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ORIGINAL RESEARCH ARTICLE

Smart parking: Multi-agent approach, architecture, and workflow

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ABSTRACT

Inefficient parking management systems in urban areas lead to limited parking capacity, congestion, and environmental contamination, resulting in time and fuel waste, increased carbon emissions, and economic inefficiency. Smart parking is a technological system that leverages the capabilities of the Internet of Things (IoT) to address urban congestion and parking management issues. It uses IoT sensors to collect real-time data on parking availability, which is then analyzed to optimize usage, improve traffic flow, and simplify the driver experience. Smart parking can be integrated into urban infrastructure, contributing to more efficient and environmentally-friendly urban mobility. Benefits include reduced time spent searching for parking, reduced traffic congestion, reduced greenhouse gas emissions, and new revenue opportunities for parking lot operators. Overall, IoT-enabled smart parking creates sustainable and user-friendly urban environments. This paper presents a multi-agent smart parking approach, providing a comprehensive architectural framework and workflow for various smart parking scenarios. The proposed methodology and structure encompass several aspects of intelligent parking management, incorporating the use of Internet of Things (IoT) technologies. It involves a multi-agent system for monitoring parking spaces, managing traffic, and providing user services. This system enhances efficiency and reduces the need for manual parking, thereby enhancing the overall efficiency of urban parking.

Keywords: multiagent-based systems; smart system; smart parking; IoT sensors; ICT; digital service and workflow

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1. Introduction

Parking in urban areas has become a major problem with the ever-increasing number of vehicles. Traffic congestion due to the search for parking spaces not only wastes time and fuel but also contributes to environmental and economic problems. In this digital age, the Internet of Things is emerging as a promising solution for improving urban parking management.

The rapid evolution of IoT technology has enabled the development of more efficient and sustainable smart parking systems, offering significant benefits for citizens, businesses, and governments. This paper focuses on the implementation of a smart parking system using IoT in line with scientific research standards. This article presents an innovative approach that draws on scientific research standards to design and implement an IoT-based intelligent parking system. This approach aims to guarantee the reliability, reproducibility, and validity of the results obtained while promoting collaboration and interoperability between smart parking systems deployed worldwide Based on the research results by Mainetti et al.[1], it has been shown that around 30% of instances of traffic congestion may be attributed to the act of searching for an available parking spot for vehicles. The process of finding a suitable parking spot typically leads to an additional duration of around 7.8 min for a car. According to Shoup[2], the act of driving at cruising speed not only exacerbates traffic congestion but also adds to environmental pollution. Specifically, in residential districts of Los Angeles, vehicles traveling to find parking spaces are estimated to produce emissions equivalent to 38 global journeys, resulting in the release of around 730 tons of carbon dioxide (CO2).

This article details the architecture, data flow, and studies of Smart Parking, an intelligent parking system designed and implemented using scientific research standards.

Our main contributions in the field of smart parking include:

- Implementation of a Multi-Agent System (MAS) architecture and approach to parking resource management, utilizing multiple intelligent software agents for flexible decision-making, responsiveness to fluctuating demand, improved parking space allocation, and congestion reduction It also provides the creation of a system and global architecture based on the IoT, outlining elements such as parking space sensors, power supply systems, backend servers, and front-end servers.
- Proposed architecture for managing parking software, including a flowchart and prototype for each management parking scenario, with an emphasis on component definitions focusing on improving driver satisfaction and efficiency by guiding vehicle positioning based on availability.

Our methodologies prioritize the incorporation of technology, data-driven decision-making, and user-centered design to achieve these goals. as well as focusing on improving driver satisfaction and efficiency by guiding vehicle positioning based on availability.

To ensure safety, an effective security system is implemented, including network video recorder (NVR) cameras and an emergency alert system. This system will facilitate tracking and documentation of occurrences, particularly in cases of malfunctions, to protect both parked cars and drivers. This comprehensive security system ensures a safe and efficient parking experience.

2. Related work

In the literature on smart parking solutions, there have been comparable initiatives and surveys, each with advantages and disadvantages. We review these efforts in this paragraph and note how they differ from our work. Chandrahasan et al.[3] addressed a very brief review of parking lot bookings in cloud-based systems. A brief description of the mechanism behind each reserve approach was provided, along with illustrative examples. A comparable study was conducted by Revathi and Dhulipala[4], but without references to specific cases from the literature. The authors have briefly discussed many categories of vehicle sensors. However, the analysis conducted was not exhaustive in nature and failed to include all potential sensor types and their associated restrictions. The insufficiency of the prior surveys was addressed and enhanced by the inclusion of more instances and arguments in the study conducted by Idris et al.[5]. The authors provided an overview of vehicle-detecting sensors, including relevant examples from the existing literature. Nevertheless, the current presentation lacks an exposition of further facets of the smart parking system (SPS), including the communication protocols and/or software systems used. In their study, the authors by Hilmani et al.[6] provided an analysis of the many implementation issues pertaining to wireless sensor communication protocols. Additionally, they put forward a novel protocol that is adaptive and self-organized. However, the researchers failed to take into account the developing patterns in low-power wide area network (LPWAN) communication protocols and mostly depended on sensors and RFID devices over the course of their investigation. The study conducted by Faheem et al.[7] provided an overview of smart parking approaches that use multi-agent systems, fuzzy logic, computer vision, and vehicular ad hoc networks (VANETs). The authors provided a basic discussion of the used software systems; however, they did not go further into the specifics of the hardware. An overview of smart parking software systems and their associated applications was provided. The authors discussed the many benefits and drawbacks associated with these systems[8]. However, as with previous surveys, crucial information and technical requirements were largely ignored. The survey conducted by Lin et al.[9] is the most relevant comparison for our research, which covered both the software and hardware aspects of smart parking solutions and architecture. Coulibaly et al.[10] identifies two main types of parking: in-garage parking and wayside parking. Roadside parking is widespread and easily accessible, often equipped with parking meters and sensors to determine the status of spaces compared to in-garage parking. While Dener[11] has focused on the implementation of an IoT parking system sensor network utilizing a basic platform, aiming to provide drivers with cost-effective access to available parking spots. The literature on parking control mechanisms is limited, with some studies focusing on wireless sensor networks and signage. There are few comprehensive parking solutions, and the main challenge is the promotion of their own products. Our parking lot uses equipment from multiple manufacturers and is well managed through our implementation and architecture techniques. In the realm of parking typology, Chen et al.[12] discuss the distinctions between fenced and unfenced parking. In their respective works, Barone et al.[13] and Màrmol et al.[14] go into the subject matter of roadside parking. In contrast, the studies by Wang et al.[15] center their research on the subject of garage parking. Several studies used the notion of magnets to monitor and trace their movements under different conditions. The identification of these entities may be accomplished via various setups[16]. The user's text is not sufficient to rewrite in an academic manner. Please provide more information. The design of implementation configurations for parking spaces aims to provide a standardized approach for managing the cost of sensors in the deployment of an autonomous Internet of Things intelligent parking system. Chen et al.[12] provides descriptions of the three primary configurations. One aspect that may be used to enhance security measures is the implementation of entry and exit monitoring systems. In this particular arrangement, sensors are strategically placed at the entry and exit locations of the parking lot, often using inductive loops or infrared sensors. In this particular case, the car park is divided into several zones, and each zone is subject to supervision for vehicle entry and exit in addition to monitoring. In this particular configuration, each parking spot is equipped with a detector that offers precise data on the occupancy status of the parking lot. In addition to the study mentioned above, other researchers have used agents and artificial intelligence in their investigations[17–20]. The authors developed Sens city, a platform using machine 2 machine architecture to manage parking services. The platform uses agents to choose the best parking spaces based on drivers' preferences, negotiate prices, and find optimal parking locations. The agents automate mission managers and handle requests from drivers seeking city center parking. Mei et al.[21] present a survey on drivers' needs for smart parking infrastructures, focusing on the latest trends in parking availability monitoring, reservation, and dynamic pricing schemes. They explore how these technologies can be integrated to create advanced parking systems that benefit drivers and operators. The paper also discusses the importance of mobile applications in utilizing these technologies in different settings to reduce waiting times, highlighting the importance of smart parking systems in urban areas. On the other hand, electric vehicles (EVs) are becoming increasingly important in modern cities and power grids due to their fast-response charge and discharge characteristics. Smart parking lots currently provide slow-charging services and may participate in demand response programs. However, the rapid rise of EV fast charging has led to the need for new installations and planning frameworks to cater to high energy demand. The paper by Khalkhali and Hosseinian[22] models the EV aggregator's task in incorporating fast-charge services using slow-charged EVs' aggregate capacity as a sourcing-sinking resource, lowering charging costs, and enhancing resource efficiency. Simultaneously, the Electric Vehicle Parking Systems (EVPS) market is facing considerable development, primarily driven by the increasing demand for electric vehicles (EVs) and the worldwide transition towards more environmentally friendly transportation alternatives[23,24]. Electric Vehicle Power Stations (EVPS) are crucial in addressing the urgent issue of effectively managing the requirements for charging electric vehicles in parking areas[25]. These systems function by employing sophisticated algorithms to compute the most efficient routes to parking spots that have charging stations. They consider multiple factors, including user preferences, the vehicle's battery level, the availability of power from the grid, and the electricity prices at different locations[26]. EVPS uses real-time communication with charging stations to provide real-time information about parking space availability. This information is accessible through web or mobile applications, displaying vehicle charge status and parking time limits. These limits ensure efficient utilization of charging infrastructure, prevent grid overloads, and maximize parking space availability. However, implementing EVPS comes with substantial costs due to charging infrastructure and grid connectivity. Some cities have introduced charging fees in parking lots to mitigate these expenses. Specific EVPS systems optimize energy consumption, promoting efficient resource utilization[23,27].

In summary, Smart parking is a technological innovation that addresses urban congestion and parking needs by utilizing IoT, mobile connectivity, and data analytics[28]. It aims to improve efficiency, reduce traffic, enhance driver experience, and contribute to environmentally sustainable cities by creating an intelligent digital ecosystem that reduces unnecessary traffic and improves the driver experience.

3. Multi-agent approach and architecture

3.1. Agent-based approach for smart parking

The agent-based approach is a revolutionary method for intelligent parking management that uses autonomous entities called agents to optimize operations. These agents, either computer programs or autonomous systems, can perceive their environment, make decisions, and interact with each other to achieve specific goals[29]. They have specific responsibilities, such as monitoring space occupancy, managing reservations, processing payments, and coordinating parking access. The agent-based approach offers advantages such as dynamic, reactive management, learning and adapting to user preferences, and enhancing the overall driver experience[30]. It can analyze parking demand data, footfall trends, and local events to adjust parking rates, promoting efficient use and reducing congestion. The use of the agent concept is seen as adequate for the development of a smart parking software system due to the substantial involvement of diverse entities in the parking process, resulting in the complex nature of its administration.

Figure 1 presents the suggested design of our multi-agent system architecture, which encompasses the communication design through the multi-agent system and the agents to be used in our smart parking solution. The use of the agent concept is deemed suitable for the development of a smart parking software system due to the substantial involvement of several players in the parking process, resulting in the intricate nature of its administration.

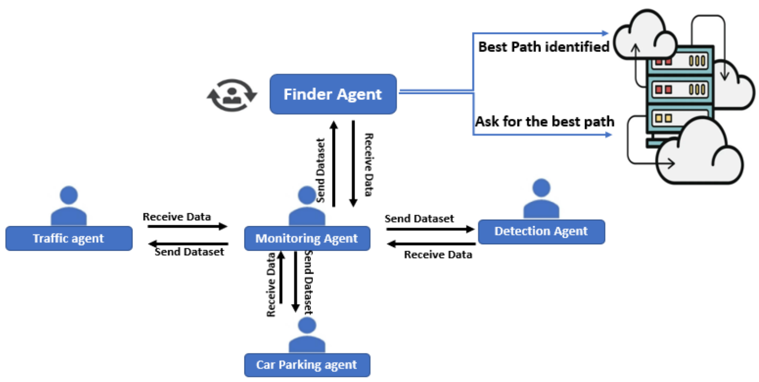

Figure 1. Multi-agent system architecture.

In our Multi-Agent System (MAS) architecture designed for smart parking, multiple agents work together to optimize the management of parking resources, increase user experiences, and improve overall parking operations. Here is an elaborate explanation of each agent incorporated into our system:

Monitoring agent: The monitoring agent is responsible for real-time data collection and monitoring parking lot status, including occupancy sensors, cameras, and barriers. They manage parking space reservations, allocate available spaces efficiently, notify users about availability, and perform initial data analysis for demand prediction and optimization.

Traffic agent: The Traffic Agent manages traffic within and around a parking facility, monitoring and controlling vehicle entry and exit, providing directions to drivers, collaborating with the Monitoring Agent to optimize parking space allocation, and integrating with surrounding traffic management systems for real-time traffic information if needed.

Finder agent: The Finder Agent is responsible for assisting users in locating available parking spaces by interacting with them through mobile apps, helping them search and reserve parking spaces, providing real-time guidance, offering user-friendly interfaces, and collaborating with the Monitoring Agent to provide accurate information.

Car parking agent: The Car Parking Agent is responsible for guiding users to their reserved parking spaces, managing vehicle-specific services like electric vehicle charging, coordinating with the Monitoring Agent to ensure parking spaces are ready upon arrival, and handling payment processing and user-specific preferences if necessary.

Detection agent: The detection agent is responsible for detecting security breaches, fraud, and irregular activities within a parking facility. It monitors for unauthorized access, triggers alerts, and collaborates with the monitoring agent to maintain safety and security.

In conclusion, the agent-based approach to smart parking has significant potential for optimizing parking space management in urban environments, contributing to smoother urban mobility, better resource utilization, and an improved parking experience for drivers.

3.2. Architectural design of smart parking

In this section, we will introduce our smart parking demonstration, as seen in **Figure 2**. In order to provide a more comprehensive understanding of our smart parking system, we conducted an in-depth analysis of its overall design, urban planning considerations, and strategic positioning. This examination aimed to provide additional insights and enhance clarity around the implementation and deployment of our smart parking solution.

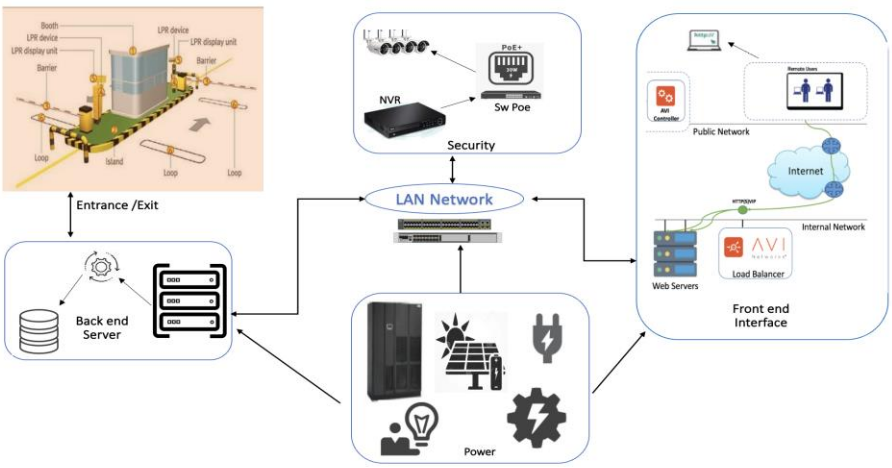

Figure 2. Smart parking prototype.

The architectural structure in **Figure 2** encompasses all the necessary equipment for the implementation of intelligent parking systems in a smart environment. This architecture may be structured into five linked modules, facilitated by a local area network (LAN), as described below.

Parking system entrances and exits: The module focuses on parking management technology, including RFID detection, ANPR license plate recognition, ticketing terminals, barrier access systems, wireless sensor networks, and signage displays. It uses a three-layer architectural system design, allowing modules to be independently updated and replaced, reducing costs and streamlining administration. The module's functionality is similar to a garage, controlling entry points with physical barriers. Vehicles' presence at entrance and exit is detected using "entry loop detectors" and "exit loop detectors". Vehicle loop detectors activate barriers for opening purposes, often linked to a loop detector. This system can accommodate large-scale and intricate applications, reducing costs and streamlining administration[31].

Back-end server: The back-end server is a crucial component in the design of a smart parking prototype, overseeing data processing, management, and basic operations. It serves as the central hub, processing and managing data and handling core functionality, ensuring the efficient functioning of the entire parking system. The back-end server is responsible for processing real-time data from sensor modules and updating the database status of parking spaces. It maintains a dedicated database to store relevant parking data, ensuring data integrity, security, and efficient retrieval. The server also manages user accounts, profiles, and access permissions, handling user registration, authentication, and authorization. It manages parking reservation creation, modification, and cancellation, storing and updating reservation details in the database. The server facilitates secure payment transactions, generates invoices and receipts, and maintains payment records. It integrates optimization algorithms and analytics engines to make data-driven decisions for space allocation, pricing strategies, and system efficiency.

Front-end interface: The front-end interface module in a smart parking prototype architecture is the user-facing component, providing a user-friendly interface for drivers and administrators to interact with the system. It allows access to information, makes reservations, and manages parking-related tasks, making it the primary point of interaction for both users and administrators.

Parking security system: To guarantee integrity and protection The parking lot is equipped with a robust security system that encompasses both external and internal security measures, ensuring the capacity to track incidents. An alarm system serves the purpose of safeguarding against illegal entry, while an NVR video surveillance system is designed to monitor inside activity. The system is categorized as a logging system, which is designed to capture and retain video surveillance data for a period of three months. This time frame is used to mitigate any potential negative impacts on the system's storage capacity.

Power supply system: The power supply system module is a crucial component in the architectural design of a smart parking prototype, providing electrical power to all components and devices within the system. Its primary objective is to ensure continuous and uninterrupted operation, even in the presence of power fluctuations or outages, ensuring dependable performance and continuous functioning.

The architectural design of smart parking systems is an innovative solution to the rising urbanization and the escalating difficulties of parking in densely populated regions. With the ongoing expansion of cities, the need for easy and effective parking options has become increasingly urgent. Smart parking systems have emerged as a technological marvel in this environment, as they seamlessly integrate sensors, data analytics, and digital platforms to transform the parking experience. This architectural concept aims to convert conventional parking facilities into smart and adaptable spaces, improving user convenience, alleviating traffic congestion, and promoting a more sustainable and interconnected urban environment. The Smart parking systems surpass the simple task of assigning parking spots. They offer up-to-date information on parking availability, simplify the process of locating and securing a parking spot, and even present possibilities for generating income and utilizing data for urban planning. This architectural design comprises both the physical components, such as sensors, data gathering devices, and central servers, as well as the digital components, including mobile apps and websites. These digital components provide consumers with easily accessible information.

4. Smart parking scenario

A smart parking scenario involves the utilization of advanced technology and data analysis to effectively oversee parking in urban and suburban locations. In this scenario, a combination of diverse sensors, data analytics, and digital platforms are employed to enhance the distribution of parking spaces, track real-time parking availability, and enhance the overall parking experience for users. The fundamental elements of a smart parking scenario involve the integration of sensors that detect the presence of vehicles in parking spaces, data collection and analysis systems, user-friendly applications or interfaces for drivers, and the ability to make informed decisions regarding urban planning and parking resource management based on the data. The scenario aims to mitigate congestion, minimize the time and effort required to find parking spaces, improve traffic flow, and foster the creation of more environmentally friendly urban environments.

4.1. Smart parking management scenario

This section will outline the optimal operating scenarios for our smart parking lot. We have prioritized security, reliability, and ease of access in our design. To achieve this, we have implemented three methods and technologies for entry and exit on our demonstrator. This approach offers a diverse range of access options and ensures high availability in the event of anomaly detection, as depicted in **Figure 3**.

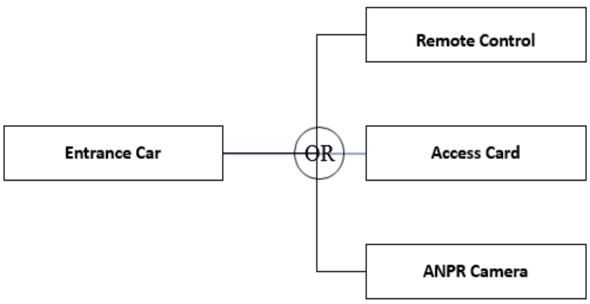

Figure 3. Parking entrance scenario method.

When a vehicle arrives at the parking lot entrance, it follows a processing procedure as detailed in the flowchart shown in **Figure 4**. Initially, it is important for the driver to carefully examine the display screen positioned at the entrance of the parking facility in order to verify the availability of parking spots. Alternatively, this task may be accomplished remotely via the online application. When examining the concept of availability, it is necessary to take into account three distinct scenarios. In order for an individual to be recognized as a licensed driver, their vehicle must possess one of the following features:

1) Remote transmitters are used with automated and electric barriers to regulate their opening or closing through radio frequencies. These transmitters, either long- or short-range, allow users to control the barrier's function from a distance, as described in **Figure 5**.
2) The radio frequency identification tag is designed for drivers who own a personal parking card. The implementation of this system enables prompt scanning of cars upon their arrival at the entry barrier and then grants or denies access based on a predetermined list. This process effectively minimizes time consumption and enhances the overall efficiency of the system, as illustrated in **Figure 5**.
3) When a user registers a subscription using their vehicle's number plate, the system uses the user's identity and control mechanism to open the barrier for entrance and exit. When the vehicle passes through a loop detector, relevant data on the vehicle and its operator is acquired using Automatic Number Plate

Recognition (ANPR) technology and panoramic lenses. The ANPR camera captures the license plate number for further analysis, and if the information matches the system's records, the door is automatically opened, as seen in **Figure 6**.

4) In the case of the exit scenario, the exit barrier for subscribers is activated upon the completion of certain actions. These actions include the scanning of the vehicle badge or driver card as well as the detection of the plate number by the ANPR cameras, as illustrated in **Figure 7**.

The use of RFID terminals at entry and exit points facilitates the ability to assess workflow and determine parking duration. The security measures implemented within our parking facility include the deployment of NVR cameras equipped with motion detection capabilities. These cameras diligently monitor all internal activities, while an additional camera is dedicated to observing external equipment.

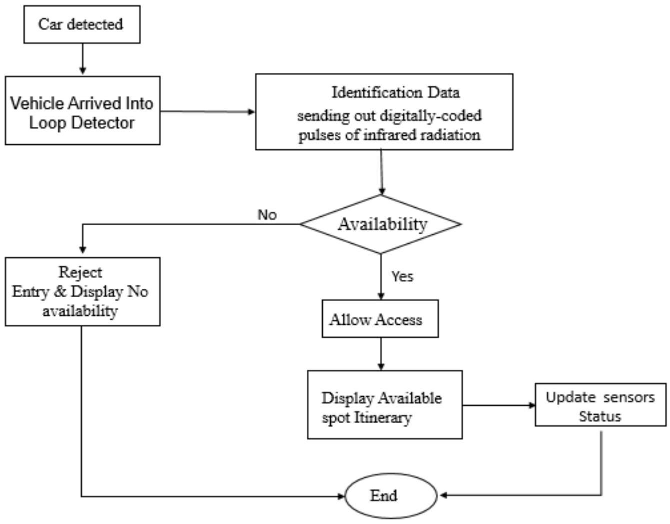

Figure 4. The parking entrance by remote control scenario.

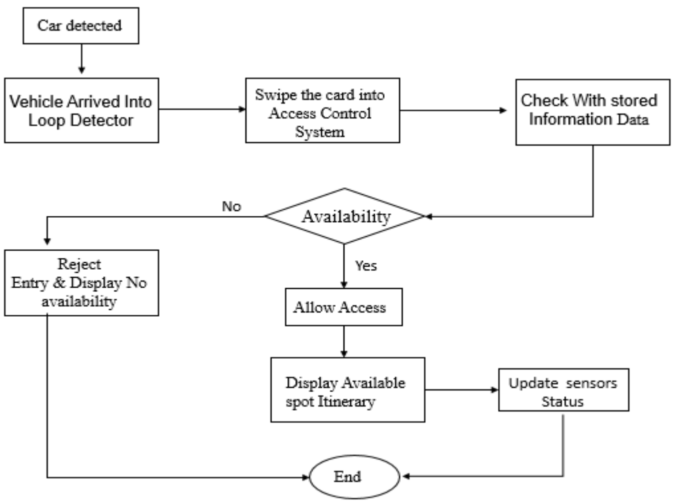

Figure 5. Entry by access card.

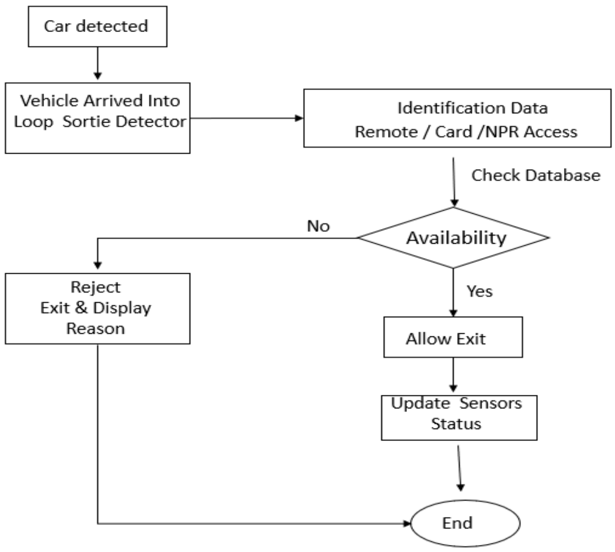

Figure 6. Parking entrance by ANPR.

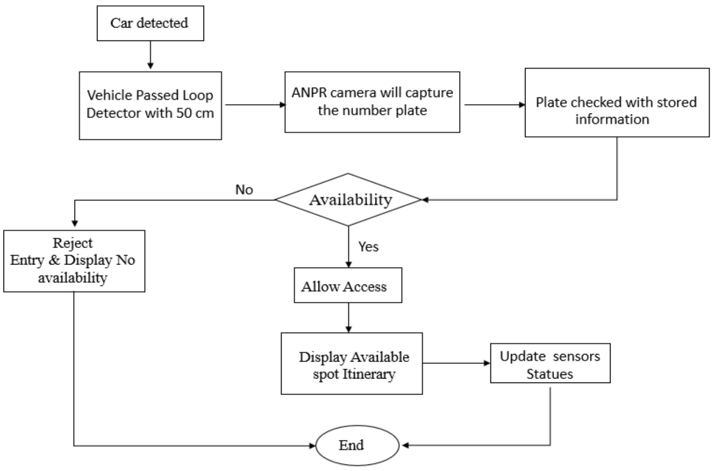

Figure 7. The parking exit scenario.

4.2. Parking software management architecture

The design and implementation of software management architecture for smart parking is a complex and constantly evolving task. It includes the integration of real-time data processing, intuitive interfaces, robust security measures, and the capacity to adapt to the changing needs of urban areas. The software management architecture plays a vital role in ensuring that smart parking solutions can effectively meet the growing needs, adapt to changes, progress, and fulfill their obligations. This analysis will concentrate on the essential elements of software management architecture specifically tailored for smart parking systems. This design facilitates the smooth exchange of information between sensors and databases, the development of user-friendly applications for drivers, and the gathering of useful data for both urgent parking requirements and long-term urban planning.

To implement the scenarios discussed in the previous section, it is necessary to ensure that our parking equipment can communicate with each other in a connected mode. **Figure 8** illustrates the software architecture of the data collection system for our demonstrator. In this system, six agents have been developed as described below:

- **The recognition agent** is responsible for identifying drivers and vehicles entering and exiting parking lots. The system has three subagents: automatic number plate recognition (ANPR), radio frequency identification (RFID), and remote control. The ANPR agent collects the unique plate identification number of detected vehicles, which is then transferred to the collecting agent. The RFID agent communicates with the RFID device and transfers the data to the collection agent, while the remote-control agent establishes communication with the CB access control card, transferring personal card data and digitally encoded infrared radiation pulses to the data collection agent.

- **The parking barrier agent** is responsible for supervising and organizing the operation, ensuring its rapid execution in response to immediate requests. A parking barrier agent is a device that controls and manages access to parking areas, either physically or software-controlled. It restricts access to authorized users, enforces payment systems, and enhances security. These agents are crucial in maintaining orderly and secure parking operations, ensuring only authorized vehicles can access and exit.
- **The loop detector agent** is responsible for activating barriers, opening gates, regulating traffic, and monitoring parking lots for vehicles that have come to a halt or are driving at a slow rate. Loop Detector Agents use inductive loop technology to monitor parking space occupancy in real-time. They detect vehicle presence by measuring electromagnetic fields. The collected data guides drivers to available spaces, optimizes space utilization, and integrates with parking guidance systems. This enhances the parking experience, reduces congestion, and improves efficiency and user-friendliness[32].
- **The screen display agent** presents messages in the parking lot via screens, facilitating interaction between drivers and the displayed content. A screen display agent is a software component that manages and renders graphical content on a display screen or monitor, acting as an intermediary between software applications and hardware displays. It handles tasks like text, images, icons, and user interface elements, ensuring content is displayed correctly and efficiently. It handles screen resolution management, refresh rates, color depth, and overall visual presentation.
- **The monitoring agent** is crucial in smart parking systems, transmitting the status of each sensor for every minute of each parking area to the collecting agent[33].
- **The collector data agent** is responsible for the collection and storage of data obtained by previous agents. This data is stored in a defined database, which serves to enhance cooperation across communicative organizations[34].
- **The communication agent** is a crucial component in a smart parking system, facilitating data flow and communication across various components. It acts as a mediator, facilitating smooth data transmission, instantaneous updates, and synchronization among modules and components. The primary function of this system is to efficiently transmit information among sensor networks, central servers, user interfaces, and other subsystems.

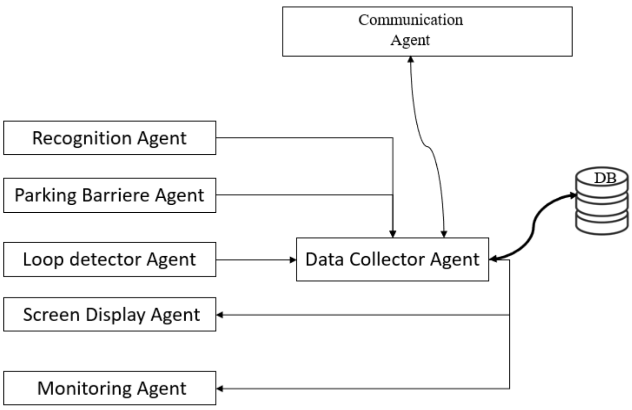

Figure 8. Parking equipment data back end software architecture.

A parking agent is a vital component in smart parking systems, driving efficiency and effectiveness in space management. It operates independently, making data-driven decisions based on real-time data from parking sensors. It collaborates with other agents and system components to maximize space utilization for users. Effective management involves meticulous configuration, setting parameters for space allocation, pricing, and system-specific behaviors. Ongoing monitoring by system administrators ensures the agent's correct operation and quality of decisions[35]. Data analysis is crucial for optimizing space allocation and pricing strategies in parking agents. Key features include dynamic space allocation, dynamic pricing, reservation support, driver guidance, user interaction, security, load balancing, fault detection, sustainability, and datalogging. These factors enhance parking efficiency and user satisfaction.

5. Conclusions and perspectives

The use of a multi-agent system (MAS) in the design of a smart parking architecture presents a revolutionary approach to effectively managing parking in metropolitan areas. The architectural design incorporates autonomous agents to create a dynamic and efficient parking ecosystem with the aim of optimizing the allocation of space, improving the user experience, and promoting sustainable urban transportation. The primary advantages include enhanced efficiency, a user-centric orientation, data-driven decision-making, stringent security measures, and scalability to varying facility sizes. Multi-agent systems are designed to enhance the efficiency of space allocation, minimize congestion, and simplify user interactions. These systems are equipped with user-friendly interfaces and provide real-time updates, enabling users to make well-informed choices. Additionally, the system offers administrators useful information, thereby ensuring the maintenance of data integrity and fostering trust among users.

In our future work, our research aims to provide detailed insights into the characteristics and behaviors of each agent within a smart parking architecture based on a multi-agent system. It will focus on their roles, responsibilities, and decision-making capabilities, such as real-time data processing, decision optimization, and user interaction. The study will also examine the inter-agent communication protocols and mechanisms used by these agents to exchange critical data and coordinate actions. The decision-making processes within the architecture will be explored, focusing on how agents use data analytics, optimization algorithms, and real-time information to make intelligent choices. The research will emphasize how these decisions impact space allocation, pricing strategies, and user interactions. The aim is to contribute valuable insights to the field of parking management and urban mobility, paving the way for enhanced system design, improved user experiences, and more efficient urban parking solutions.

Author contributions

Conceptualization, AS and TM; methodology, AS; software, AS; validation, AS, TM and MB; formal analysis, AS and MB; investigation, AS; resources, AS and TM; data curation, MB and TM; writing—original draft preparation, AS; writing—review and editing, AS; visualization, AS, TM and MB; supervision, TM; project administration, AS. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare no conflict of interest.

Abbreviation

IoT, Internet of Things; NVR, network video recorder; CO2, carbon dioxide; SPS, smart parking system; LPWAN, low-power wide area network; VANETs, vehicular ad hoc networks; EVs, electric vehicles; EVPS, Electric Vehicle Power Stations; LAN, local area network; ANPR, Automatic Number Plate Recognition; RFID, Radio frequency identification; MAS, multi-agent system.

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