Smart Parking Management Systems

Subjects: Computer Science, Interdisciplinary Applications

Contributor: Irina Makarova , Vadim Mavrin , Damir Sadreev , Polina Buyvol , Aleksey Boyko , Eduard Belyaev

Urbanization, which causes the need for population mobility, leads to an increase in motorization and related problems: the organization of parking spaces in cities, both near work places and recreational spaces, and not far from residential locations. This has a number of consequences. Therefore, the occupation of parking spaces near shopping centers and sports and recreation facilities, intended only for customers of these organizations, makes it difficult for direct customers to access services. This forces potential customers to look for a parking space in adjacent areas, often far from the target location. At the same time, the search for a parking space is stretched over time, negatively affecting the environment in the form of emissions and noise. On the other hand, there is a risk of losing a client. Using simulation models to find rational options for the organization of access to parking spaces and further using such models in decision support systems (DSS) as an intellectual core may solve this problem.

parking management systems smart parking simulation models decision support systems

1. Introduction

One of the modern city problems, which is aggravated by the increase in the motorization level, is the lack of parking spaces, which refers both to places where short-term demand is formed (near business, cultural, shopping, entertainment centers) and to population residence places (long-term vehicle storage). This problem has a number of consequences associated with the formation of spontaneous parking lots that impede the transport traffic, leading to traffic jams and congestion, as well as worsening the environmental situation in cities [1][2][3]. The issue of parking management is solved by creating parking management systems. However, there are a number of unresolved issues that are typical for medium and small cities with small budgets: implementation of such a system should guarantee its quick payback, which is associated with the efficiency of use, as well as with the effects obtained from the solution's implementation (road situation improvement, reducing vehicle emissions, solving social population problems, etc.).

2. Forecasting and Managing Parking Demand

Most cities have limited parking spaces, and, since it is difficult and costly to create new parking spaces, it is imperative to make the most of existing parking spaces. The article [4] presents a city parking management system based on equal access to the parking infrastructure for any road user. The method is based on the use of three ensemble regressors. The authors proposed a combination of models to predict the number of vacancies in a given area at a specific time of day.

Research [5] examines traffic, including in relation to parking regulations. The authors investigate traffic in the city of Uherske Hradiste near specific parking spaces, including paid parking zones, especially designated parking spaces near institutions and for time-limited free parking, in order to develop measures and proposals to improve the efficiency of the city's transport system within the framework of the Smart City concept.

Since finding a parking space has become increasingly difficult and expensive lately, the authors [6] propose a balancing mechanism for efficiently sharing both public and private parking lots (PL). The problem of distributing parking lots contains two goals: (1) minimization of parking costs and (2) balancing the demand for parking among several PLs. The authors use an algorithm based on the variable direction multiplier method, which can provide a distributed implementation and has a positive effect. In addition, due to the growing fleet of electric vehicles, the authors plan to use a balanced demand mechanism to balance electricity congestion between multiple charging stations.

Article [7] describes the booking methods used in the field of intelligent parking management systems. This allowed us to define three steps required for a booking system: discovery, optimization and assignment. The authors highlighted the most important features of a high-performance booking system: taking into account driver preferences and optimizing distances and delays in selection, which is necessary to ensure the scalability and stability of the system.

The article [8] proposes a distributed structure for allocating parking spaces based on the adaptive pricing algorithm, hashgraph consensus and virtual voting. Using the model, all users and parking owners can easily agree on the allocation of a parking space using the minimum bandwidth. In addition, an adaptive pricing model is proposed to increase the total income of parking owners and the convenience of users. The simulation results show that the proposed model is very useful for saving the user's time in searching for free parking spaces, avoiding congestion and making optimal use of resources.

The article [9] proposes a new method of parking space management for shared vehicles based on open big data available, including the visualization of GPS order data and analysis of data distribution on the road. The authors apply a clustering algorithm using GPS data for clustering. The optimization algorithm is used to set the sum of the distances from the location of all orders to the closest stopping point as the optimization target, optimize the location of parking spaces and reduce the walking distance of customers.

The article [10] proposed short-term methods for predicting the available parking space. The results showed that compared to the most used approaches, the stability and accuracy of predictions are significantly improved, although there are limitations in the form of an unsatisfactory waste of time.

3. Models and Algorithms for Finding Vacant Places for Smart Parking

One of the main reasons for the high traffic congestion in cities is the disorganized search for free parking spaces. Thus, the results obtained by Bischoff J. and Nagel K. [11] show that parking search traffic constitutes up to 20% of the total traffic in a residential area and has a significant impact on the total travel time of agents traveling by vehicle. This leads to financial and environmental problems. The allocation of parking lots is a dynamic task since the input data are constantly updated. The article [12] proposes a method to solve the problems of updates in real time using a greedy heuristic, which, according to the authors, is rational if there is enough space in the parking lot to accommodate all vehicles. However, when there is a decrease in capacity or a large number of vehicles, the exact algorithm is the best choice. To provide a more accurate distribution, especially when the vehicle speed is not considered constant, the authors propose to include a double horizon heuristic that will track the effect of the current decision and adapt future ones.

A study of various types of intelligent parking systems has revealed a number of problems that are associated with the serious and costly modernization of parking spaces, such as a wired power supply or regular battery replacement. The proposed system [13] can control up to four parking spaces from one node, transmits data via a wireless network and uses solar panels for operation, which does not require maintenance and ensures environmental friendliness. The authors propose an application for the phone, which, using Google Maps, can indicate routes on a map to a destination.

The article [14] proposes a structure based on the adaptation of the “day–night” domain; the key idea of the framework is to embed images in two spaces. Taking advantage of the two-domain exchange, the framework not only transfers knowledge and tags between domains, but also synthesizes images, which allows the parking system to more efficiently determine the status of places at night. The proposed framework will help to extend this parking inference system to new environments with reduced data collection and tagging costs.

Vehicle drivers spend a lot of time looking for free spaces in multistory vehicle parks, which creates queues and congestion on the roads. In the study [15], an intelligent parking system based on image processing was developed for multi-storey garages. The proposed system design using Python IDLE and the OpenCV library uses combined edge detection and anchored pixel coordinates to determine if a parking space is occupied in the resulting footage.

The paper [16] proposes a research methodology for empirically measuring the impact of street parking policies based on automated parking transactions for visitors in central Stockholm, Sweden. As the authors have found, the average occupancy rate does not reflect the ease of finding a free parking space, and this should be taken into account when predicting the consequences for cruise traffic. The process of finding parking on the street, according to the authors, can be simplified by considering a sequence of independent Bernoulli tests with a failure rate corresponding to the average parking load in a given area.

The explicit parking search is not as widely integrated into the transport’s modeling and transport models. The article [11] demonstrates the integration of parking search simulation in MATSim (Multi-Agent Transport Simulation). This includes integration into agent modeling logic using the day’s rescheduling methodology, splitting vehicle trips into multiple segments for each leg of the trip, parking search behavior and a data structure for parking

infrastructure. Research results for a district in Berlin show that the average time that it takes to find parking and walk to the actual destination (or back to the vehicle) in this area is 8 min. Further research should include the impact of different parking search strategies and their impact on travel times.

Finding a parking spot leads to congestion, increased air pollution and negative emotions. In the article [17], the authors propose to determine the congestion of open parking spaces using real-time vehicles with a thermal imager and deep learning, believing that such information will help to reduce congestion and subsequent air pollution. A thermal camera is used to collect videos in various environmental conditions, and frames are extracted from these videos to prepare the dataset. The authors investigate deep learning networks (Yolo, Yolo-conv, GoogleNet, ReNet18 and ResNet50) for vehicle detection. The Yolo fast detector has been modified using convolutional and residual layers, which has hardly improved its performance. The use of filters can improve the performance of the detectors, but also increases the computational time of the detector, which is not suitable for real-time parking occupancy detection.

The article [18] presents a solution using smartphones for intelligent parking (ParkUs), with the provision of information about the parking availability at the selected destination. It is a crowdsourced approach based on mobile device detection and automatic part tagging of the user's journey with cruise/non-cruise events. This study's results show that reducing the search time for a parking place by even a few seconds will result in improved air quality and significant reductions in CO_2 emissions, which is the rationale for using ParkUs.

The document [19] proposes an application by which the driver selects a preferred parking spot, tracks the elapsed time and uses electronic payments to avoid monetary transactions between staff. The quick response (QR) code is the key to reserving a parking space, confirming reservations and payments, as well entering and exiting. This system is convenient because it will provide non-cash transactions, and reduce interactions between people, congestion in the parking lots and paper waste. In addition, the monitoring system increases the safety of parked vehicles.

The article [20] introduces the Smart Car Parking System, which will help car owners to quickly find parking spots using an Android-based application system that stores both driver and parking provider information in a wireless database. The system concept includes both hardware and software for building the system. The system is integrated with a hardware solution using sensors; the LCD display is controlled by a microcontroller. However, there is room for improvement, especially with regard to security measures. To ensure security, a QR scanner, namely a VLP scanner, is involved.

The study [21] proposed an algorithm for extracting data from parking space sensors. Experiments and results show that the accuracy of the proposed algorithm can reduce the number of errors by retaining the total sleep time.

The Raspberry Pi system proposed in article [22] addresses the problem of existing smart parking systems using microcontrollers by developing a new application for an Android mobile phone. This allows any number of users to find a parking lot without registration due to vehicle detection units and the transmission of information about the

availability of a parking space on each floor of the parking lot. This system can be implemented for shopping centers, buildings and cities in real time as a multi-level parking system, where the driver will park manually.

Study [23] describes the architecture of an intelligent parking management system with a wireless sensor network. Since the system is implemented using very low-cost devices, this can reduce the development costs.

The authors [24] propose an intelligent parking solution using wireless radio technology to locate a parked vehicle and transmit data from sensors to a central control system. The proposed system uses a self-forming network of dual-mode Bluetooth sensors in the parking lot. The localization technique is based on radio fingerprints using received signal strength indicator (RSSI) values from a beacon and a random forestry machine learning classifier that predicts where the vehicle is parked. The implementation uses Python on common Internet of Things (IoT) hardware, which allows for a variety of parking applications.

The authors of [25] are developing an intelligent parking system based on the ZigBee wireless sensor network. Thanks to the online and offline interactive management of parking spaces, the utilization rate of parking spaces is increased, and the problem of urban parking chaos is effectively solved, which is of practical importance.

Internal electronic devices not only make tasks easier for administrators, but also make parking smart. Thus, article [26] proposes an inexpensive, highly efficient and easy-to-manage parking management system based on the Alibaba Cloud platform and machine learning, which allows one to count the number of vehicles entering the parking lot and to recognize license plates, which is not only convenient for management but also helps drivers to find parking spaces. The system implements voice control both for parking and through the application.

The article [27] proposes a received signal strength indicator (RSSI) approach for detecting available parking spaces. The system uses a scalable message queue telemetry protocol to ensure its security. The advantage of the proposed system is the possibility of remote real-time detection of free parking spaces using the developed mobile application, which significantly saves time and money for vehicle owners and allows the system to be used in several parking lots; vehicle data are stored in a central database.

The integration of several effective technologies, such as the Internet of Things (IoT), unmanned aerial vehicles (UAVs) and 5G communications, can simplify the monitoring and management of parking spaces. The article [28] proposes an intelligent parking system that uses multiple sensors to track the occupancy of parking spaces, as well as surveillance from a UAV to improve accuracy. The system uses a magnetic sensor and an ultrasonic distance sensor, using the UAV to detect and correctly predict the presence of a vehicle in a parking space, which is used to inform users of the location of the nearest unoccupied parking space.

Study [29] is another example of the use and development of drone technology, namely the use of a quadcopter for counting vehicles in an open parking lot. The researchers recommend using a template that needs to be placed on parking spaces to more accurately determine if parking spaces are occupied or not and eliminate additional false positives.

The authors [30] proposed a semi-guided and multi-tasking learning environment for determining the status of parking spaces using a magnetic signal for solving practical problems in street parking, such as environmental noise, non-unified coordinates of magnetic sensors, signal variations due to vehicle type, sensor location and adjacent moving vehicles. In addition, the authors propose a multitasking module for exploring distinctive and generalized characteristics using information from both tagged and untagged data.

Real-time automatic detection of the occupied parking space with a high level of accuracy is a useful concept for realizing intelligent parking. The authors [31] proposed a new form of automatic parking space detection system based on the Laplacian Edge Detection method in order to recognize when parking spaces are occupied or when the vehicle is parked incorrectly.

Since the volume of exhaust gases increases proportionally with an increase in the time for which a vehicle searches for a free parking space, the researchers focused on the primary task of developing algorithms, methods, applications and devices for recognizing unoccupied parking spaces and building the shortest route for the driver to them. In this case, computer vision methods, a magnetic sensor and an ultrasonic distance sensor are used.

4. Machine Learning Algorithms for Parking Management

Article [32] discusses the creation of simulation software that can provide information on available parking spaces. Methods used include character recognition with the EAST text detector algorithm, vehicle detection with the Haar cascade classification algorithm and free parking space detection. The study presents a detector that uses functional text to detect vehicles in parking spaces. These three methods are then combined into a modeling system that uses the Python and OpenCV libraries as tools. For further development, according to the authors, the Internet of Things (IoT) can be implemented.

The article [33] presents a virtual intelligent parking system based on a signal request mechanism. The free parking space selection mechanism is based on the proximity principle, the path planning is based on Dijkstra's algorithm, and the deadlock conflict resolution method is based on the signal request mechanism. The authors introduce a new type of dynamic priority that effectively improves the efficiency of resolving problems caused by deadlock conflicts.

The study [34] expands the application of federated learning to parking management by proposing FedParking, where parking operators (PLO) co-train a long-term short-term memory model to estimate a parking space. The authors formulate the interaction between PLO and vehicles as a Stackelberg multiplayer game. Given the dynamic arrivals of vehicles and time-varying parking capacity constraints, a deep learning, multi-agent approach and a DRL approach are applied to achieve Stackelberg equilibrium in a distributed but privacy-safe manner.

Research [35] offers smart parking solutions using big data analytics and deep learning techniques based on a convolutional neural network (CNN). The authors propose a cost-effective and convenient parking ecosystem that uses computer vision and deep learning to guide the user to the nearest parking space using a mobile app. The

main focus of the work is on reducing the model training time and describing the classification model that is used for vehicle detection. CNNs are used to build a supervised classification model that detects vehicles in a parking lot.

The authors [36] propose to apply machine learning to automatically detect free spaces in delimited parking spaces, followed by an extension to non-delimited parking spaces. This approach requires fewer images to train the classifier, accepts non-rectangular images of variable size as input and can also be applied to non-delimited parking spaces.

The paper [37] proposes a low-power wide-area network (LPWAN)-based urban parking space monitoring system with a focus on system design, including software, hardware and algorithms. LoRa technology and NB-IoT technology provide an opportunity in the future to form a large-scale low-power wireless sensor network for urban smart parking. Compared with other wireless sensor networks, the proposed parking space monitoring system has obvious advantages for advancements in urban smart parking projects.

The article [38] proposes a model for the joint distribution of overnight parking spaces between a residential area and an adjacent business area based on shared parking in the adjacent areas. The research findings of this article can provide a method for planning and managing shared parking in the surrounding areas of major cities in China. Based on the concept of shared parking and its premise, this article proposes building a model for the total distribution of nighttime parking spaces and defines the process of building a model and solving it by checking the correctness of the model assumptions.

The authors [39] have developed an intelligent parking system based on positioning and navigation technology in an ultra-wideband range. The whole system consists of three modules: an indoor positioning module, consisting of a UWB intelligent positioning bracelet (tag) and a positioning base station; a parking and shopping center data management module; and the user’s mobile phone application module. The iParking smart parking system proposed in this article has more advantages than the video induction and reverse vehicle search system, both in function and cost, which will improve the level of parking intelligence, helping to transform traditional parking into intelligent parking.

The Integrated Intelligent Parking System (ISPS) includes empty parking space detection and offers the shortest route to a location, focusing on minimizing time and reducing unnecessary trips. In the study [40], ISPS supports users with automatic parking management and information about vehicle fuel use, helping to reduce congestion, human effort and carbon emissions.

The article [41] proposes a parking distribution model for a smart city, which uses a resource processing module (RHM) and a custom application to provide smart parking services, taking into account such parameters as distance, cost, time and traffic. Since the system takes into account several factors, this solution provides a more accurate estimate of the time required to reach the goal and helps to minimize errors.

The article [42] proposes a new scheme for optimizing parking costs for long-distance autonomous parking: AVPark. The system selects a temporary checkpoint where the client can pick up the AV for the trip. The user leaves the AV at the drop-off point, and the AV independently determines the optimal parking, using AVPark, taking into account the cost of parking, fuel consumption and the distance to a free parking space, and also seeks to minimize the distance for both drivers and the AV (traveling there and back from the drop-off point to the vehicle park). In the future, there will be great interest in integrating AVPs with edge computing and the cloud to support IoT services.

The article [43] proposes a parking system for resource management in an environment of mixed automated and human-driven vehicles as a problem of dynamic resource allocation of mixed-integer linear programming at each decision point in order to minimize the total costs for users. Based on the tree representation of the decision space for matching pairs, the Monte Carlo tree search and some heuristics are combined to find the optimal matching order (parking users and resources) in a short time. This online resource allocation system can effectively solve the city-wide parking problem and greatly improve the quality of service provided to human drivers based on the interaction mechanism developed in the mixed environment of automated and human-driven vehicles.

The next stage of development is the intellectualization of parking resource management by using machine learning algorithms, including for automated vehicles.

5. Smart Parking Management Systems

The parking lot is currently managed by parking assistants. When drivers are looking for a parking place, many vehicles move around, causing congestion and wasting time. The document [44] presents a computer vision-based parking monitoring and management system that makes it easier for drivers to find an empty parking space. The HAAR cascade classifier method detects and counts parked vehicles and then compares them to the available parking spaces. The accuracy rate for detecting vehicles for this study is 90%, and the accuracy rate for detected vacant parking spaces is 80%.

The article [45] describes the development and implementation of a parking management system that solves the problems of parking complexity and complex vehicle management, where the administrator can check the parking space and vehicle information at any time, and the driver can reserve a parking space via keywords. At the same time, this article analyzes the complexity of various path navigation algorithms, taking into account the different requirements for a real-time map in parking and off-site route navigation. For the parking space management module, this article analyzes Dijkstra's Heap Optimization Algorithm, Floyd's Algorithm and the Ant Colony Algorithm.

Sharing private parking spaces during idle periods has great potential to address urban traffic congestion and illegal parking in Smart Cities. The article [46] proposes a new privacy-enhancing parking sharing incentive scheme where parking space providers (PSPs) and customers are treated as buyers and dealers. At the same time, the distance between the customer's destination and the allocated parking space is minimized by solving a mixed-

integer nonlinear programming problem, and the location confidentiality of customers' destinations is protected by the Laplace mechanism.

In the article [47], the authors point out that the growth in demand for parking requires the optimization of existing parking spaces. They propose the optimization of the parking of the sports center Enrique Razona in DLSU (Manila) using linear programming. Because its current access road is much wider than the minimum width required by the Philippines Building Code, it could be narrowed to make room for new parking spaces. This, in turn, will lead to reduced waiting times for drivers in the mornings and ultimately solve the parking problem at the university.

The article [48] proposes a new structure of a network model based on a recurrent neural network (RNN) and an ensemble learning algorithm called E-RNN. The ensemble learning algorithm model is used as the main learner, and the neural network is used as the secondary learner in ensemble learning. The new model parameters are optimized using the Particle Swarm Optimization (PSO) algorithm, which improves the model. Experimental results show that the algorithm has high accuracy and reliability for predicting parking spaces with small datasets.

The article [49] presents the structure of a blockchain-based parking management system designed to preserve the users' privacy without relying on a trusted third party. The proposed system combines BlockChainOpenSource (BCOS) and smart contract technology to share parking spaces.

The use of blockchain technology allows one to reduce intermediary costs through smart contracts. An important point in this ecosystem is the confirmation of participants' identities on the blockchain network. The article [50] proposes a blockchain-based collaborative mobility platform and demonstrates its validity. Based on ERC-721 tokens, a decentralized concept is created, implemented in a smart contract and supplemented by a hardware security module (HSM) to protect confidential key material. Finally, the system's evaluation by comparison with modern solutions has shown that the proposed solution has an advantage in security terms.

References

1. Makarova, I.; Buyvol, P.; Magdin, K.; Pashkevich, A.; Boyko, A.; Shubenkova, K. Usage of microscopic simulation to estimate the environmental impact of road transport. Transp. Res. Procedia 2020, 44, 86–93.
2. Makarova, I.; Shubenkova, K.; Mavrin, V.; Magdin, K. Environmental safety of city transport systems: Problems and influence of infrastructure solutions. Lect. Notes Netw. Syst. 2019, 68, 24–34.
3. Yakupova, G.; Buyvol, P.; Mukhametdinov, E.; Boyko, A. Road safety analysis from a viewpoint of influencing factors. In Proceedings of the International Conference on Developments in eSystems Engineering, DeSE, Kazan, Russia, 7–10 October 2019; pp. 806–811.

4. Errousso, H.; El Ouadi, J.; Benhadou, S.; Medromi, H.; Malhene, N. Improving delivery conditions by dynamically managing the urban parking system: Parking availability prediction. In Proceedings of the 2020 IEEE 13th International Colloquium of Logistics and Supply Chain Management (LOGISTIQUA), Fez, Morocco, 2–4 December 2020; pp. 1–6.
5. Růžička, J.; Navrátilová, K.; Tichý, T. Respecting the parking rules in city centres. In Proceedings of the 2019 Smart City Symposium Prague (SCSP), Prague, Czech Republic, 23–24 May 2019; pp. 1–6.
6. Kim, O.T.T.; Tran, N.H.; Pham, C.; LeAnh, T.; Thai, M.T.; Hong, S.H. Parking Assignment: Minimizing Parking Expenses and Balancing Parking Demand Among Multiple Parking Lots. IEEE Trans. Autom. Sci. Eng. 2020, 17, 1320–1331.
7. Elkhalidi, N.; Benabbou, F.; Sael, N. Survey of Reservation Techniques in Smart Parking. In Proceedings of the 2019 1st International Conference on Smart Systems and Data Science (ICSSD), Rabat, Morocco, 3–4 October 2019; pp. 1–6.
8. Hassija, V.; Saxena, V.; Chamola, V.; Yu, F.R. A Parking Slot Allocation Framework Based on Virtual Voting and Adaptive Pricing Algorithm. IEEE Trans. Veh. Technol. 2020, 69, 5945–5957.
9. Xing, J.; Chu, L.; Guo, C.; Hou, Z.; Qiao, Y.; Jiang, S. Parking Spaces Planning for Shared Vehicles Based on Visualized Data Analysis. In Proceedings of the 2020 Chinese Automation Congress (CAC), Shanghai, China, 6–8 November 2020; pp. 582–587.
10. Ye, X.; Wang, J.; Wang, T.; Yan, X.; Ye, Q.; Chen, J. Short-Term Prediction of Available Parking Space Based on Machine Learning Approaches. IEEE Access 2020, 8, 174530–174541.
11. Bischoff, J.; Nagel, K. Integrating explicit parking search into a transport simulation. Procedia Comput. Sci. 2017, 109, 881–886.
12. MMladenović, a.; Delot, T.; Laporte, G.; Wilbaut, C. A scalable dynamic parking allocation framework. Comput. Oper. Res. 2021, 125, 105080.
13. Islam, M.R.; Azam, S.; Shanmugam, B.; Karim, A.; El-Den, J.; DeBoer, F.; Jonkman, M.; Yadav, A. Smart Parking Management System to Reduce Congestion In Urban Area. In Proceedings of the 2020 2nd International Conference on Electrical. Control and Instrumentation Engineering (ICECIE), Kuala Lumpur, Malaysia, 28 November 2020; pp. 1–6.
14. Zheng, W.Z.; Tran, V.Z.; Huang, C.C. D2NA: Day-To-Night Adaptation for Vision based Parking Management System. In Proceedings of the ICASSP 2020–2020 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), Barcelona, Spain, 4–8 May 2020; pp. 1573–1577.
15. Crisostomo, C.I.C.; Malalis, R.V.C.; Saysay, R.S.; Baldovino, R.G. A Multi-storey Garage Smart Parking System based on Image Processing. In Proceedings of the 2019 7th International

Conference on Robot Intelligence Technology and Applications (RiTA), Daejeon, Korea, 1–3 November 2019; pp. 52–55.

16. Cats, O.; Zhang, C.; Nissan, A. Survey methodology for measuring parking occupancy: Impacts of an on-street parking pricing scheme in an urban center. Transp. Policy 2016, 47, 55–63.
17. Paidi, V.; Fleyeh, H.; Nyberg, R.G. Deep learning-based vehicle occupancy detection in an open parking lot using thermal camera. IET Intell. Transp. Syst. 2020, 14, 1295–1302.
18. Aftab, K.; Kulkarni, P.; Shergold, I.; Jones, M.; Dogramadzi, M.; Carnelli, P.; Sooriyabandara, M. Reducing Parking Space Search Time and Environmental Impacts: A Technology Driven Smart Parking Case Study. IEEE Technol. Soc. Mag. 2020, 39, 62–75.
19. Bagadiong, M.A.; De Leon, L.A.; Dizon, A.A.; Young, M. Car Park Reservation Using QR System: Proposed Flow. In Proceedings of the 2020 IEEE 7th International Conference on Engineering Technologies and Applied Sciences (ICETAS), Kuala Lumpur, Malaysia, 18–20 December 2020; pp. 1–5.
20. Usha, R.T.; Sejuti, F.S.; Hossain, M.; Islam, S. A Smart Approach of Parking Services and Minute Coin Concept. In Proceedings of the 2019 22nd International Conference on Computer and Information Technology (ICCIT), Dhaka, Bangladesh, 18–20 December 2019; pp. 1–6.
21. Khamgerd, S.; Khoenkaw, P. Pull-Based Algorithm for Parking Space Sensor Data Reading. In Proceedings of the 2019 Joint International Conference on Digital Arts, Media and Technology with ECTI Northern Section Conference on Electrical, Electronics, Computer and Telecommunications Engineering (ECTI DAMT-NCON), Nan, Thailand, 30 January–2 February 2019; pp. 339–342.
22. Aravindh, G.; Kumar, M.A. An Efficient Car Parking Management System using raspberry-pi. In Proceedings of the 2020 3rd International Conference on Intelligent Sustainable Systems (ICISS), Thoothukudi, India, 3–5 December 2020; pp. 154–158.
23. Fernando, E.; Warnars, H.L.H.S. Innovation Architecture Smart Car Parking System with Wireless Sensor Networks. In Proceedings of the 2020 7th International Conference on Information Technology, Computer, and Electrical Engineering (ICITACEE), Semarang, Indonesia, 24–25 September 2020; pp. 258–262.
24. Seymer, P.; Wijesekera, D.; Kan, C. Secure Outdoor Smart Parking Using Dual Mode Bluetooth Mesh Networks. In Proceedings of the 2019 IEEE 89th Vehicular Technology Conference (VTC2019-Spring), Kuala Lumpur, Malaysia, 28 April–1 May 2019; pp. 1–7.
25. Zhang, J. Research and Implementation of Intelligent Parking System Based on ZigBee. In Proceedings of the 2019 2nd International Conference on Information Systems and Computer Aided Education (ICISCAE), Dalian, China, 28–30 September 2019; pp. 608–612.

26. Liao, W.; Xie, L.; Xi, J.; Bai, Y.; Zhang, T.; Wu, Y. Intelligent parking lot control system based on Alibaba Cloud platform and machine learning. In Proceedings of the 2021 6th International Conference on Intelligent Computing and Signal Processing (ICSP), Xi'an, China, 9–11 April 2021; pp. 908–911.
27. Weliwita, T.; Ekanayake, H. RSSI Based Real-Time and Secure Smart Parking Management System. In Proceedings of the 2020 IEEE Global Conference on Artificial Intelligence and Internet of Things (GCAIoT), Dubai, United Arab Emirates, 12–16 December 2020; pp. 1–6.
28. Gogoi, P.; Dutta, J.; Matam, R.; Mukherjee, M. An UAV assisted Multi-Sensor based Smart Parking System. In Proceedings of the IEEE INFOCOM 2020-IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS), Toronto, ON, Canada, 6–9 July 2020; pp. 1225–1230.
29. Del Rosario, J.R.B.; Azarraga, E.J.C.; Chiu, M.J.C.; Del Rosario, A.J.C.; Jarabelo, A.B.S.; Bandala, A.A. Development of a Vision Based Parking Monitoring System Using Quadrotor UAV. In Proceedings of the 2020 IEEE 12th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment, and Management (HNICEM), Manila, Philippines, 3–7 December 2020; pp. 1–6.
30. Tran, Y.; Wu, V.; Huang, C. Semi-Supervised and Multi-Task Learning for On-Street Parking Space Status Inference. In Proceedings of the 2019 International Conference on Multimedia Analysis and Pattern Recognition (MAPR), Ho Chi Minh City, Vietnam, 9–10 May 2019; pp. 1–6.
31. Noor, M.; Shrivastava, A. Automatic Parking Slot Occupancy Detection using Laplacian Operator and Morphological Kernel Dilation. In Proceedings of the 2021 10th IEEE International Conference on Communication Systems and Network Technologies (CSNT), Bhopal, India, 18–19 June 2021; pp. 825–831.
32. Harahap, R.A.; Wibowo, E.P.; Harahap, R.K. Detection and Simulation of Vacant Parking Lot Space Using EAST Algorithm and Haar Cascade. In Proceedings of the 2020 Fifth International Conference on Informatics and Computing (ICIC), Gorontalo, Indonesia, 3–4 November 2020; pp. 1–5.
33. Ning, S.; Zhong, J.; Zheng, X. Design of Virtual Intelligent Parking Lot System Based on Signal Request Mechanism. In Proceedings of the 2021 IEEE 24th International Conference on Computer Supported Cooperative Work in Design (CSCWD), Dalian, China, 5–7 May 2021; pp. 593–597.
34. Huang, X.; Li, P.; Yu, R.; Wu, Y.; Xie, K.; Xie, S. FedParking: A Federated Learning based Parking Space Estimation with Parked Vehicle assisted Edge Computing. IEEE Trans. Veh. Technol. 2021, 70, 9355–9368.
35. Mettupally, S.N.R.; Menon, V. A Smart Eco-System for Parking Detection Using Deep Learning and Big Data Analytics. In Proceedings of the 2019 SoutheastCon, Huntsville, AL, USA, 11–14

April 2019; pp. 1–4.

36. Varghese, A.; Sreelekha, G. An Efficient Algorithm for Detection of Vacant Spaces in Delimited and Non-Delimited Parking Lots. IEEE Trans. Intell. Transp. Syst. 2020, 21, 4052–4062.
37. Meng, X.; Wan, H.; Qin, T. Design of Urban Parking Space Monitoring System Based on LPWAN. In Proceedings of the 2020 IEEE 20th International Conference on Communication Technology (ICCT), Nanning, China, 28–31 October 2020; pp. 1029–1034.
38. Liu, X.; Hu, H.; Deng, Z. The Shared Allocation Model of Night Parking Spaces between Residential Areas and Adjacent Business Districts. In Proceedings of the 2019 International Conference on Artificial Intelligence and Advanced Manufacturing (AIAM), Dublin, Ireland, 16–18 October 2019; pp. 527–532.
39. Zhao, J.; Wu, Q.; Chen, J.; Huang, Y. Parking, Intelligent Parking System. In Proceedings of the 2019 IEEE 4th Advanced Information Technology, Electronic and Automation Control Conference (IAEAC), Chengdu, China, 20–22 December 2019; pp. 2262–2267.
40. Al Maruf, M.A.; Ahmed, S.; Ahmed, M.T.; Roy, A.; Nitu, Z.F. A Proposed Model of Integrated Smart Parking Solution for a city. In Proceedings of the 2019 International Conference on Robotics, Electrical and Signal Processing Techniques (ICREST), Dhaka, Bangladesh, 10–12 January 2019; pp. 340–345.
41. Iyer, P.; Nambiar, N.; Venkat, G.; Surendran, S.; Anand, S. Smart Resource Handling Module for Parking. In Proceedings of the 2020 International Conference on System, Computation, Automation and Networking (ICSCAN), Pondicherry, India, 3–4 July 2020; pp. 1–6.
42. Khalid, M.; Cao, Y.; Aslam, N.; Raza, M.; Moon, A.; Zhou, H. AVPark: Reservation and Cost Optimization-Based Cyber-Physical System for Long-Range Autonomous Valet Parking (L-AVP). IEEE Access 2019, 7, 114141–114153.
43. Zhao, C.; Chen, I.; Li, X.; Du, Y. Urban Parking System Based on Dynamic Resource Allocation in an Era of Connected and Automated Vehicles. In Proceedings of the 2019 IEEE Intelligent Transportation Systems Conference (ITSC), Auckland, New Zealand, 27–30 October 2019; pp. 3094–3099.
44. Bachtiar, M.M.; Besari, A.R.A.; Lestari, A.P. Parking Management by Means of Computer Vision. In Proceedings of the 2020 Third International Conference on Vocational Education and Electrical Engineering (ICVEE), Surabaya, Indonesia, 3–4 October 2020; pp. 1–6.
45. Chen, R.; Hu, X.; Mu, W. Research on parking lot management system based on parking space navigation technology. In Proceedings of the 2020 IEEE International Conference on Power, Intelligent Computing and Systems (ICPICS), Shenyang, China, 28–30 July 2020; pp. 773–777.
46. An, D.; Yang, Q.; Li, D.; Yu, W.; Zhao, W.; Yan, C.B. Where Am I Parking: Incentive Online Parking-Space Sharing Mechanism With Privacy Protection. IEEE Trans. Autom. Sci. Eng. 2020,

19, 143–162.

47. Crisostomo, C.I.C.; Baldovino, R.G. Parking Space Optimization Using Simplex Method Linear Programming. In Proceedings of the 2019 International Conference on Mechatronics, Robotics and Systems Engineering (MoRSE), Bali, Indonesia, 4–6 December 2019; pp. 30–33.
48. Lv, K.; Chen, H.; Lv, Y. Parking Space Prediction Algorithm Based on Recurrent Neural Network and Ensemble Learning Algorithm. In Proceedings of the 2019 IEEE 6th International Conference on Cloud Computing and Intelligence Systems (CCIS), Singapore, 19–21 December 2019; pp. 114–119.
49. Hu, J.; He, D.; Zhao, Q.; Choo, K.R. Parking Management: A Blockchain-Based Privacy-Preserving System. IEEE Consum. Electron. Mag. 2019, 8, 45–49.
50. Pirker, D.; Fischer, T.; Witschnig, H.; Steger, C. Velink—A Blockchain-based Shared Mobility Platform for Private and Commercial Vehicles utilizing ERC-721 Tokens. In Proceedings of the 2021 IEEE 5th International Conference on Cryptography, Security and Privacy (CSP), Zhuhai, China, 8–10 January 2021; pp. 62–67.