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Smart parking management system: a seamless parking solution using YOLO and QR code payment technology

Sumit Kumar[1], Ruchi Rani[2], Sanjeev Kumar Pippal[3]
[1]Department of Artificial Intelligence and Machine Learning, Symbiosis Institute of Technology Pune, Symbiosis International (Deemed University), Pune, India
[2]Department of Computer Engineering and Technology, School of Computer Science and Engineering, Dr.Vishwanath Karad MIT World Peace University, Pune, India
[3]School of Computer Science and Information Technology, Noida Institute of Engineering and Technology, Greater Noida, India

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ABSTRACT

The inefficiencies of traditional parking systems, including manual entry and reliance on sensors, as well as slow payment lines, contribute to congestion and a lower level of user satisfaction. This paper suggests a smart parking management system (SPMS) based on the license plate recognition (LPR) technology using you only look once version 5 (YOLOv5) model in combination with a QR code based payment system, to automate the parking system. It's able to detect vehicle license plates in real-time, which means that data doesn't have to be entered manually, and it also avoids the need for physical sensors, which cuts down on infrastructure costs. With a centralized database, the efficient tracking of vehicles is achieved, and QR-based payment will facilitate contactless payments at exit. Experimental evaluation shows that the proposed system out performs than the other systems, with an accuracy of 98.09% and recall of 98.25% in case of LPR. This system drastically decreases processing time, congestion and improves overall user experience. SPMS is more efficient, scalable, and reliable than traditional and existing smart parking systems. The results show that the proposed method is a cost-effective and practical solution for solving the modern parking management problem.

Corresponding Author:

Sumit Kumar
Department of Artificial Intelligence and Machine Learning, Symbiosis Institute of Technology Pune
Symbiosis International (Deemed University)
Pune 412115, Maharashtra, India
Email: er.sumitkumar21@gmail.com

1. INTRODUCTION

As urban areas expand and vehicle ownership rises, parking management has become a significant challenge for city planners and residents. Traditional systems of parking that use manual entry for license plate numbers and older payment methods have reached a stage where they are becoming completely unrealistic for modernized urban centers. These systems are prone to errors, revenue losses, and inefficiencies in operations. Manual processes in recording car information tend to be error-prone, and traditional payment methods are usually slow and inconvenient [1], [2]. Recent technological advancements introduce promising alternatives to traditional approaches. Automation, artificial intelligence (AI), and real-time data processing can transform parking management because they enhance the facilities' accuracy, efficiency, and convenience [3], [4]. For example, license plate recognition (LPR) technology is an automatic number-plate recognition system that has been revealed to be a promising application that assists in tracing and tracking vehicles, which reads license plates accurately and quickly without human intervention [5], [6]. In addition, the development of payment technologies, such as QR codes, has made the checkout process much more efficient, with contactless payment options, minimizing waiting time and better satisfaction towards usage [7], [8]. Such integration of these technologies into a unified automated parking solution presents a big step forward in overcoming the existing limitations of traditional parking systems. Advanced algorithms and automation create more possibilities for efficiency in parking, reduced operational costs, and seamless experience for users and operators alike [9], [10]. Such technology-driven solutions are essential for modernizing current urban parking infrastructure to adapt to the needs of ever-changing city environments.

One of the major problems with conventional parking management systems, which depend on hands-on mechanics and outdated technology, is that license plate numbers are entered manually in these mechanisms, making it erroneous and increasing inaccuracy in tracking the vehicle leading to revenue leakage [11], [12]. Inefficient payment methods, such as cash and card terminals, create long wait times that users do not appreciate [13]. Furthermore, the physical sensors and the complexity of this infrastructure increase the costs of maintenance and hampers system management [14]. It contributes as much to reduce operational efficiency as it lowering the quality of the general parking experience in urban areas. As cities expand, the numbers mount, and as vehicle registrations grow, the insurmountable limitations of such systems begin to prevail better and assume a new solution urgently. Moreover, supporting these deficits is necessary for urban parking management to avoid congestion, loss of revenues, and user inconvenience. Therefore, some innovative approaches involving technology are required [15], [16].

To overcome the drawbacks of the traditional parking management system, the automated parking solution proposes the integration of advanced technologies to improve efficiency, accuracy, and user convenience. The proposed system has automatic license plate recognition (ALPR) using the you only look once version 5 (YOLOv5) model to capture the number of license plates with a high level of precision at the entry point for each vehicle. This implies that there is no provision for manual data entry in this automated system, thus eliminating error possibilities and ensuring accurate billing [17], [18]. The system employs a sensor-free infrastructure, capturing only the plate number from the vehicle to track, thus simplifying the system's architecture and reducing maintenance costs [19]. To enhance the user experience even further, QR code payment has also been incorporated into the system at the exit, which makes payment even simpler and reduces waiting time at booths [20], [21].

All these technologies are integrated, allowing an optimal use of the space, and making operations more efficient and pleasant for users and operators. The simulations showed that the system was able to effectively alleviate congestion and improve revenues [22], [23]. This new solution can thus be used to successfully solve the new challenges of parking: parking facilities in the cities of the future.

The main goal of the proposed smart parking management system (SPMS) is to create an intelligent and automated approach to improve the efficiency, accuracy, and user experience in today's parking landscapes. It uses state-of-the-art technology, including YOLOv5-based ALPR, for rapid and accurate vehicle recognition at access points, eliminating manual data entry and mitigating human error. It is an infrastructure that does not require any sensor to use the vehicle license plate information to track vehicles, which reduces the complexity of the system and lowers maintenance costs. Besides, QR code payment will be incorporated at the exit, which will create a seamless, contactless, and efficient payment process, avoiding the need to have payment stations and reduce payment time. In addition, the proposed system is designed for space optimization and efficient overall operations, which will allow the system to manage parking resources effectively and contribute to an enhanced user experience, both for the operators and vehicle owners.

The remainder of this paper is organized as follows. Section 2 deals with the state of the art of parking techniques. Section 3 describes the methodology of the SPMS model. Section 4 presents and discusses the results. Finally, section 5 concludes the paper.

2. LITERATURE REVIEW

With the development of smart parking management, many innovative solutions have been proposed to solve urban parking problems. These approaches utilize advanced technologies such as internet of things (IoT), deep learning, and automated systems to enhance parking solutions' efficiency, convenience, and sustainability. Here is a comparison of some noteworthy recent literature contributions available in Table 1. It offers a clear example of the different technologies and models used, of the main characteristics of each study, and of the main contributions of each, thereby highlighting the state of research and the diversity of strategies used to improve parking management systems.

Table 1. Literature review of parking management systems

Ref.	Model used	Characteristics	Advantages
[1]	Backcasting approach	Reuse and reallocation of parking and roadspace	Policy measures for autonomous vehicle (AV) implementation and urban planning
[2]	Android app with IoT module	Real-time parking space notification and reservation	Low-cost enterprise solution for smart parking
[3]	Dynamic and proactive planning system	Sensor technology and automated carriers	Improved operational efficiency via simulation–optimization
[4]	Various sensors and data analysis	Occupancy detection and dynamic pricing	Challenges and opportunities in implementing smart parking
[5]	Various innovations and technologies	Unbundling parking costs and reducing minimums	Identifies and outlines five key developments in parking
[6]	Willingness to pay (WTP) model	Hypothetical permit program and double hurdle model	Estimates residents' WTP for parking permits
[7]	Open source computer vision library (OpenCV), numpy library and ArUco markers	Measurement of vehicle size and real-time detection	Efficient space allocation and vehicle monitoring
[8]	Deep learning-based object detection	LPR and disability badge verification	Efficient and real-time management of accessible parking spaces
[9]	Convolutional neural networks (CNN)	Image classification, localization, and detection	Role of deep learning in visual recognition systems
[10]	YOLOv5 for vehicle detection	Real-time performance and high accuracy	Scalable and efficient data-driven parking solution
[11]	YOLO-based model	Real-time detection and number plate recognition	High accuracy in vehicle and plate detection
[12]	YOLOv5l, convolutional recurrent neural network (CRNN) and adaptive feature fusion network (AFF-Net)	High accuracy and cloud deployment	Robust LPR system for outdoor parking toll
[13]	YOLOv5 neural networks	Real-time vehicle detection and false count prevention	Efficient real-time vehicle video detection
[14]	Raspberry Pi and deep learning tools	Real-time availability and automatic billing	Cost-effective and time-saving smart parking solution
[15]	IoT and various smart applications	Advance reservation and cashless billing	Comprehensive features for smart city integration

3. METHOD

The SPMS is designed with an emphasis on automation, efficiency, and user convenience. The system architecture is divided into four modules: admin panel, LPR, user entry, and user exit. These modules work in tandem to provide a seamless parking experience. The core components of this model include the YOLOv5 [22]–[26] model for ALPR, a centralized database for vehicle tracking, and a QR code-based payment system. Figure 1 demonstrates the SPMS. The admin panel manages parking lots, configures fees, and tracks space availability in real-time. LPR automates vehicle license plate number extraction and database entries. QR code-based payment makes it convenient for users to make payments. The system completes the payment using a QR code when the user leaves. This process makes controlling traffic movements in parking zones easier and improves operational efficiency. In this module, a good quality camera is used to capture the vehicle license plate at the entrance, which guarantee a high-resolution image carrying all essential details of that image, which is the foremost thing for image processing. Figure 2 demonstrates the working of the LPR module. After capturing the license plate images, some preprocessing techniques are applied to the pictures as the captured images are in the form of red, green, and blue (RGB), which is converted into grayscale. Different filtering techniques remove noise from the pictures to improve the picture quality. Images are resized into a particular format afterward. Image resizing smoothens processing by the CNN.

CNN architecture is employed to identify license plate regions. It extracts relevant features specific to the license plates. Pooling layers reduce the dimensionality of extracted feature maps and the rectified linear unit (ReLU) activation function is used to learn complex patterns in images. Dropout layers are used to reduce the overfitting of the model. Once the license plate has been detected, individual characters are segmented from that plate region. The segmented characters are then passed through an optical character recognition (OCR) engine that converts them to alphanumeric text. The exact license plate number is the system's final output. The extracted text and alphanumeric characters automatically get written into the database along with the timestamp of the user who made the request and selected block information. This process is automated, eradicating the need to manually input data and ensuring the vehicle's entry and exit times timestamping.

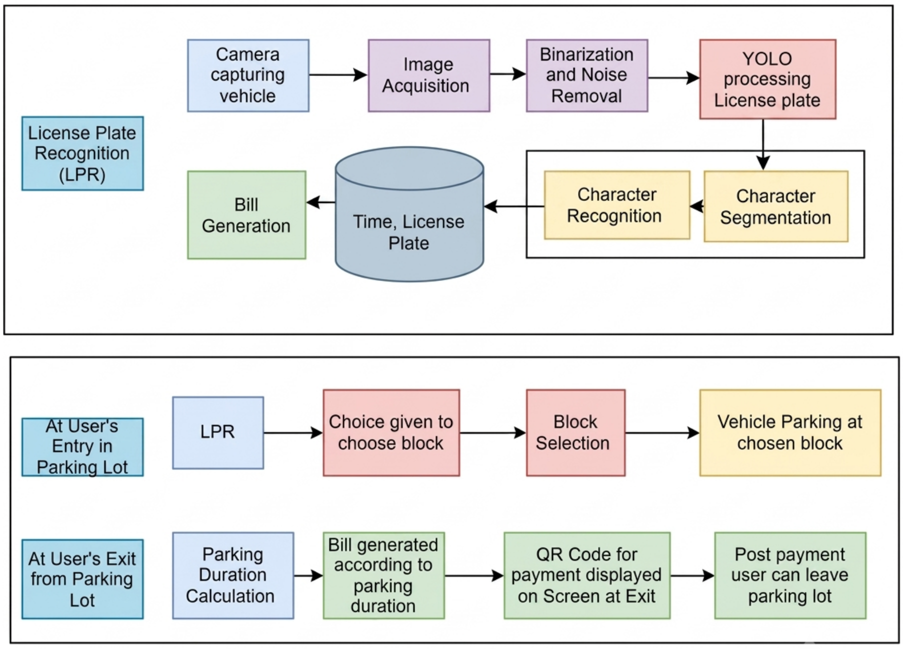

Figure 1. SPMS methodology

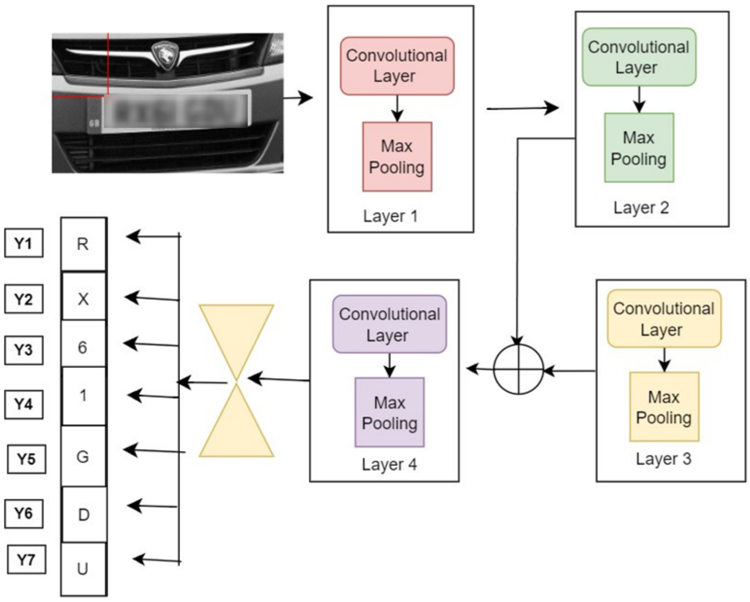

Figure 2. LPR modules

As soon as the user steps into the parking area, LPR is automatically invoked, wherein the number plate will be identified and the number picked up. Following this, the user will be asked to choose a parking block. Three attempts are given to the user to arrive at the correct block. For every attempt performed, an alternative block is returned. If the user refuses the three options, the block automatically gets assigned. After determining the block, it inserts the database entry and its timestamp. The occupied and available blocks are displayed on the screen for the user. At the exit, the dynamic QR code is displayed on the light emitting diode (LED) screen. The parking fee is calculated based on the period a vehicle has been kept in the parking by computing the difference in timestamp values from the entry to exit time stamp. Although the parking fee was computed hourly, the payment can be managed with the help of the above-mentioned QR code through very rapid contactless payments without any cash handling. Once payment is confirmed, the barrier opens and the vehicle is free to leave.

The YOLO architecture, as shown in Figure 3, is built around a sequence of convolutional layers that progressively extract visual features, supported by residual connections that help retain information across deeper layers. Max pooling reduces spatial complexity, while concatenation layers merge feature maps from different stages to preserve both fine-grained and high-level details. Figure 4 presents the use case diagram for the SPMS, outlining the key interactions between users, vehicles, and the system across entry, payment, and exit scenarios.

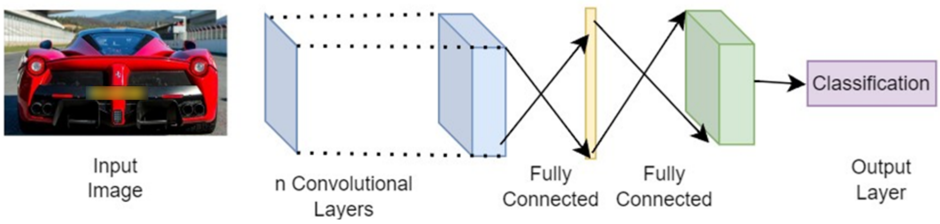

Figure 3. YOLO architecture

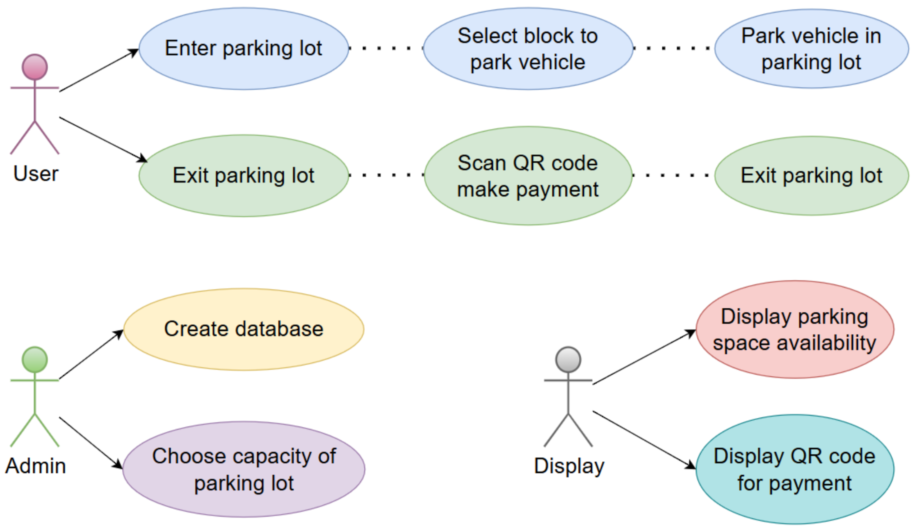

Figure 4. Use case diagram

There are two users in the system: the admin and the user. The admin manages and configures the system; therefore, it has all the needed permissions. The ’enter parking lot’ activity describes the flow of entering a parking lot. In this activity, the user chooses a parking block by selecting one, then goes and looks for his vehicle in a given spot by scanning it in. The ’exit parking lot’ activity describes the user’s exit process. The user scans a dynamic QR code to settle his payment before leaving the parking lot. The receipt is generated after the exit and a QR code for the payment are issued. After scanning the code at the payment, the vehicle is released from the parking lot. Such an automated system will save managers and car owners much time by cutting off human interference in managing permits. The system tracks vehicles using ALPR technology without a sensor. By doing this, ground loops and other conventional parking sensors—prone to wear and tear and necessitate frequent maintenance and replacement costs—are no longer necessary. The SPMS system simplifies infrastructure setup and reduces long-term maintenance requirements by using LPR data for vehicle identification and tracking throughout the parking duration.

This approach enhances user convenience and eliminates errors associated with manual data entry, improving data accuracy for billing and tracking purposes. Target detection using the YOLO model, the system identifies the vehicle at the entrance by using YOLO for real-time object detection. The single-stage approach makes YOLO more computationally efficient and allows the video stream from the camera at the entrance to be processed in real-time. Once the user exits the parking lot, a QR code will appear on the screen. Users automatically connect to a secure payment site by scanning a QR code with their smartphone. This eliminates traditional payments and waiting times. The QR code payment system also simplifies the payment process for employees and reduces the complexity of managing cash or physical payment facilities.

Figure 5 shows the overall workflow of the system. The diagram shows the detection of the license plate; if the license plate is not detected, a repetition of the process is performed, followed by inserting the detected license plate in the database, further calculating the time of the vehicle as the user selects the slot. The main interface of the vehicle parking system gives a live view of all parking slots, clearly showing which spots are taken and which are free. Free slots are highlighted in green, while occupied ones appear in red. The panel on the left walks through the vehicle entry process. The user selects a car image, and the LPR module, powered by YOLO, automatically reads the plate number and saves it to the system database. The right-side window demonstrates the exit process, displaying the current vehicles parked. Upon clicking the exit button, a QR code is generated. When a user scans the QR code, a summary, including the payable amount, is provided to the user.

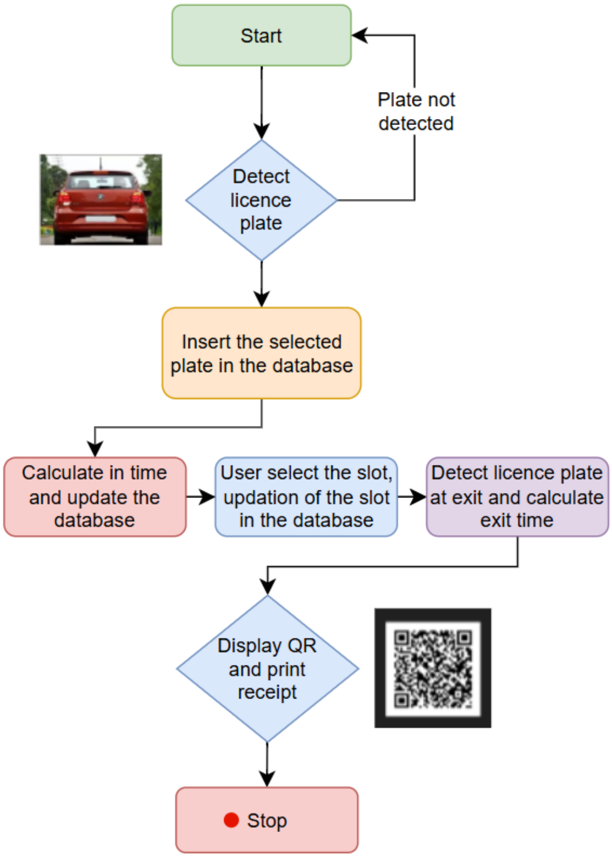

Figure 5. Workflow diagram of the system

4. RESULTS AND DISCUSSION

The performance of the proposed SPMS meets and even outperforms in certain aspects the previous studies related to intelligent parking and LPR. Recently, deep learning-based LPR methods, such as YOLO variants and CNN-based methods [9], have achieved high accuracy of 95%–98% based on the complexity of the dataset and the environment in which they are applied. For example, YOLO-based LPR models [10]–[13] have proven to be efficient and robust for real-time license plate detection in controlled conditions, but their performance drops slightly in the real world where lighting changes, occlusion and motion blur exist. In contrast, the accuracy and recall of the proposed system are 98.09% and 98.25%, respectively, which are competitive and reliable results even in practical considerations.

Moreover, previous studies on smart parking systems using IoT and image processing technologies [15] have pointed out the benefits of improvement in the automation of the parking system and the reduction of congestion, but many of these systems are based on sensor-based infrastructures or semi-automated work flows, adding to maintenance costs and system complexity. The proposed SPMS, on the other hand, reduces the dependency on physical sensors, uses vision based LPR and reduces infrastructure overhead while maintaining high accuracy. Besides, the use of QR code for payment has been considered in some recent studies on smart mobility as a way to improve the ease of use for users, but in the previous ones it is not widely connected to capabilities of real-time LPR and automatic slot allocation.

The proposed system outperforms the existing systems in terms of providing a more comprehensive and more scalable solution, where the YOLO-based LPR, automated database management and contactless QR-based payment are considered. The results of this study further confirm that the proposed SPMS is not only consistent with the state-of-the-art methodologies but also to provide an improvement regarding operational efficiency, human intervention reduction and user experience. The performance comparison shown in Figure 6 demonstrates that the proposed SPMS achieves superior results compared to existing systems. The model attains an accuracy of 98.09% and a recall of 98.25%, which are significantly higher than traditional approaches. This improvement is primarily attributed to the use of the YOLO-based LPR module, which ensures efficient and precise detection in real-time scenarios. The results validate the robustness and reliability of the proposed system.

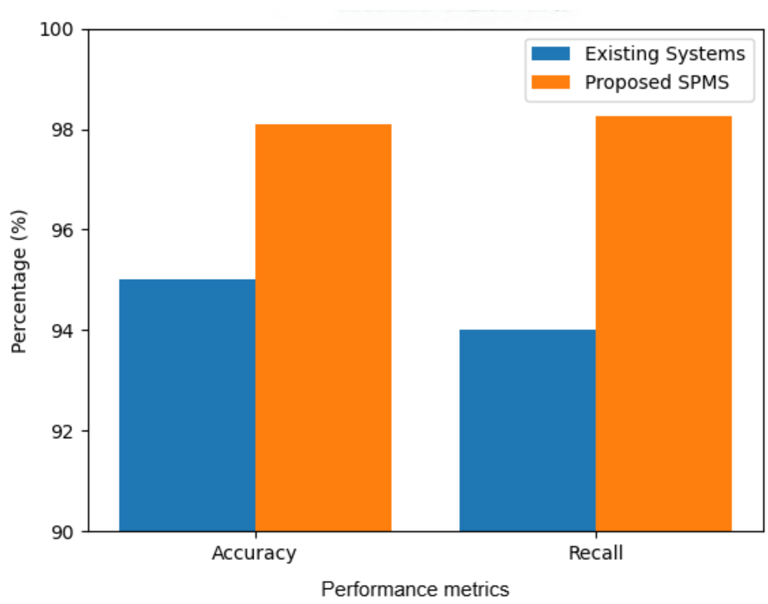

Figure 6. Performance comparison of the proposed SPMS with existing systems

A comparative analysis of both the traditional parking system and the proposed SPMS is shown in Figure 7 with regard to various performance objectives dimensions like efficiency, accuracy, and the satisfaction of the user. The automated workflow, minimal human involvement and real-time processing of the SPMS make it a significant improvement over the traditional system. QR code payment and ALPR are also integrated into improve the user experience and reduce the workload.

The comparison processing time of the proposed SPMS and other traditional methods presented in Figure 8 points out the efficiency of the proposed method in minimizing the processing time. The system can substantially reduce the waiting time for vehicles to enter, pay for, and leave parking spaces from the conventional parking mode. Through the use of automated LPR and contactless QR code payment, the system eliminates manual operations and reduces waiting time, thus promoting a seamless and efficient traffic flow in the parking area.

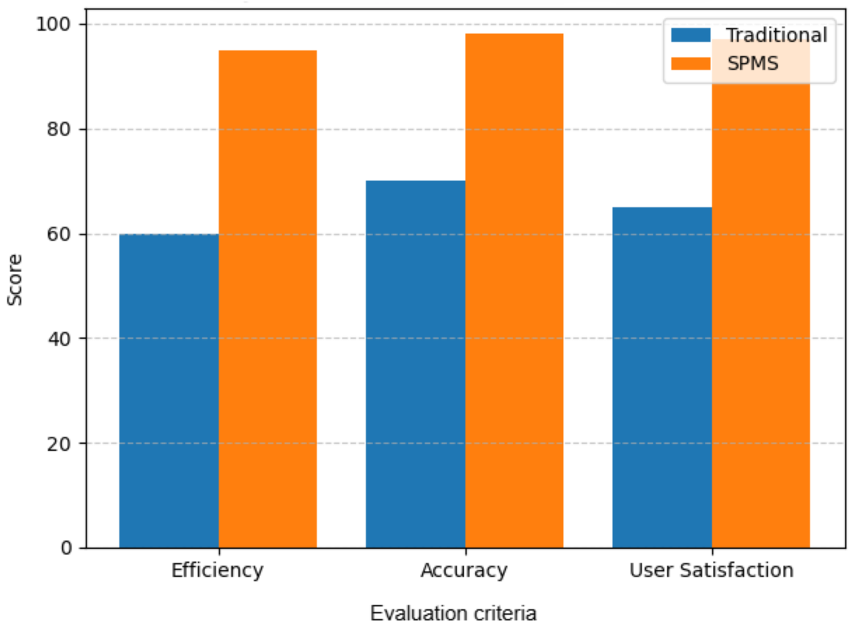

Figure 7. Comparison of traditional parking system and proposed SPMS

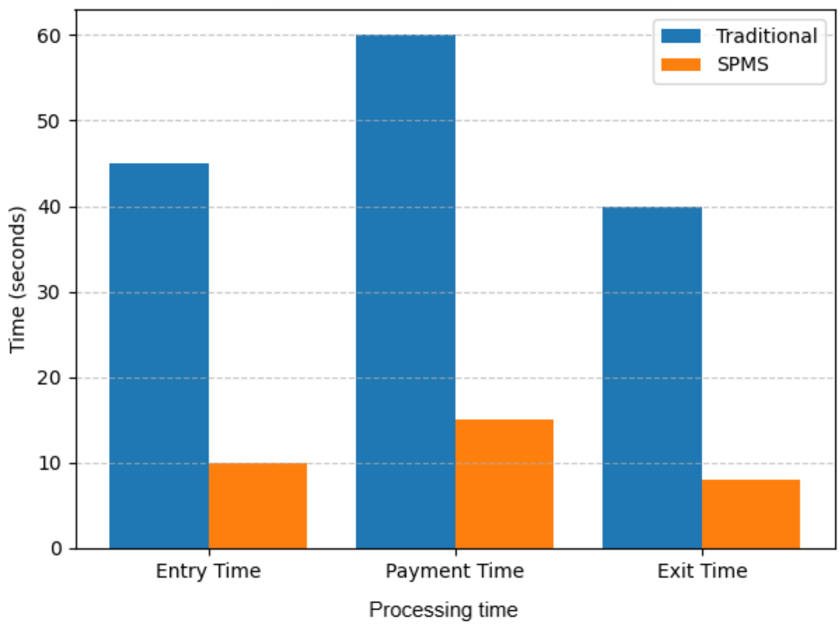

Figure 8. Processing time comparison between traditional parking system and SPMS

In Table 2, the comparisons of the SPMS and the traditional parking management system are shown with advantages and disadvantages. From the table, it is evident that the system outperforms traditional systems in many respects. The effectiveness of the LPR system has been verified since the related accuracy and recall rates are quite high. QR code payment automation helps to complete the process with fewer human errors and increased user satisfaction. The system utilizes optimal space and generates more revenue through well-designed systems. However, the system has disadvantages such as a higher initial cost and greater reliance on technology than conventional systems. Despite these issues, the all-around benefits in efficiency, accuracy, and user-friendliness point to a highly desirable system compared with conventional parking management approaches.

Table 2. Comparison of proposed SPMS and traditional parking system

Feature	SPMS	Traditional parking system
License plate entry	ALPR using YOLO model	Manual entry
Payment method	QR code payment	Payment centers with cash or card
Efficiency	High, streamlined process	Low, manual processes
Human error	Minimal, automated system	High, prone to mistakes
Congestion	Reduced	Higher due to manual operations
User satisfaction	Increased	Lower
Convenience	High, due to automation and QR code payment	Low, manual processes and payment centers
Accuracy	High	Variable, depends on manual input
Initial cost	High	Low
Technology dependency	High	Low
Space utilization	Optimized	Less optimized
Revenue generation	Increased due to efficiency and optimized space use	Standard, depends on usage
Adaptability and capacity building	Potential for high adaptability and capacity building with further improvements	Limited

5. CONCLUSION

This study proposes a new SPMS that takes the concept of traditional parking to the next level with advanced technologies. SPMS offers ALPR technology with YOLO models, which facilitates vehicle tracking and billing while minimizing the complexity of processes by lowering the need of manual entry operations. The parking experience has been enhanced, and customer convenience has been improved with QR code payment. Through extensive simulation and real world executions, it has been demonstrated that SPMS can save money, generate revenue, and enhance customer satisfaction. The exploration also offers many benefits for parking system optimization, as it offers a new fashion and can have the potential to be widely used in civic contexts. Overall, the SPMS is a significant advancement in parking solutions, providing a more efficient and environmentally friendly way to address the challenge of parking in modern cities. The results highlight the significant changes that can be achieved by incorporating state-of-the-art technologies into parking systems. They are also used to illustrate the way automated systems can solve the problems faced by traditional systems and to open the way for new innovations in urban transport infrastructure. The findings of the study provide researchers with suggestions for improving the accuracy and efficiency – something that can be used in smart city technologies. The decongestive, convenient and revenue generating properties of the SPMS are very beneficial to the community. The system will re-engineer parking and enhance user experience in any urban setting to make it manageable and efficient. In the future, improvements might be needed for the system so that real-time data analytics and machine learning algorithms can be applied to better facilitate dynamic parking management and predictive analytics. Additional research into scalability will help to further improve efficiency of different urban and types of parking facilities. Further improvement can be made through dynamic pricing (based on demand) and advanced analytics (based on users) that would ultimately increase scalability of the system. It will help maintain the SPMS as dynamic and with respect to the growing urban parking challenges.

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AUTHOR CONTRIBUTIONS STATEMENT

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Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Sumit Kumar	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓	
Ruchi Rani		✓				✓		✓	✓	✓	✓	✓		
Sanjeev Kumar Pippal	✓		✓	✓		✓			✓		✓		✓	

C	: **C**onceptualization	I	: **I**nvestigation	Vi	: **Vi**sualization
M	: **M**ethodology	R	: **R**esources	Su	: **Su**pervision
So	: **So**ftware	D	: **D**ata Curation	P	: **P**roject Administration
Va	: **Va**lidation	O	: Writing - **O**riginal Draft	Fu	: **Fu**nding Acquisition
Fo	: **Fo**rmal Analysis	E	: Writing - Review & **E**diting		

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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BIOGRAPHIES OF AUTHORS

Sumit Kumar received a bachelor’s degree in Electronics and Telecommunication from Kurukshetra University, Kurukshetra, India in 2005, the master’s degree from Guru Jambheshwar University of Science and Technology, Haryana, India in 2008, and a Ph.D. degree from Jamia Millia Islamia, Delhi, India in 2017. He works as a professor at the Department of Artificial Intelligence and Machine Learning, Symbiosis Institute of Technology Pune, Symbiosis International (Deemed University), Pune, Maharashtra, India. His research areas are machine learning and deep learning. He can be contacted at email: er.sumitkumar21@gmail.com.

Ruchi Rani received a bachelor’s degree in Computer Science Engineering from Kurukshetra University, Kurukshetra, India in 2008, the master’s degree from Maharshi Dayanand University, Haryana, India in 2012. She is currently pursuing a Ph.D. degree from the Department of Computer Science Engineering, Indian Institute of Information Technology, Kottayam, Kerala. She working as an assistant professor at the Department of Computer Engineering and Technology, School of Computer Science and Engineering, Dr. Vishwanath Karad MIT World Peace University, Pune 411038, Maharashtra, India. Her research interests include machine learning and deep learning. She can be contacted at email: ruchiasija20@gmail.com.

Sanjeev Kumar Pippal received B.Tech. degree from MJP Rohilkhand University, M.Tech., and Ph.D. from Motilal Nehru National Institute of Technology Allahabad. He is currently working as a professor in the Department of Computer Science and Engineering at Noida Institute of Engineering and Technology, Greater Noida. His area of interest is cloud computing, distributed computing, and blockchain. He is certified in machine learning and deep learning. He has published over 30 research papers in SCI/ Scopus international journals and conferences. He has filed four patents and published two patents. He can be contacted at email: sanpippalin@gmail.com.