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Smart Indoor Assistive Navigation Robot using SLAM

Muhammed Ramees E K[1], Akash Rajeev[2], Muhammed Lisan K[3], Neetha John[4], Neethu Salim[5]
Electrical and Electronics Department, Mar Athanasius College of Engineering, Kothamangalam

Abstract: Indoor navigation remains a significant challenge for visually impaired individuals due to the absence of reliable positioning systems in enclosed environments. Conventional assistive tools provide limited obstacle detection but lack intelligent path planning and destination-based guidance. This paper presents a smart indoor assistive navigation robot that integrates LiDAR-based Simultaneous Localization and Mapping (SLAM), autonomous navigation, and offline voice interaction within a ROS 2 framework. A distributed processing architecture is implemented in which a Raspberry Pi 4 manages hardware interfacing and motor control, while mapping and path planning are executed on an external laptop to maintain efficiency at low cost. The robot employs differential drive locomotion with real-time obstacle avoidance and supports destination-based voice commands without internet dependency. Experimental evaluation in indoor environments demonstrates reliable mapping, stable localization, and consistent autonomous navigation. The proposed system offers a cost-effective and infrastructure-independent assistive mobility solution to enhance safety and independence for visually impaired individuals.

Keywords: Assistive Robotics, Indoor Navigation, Simultaneous Localization and Mapping (SLAM), ROS 2, LiDAR, Autonomous Mobile Robot, Voice Interaction, Distributed Processing, Obstacle Avoidance.

I. INTRODUCTION

Independent indoor mobility remains a persistent challenge for visually impaired individuals, particularly in environments where Global Positioning System (GPS) signals are unavailable. Traditional assistive tools such as white canes and guide dogs provide immediate obstacle detection but do not support intelligent path planning, spatial awareness, or destination-based navigation. As public and institutional buildings grow increasingly complex, there is a critical need for intelligent assistive technologies capable of enabling safe and autonomous indoor movement.

Recent advancements in robotics and sensing have enabled autonomous mobile systems to perform indoor mapping and localization using Simultaneous Localization and Mapping (SLAM) techniques. LiDAR-based SLAM offers reliable perception without requiring dedicated infrastructure, making it suitable for assistive applications. While wearable devices and infrastructuredependent localization systems have been proposed, many solutions increase user cognitive load, require environmental modification, or rely on continuous internet connectivity. Robotic guidance platforms provide a promising alternative by combining autonomous navigation with physical interaction, thereby improving user confidence and safety.

Despite these developments, practical deployment remains constrained by high system cost, computational complexity, and limited portability. Many existing prototypes rely on high-performance embedded systems that reduce affordability and scalability. Therefore, there is a need for a low-cost, infrastructure-independent assistive navigation system that balances performance and practicality.

In this work, a smart indoor assistive navigation robot is developed using LiDAR-based SLAM, autonomous navigation, and offline voice interaction within a distributed processing framework. The system aims to provide reliable indoor mobility while maintaining affordability and user accessibility.

II. RELATED WORK

Assistive navigation systems for visually impaired individuals can be broadly categorized into wearable solutions, infrastructurebased localization systems, and robotic guidance platforms.Wearable and smartphone-based systems typically provide audio or haptic cues derived from sensor data or pre-mapped environments. Although portable and cost-effective, these approaches often increase cognitive load and lack physical guidance, limiting their effectiveness in complex indoor environments.

Infrastructure-based indoor localization methods, including RFID, Bluetooth beacons, Wi-Fi, and ultra-wideband systems, offer reasonable positioning accuracy but require environmental modifications and dedicated installations. Such dependence on external infrastructure restricts scalability and adaptability across different locations.

Robotic assistive platforms have emerged as a promising alternative by combining autonomous navigation with physical interaction. Robots equipped with LiDAR or vision sensors can perform real-time mapping, localization, and obstacle avoidance. Physical guidance mechanisms enhance user confidence and reduce navigation error compared to purely wearable systems. SLAM-based approaches, particularly when integrated with robotics middleware such as ROS, enable infrastructure-independent indoor navigation.

Recent studies have also explored voice-based human–robot interaction for intuitive command input. However, many implementations rely on cloud-based processing, introducing latency and privacy concerns.Despite advancements, practical deployment remains constrained by high system cost, computational requirements, and limited portability. Motivated by these challenges, the present work proposes a cost-effective, SLAM-based assistive navigation robot that integrates offline voice interaction within a distributed processing framework to enhance affordability, privacy, and real-world usability.

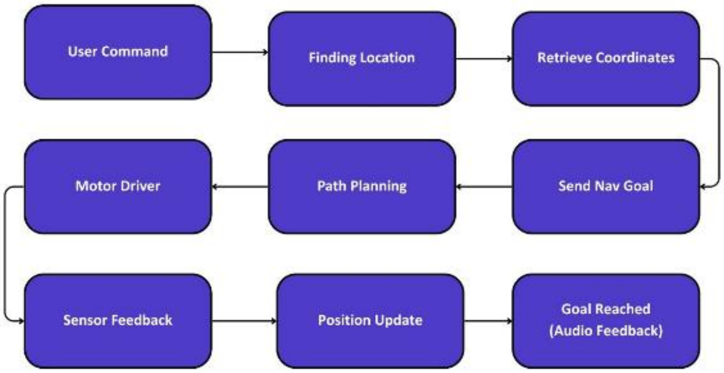

Figure 1: Operational workflow of the assistive navigation robot

III. SYSTEM ARCHITECTURE

The proposed assistive navigation robot integrates perception, navigation, user interaction, and distributed computation within a ROS 2-based framework. The system combines onboard hardware control with external processing to achieve reliable real-time performance using cost-effective components.

A. Architecture Overview

The system consists of four main functional modules:

1) *Perception and Mapping:* A LiDAR sensor captures environmental distance measurements, which are processed using a
2) SLAM algorithm to generate a 2D occupancy grid map. The same sensor data support real-time localization during navigation.
3) *Navigation and Control:* Using the stored map, the navigation module computes an optimal path to the target location. A local planner ensures dynamic obstacle avoidance. Motion commands are transmitted to the motor driver via the Raspberry Pi, enabling differential drive locomotion.
4) *Human Robot Interaction:* An offline voice interface allows users to specify predefined destination labels. Upon command recognition, the system retrieves the corresponding coordinates and initiates navigation. A physical handle provides tactile guidance during movement.
5) *Distributed Processing:* To overcome onboard computational limitations, SLAM and high-level navigation tasks are executed on an external laptop. The Raspberry Pi handles sensor acquisition and motor control. Communication between devices is established using ROS 2 over a wireless network.

B. System Workflow

The workflow begins with a voice command specifying a destination. The system retrieves the associated coordinates, performs path planning, and executes motion control. Continuous LiDAR and odometry feedback enable real-time localization and obstacle avoidance. Upon reaching the destination, audio confirmation is provided to the user.

IV. HARDWARE DESIGN

The hardware architecture of the proposed assistive navigation robot is designed for reliable indoor mobility while maintaining low cost and portability. The system integrates a differential drive mechanism, onboard processing unit, LiDAR-based perception, motor control circuitry, power supply, and a tactile guidance interface.

A. Mechanical and Actuation System

The robot employs a differential drive configuration with two rear DC motors and front caster wheels for balance. Motor speeds are regulated using PWM signals through a motor driver interfaced with the Raspberry Pi. Differential drive kinematics enables precise linear and rotational motion required for indoor navigation and obstacle avoidance.

B. Processing and Communication

A Raspberry Pi 4 serves as the onboard controller, handling sensor interfacing, motor control, and communication. Computationally intensive tasks such as SLAM and navigation planning are executed on an external laptop via a wireless ROS 2 network, enabling distributed processing and real-time data exchange.

C. Perception and Localization

Environmental perception is achieved using a LiDAR sensor that provides distance measurements for mapping, localization, and obstacle detection. Odometry derived from wheel motion supports pose estimation and improves localization accuracy through sensor fusion.

Figure 2: Raspberry Pi 4 onboard controller

Figure 3: LiDAR sensor used for perception

D. Power and User Interaction

The robot is powered by a rechargeable battery system with voltage regulation for stable operation. A vertical handle provides tactile guidance, while an audio feedback module communicates navigation status and destination confirmation, enabling intuitive human–robot interaction.

V. SOFTWARE IMPLEMENTATION

The assistive navigation robot is developed using Ubuntu and the ROS 2 framework, which provides modular integration of perception, localization, navigation, and human–robot interaction components. A distributed architecture is employed in which computationally intensive processes execute on an external laptop, while the Raspberry Pi manages sensor interfacing and motor control.

A. Middleware and Communication

ROS 2 serves as the middleware, enabling communication between modules using a publisher–subscriber architecture. The Raspberry Pi and external laptop are connected through a wireless ROS 2 network, allowing real-time transmission of sensor data and navigation commands.

B. SLAM and Map Generation

LiDAR-based SLAM is used to generate a two-dimensional occupancy grid map while estimating the robot's pose. During the mapping phase, teleoperation is employed to explore the environment and collect sensor data. The generated map is stored for autonomous navigation, and semantic labels are assigned to predefined locations for voice-based destination selection.

C. Localization and Navigation

Autonomous navigation is implemented using the ROS 2 Nav2 stack. Localization is performed by estimating the robot's pose within the pre-built map using LiDAR and odometry data. The navigation system includes:
Global Planner: Computes an optimal path to the target destination.
Local Planner: Adjusts motion commands in real time to avoid dynamic obstacles.
Continuous sensor feedback ensures safe trajectory execution and obstacle avoidance.

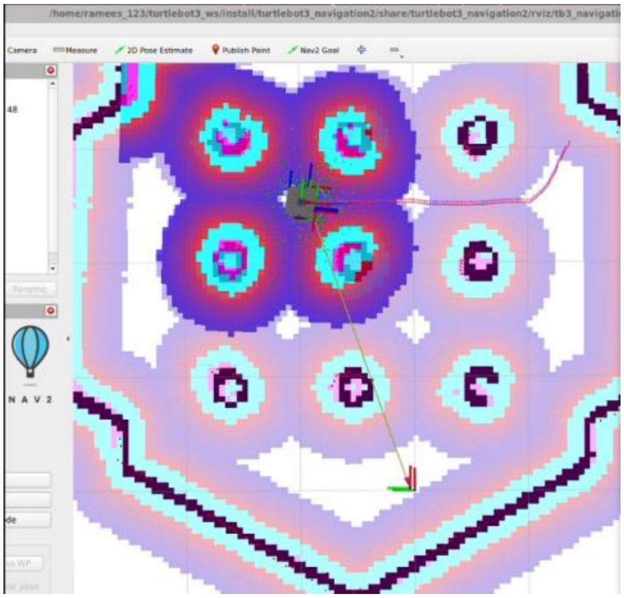

Figure 4: Generated occupancy grid map

D. Voice Interaction and Distributed Processing

An offline voice recognition module converts speech commands into predefined destination labels without internet dependency. Upon command validation, the corresponding coordinates are sent to the navigation module for execution.Due to limited onboard computational capability, SLAM and high-level planning are executed on the external laptop.

The Raspberry Pi handles hardwarelevel control, sensor acquisition, and motor actuation. This distributed framework improves system efficiency while maintaining low-cost hardware implementation.

E. Operational Sequence

The system first performs map generation via teleoperation. During assistive operation, voice commands trigger destination retrieval, path planning, and closed-loop navigation with continuous localization updates until the goal is reached.

VI. WORKING PRINCIPLE

The proposed assistive navigation robot operates through the integration of SLAM-based mapping, localization, autonomous navigation, and voice interaction within a closed-loop control framework. The system functions in two main phases: mapping and assistive navigation.

A. Mapping Phase

During the initial stage, the robot is teleoperated to explore the indoor environment. LiDAR data are processed using a SLAM algorithm to generate a two-dimensional occupancy grid map while estimating the robot's pose. The completed map is stored, and predefined locations are assigned semantic labels for destination-based navigation.

B. Assistive Navigation Phase

In assistive mode, the user specifies a destination through the offline voice interface. The recognized command is matched with stored location labels, and the corresponding coordinates are sent to the navigation module. A global planner computes an optimal path, while a local planner performs real-time obstacle avoidance using continuous LiDAR and odometry feedback.Motion commands are transmitted to the motor driver via the Raspberry Pi, enabling differential drive locomotion. Localization algorithms continuously update the robot's pose, forming a closed-loop system that ensures safe and accurate trajectory execution.A physical handle provides tactile guidance, and audio feedback communicates navigation status and destination arrival. The overall workflow integrates perception, planning, control, and interaction to achieve reliable indoor navigation.

VII. EXPERIMENTAL SETUP

The proposed assistive navigation robot was evaluated in structured indoor environments to validate mapping accuracy, localization stability, navigation performance, obstacle avoidance, and voice interaction capability.

A. Experimental Configuration

The experimental platform consisted of the mobile robot equipped with a LiDAR sensor, Raspberry Pi 4 controller, motor driver, and differential drive system. An external laptop performed SLAM computation and navigation planning. Tests were conducted in corridors and rooms containing both static and dynamic obstacles. ROS 2 tools were used to monitor mapping and localization performance.

Figure 5: Developed assistive navigation robot prototype

B. Mapping and Localization

The LiDAR-based SLAM algorithm successfully generated consistent two-dimensional occupancy grid maps. The robot maintained stable pose estimation during navigation, with minor deviations corrected through continuous sensor feedback.

C. Navigation and Obstacle Avoidance

The navigation module computed collision-free paths to predefined destinations. Smooth trajectory tracking was achieved using differential drive control. Real-time obstacle avoidance enabled safe navigation around unexpected objects. The closed-loop system ensured reliable operation under moderate disturbances.

D. Voice Interaction and System Performance

The offline voice module successfully interpreted predefined destination commands without internet dependency. Recognition accuracy remained satisfactory under typical indoor noise conditions.The distributed processing framework improved overall system efficiency by reducing onboard computational load. The robot demonstrated stable operation during extended testing, and the tactile handle combined with audio feedback enhanced user usability.

E. Discussion

Experimental results confirm reliable indoor navigation performance using cost-effective hardware. Although operation is limited to pre-mapped environments and voice recognition may be affected by high noise levels, the system demonstrates practical feasibility and scalability for assistive mobility applications.

VIII. FUTURE SCOPE

Although the proposed assistive navigation robot demonstrates reliable indoor performance, several enhancements can improve its scalability and robustness.The current system operates using a pre-generated occupancy grid map and therefore cannot autonomously navigate unknown environments without prior mapping. Future work may incorporate real-time adaptive mapping and dynamic map updating to improve flexibility in changing indoor conditions.Onboard computational capability is limited by the Raspberry Pi platform, necessitating distributed processing with an external laptop. Integrating more powerful embedded processors would enable standalone operation and support advanced algorithms such as high-resolution SLAM and deep learning-based perception.

LiDAR-based localization may experience reduced accuracy in feature-sparse or reflective environments, and excessive dynamic obstacles can affect short-term planning efficiency. Incorporating multi-sensor fusion techniques, such as vision-based perception or depth sensing, could enhance robustness.The offline voice recognition module may be sensitive to background noise and pronunciation variations. Improved speech models and noise filtering techniques can enhance recognition reliability.Battery life and mechanical constraints also limit extended deployment and operation on uneven terrain. Future improvements in power management, chassis design, and mobility mechanisms can broaden application scenarios.Overall, integrating advanced perception, improved processing capability, and enhanced mobility design will further strengthen the system’s effectiveness for real-world assistive navigation applications.

IX. SUSTAINABILITY AND SOCIAL IMPACT

The proposed assistive navigation robot aligns with the United Nations Sustainable Development Goals (SDGs), particularly SDG 3 (Good Health and Well-Being), SDG 9 (Industry, Innovation, and Infrastructure), and SDG 10 (Reduced Inequalities). By addressing mobility challenges faced by visually impaired individuals, the system promotes independent living, safety, and improved access to indoor spaces.The integration of autonomous navigation and offline voice interaction enhances accessibility and supports inclusive infrastructure development, contributing to reduced social and mobility inequalities. The low-cost hardware implementation improves affordability and scalability, enabling deployment in educational institutions, healthcare facilities, and public buildings, especially in resource-constrained environments.

From an environmental perspective, the use of energy-efficient embedded systems and rechargeable power sources minimizes resource consumption. The modular architecture supports incremental upgrades without full system replacement, reducing electronic waste and extending system lifecycle.Additionally, the implementation of offline voice processing ensures data privacy and ethical technology usage by eliminating dependence on cloud-based services. Overall, the system contributes to sustainable, inclusive, and human-centered technological development.

X. RESULTS AND DISCUSSION

The performance of the proposed smart indoor assistive navigation robot was evaluated through experimental trials conducted in structured indoor environments. The evaluation focuses on mapping accuracy, localization stability, navigation reliability, obstacle avoidance capability, and overall system responsiveness. These experiments were designed to verify whether the proposed system can provide consistent and reliable indoor guidance for visually impaired users.

A. Mapping Accuracy

The mapping performance of the system was evaluated using the LiDAR-based SLAM algorithm integrated within the ROS 2 framework. During the mapping phase, the robot was teleoperated through corridors and rooms to collect LiDAR scan data. These scans were processed to generate a two-dimensional occupancy grid map representing the spatial structure of the environment.

Experimental results showed that the SLAM implementation produced consistent and repeatable maps with clearly defined environmental features such as walls, corridors, and door openings. The generated maps exhibited minimal distortion, indicating stable scan matching and accurate pose estimation during the mapping process. The average mapping completion time for a medium-sized indoor area of approximately 150–200 m² was observed to be between 8 and 12 minutes, depending on the complexity of the environment and the exploration path taken during teleoperation.The quality of the generated maps demonstrates that LiDAR-based SLAM provides sufficient spatial accuracy for indoor assistive navigation applications. Accurate mapping is essential because it directly influences localization reliability and path planning efficiency during autonomous navigation.

B. Localization Performance

Localization performance was assessed by analyzing the robot’s ability to estimate and maintain its position within the previously generated map during navigation trials. The localization module utilized LiDAR scan matching combined with odometry data obtained from wheel motion.Experimental observations indicate that the robot maintained stable pose estimation throughout repeated navigation tests. During short-range navigation tasks, the system exhibited negligible positional drift, allowing the robot to accurately follow planned trajectories. In areas with strong geometric features, such as corridors and corners, localization remained highly stable due to reliable scan matching.

Minor deviations in pose estimation were occasionally observed in feature-sparse regions where LiDAR measurements provided limited reference points. However, these deviations were automatically corrected through continuous sensor updates and probabilistic localization algorithms. As a result, the robot was able to quickly recover from small localization errors without affecting navigation performance.The localization module demonstrated reliable operation under both stationary and dynamic conditions. The integration of LiDAR observations with odometry feedback enabled robust position tracking, which is essential for accurate path planning and safe autonomous navigation in indoor environments.

XI. CONCLUSIONS

This paper presented the design and implementation of a smart indoor assistive navigation robot based on lidar-driven slam, autonomous navigation, and offline voice interaction. The system was developed to support visually impaired individuals in navigating indoor environments safely and independently. By integrating mapping, localization, path planning, obstacle avoidance, and multimodal user interaction within a distributed processing architecture, the proposed solution demonstrates the feasibility of a low-cost yet reliable assistive robotic platform. The implementation using ros 2 and ubuntu provided a modular and scalable framework, while the combination of raspberry pi and external computing resources enabled efficient execution of computationally intensive tasks without requiring expensive embedded hardware. The differential drive mechanism ensured smooth mobility, and the physical handle interface offered intuitive tactile guidance for users. Experimental evaluations confirmed accurate map generation, stable localization, reliable obstacle avoidance, and effective voice-based destination control. Although certain limitations remain, including dependence on a pre-mapped environment and reliance on distributed processing, the developed prototype establishes a strong foundation for future enhancements in assistive robotics. The proposed system demonstrates that affordable, infrastructureindependent navigation robots can significantly improve indoor mobility support for visually impaired individuals. Overall, this work contributes to the advancement of human-centered assistive robotics by combining autonomy, accessibility, and cost.

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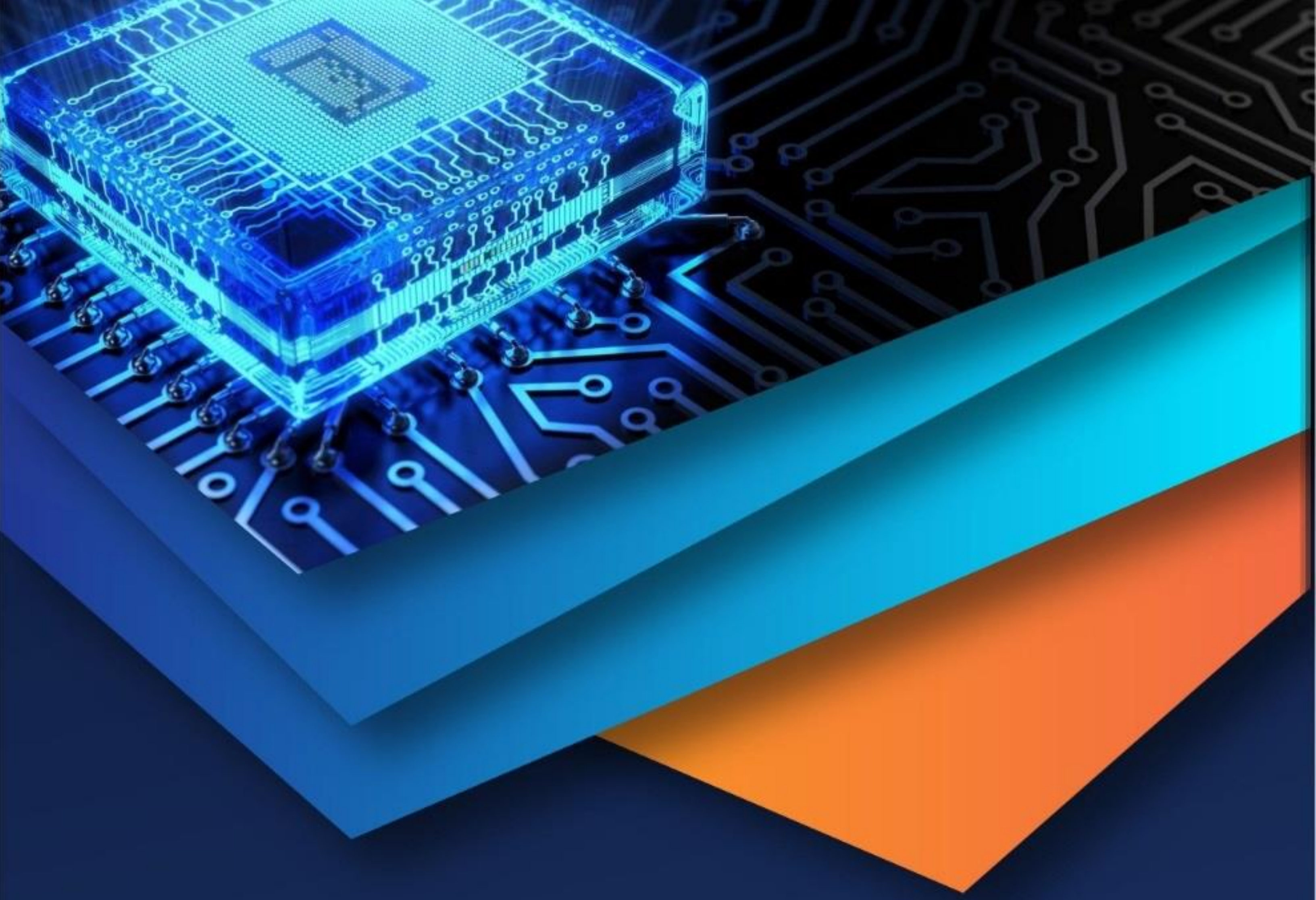

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