A Method for Navigating Cars in Multilevel Parking Facility

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1. Introduction

In this paper, we propose a method for reducing congestion at large parking facilities using car navigation systems with inter-vehicle and infrastructure-to-vehicle communication. In Japan, due to high land prices, most store buildings have large multi-level parking facilities with multiple parking zones. These parking zones are not equally favored by customers due to differences in distances from the entrance of the parking facility or to the entrances of the shopping areas. This leads to many cars concentrating at some parking zones while other zones are not occupied. It is not easy for a car driver entering a large parking facility to know which parking zones are vacant. It is fairly common that parking facilities have indicators that show occupancy information to the drivers. However, since these indicators deliver the same information to all drivers, this method tends to make a new congested zone by sending many drivers to that zone.

In this paper, we propose a system that provides each driver with a recommended route in the parking facility that minimizes the expected parking time. Our method estimates the occupancy of each zone from the information sensed by the cars that implement the proposed method. This information is collected to a server installed in the facility, and then the server disseminates the processed information to the cars. The cars then calculates the recommended route from this information. We conducted a simulation-based evaluation of the proposed method using a realistic model simulating a real parking facility in Nara. As a result, we confirmed that the proposed method reduced parking waiting time by 20%–70% even with low penetration ratio.

Keywords: parking route, crowded parking, multilevel parking facility

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Abstract: In this paper, we focus on multilevel parking facilities and propose a navigation system that minimizes the time required for cars to find vacant parking spaces. Parking zones at large parking facilities provide drivers conditions to drivers due to differences in distances from the entrance of the parking facility or to the entrances of the shopping areas. This leads to many cars concentrating at some parking zones while other zones are not occupied. It is not easy for a car drivers entering a large parking facility to know which parking zones are vacant. It is fairly common that parking facilities have indicators that show occupancy information to the drivers. However, since these indicators deliver the same information to all drivers, this method tends to make a new congested zone by sending many drivers to that zone.

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Fig. 1 Typical congestion in a parking facility.

Fig. 2 Operations of parking management server.

Fig. 3 Overview of proposed method.

Fig. 4 Flap lock type parking.

cility. In the simulation, we used the structure information and trace data taken from a real parking facility located in Nara. We compared our method with a few other methods and we confirmed that our method reduced the waiting time by 20% on average and 70% at maximum. Especially, the proposed method showed good performance in case of low penetration rate.

2. Related Work

In this section, we introduce several related methods.

2.1 Collecting Occupancy Information [2], [3]

Sensor Flap Parking System is a parking facility in which an occupancy sensor is installed in each parking space (Shown in Fig. 4). A flap plate for settling a car is raised when a car is parked in the space. This method has an advantage in its ability to exactly sense a parked car. However, due to high installation cost and maintenance, this method is difficult to install and operate in large facilities.

Billboard Advertising is to show the current occupancy status of each parking zone to the drivers (Shown in Fig. 5). The number of cars passing through sensing gates is counted. The congestion status of each zone is calculated from these numbers. This method is utilized in most parking facilities because of the cost advantage. However, the system tends to make all drivers go to the same parking zone, resulting in making this zone congested.

2.2 Parking Route Guidance [5], [12], [14], [15]

Chirungrueng et al. proposed a parking route guidance
method that collects parking status information in real-time through wireless sensor networks, and informs drivers of a different parking space [4]. Tan et al. proposed a method which provides a parking guidance service using low cost sensors [6]. In this method, nodes are installed at each parking space and pathway for monitoring. Maintaining these nodes tends to be troublesome, and this disadvantage cancels out the benefits of using low-cost sensors.

Lu et al. proposed a smart parking scheme for a large parking facility (SPARK) that utilizes vehicular communication [7]. With this method, a central server collects the parking space status information using sensors, and locates the position of cars using infrastructure-to-vehicle (I2V) communication. Based on the collected information, the server issues each car with an electronic ticket that assigns a specific parking space to the car. Cars are only allowed to park at spaces that are specified on the ticket. However, there are two problems: (1) In a crowded parking facility, it is difficult to get to the specified parking space, and (2) There is no guarantee that the drivers park at the specified parking space, and the system will fail if the drivers do not comply with it. The concept is shown in Fig. 6.

2.3 Localization of Vehicle Position

Since GPS cannot be used inside buildings, we need an alternative positioning method in order to locate vehicle positions in a multilevel parking facility. Many indoor localization methods have been proposed recently. Some of these are range-based positioning methods based on Received Signal Strength Indication (RSSI) [16], [17], [18], using WiFi, 3G Cellular, etc. Common to these methods is their being based on trilateration or namely, the system estimates the distance between a target object and at least three anchors, according to the RSSIs sent from anchors. The system then estimates the position of the target object by using the distance information and the anchor positions. The typical estimation error is about 5–10 meters. The concept is shown in Fig. 7.

3. Proposed Navigation System

In this section, we first describe the assumptions in this paper, and then present the algorithms for the proposed system.

3.1 Assumption

A parking zone consists of multiple parking spaces and paths (as shown Fig. 8). The sets of all intersections (in-1) and parking zones (pz-1, pz-2, ...) are denoted by IN and PZ, respectively. The sets of all entrances to the parking facility (g-1, g-2, ...) and all entrances to the store (ce-1, ce-2) are denoted by G and CE, respectively. The entire facility is represented by a graph \((V, E)\) where \(V = G \cup IN \cup PZ \cup CE\). E is the set of all paths in the facility. A parking space is the minimum unit of space that is needed for a car to park. The numbers of parking spaces in each zone are also given.

We assume that the parking facility provides WiFi access to the cars. A WiFi access point is installed at each parking zone. We also assume that the facility has a central server that gathers and broadcasts occupancy information of the facility to the cars via the WiFi network.

The users of the proposed method are customers by car. We do not assume 100% penetration rate of the proposed method. Some of the cars have on-board devices that can execute the proposed method and show information to the driver. This could be a car navigation system or a smart phone. These on-board devices can access the network via WiFi. An on-board device has a function to estimate the zone it is positioned at by utilizing an existing indoor positioning method.
3.2 Overview

The proposed method consists of the server component and the vehicle component. The server component is executed on the central server. Based on the information sent from the on-board devices on the cars, the server estimates and announces the parking occupancy information periodically. The vehicle component receives the announcement and finds the route that has the shortest expected parking waiting time.

A car equipped with the proposed system moves to the next parking zone in the route if it cannot park in some parking zone in the route. If the car cannot park at any zones in the route, the car will automatically calculate a new parking route.

3.3 Server Component

If there is no parking occupancy information available from any external systems, the parking server obtains the occupancy information in the way described below.

The input of the server component is the number of cars that have passed through or parked at each zone over the preceding 30 minutes. It calculates the probability for the next car entering each zone to find a vacant space in the zone. Since we do not assume 100% penetration rate, the server cannot know the exact occupancy of the zones or behavior of all cars. If the central server detects that a car passing through at a certain time, the server assumes that there is no vacant parking space in that zone. For example, if two cars with the proposed method have passed through a certain zone and six cars have parked in the same zone over the last 30 minutes, the probability for the next car to find a vacant space in that zone is estimated to be 75%. If no car has visited a certain zone in the last 30 minutes, the server assumes that the probability is 50%. After the server calculates the parking information, it broadcasts the probabilities to each zone. The detailed algorithm for the server component is shown in Algorithm 1.

3.4 Vehicle Component

When a car enters the parking facility, it finds its position by an existing positioning method based on the RSSIs from WiFi anchors [19]. It then communicates with the central server and finds the parking route. Cars periodically send its position and status (running, parked or leaving a parking space) to the server and receive the parking occupancy information. Once a car needs a recommended parking route (when entering the parking facility, or the car reaches the end of the previously found parking route), it calculates a parking route by which the parking waiting time can be minimized. This process is shown in Algorithm 2.

In order to find the parking route, the expected time until the vehicle can park is calculated for all possible routes. Finding the expected time for all possible routes in the strict sense requires a large amount of computation, and thus we only calculate the routes up to a certain length, and we treat these values as approximations for longer routes. In this paper, we set this length to 4.

In the proposed method, basically the best route is shown to the driver. However, if we show the same best route to all users, the all users will follow the same route, and this route will get congested. To avoid this, we select the best three routes and present one of them at random. Congestion relief can be expected by increasing route candidates up to the number of backbone roads. In a certain size parking facility, 3 route candidates are considered enough to balance car flow.

The length of the route shown to the user is 4, and if the car cannot park until it reaches the end of this route, the system finds a new route according to the latest situation and shows it to the driver.

\[
\text{Exp}(rpr) = \sum_{i \in \text{route}} (P_{zi}(T_{z1} + T_{z2}) \prod_{i=1}^{4} (1 - P_{zi}))
\]  (1)

The expected parking time for route rpr is denoted by Exp(rpr) which can be calculated by Eq. (1). P_{zi}, T_{z1}, and
 denote the parking probability in parking zone \( i \), the moving time in zone \( i \) and the time to reach zone \( i \) from the previous place, respectively. In Eq. (1), \( \text{term}_1 \) shows the expected time to reach and park in zone \( i \), and \( \text{term}_2 \) shows the probability to reach zone \( i \). Figure 9 is an example for calculating the expected parking time.

**Example:** In Fig. 9, the \( \text{Exp}(rpr) \) for route \( rpr \) that includes zones \( pz1, pz2 \) and \( pz3 \) is calculated as below.

\[
\begin{align*}
\text{Exp}(rpr) &= 0.5 \cdot (2 + 1) + (1 - 0.5)(0.3 \cdot (7 + 1)) \\
&+ (1 - 0.5)(1 - 0.3)(0.2 \cdot (12 + 1)) = 3.61
\end{align*}
\]

## 4. Evaluation

In order to evaluate the proposed method, we conducted a simulation reproducing the structure of a large parking facility located in Nara, Japan. This structure is shown in Fig. 10. We also used traffic trace data collected in the facility. We measured the parking wait time in several contexts and analyzed the characteristics of the proposed and the compared methods.

### 4.1 Parking Simulator

Since we are trying to reproduce traffic in a parking facility, we needed to develop a new traffic simulator for the purpose. The simulator is based on a cellular automaton, and each cell corresponds to a 5 m \( \times \) 5 m space that represents a space that a car occupies. An example is shown in Fig. 11. Each path or parking space is represented by a cell. A vehicle can move to one of the 8 neighboring cells which are not occupied by another vehicle. All moving cars move to a neighboring cell every unit time (1 second), which corresponds to a speed of 5 m/s. The trace data consists of the number of the cars entering and leaving the facility each hour. These data do not include the numbers of cars for each gate, since the computer system in the shopping center only counts the number of issued and collected parking tickets.

We now explain the configurations in our simulation.

**Driver Behavior** Drivers are assumed to always park at the parking spaces when they find one available, regardless of the guides provided by the system. Each car randomly parks for 30, 60 or 90 minutes and departs.

**Structure of Parking Facility** The graph representing the structure of the parking facility used in the simulation is shown in Fig. 12 (a). \( ce, pz, in \) and \( g \) denote store entrances, parking zones, intersections and a parking facility entrances, respectively. This parking facility has 5 zones, and the properties of each zone are set based on the real trace data. The data includes zone capacity, walking time to the store and so on. We started the simulation with an vacant parking facility. If all spaces are filled, cars entering the facility are blocked at the entrances. Each zone is assigned a different popularity according to the time to walk from the zone to the store building. Table 1 shows capacity and walking time to the closest shop entrance from each parking area. We used the following 4 configurations of the map for the simulation.

- **Map1:** The original map (Fig. 12 (a)), capacity 818.
- **Map2:** Zone \( pz-3 \) closed (Fig. 12 (b)), capacity 697.
- **Map3:** Zone \( pz-5 \) and the store building entrance \( ce-1 \) closed (Fig. 12 (c)), capacity 418.
- **Map4:** Zones \( pz-3, pz-5 \) and the store building entrance \( ce-1 \) closed (Fig. 12 (d)), capacity 297.

**Penetration rate** We investigated the two cases shown below.

- **High (100%):** All cars search vacant space by following...
Table 1 Parameters for simulation.

<table>
<thead>
<tr>
<th>Parking zone</th>
<th>Parking capacity</th>
<th>Walking time (Sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pz-1</td>
<td>28</td>
<td>35</td>
</tr>
<tr>
<td>pz-2</td>
<td>100</td>
<td>20</td>
</tr>
<tr>
<td>pz-3</td>
<td>121</td>
<td>40</td>
</tr>
<tr>
<td>pz-4</td>
<td>169</td>
<td>25</td>
</tr>
<tr>
<td>pz-5</td>
<td>400</td>
<td>30</td>
</tr>
</tbody>
</table>

Table 2 Results of influence of penetration rate, full map (capa = 818, search length = 4).

<table>
<thead>
<tr>
<th>Method</th>
<th>Parking Time (s)</th>
<th>Ave. / Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equalized</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proposed [Penetration 100%]</td>
<td>79 / 216</td>
<td>100 / 549</td>
</tr>
<tr>
<td>Proposed [Penetration 10%]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All Cars</td>
<td>121 / 961</td>
<td>130 / 1193</td>
</tr>
<tr>
<td>Equipped Cars</td>
<td>96 / 219</td>
<td>109 / 575</td>
</tr>
<tr>
<td>Not Equipped Cars</td>
<td>124 / 961</td>
<td>132 / 1193</td>
</tr>
<tr>
<td>Random</td>
<td>121 / 1184</td>
<td>226 / 1792</td>
</tr>
<tr>
<td>Billboard Guided</td>
<td>109 / 997</td>
<td>161 / 1716</td>
</tr>
<tr>
<td>Greedy</td>
<td>244 / 3964</td>
<td>375 / 5834</td>
</tr>
</tbody>
</table>

4.2 Comparing Benchmark Methods

We compared our method and the methods explained below.

Random Parking: Each car randomly chooses a destination zone. If the car cannot park because the chosen zone is full, then the car will choose the next zone randomly.

Billboard-guided Parking: Cars select the most popular vacant zone shown on the billboard as the destination. If the car cannot park because the destination zone is full, then the car selects the next destination randomly.

Greedy Parking: In this case, 50% of cars randomly choose destination zones. The remaining 50% of cars select the highest popular zone as their destinations. If the destination zone is full, the driver continues to search for an empty space in the same zone for 4 times. If a vacant space still cannot be found, the driver goes to the 2nd best popular zone.

4.3 Results of the Simulation

We evaluated our method from three aspects. Each result is the average value of 5 trials.

4.3.1 Influence of Penetration Rate

We measured the time until cars can park when each of the compared methods is used with either the equalized or the imbalanced entrance setting is used. The results are shown in Table 2. The cumulative distribution function of the results are shown in Fig. 13 (a)–(b). We can see that the parking waiting time with the proposed method is shorter than the other methods. The average waiting time is shorter when the penetration rate is higher. In both cases of equalized and imbalanced entrance, the result of high penetration cases are better than the low penetration cases. The reason seems to be that the distribution of cars is balanced if the system penetration is high. When the penetration rate is 10%, the difference between the cars with and without the proposed method was significant, and the parking time was shortened by 23% (Equalized case) and 18% (Imbalanced case), respectively. Especially in the case of imbalance environment, average parking time was greatly shortened by the route navigation system even with low penetration rate. In this case, the average parking waiting time was significantly shortened by the small number of cars equipped with the proposed method. This is because the proposed method regulates the car flow in the parking facility.
4.3.2 Effects from Facility Topology

We compared 4 different configurations of the facility structure shown by Fig. 12 (a)–(d). The entering cars have been adjusted to suit the capacity of each map, respectively. The results are shown in Fig. 14 (a)–(b).

We can see that the parking waiting time increases as the capacity and the number of zones in the parking facility increases under the same car entering rate. This is because more congestion is seen in popular zones as the capacity of the facility increases, and this worsens the average waiting time. The proposed method can prevent this congestion by regulating the car flow, leading to shorter overall parking time. We noticed that the parking times of the Random and the Billboard methods decreased in the case of the highest parking capacity. To some extent, these methods could balance car flow if the parking facility is enough large.

4.3.3 Influence of Search Length

Here, we investigate the influence of the search length of the parking route that is performed in the vehicle part. We used the map having a capacity of 818 cars and 10% penetration rate in both entrance models. We varied the search length from 2 to 6, and the result is shown in Fig. 15. Notice the Imbalance entrance result, the parking waiting time is 160 s when the search length is 2, which is close to the Billboard-guided method in Table 2 (in Section 4.3.1). This is because that the method is similar to the Billboard method if the search length is too short. According to this result, we can say that the search length of 3 to 4 is reasonable.

5. Conclusion

In this paper, we propose a route navigation method for minimizing parking waiting time in a large parking facility. The advantage of our method is that the system performs well under low penetration rate. We evaluated the proposed route navigation system in a simulation-based study with structure data from an actual parking facility in Nara, and a trace data of traffic taken at the facility. As a result, we confirmed that the proposed system can significantly reduce parking waiting time under a low system penetration rate. As a future work, we are planning to implement the system and evaluate our method with real vehicles.
References


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tional privacy preservation protocol for secure vehicular communica-


Editor’s Recommendation

This paper proposes new method for navigating cars in mul-
tilevel parking facility for reducing parking waiting time. The proposed method is evaluated by simulation-based experiments using a realistic parking facility model with various parameters, and is confirmed to be very effective. Especially, the method per-
forms well even under low penetration rate.

(Chairman of SIGDSP Michiaki Katsumoto)

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