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Smart Vehicle Parking System with Rfid-Based Authentication and Ai-Powered Slot Detection

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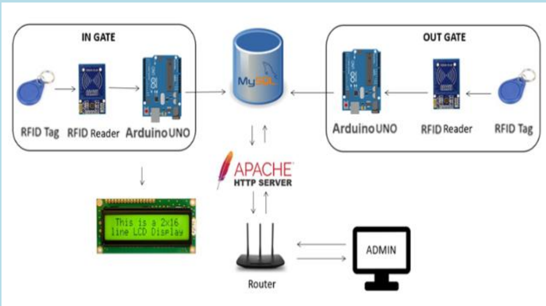
Abstract: As the population of cities grows and the need for transportation increases, urban parking congestion is becoming a bigger issue. The study highlights the need for smart parking systems to provide on-demand parking solution that reduces traffic and inconvenience. In order to solve the common issue of parking space scarcity in large cities, the study presents a novel solution that is based on real-time slot recognition and car identification. Current parking systems that rely on manual procedures waste time and energy consumption. The proposed method uses Radio-frequency identification (RFID) technology to authenticate cars and prioritize suitable parking spaces, aiming to reduce parking congestion and improve efficiency. In order to streamline parking procedures and maximize resource utilization, this technique attempts to keep an eye on entry and exit timings and notify security personnel of vehicles parked for extended periods of time. Additionally, to find parking spaces for cars in real-time, the study uses the Faster R-CNN (Region Convolutional Neural Network) algorithm, which is well-known for its quick object detection abilities. A crucial gap in smart parking solutions is filled by the research by incorporating sophisticated computer vision-based artificial intelligence into parking systems. This strategy to mitigate urban parking difficulties is shown feasible and effective, as evidenced by the successful testing of the implemented prototype of the suggested system in a university parking space.



Keywords: RFID, Faster R-CNN Algorithm, Vehicle Authentication, Smart Parking System, Energy-Efficient Transportation, Sustainable Urban Mobility, Environmental Impact Reduction, And Intelligent Image Processing.

Introduction

Transportation complexity has significantly increased in recent years due to global population growth. With the surge in vehicle numbers, parking issues have worsened, causing drivers to spend more time searching for available parking spaces and thereby increasing travel time. Figure 1 [1] illustrates the growth rate of vehicles in India. Given the complexity of parking and the rising number of vehicles on the road, parking has become an essential aspect of the driving process.

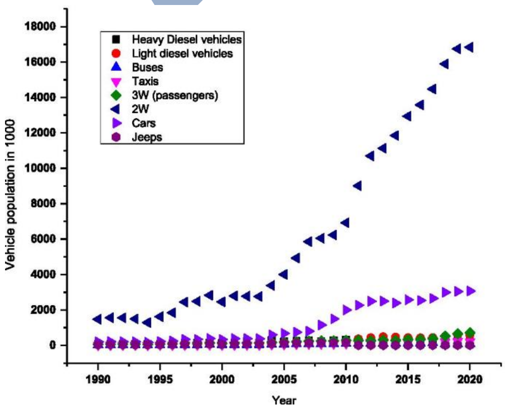


Figure (1): Growth rate of vehicle population in India [1].

Efficient management of parking spaces relies on accurate identification of parking occupancy. Reducing the time spent searching for an available parking spot can be achieved by providing real-time information about parking space availability to users. Automatic parking space detection plays a vital role in enabling such systems [2], [3]. Traditional methods employ sensors, such as ultrasonic, geomagnetic, or infrared, to detect cars in parking spaces. However, these conventional parking spot detection technologies require the installation and maintenance of sensors in each parking space, which can be costly, especially in large parking lots. Although this approach offers higher accuracy, the expenses involved limit its widespread adoption. Another drawback is the requirement for intelligent infrastructure in the parking spaces, which further increases commercialization costs.

Radio frequency identification (RFID) technology utilizes radio waves to identify individuals or items without the need for physical contact or a direct line of sight. A wireless device or "tag" can be read remotely by a specialized device, enabling data retrieval. RFID usage has been expanding as society embraces the information age. Figure 2 [4] showcases the application of RFID in vehicle authentication systems. The ability of RFID to operate without line of sight and perform simultaneous readings holds great potential. Leveraging this technology, vehicles can

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be identified, and parking validations can be collected automatically.By combining automated parking space detection with RFID-based vehicle authentication, parking administration can be significantly improved [5]. Real-time availability of parking spaces can be communicated to users, streamlining the search for parking and reducing congestion. The use of RFID eliminates the need for extensive sensor installations, resulting in cost savings and simplified implementation. Furthermore, the non-contact nature of RFID enhances convenience and efficiency for both vehicle owners and parking management.

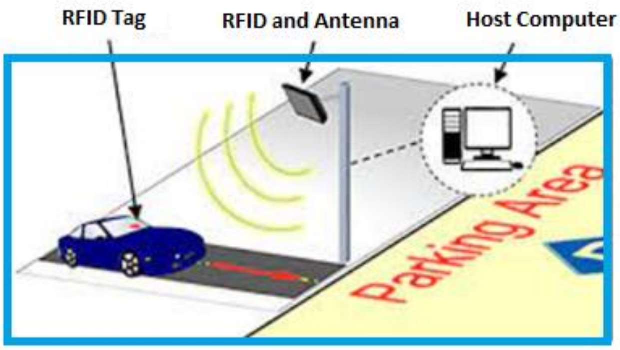

Figure (2): RFID based vehicle authentication system [4].

The proposed system leverages RFID readers, Client-Server PCs, and network connections to create an automated approach for efficient parking lot management and monitoring. This setup enables seamless data collection and access to essential reporting, with the added advantage of remote administration through the establishment of a central database. Administrators can remotely monitor the performance and functionality of both the RFID system and parking lots. Through internet access, they can view tag IDs and user-vehicle information.Deep learning and neural networks have revolutionized the field of computer vision. Deep Convolutional Neural Networks (CNNs), a type of deep learning model, have shown remarkable success in tasks such as object detection, semantic segmentation, and image classification. To address the limitations of ultrasonic parking slot detection, a vision-based parking slot recognition approach is proposed. This method utilizes a camera mounted around the vehicle and employs image processing techniques to identify available parking spaces [6].

The proposed work builds upon previous research that explores state-of-the-art technologies and algorithms for detecting free parking spaces. In this system, parking slots are detected using the Faster R-CNN algorithm, as demonstrated in Figure 3. The Faster R-CNN algorithm outperforms its predecessors in terms of speed and accuracy [7]. Leveraging the capabilities of PyTorch pre-trained Faster R-CNN, this system can identify open parking spaces in real-time.

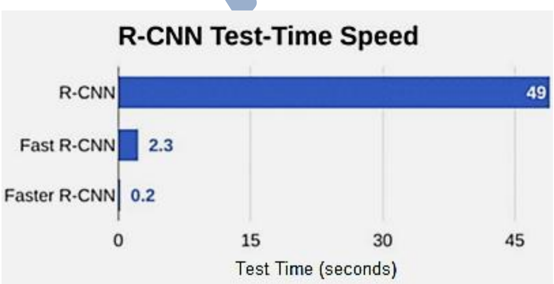

Figure (3): Comparison of object detection algorithms [7].

In scenarios where challenges like shadows and diverse lighting conditions may introduce disruptions, Faster R-CNN emerges as a dependable and valuable solution. It exhibits a strong generalization capability, enabling it to perform effectively across different environments. The training of algorithms plays a vital role in the development of such object detection systems [8]. By employing these techniques, an instance segmentation model is employed to extract and differentiate various objects within an image. This process operates in real-time, delivering data within a predetermined time interval. The forthcoming sections of the paper will comprehensively cover the related works, methodology of the proposed system, implementation details and results, culminating in a conclusive discussion and conclusion.

Related Works

The system proposed in [9] explores the integration of passive Radio Frequency Identification (RFID) tag-to-tag communication in smart parking systems to enhance energy efficiency and operational effectiveness. The study focuses on optimizing joint routing and minimizing RFID reader transmission power while leveraging tag-to-tag interactions. The proposed framework outperforms conventional direct RFID reader-to-tag communication by: (i) reducing RFID reader transmission power to the minimum required for connectivity and (ii) extending the coverage area, allowing communication with distant tags that would otherwise be inaccessible through direct transmission.

The growing number of vehicles has led to significant challenges, highlighting the need for efficient and reliable parking management as a key component of smart city development. This paper [10] proposes an intelligent parking system based on RFID technology, where vehicles are identified using RFID tags and readers. The system enables contactless access and cashless payments, effectively addressing common issues in traditional parking fee collection, such as inefficiencies, resource misallocation, and revenue losses, ultimately improving the overall effectiveness of urban parking management.

Currently, many parking management systems still depend on human intervention to handle a large number of transactions, which becomes increasingly challenging in high-traffic parking areas. This reliance leads to issues such as unauthorized access, reduced public security, and payment fraud. To address these challenges, this paper [11] proposes an automated parking system utilizing Radio Frequency Identification (RFID) technology. With RFID-based access control, only registered users with RFID tags can enter, enabling fast and seamless check-ins and check-outs while reducing congestion and wait times at parking terminals. The system enhances security by restricting access to authorized users only. Additionally, an automated parking access control system is designed and implemented through a simulated gate portal using RFID technology, ensuring a more efficient and secure parking management process.

In [12], a Region Proposal Network (RPN) was introduced, sharing full-image convolutional features with the detection network. This RPN, which is part of a fully convolutional network, predicts object boundaries and objectness scores at each point, enhancing object detection processes. The RPN, through comprehensive training, generates high-quality region proposals used for object detection with methods like Fast R-CNN. This approach, utilizing alternating optimization, achieves superior performance on object detection tasks and is highly efficient, running at fast speeds on a K40 GPU.

The method proposed in [13] enhances object detection by incorporating skip pooling and contextual information fusion within the Faster R-CNN framework. This technique captures contextual information, particularly in cases where objects are obscured or deformed, by introducing a feature extraction model after the convolutional layer's conv5 3 and incorporating skip pooling. The improved approach replaces the region proposal network (RPN) with a more effective technique, yielding a 6.857% improvement in mean average precision (mAP) over traditional algorithms like YOLOv3 and SSD512, while maintaining specific recall rates and improving overall detection accuracy.

The Video-based Intelligent Transportation Systems (V-ITS) proposed in [14] aim to improve transportation-related applications by utilizing AI techniques to extract relevant data from video camera outputs. Convolutional neural networks (CNNs) are employed for vehicle recognition, a critical component in V-ITS applications. The method uses a Faster R-CNN architecture to recognize vehicles in video frames in near real-time, achieving high accuracy with a sensitivity level of 0.985 and detecting vehicles in an average of 74 milliseconds.

In [15], an IoT-based cloud-integrated smart parking system was introduced. This system employs IoT modules to track and transmit the availability of parking spaces. Users can check parking availability and make reservations through a smartphone application. The system leverages IoT technology to improve productivity and reliability in urban environments, addressing challenges such as traffic congestion, limited parking, and road safety. This system aligns with the broader concept of smart cities.

The system described in [16] tackles issues in traditional parking systems by offering dynamic parking slot allocation that considers the overall parking situation. Using AI-based applications, the system allows for specific parking slot reservations and ensures vehicles are parked in the designated spots. The system offers two cost-flexible technical solutions based on motion sensors and range-finder sensors. Additionally, an IoT device, through a plate detection and recognition system, identifies vehicle number plates.

A smart parking system utilizing a CNN model and transfer learning-based approach was proposed in [17] for vehicle detection and number plate recognition. The system scans for vehicle type and number as cars enter the parking lot. Based on the car type, the system allocates the most appropriate parking space. Additionally, the system includes surveillance with webcams and a number plate recognition model. If a vehicle is parked in an incorrect spot, the user is alerted. The system also calculates parking charges automatically when the vehicle exits.

The work presented in [18] introduces an Intelligent Parking System (IPS) that uses IoT architecture to collect real-time data, send it to the cloud, and recommend nearby parking spaces for users. This system is implemented using IR sensors, RFID, NodeMCU, and Raspberry Pi, helping to optimize parking management in urban settings.

The proposed project introduces several innovative features that improve upon previous research in the field of smart parking systems. By integrating RFID technology with a Raspberry Pi camera and leveraging the Faster R-CNN algorithm, our approach enhances parking space detection accuracy and efficiency. Unlike earlier studies, we utilize an IoT-based cloud integration system that ensures seamless data storage via MySQL and smooth communication through an Apache HTTP server, connecting to the router. This combination of advanced technologies, including RFID, cloud integration, and machine learning, offers superior performance, greater scalability, and real-time data management compared to previous solutions.

Methodology

The proposed system consists of two modules: the Gate module and the Parking slot detection module. Figure 4 illustrates the block diagram representation of the Gate module, which is responsible for vehicle authentication. The Gate module of the approach makes use of components such the RFID reader, Arduino Uno, LCD, and MySQL database. These options guarantee efficient vehicle and human identification tracking. Real-time data transmission and safe entry and exit data storage are ensured by the Gate module's configuration. System dependability and user experience are improved by utilising industry standards such as RFID and Arduino Uno. When MySQL is used as the database management system, data management is made easier and important data may be stored and retrieved quickly. Furthermore, this method incorporates a Convolutional Neural Network (CNN) with deep learning for the purpose of detecting parking slots. CNNs are the best choice for real-time slot recognition because of their well-known abilities in image processing applications [19]. The objective is to automate the process of learning and extracting pertinent information from images of parking slots by utilising CNNs. In general, this approach aims to detect parking spaces with high accuracy and efficiency.

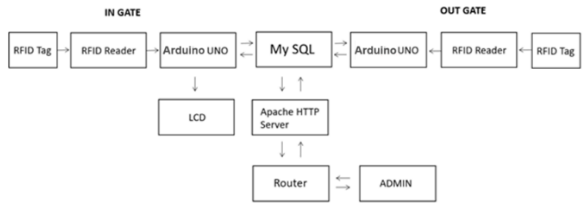

Figure (4): Block Diagram of RFID - based authentication module.

The functional diagram of RFID-based authentication model that clearly depicts the different components used in this module is shown in Figure 5.

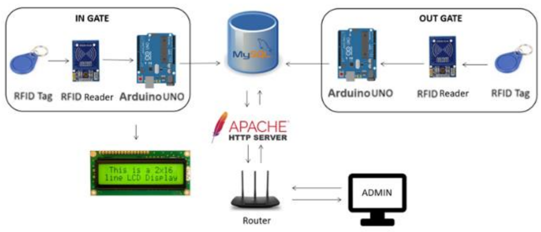

Figure (5): Functional Diagram of RFID based authentication model.

The Parking slot detection module isan AI-based module that consists of a camera, a Raspberry Pi and an LCD display unit. The block diagram of the parking slot detection module is shown in Figure 6.

Figure (6): Block Diagram of parking slot detection module.

The functional diagram of the Parking module shown in Figure 7 gives a clear picture of various components involved in this module.

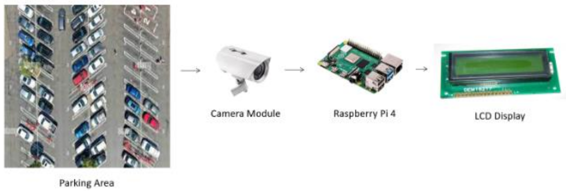

Figure (7): Functional Diagram of parking slot detection module.

The color space of the Pi camera is used to capture the parking lot, which will later be analyzed. The color filtering procedure is the image processing stage in this system. This procedure is used to extract pixels from an image with a specific color intensity value. The thresholding procedure, which is the following step after getting a specific color object, seeks to convert the image from a binary (or black and white) image to a degree of grey so that it can be seen which area includes the object and background of the image. The marking phase is intended to identify all parking places for further analysis.

In the process of Parking slot detection, the parking area image is taken using a Pi camera module every 15 seconds.The purpose of Parking slot detection is to detect the parking slots and then determine the target parking slot. The detection threshold for the Intersection over Union (IoU) evaluation metric is set to 0.6, meaning that a prediction is considered correct if its overlap with the ground truth bounding box is at least 60%. To realize the real-time detection of parking slots in automatic parking, a deep convolution neural network is designed to detect parking slots. The image is first initialized for different parking slot coordinates and then a further image processing algorithm is used for parking slot detection. The faster R-CNN model with resent backbone is used for detecting the free parking slot in the given coordinates. The model was first tested for different input dataset from the database and then it was used for real time image processing.

Gate Module Algorithm

The two essential components of an RFID system, or radio frequency identification system, are a transponder or tag affixed to the item to be identified and a transceiver, sometimes referred to as an interrogator or reader. An antenna that generates a high frequency electromagnetic field and a radio frequency module make up a reader. Instead, it has a microprocessor that stores and processes data together with an antenna for signal reception and transmission.

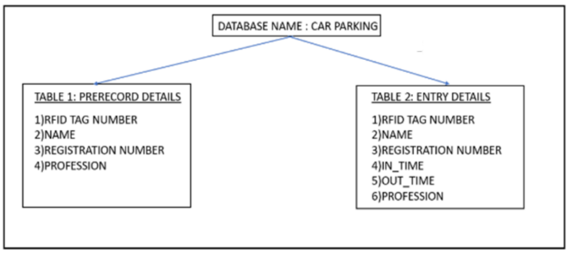

Figure (8): Database Structure of gate module.

A tag needs to be positioned close to the Reader in order to be read (does not need to be within direct line-of-sight of the reader). An electromagnetic field produced by a reader causes electrons to flow through the tag's antenna and power the chip. When the reader requests the stored data, the powered chip inside the tag responds by sending the reader another radio signal. It's known as backscatter. The reader recognizes and interprets the backscatter, or change in the electromagnetic/RF wave, and then transmits the information to a computer or microcontroller. Figure 8 depicts the structure of the MySQL database.

An individual RFID number is produced and sent to the Arduino Uno when the user places the RFID tag in the RFID reader at the IN-gate. The RFID tag is first authenticated by sending the details of that tag number, such as Name, Registration Number, and Profession to the database, if it is present in the pre-record database table. Entry details with In-time and Out-time both empty contain this information. When a user exits a parking space, they must present their RFID tag to the scanner in order for the table to reflect the updated time.

Free Parking Slot Detection Module Algorithm

The faster R-CNN stepwise method used for free slot detection is described as follows [19]:

1. Convolution Layer: Convolution layers, which incorporate convolution Rectified Linear Unit (ReLU), the most commonly used activation function in deep learning models, and pooling processes are used to create feature maps.
2. Region Proposal Network (RPN): Anchors are utilized to provide accurate region suggestions by RPN, which generates region proposals. Two branches make up the RPN network. In order to produce accurate proposals, the first branch detects whether it is foreground or background, and the second branch computes the bounding box regression offset for anchors. Very small suggestions and proposals outside the bounds are excluded by the proposal layer, which also chooses the foreground anchors with precise bounding box regression offset.
3. RoI Pooling Layer: After RPN, proposed areas of various sizes produce feature maps of various sizes. The RoI pooling layer shrinks the input feature maps to the same size by gathering recommendations. Time spent on testing and training is drastically cut.
4. Classification: Using a fully connected layer and a SoftMax layer to forecast class probabilities, fixed-size feature maps are employed to determine the proposal's class. An accurate target detection box is produced by using bounding box regression to predict bounding box offsets.

Implementation and Results

Results for Gate Module

The RFID reader used in this system is the RC522 card reader, which is a small range reader. This reader operates at a frequency of 13.56MHz. The RC522 card reader is designed to provide access control. It is linked to an access controller, which is located at the main gate or in a specific parking lot to restrict access to authorised vehicles only. The experimental setup and the results obtained for Parking Module and Gate Level Module are discussed under this section. The Figure 9 shows the experimental setup for gate module which includes RFID reader and Arduino.

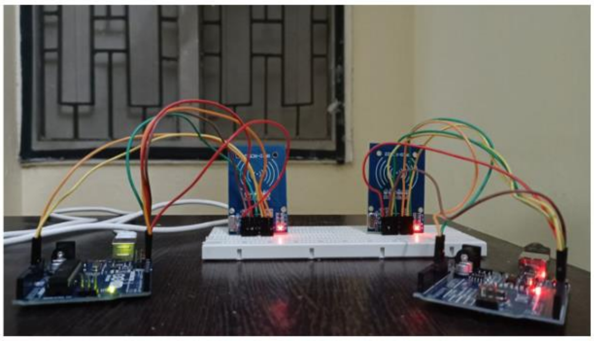

Figure (9): Experimental setup for gate module.

Figure 10 shows that RFID tag is displayed in front of RFID reader when the car enters the zone.

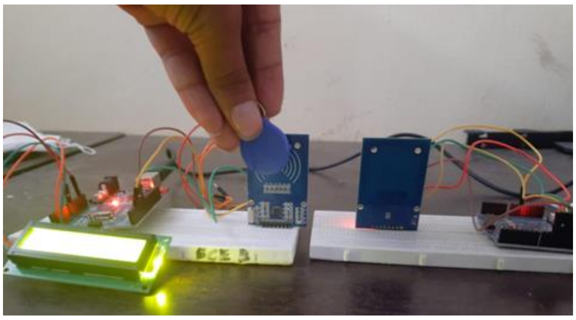

Figure (10): RFID reader in In-Gate.

When the car is authenticated by Arduino using RFID reader, the In-time record is stored in database using MYSQL is depicted in Figure 11.

Names	Registration No	In Time	Out Time	Person Detail	Slot
Aleem	TN 78 BL992	2022.06.08 23:59	0000.00.00 0:00	Professor	2

Figure (11): In-time recorded.

After the data is registered in MYSQL, the updated parking slot is shown in LCD display as shown in Figure 12.

Figure (12): LCD display for In-gate.

Figure 13 represents the reading of RFID tag in the out gate as the user places the tag near the RFID reader as the car leaves the zone.

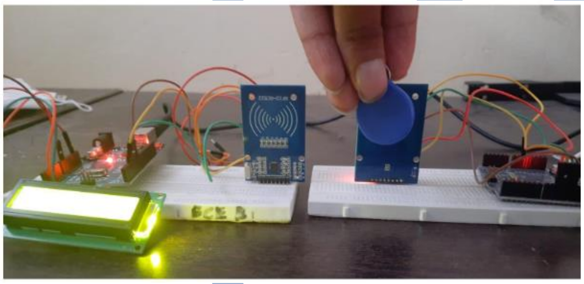

Figure (13): RFID reader in Out-Gate.

When the Car is leaving, the Out-time record is updated in data base using MYSQL is depicted in Figure 14.

Names	Registration No	In Time	Out Time	Person Detail	Slot
Aleem	TN 78 BL992	2022.06.08 23:59	2022.06.09 02:23	Professor	2

Figure (14): Out-time recorded.

When the vehicles don't leave the parking slot then its registered car id will be highlighted and the same is depicted in Figure 15.

Names	Registration No	In Time	Out Time	Person Detail	Slot
Munna	TN 32 BH778	2022.06.09 07:53	0000.00.00 00:00	Student	2

Figure (15): Non-Existed vehicle information.

Results for Parking Module

Once the parking spots are determined on the camera view, the next step is to detect the object at those particular spots. When some object exists at the pre-defined spots, the system will start detecting whether it is a car. The faster R-CNN model is first tested using simulation results and then it was implemented in real time.

Simulation results

The input images used in the simulationare sourced from the master dataset [20].

Figure (16): Input Image 1 for simulation.

Figure 16 is the Input Image 1 for simulation and Figure 17 is the output image which shows free slots information for parking area in green color and the space occupied by the vehicles are highlighted in red color.

Figure (17): Simulation result for Image 1

Output:

Total no. of slots: 16

Total no. of occupied slots: 14

Total no. of free slots: 2

Figure 18 shows the second input image from CNR parking dataset considered for simulation.

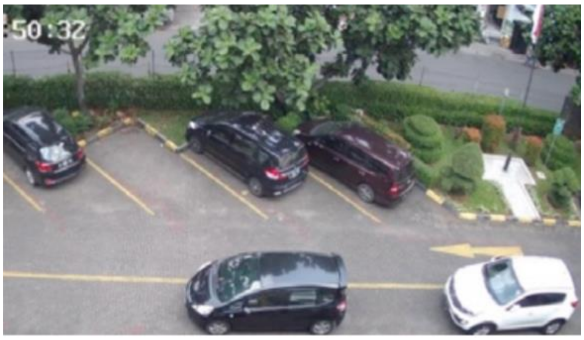

Figure (18): Input Image 2 for simulation.

The simulation output for image 2 is shown in Figure 19 that highlights the free space in green color and occupied space in red color.

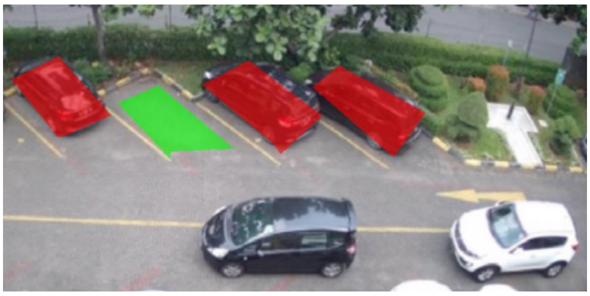

Figure (19): Simulation result for Image 2

Output:

Total no of slots: 4

Total no of occupied slots: 3

Total no of free slots: 1

The third input image from CNR parking dataset considered for simulation is shown in Figure 20.

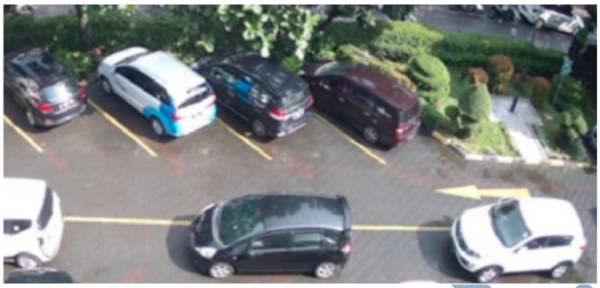

Figure (20): Input Image 3 for simulation.

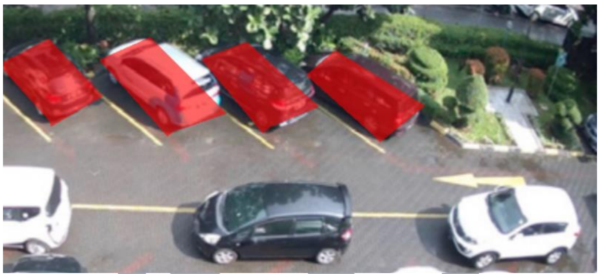

Figure (21): Simulation result for Image 3

Output:

Total no of Slots: 4

Total no of occupied slots: 4

Total no of free slots: 0

Figure 21 is the output image which shows that the parking area is fully occupied by the vehicles and highlighted in red color. The simulation results show a high degree of accuracy in both detecting free and occupied slots, with the system performing well across different parking lot configurations.

Hardware Implementation of Parking Module

The camera module is plugged into the connector on the Raspberry Pi as shown in Figure 22.

Figure (22): Raspberry Pi connected to Pi camera.

The camera is connected to the white connector near the USB and Ethernet ports. The other port, on the opposite side of the single-board computer, is used to connect a display. For every 15 seconds, the Raspberry Pi transfers the image to online SQL database. Figure 23 shows the parking area of the BSA Crescent University campus captured using the Pi camera which is further used for processing and detecting the free space in the image.

Figure (23): Real time input image.

Figure 24 is the processed image that was captured in real time using Pi camera which shows the details regarding the free space and occupied space in the parking area.

Figure (24): Result of hardware implementation.

OUTPUT:

Total no of slot: 14

Total no of occupied slots: 14

Total no of free slots: 0

The results shows that all the slots in the parking area are occupied using red color.

In the real-time scenario, the system was able to detect all occupied spaces, which suggests that the system works effectively in real-world conditions.

Conclusion

The proposed work concludes with the effective development and implementation of a smart parking system that makes use of RFID technology to provide efficient data management and vehicle authentication at the gate module. The total performance and security of the parking system are improved by using RFID technology, which guarantees effective and secure entry and exit tracking. Additionally, by offering a novel deep learning-based technique, work tackles the crucial problem of parking spot detection in automated parking systems. The suggested deep learning-based methodology performs better than conventional techniques in terms of real-time recognition accuracy, according to comprehensive testing and evaluation. The data collected demonstrate that the recall and precision of detection exceed 90%. At various combinations of training and testing subset, the trained deep classifier demonstrates high precision, obtaining region of consideration over 0.99. Despite these successes, it is important to acknowledge the limitations of our current approach. Specifically, the performance of the Faster R-CNN model may be compromised in scenarios where pre-training data is insufficient or when vehicles are parked in shaded areas under trees. These limitations highlight the need for further advancements and refinements in our methodology. Looking ahead, future enhancements to our smart parking system will focus on incorporating oblique imagery to overcome these limitations. By capturing multiple oblique views in a single frame, we aim to improve data quality and visibility, particularly for vehicles concealed by tree shade. These enhancements will contribute to the overall performance, reliability, and usability of our smart parking system in real-world scenarios.

Author's contribution

The authors confirm contribution to the paper as follows: study conception, design and modeling: S.Kalaivani, data analysis and validation: S.Kalaivani and Parnasree Chakraborty. draft manuscript preparation: S.Kalaivani, Parnasree Chakraborty and Mahalakshmi Alias Isakki. All authors reviewed the results and approved the final version of the manuscript.

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Conflicts of interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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