Urban Intelligent Parking System Based on the Parallel Theory

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***Abstract*—Nowadays, urban parking circumstances are becoming more and more challenging. To solve this problem, many methods have been proposed, such as infrastructure expansion, economic leverage and technical theory. However, these solutions are generally used independently, thus it is infeasible to solve all existing problems. Therefore, a novel and revolutionary solution is urgently required. In this paper, we first comprehensively investigate the background of parking difficulties, and find that all of the current existing solutions are not able to meet the requirements of dynamic, systematization, high efficiency and accuracy. Then we briefly introduce the parallel theory, and propose the intelligent parking system based on the parallel theory, which can provide a systematic intelligent solution to meet the needs of current parking systems. The parallel parking system is made up of three parts, including the artificial system, the computational experiments, and the parallel execution. The proposed parallel parking system not only provides a novel direction to solve the parking problem, but also is an important guidance for the specific implementation of parallel parking theory.**

I. Introduction

With the development of technology and economy, more and more citizens have their own vehicles, which significantly facilitate the movement of residents. Even though travel time on the road is greatly saved by utilizing the vehicles, finding a suitable parking space still needs more time, especially for prosperous areas. In the last few years, most of the researchers are interested in the concept of "cruise". That is to say, when the vehicle arrives at the destination but it cannot find a parking space, it has to search around the destination for a long while. This situation would be worse during peak hours or around urban crowd center. This phenomenon is caused by two main reasons. On one hand, the expansion of parking infrastructure cannot catch up with the sharply increasing number of vehicles. On the other hand, the parking process is lack of efficient guidance and management. The parking trouble has become more and more serious, and has led to various other problems, such as the waste of time and energy, air pollution, traffic congestion, and traffic accident and so on. Therefore, solving the parking problem is a pressing research topic.

To solve parking problems, great efforts have already been made in different aspects. For example, government establishes some policies and regulations to increase parking spaces around commercial and residential buildings. In addition, the economic leverage is also helpful to balance parking resources. With the development of high technologies, many advanced solutions were proposed by researchers, such as fusion-based, ultrasonic-based, and geomagnetic sensor for detecting and tracking vacant parking slot [1]–[3], intelligent video system for parking lot management [2], applications of RFID technology for entering and existing parking lots [4], global positioning system (GPS) for self-localization and Web-based/ZigBee-based smart parking guidance system [5]. The burden of parking has been alleviated to some extent by using the existing technologies or solutions mentioned above. By analyzing these methods, we conclude that a modern smart parking solution should satisfy several characteristics, i.e., automatic, real-time, accurate, efficient and economic. Furthermore, it should take two aspects of functions into account. For drivers, it has to be convenient to find an available parking space quickly; while for the management, it could assist in managing and planning of parking lots. However, most of the existing schemes cannot satisfy all of the above requirements. This means a further study is indispensible to find a novel and multidisciplinary approach to solve the parking problem.

In 2004, with the deeper research of the complex system, the parallel system methods [6] were proposed to solve the management and control of complex systems. As described in [6], the parallel system refers to a common system that consists of a natural actual system and its corresponding one or multiple virtual or ideal artificial systems. According to the parallel system theory framework, the ACP theory is concluded to deal with the complex system problem. Due to the development of technologies, i.e., internet of things, big data and cloud computing, the ACP theory has been widely applied in many areas [7]–[9], such as, metropolitan transportation, logistics, ecosystems, emergency evacuation systems, enterprise production and management, etc. Especially, a successful application of the ACP theory in the intelligent transportation systems (ITS) [10]–[12], parallel transportation management systems (PtMS) [13], shows a new perspective in solving the parking issue.

In this paper, we propose a novel concept of parallel parking system, which is based on the ACP theory. Similar

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to the traditional traffic system, it is clear that the parking system is a typical complex system, which involves a variety of disciplines. Furthermore, the decision-making and parking result is easy to be influenced by travel time, drivers, traffic situation, location and other complex factors. Combing with the existing technologies and parallel parking methods, the parking problem will be solved in the level of Cyber-Physical-Social Systems (CPSS) [14].

The rest of this paper is organized as follows. In section II, we introduce the basic concepts and content of the parallel system method. In Section III, by introducing the background and reviewing the existing solutions of parking problem, we propose an intelligent solution, i.e., the parallel parking system. In section IV, three applications are given to illustrate the concrete implementation of parking system. Concluding remarks are provided in section V.

II. Parallel Control and Management

The architecture of parallel system is illustrated in Fig. 1, which mainly includes the actual system and the artificial system. The interactions between these two systems help to accomplish management and control of actual system, experimentation and evaluation of behaviours and decision, learning and training of operators and administrations. The purpose of parallel system is to connect actual system and its artificial counterparts in various modes for different purposes. By comparing and analyzing actual and artificial behaviours, the future actions could be predicted, and the control and management strategies could be planned and modified.

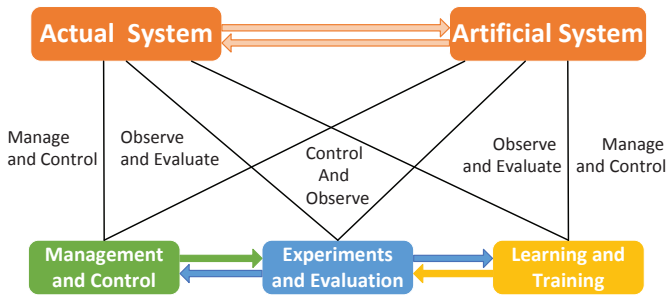

Fig. 1. The framework of parallel systems

Based on the ACP theory, the parallel system is the combination of artificial societies, computational experiments and parallel execution.

Artificial Societies: The characteristics of artificial systems have offered many advantages for modeling complex systems. For example, firstly, artificial systems emphasize the importance of interactivity, interrelationship and integration among complex systems; secondly, by using artificial systems in real, simulated or mixed environments, this approach can generate complex interactions and behavior patterns [15], [16]. With these characteristics, especially the second one, artificial systems can adapt complex features of actual systems, thus support various controllable and precise computational experiments, so as to quantitatively analyze and evaluate different behaviors as well as different influence factors.

Computational Experiments: The basic idea of computational experiments is to create artificial objects and to proactively generate diverse behaviors of experimental systems in a bottom-up fashion via interactions of artificial objects. Meanwhile, the influence of various factors on these behaviors must be taken into consideration of analyzing overall system behaviors. Besides, various concepts and methods of the experimental analysis and detection can be directly used to solve the corresponding problems in computational experiments. Furthermore, fast, parallel and economic experiments will help those methods to be more large-scale, accurate and comprehensive.

Parallel Execution: The key concept of parallel execution is to explore the potential of artificial systems from offline to online, from static to dynamic and from passive to proactive, so as to make artificial systems play equivalent roles as actual systems. Various parallel systems are decided by the practical requests and the development progress of artificial systems. Generally, there are no optimal solutions for complex systems. Parallel execution provides an effective mechanism to implement various solutions, as well as evaluate, validate, and improve their performance.

III. Parallel Parking System

A. Current Parking Status

Over the last two decades, the quantity of vehicles is increasing sharply in China. In February 26, 2015, China's National Bureau of Statistics released the "Statistical Communique of the People's Republic of China on the 2014 National Economic and Social Development" [17]. It announced that, by the end of 2014, the ownership of private vehicles has been 125.84 million, which increased 15.5 % over last year. On one hand, the rapid growth of the number of vehicles represents improved peoples' living standard. On the other hand, this phenomenon also leads to some traffic problems. For example, it is too difficult to find an available parking space in a congested area or a large parking lot. Thus, drivers commonly have to keep cruising to find a vacant parking space. Firstly, it weakens the efficiency of the urban traffic, which is an important part of the citizens' daily life. Secondly, it causes a waste of energy and leads to the corresponding serious air pollution, whose effect is irreversible for the environment. Thirdly, as parking process is time-consuming, drivers prefer to take risk of parking on the roadside illegally; thus, traffic congestion will turn to more serious, and "parking wars" would occur more frequently. Even worse, additional traffic accidents are tightly related to the parking difficulties. Consequently, it is urgent to propose a novel parking system in order to achieve high efficiency and safety for parking management and guidance.

As mentioned above, there are three critical aspects in the parking dilemma. One is, from the point of view of the existing parking infrastructure, the shortage of existed parking lots. The second one is that the parking lots management is relatively inefficient for the parking situation. In addition, the last but not least one is that although there exist amount of information and intelligent technologies to solve the parking dilemma, an global and continuous solution is still nonexistent due to the complexity of the actual parking system.

B. Parking Schemes

With respect to the aforementioned three aspects in parking dilemma, potential parking solutions for the parking difficulties can be classified into three categories, which are infrastructure construction, management, and technology. To increase the infrastructure construction, we can build up the ground/underground parking lots, or three-dimensional garage to increase the number of urban parking lots. However, in a short time, building a large number of parking lots needs huge investment. What's more, it is essential to dig out the potential of the existing parking resources by adopting effective management. Firstly, more reasonable construction plan to acquire more parking lots in a certain area. Secondly, in view of all the existing parking lots, the effective price leverage to adjust the parking distribution can be used. The parking fee is collected according to the elements such as parking time, parking period, parking location and so on. Thirdly, making relevant policies and regulations is important to ensure the legalization of management.

However, these existing solutions cannot solve the parking dilemma perfectly. For example, it is still hard to find a parking space in a specific time period or a particular area, such as hospital, conference center, and stadium. Especially, when a driver is not familiar with the environment of the district, this problem may be more serious.

Recently, with the development of technology, the smart parking schemes have attracted the attentions of researchers, and it has been regarded as an important potential option for alleviating parking dilemma. Now, many kinds of smart parking systems have been proposed or applied in actual parking system, such as the parking guidance system based Web, Wi-Fi, RFID technology or ZigBee and geomagnetic sensor technology. By these technologies, the efficiency of the parking management is improved and the parking process is more convenient for drivers. However, from the literature review, the traditional smart parking systems are designed based on simulation results and get the optimized methods by offline analysis. Moreover, the rolling optimization process is lacked between the actual and simulation system. That is why this method is limited for its application. In other words, the purpose of these smart parking system is trying to simulate and follow the actual system. At the same time, all of these smart systems can only solve parts of parking systems' problems. Therefore, a more perfect system is urgently needed to analyze and solve the parking problems integrally.

C. Parallel Parking System

As illustrated in the section II, the parallel theory is specially proposed for the management and control of complex system, which has been successfully applied in urban traffic management and control, i.e., the PtMS. It is well known that the ITS is helpful for current traffic situation, but improvements are needed for the increasing transportation needs. This prompts PtMS, which jointly considered the ITS and the ACP theory.

1) System Framework: A new direction to solve the parking problems is extending the ACP theory into parking systems, i.e., parallel parking system. This system is expected to be more dynamic, real-time, systematic, effective, as well as economic and practical [18], [19]. Firstly, it is obvious that parking system is a sub-complex system of the transportation field. Secondly, it obeys the two basic assumptions, and makes the parallel system methods be possible to be applied.

In the proposed parallel parking system, there is an actual parking system and an artificial parking system. These two systems are connected by advanced computational methods. The actual system transmits the information to the artificial system, and experiment and analysis are then used for the action of the complex actual system under the help of artificial system. By the interactions between the actual and artificial system, the parking resources will be better planed, the management is regular and the guidance of parking will be more intelligent. In other words, the efficiency of parking system would be significantly improved.

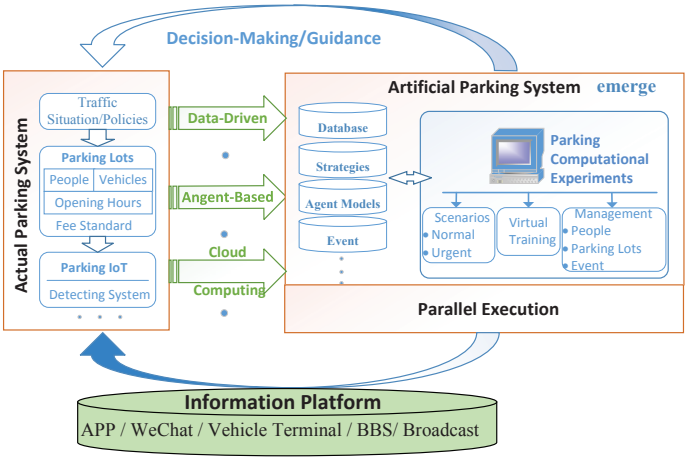

Fig. 2. The framework of parallel parking system

The main processes of parallel parking system are illustrated in Fig.2. The first step is to build the parking artificial system based on cloud computing, parallel computing and data-driven techniques. Then, based on the agent technology [20], we can build agent models for vehicles and drivers. Its behavior characteristics are strongly random, and its individuals are numerous. At the same time, other models, such as the road models, parking field models, equipment models, event models and so on, are also built in the artificial parking system. Corresponding to the general modelling and simulation process, the purpose of the modelling of parallel artificial system is not trying to identically simulate the actual system. By the exquisite learning of the actual system from micro perspective, we can build the models, and then emerge the macroscopic phenomena. Through the interactions between actual parking system and artificial parking system, we could constantly develop and optimize artificial parking system. Finally, the artificial system and the actual system tend to be "equivalent".

2) Actual Parking System: In the actual parking system, various sensors could be used in parking spaces with the development of internet of things. These sensors could be the underground sensing coil, geomagnetic sensor [21], [22], sensor fusion-based, ultrasonic detector, infrared detector, and so on. Besides the information of the hardware facility, the traffic situation, the related policy and regulations, and other

facts, could also be the input of parallel parking system.

3) Computational Experiments: Another part of parallel parking system is to analyze the behavior of the parking system and assess the possible results by utilizing computational experiments. Specifically, in the artificial parking system, online and/or offline computing are implemented. Another key task is to make sure whether the system could get the actual effect by assessing and validating various issues under different environments and different indicators. These indicators include the construction of parking lots, the management and utilization of parking spaces, the management of the staff, and the scenario of emergency or temporary parking. Meantime, by jointly considering the computational experiments with artificial systems, it could help to optimize and update the existing scenarios. It means that when a new problem occurs, the proposed parallel parking system could provide a suitable solution by the experiments in the artificial system. Therefore, it could not only improve the ability to solve burst problems, but also be an anti-risk function. In addition, the virtual training for the manager and maintainer of parking lots can also been done in artificial system, which can improve learning efficiency and operational reliability.

4) Parallel Execution: The most important part of the proposed parallel parking system is parallel execution between the actual parking system and the artificial parking system. By the interactions between the actual system and artificial system, the decision-making information could be transmitted to the actual system to realize the intelligent control, management and operation of the parking system. On one hand, various results of computational experiments would guide the actual parking system to achieve the global optimization. On the other hand, the actual parking system data can be taken as the feedback to the artificial parking system for its amendment and adjustment, in order to further improve the current operating status of the actual and artificial parking systems.

Overall, the parking parallel system will utilize all possible resources and superiority of the ACP theory to solve the parking troubles. There are normally more than one artificial parking systems used in parallel parking control and management. Different artificial parking systems can be created, respectively, for the purposes of historical parking situations, normal and average performance, optimal and ideal operations, or worst-case scenarios for emergency management. Through the interactions and parallel operations between an actual parking system and its corresponding multiple artificial parking systems, the effectiveness of different parking strategies under various conditions and expectations can be evaluated and analyzed, both offline and online, and useful information can be obtained timely and combined to generate and select decisions for control and management.

IV. Application of Parallel Parking System

A. Resource Management and Control System

The resource management and control system could optimize the entire district or city parking resource management and control, and obtain more efficient parking resource utilization.

In the research work of the complex parking system, both of the engineering complexity and social complexity should be taken into consideration. As illustrated in Fig. 3, all the parking lots including public lots, private lots and commerce parking lots are considered. But almost all of parking resources are working separately like information islands. The integration of parking resources is a mass engineering. Besides, by analyzing and predicting road information, vehicle information [23]–[25], drivers behaviour and other social facts, the proposed system could provide an optimized global resource manage and control scheme.

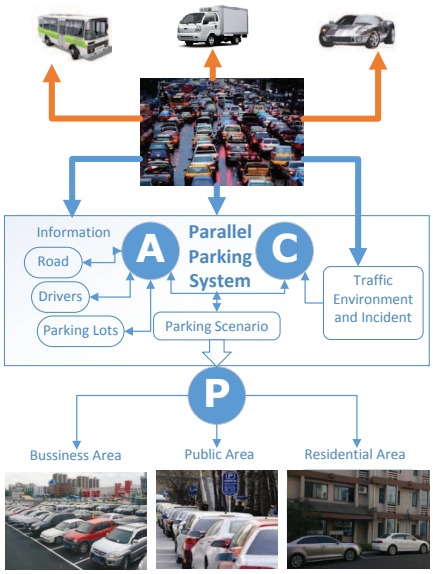

Fig. 3. The parking resource management and control system

For example, the parking lot of commercial office building is available in workdays, because most people are not willing to work overtime. However, since people prefer entertainment on weekends, the market parking resource may be in short supply. Thus we find a common phenomenon: a driver could not find a parking space in the market; however, the parking resource is abundant in somewhere not far from the market.

The parallel parking system could help to solve these problems. It would collect and analyze these historical information, and then provide valuable suggestions to the managers. For this example, the market will take on the role of manager and sharer of parking resources, and give reasonable suggestions to the drivers about where is the available parking lot near the market, and they can get the authority from the market to park their vehicles there. With the guidance of the parallel parking system, not only the local shortage of parking resources could be improved, but also the resources' utilization could be increased.

B. Parking Guidance and Information System

Considering the parking resource and the driving behaviour, the parking guidance and information system could guide the driver to a suitable parking space.

The parking resource is always changing as the vehicles are in and out. This is a typical trait of a complex system. By analyzing these collected information, the artificial system will provide several alternative parking spaces from the available

resource. Though the system could message the driver a most suitable parking space, the driver may not follow the advice because parking is an apparently random human behaviour. Therefore, the parallel parking system is needed to be able to analyze the driver's behaviour, such as driver's parking space preference, driving skills, and so on. Combining the behaviour information and the alternative parking space information (Such as the parking space is close to entrance or exit, the parking space is in the middle or at the corner of the parking lot.), the system can provide parking spaces information and corresponding route planning to the driver, and guide the vehicle to the most suitable parking space [19].

V. Concluding Remarks

Parking system is one of the most important component of ITS, and its performance has a great effect on the entire transportation system. As traditional parking technologies and methods cannot satisfy the modern parking requirements, we proposed the parallel parking system to improve the current situation and solve the difficulties of parking systems in this paper.

With the help of current technologies and the ACP theory, we proposed the framework and the construction method for parallel parking system, detailed the parallel resource management and control system, and the parallel parking guidance and information system. The parallel parking system could effectively optimize the parking system operations via the interactions between actual and artificial parking systems. By the computational experiments and analysis of the artificial parking system, a control strategy to parking problems can be continuously updated and tracked on a real-time basis; meanwhile, the collected operating status of the actual parking system can also be used to optimize the model of the artificial parking system. Therefore, the parallel parking system could solve the current parking problems more efficiently, and it plays an important role to alleviate the pressure of urban parking.

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