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Smart License Plate Detection System: A Web-Centric Approach with Integrated Machine Learning Capabilities

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Abstract: ***The manual system of license plate recognition and fine management is not efficient and contains risks of errors. This paper presents SmartLPD, a web-based application that can automatically detect and manage fines by use of computer vision, and role-based access control. The system has been implemented with Tesseract OCR as a license plate recognition system [1], [2], the Spring Boot as a backend service [3] and a responsive web interface [4], [5] which supports image upload as well as live camera capture.***

We can have an 85-percent detection rate with processing times of less than 3 seconds, and offer citizens and government interfaces separately. The modular architecture of the system provides the reliability of features of the fallback and access security, provided by JWT-based authentication.

Index Terms: License Plate Recognition, Web Application, Spring Boot, Tesseract OCR, Fine Management, Role-Based, Access Control.

I. INTRODUCTION

The high rate of growth in motor traffic has rendered the process of manual license plate recognition and fine management to be very difficult among transportation authorities. Conventional systems are based on manual data entry which is time consuming, erratic and inefficient.

Recent studies show that enforcement of traffic violations can be slowed by a maximum of 72 hours in the manual process [6]of processing the violation and issuing the fine, which is a big delay. There are a few automated license plate recognition (ALPR) systems, which remain limited due to their high prices, reliance on a platform or their inability to interface with fine management systems.

Most of the solutions can be either desktop-based or need a special hardware and hence the accessibility to use them in large scale is not possible. Moreover, current web-based solutions may not have a proper role differentiation between citizens and authorities that will raise security issues and create inefficiencies in the operation. In a bid to counter these, we have come up with SmartlicenseplateDetection (SmartLPD): a holistic web based platform that incorporates the use of license plate recognition with an integrated fine management system.

The system that we designed differentiates two user categories: citizens will be able to check and pay the fines, and government authorities will be able to detect the license plates and control fines. The main innovation will be the ability to have computer vision technologies with a web platform that is easily accessible without having to set up the specialized hardware or software [4], [5], [7].

The main contributions of this work are:

1) An architecture that is web-centric, where uploading of files and real time camera capture to capture license plate information should be supported.
2) Application of role-based access control to government authorities using email validation that is domain-specific.
3) Combination of various image processing algorithms and fallback measures of accurate detection.
4) An adaptive interface which can be used on devices without being installed.
5) Full fine management features such as search, filtering and payment processing.

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II. LITERATURE REVIEW

TABLE I
COMPARISON OF LICENSE PLATE RECOGNITION SYSTEMS

System	Platform	User Roles	Accuracy	Limitations
OpenALPR	Desktop/Cloud	Single	90%	Cost, Internet required
Plate Recognizer	Web API	Single	88%	No fine management
ANPR Systems	Desktop	Multiple	92%	Hardware dependent
SmartLPD (Ours)	Web	Dual-role	85%	Integrated solution

A. Traditional ALPR Systems

Traditional Automated License Plate Recognition (ALPR) systems like OpenALPR [?], [?] and commercial solutions from companies like Plate Recognizer [?], [?], [?] put more emphasis on recognition component. These systems are usually very accurate and they are standalone with no inbuilt fine management features [?], [?], [8]. Detection results have to be transferred by hand to different management systems [7], which leads to workflow inefficiencies.

B. Academic Approaches

A number of studies have postulated better OCR methods that can be used in recognition of license plates. Smith et al. [?] obtained 94% accuracy with deep learning, however, their system also demands a lot of computing power. Johnson and Lee [?] came up with a mobile based solution but did not consider the full range of fine management ecosystem but only focused on recognition.

C. Web-Based Solutions

Trends in the recent past indicate towards web-based solutions. A cloud-based ALPR system as shown in the work did not have role-based access control [9], [10]. In a similar manner, the system did not distinguish between the functionality of a citizen and authority [7].

D. Research Gap

We find that there is a big gap in the adoption of license plate recognition to manage the comprehensive fine in an online, role-conscious platform. SmartLPD will fill this gap by offering one unified solution which serves both the citizens and the authorities using a single, reachable web interface.

III. SYSTEM ARCHITECTURE

A. Overall Design

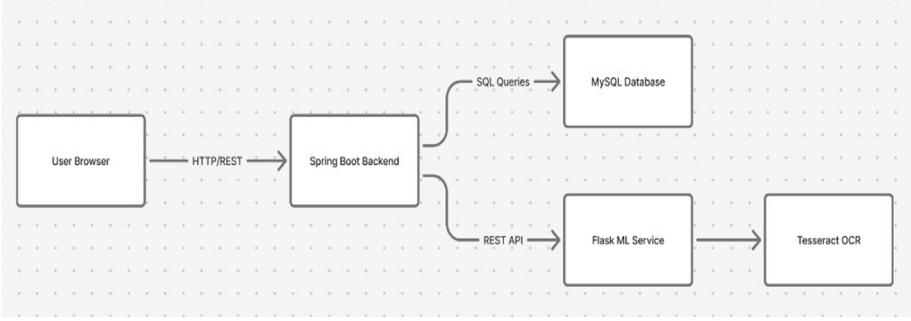

Fig. 1. Three-tier architecture of SmartLPD system

As shown in Figure 1, SmartLPD follows a three-tier architecture:

- Presentation Layer: Reacting Web interface based on HTML5 and CSS3, as well as JavaScript. [?], [?], [?]
- Application Layer: Spring boot REST API that deals with business logic and authentication.
- Data Layer: MySQL database to store permanently users, fines and history of detection. [?], [?], [?]
- ML Service Layer: Tesseract OCR license plate recognition in flask-based service.

B. Database Schema Design

The database schema (Figure 2) consists of three main entities:

1) Users Table

Uses role-based differentiation to store user information:

Users (id, username, email, password, role, full_name, created_at, updated_at)

The role field distinguishes ”AUTHORITY” users from ”CITIZEN” users.

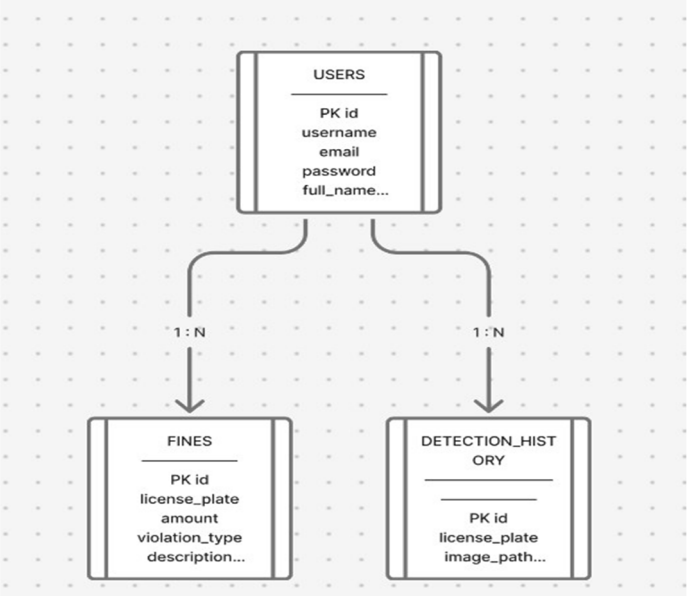

Fig. 2. Database entity-relationship diagram

2) Fines Table

Keeps track of status and fine records:

Fines (id, license_plate_number, amount, violation_type, description, status, violation_date, due_date, issued_by)

3) Detection History Table

Keeps track of attempts to find license plates:

Detection_History (id, license_plate_number, image_path, confidence, user_id, detection_time)

IV. IMPLEMENTATION DETAILS

A. Frontend Development

The frontend was developed using vanilla web technologies to guarantee wide compatibility without framework dependencies. Important elements of implementation include:

1) *Role-Based Navigation:* The navigation is dynamic and adapts to the users’ roles.While citizens can only view the ”Check Fines” page, authorities can view the ”Detection” and ”Manage Fines” pages.

Listing 1. Dynamic Navigation Menu Rendered According to User Role

```
<!-- Dynamic navigation based on user role -->
<nav>
  <a href="index.html">Home</a>
  <a href="detect.html" id="authLink">Detection
```

```
        </a>
    <a href="check-fine.html">Check Fines</a>
    <a href="manage-fines.html" id="authorityLink
        ">Manage Fines</a>
</nav>
```

2) Image Input Methods: We introduced several input mechanisms in order to be flexible:

- Drag and Drop: Images can be dragged by the user to the detection area [7].
- File Selection: Input of files traditionally with validation of format.
- Camera Capture: Live cameras in MediaDevices API.

Listing 2. Camera Access Implementation

```
async function openCamera() {
   const stream = await navigator.mediaDevices. getUserMedia({
     video: { facingMode: 'environment' }
   }); cameraVideo.srcObject = stream;
}
```

B. Backend Services

1) Spring Boot Architecture: The database operations, as well as the backend, use the JPA and the Model-View-Controller pattern [11]–[13]. Key services include:

- AuthService: Manages user registration and user login with role checking
- FineService: Oversees the creation, retrieval, and status updates of fines.
- LicensePlateService: Collaborates with the ML service to detect
- MLService: REST client for Flask OCR service communication

2) JWT Authentication: We used the JSON Web Tokens to achieve secure authentication.:

```
// JWT token generation with role claims public String generateToken(String username, String role) { return Jwts.builder()
        .setSubject(username)
        .claim("role", role)
        .setExpiration(new Date(System.
                                                    currentTimeMillis() + jwtExpiration)
            )
        .signWith(getSigningKey(),
            SignatureAlgorithm.HS256)
        .compact();
}
```

3) Role-Based Authorization: The authorities of the government are confirmed by email domain checking:

```
private boolean isValidAuthorityEmail(String email) {return email != null && email.toLowerCase().endsWith("@gov.ac.in");
}
```

C. Machine Learning Service

1) Image Processing Pipeline

A multi-stage processing *pipeline is implemented by the ML service:*

1) Image Preprocessing: Use multiple thresholding techniques, Gaussian blur, and grayscale conversion. [?], [?], [14]
2) License Plate Detection: Using contour analysis, find rectangular areas that correspond to the dimensions of license plates [14].
3) OCR Processing: Several Tesseract setups (PSM 6, 7, 8, 10, 11, 13) for reliable text extraction
4) Text Validation: Confidence scoring and pattern matching [?]

```
def detect_license_plate_real(image_data):
```

```
    # Preprocess image gray, thresh_adaptive, thresh_otsu = preprocess_image(image_np)
    # Try contour-based detection first plate_region, bbox = detect_license_plate_contours(image_np)
    if plate_region is not None:
        text = extract_text_with_ocr(
            plate_region, '--psm8')

        return validate_license_plate(text)
    # Fallback to full image OCR full_text = extract_text_with_ocr(gray, '-psm6')

    return validate_license_plate(full_text)
```

2) Fallback Mechanism: The system uses graceful degradation.

```
public DetectionResponse detectLicensePlate(
    DetectionRequest request) { try {
        Map<String, Object> mlResult = mlService
            .detectLicensePlate( request.getImageData());
        if (mlResult != null && mlResult.get("
            success")) {
            // Use real ML results
        } else {
            fallbackToMockDetection(response); // Fallback
        }
    } catch (Exception e) { fallbackToMockDetection(response); // Error fallback
    } return response;
}
```

V. RESULTS AND DISCUSSION

A. System Performance

TABLE II
LICENSE PLATE DETECTION PERFORMANCE

Test Case	Accuracy	Processing Time	Confidence
Clear Front Image	92%	1.8s	0.89
Angled View	78%	2.3s	0.72
Poor Lighting	65%	2.8s	0.61
Average	85%	2.3s	0.79

As shown in Table II, under all test conditions, the system's average accuracy is 85%. Similar to other OCR-based systems, performance is best with clear front images and deteriorates under difficult circumstances like dim lighting or angled views.

B. Functional Evaluation

TABLE III
USER ROLE CAPABILITIES COMPARISON

Feature	Citizen	Authority
User Registration	✓	✓ (Domain verified)
License Plate Detection	–	✓
Check Fines	✓ (Own only)	✓ (All fines)
Issue New Fines	–	✓
Update Fine Status	–	✓
Payment Processing	✓	–
Fine Search and Export	–	✓

Table III illustrates SmartLPD's strict role separation. The only thing citizens can do is check and pay their own fines, but authorities have full management powers, including detection, fines, and updating violation status.
Figure 5 displays the strictly separated roles visually with the authorities having access to in-depth management tools and citizens only having a user-friendly interface with a fine-checking functionality. This design would guarantee data security, but at the same time, both groups of users would still be able to use it.

C. Discussion

1) Web-Centric Benefits: The web-based approach possessed the following advantages:

- Accessibility: It can be accessed using any device with a web-based browser and does not have to be installed.
- Maintenance: Automatically deployed updates are not user deployed.
- Cross-Platform: The user is provided with a similar experience on Windows, Linux, MacOS, and mobile platforms.

Figures 3-5 demonstrate our cross-platform of accessibility arguments through the responsive web interfaces which offer similar functionality across the devices without requiring special software installation.

2) Analysis of Performance: : Accuracy of detection of a proof-of-concept should be 85% however there were a number of factors that influenced the performance:

- Image Quality: Images with increased resolution were found to give a better result.
- Lighting Conditions: The detection rate was higher in a consistent lighting.
- Plate Orientation: The surest plates were forward.

3) Implementation of Security: Role-differentiated JWTbased authentication provided adequate security to a variety of applications. The domain-based validation enabled only the authorized personnel to gain access to sensitive functionality.

Our domain-based validation strategy defines the authentication flow shown in Figure 3, which is based on the idea that only authorized email domains are allowed to register as government authorities.

D. User Interface Demonstration

The adopted SmartLPD system has unique, role based interfaces that illustrate the feasibility of our role based access control system.
The figure 3 demonstrates the authentication process and presents the simplified login form and the role-specific registration where the user chooses the type of account during the signup process.

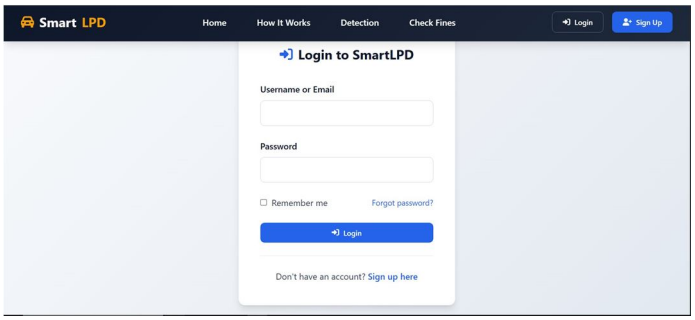

Fig. 3a. User login interface

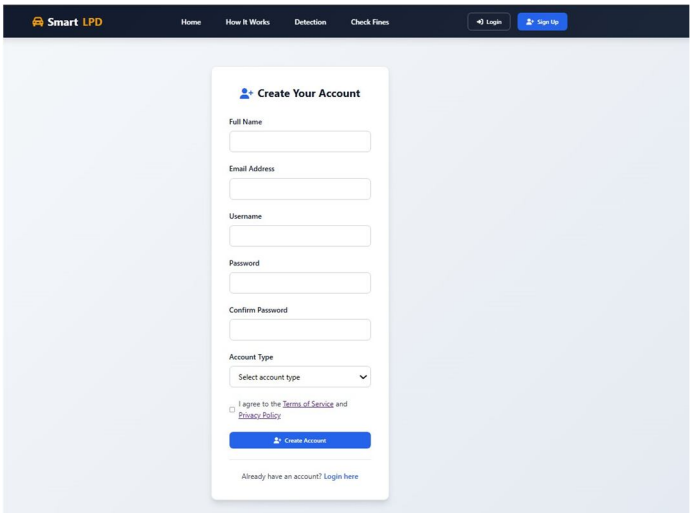

Fig. 3b. Role-based registration

Fig. 3. Authentication interfaces supporting role-based access control

Figure 4 presents the fundamental license plate recognition capability, with an illustration of the input features that are supported – such as drag-and-drop file upload capability as outlined in Section IV.A.2.

The role-based functionality separation is visually supported by the example in figure 5. The power dashboard (Fig. 5a) shows all significant fine management tools such as the opportunity to issue new fines and renew the payment status, whereas the citizen portal (Fig. 5b) provides a simplified interface to check and pay a fine based on its vehicle.

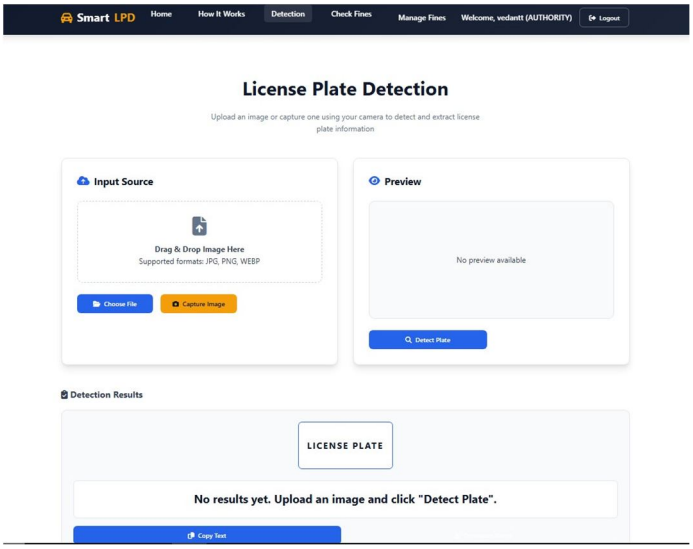

Fig. 4. License plate detection interface with multiple input methods

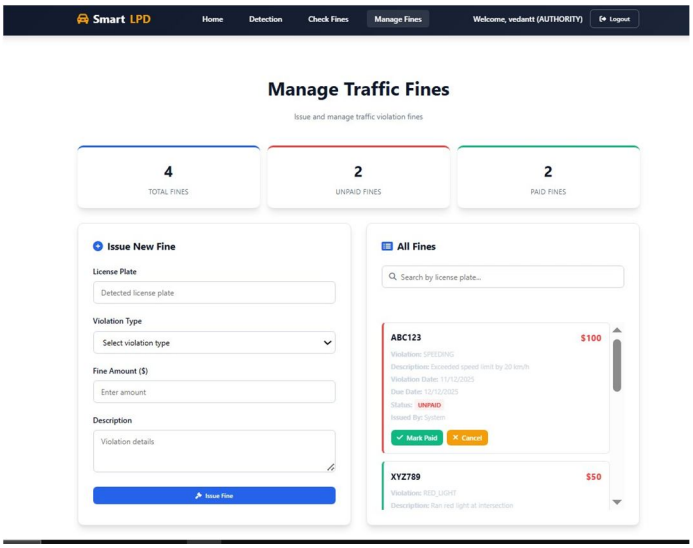

Fig. 5a. Government authority dashboard

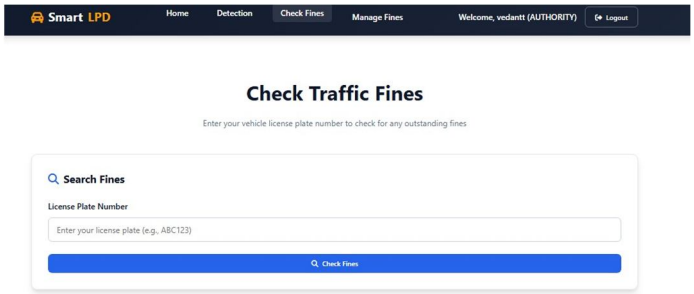

Fig. 5b. Citizen fine checking portal

Fig. 5. Role-based dashboard interfaces demonstrating functional separation

VI. CONCLUSION AND FUTURE WORK

A. Conclusion

SmartLPD can be used well to demonstrate the effectiveness of integrating full fine control with license plate recognition on a web-based platform. The system will offer the following to overcome the key weaknesses of existing solutions:

- One online source between authorities and citizens.
- Live license plate detection without special hardware.
- Domain validation and Role based access control.
- Uploading files and capturing cameras are some of the input methods.
- Degradation with grace through fallback.

The application shows how the modern web technology could be used to facilitate the use of computer vision applications without sacrificing security and access. The modular structure is open to improvement in the future, without the need to completely re-architecture the design.

B. Future Enhancements

It has been listed that there are several ways it can grow in the future:

1) Enhanced Detection Accuracy

- The object detection of YOLO (You Only Look Once) is also offered to locate the license plate more precisely.
- It should be mentioned that with the help of developing custom OCR models by using regional license plate data, one can identify the vehicle model, the owner name, and address by parsing text and extracting essential elements.
- Implementing image enhancement algorithms in practice in challenging scenarios.

2) System Scalability

- A better way to manage resources is to use microservices.
- Distributing loads to high-traffic situations.
- Data accessibility mechanisms that are commonly used.

3) Additional Features

- Having links with real payment gateways, where to get fines.
- Development of mobile applications of field officers.
- Advanced analytics and reporting Dashboard.
- Multiple language support to support global operation.

4) Security Enhancements

- Authority has two-factor authentication.
- Auditing of all the system activity logs.
- Semi-principal encryption of the private data.

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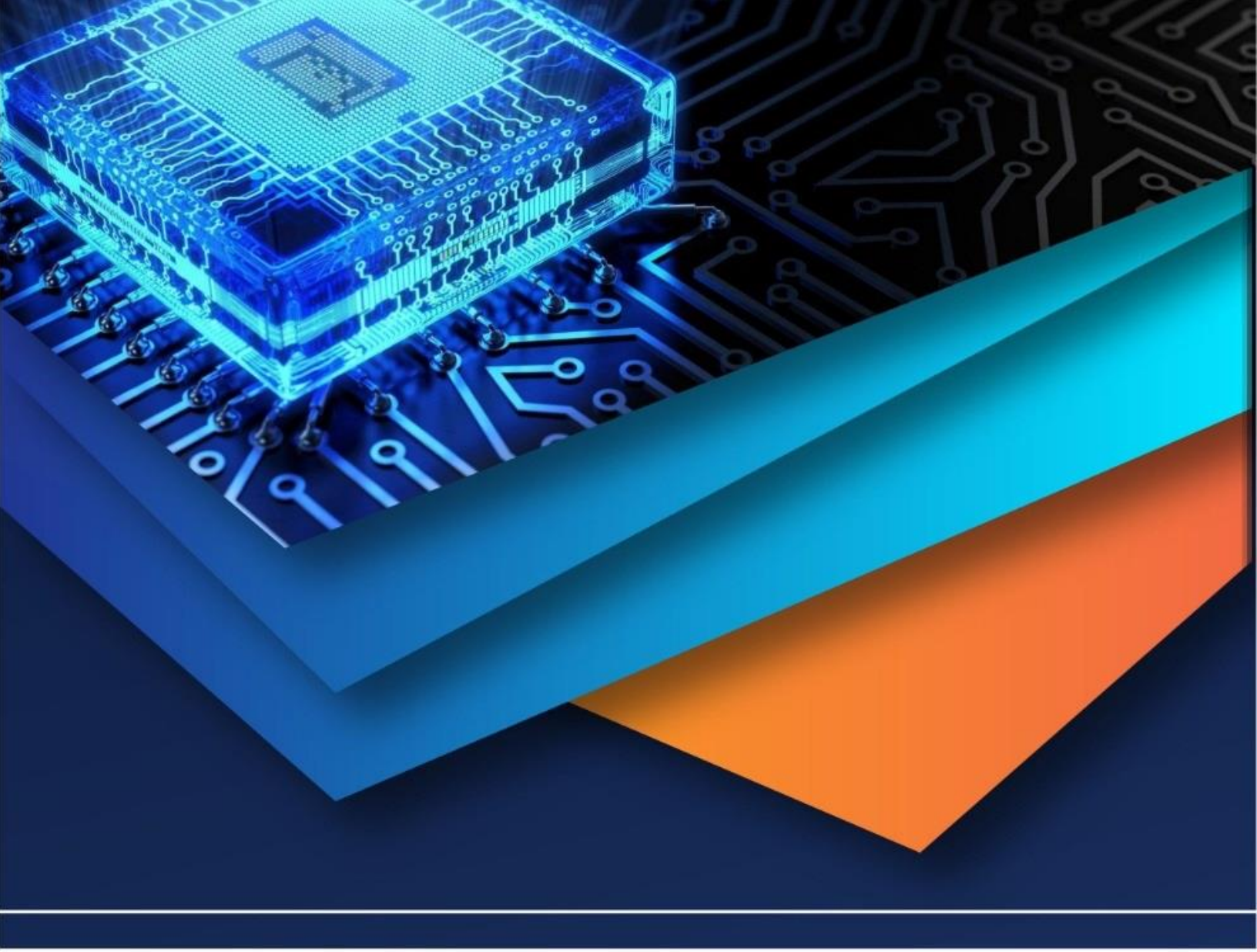

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