Deep learning for parking spaces prediction in the context of smart and sustainable cities: a systematic literature review

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Abstract. The search for solutions to mitigate traffic congestion is a major challenge for densely populated cities. Studies have shown that more than 40% of traffic jams are caused by prolonged searching for parking spaces in crowded cities. Therefore, predicting the availability of parking spaces in advance is a crucial step in helping drivers quickly find free spaces and thus reduce traffic jams and their negative impacts on the environment, economy, and public health. Various approaches have been proposed to solve traffic congestion related problems. Deep learning, a technique in machine learning, has seen increasing use and has shown much effectiveness compared to other machine learning techniques for predicting parking space availability. In this study, we analyzed the use of deep learning techniques through a systematic literature review. The review process included formulating the research question, establishing search strategies, as well as data extraction and analysis. As a result, we identified four major families of deep learning techniques commonly used for predicting parking space availability. Additionally, we observed that recurrent neural networks and convolutional neural networks are the most widely used techniques.

1 Introduction

In recent years, traffic congestion has become one of the major problems of large urban cities. Traffic jams have proven to have considerable impacts on the various sectors of activity. In the United States, it was estimated at the end of 2020 an economic loss of more than 101 billion dollars due to traffic jams, mainly caused by fuel consumption and delays in journeys [1] . With traffic jams, the average duration of vehicles in traffic increases, which leads to additional fuel consumption. The combustion of fuel by vehicles leads to the increased releases of harmful substances into the environment and negative impact of health [2], including respiratory and cardiovascular diseases and premature deaths. According to the World Health Organization, in 2012, China and India recorded more than 1 million and 600 thousand deaths related to outdoor air pollution [3]. Therefore, the search for solutions that will help reducing traffic-related air pollution is more than a necessity.

Studies [4] have shown that in most large cities more than 40% of traffic congestion is due to the search for a parking space. Indeed, the inefficient search for available parking

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spaces leads to longer search times and queues that congest traffic. For example, in the United States, drivers spend an average of 17 hours per year searching for a parking space [5].

To eradicate this problem, several data-driven approaches have been suggested to predict the future availability of parking spaces, with the aim of assisting motorists in their search. Although machine learning methods have been widely exploited, their effectiveness has proved limited in the face of the varied complexity of urban parking characteristics, both temporal and spatial. Consequently, in recent years, advanced techniques such as deep learning have been increasingly employed in this field. Indeed, deep learning models have demonstrated marked effectiveness in a variety of fields, thanks to their high capacity to extract features from data. Many deep learning techniques are now being used to anticipate parking occupancy, showing higher levels of efficiency and promising results compared to traditional prediction models. Consequently, a thorough understanding of advances in the use of deep learning techniques for parking space prediction is of crucial importance for the successful application of these methods.

The aim of our work is to establish a study framework and carry out a thorough systematic literature review, in order to gain a better understanding of the research undertaken and emerging trends in the field of parking space availability prediction using deep learning. Our focus is specifically on how previous studies have exploited the capabilities of deep learning techniques to anticipate parking conditions in urban areas. The remainder of this paper is structured as follows: the next section reviews the state of the art in parking prediction research, while section 3 describes the methodology adopted in this work. Section 4 is devoted to answers to the research questions and related discussions. Finally, Section 5 presents the conclusions drawn from this systematic literature review.

2 Literature review

In recent years, a number of studies have been carried out to investigate the most appropriate machine learning methods for anticipating parking space occupancy. For example, Awan, Faraz Malik and al. compared the performance of five machine learning models: k-nearest neighbor (KNN), decision tree, random forest and ensemble learning (EL) [6]. Their analyses showed that, irrespective of data volume, less complex algorithms such as Decision Tree, Random Forest and KNN outperformed the other algorithms in terms of parking space availability accuracy. In other work [7], led by Zhao, Ziyao, Yi Zhang and Yi Zhang, compared the performance of various machine learning models such as linear regression (LR), support vector machines (SVM), back-propagation neural networks (BPNN) and autoregressive integrated moving averages (ARIMA). The results demonstrated that SVMs offer stable and accurate performance for prediction in different parking lot configurations and sizes. In the context of our previous studies [8], we also evaluated the effectiveness of more than 10 machine learning algorithms, in the long-term prediction of parking space availability. Our work revealed that the best performing method for this type of prediction was the random forest.

More recently, deep learning methods have regained popularity in various fields, including smart parking. Some previous studies [9] have achieved advanced predictions of parking occupancy with a 6-hour lead time by exploiting a deep learning model called the Gated Recurrent Unit (GRU). These models were trained by merging sensor data with weather and calendar information. Evaluation of these models revealed a mean squared error of residuals (RMSE) reaching a rate of 0.0828. In a separate approach, Amato and al [10] developed a parking space occupancy detection system using surveillance cameras. This approach combined the use of a convolutional neural network (CNN) to extract visual features, coupled with an SVM classifier for detection. This strategy resulted in a remarkable detection accuracy of 99.7% on observed data.Other researchers [11] formulated a hybrid

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deep learning architecture by combining convolutional graphs (GCNN), short-term memories (LSTM) and a decoder. Their objective was to anticipate parking space occupancy by integrating various data sources such as weather conditions and traffic speed. Their model was evaluated on a dataset collected in the city of Pittsburgh, Pennsylvania, USA. This innovative approach outperformed fundamental models such as LSTM and LASSO, showing a significant improvement in the prediction of parking space occupancy for all street blocks, with a mean absolute error (MAE) rate of 1.39. In many previous studies comparing traditional machine learning approaches, tree-based models such as random forests have generally been considered the most effective for predicting parking space occupancy. However, it is important to note that unlike previous research that has examined the different families of conventional machine learning algorithms, there is as yet no in-house study that has evaluated the effectiveness of the various families of deep learning methods for parking space occupancy prediction. Our study aims to fill this gap by proposing a systematic approach to thoroughly evaluate the performance of different families of deep learning methods in this specific prediction task. Given the diversity of techniques available in deep learning, such an analysis could provide clarity on the suitability of each method family for anticipating parking space occupancy. To our knowledge, our systematic study is the first to explore in depth the application of deep learning to this particular task. The results thus provide a solid basis for guiding future research in the field of parking space occupancy prediction by exploiting deep learning techniques.

3 Methodology

The methodology used in this study is based on the methodology proposed by Kitchenham and Charters [12]. Our search strategy includes five main steps, as illustrated in Figure 1: formulation of the research questions that will be addressed in this systematic review, search for relevant articles in the scientific literature, definition of the criteria for article selection, synthesis of the selected articles, analysis and discussion of the results obtained.

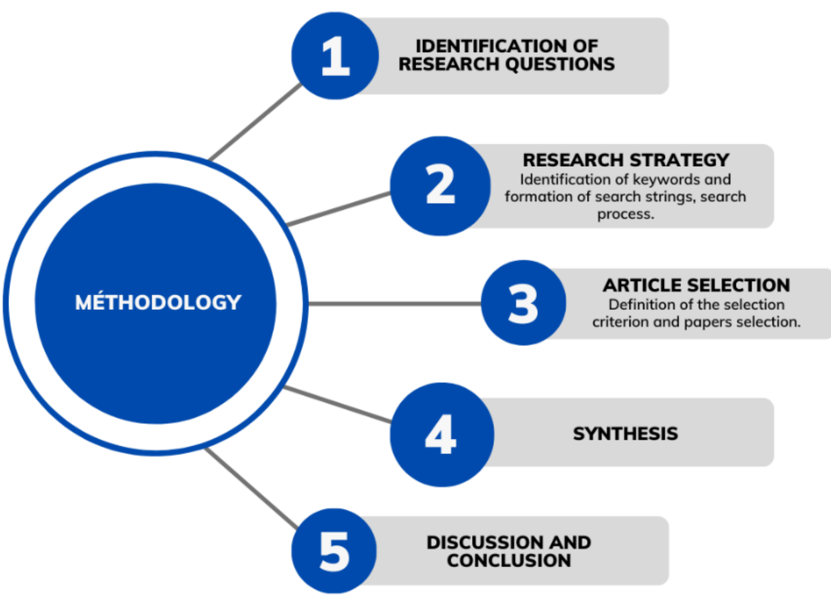

Fig.1. Steps of our methodology

3.1 Research questions

Based on our research objective, we have defined three questions that will serve as guidelines for our study.

Q1: What is the main objective of parking space prediction?
Q2: What are the trends in the use of deep learning for parking space prediction?
Q3: What are the frequently used deep learning models/approaches in parking space prediction?

These questions will be answered through our literature review.

3.2 Research Strategy

Our literature review was based on relevant keywords that we selected according to our research objective. These keywords are presented in figure 2.

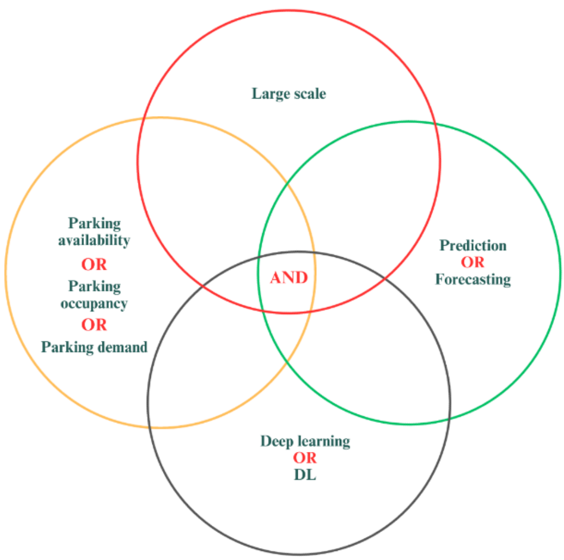

Fig.2. Search keywords

Using these keywords, we established a search string to find articles in google scholar. The search string that we defined is as follows: "Parking availability" OR "Parking Occupancy" OR "Parking demand" AND "Prediction" OR "Forecasting" AND "large scale" AND "deep learning" OR "DL".

3.3 Article Selection

Studies were included or excluded from our study based on the criteria defined in Table 1.

Table 1. Selection criteria

Criteria	Inclusion	Exclusion
Type of article	○ Research articles and conference papers. ○ Articles related to the prediction of parking space availability on a large scale using deep learning as a prediction method.	○ Articles that are not related to the prediction of parking space availability on a large scale. ○ Articles using prediction methods other than deep learning.
Year of publication	Between 2014 and 2022	After 2014
Language	English	Other than English

4 Results

Based on the pre-defined keywords and search string, we identified a total of 721 articles. After applying the selection steps (see Figure 3), we selected 36 relevant articles as the basis for our analysis. All results presented below are based on these 36 selected articles.

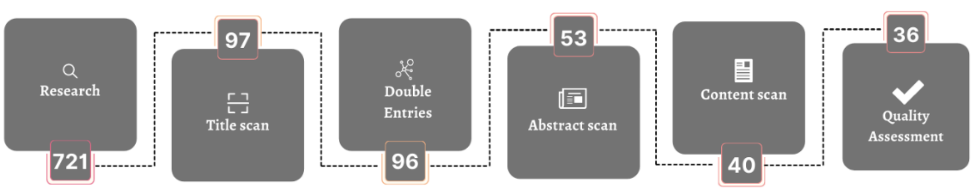

Fig. 3. Selection process

RQ1: The main objective of parking prediction

Deep learning has gained great popularity in recent years, and its use has extended to many fields, including predicting parking space availability. Making this prediction as effective as possible is crucial to overcoming some of the important challenges in the transportation system and eradicating the problem of urban traffic congestion. Through multi-source data collection and the use of deep learning techniques, information on parking space availability has become increasingly accurate in recent years. Predicting parking space availability is not only aimed at providing information on future parking occupancy, but several intelligent systems are designed around this prediction, such as the concept of smart parking. Smart parking offers solutions to reduce traffic congestion and facilitate urban mobility. It is composed of several elements, among which the parking guidance and information system and the parking reservation system play an essential role in reducing urban congestion. The parking guidance and information system aims to provide information on available parking spaces and advice on finding these spaces. Such a system will allow drivers to spend less time searching for parking spaces, which will reduce congestion in certain areas. For better applicability of the parking guidance and information system, it is necessary to address several related questions, such as how to avoid multiple drivers racing towards the same parking space. The parking reservation system ensures, in addition to intelligent pricing management, a reservation management system including advance booking of parking spaces, which avoids many vehicles continuing to circulate in search of available parking spaces. Intelligent parking space management is made possible by using techniques that dynamically price parking spaces and make current availability information more reliable. Most of the smart parking components mentioned above, such as the ERP and PRS, rely mainly on effective prediction of parking space availability.

RQ2: Trends in the use of deep learning in parking prediction

Figure 4 displays the annual distribution of the 36 scientific publications. Since 2014, the use of deep learning techniques has been steadily increasing. In 2022, the number of research papers that utilized deep learning has multiplied by 11 compared to 2014, representing an increase of over 1000%, and over 57% compared to 2021. There was a period of stability between 2014 and 2016, with a low number of publications using deep learning, i.e., one publication per year during this period. The same situation was observed between 2020 and 2021, but this time with a 600% increase in publications compared to 2014-2016, i.e., 7 publications per year. 2022 was the year with a significantly higher number of publications, with 11 publications during that year.

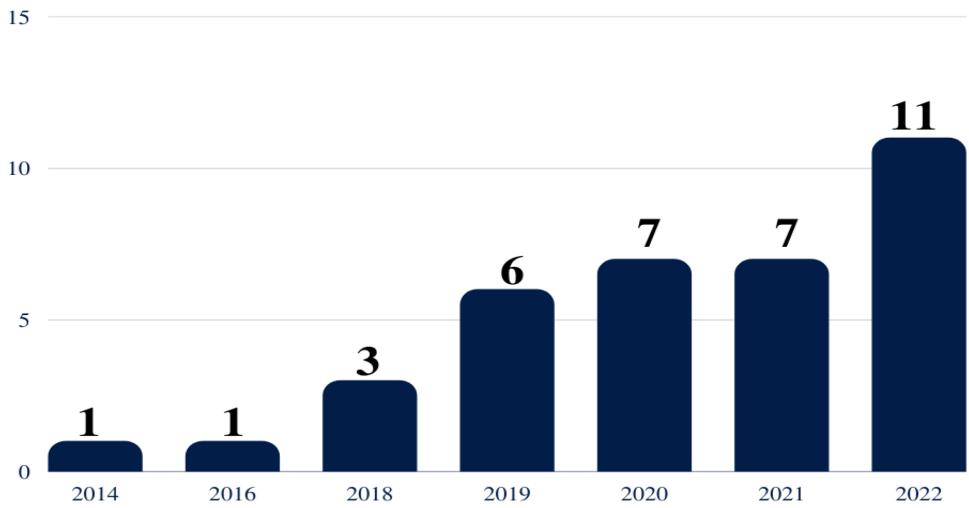

Fig. 4. Publications by year with on the abcissa axis the years and on the ordinate axis the quantity

RQ3: Deep learning models/approaches frequently used in parking space prediction

Deep learning techniques can be classified into several families, as illustrated in Table 2. Various types of neural network architectures were used for parking occupancy prediction. As shown in figure 5, the most common families are feedforward, recurrent (RNN), convolutional (CNN), hybrid, and other types of networks such as DNNs and sequence graphs. Among these architectures, CNN is the most widely used with a usage frequency of over 41.67% since 2014. These architectures are often used in image recognition to detect the condition of parking lots from the images collected by cameras.

Table 2. Families of deep learning techniques

Method Family	Most Common Use Cases
Feedforward neural networks	Image recognition, text classification, time series prediction
Convolutional neural networks	Computer vision, image recognition, speech processing
Recurrent neural networks	Sequence processing, machine translation, speech recognition
Generative adversarial networks	Image generation, image quality enhancement, voice synthesis
Long short-term memory networks	Natural language processing, speech recognition, sequence prediction
Autoencoders	Data compression, image reconstruction, anomaly detection
Residual neural networks	Image recognition, image segmentation, speech recognition
Attention-based neural networks	Natural language processing, image recognition, machine translation
Capsule neural networks	Image recognition, natural language processing, voice synthesis

Other types of models such as recurrent neural networks are used for sequential prediction of the future parking spaces availability using temporal data collected by sensors on the parking spaces, such as ultrasonic sensors. Recurrent neural networks are most commonly used for this task using these types of data. The usage rate of these types of architectures represents more than 22.22% since 2014, mainly due to methods such as LSTM or even GRU having significant temporal feature extraction capabilities. Some works combined multiple prediction methods to leverage the strengths of each method. These types of architectures are then classified as hybrid models and represent more than 19.44% of the use cases. CNNs and RNNs are the most common combination, with the goal of extracting spatial information in the parking data using the CNN and extracting temporal information using the RNN to make the prediction effective. The other types of models, including Deep Neural Network and graph to sequence, complete the set of deep learning families used in parking space state prediction with a usage of over 5.56%. Table 3 shows the distribution of the use of different techniques by year and by learning method family.

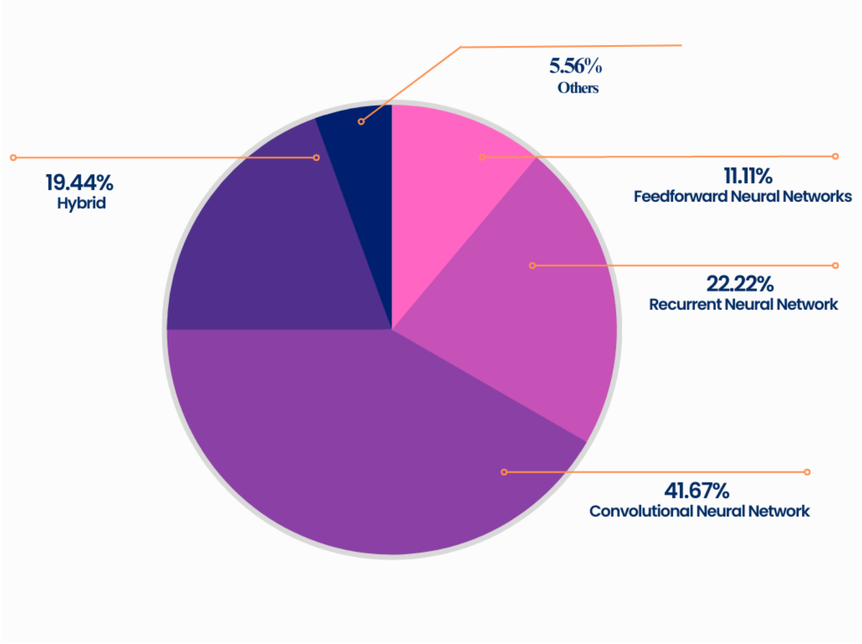

Fig 5. Use of deep learning techniques in the prediction of parking space availability

Table 3. Distribution of the use of deep learning techniques by year

		Feedforward Neural Networks	RNN	CNN	Hybrid	Other
Year	2014		[13]			
	2016			[10]		
	2018		[14, 15]	[16]		
	2019	[17]	[9, 18]	[19, 20]	[9]	
	2020	[7]	[21]	[22, 23]	[24]	
	2021	[25, 26]		[27, 28]	[29, 30]	
	2022		[31, 32]	[33, 34]	[35, 36]	[37, 38]

5 Discussion

Careful analysis of the data collected clearly illuminates the clear predominance of convolutional networks (CNNs), which stand out with a notorious prevalence exceeding 41.67% since the year 2014. This preeminence is rooted in the intrinsic ability of CNNs to extract foreground spatial features from images, a decisive capability for apprehending the condition of parking areas from visual data from surveillance devices.

However, it should be stressed that the problem of predicting parking lot occupancy cannot be approached exclusively from a spatial perspective. Temporal aspects are of substantial importance, lending relevance and credibility to recurrent neural networks (RNN). In particular, the incorporation of architectures such as LSTM and GRU has generated proven capabilities for capturing temporal relationships within parking data, capitalizing on information emanating from sensors such as ultrasound. This category of models has exceeded 22.22% usage since 2014, underlining their relevance for sequential prediction contexts.

A highlight of this systematic review relates to the advent of hybrid architectures. The judicious aggregation of convolutional and recurrent networks marked a turning point from 2019, totaling a share of usage exceeding 19.44%. This hybrid approach brings an intrinsic advantage, enabling the simultaneous exploitation of the advantages inherent in these two categories of architectures, thus authorizing a comprehensive apprehension of spatial and temporal elements. This convergence is promising, given the confluence of spatial and temporal dimensions in the context of urban parking, and can make a substantial contribution to increasing the accuracy of predictions.

However, it should be noted that the widespread adoption of these hybrid architectures could come up against infrastructural limitations. The design and implementation of these models require substantial computational resources, which could potentially pose logistical challenges in various circumstances. With this in mind, identifying a pragmatic balance between model complexity and available resources becomes imperative to ensure successful implementation of these methodological frameworks.

6 Conclusion

Finding a parking space is a major cause of traffic jams in large urban cities. Deep learning, an artificial intelligence technique, can be used to solve this problem. In this systematic literature review, we examined the use of deep learning techniques to predict parking space availability. Thirty-six relevant papers were selected for further study. We found that the use of deep learning techniques to predict parking space condition has been growing since 2014. Convolutional and recurrent neural networks are the most widely used models, with usage rates of 41.67% and 22.22%, respectively. Since 2019, hybrid models have been used to leverage the advantages of both types of architectures, with a usage rate of over 19%. In our future work, we plan to contribute to parking occupancy prediction by proposing a hybrid architecture for more efficient prediction. It is important to highlight the importance of using deep learning in parking space prediction to solve parking problems in large cities. The results of this systematic literature review show that deep learning techniques have great potential in this area, especially the use of hybrid models. Therefore, further research is crucial for finding more effective solutions and improve parking management in large urban cities.

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