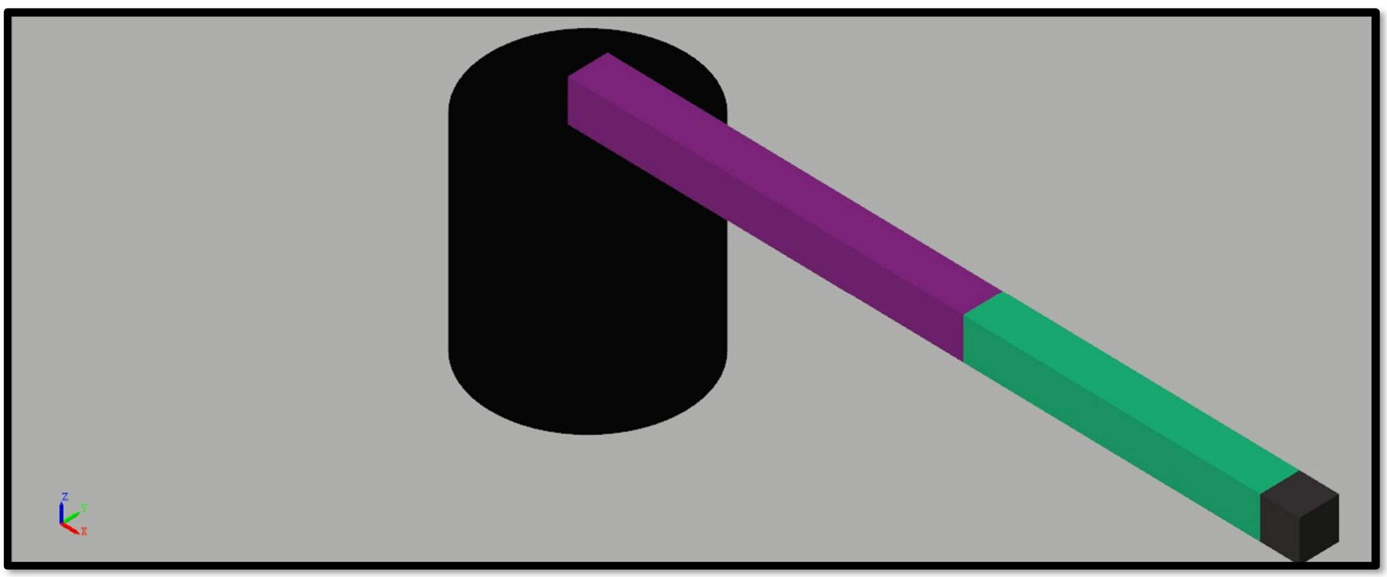

Fig. 3. Isometric view of the model through mechanical blocks

IV. CONTROL AND SIMULATION USING SIMULINK

Simscape's Multibody Toolboxes employed to develop the virtual model. Simscape's Multibody Toolbox is utilized to develop the robotic manipulator's digital twin. Reference frames and motion constraints are defined to establish a physically accurate simulation. Revolute joints are integrated for controlled movement, and rigid transformations align components for proper motion execution. The white-box approach ensures that forces such as gravity and joint torque are explicitly modelled rather than approximated from empirical data. Figure 4 presents the assembled Simscape model. A sine wave generator provides joint input signals, ensuring continuous and smooth motion. Signal converters facilitate communication between Simscape's physics-based environment and Simulink's computational framework.

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The white-box model approach ensures that motion control parameters are derived from first-principal equations rather than machine-learned approximations.

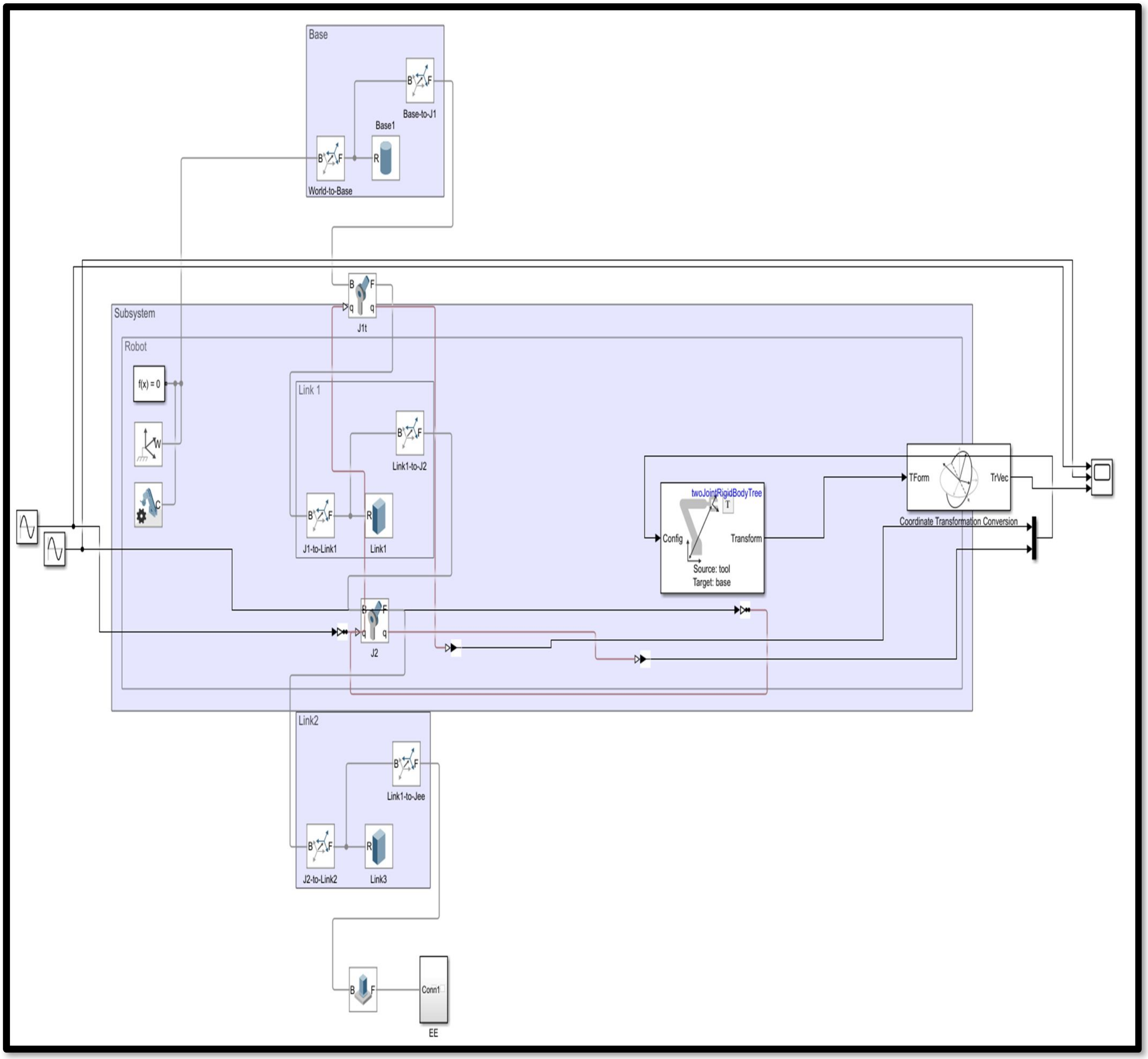

Fig. 4. Simulink final model

Here, I constructed a rigid body tree for 2DOF for delivering motion to particular links which is provided using a Get Transform block. Now the robot is going to move and sensors will sense the position in which it has moved. For that movement we will use that block and give algorithms and angles for forward kinematics. Therefore, the initial snippet for rigid body tree is provided below:
[test, info] =importrobot('Simulation'); Ts = 0.001;

A. Simscape

After connecting all the building blocks of simscape multibody in Simulink, it will generate the graph in Sim Mechanics showing the results using a Scope block in the model. The parameters in this model need to be defined by user are: motor power, torque acting, its frequency. Therefore, the physics-based model is best is the best approach and more transparent than data-driven model.

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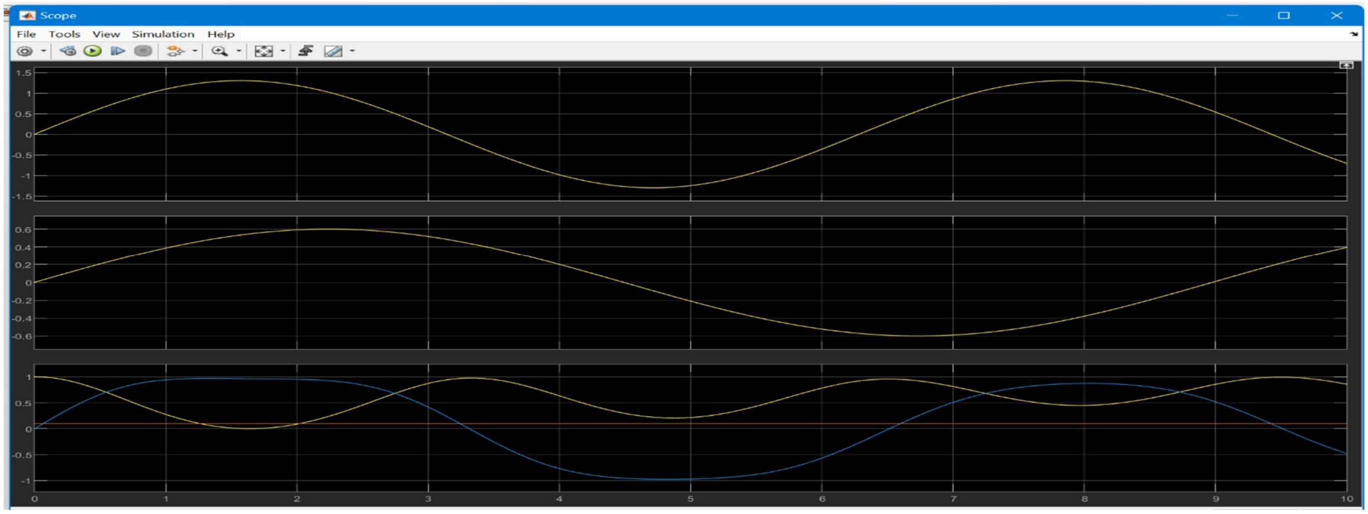

Fig. 5. Joint angles and end-effector plot

B. Simulink

Now, modelling a DC motor to move robot arm forward and backward, where the electrical energy will be provided to DC motor which is converted to mechanical energy. In detail the electrical energy is transferred to rotation energy of shaft which in turn provides angular momentum due to the attached arm in the motor. For that, the equation is to be achieved by deriving the conservation of energy between the applied torque and the position travelled respectively. Speed, torque, current and angle was plotted using scope block.

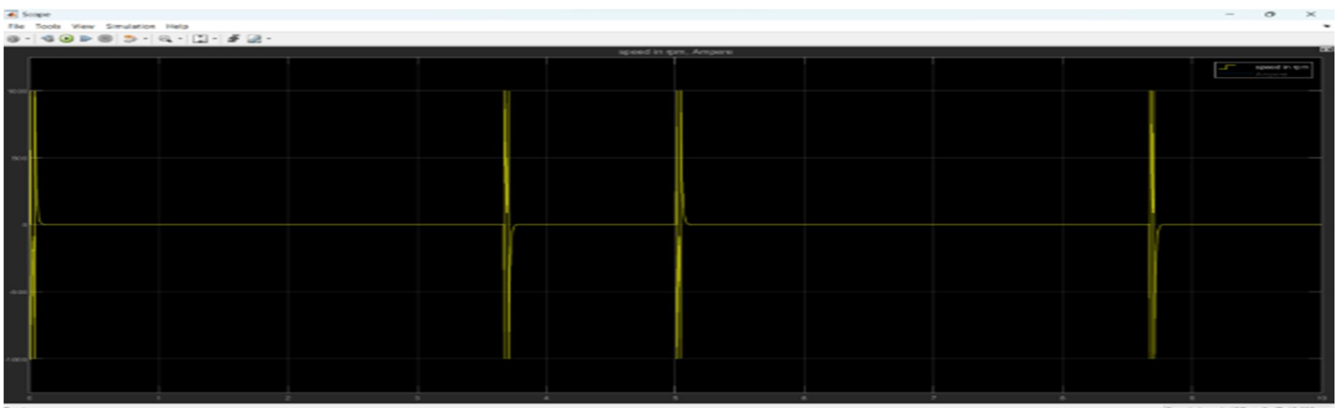

Fig. 6. Speed data(rpm)

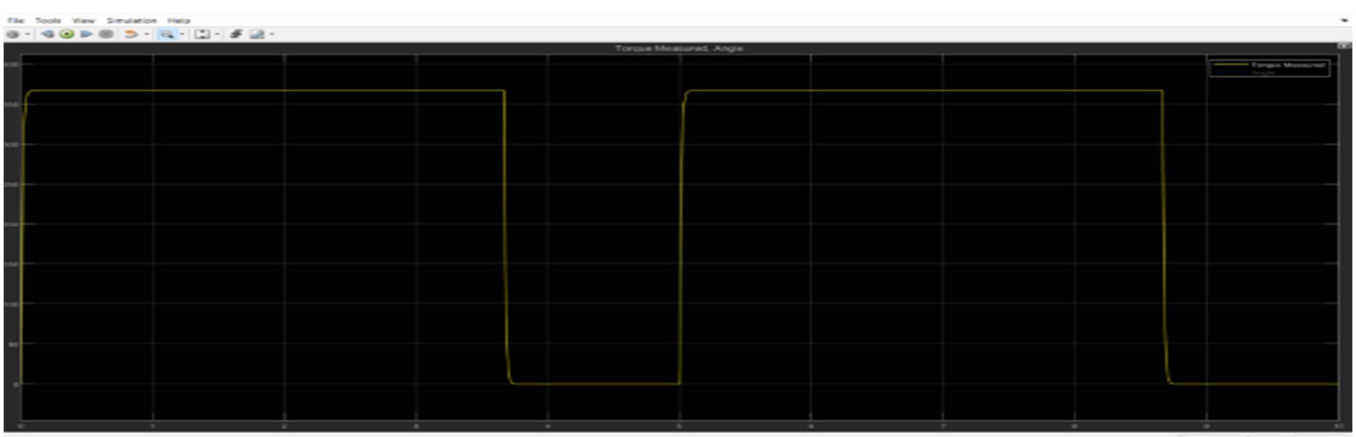

Fig. 7. Torque data

V. KEY OUTCOMES AND PROJECT DELIVERABLES

This successfully implements a two-DOF robotic manipulator, demonstrating the effectiveness of a **white-box model** in ensuring precise motion control. The final deliverables include a validated kinematic model and a functional Simulink simulation, enabling further research on control refinement illustrates the final end-effector movement within the simulated environment.

Simulation video can be found in the following link:
https://drive.google.com/file/d/12gIDHw9TIkib0icO2B_FcRu6WesFzgN3/view?usp=drivesdk
Other project resources can be found in this drive folder:
https://drive.google.com/drive/folders/1fLAdHqFw7kjZ6dgVyIHyfdzOrwCynmPz

VI. CONCLUSION

This experiment successfully implements and validates a **white-box model** for a two-DOF planar robotic manipulator, demonstrating the effectiveness of forward kinematics in motion control. The study provides a solid foundation for future enhancements, including AI-driven control, inverse kinematics, and expanded industrial applications using concept of digital twin.

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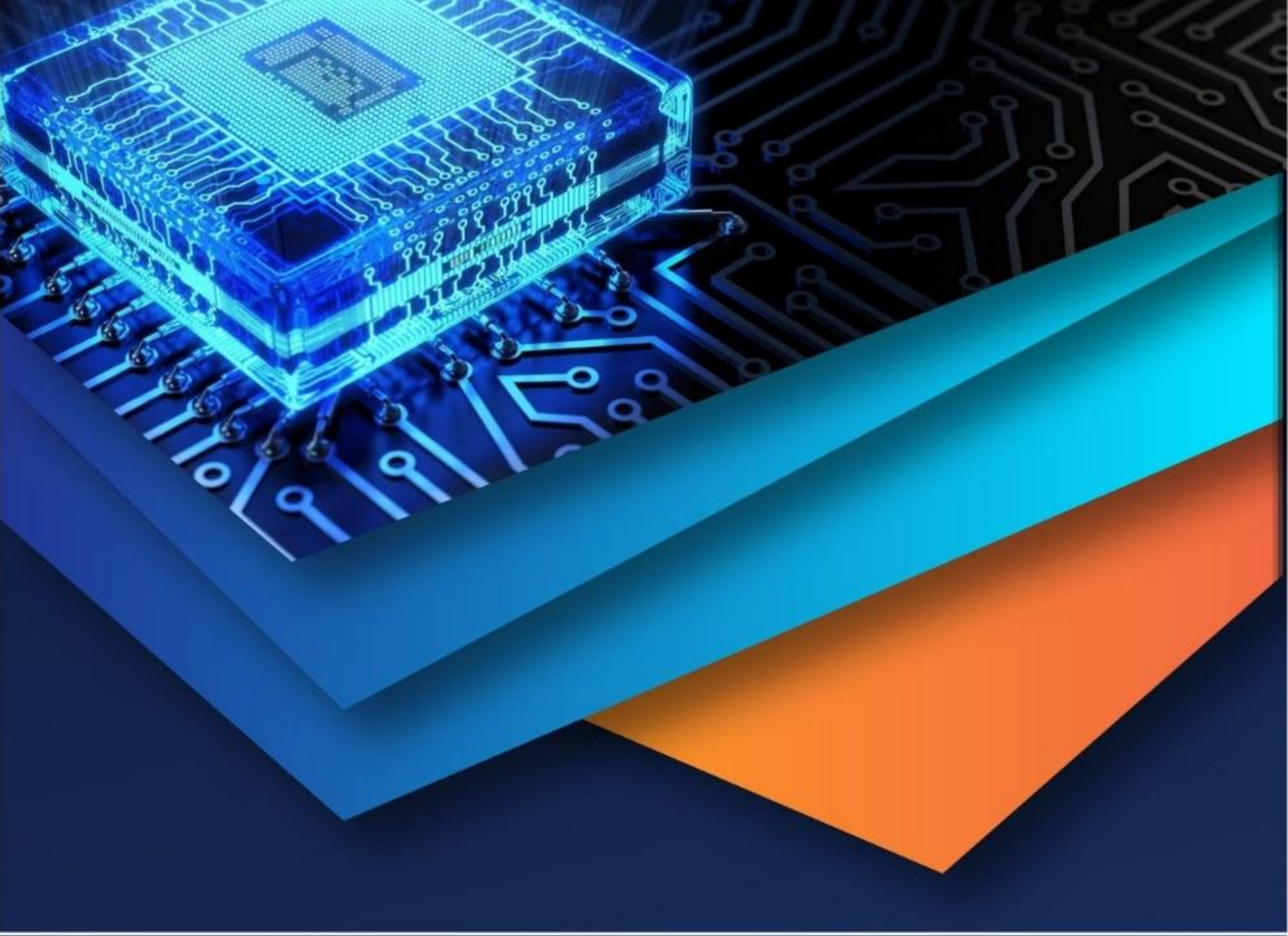

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