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Smart Parking Infrastructure Using Visual Analytics For Sustainable Urban Mobility

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Abstract. *This paper presents a smart parking infrastructure leveraging a camera-integrated Raspberry Pi system and OpenCV-based visual analytics to enhance urban mobility and promote sustainable parking practices. The system continuously monitors parking spaces, detects available slots, and identifies them using unique slot numbers, providing real-time updates to users. To ensure efficient space utilization and avoid congestion, the system dynamically restricts access to slots adjacent to oversized or improperly parked vehicles. Additionally, it maintains a comprehensive database of incoming and outgoing vehicles, parking durations, and fare calculations (if applicable). By integrating visual recognition, intelligent decision-making, and automated record-keeping, the proposed solution contributes to reduced traffic congestion, lower emissions from vehicle idling, and improved parking efficiency in smart urban environments.*

Keywords: *Smart Parking, Computer Vision, Raspberry Pi, Sustainable Urban Mobility, Parking Slot Detection.*

1 INTRODUCTION

Everything in this world is becoming easier due to the intervention and proper usage of Science and Technology. From space to streets, technology plays a pivotal role in our day-to-day lives, and imagining a life without it is a nightmare. A problematic scenario for drivers and employees is to find a perfect parking spot in malls, parking lots and offices. There are solutions, like an Automated Parking System, where parking spaces use truck-sized machinery and various sensors for parking cars at random available places. This project aims for zero usages of mechanical machinery and allows users to park according to their convenience. Also, if found to be improperly parked, or next to a larger vehicle, according to the size of the wheeler coming in, the slot will be closed to avoid potential damage to either vehicle and to create a more comfortable and easier parking experience.

1.1 Current Parking scenario and its demerits

Most parking spaces today are under human surveillance and management. Staff members are stationed at the entrances and exits to monitor the duration of parking and collect fees, ensuring smooth traffic flow. However, this reliance on human management can sometimes lead to inefficiencies, causing unnecessary delays in the parking process. Additionally, during peak hours, there is often a long queue at the billing area as staff manually enter and process the billing information.

While few parking lots display the total number of available slots at the entrance or on each level, this information is usually based on the number of vehicles entering or exiting, rather than a live count. The count is only updated once a car successfully exits the parking space. As a result, drivers may mistakenly assume that there are no available parking spaces even if vehicles are leaving the parking lot.

To avoid the time-consuming process of parking, and to create an easy and hassle-free experience, this project aims to completely automate the parking space- from data management to billing, to slot displaying.

2 PROPOSED PLAN

The project's main goal is to capture and store incoming vehicles' number plates and display parking slot availability. It can also identify and close improperly parked spots. Exempted vehicles will not be billed, only their entry and exit time will be recorded. Customers and the public will be charged based on their entry and exit time, with the fare displayed for reference.
The detailed process and methodology will be explained below.

2.1 Methodology

Cameras are placed at entry and exit points if not already present. The system is connected to a database for storage and calculations. Before being made available to the public, the entire system is installed and evaluated. At the entry point, the system captures the vehicle's number plate image and extracts the text using OCR recognition in Python. This, along with the entry time, is stored in the database. Real-time monitoring of parking spaces is done using cameras, and the availability of slots is displayed at the entrance.
When a car enters a slot, the slot is closed, and the count is updated automatically. If a vehicle is improperly parked, the nearby slot is closed to prevent damage.

Upon exiting the parking spot, the slot is immediately opened for incoming vehicles. The number plate is captured again at the exit point and the text is extracted. It is then checked against a set of data to determine if the vehicle is exempt from the fare. If exempt, no billing occurs. If not, the fare is calculated using the entry time to provide a bill amount.

2.2 Flow Chart

The flow chart in Fig. 1 will clearly explain the working of the project.

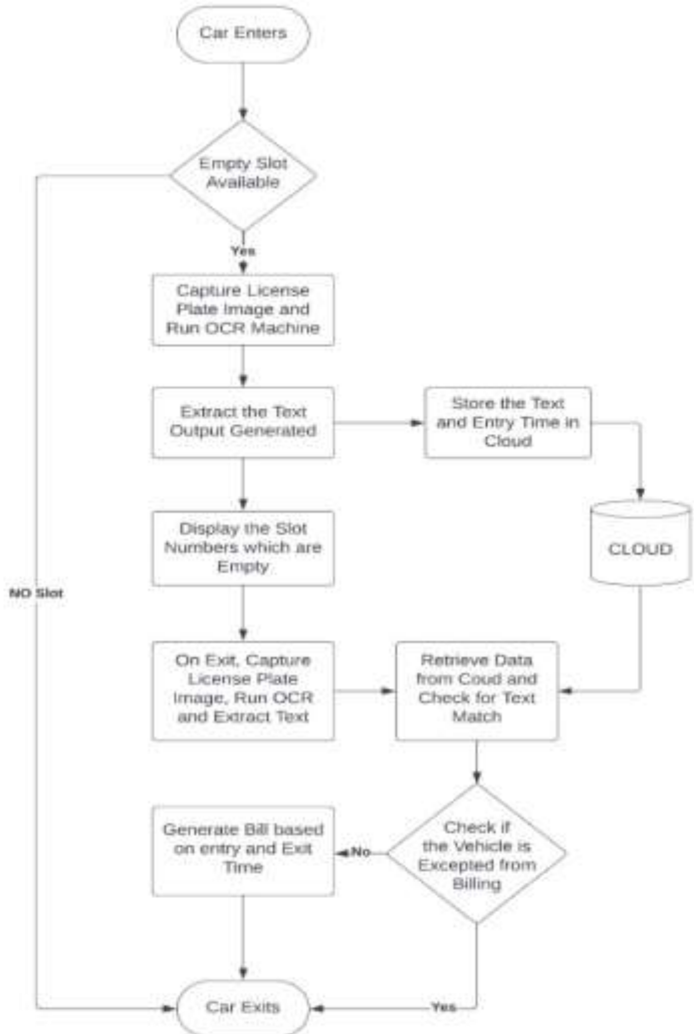

Fig. 1. Working of the project

3 HARDWARE

The prominent hardware components that are used in our project are Raspberry Pi 4, Raspberry Pi NoIR Camera V2, and small-size camera modules (Webcam).

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3.1 Raspberry Pi 4

Raspberry Pi 4 (Fig. 2) is a small single-board computer of dimensions 85mmx56mm. The Raspberry Pi 4 is a microprocessor controller board that allows user to compute data, generate valuable outputs, and control components in a system based on the results of its computation. It has a set of ports, out of which the two most important ports are Raspberry Pi camera port (2-lane MIPI CSI) and Raspberry Pi display port (2-lane MIPI DSI). In our project, the Raspberry Pi 4 acts like a compact computer that allows us to control electronic components and explore IoT (Internet of Things). It is used as a small control unit, through which all the cameras (including the NoIR Camera Module) are connected, and the data is processed.

Fig. 2. Raspberry Pi 4

3. 2 Raspberry Pi NoIR Camera V2

Raspberry Pi NoIR Camera V2 is an 8-megapixel Sony IMX219 image sensor module by Raspberry Pi Corporation for exceptional image quality. It can be integrated with Raspberry Pi through the dedicated CSI interface. It is compactly designed, measuring approximately 25mm x 23mm x 9mm. It can capture 1080p high quality videos. The NoIR stands for No- Infra Red, meaning the module lacks an infrared filter, resulting in this module being an excellent choice for low- light applications, like home and wildlife observance, surveillance systems. This is used here for experimental purposes, to mimic the real-life parking complexes mostly lack light and are rarely properly illuminated.

Fig. 2. Raspberry Pi NoIR Camera V2 Module

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3.3Multiple Web-Cameras
There are other cameras used in this project, which are Webcams. They are used to capture data for various parts of the small-scale model for functions like real-time parking space monitoring (for live slot updating), number plate extraction at exit/entrance and more.

3.4Hardware Specifications
The specifications of the hardware components used are listed below.

Component	Specifications
Raspberry Pi 4	8GB Ram
Raspberry Pi NoIR Camera V2 Module	Sony IMX219 8-MP sensor
Webcams	5MP sensor

4 ALGORITHM, TESTING AND OUTPUTS
The program is coded in Python 3.12, using modules such as OpenCV, Tesseract, Firebase Admin, and OpenCV being the most used module.

4.1 Definition of Parking Slots
This process is done before the opening of the parking complex to the public; it involves the definition of boundaries for each individual parking slots, to observe the movement and position of car present or absent. The marking can be done manually or automatically but is mostly preferred to be done manually to avoid errors and mismarking.

There are two ways to define a slot- either by creating a pre-defined shape, marked with the click of a mouse, or defining the shape of the slot by drawing dots around the desired region. Although the latter is more accurate, it is evaluated for research purposes but not used in this project to avoid complexity and prevent time consumption every time a slot is created.

Fig. 3. Model Parking Space for project purposes

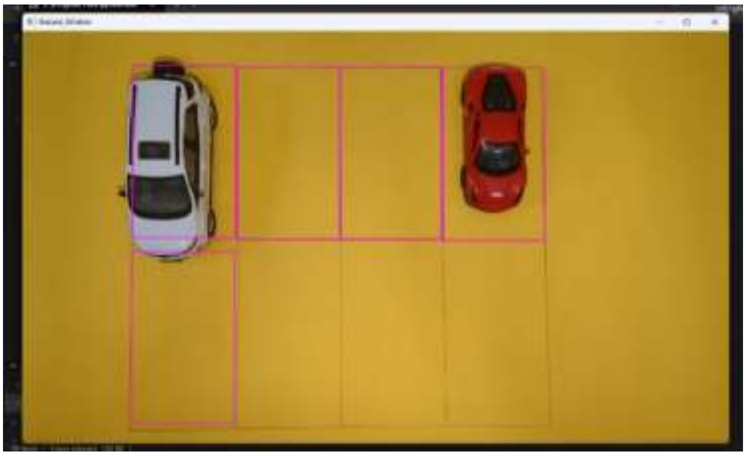

Fig. 4. Slot Definition (manual, highlighted in pink border- marked slots)

Fig. 3 shows the model parking complex, and Fig. 4 shows the completion of the marking process, and the slots are identified and monitored in real-time for any change in data (incoming/outgoing cars).

4.2 Number Plate Extraction

This is one of the most crucial parts of the project, where the number plate is captured in the entry point of the parking complex. This acts as the primary key, since no other information- name, phone number, unique ID are generated.

Using Tesseract OCR, the number plate is captured, and the text is extracted. Since the scale of the cars are small, it was not possible to attach/paste number plates on small toy cars. Stock images are used, and capturing the number plate using a camera is also achieved.

Fig. 5. Number Plate Text Extraction
Fig. 5 shows the raw image and the extracted text from the image.

To prevent undesirable characters from being recognized, the program filters out any improper symbols/characters from the raw output and gives in the final text.

4.3 Uploading the Number Plate to Firebase

Google Firebase is a free platform from Google Inc. for data management and storage. This is used as it is connected to the Internet, so it can be accessed from anywhere across the globe easily. Data processing, viewing, and retrieving is much easier in this than conventional offline database management systems. Here, the final extracted text of the number plate is uploaded into Google Firebase, along with the entry time of the car. This is demonstrated in Fig. 6 where the details are stored acc. to the number plate of the vehicle.

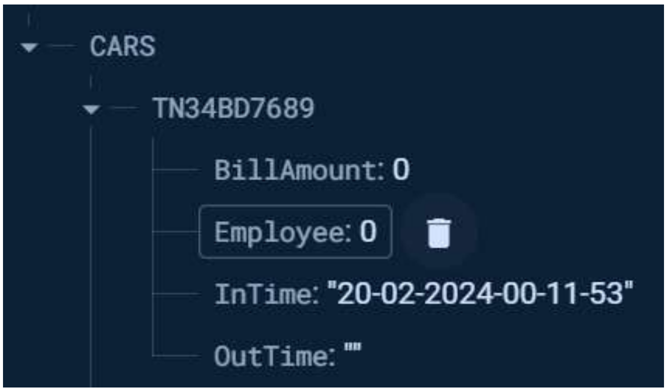

Fig. 6. Uploaded data in Google Firebase with entry date and time

4.4 Live Slot Count

If a car enters a slot that is defined, using OpenCV, with processes such as contour detection, greyscale processing, change in pixels, intersection over union, and more individual steps involved, the slot is closed.
Once a car starts entering, the threshold value (output of all the mentioned processes in form of numbers) starts to vary. If the value increases beyond the set value, the slot is occupied. If less than the set value, it is considered free/unoccupied.

Fig. 7. Available slot count (on the top left), Occupied slots (red bordered), and unoccupied slots (green bordered)

Fig. 7 indicates the available slots in the parking space are four out of five total defined slots. The one slot in which the car is parked results in a threshold value that is much greater than the set value- marking the slot CLOSED.

Fig. 8. The change in threshold value of the slot due to the incoming car

Fig. 8 shows that as a new car enters the defined slot, the threshold of the slot increases, resulting in closing of the slot. This reduces the available slots to three, from the previous availability of four slots.

Fig. 9. Final parking position of the new car, resulting in a large threshold value and closing of the slot

Once the car is completely parked, the threshold value is large enough to reduce, thus preventing to open the slot accidentally. This can be observed in Fig. 9 where the threshold value of the new car is much greater than the values of the empty parking slots.

After the car exits the slot, the threshold value will automatically reduce below the set value and the slot will be opened, updating the available slot count in real time.

4.5 Exiting of the vehicle and Billing

Once the car reaches the exit point, it is necessary to check whether the vehicle is exempted from billing or not. To achieve this, the number plate is again captured, and the text is extracted, filtered, and compared to the existing database of exempted vehicle list. If the vehicle is found in that list, billing will not take place. If not found, the bill amount is calculated based on the in-time and out-time.

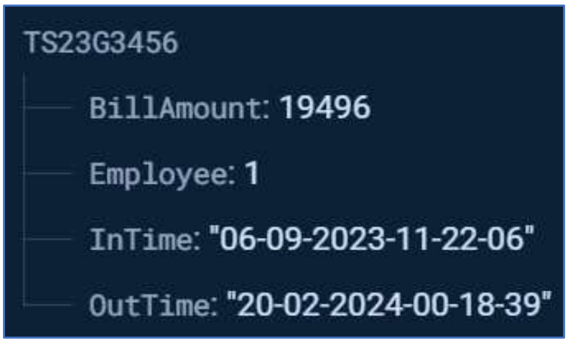

Fig. 10. Vehicle of an employee

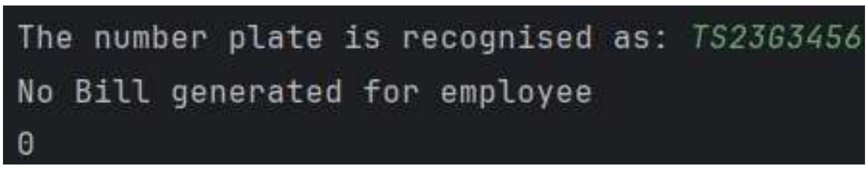

Fig. 11. Billing for an employee

Fig. 10 and Fig. 11 show that employees are not being billed for their respective parking time in the complex.

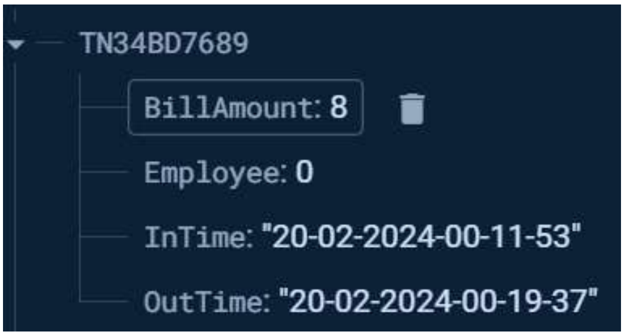

Fig. 12. Vehicle of a visitor

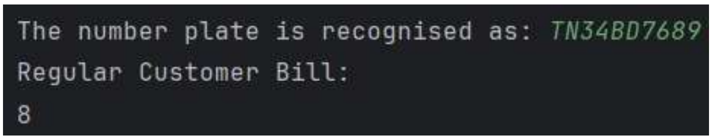

Fig. 13. Billing for a visitor

Fig. 12 and Fig. 13 show how a visitor is billed for the time of parking in the complex.

5 CONCLUSION

The proposed smart parking infrastructure leverages visual analytics and automation to address key inefficiencies in traditional parking systems, particularly within large urban facilities. By eliminating the need for manual monitoring at entry and exit points, the system enhances user experience through real-time parking slot identification, automated billing, and reduced queuing times. The integration of computer vision via Raspberry Pi not only optimizes parking space utilization but also contributes to decongesting traffic flow and minimizing idle emissions, supporting the broader goals of sustainable urban mobility. Furthermore, the inclusion of an exempted vehicle list accelerates access for authorized users, while comprehensive data logging ensures secure tracking of vehicle entry, duration of stay, and fare computation. Overall, this initiative demonstrates how minor technological interventions can yield significant improvements in operational efficiency, environmental sustainability, and urban transport management.

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