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HAAD: Human Aid and Assistive Drone

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Abstract: "HAAD: Human Aid and Assistive Drone " presents the design and implementation of a smart drone system, HAAD (Human Aid and Assistive Drone), aimed at supporting individuals in outdoor environments. The drone is capable of performing two core functions: item picking using a servo-based gripper and autonomous person following. Built on a Pixhawk flight controller and integrated with GPS, ESCs, brushless motors, and a custom gripper, the drone navigates using real-time location data and responds to user commands through a remote or app interface. The system combines autonomous flight control, human assistance logic, and field testing to demonstrate reliable performance in real-world scenarios such as aiding elderly or visually impaired individuals. HAAD highlights how aerial robotics can extend human capabilities and support daily tasks with mobility and precision.
Keywords: Assistive Robotics, Follow-Me Mode, Pixhawk 2.4.8, Autonomous Navigation, PID Control.

I. INTRODUCTION

The swift convergence of an aging global populace alongside the rise of autonomous systems has generated a significant demand for assistive robotics that can operate in unstructured environments. Although indoor robotic solutions have made considerable advancements, a substantial technological gap persists for systems that offer physical assistance in dynamic outdoor locations, such as backyards or public parks. Unmanned Aerial Vehicles (UAVs), particularly quadcopters, have surfaced as a leading platform to meet this requirement. The transformation of these devices from specialized military instruments into adaptable, intelligent aides has been propelled by advancements in embedded computing, effective sensor fusion, and advanced autonomous navigation algorithms. This democratization of high-performance robotics facilitates the creation of affordable and practical assistance solutions. HAAD (Human Aid and Assistive Drone) is a comprehensive system designed to serve as an intelligent robotic companion for individuals with mobility or visual challenges. For these users, even simple tasks such as picking up dropped keys, a phone, or medication can prove to be difficult or dangerous. By incorporating GPS for global positioning, a range of onboard sensors for stability, and computer vision for improved interaction, the project offers a dependable "helping hand" from the sky. The primary objective is to enhance the quality of daily life, encourage greater independence, and instill a sense of security through a dependable and intuitive aerial support system.

II. SYSTEM ARCHITECTURE AND FUNCTIONAL ANALYSIS.

A. System Architecture

The architectural design of the Human Aid and Assistive Drone (HAAD) is focused on a high-performance mechatronic framework, with the flight controller serving as the main processing and integration hub. This centralized setup is crucial for ensuring that all electrical, electronic, and computational subsystems function in a coordinated manner, enabling the reliable execution of complex flight commands and autonomous operations. The architecture is functionally divided into four interacting modules: the command and control interface, the central processing core, the power distribution network, and the electromechanical propulsion system. The command and control interface acts as the bridge between humans and machines, allowing users to provide high-level instructions through a remote or mobile application. These signals are received by an onboard receiver and transformed into standardized digital protocols, such as SBUS, for real-time interpretation by the autopilot system.

B. Central Processing and Navigational Core

The core computational element of the HAAD system is the Pixhawk 2.4.8 flight controller, which runs the ArduPilot firmware and oversees the integration of data from various onboard sensors. In order to ensure stability and orientation, the controller incorporates a barometer for maintaining altitude and a gyroscope/accelerometer for controlling attitude. A vital part of this system is the Ublox M8N GPS module, which delivers ongoing data about the drone's geographical location, altitude, and speed.

This GPS integration is essential for all autonomous functions, such as position hold, return-to-launch (RTL), and the sophisticated tracking necessary for the Follow-Me mode.

C. Power Distribution and Propulsion Network

Energy management is overseen by a high-capacity battery linked to a Power Distribution Board (PDB), which controls the high-current output required for the propulsion system while also supplying stable, low-voltage power to sensitive electronics such as the receiver and GPS. The propulsion system comprises four 920KV brushless DC (BLDC) motors that are regulated by Electronic Speed Controllers (ESCs). The flight controller transmits accurate PWM signals to the ESCs, which adjust the electrical energy supplied to the motors to produce the necessary aerodynamic thrust and torque for flight. By differentially controlling the rotational speed of each motor, the drone can exert precise forces, ensuring stable and agile maneuverability.

D. Functional Analysis and Operational Logic

The system's functional integration facilitates its transformation from a conventional UAV into an active assistive platform that can provide physical support. By analyzing real-time coordinates, the navigation planner produces velocity setpoints that allow the drone to follow a user at a steady and safe distance. For physical engagement, the system employs a specialized servo-actuated gripper mechanism that is engineered to grasp everyday objects of various shapes. To guarantee operational safety, the logic incorporates comprehensive failsafe protocols that initiate an automatic Return to Launch (RTL) sequence in the event of communication loss or a controlled landing if the battery level falls below 20%. This collaboration between propulsion, intelligence, and mechanical actuation empowers the drone to execute intricate tasks, such as retrieving medication or keys, thereby significantly improving the autonomy of individuals with limited mobility

III. METHODOLOGY AND REQUIREMENT ANALYSIS

A. Development Methodology

The development of the Human Aid and Assistive Drone (HAAD) follows a structured mechatronic engineering lifecycle, organized into four distinct phases: requirement analysis, hardware selection, software configuration, and a dual-stage validation process involving simulation and field deployment. This systematic approach ensures that every functional specification is addressed through a quantitative foundation before physical implementation, significantly reducing the risks associated with outdoor flight operations. By establishing a clear progression from theoretical design to virtual testing, the methodology guarantees that the final platform is capable of executing complex assistive tasks, such as autonomous tracking and object manipulation, with high reliability.

B. Functional and Performance Requirement

Requirement Analysis serves as the baseline for the system’s architecture, explicitly defining the capabilities necessary for effective human assistance in outdoor settings. The primary functional requirement is the Payload Capacity, which demands that the system lift and deliver small items like keys or medication. To support this, the propulsion system must maintain a 2:1 thrust-to-weight ratio to ensure stability during maneuvers. Performance criteria further specify that the drone must achieve a minimum flight time of 20 minutes and possess the structural integrity to resist wind speeds of up to 10 m/s within a 500-meter operational range. Additionally, sensor requirements dictate real-time object detection at speeds exceeding 15 FPS and a tracking error margin of less than 1 meter during the Follow-Me mode to ensure user safety.

C. Technical Design Constraint

The technical constraints are established to guarantee safety and operational integrity throughout all flight modes. A comprehensive Failsafe Protocol is essential, necessitating the system to initiate an automatic Return-to-Launch (RTL) sequence in the event of a prolonged communication loss or to perform a controlled landing if the battery level falls below 20%. Regarding physical interaction, the gripper mechanism must be adept at managing irregularly shaped objects with regulated force while delivering grasp feedback to the controller. These non-functional requirements are reinforced by a Ground Control Station (GCS) that offers continuous real-time telemetry and a manual override feature, ensuring that the human operator retains control during the execution of autonomous missions.

IV. DESIGN CALCULATIONS AND HARDWARE SELECTION

A. Propulsion and Thrust Modeling

The choice of the propulsion system represents a vital engineering decision that influences the flight stability and payload capacity of the HAAD system. To guarantee a safe and responsive operation in outdoor settings, a standard thrust-to-weight ratio of 2:1 has been established.

Considering the projected total takeoff weight of 1400g.which includes the frame, electronics, and battery.the propulsion system is required to produce a minimum total thrust of 2.8 kg.

The decision to utilize 920KV Brushless DC (BLDC) motors was made due to their capability to deliver approximately 860g of thrust per unit, leading to a total thrust of 3.44 kg for the quadcopter configuration. This results in a substantial thrust margin exceeding 20%, ensuring that the drone can accommodate the extra weight of retrieved objects while effectively countering external wind forces of up to 10 m/s.

B. Battery and Power Analysis

The power system should be able to supply high peak currents during takeoff and intense maneuvering without experiencing considerable voltage drops.

The system employs a 5000mAh Li-Po battery to ensure sufficient flight duration for assistive missions. With a peak current draw projected at 60A across four motors, the battery's discharge capability is confirmed through its C-rating. By opting for a battery with a 13C rating, the rated current capacity is validated as follows:

$$\text{Rated Current} = \text{Peak Current}/\text{C-Rating} = 70A/13C = 5.3A \quad (1)$$

This computation guarantees that the selected power supply fulfills the rigorous performance requirements of the flight controller and the mechanical gripper, all the while providing a consistent voltage for the delicate GPS and telemetry systems.

C. Hardware Selection Logic

The essential electronic components were chosen for their established reliability in autonomous flight applications. The Pixhawk 2.4.8 was selected as the primary flight controller due to its robust 32-bit STM32F427 Cortex M4 core and comprehensive sensor integration, which includes a barometer and gyroscope. For navigation purposes, the Ublox M8N GPS module was incorporated for its exceptional positional accuracy and swift satellite acquisition, both of which are essential for the Follow-Me tracking mode. The structural support is supplied by a lightweight yet durable F450 frame, which provides the required rigidity for affixing the custom servo-based gripper mechanism.

D. Mechanical Gripper Design

In order to achieve the main assistive goal of object retrieval, a dedicated mechanical actuator has been created. The design incorporates a lightweight, servo-actuated gripper that is directly controlled through the PWM outputs of the flight controller. This mechanism is designed to manipulate everyday objects of irregular shapes with a controlled force, offering a practical "helping hand" from the air. The combination of this mechanical system with the GPS-guided navigation core enables the drone to execute accurate pick-and-place operations, effectively connecting aerial mobility with physical assistance.

V. SIMULATION AND RESULTS

A. Simulation Environment and Methodology

The flight control system of the Human Aid and Assistive Drone (HAAD) was validated through a comprehensive two-stage simulation approach designed to verify both low-level stability and high-level autonomous features. The initial stage utilized MATLAB Simulink to construct a high-fidelity model of the drone's rotational and linear dynamics, motor-propeller assemblies, and cascaded PID control loops. This stage focused on diagnosing component-level performance, such as attitude stabilization and transient response. The second stage involved integrating this logic into a ROS-Gazebo environment, which provided a real-world physics engine to confirm the execution of the "Follow-Me" tracking algorithm and navigation planners in a dynamic virtual space.

B. Simulation Circuit of HAAD

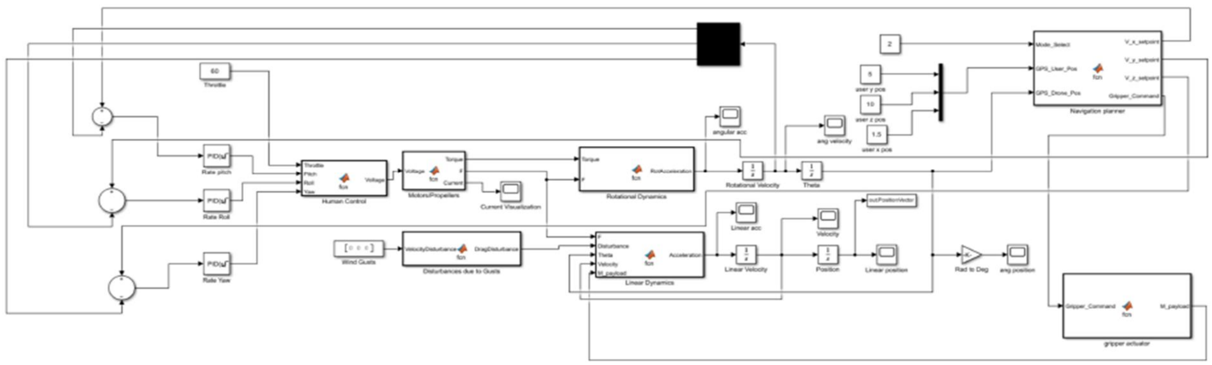

Figure.1 Simulation circuit of Human Aid and Assistive Drone

The flight dynamics and control system of the HAAD drone were modeled and validated using the simulation environment shown in fig. 5.1 using MATLAB Simulink.The model is build around a core control architecture that includes three PID controllers responsible for stabilizing the drone's attitude by regulating its pitch, roll and yaw rates.The output from these controllers is sent to a motors block, which simulates the conversion of electrical signals into the physical thrust and torque that drive the drone's motion. These forces are then fed into rotational dynamics and linear dynamics blocks,which model the physical response of the drone calculating its resulting position, velocity, and orientation. The simulation also incorporates a high level navigation planner block, which represents the autonomous follow me mode logic by generating velocity setpoints based on the drone's and the usesr's GPS positions. To ensure robustness, the model includes a wind gusts block to simulate external disturbances and a gripper actuator block that models the dynamic effect of picking up a payload. This comprehensive simulation allows for the thorough testing of both the low level flight stability and the high level autonomous navigation before physical implementation

C. Result

The validation of the HAAD flight control system was achieved through a high-fidelity MATLAB/Simulink environment, which modeled the drone's rotational and linear dynamics alongside cascaded PID control loops responsible for attitude stabilization. Analysis of the angular acceleration plots revealed high-magnitude corrective spikes at the simulation's start ($t=0$) that rapidly decayed to near zero within approximately 1 second, confirming the effectiveness of the PID controllers in neutralizing initial orientation errors and stabilizing the airframe. Furthermore, motor current visualization demonstrated that initial fluctuations across the four propulsion units converged into an identical, steady-state value after approximately 4 seconds. This convergence signifies an equilibrium of balanced thrust, which is a critical prerequisite for achieving a stable, level hover. By successfully modeling these responses and accounting for external disturbances like wind gusts and payload mass, the simulation provided quantitative evidence that the control strategy is robust and ready for physical implementation

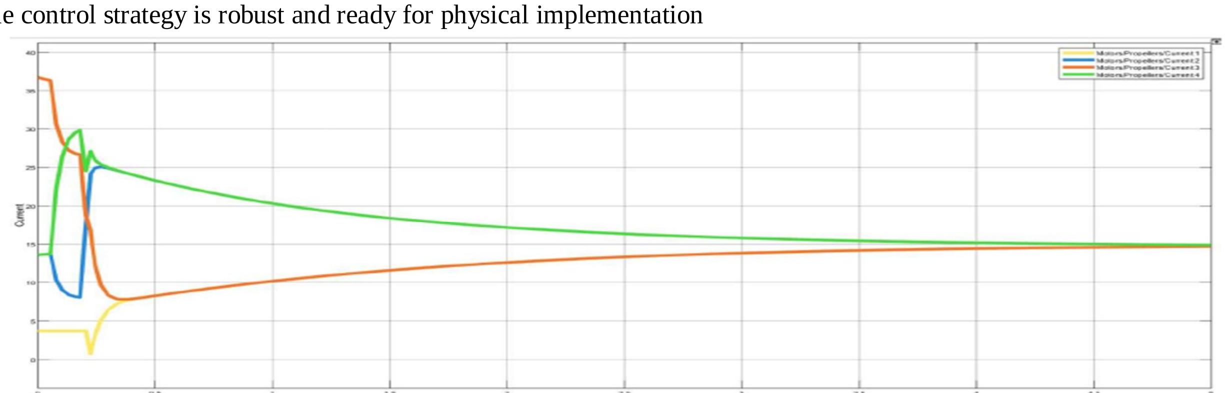

Figure.2 Motor Current Visualisation

D. Gazebo Validation

The Gazebo simulation acted as a practical demonstration for the advanced Follow-Me algorithm. Within this setting, the Navigation Planner handled real-time coordinates of a human target (depicted by a red figure). Logging to the console throughout the test verified that the drone effectively produced error correction signals for lateral movement, successfully following the target while navigating around obstacles in the dynamic virtual environment.

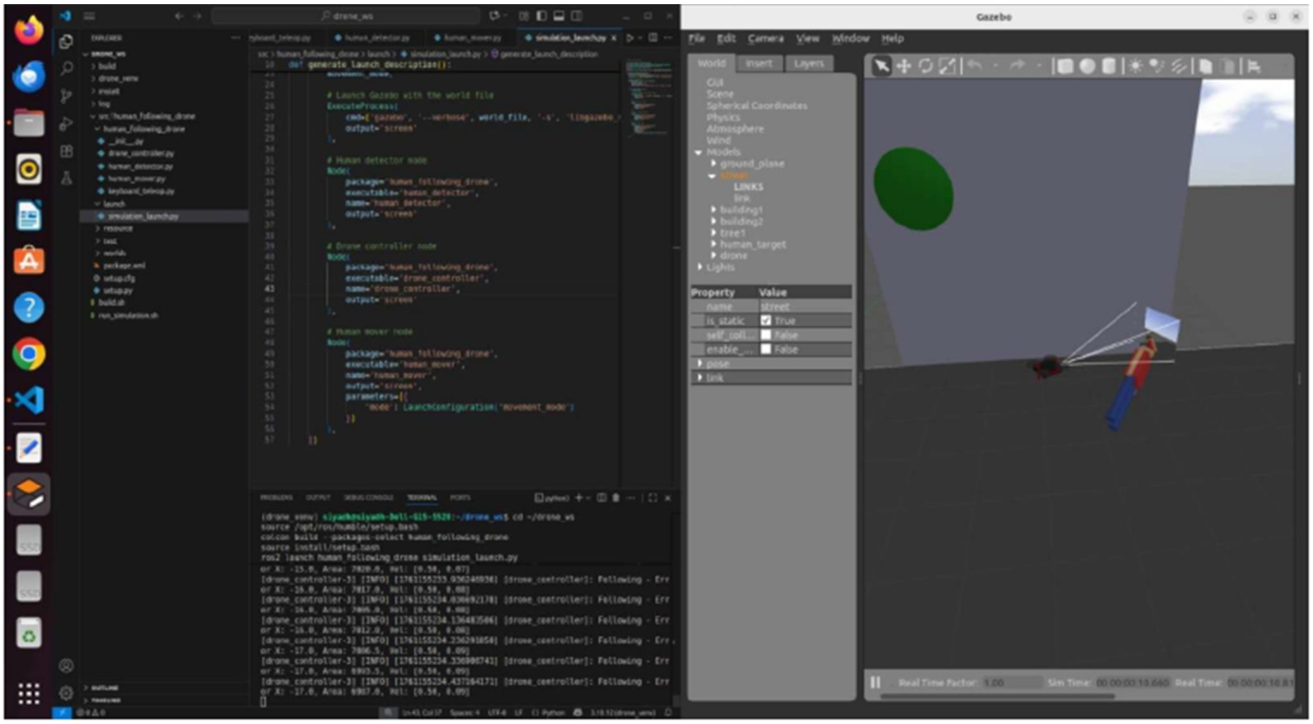

Figure.3 Simulation Window in Gazebo

VI. CONCLUSION

The effective design and theoretical validation of the Human Aid and Assistive Drone (HAAD) have been achieved through a methodical engineering process that includes requirement analysis, strategic hardware selection, and high-fidelity simulation. By utilizing a centralized control architecture and robust PID control strategies, the essential viability of an assistive aerial platform was distinctly demonstrated. Comprehensive simulations validated the system's capability to maintain a stable hover, which is a crucial prerequisite for any practical physical manipulation task in outdoor environments. The research highlights the significant potential for broadening the application of Unmanned Aerial Vehicles (UAVs) from mere observation to more intricate, interactive roles that offer direct support to humans. The results affirm the feasibility of the project, showing that a drone built with the specified components including the Pixhawk 2.4.8 and Ublox M8N GPS can successfully execute its primary functions of autonomous object retrieval and intelligent user tracking. By tackling the fundamental challenges of stability and control through a dual-validation approach utilizing MATLAB/Simulink and ROS-Gazebo, this study lays a solid groundwork for the future advancement of practical and accessible aerial robotic assistants aimed at enhancing the independence of vulnerable populations.

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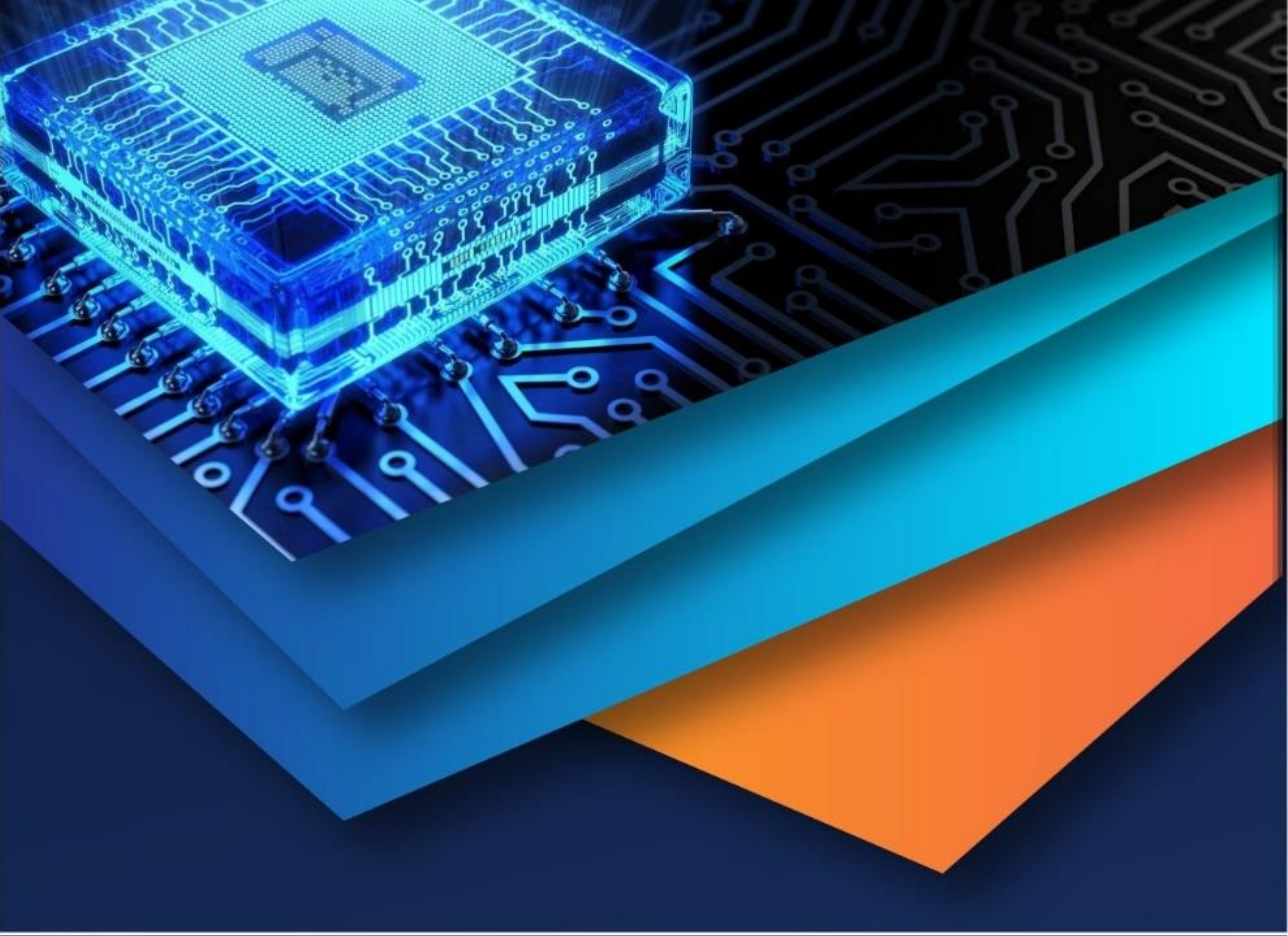

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