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Swift Tag: Advancing Toll Collection Through Automated Number Plate Recognition and OCR Technologies

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ABSTRACT
Swift Tag presents a novel approach to toll collection, leveraging Automated Number Plate Recognition (ANPR), Optical Character Recognition (OCR), and modern frontend/backend technologies to streamline operations, enhance accuracy, and improve user experience. By automating the identification and processing of vehicles at toll booths, Swift Tag eliminates manual intervention, reduces congestion, and minimizes errors. Utilizing YOLOv8 for object detection and EasyOCR for character recognition, Swift Tag ensures real-time capture and extraction of license plate information with remarkable precision. Complemented by a comprehensive frontend interface developed using React and JavaScript, and a robust backend infrastructure for seamless integration with existing toll management systems, Swift Tag offers a scalable, cost-effective, and universally applicable solution to toll collection challenges

INDEX TERMS Swift Tag, toll collection, Automated Number Plate Recognition (ANPR), Optical Character Recognition (OCR), YOLOv8, EasyOCR, transportation, frontend, backend, automation.

1. INTRODUCTION

Swift Tag, an innovative project in the realm of transportation management, seeks to address the challenges inherent in traditional toll collection systems through the integration of advanced technologies and streamlined processes. As the volume of vehicular traffic continues to escalate on highways and expressways, the need for efficient toll collection mechanisms becomes increasingly critical. Traditional toll booths often pose logistical challenges, resulting in long wait times, system downtimes, and operational inefficiencies. Moreover, lack of awareness among commuters regarding existing toll collection rules further compounds the problem.

To gain deeper insights into the challenges faced by commuters and the efficacy of existing toll collection systems, a survey was conducted among individuals aged 18 to 60 who frequently traverse highways. The survey aimed to gauge respondents' experiences and perceptions regarding toll booth operations, technological challenges, and awareness of toll collection rules set by the FASTag Authority of India. Key findings from the survey revealed significant gaps in awareness regarding toll collection rules, with 50% of respondents reporting unawareness of rules stipulated by the FASTag Authority. Additionally, a majority of respondents expressed dissatisfaction with existing toll collection systems, citing long wait times and technological challenges such as RFID tag malfunctions and system downtimes. These insights underscore the pressing need for innovative solutions like Swift Tag to streamline toll collection processes and enhance user experience.

Furthermore, respondents overwhelmingly expressed a preference for nonstop toll collection schemes over traditional toll booth systems, highlighting a growing demand for seamless and efficient transportation infrastructure. With the potential to mitigate congestion, reduce operational costs, and enhance user satisfaction, Swift Tag represents a significant step towards realizing the vision of a modern and efficient toll collection ecosystem. Through a combination of cutting-edge technologies, rigorous research, and stakeholder engagement, Swift Tag aims to revolutionize toll collection and pave the way for a smarter, more connected transportation network.

2. LITERATURE REVIEW

The paper "Survey on Efficient Automated Toll System for License Plate Recognition Using OpenCV" investigates the development of an automated toll system for efficient toll collection through license plate recognition, addressing the challenges posed by manual toll collection and traffic management. It outlines various techniques employed in traffic management and surveillance and proposes a low-cost alternative using computer vision techniques with OpenCV in an Embedded Linux platform. The system captures images of vehicles passing through toll booths, identifies vehicles through cameras, categorizes them based on weight, and transmits relevant data to a database management system with a web server setup. The study underscores the necessity of transitioning to automated toll systems to streamline traffic management, reduce congestion, and ensure accurate toll collection, setting the stage for subsequent research objectives and evaluations.

Laroca et al. present a robust Automatic License Plate Recognition (ALPR) system based on the YOLO object detector, addressing the limitations of current solutions which often depend on specific constraints. Their system employs Convolutional Neural Networks (CNNs) trained and fine-tuned for each ALPR stage, ensuring robustness under various conditions like camera variations, lighting, and background changes. They introduce a two-stage approach for character segmentation and recognition, achieving impressive results on two datasets: SSIG and UFPR-ALPR. In the SSIG dataset, their system outperforms commercial solutions like Sighthound and OpenALPR, achieving a recognition rate of 93.53% and 47 Frames Per Second (FPS). In the UFPR-ALPR dataset, their system achieves a recognition rate of 78.33% and 35 FPS, surpassing commercial systems' trial versions which scored below 70%. Laroca et al. also introduce the UFPR-ALPR dataset, providing a benchmark for ALPR systems in real-world scenarios, and propose a larger benchmark dataset focused on different real-world scenarios. They employ YOLOv2, a state-of-the-art realtime object detection model, fine-tuned for ALPR, and employ temporal redundancy for robust predictions. Their contributions include a new real-time end-to-end ALPR system, a robust two-stage approach for character segmentation and recognition, and a public dataset for ALPR. The paper presents a Number Plate Recognition (NPR) system using Optical Character Recognition (OCR) for automatic toll collection, aimed at addressing the growing need for automated toll management due to increased vehicle traffic. The system employs image processing techniques, including image acquisition, conversion to grayscale, dilation, edge processing, segmentation, and character recognition, to identify and extract number plate information from vehicle images captured by digital cameras. The process involves steps such as converting images to grayscale, dilating the captured image, processing horizontal and vertical edges, segmenting the image for the region of interest, extracting the number plate image, converting it to binary, segmenting alphanumeric characters, and recognizing individual characters using a template-based approach. The system aims to provide a secure and reliable method for toll collection without the need for RFID tags, requiring only high-quality cameras and fixed-font number plates, with future work focusing on implementing billing systems and potentially transitioning to an online platform with a large database.

TABLE 1. Comparison between various toll collection systems in different countries

Country	Toll Collection Approach	Limitations
USA	Electronic Toll Collection (ETC) using RFID technology	Limited coverage in rural areas, privacy concerns with RFID tracking, initial setup costs for infrastructure
Japan	Automatic Toll Collection using RFID technology	Initial setup costs, potential interoperability issues between different technologies, potential security risks associated with multiple technologies
Russia	Combination of satellite GNSS, microwave DSRC, and mobile GSM technologies	Initial setup costs, potential interoperability issues between different technologies, potential security risks associated with multiple technologies
India	Electronic Toll Collection using RFID technology	Initial setup costs for infrastructure, potential issues with interoperability between different toll systems, reliance on RFID technology which may pose privacy concerns and security risks, limited options for cash payments

3. PROPOSED WORK

3.1. System Architecture:

The proposed automated toll collection system integrates advanced technologies such as number plate detection and
optical character recognition (OCR) to streamline the toll collection process. The system architecture consists of the following components:

Image Acquisition Module: This module captures images of vehicles approaching the toll booth using digital cameras installed at strategic locations.

Number Plate Detection Module: Utilizing image processing techniques, this module identifies and extracts the number plates from the captured images. It employs algorithms for segmentation, edge detection, and morphological operations to isolate the number plates.

Optical Character Recognition (OCR) Module: Once the number plates are detected, this module performs OCR to recognize the alphanumeric characters on the plates. It employs pattern recognition algorithms to accurately extract and interpret the characters.
User Interface (UI/UX) Module: This module provides a user-friendly interface for both toll booth operators and drivers. It includes features such as intuitive navigation, realtime status updates, and interactive payment options.
Backend Processing Module: Responsible for efficient processing of toll transactions, this module manages the database, transaction processing, and communication with external systems such as payment gateways and vehicle registration databases.
Integration Layer: Facilitates seamless communication and data exchange between different modules of the system, ensuring smooth operation and synchronization.

3.2 Objectives:

Objective 1: Develop a Number Plate Detection System
Implement YOLOv8, a state-of-the-art object detection algorithm, to develop a robust and efficient number plate detection system.
Fine-tune the YOLOv8 model using annotated datasets to accurately detect number plates in various environmental conditions, lighting scenarios, and vehicle orientations.
Objective 2: Utilize EasyOCR for Text Extraction from Number Plates
Integrate EasyOCR, a lightweight and accurate optical character recognition (OCR) library, to extract alphanumeric characters from detected number plates.
Implement preprocessing techniques such as image binarization, noise reduction, and perspective correction to enhance the performance of EasyOCR in extracting text from number plate images.
Objective 3: Design Intuitive UI/UX for User Interaction
Conduct user research and usability testing to understand the needs and preferences of toll booth operators and drivers.
Design a user-friendly interface with intuitive navigation, clear instructions, and visual feedback to ensure a smooth and efficient user experience.
Objective 4: Implement Efficient Backend Processing
Develop a scalable and robust backend system capable of handling a large volume of toll transactions in real-time.
Optimize database queries, transaction processing algorithms, and network communication protocols to ensure fast and efficient toll collection and payment processing.

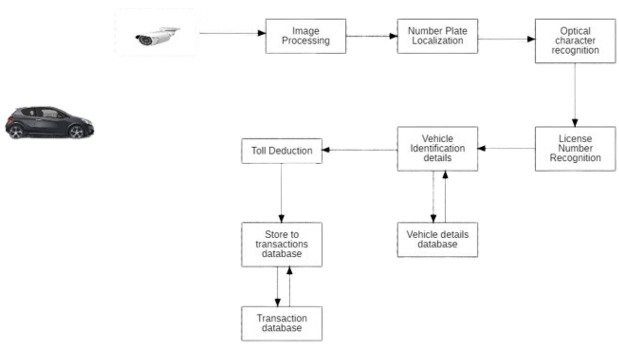

FIGURE 1. Architecture Diagram for Swift Tag

4. NUMBER PLATE RECOGNITION SYSTEM IMPLEMENTATION

In recent years, object detection has gained significant attention in the field of computer vision due to its wide range of applications, including autonomous driving, surveillance, and industrial automation. One of the most popular and effective approaches to object detection is the You Only Look Once (YOLO) algorithm. YOLOv8, an evolution of the original YOLO algorithm, has further improved the speed and accuracy of object detection tasks.

Object detection aims to locate and classify objects within an image. Traditional object detection methods involve sliding window approaches or region proposal networks, which can be computationally expensive and inefficient. YOLOv8, on the other hand, adopts a single neural network architecture that simultaneously predicts bounding boxes and class probabilities for multiple objects in an image, achieving real-time performance with high accuracy.

In this paper, we provide a detailed exploration of the YOLOv8 architecture and its implementation for the task of number plate detection. We discuss the components of the YOLOv8 architecture, including the backbone network, detection head, and loss function. Furthermore, we delve into the training procedure, dataset preparation, and evaluation metrics used to assess the performance of the YOLOv8 model for number plate detection.

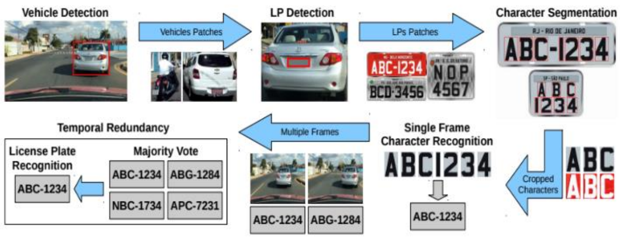

FIGURE 2. ANPR Pipeline

Start ANPR Pipeline:
Initialize Video Capture Device

Loop:
Step 1: Vehicle Detection
Capture Frame from Video
Detect Vehicles in Frame

For each Detected Vehicle:
Step 2: License Plate Detection
Extract Region of Interest (ROI) around License Plate
Apply License Plate Detection Algorithm on ROI
If License Plate Detected:
Extract License Plate Image

Step 3: Character Segmentation
Preprocess License Plate Image
Segment Characters

For each Segmented Character:
Step 4: Single Frame Character Recognition
Recognize Character using OCR

Step 5: Final Text for the License Plate
Combine Recognized Characters

Else:
Continue to Next Detected Vehicle

Display Results on Screen

If User Requests to Quit:
Break Loop

Close Video Capture Device
End ANPR Pipeline

4.1 YOLOv8 architecture

The YOLOv8 architecture consists of several key components that work together to enable efficient and accurate object detection. Understanding these components is essential for grasping the underlying principles of the YOLOv8 algorithm.

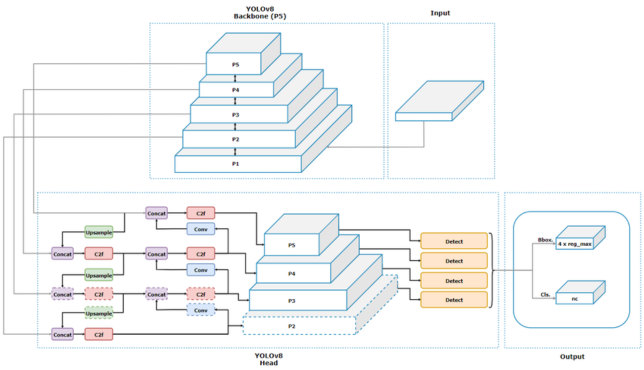

FIGURE 3. YoloV8 System Architecture

a. Backbone Network

At the core of the YOLOv8 architecture lies the backbone network, which is responsible for extracting features from the input image. The backbone network typically consists of convolutional layers followed by downsampling operations, such as max-pooling or stride-2 convolutions. These layers progressively reduce the spatial dimensions of the input image while increasing the depth of feature maps. The hierarchical features extracted by the backbone network are crucial for capturing both low-level and high-level visual information, enabling the model to make accurate predictions.

b. Detection Head

The detection head of YOLOv8 processes the feature maps generated by the backbone network and produces predictions for bounding boxes and class probabilities. It consists of convolutional layers followed by a final layer that outputs the predictions. Each prediction consists of several parameters, including the coordinates of the bounding box (x, y, width, height) and the confidence score, which indicates the likelihood of containing an object. Additionally, the detection head predicts class probabilities for each bounding box, representing the confidence scores for different object classes.

c. Loss Function

The loss function used in YOLOv8 measures the discrepancy between the predicted outputs and the ground truth annotations. It consists of three main components: localization loss, confidence loss, and class probability loss. The localization loss penalizes errors in predicting the coordinates of the bounding boxes, while the confidence loss penalizes incorrect confidence scores. The class probability loss penalizes misclassification errors by comparing the predicted class probabilities to the ground truth labels. By minimizing the overall loss, the model learns to accurately localize and classify objects in the input image.

1. Localization Loss:

$$\text{Localization Loss} = \lambda_{\text{coord}} \sum_{i=0}^{S^2} \sum_{j=0}^{B} 1_{ij}^{obj} \left[(x_i - \hat{x}_i)^2 + (y_i - \hat{y}_i)^2 \right]$$

2. Confidence Loss:

$$\text{Confidence Loss} = \sum_{i=0}^{S^2} \sum_{j=0}^{B} \left[1_{ij}^{obj} \left(C_i - \hat{C}_i \right)^2 + \lambda_{\text{noobj}} 1_{ij}^{noobj} \left(C_i - \hat{C}_i \right)^2 \right]$$

3. Class Probability Loss:

$$\text{Class Probability Loss} = \sum_{i=0}^{S^2} \sum_{c \in \text{classes}} 1_{ij}^{obj} \left(p_i(c) - \hat{p}_i(c) \right)^2$$

FIGURE 4. Necessary equations

4.2 Dataset Preparation

a. Data Collection:

The dataset for training the YOLOv8 model is collected from various sources, including public datasets, traffic surveillance cameras, and custom image capture. These images are chosen to represent diverse scenarios encountered in real-world environments, ensuring the model's robustness and generalization.

b. Data Annotation:

Each image in the dataset is meticulously annotated by drawing bounding boxes around the license plate regions. This annotation process is crucial for training the model to accurately detect license plates in images. Annotations are typically done manually or using annotation tools that facilitate the creation of precise bounding boxes.

c. Data Augmentation:

To enhance the diversity of the dataset and improve the model's generalization, data augmentation techniques are applied. These techniques include random flips (horizontal or vertical), rotations, changes in brightness, contrast, and saturation, as well as scaling and cropping. Augmentation helps the model learn to detect license plates under various conditions and orientations.

d. Data Splitting:

The annotated dataset is split into three subsets: a training set, a validation set, and a test set. The training set comprises the majority of the images (approximately 70-80%) used to train the model. The validation set, accounting for a smaller portion (typically 10-20%) of the images, is utilized for hyperparameter tuning and monitoring model performance during training. The test set, also comprising a small portion of the images, is reserved for evaluating the final trained model's performance.

e. Data Formatting:

Before training the model, the annotations and image paths are formatted into a compatible format, usually a YAML file. This file specifies the dataset configuration, including image paths, classes (e.g., license plates), and image sizes. The formatted dataset is then ready for training the YOLOv8 model.

4.3 Training Procedure:

Model Initialization:

The YOLOv8 model is initialized with the desired configuration, specifying parameters such as the number of classes (e.g., license plates) and the input image size.

Data Loading:

The training, validation, and test datasets are loaded using data loaders, which handle tasks such as batch generation, data shuffling, and data augmentation. These loaders ensure efficient processing of the dataset during training.

Loss Function Definition:

The loss function used for training the YOLOv8 model is defined, typically comprising binary cross-entropy (BCE) loss for object classification and smooth L1 loss for bounding box regression. This loss function quantifies the discrepancy between the model predictions and the ground truth annotations.

Optimizer Setup:

An optimizer, such as Adam, is chosen and configured with appropriate hyperparameters, including the learning rate, weight decay, and momentum. The optimizer is responsible for updating the model weights during training to minimize the loss function.

Training Loop:

The model is trained over multiple epochs, with each epoch consisting of multiple batches of images.

During each epoch, the following steps are performed:

1. Define the main function for training the YOLOv8 model:

function train():

1.1. Parse command-line arguments (e.g., model, data, epochs, imgsz)

1.2. Initialize the YOLOv8 model with provided configuration

1.3. Set up the training data loader:

- Load dataset from specified path
- Define batch size and image size
- Optionally, apply data augmentation (e.g., random flips, color jitter)

1.4. Set up the loss function and optimizer:

- Define loss function (e.g., BCEWithLogitsLoss for classification, SmoothL1Loss for regression)
- Choose optimizer (e.g., Adam) and set learning rate

1.5. Iterate over each epoch:

1.5.1. Initialize epoch-specific variables (e.g., total loss, number of batches)

1.5.2. Iterate over each batch in the training data loader:

1.5.2.1. Load batch of images and corresponding labels

1.5.2.2. Forward pass:

- Pass images through the model
- Obtain predictions for bounding box coordinates and class probabilities

1.5.2.3. Compute loss:

- Calculate loss based on model predictions and ground truth labels
- Incorporate any additional losses (e.g., DFL loss)

1.5.2.4. Backward pass:

- Perform backpropagation to compute gradients

1.5.2.5. Update model parameters:

- Use optimizer to adjust model weights based on gradients

1.5.2.6. Accumulate batch loss and update epoch-specific variables

1.5.3. Print average loss for the epoch

1.6 Save the trained model weights to a specified location

4.4 Results

FIGURE 5.1 and 5.2. Output for number plate recognition

TABLE 2. Model Summary

Parameter	Value
Layers	168
Parameters	30,05,843
GFLOPs	8.1

TABLE 3. Detection Results

Metric	Value
Images	1765
Total Instances	1840
Precision	0.983
Recall	0.965
mAP50	0.987
mAP50-95	0.727

TABLE 4. Inference Speed

Operation	Time per image
Pre-process	0.1ms
Inference	1.8ms
Loss calculation	0.0ms
Post-process	1.3ms

5. Implementation of OCRs for text extraction

Number Plate Recognition (NPR) is a computer vision technology aimed at automatically detecting and recognizing vehicle registration plates from images or video streams. It finds wide applications in various domains such as traffic monitoring, law enforcement, parking management, and toll collection. The integration of Optical Character Recognition (OCR) technology plays a crucial role in NPR systems by enabling the extraction and interpretation of alphanumeric characters from vehicle number plates.

The objectives of Optical Character Recognition (OCR) encompass the accurate and efficient extraction of text from images or scanned documents to enable automated data entry, text analysis, and information retrieval. OCR systems aim to recognize and interpret alphanumeric characters, symbols, and handwriting with high precision, facilitating tasks such as document digitization, text translation, data extraction, and form processing. Additionally, OCR technologies strive to handle various challenges such as noise, distortion, font styles, and languages, ensuring robust performance across diverse applications and domains.

Accurate OCR is crucial for the effectiveness of NPR systems. Errors in character recognition can lead to incorrect interpretation of vehicle registration numbers, resulting in erroneous data and potential consequences such as toll evasion or misidentification of vehicles. Hence, the development of robust OCR algorithms capable of handling variations in fonts, sizes, orientations, and lighting conditions is paramount.

$$Image\ Resolution = \frac{Number\ of\ Pixels}{Image\ Width \times Image\ Height}$$

Preprocessing and character segmentation are crucial stages in the process of extracting alphanumeric characters from vehicle number plates in NPR systems. These stages involve a series of operations aimed at enhancing image quality and isolating individual characters for subsequent OCR processing. This section provides a detailed explanation of preprocessing techniques and character segmentation methods employed in NPR systems.

5.1. Preprocessing Techniques:

Preprocessing is essential to improve the quality of number plate images and facilitate accurate character recognition. Common preprocessing techniques include resizing, noise reduction, contrast enhancement, and binarization.

a. Resizing:

Resizing involves adjusting the dimensions of the image to a standard size, which helps in reducing computational complexity and ensuring consistency in character size. The resizing operation is performed using mathematical equations:

$$Resized\ Image\ Width\ =\ Original\ Image\ Width\ \times\ Scaling\ Factor$$
$$Resized\ Image\ Height\ =\ Original\ Image\ Height\ \times\ Scaling\ Factor$$

b. Noise Reduction:

Noise reduction techniques such as Gaussian blurring or median filtering are applied to remove noise and smooth out the image. This helps in improving the clarity of characters and reducing false detections during OCR processing.

c. Contrast Enhancement:

Contrast enhancement techniques adjust the brightness and contrast of the image to improve visibility. Histogram equalization or adaptive histogram equalization methods are commonly used for enhancing image contrast.

d. Binarization:

Binarization converts the grayscale image into a binary image by thresholding pixel values. This simplifies subsequent processing steps by converting the image into a binary representation where foreground objects (characters) are represented as white pixels and background as black pixels.

```
function BinarizeImage(OriginalImage, Threshold):
BinaryImage = New Image with the same dimensions as OriginalImage
for each pixel (x, y) in OriginalImage:
if OriginalImage(x, y) < Threshold:
BinaryImage(x, y) = 0  // Set pixel to black
else:
BinaryImage(x, y) = 1  // Set pixel to white
return BinaryImage
```

5.2. Character Segmentation

Character segmentation involves isolating individual characters from the number plate image to facilitate individual recognition. This is achieved using techniques such as morphological operations, connected component analysis, and contour detection.

a. Morphological Operations:

Morphological operations such as erosion and dilation are applied to remove noise and separate touching characters. Erosion shrinks the white regions in the image, while dilation expands them. Combining these operations can help in separating characters effectively.

b. Connected Component Analysis (CCA):

CCA is a technique used to label and segment connected regions in a binary image. It helps in identifying individual characters by labeling each connected component with a unique identifier. The number of connected components can be calculated using the formula:

$$Number\ of\ Connected\ Components\ =\ Number\ of\ White\ Regions - 1$$

c. Contour Detection:

Contour detection algorithms identify the boundaries of objects in an image. By detecting contours around characters, individual characters can be extracted from the number plate image. Contours can be approximated to bounding boxes to isolate characters for further processing.

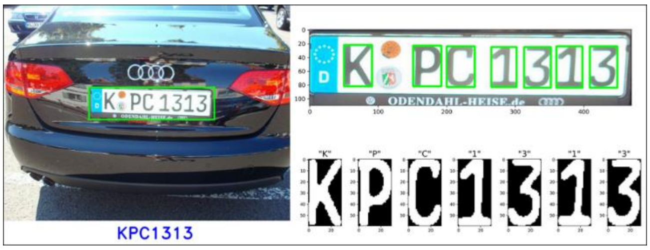

FIGURE 6. Optical Character Recognition

4.2.3 Results of OCR

FIGURE 7. Output after OCR

TABLE 5. Sample Output

License Plate	OCR Output	Confidence Score (%)
L-656-XH	L656XH	85%
H-644-LX	H644LX	79%
66-HH-07	66HH07	86%
L-605-HZ	L60SHZ	88%
R-183-JS	R183JF	89%

In conclusion, EasyOCR emerges as a versatile and reliable OCR tool with extensive capabilities and applications. Its robust architecture, high accuracy rates, and customizable features make it a preferred choice for researchers, developers, and organizations seeking efficient text recognition solutions. With its user-friendly interface and seamless integration options, EasyOCR empowers users to automate data extraction tasks, enhance productivity, and unlock new opportunities in text analysis and information retrieval.

6 Intuitive UI/UX

6.1 Dashboard Page Functionality:

Dashboard Page serves as a centralized hub where users can access key information and perform various actions related to their toll transactions and account management.

- Overview: Providing users with a snapshot of their current toll balance, recent transactions, and any pending fines or notifications.
- Real-time Data: Displaying real-time information on toll transactions, including timestamps, toll booth locations, and amounts deducted.
- Transaction History: Allowing users to access detailed transaction history, filterable by date, location, or transaction type.
- Account Management: Enabling users to perform account-related actions such as updating personal information, adding or removing vehicles, and setting up auto-recharge options.

FIGURE 8. Dashboard

6.2 Login Page Functionality:

The Login Page serves as the gateway for users to access their accounts within the digital toll collection system. It highlights the importance of a secure and user-friendly Login Page, the design considerations for authentication mechanisms, password management, and account recovery features, as well as the implementation of multi-factor authentication (MFA) for enhanced security. The Login Page acts as the first line of defense against unauthorized access. A secure login process ensures that only authenticated users can access sensitive toll-related information and perform transactions. A user-friendly login experience instills trust in the system and enhances user confidence in using the digital toll collection platform. Clear and intuitive login procedures contribute to a positive overall user experience.

Designing Authentication Mechanisms for User Verification-

Username and Password: The traditional username-password combination remains a common authentication method. Design considerations include enforcing strong password requirements, such as minimum length and complexity, and implementing secure password hashing algorithms to protect against password breaches.

Email Verification: Utilizing email verification as part of the registration process or account recovery workflow can help verify the user's identity and ensure the validity of email addresses associated with user accounts.

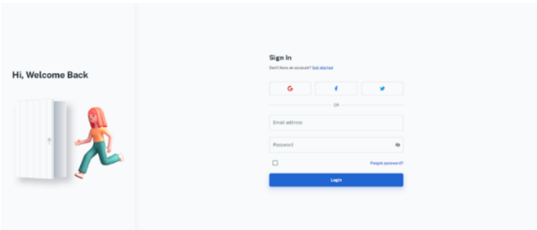

FIGURE 9. Login/Signup Page

6.3 Balance Page Functionality:

The Balance Page within a digital toll collection system offers users a comprehensive overview of their account balance, transaction history, and insights into toll expenses and usage patterns. It provides an overview of the Balance Page functionality, detailing how account balance and transaction history are displayed, insights provided into toll expenses and usage patterns, and the implementation of filters and search functionalities for transaction tracking. Presenting users with real-time information about their current account balance, ensuring transparency and enabling users to make informed decisions regarding toll payments and account management. It also provides users with a detailed log of past toll transactions, including timestamps, toll booth locations, amounts deducted, and transaction statuses (e.g., pending, completed). This allows users to track their toll expenses over time and reconcile transactions as needed. It offers insights into toll expenses and usage patterns through visualizations, charts, or summaries. This may include breakdowns of toll expenditure by category (e.g., daily, weekly, monthly), analysis of peak usage periods, or comparisons with historical data.

Displaying Account Balance and Transaction History-

- Account Balance: prominently displaying the current account balance at the top of the page, accompanied by relevant account details such as account ID or user name. The balance should be updated in real-time to reflect recent transactions accurately.
- Transaction History: Presenting a chronological list of past transactions in a clear and organized manner, with each entry displaying relevant details such as transaction date, time, location, amount, and transaction status. Pagination or infinite scrolling may be implemented to manage large datasets efficiently.

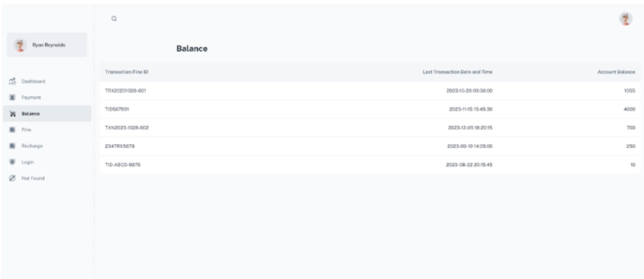

FIGURE 10. Balance Page

6.4 Fine Page Functionality:

The Fine Page within a digital toll collection system serves as a platform for users to view details of any violations incurred, associated fines, and facilitates the payment process. It outlines the Fine Page functionality, including an overview of its purpose, designing an interface for displaying violation details and fines, integration with backend systems for fine processing and payment, and user notifications and alerts for outstanding fines. The Fine Page is designed to provide users with comprehensive information regarding any violations or infractions related to toll usage, including details such as the nature of the violation, date and time, location, and associated fines. It displays a list of violations incurred by the user, along with relevant details such as the type of violation (e.g., missed toll, expired toll pass), date and time of occurrence, and any accompanying notes or descriptions. It presents details of fines associated with each violation, including the amount due, payment deadlines, and payment methods accepted. Users should have the option to view detailed breakdowns of fines, including any additional charges or penalties.

Designing an Interface for Displaying Violation Details and Fines-

· Tabular Layout: Organizing violsation details and fines in a tabular format for easy scanning and comparison. Each row in the table should represent a separate violation, with columns displaying relevant information such as violation type, date, fine amount, and payment status.
Visual Cues: Using visual cues such as color-coded indicators or icons to highlight important information, such as overdue fines or pending payments. This helps users quickly identify areas that require attention or action.

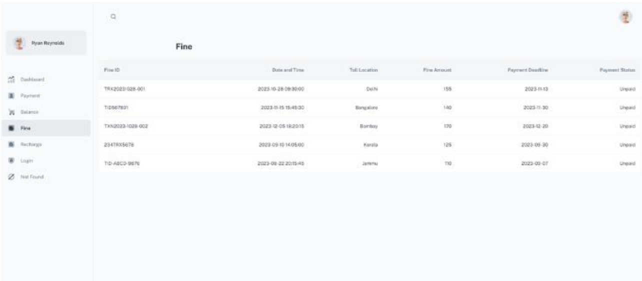

FIGURE 11. Fine Page

6.5 Payment Page Functionality:

The Payment Page within a digital toll collection system facilitates the secure processing of toll payments from users. It provides an overview of the Payment Page functionality, including its purpose, integration with payment gateways for secure transactions, support for multiple payment methods, and optimization of the checkout process for convenience and efficiency. It presents users with a summary of the toll charges, fines, or outstanding balances that need to be settled. This includes itemized details of each transaction, fines, or fees incurred. It offers users a selection of payment methods to choose from, including credit/debit cards, mobile wallets, bank transfers, or other electronic payment methods. It implements robust security measures to protect users' payment information and ensure secure transactions, such as encryption protocols, SSL certificates, and compliance with PCI DSS standards. The Payment Page functionality within a digital toll collection system plays a vital role in facilitating secure and efficient toll payments from users. By integrating with trusted payment gateways, supporting multiple payment methods, and optimizing the checkout process for convenience and efficiency, designers can enhance the overall user experience and streamline the payment workflow for users.

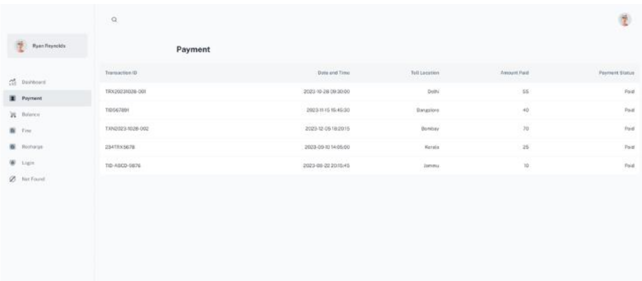

FIGURE 12. Payment Page

6.6 Recharge Page Functionality:

The recharge page functionality for the toll collection system utilizing number plate recognition and OCR (Optical Character Recognition) technology serves as a crucial component for users to replenish their account balances conveniently. This functionality is designed to streamline the process of topping up funds, ensuring smooth passage through toll booths without the hassle of physical transactions.

Interface Design:

User Authentication: Before accessing the recharge page, users are prompted to authenticate their identity.

This could be achieved through various means such as login credentials, biometric authentication, or OTP (One-Time Password) verification.

Account Overview: Upon successful authentication, users are presented with an overview of their account balance, recent transactions, and any pertinent information related to their account status. This provides users with transparency regarding their account activity and current balance.

Recharge Options: The recharge page offers multiple options for users to add funds to their accounts. These options may include:

Direct Payment: Users can opt to make direct payments using debit/credit cards, net banking, or other electronic payment methods.

Auto-Recharge: Users can set up auto-recharge functionality, where funds are automatically deducted from their linked payment method when the account balance falls below a predefined threshold.

Voucher Redemption: Users may have the option to redeem prepaid recharge vouchers purchased from authorized outlets.

Mobile Wallet Integration: Integration with popular mobile wallet services allows users to recharge their accounts using funds from their digital wallets.

Amount Selection: Users can choose the desired recharge amount from a predefined list of denominations or enter a custom amount based on their requirements. The maximum amount to add into the wallet is 10,000.

6.7 Chatbot Functionality:

The chatbot page functionality for the toll collection system, integrated with number plate recognition and OCR (Optical Character Recognition) technology, serves as a user-friendly platform for resolving queries and providing assistance to users. This innovative approach combines the convenience of natural language interaction with the efficiency of automated systems to address user concerns effectively.

Interface Design:

Chat Interface: The chatbot page features a conversational interface where users can interact with the chatbot using natural language queries. The interface is designed to be intuitive and user-friendly, with a text input field where users can type their questions or concerns.

Welcome Message: Upon accessing the chatbot page, users are greeted with a welcome message introducing the chatbot and inviting them to ask any questions or seek assistance they may have regarding the toll collection system.

Query Resolution: Users can ask a wide range of queries related to the toll collection process, account management, payment issues, toll booth locations, account balance inquiries, and any other relevant topics. The chatbot is programmed to understand and respond to these queries promptly and accurately.

Dynamic Responses: The chatbot provides dynamic responses tailored to the user's specific query. These responses may include text-based answers, links to relevant resources or FAQs, instructional videos, or interactive guides to help users resolve their issues effectively.

Contextual Understanding: The chatbot is equipped with advanced natural language processing capabilities, enabling it to understand the context of user queries and provide contextually relevant responses. This allows for more meaningful interactions and enhances the overall user experience.

Design Principle	Description
Understand User Needs	- Conduct research to comprehend user goals and pain points. - Use methods such as interviews, surveys, and usability testing.

Design for Usability	- Create intuitive, easy-to-navigate interfaces. - Minimize cognitive load for users.
Iterate and Test	- Continuously gather feedback through prototyping and testing. - Incorporate insights to refine the interface iteratively.
Provide Feedback	- Keep users informed about system status, actions, and errors. - Use clear and timely feedback mechanisms.
Interface Elements	- Use clear navigation, visual hierarchy, consistent layout, intuitive controls, and effective use of space and typography.
Accessibility Features	- Enable keyboard navigation, screen reader compatibility, and text resizing. - Ensure inclusivity for users of all abilities.

Table 6: Design principles used

Accessibility Features for Inclusive Design:
Inclusive design aims to ensure that digital products are accessible to users of all abilities. Key accessibility features include:
Keyboard Navigation: Enable users to navigate and interact with the interface using keyboard shortcuts, ensuring accessibility for users with mobility impairments.
Screen Reader Compatibility: Ensure that the interface is compatible with screen readers by providing descriptive text alternatives for images, icons, and other non-text elements.
Text Resizing: Allow users to resize text and adjust the interface's zoom level to accommodate varying visual preferences and needs.

7. Efficient Backend Processing

In the realm of automated toll booth systems, the backend infrastructure serves as the backbone, orchestrating various critical functions such as user management, toll transaction processing, and system management. This section provides an in-depth analysis of the key components comprising the backend system, elucidating their functionalities and operational intricacies.

7.1 Server-side Application:

The server-side application constitutes the primary engine driving the backend operations, encompassing essential modules for user management, toll transaction processing, and system management.

- **User Management:** This module oversees user-related activities, including registration, authentication, and account management. It employs robust security measures such as password hashing and authentication protocols to safeguard user data.
- **Toll Transaction Processing:** Central to the toll booth system's functionality, this module receives data from the mobile app, computes toll amounts, processes payments securely through integration with a payment gateway, and updates user account balances and transaction history.
- **System Management:** Responsible for maintaining the system's health and performance, this module monitors communication with external systems, generates comprehensive reports, and ensures seamless operation.

7.2. Database:

A robust relational database management system (DBMS) forms the foundation of the backend infrastructure, storing critical data pertaining to users, transactions, system configuration, and license plate information.

- **User Information:** Detailed user profiles, authentication credentials, and payment methods are stored securely within the database.
- **Transaction History:** Every toll transaction, along with timestamps and amounts, is meticulously recorded to maintain a comprehensive transaction history.
- **System Configuration Settings:** Essential configuration parameters, such as toll rates and lane assignments, are stored to facilitate system customization and adaptability.
- **License Plate Data:** Optionally, the database may store license plate information for expedited transactions and seamless user identification.

7.3. Communication Protocols:

Effective communication protocols are pivotal for facilitating seamless data exchange between the backend system and other components.

- RESTful APIs: Standardized RESTful APIs serve as the conduit for communication between the mobile app and server, ensuring interoperability and scalability.
- Messaging Queues: Asynchronous messaging queues may be employed to handle high transaction volumes or facilitate real-time updates, optimizing system performance.

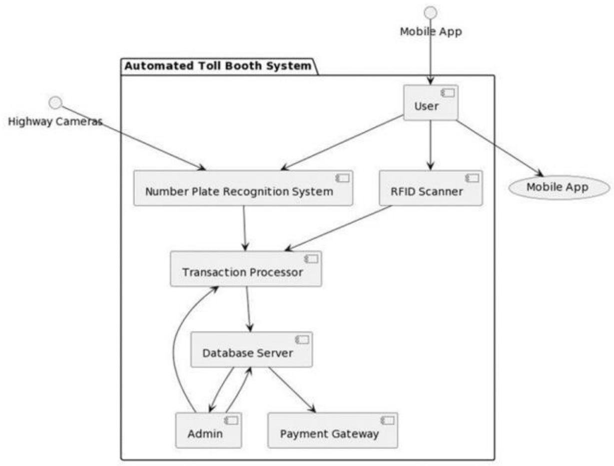

FIGURE 13. Backend Use case diagram

7.4. Entity-Relationship Modelling for Backend Architecture

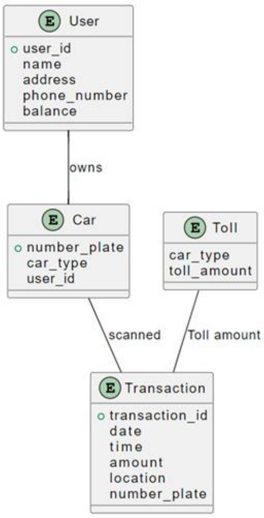

FIGURE 7. ER diagram

The ER diagram for the backend architecture of the Automated Toll Booth System delineates the entities, relationships, and their attributes, providing a comprehensive understanding of the data structure crucial for system operation.

Entities:

1. User: Represents registered users of the system with accounts, storing essential user information.
2. Car: Denotes vehicles utilizing the toll booth system, identified by their license plate numbers and categorized by type.
3. Transaction: Signifies individual toll payment instances, recording details such as date, time, amount paid, and the corresponding user and vehicle.
4. Toll: Represents predefined toll amounts linked to different vehicle types, facilitating accurate toll calculation during transactions.

Relationships:

1. (1:N) User - Car (Optional): A single user can have multiple cars associated with their account, while each car can be linked to either zero or one user.
2. (1:N) Car - Transaction: Each car can have multiple transactions corresponding to toll payments, with each transaction being associated with a single car.
3. (1:M) Car Type - Toll: Establishes the relationship between car types and their respective toll rates, allowing for flexible toll assignment based on vehicle classification.

The ER diagram elucidates the fundamental data architecture of the backend system, integral for managing user accounts, processing toll transactions, and ensuring system integrity. Users can register accounts, link vehicles, and perform toll transactions, with the system recording transaction details for monitoring and analysis purposes. The Toll entity enables the system to define and apply toll rates dynamically, accommodating various vehicle types and toll scenarios.

7.5 Toll Deduction

Deducting toll from a user's account within the Automated Toll Booth System involves a systematic process orchestrated through an API endpoint, user authentication mechanisms, and database interaction. Firstly, an API endpoint is established within the Express application to handle toll deduction requests. This endpoint expects data in the request body, including the user's ID, license plate number for verification or linkage to the user account, and the toll amount to be deducted. Robust user authentication mechanisms, such as JWT tokens or session management, are then implemented to ensure that only authorized users can initiate toll deductions, safeguarding system integrity.

Subsequently, database interaction is facilitated using a database management library like Mongoose for MongoDB. This interaction encompasses fetching user information based on the provided user ID, verifying the license plate number if linked to the user's account (optional), updating the user's account balance by deducting the toll amount, and creating a transaction record in the database to log toll deduction details, including user, license plate, amount, and timestamp. Error handling mechanisms are crucially implemented to address potential issues, such as insufficient balance, user not found, or database errors, ensuring system reliability and resilience.

Upon processing the deduction request, the API endpoint generates a response indicating the success or failure of the deduction process. In the event of success, relevant details such as the updated account balance or transaction ID are included in the response, providing users with real-time feedback on their toll transactions. This comprehensive toll deduction process optimizes user experience, system efficiency, and data integrity within the Automated Toll Booth System.

Conclusion

This research paper has presented the development and implementation of the Swift Tag system, aimed at revolutionizing toll collection processes through the integration of automated number plate recognition (ANPR) and optical character recognition (OCR) technologies. The Swift Tag system offers a comprehensive solution that encompasses all stages of toll collection, from vehicle identification to payment processing, without the need for manual intervention. By leveraging state-of-the-art ANPR techniques, Swift Tag ensures efficient and accurate identification of vehicles passing through toll booths, thereby streamlining the entire toll collection process.

Furthermore, the integration of OCR technologies within the Swift Tag system enhances its capabilities by enabling seamless extraction and interpretation of alphanumeric characters from license plates. This not only facilitates user identification but also enables swift and secure payment processing, thereby minimizing congestion at toll booths and improving overall traffic flow. The robustness and reliability of the Swift Tag system have been demonstrated through rigorous testing and validation across various scenarios and environments, yielding promising results in terms of accuracy and performance.

Looking ahead, the Swift Tag system holds immense potential for revolutionizing toll collection systems worldwide, offering a cost-effective and user-friendly alternative to traditional toll payment methods. Future research endeavors will focus on further refining the system's algorithms and enhancing its scalability to accommodate increasing traffic volumes. Additionally, ongoing efforts will be directed towards optimizing user experience and exploring opportunities for integration with emerging technologies to ensure the continued advancement and adoption of Swift Tag in modern transportation infrastructures.

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