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Research Article

Applications of AI and IoT to Develop Intelligent Car Parking Systems in Hanoi, Vietnam

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Abstract - *Hanoi is the capital of Vietnam. Every day, more than 1.5 million cars travel throughout the city. Hanoi is experiencing serious traffic congestion and a major shortage of parking spaces, with current facilities satisfying only 8–10% of total demand. The rapid increase in private vehicle ownership, growing by 10–15% each year, has encouraged the city to implement Intelligent Parking Systems (IPS) powered by IoT and AI technologies. Key strategies include the construction of high-rise mechanical parking structures and underground parking facilities integrated with new Metro stations. These systems use ultrasonic and geomagnetic sensors to detect parking occupancy and send real-time data to a centralized database. In addition, advanced computer vision algorithms based on OpenCV are applied for automatic license plate recognition and security surveillance. Drivers can access parking information through mobile applications, allowing them to reserve spaces online and navigate efficiently to available parking spots. Although the high urban density of historic areas such as Hanoi Old Quarter presents challenges, Transit-Oriented Development (TOD) models provide a sustainable solution for urban integration. Studies have shown that these smart parking technologies outperform traditional parking management methods in terms of accuracy, reliability, and reduced search time. Ultimately, the development of intelligent parking systems is expected to improve Hanoi's urban infrastructure by easing traffic congestion and enhancing the overall driver experience. The paper presents solutions that applied IoT and AI technologies for the development of intelligent parking systems in Hanoi, Vietnam.*

Keywords - *Internet of Things, AI, Intelligent Car Parking System.*

I. INTRODUCTION

The rapid pace of global industrialization and population growth has led to a significant increase in vehicle ownership, resulting in severe urban traffic congestion and a shortage of available parking spaces. Traditional parking structures often fail to meet modern demands, frequently forcing motorists to spend excessive time averaging up to 20 minutes in some cities searching for a vacant spot. These inefficiencies contribute to increased fuel consumption, noise, air pollution, and driver frustration [1]. To address these challenges, Intelligent Parking Systems (IPS) have emerged as a critical component of Intelligent Transportation Systems (ITS) [2]. Intelligent Parking Systems (IPS) are advanced parking management solutions that use technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), wireless sensors, computer vision, and mobile applications to improve parking efficiency, reduce traffic congestion, and enhance the user experience. These systems aim to provide real-time information on parking availability, assist drivers in locating free spots, handle payment and security systems automatically, and enhance urban transportation infrastructure.Hanoi is facing a serious parking and traffic congestion challenge due to rapid urbanization, increasing vehicle ownership, and limited parking infrastructure. Intelligent Car Parking Systems (ICPS) are emerging as central elements of

Hanoi's smart city and intelligent transportation programs. By integrating Internet of Things (IoT) and Artificial Intelligence (AI) [3], these systems aim to optimize parking space utilization and enhance the overall driver experience through real-time updates and automated management. Fig.4 shows an example of an ICPS. Drivers can easily find the correct places to park their cars. Then, they will be able to locate and retrieve their vehicles in an expedient manner. The IoT and AI tech assist drivers to park at proper locations conveniently.

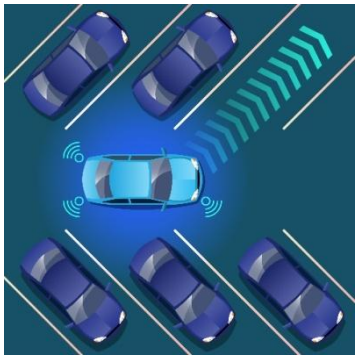

Figure 1. An Example of an ICPS [4]

The paper introduces the solution to develop ICPS. IoT sensors provide real-time monitoring of parking space availability, reducing the time drivers spend searching for parking. AI algorithms analyze traffic and parking patterns to optimize space allocation and improve traffic flow. Intelligent parking systems enhance security through automated surveillance and license plate recognition technologies. Mobile apps that are linked to IoT networks enable people to book parking spaces and get navigation directions. These technologies contribute to the reduction of traffic congestion, fuel consumption and environmental pollution, and overall improvement in urban mobility. Morover, we present some examples of solutions of ICPS in Hanoi, Vietnam to illustrate the advantages of the ICPS for Vietnamese drivers.

II. PROPOSED METHOD

This section presents the proposed method based on IoT and AI to develop ICPS.

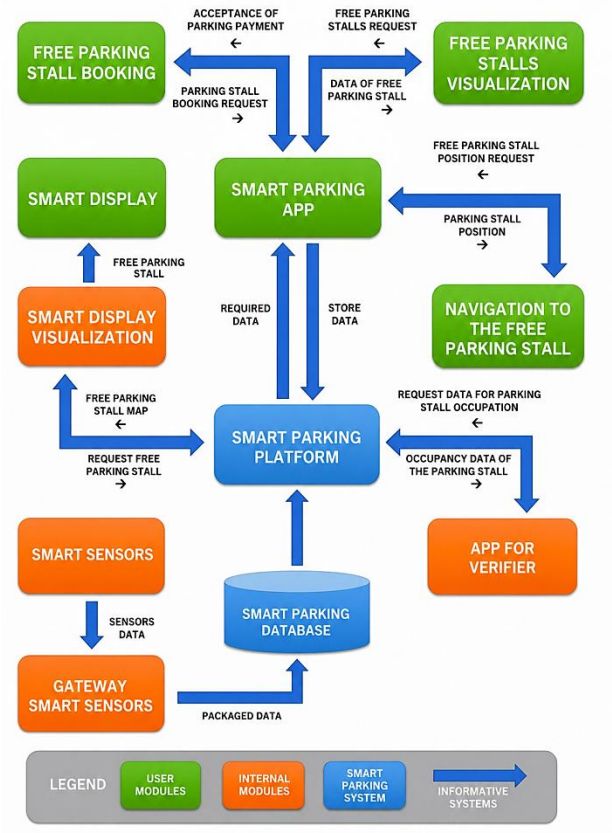

Figure 2. The Key Modules of ICPS [5]

The key modules of ICPS are described in Fig.2. Detail information of the modules are described as follows.

A. AI Solutions in Intelligent Parking Systems

Artificial Intelligence is playing an important part in the smart parking system. AI-powered computer vision technology uses cameras and image recognition algorithms to monitor parking lots and detect vehicle occupancy automatically. AI cameras can identify illegal parking activities and record the violations on an ongoing basis. Hanoi traffic police have already deployed AI camera systems at major intersections and busy streets to improve traffic monitoring and parking enforcement.

AI can also be used for predictive analytics. By analyzing historical parking data, weather conditions, traffic patterns, and event schedules, AI systems can predict parking demand and future space availability. When the parkings are high during a festival or weekend around Hoan Kiem Lake, for instance, AI can predict and direct drivers to other parking spots. Predictive analytics can improve the allocation of parking and alleviate congestion.

Machine learning algorithms further improve parking efficiency by continuously learning from traffic and parking behaviors. AI systems can dynamically price parking slots according to demand, which can help to distribute vehicles more evenly around the city. Parking charges may be raised during busy hours to prevent unnecessary parking and lowered during off-peak hours to promote the use of available space.

AI solutions enhance parking garage security as well. Smart surveillance can identify suspicious activity, unauthorized usage and parked cars. Real-time alerts can be sent to security personnel immediately, reducing risks of theft and vandalism. Fig. 6 demonstrates AI solutions for ICPS. The image processing and camera-AI helps to recognize car plates and find correct parking places.

Figure 3. The AI Technologies Including Plate Recognition, Finding Car Parking Places [6]

B. IoT Solutions in Intelligent Parking Systems

The Internet of Things (IoT) is the technology backbone of smart parking solutions. The IoT devices comprise sensors, cameras and communication networks, as well as cloud platforms, all of which are used to deliver real-time parking information. In parking spaces, there are various sensors to be installed, which are ultrasonic sensors, infrared sensors and magnetic sensors used for detecting vehicles. These sensors then send data to the central cloud server via wireless communication networks such as Wi-Fi, LoRaWAN or 5G networks. Mobile applications are another important IoT component.

Drivers can use smartphone apps to check parking availability, reserve spaces, receive navigation guidance, and make online payments. This substantially saves time spent in parking search and enhances user convenience. IoT-enabled smart gates and barriers automate vehicle entry and exit. Technologies such as RFID, QR codes, and Automatic Number Plate Recognition (ANPR) allow vehicles to pass through parking gates without manual checks. This speeds up the waiting time and helps traffic flow within parking facilities.

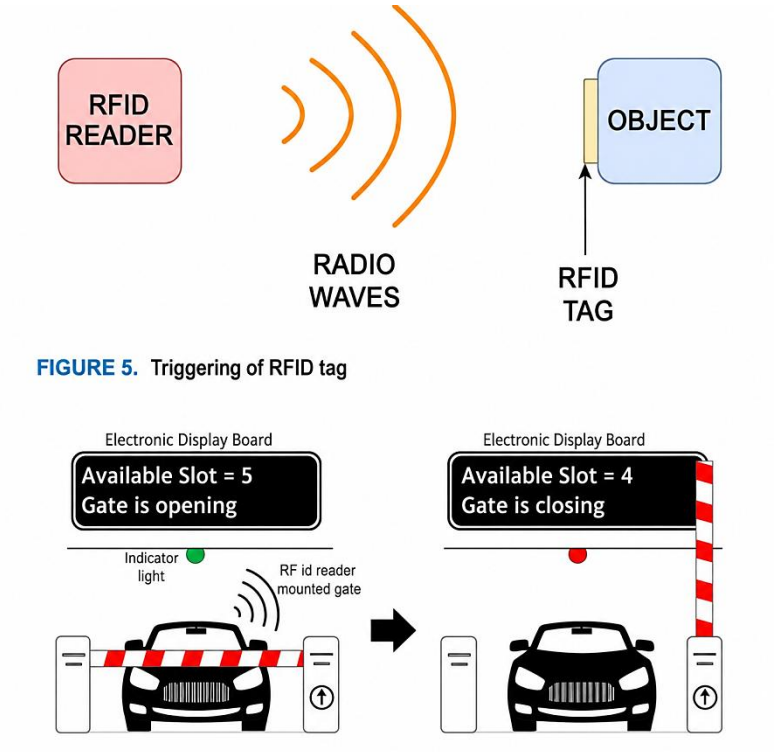

Figure 4. The IoT Technologies Applied for ICPS

Radio frequency Identification (RFID) is an automatic identification and tracking system that transmits information via radio frequency waves. In the modern transportation and parking system, RFID has emerged as a critical solution for car checking as it offers rapid, secure, and automated vehicle identification. The RFID technology has many applications such as intelligent parking system, toll collection system, access control, fleet management, and smart transportation system. An RFID car checking system mainly consists of three components: RFID tags, RFID readers, and a central database system.

The RFID tag is placed on the vehicle typically on the windshield or the license plate area. Each tag has an individual ID number to store information about the vehicle, including the owner's identity, parking membership details or access permissions. RFID readers are mounted at parking entrances, exits, check points or toll gates. A vehicle approaches the checkpoint; the RFID reader transmits radio signals to the tag, the tag then transmits the information stored in its memory back to the RFID reader. The collected data is then sent to the central management system for verification and processing.

The operation of RFID-based car checking is simple and highly efficient. As the vehicle enters a parking area or checkpoint, the RFID reader detects the tag instantly without requiring physical contact or manual scanning. The system verifies the vehicle information in real time and automatically opens the gate if authorization is approved. Meanwhile, the system documents the time of entry, vehicle identification, and other pertinent information. As the vehicle leaves, the RFID reader performs a duplicate check and updates the parking duration, payment or travel information automatically.

RFID technology offers many advantages in car checking systems. First, it significantly reduces waiting time because vehicles do not need to stop for manual inspection or ticket collection. This improves traffic flow and reduces congestion at parking entrances and exits. Second, RFID systems improve accuracy and minimize human errors because vehicle information is processed automatically. Third, RFID contributes to security by ensuring safety against unauthorized use and real-time vehicle tracking. The system can automatically alert security staff in case of entry of an unregistered or suspicious vehicle into a restricted zone.

Another important benefit of RFID car checking is its integration with smart parking and intelligent transportation systems. RFID can work together with Artificial Intelligence (AI), IoT sensors, surveillance cameras, and cloud computing platforms to create a fully automated transportation environment. For example, AI cameras can combine license plate recognition with RFID verification to improve accuracy and prevent fraud. Mobile applications can also connect with RFID systems to provide drivers with automatic payment, parking reservations, and real-time notifications.

Despite its advantages, RFID technology also faces several challenges. The initial setup of the RFID infrastructure can also be expensive due to the need for readers, network systems, and database integration. Metals or environmental conditions can cause interference in some situations that may affect reading accuracy. In addition, cybersecurity and data privacy are important concerns because RFID systems store sensitive vehicle and owner information.

In conclusion, RFID is a promising and dependable way to check cars in the current transportation systems. It offers rapid vehicle identification, alleviates traffic jam, enhances security, and enables intelligent parking management. With the continued development of smart transportation infrastructure in cities, the car checking system based on RFID technology will become more and more vital to forming an efficient, secure and smart transportation system. Figure 4 shows the IoT technologies applied for ICPS. Cloud computing platforms also play a key role in IoT-based parking systems. Cloud servers collect and analyze data from thousands of sensors and cameras across the city. Parking operators can monitor occupancy rates, revenues, maintenance requirements, and traffic patterns in real time. Cloud-based management improves scalability and allows integration with broader smart city systems.

III. THE DEVELOPMENT OF ICPS IN HANOI, VIETNAM

The intelligent parking system offers many advantages to Hanoi. The most important benefit is the reduction of traffic congestion. By guiding drivers directly to available parking spaces, smart parking systems reduce unnecessary driving and improve traffic flow. This makes travel time shorter and more hassle-free for drivers. Another major benefit is environmental protection. Reduced vehicle circulation decreases fuel consumption and lowers carbon dioxide emissions. Cleaner air contributes to better public health and supports Hanoi's sustainable urban development goals. Smart parking systems also enhance the efficiency of an operation. Automated management eliminates human errors, saves labour costs, and improves the utilisation of parking space. Parking operators enjoy precise revenue tracking and minimise their financial losses due to manual cash handling.

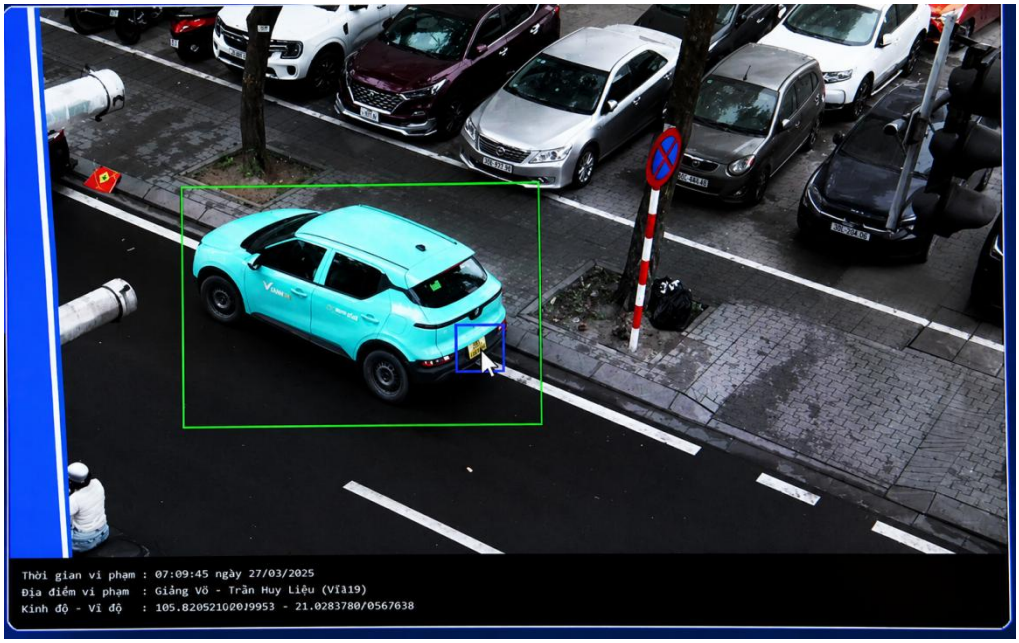

Figure 5. Example of the Application of AI solution for Car Tracking in Hanoi, Vietnam [7]

From the user perspective, intelligent parking systems provide convenience and better customer experience. Drivers can locate parking spaces quickly, reserve spots in advance, and make cashless payments through mobile applications. This saves time and reduces stress in crowded urban environments. Fig.5. shows an example of the application of AI solution for car tracking in Hanoi, Vietnam. Finally, intelligent parking systems align with Hanoi's overall Smart City initiative. The integration of AI and IoT technologies has the potential to revolutionize urban planning, transportation management, and sustainable infrastructure development. These technologies contribute to creating a modern, efficient, and environmentally friendly city [8].

IV. CONCLUSION

In conclusion, intelligent car parking systems are becoming increasingly important in Hanoi due to rapid urbanization, growing vehicle ownership, and severe traffic congestion. Traditional parking management methods are no longer sufficient to address the city's transportation challenges. AI and IoT solutions include real-time parking monitoring, predictive analytics, automated enforcement, digital payments, and smart traffic integration, all of which offer effective solutions. Although challenges such as high implementation costs and infrastructure limitations remain, the benefits of intelligent parking systems are significant. These systems reduce congestion, lower pollution, improve parking efficiency, enhance security, and support Hanoi's smart city development. As Hanoi continues its digital transformation, intelligent parking systems will play a critical role in creating a more sustainable and efficient urban transportation environment.

Conflicts of Interest

The authors declare that there is no conflict of interest concerning the publishing of this paper.

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