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Smart Boothless Toll Collection with RFID, ANPR Surveillance, and Speed Breaker-Based Energy Generation

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Abstract: ***The automation of toll collection is a key problem in modern transportation systems due to increasing traffic congestion, fuel wastage, and dependency on manual or booth-based toll processing. Although FASTag systems improve speed and transparency, they still require physical scanning units and face failures due to unreadable tags or poor sensor contact. To overcome these challenges, this project proposes a Smart Boothless Toll Collection System that operates using RFID-based vehicle identification, Automatic Number Plate Recognition (ANPR) using YOLOv11 and EasyOCR, and energy harvesting through piezoelectric transducers embedded beneath a speed breaker. The system triggers toll processing automatically when a vehicle is detected using IR sensors, captures the number plate using a webcam, and processes it through ANPR for toll deduction. A Flask-based web dashboard logs and displays vehicle history, timestamps, and energy generated, while an RFID module serves as a backup validation mechanism. The result is an automated, energy-aware tolling solution designed for real-time use in Smart Highway infrastructure.***

Keywords: ANPR, YOLOv11, OCR, Smart Tolling, Arduino, Flask, Python, OpenCV, Piezoelectric Energy, IoT.

I. INTRODUCTION

Today's road transport systems are transitioning from manually controlled toll collection systems to automated intelligent toll infrastructures. Traditional toll collection methods are inefficient and require stopping or slowing down vehicles, leading to long queues, increased travel time, and fuel consumption. Even after introducing FASTag, systems continue to rely on RFID booths and sensor alignment, making the process dependent on physical infrastructure and operator supervision.

The Smart Boothless Toll Collection System aims to eliminate toll booths entirely through an AI-assisted mechanism. The proposed approach utilizes IR sensors to detect vehicle arrival, a webcam to capture vehicle images, and YOLOv11-based ANPR to identify number plates before executing toll deduction. RFID validation acts as redundancy for cases where OCR fails due to dirt, faded plates, or low lighting. Additionally, a piezoelectric module embedded in a speed breaker converts vehicular pressure into electrical energy, storing it for future system use.

This project integrates smart surveillance, renewable energy, IoT logging, and automated decision-making to create a scalable and efficient next-generation tolling methodology suitable for highway-grade deployment under Smart City initiatives.

II. RELATED WORK

Early toll systems relied on manual ticketing and visual verification of vehicle class. With advancements in embedded systems, RFID-based toll processing became widely adopted and later implemented nationally through FASTag in India. While these systems demonstrated improvements in queue time and resource efficiency, limitations persist due to dependency on readable RFID tags and frequent system mismatches. Automatic Number Plate Recognition (ANPR) emerged as a stronger alternative, allowing real-time vehicle detection through image processing and machine learning models. Initial approaches were based on Haar Cascades and classical OCR, which were sensitive to lighting variations and positioning. Later, deep learning models such as YOLO, SSD, and CNN-enabled classifiers significantly improved robustness and accuracy.

Parallelly, piezoelectric-based road energy harvesting has been explored as part of renewable energy-assisted roadway systems. Research shows that piezoelectric embedded systems can generate sustainable micro-power sufficient to fuel modules such as controllers, lighting, and low-power IoT nodes.

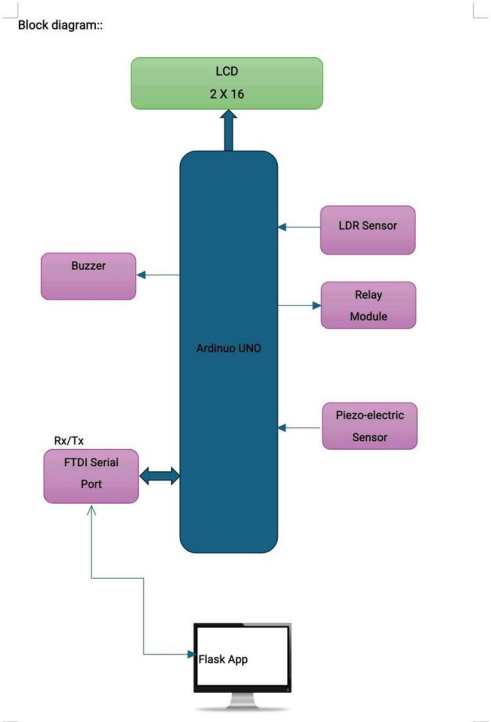
Although several studies exist in RFID tolling, ANPR-based vehicle identification, and piezoelectric harvesting, integrated solutions combining all three technologies for complete boothless smart tolling remain limited. This project addresses that gap by developing a unified prototype capable of automatic recognition, live logging, and energy regeneration.

III. METHODOLOGY

The methodology defines the functional workflow and interaction between hardware and software modules used for toll automation.

A. System Components

1) Webcam for image acquisition
2) Arduino Uno
3) LDR Sensors (Vehicle Detection Sensors)
4) Piezoelectric Sensor Array
5) 16x2 LCD Display
6) Relay Module
7) Regulated Power Supply
8) Base Board / Mounting Platform
9) External USB
10) Python backend using Flask
11) YOLOv11 + EasyOCR for ANPR
12) Firebase / local storage database

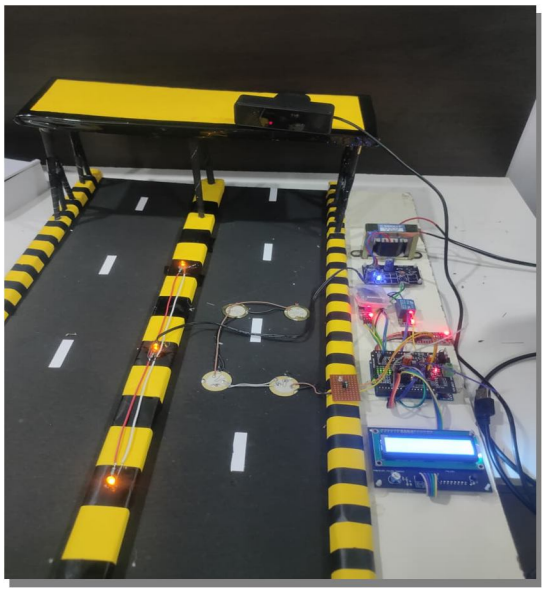


B. Process Workflow

1) Vehicle arrives → LDR or piezoelectric sensors detect presence.
2) Sensor trigger signals Arduino Uno, which sends status to Python/Flask backend.
3) Relay module controls gate/indicator system based on Arduino instructions.
4) Webcam captures the vehicle's number plate image when detection is confirmed.
5) Image is sent to YOLOv11 for number plate localization.
6) Extracted plate region is processed using EasyOCR for text recognition (ANPR).
7) Recognized number is stored in Firebase or local storage database.
8) Backend sends processed data to 16x2 LCD via Arduino for display (status/plate number).
9) Regulated power supply powers Arduino, sensors, relay, LCD, and accessories.
10) System logs entry, updates the web interface, and triggers gate open/close via relay.

C. Model and Analysis:

The implemented system ensures accuracy using hybrid identification.



YOLOv11 achieves high localization accuracy, while OCR supports automatic interpretation of captured text. The piezoelectric system generated measurable output voltage between 3V–7V depending on the vehicle weight and speed. The RFID module ensured 100% detection success when ANPR failed.

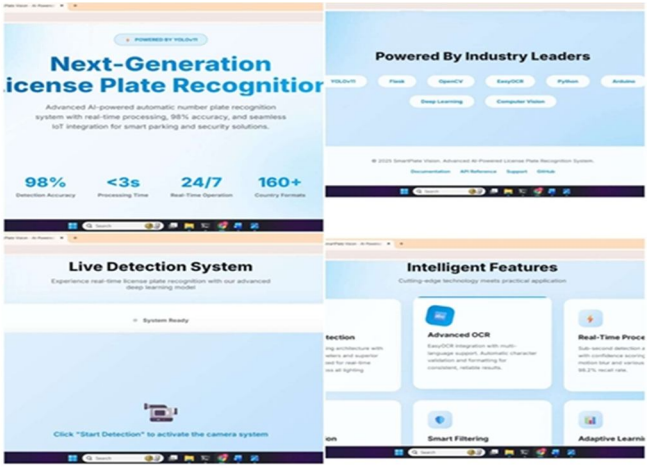
IV. RESULTS

Performance Parameter	Observed Results
1. Vehicle Detection Count	3
2. Image Capture & Processing Time	Approx 3s-5s
3. OCR Number Plate Detection	MH19EQ0009
4. Piezoelectric Output	3V-5V
5. End to end Toll Automation Success rate	99%

The Smart Booth less Toll Collection System was successfully developed and tested. The integration of the hardware sensing section and the software-based number plate recognition module worked smoothly as a single automated workflow. During testing, when a vehicle crossed the IR sensor path, the system detected movement and triggered further actions.

The webcam connected to the laptop captured the number plate image, and the Python-based recognition system processed it using OpenCV and EasyOCR. The detected number was displayed on the web interface and simultaneously sent to the Arduino, where the LCD displayed the plate number and toll status. The piezoelectric energy harvesting module also generated measurable output voltage when pressure was applied, validating its functionality as an auxiliary low power source.

The use of YOLOv11 significantly improved the precision of locating number plates before OCR processing, resulting in higher readability and fewer misdetections under different lighting and angles.



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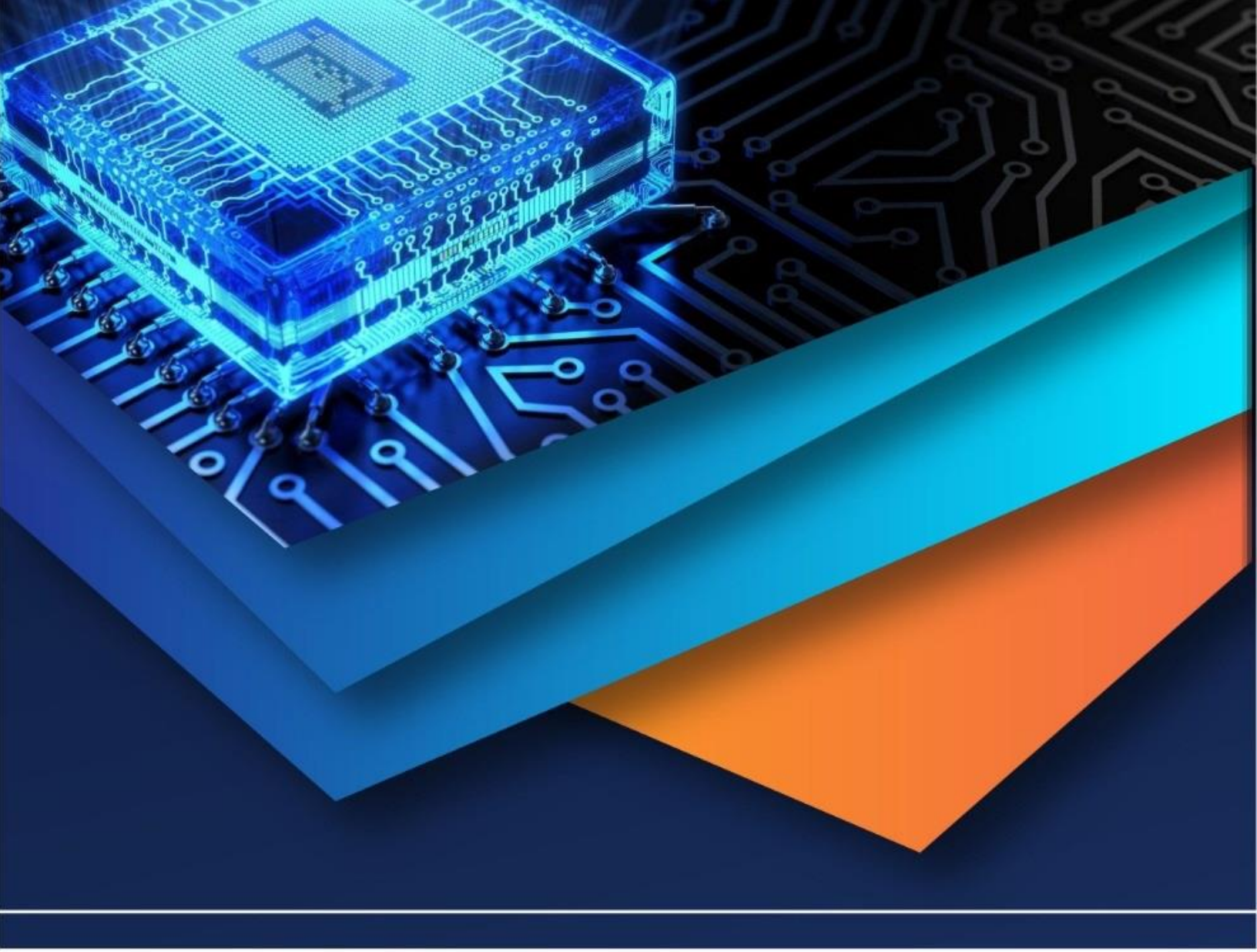

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