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Dynamic control of intelligent parking guidance using neural network predictive control

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ABSTRACT

The parking problem is a very important issue in city life because many citizens waste a large amount of energy and time trying to find suitable parking lots. To resolve this problem, various intelligent parking guidance systems have been introduced. However, the method of operating an intelligent parking guidance system remains in the infant stage. For successful operation, it is important to develop an effective method that assesses and selects the best parking lot in a real-time environment. In this vein, this study proposes a neural network-based predictive control approach that finds suitable weights for multiple factors dynamically so that the best performance of the intelligent parking guidance system can be achieved. The proposed method can enhance the performance of an intelligent parking guidance system via dynamic control in selecting the best parking lot. To evaluate the proposed approach, simulation tests and comparison with a traditional model have been conducted. As a result, the proposed approach provides a robust solution in an efficient manner under diverse parking environments. With the proposed approach, from the public interest viewpoint, the car parking problem can be approached more effectively.

1. Introduction

Recently, the number of cars in big cities has explosively increased as urban life becomes increasingly more complex and fast-paced. The increased number of cars gives rise to high traffic congestion in many cities, leading to several side effects such as environmental problems, the greenhouse effect, air and noise pollution, and parking problems. Among them, the parking problem has become one of the most urgent issues in city life because many citizens waste large amounts of energy and time trying to find suitable parking lots. To resolve this problem, many cities have tried to increase parking spaces by building new parking facilities, e.g., rotary parking systems (Hwang & Lee, 1998). However, the supplement of parking spaces cannot be a fundamental solution because it cannot meet the growing demand, and the spatial resources of a city are also limited and expensive. Thus, it is necessary to examine alternative ways to solve the parking problem.

As one alternative, many cities have adopted intelligent parking guidance based on emerging information and communication technologies (ICTs). The aim of intelligent parking guidance is to solve the parking problem by efficiently managing available parking resources. The most common system for parking guidance involves variable message signs (VMSs), which can provide drivers with the vacant number of parking spaces near their current location and some rough directions via texts on the road-side board. However, owing to the text message type of VMS, the information is limited and passive, and as a result, the benefit of parking management using VMS is somewhat limited (Teodorović & Lučić, 2006).

To overcome the drawbacks of VMS, an enhanced parking management system, called an *intelligent parking guidance system*, is attracting attention, and is gradually substituting conventional VMS. One of the key features of the intelligent parking guidance system compared to conventional VMS is that it generates personalized parking guidance information based on real-time data to assist a driver's decision on parking selection. To achieve this, the intelligent parking guidance system includes sensor networks and telecommunication systems that make it possible to monitor parking lots remotely in real time, collect the parking data, generate personalized parking guidance information for each driver, and provide each driver with detailed directions via a graphical user interface. To date, the infrastructure to realize intelligent parking guidance systems has been developed by various companies,

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and some commercial products are already on the market. However, a proper methodology to operate the intelligent parking guidance system using newly collected data is still in the infant stage.

The operation of the intelligent parking guidance system requires complex procedures for various issues such as handling real-time parking data, transforming it into useful guidance information for drivers. A key issue is to find the best parking lot that can satisfy the driver, which can be selected by the proper assessment of available parking spaces. To evaluate each parking lot, this study applies a utility function which takes the form of a generalized cost function. The utility function is formulated as a weighted sum of multiple factors affecting parking selection. The weight on each factor indicates the relative importance among multiple factors such as the number of congested cars (cars seeking parking guidance), walking distance, and parking cost, for each parking lot. Based on comparison of the values of the utility function, it is possible to find the best lot to park in. Depending on the weights of multiple factors, the utility value will vary, which affects the best parking lot selection. Hence, it is very important to find a proper weight configuration for the multiple factors in the intelligent parking guidance system.

Considering the complex relationships among multiple factors in the utility function, their weights should be well-configured without any loss of overall performance of parking guidance. However, it is not an easy task to find an optimal weight configuration of multiple factors, as some factors are inter-correlated while others have negative correlations with each other. Furthermore, the dynamic parking environment where parking information (e.g., the number of available parking lots and cars requesting parking guidance, traffic congestion, and utilization rate of parking facilities) is frequently changed, so it is more difficult to find the proper weight configuration. Finding the optimal weight configuration should occur in real time because parking guidance should be provided without any delay to drivers on the road. Despite these difficulties, it is critical to find a proper weight configuration for the effective operation of the intelligent parking guidance system. In this vein, this study proposes a method that finds suitable weights for multiple factors dynamically to improve the performance of the intelligent parking guidance system. In the proposed method, the weight configuration is decided by a neural network-based predictive control approach, called NNPC. The NNPC makes it possible to predict the future performance of parking guidance by the modification of weight configurations so that the best weight configuration can be determined. According to the local parking environment, the weight configuration is controlled dynamically so that the best performance of the intelligent parking guidance system is maintained. In this study, to evaluate the proposed method, simulation tests and comparison with a traditional model have been conducted and results are discussed.

This study is organized as follows. In Section 2, relevant previous studies are discussed and contributions of the proposed approach are described based on comparison with previous work. Section 3 explains the system architecture and performance measures of the intelligent parking guidance system, its utility function for the assessment of parking lots, and weight configuration in detail. Section 4 introduces the proposed approach that efficiently assesses parking lots and selects the best one in a dynamic parking environment. The computational experiments and result analysis are described in Section 5. Finally, this study is concluded in Section 6.

2. Literature review

The parking guidance and information system (PGIS) has evolved along with the advance of ICTs. The use of advanced sensor networks makes it possible to manage parking lots in a more efficient manner. Some parking facilities located in hospitals, department stores, and airports are already using sensor network technologies to provide drivers with parking lot status, and guide the drivers to vacant parking spaces efficiently. Today, in-vehicle information communication systems can combine telecommunications, geographical information system (GIS), and global positioning systems (GPS) (Chou, Lin, & Li, 2008), so that information can be transmitted to cars through wireless and/or mobile technologies for better parking decisions.

To date, several research studies have begun to consider the parking management of a city as part of an intelligent transportation system (ITS). VMS has been actively studied as the most common type of parking guidance system for a city. To enhance the information quality of VMS, a better update frequency of parking information (Thompson, Takada, & Kobayakawa, 2001) and more precise prediction of the available number of parking spaces (Mei & Tian, 2011) have attracted increased attention. However, despite the usefulness of VMS, its effectiveness is limited owing to its form of text board. To cover the drawbacks of VMS, intelligent parking guidance systems (Chou et al., 2008; Geng & Cassandras, 2012; Giuffrè, Siniscalchi, & Tesoriere, 2012; Rodier & Shaheen, 2010; Shin & Jun, 2014; Teodorović & Lučić, 2006) have been introduced. Using the collected real-time parking resource data through sensor networks, intelligent parking guidance systems could provide personalized parking guidance and new functions (e.g., reservations), and adopt a detailed graphical navigation for the convenience of drivers, to assist in the overall management of parking resources in a city.

Although the technology necessary to realize an intelligent parking guidance system is fully matured, its operation is in the developing stage. In the operation of intelligent parking guidance systems, the key is parking lot assignment. To this end, until now several previous studies have focused on the behavior model of parking choice or parking lot assignment issues with agent-based or model-based simulations. As examples of agent-based approaches, Chou et al. (2008) proposed an intelligent agent system to suggest the optimal parking lot for the driver considering negotiable parking prices. They proposed an agent-based approach and applied e-commerce models to provide better matching of supply and demand for drivers and parking lot operators, namely the parking negotiation and guidance system (PNGS). The proposed system has two core functions: (1) parking lot allocation based on three criteria such as parking fees, the distance from the current location to the parking lot, and the parking lot's booking and reservation policies, and (2) route guidance to facilitate the search for available parking spaces, negotiation of parking fees, reservation of parking spaces, and the derivation of optimal paths. They used a decision hierarchy based on multi-attribute utility theory (MAUT) for representing the subjective multiple attribute preference of a driver. Dieussaert, Aerts, Steenberghen, Maerivoet, and Spitaels (2009) developed an agent-based model, called SUSTAPARK, in order to provide a spatio-temporal tool for modeling traffic generated by parking search behavior. In their model, the initial parking strategy for every agent is based on assessment time, search time, egress time, and expected parking fee. Recently, Napoli, Nocera, and Rossi (2014) addressed the parking space allocation problem based on a negotiation mechanism which creates an agreement between parking providers and parking requestors. In their model, they considered user requirements on a parking space in terms of its location and parking cost, and the vendor requirements in terms of parking space availability and distance of a parking lot from a city center. They mentioned that the parking guide information system could provide users with the city map, city regulations, and estimated time to the destination via the Google map API.

Furthermore, there have been some model-based approaches proposed to resolve parking search issues. Dell'Orco, Ottomanelli, and Sassanelli (2003) classified parking search models into two groups: Network-based models and discrete-choice models. The network-based models attempt to implicitly simulate parking selection where the parking selection is modeled as part of a traffic assignment model. Hence, the usual graphical representation of road networks (Bifulco, 1993; Cascetta, 2001) is generally used for network-based models. However, in real-world applications, network-based models require high processing overhead to model all roads in a city and simulate them