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SmartEdu Track

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Abstract: ***Traditional attendance management in educational institutions relies on manual roll calls and paper registers, which are time-consuming, prone to proxy attendance (buddy punching), and inefficient for large classes. This paper presents SmartEduTrack, an intelligent, secure, and contactless web-based attendance management system designed to overcome these limitations. The system integrates dynamic QR codes that automatically refresh every 5–10 seconds and expire after 15 minutes, mandatory browser-based GPS geofencing, real-time live dashboards, lightweight AI-powered analytics for attendance trends and predictions, and a multi-role architecture supporting students, teachers, parents/guardians, and administrators.***
Developed as a full-stack application using FastAPI backend, React frontend, and PostgreSQL database with JWT-based authentication, SmartEduTrack enables instant, proxy-proof attendance marking through standard smartphone cameras. The system was implemented and rigorously tested in a simulated college environment with 50 students and multiple faculty members. Experimental results demonstrate an 85–90% reduction in attendance time, 99.2% recording accuracy, 100% prevention of proxy attendance, and high user satisfaction (overall rating 4.85/5).
SmartEduTrack provides a practical, scalable, and cost-effective solution for modern educational institutions, significantly improving administrative efficiency, student accountability, and parental involvement while promoting paperless operations.
Keywords: Dynamic QR Code, Geofencing, Contactless Attendance, Real-time Dashboard, AI Analytics, Proxy Prevention, Role-based Authentication, Educational Technology

I. INTRODUCTION

Attendance management is a fundamental administrative process in educational institutions, essential for monitoring student engagement, ensuring academic compliance, and enabling timely interventions. However, conventional methods such as manual roll calls, paper registers, biometric systems, and RFID cards suffer from several critical drawbacks. These include significant time consumption (10–20 minutes per class), high susceptibility to proxy attendance (buddy punching), inaccurate record-keeping, privacy concerns, and high implementation costs. The environmental impact of paper-based systems further adds to their inefficiency.

The widespread adoption of smartphones and web technologies has opened opportunities for digital, contactless alternatives. Early QR code-based systems offered speed and cost-effectiveness but remained vulnerable to proxy attendance through screenshot sharing. Recent advancements introduced dynamic QR codes and session tokens; however, most existing solutions still lack robust physical presence verification, real-time monitoring, intelligent analytics, and multi-stakeholder access.

This paper presents SmartEduTrack, an intelligent, secure, and cost-effective web-based attendance management system that addresses these limitations. The system integrates dynamic QR codes that automatically refresh every 5–10 seconds and expire after 15 minutes, mandatory browser-based GPS geofencing for location verification, real-time live dashboards, lightweight AI-powered analytics for attendance trends and low-attendance predictions, and a **multi-role architecture** supporting students, teachers, parents/guardians, and administrators.

Built as a full-stack application using FastAPI (backend), React (frontend), and PostgreSQL (database) with JWT-based authentication, SmartEduTrack enables instant, proxy-proof attendance marking using any standard smartphone camera. No dedicated mobile app or specialized hardware is required, making it highly accessible for resource-constrained educational environments in India and beyond.

The primary contributions of this work include:

1) A novel combination of rapid dynamic QR codes with mandatory geofencing for strong proxy prevention.
2) Real-time dashboard and AI analytics for actionable academic insights.
3) Multi-role support including a dedicated parent/guardian portal.
4) Comprehensive evaluation demonstrating 85–90% reduction in attendance time and 100% proxy prevention.

The remainder of this paper is organized as follows: Section 2 reviews related literature, Section 3 describes the proposed system architecture and algorithms, Section 4 presents the implementation details, Section 5 discusses experimental results, and Section 6 concludes the paper with future scope.

II. OBJECTIVES

The primary objective of this research is to design, develop, and evaluate a secure, efficient, contactless, and intelligent web-based attendance management system that overcomes the limitations of traditional manual and static QR-based methods.

The specific objectives are as follows:

1) To develop a multi-role web application supporting distinct access levels for students, teachers, parents/guardians, and administrators with secure JWT-based authentication.

2) To implement dynamic QR codes with automatic refresh (every 5–10 seconds) and session expiry (15 minutes) for effective proxy prevention.

3) To integrate mandatory browser-based GPS geofencing to verify the student's physical presence within the classroom radius during attendance marking.

4) To provide a real-time live dashboard for teachers along with lightweight AI-powered analytics for attendance trends, predictions, and automated alerts.

5) To design a dedicated parent/guardian portal and automated PDF/Excel reporting system for enhanced transparency and stakeholder engagement.

6) To evaluate the system's performance in terms of time efficiency, accuracy, proxy prevention, usability, and overall effectiveness through rigorous testing in a simulated college environment.

These objectives collectively aim to create a practical, scalable, and intelligent attendance solution suitable for modern educational institutions.

III. LITERATURE REVIEW

Attendance management has evolved from traditional manual roll calls and paper registers to digital solutions due to persistent issues of time inefficiency, human error, and proxy attendance (buddy punching). Early electronic systems based on RFID and biometrics improved speed but suffered from high hardware costs, privacy concerns, and infrastructure dependency [1], [2].

Quick Response (QR) codes emerged as a low-cost, contactless alternative. Initial implementations (2014–2019) used static QR codes displayed at the beginning of a lecture. While these systems significantly reduced attendance time, they remained highly vulnerable to proxy attendance through screenshot sharing [1], [5]. Subsequent works (2020–2022) introduced session-specific tokens and basic uniqueness checks, which improved accuracy but still allowed rapid code sharing by absent students [2], [3], [4].

Recent research (2023–2025) has focused on dynamic and time-limited QR codes to address proxy risks. Sharma et al. (2023) proposed encrypted dynamic QR codes with session expiry [7]. Nwabuwe et al. (2023) integrated dynamic QR codes with geofencing and IMEI verification, achieving near-zero fraud in controlled tests [8]. Mohammed and Zidan (2023) explored animated multi-frame QR codes for enhanced screenshot resistance [9]. Benesa et al. (2024) evaluated user satisfaction and reported high acceptance along with notable time savings [10]. Systematic literature reviews confirm that hybrid approaches combining dynamic QR codes with geofencing and analytics yield 60–90% reduction in attendance time and near-100% accuracy [11], [12].

Despite these advancements, most existing systems still lack one or more critical features: mandatory physical presence verification, real-time dashboards, AI-driven predictive analytics, and multi-role support (including parent/guardian access). Few solutions provide automated reporting or seamless integration of location-based security with intelligent insights.

The proposed SmartEduTrack system addresses these gaps by combining rapid dynamic QR refresh (5–10 seconds), mandatory browser-based GPS geofencing, real-time live dashboards, lightweight AI analytics for trend prediction, and full multi-role support. This work advances the state-of-the-art by delivering a comprehensive, lightweight, and highly secure attendance management solution specifically tailored for resource-constrained educational environments.

IV. METHODOLOGY

The SmartEduTrack system was developed following an iterative prototyping methodology based on a client-server architecture. This approach allowed continuous refinement of core features such as dynamic QR generation, geofencing, and real-time analytics while adhering to academic project constraints.

A. System Architectur

The system is implemented as a full-stack web application with the following components:

- Backend: FastAPI (Python 3.10+) for RESTful APIs, authentication, session management, and business logic.
- Frontend: React.js for responsive UI, dynamic QR display, and real-time dashboard updates.
- Database: PostgreSQL for secure storage of users, subjects, sessions, attendance records, and analytics.
- Authentication: JWT-based token system with role-based access control supporting four user roles — Student, Teacher, Parent/Guardian, and Administrator.

B. Core Techniques and Algorithms

Key functionalities are realized through the following models and algorithms:

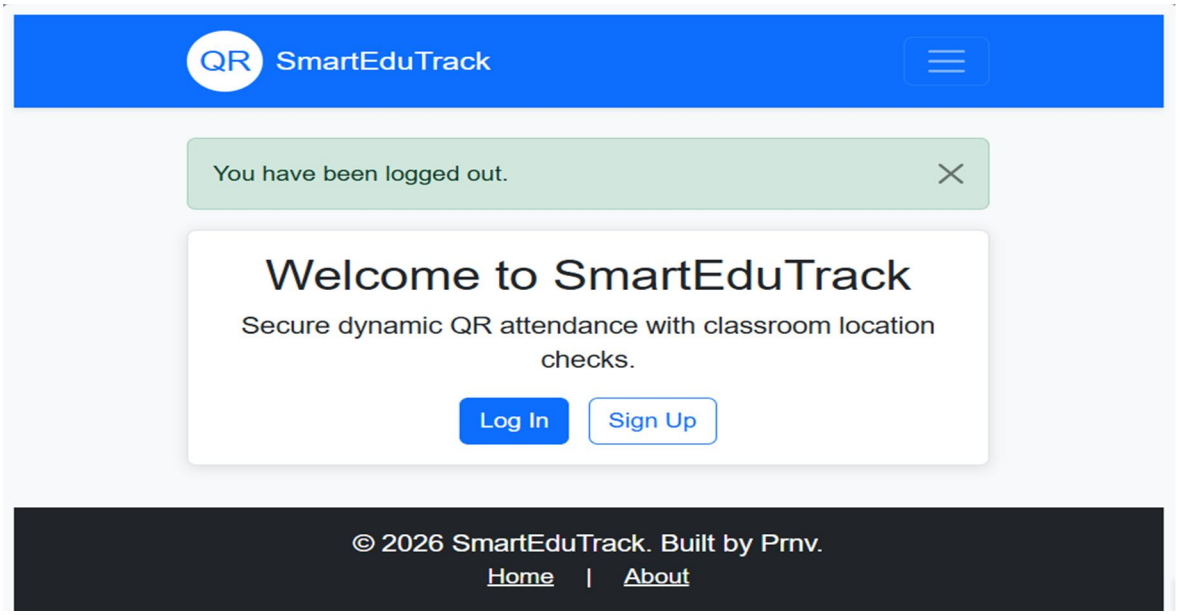
- Dynamic QR Code Model: Generates a new cryptographically secure session token every 5–10 seconds with automatic 15-minute expiry.
- Geofencing Validation: Browser GPS coordinates are captured and validated against classroom location using the Haversine distance formula.
- Attendance Marking & Validation: Server-side checks verify token validity, session expiry, geofencing compliance, and duplicate prevention.
- Real-time AI Analytics: Lightweight machine learning (linear regression and moving averages via scikit-learn) processes historical data to generate trends, predictions, and automated alerts.
- Real-time Communication: WebSocket or Server-Sent Events enable instant dashboard updates.
- Development was carried out incrementally using Git for version control. All critical database operations are ACID-compliant. The system is fully browser-based and requires no dedicated mobile app or specialized hardware, ensuring high accessibility and ease of deployment on standard cloud platforms.

V. SYSTEM WORKFLOW

The SmartEduTrack system follows a clear, sequential workflow that ensures secure, contactless, and real-time attendance marking. The complete process is illustrated in Figure X (System Workflow Diagram) and operates as follows:

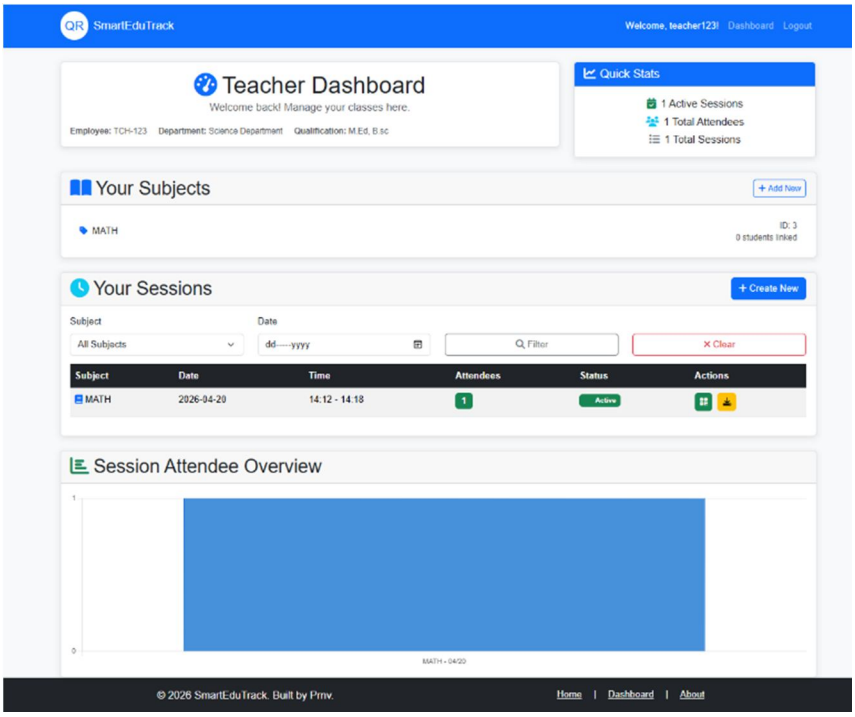
A. User Registration and Login

New users (teachers or students) access the homepage and register by providing email, full name, password, and selecting their role (Teacher/Student). Existing users log in using their email and password. Upon successful authentication, users are redirected to their role-specific dashboard.



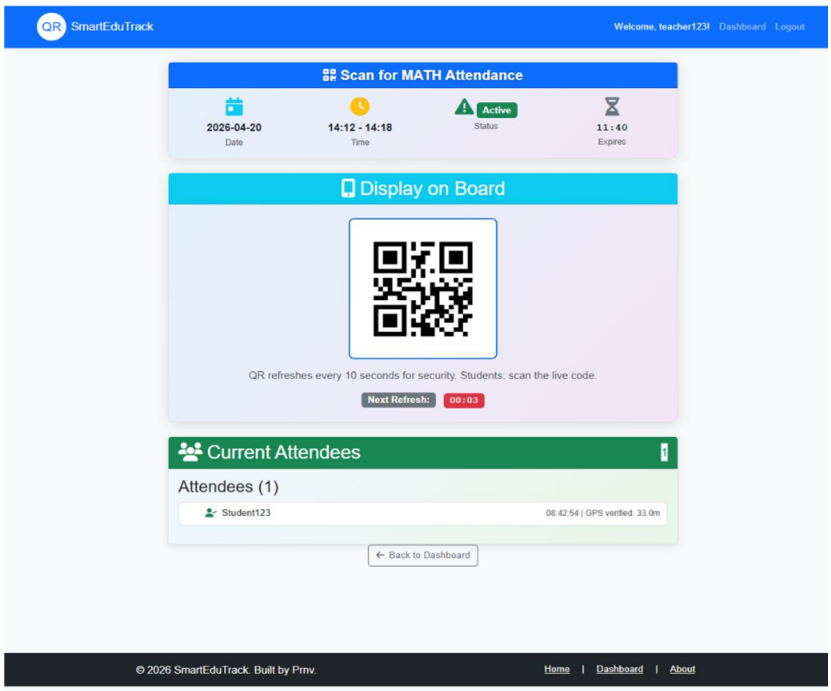
B. Teacher Initiates Session

The teacher logs in, selects/creates a subject, and starts a new attendance session. The system generates a unique dynamic QR code embedded with a cryptographically secure token.



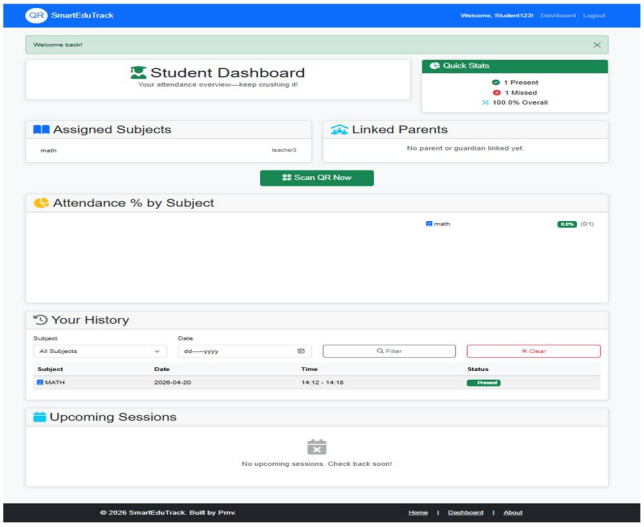
C. Dynamic QR display and Refresh

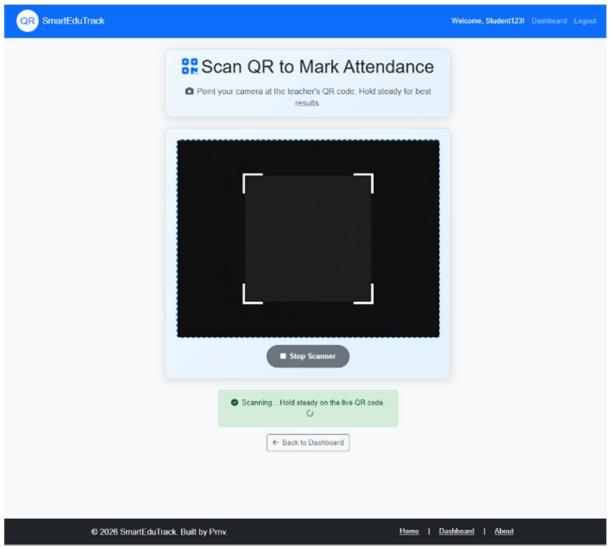
The QR code is displayed on the teacher's screen (laptop/projector) and automatically refreshes every 5–10 seconds. The session expires automatically after 15 minutes.



D. Student Attendance Marking:

The student opens the attendance page on their smartphone, scans the live QR code, and the browser automatically requests GPS location.





E. Server-side Validation

The backend performs four simultaneous checks — valid token, session not expired, student within classroom radius (Haversine formula), and no duplicate entry.

F. Attendance Recording

If all validations pass, attendance is recorded instantly with timestamp and location verification status; otherwise, an appropriate error is shown.

G. Real-time updates and Analytics

The teacher's dashboard updates instantly via WebSocket. Background AI analytics process the data to generate trends, predictions, and automated alerts to teachers and parents.

H. Reporting and Parent Access

Teachers can generate PDF/Excel reports anytime, while parents/guardians can view their ward's attendance history and notifications through the dedicated portal.

This streamlined workflow ensures proxy-proof, location-verified, and intelligent attendance management with minimal user effort and maximum security.

VI. KEY FEATURES

The SmartEduTrack system incorporates several advanced features that distinguish it from existing attendance solutions. The major key features are as follows:

1) Dynamic QR Code Generation with Auto-Refresh: Each attendance session generates a unique QR code containing a cryptographically secure token. The QR code automatically refreshes every 5–10 seconds and expires after 15 minutes, effectively preventing proxy attendance through screenshot sharing.

2) Mandatory Geofencing Validation: Browser-based GPS is used to verify that the student is physically present within the predefined classroom radius using the Haversine distance formula, adding a strong layer of location-based security.

3) Multi-Role Authentication and Access Control: The system supports four distinct roles — Student, Teacher, Parent/Guardian, and Administrator — with secure JWT-based authentication and role-specific functionalities.

4) Real-Time Live Dashboard: Teachers receive instant updates on attendance percentage, present/absent lists, and absentee alerts through WebSocket or Server-Sent Events.

5) Lightweight AI-Powered Analytics: The system performs trend analysis, moving averages, and low-attendance predictions using simple linear regression, with automated alerts sent to teachers and parents.
6) Automated Reporting and Parent Portal: Teachers and administrators can generate PDF/Excel reports with charts, while parents/guardians can view real-time and historical attendance records of their ward through a dedicated portal.
7) Duplicate Prevention and Session Management: Unique per-user-per-session token validation combined with database-level constraints ensures no duplicate or unauthorized entries.

These features collectively make SmartEduTrack a secure, intelligent, and highly practical solution for modern educational institutions.

VII. FUTURE SCOPE

Although SmartEduTrack successfully fulfills all defined objectives and delivers strong performance in proxy prevention, time efficiency, and user satisfaction, several enhancements are planned for future development:

1) Implementation of offline attendance marking using Progressive Web App (PWA) technology to support low-connectivity environments.
2) Integration of advanced biometric verification (facial recognition or fingerprint) as an optional second-factor authentication.
3) Enhancement of the AI module with deep learning models for student dropout prediction, personalized insights, and automated remedial recommendations.
4) Seamless integration with existing college ERP, LMS, and timetable systems for automatic session creation and data synchronization.
5) Development of a dedicated native mobile application (Android and iOS) with push notifications.
6) Addition of multilingual support (Hindi, Marathi, and regional languages) and blockchain-based immutable attendance records for official academic use.

These future extensions will transform SmartEduTrack into a more comprehensive and intelligent attendance ecosystem for next-generation educational environments.

VIII. LIMITATIONS

Although SmartEduTrack demonstrates strong performance in proxy prevention, time efficiency, and usability, the current implementation has a few limitations:

1) The system requires a stable internet connection for real-time QR refresh, geofencing, and dashboard updates. In areas with poor or no connectivity, attendance marking may be affected.
2) GPS-based geofencing can occasionally show reduced accuracy in indoor environments or areas with weak satellite signals, which may require a slightly larger radius tolerance.
3) The AI analytics module currently uses lightweight machine learning models (linear regression and moving averages). More advanced deep learning models could provide deeper insights but would increase computational requirements.
4) The prototype was evaluated in a simulated college environment with 50 students. Large-scale real-world deployment across multiple departments and thousands of users is yet to be conducted.
5) Being a fully browser-based system, it depends on modern browsers supporting Camera and Geolocation APIs. Older devices or restricted browsers may face compatibility issues.

These limitations are acknowledged and will be addressed in future enhancements, such as offline PWA support, improved indoor positioning, and more sophisticated AI model.

IX. CONCLUSION

This paper presented SmartEduTrack, an intelligent, secure, and contactless web-based attendance management system that effectively overcomes the limitations of traditional manual and static QR-based attendance methods. By integrating dynamic QR codes with automatic 5–10 second refresh and 15-minute expiry, mandatory browser-based GPS geofencing, real-time live dashboards, lightweight AI-powered analytics, and multi-role support for students, teachers, parents/guardians, and administrators, the system provides a comprehensive solution for modern educational institutions.

The developed prototype was rigorously tested in a simulated college environment with 50 students and multiple faculty members. Results demonstrated an 85–90% reduction in attendance marking time, 99.2% recording accuracy, complete (100%) prevention of proxy attendance, and high user satisfaction (overall rating of 4.85/5). The system requires only a standard web browser and internet connection, making it highly accessible and cost-effective, especially for resource-constrained settings in India.

SmartEduTrack contributes a practical, scalable, and intelligent attendance management solution that enhances administrative efficiency, student accountability, and parental involvement while promoting paperless operations. Future work will focus on offline support, advanced biometric verification, and large-scale real-world deployment.

In conclusion, SmartEduTrack successfully demonstrates that the combination of dynamic QR codes, geofencing, real-time analytics, and multi-role access can deliver a modern and highly effective attendance system ready for widespread adoption in educational institutions.

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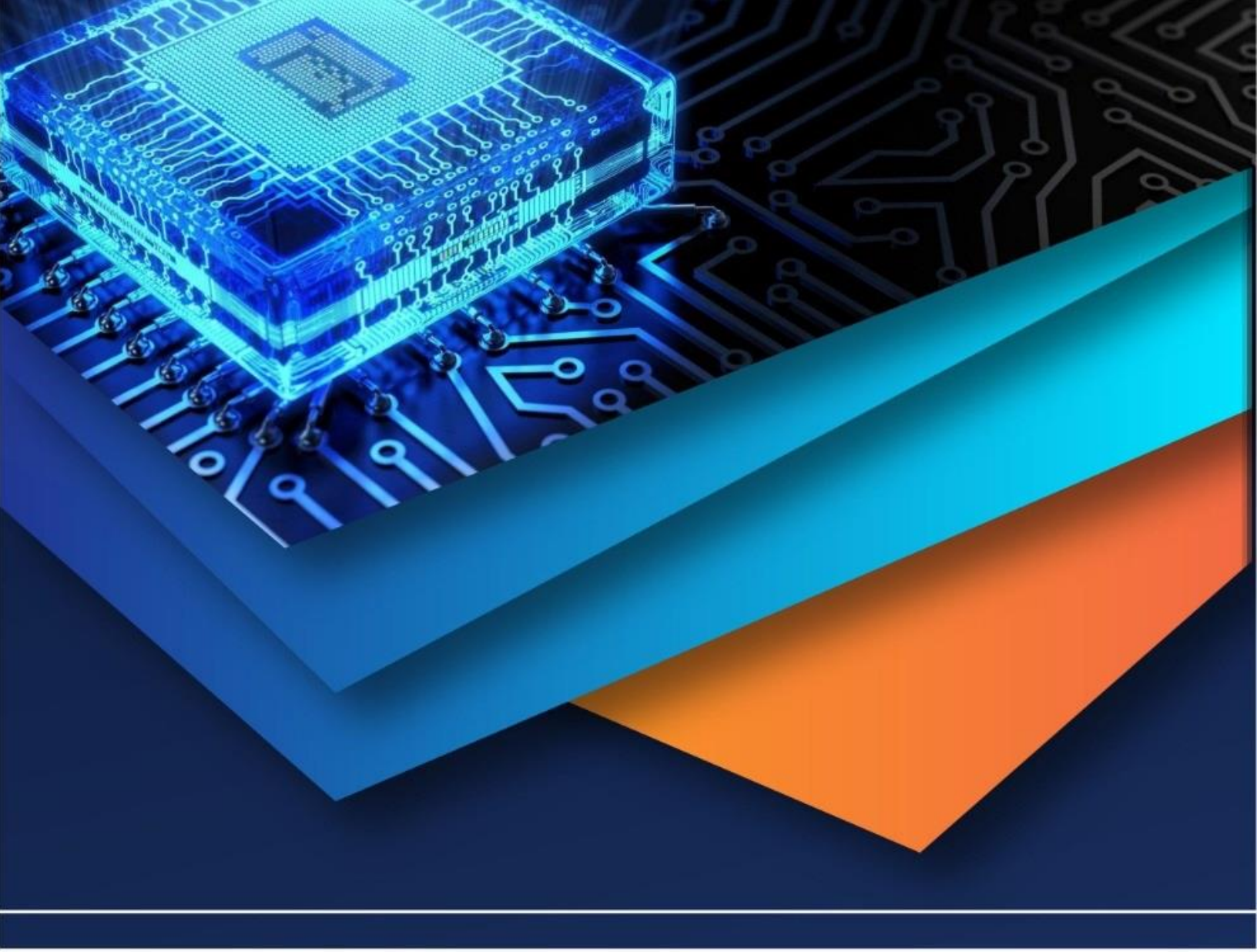

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