Parking Navigation for Alleviating Congestion in Multilevel Parking Facility

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***Abstract*—Finding a vacant parking space in a large crowded parking facility takes long time. In this paper, we propose a navigation method that minimizes the parking time based on collected real-time positional information of cars. In the proposed method, a central server in the parking facility collects the information and estimates the occupancy of each parking zone. Then, the server broadcasts the occupancy data to the cars in the parking facility. Each car then computes a parking route with the shortest expected parking waiting time and shows it to the driver. We conducted simulation-based evaluations of the proposed method using a realistic model based on trace data taken from a real parking facility. We confirmed that the proposed method reduced parking waiting time by 20%–70% even with low system penetration.**

***Keywords*-smart parking; navigation**

I. Introduction

In this paper, we focus on traffic congestion in a large parking facility next to a large store building and propose a method for resolving the congestion problem using car navigation systems with inter-vehicle and infrastructure-to-vehicle communication. In Japan, due to high land prices, most major store buildings have large multilevel parking facilities with multiple parking zones. These parking zones are not equally favored by customers due to difference of distances from the entrance of the parking facility or to entrances of the shopping area. This leads to the frequently observed phenomenon of a concentration of many cars in some parking zones and low use of other zones. It is not easy for a car driver entering a large parking facility to know which parking zones are vacant. Moreover, once a car is stuck in a congested area, it takes long time to get out of the area. Long waiting time for parking means opportunity losses for the store. Thus, resolving congestion is important for both customers and owners of the store. Some buildings have indicators to show vacant zones to the drivers. These indicators only show vacancy of the whole parking facility or whole level. Since the same information is delivered to the all drivers at a time, the drivers tend to make the same decision and try to go to the same parking area. This sometimes leads to a worse situation where a new congested area is made by the indicator and the problem is not solved.

In this paper, we propose a parking navigation method that minimizes overall waiting time and the time needed to drive until the driver finds a vacant parking space. We assume that many cars are entering and leaving zones and the number of vacant parking spaces in each zone changes continually. We formulate the problem to find the best route in parking facility taking into account the deployment cost, low penetration rate of the proposed method, and selfishness of the drivers. In the proposed method, we assume that a central server is installed in the parking facility, and it collects occupancy information from parking zones in realtime from car navigation systems via a wireless LAN. Then, the server composes the information on parking zone conditions and waiting time and broadcasts it to the cars. The navigation system then computes the route with the shortest waiting time for the car and shows the best route to the driver.

To evaluate the effectiveness of the proposed method, we conducted a simulation-based study of traffic in a parking facility. In the simulation, we used 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% in average and 50% to 70% at maximum.

II. Related Work

In this section, we introduce some related works.

A. Collecting Occupancy Information

Sensor Flap Parking System is a parking facility in which an occupancy sensor is installed in each parking space. 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, while deployment and maintenance cost tends to be high.

Billboard Advertising is to show the current occupancy status of each parking zone to the drivers. The number of cars passing through sensing gates are counted, and congestion status of each zone can be easily calculated from these numbers. This method is utilized in most parking facilities because of the cost advantage. However, the system gives the same information to all drivers and this leads to the situation where drivers make the same decision and go to the same parking zone, and that zone gets congested. This problem is reproduced and observed in our simulation.

B. Parking Route Navigation

Chinrungrueng et al. proposed a method based on wireless sensor networks[2]. The system collects parking status

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information in real-time through wireless sensor networks, and informs each driver of a different parking space. However, the deployment cost of wireless sensors is not low. With the same objective, Tang et al. proposed a method which provides a parking navigation service using low cost sensors[1]. Unfortunately, maintaining this system tends to be troublesome, and this disadvantage cancels out the benefits of the low deployment cost.

Lu et al. proposed a smart parking scheme for large parking facility (SPARK) that utilizes vehicular communication technology[6]. 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) communications. 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 not allowed to park at spaces that are not specified by the tickets. However, there are two critical problems: (1) In a crowded parking facility, it is difficult to get to the specified parking space, and (2) If drivers do not park at the specified parking space, the system will fail (which we call the *Selfish Driver Problem*).

C. Localization of Vehicle Position

Because GPS cannot be used inside buildings, we need an alternative positioning method in order to locate vehicle position 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) [7], [8], [9], using WiFi, 3G Cellular, etc. Common to these methods is their being based on trilateration: 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 anchors' positions. The typical estimation error is about 5-10 meters.

III. Proposed Method

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

A. Assumption

We assume that our method is used in a multilevel car parking facility. An example of the facility is shown in Fig.1. In this paper, a parking facility is represented by a graph, where the nodes are parking zones and links are paths between zones. A parking zone consists of multiple parking spaces and paths. 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. All entrances of the facility, crossroads, parking zones and building entrances are denoted by G, IN, PZ and CE, respectively. The entire facility is represented by a graph (V, E) where $V = G \bigcup IN \bigcup PZ \bigcup CE$ and E are the set of all paths in the facility. We assume that the parking facility provides WiFi access to the cars. Each parking zone has a WiFi AP installed. 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.

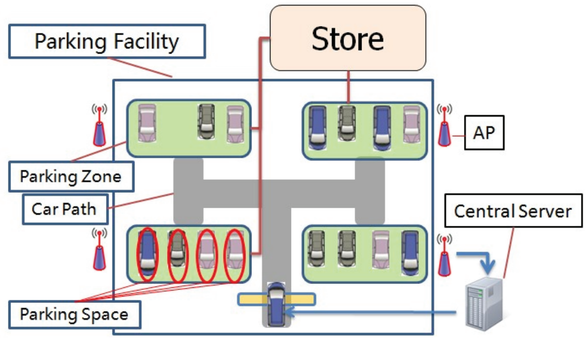

Figure 1. Example structure of parking facility

The users of the proposed method are customers visiting the facility and store by cars. We do not assume 100% penetration rate of the proposed method to the cars in the facility. 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. These on-board device has an ability to estimate the zone they are positioned at using an existing indoor positioning method.

B. Overview

The proposed method consists of the server part and the vehicle part. The server part is executed on the central server. Based on the information sent from the on-board device on the cars, the server estimates and announces the parking occupancy information periodically. The vehicle part receives the announcement and finds the route that has the minimum expected time until the car parks.

A car using the proposed system will move to the next specified parking zone if it could not park in a parking zone specified in the recommended parking route. Moreover, if the car could not parking in all specified zones in the route, the car will automatically calculate a new parking route.

C. Server Part

If there is no parking occupancy information available from any external systems, the parking server use following mechanism to obtain the occupancy information.

The input of the server part is the number of cars that have passed through or parked in 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. If the central server detects a car passes through a certain zone, the server assumes that there is no vacant parking space in that zone. Please note that the server cannot know the exact occupancy of the zones or behavior of all cars due to low penetration rate. For example, if 2 cars with the proposed method have passed through a certain zone and 6 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 the probability to be 50%. After the server calculates the parking information, it broadcasts the probabilities for each zone with 10 seconds interval. The algorithm for the server part is shown as algorithm 1.

Algorithm 1 Server algorithm

```
Server.thread 1{
while true do
    Receive information from cars
    Store the information to the memory
end while
}
Server.thread 2{
while true do
    Calculate parking info. over last 30 min
    Broadcast parking info.
    WAIT(10 seconds)
end while
}
```

Algorithm 2 Vehicle algorithm

```
Vehicle.thread 1{
while true do
    Estimate current position
    Send current position and status to server
    WAIT(10 seconds)
end while
}
Vehicle.thread 2{
while true do
    Wait until parking route is needed
    Receive parking info. from server
    Calculate parking route (length = k)
    Randomly select 1 parking route from top 3
    Show parking route to driver
end while
}
```

D. Vehicle Part

When a car enters the parking facility, it finds its position by an existing positioning method based on the RSSIs from WiFi anchors[9]. It then communicate 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 reached 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 the all possible routes in the strict sense requires a large amount of calculation, and thus we only calculate the routes up to a certain length, and we treat these values as approximation 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 the all users, the all users follow the same route, and this route could get congested. To avoid this, we select the best three routes and present one of them at random. The route shown to the user has length of 4, and if the car cannot park until it reaches the end of this route, then the navigation system finds a new route according to the latest situation and show it to the driver.

$$Exp(rpr) = \sum_{i \in rpr} (\underbrace{Ppz_i(TPe_i + TZpz_i)}_{term_1}) \underbrace{\prod_{k=1}^{i-1} (1 - Ppz_k))}_{term_2} \quad (1)$$

The expected parking time for route rpr is denoted by $Exp(rpr)$ which can be calculated by formula (1). Ppz_i, $TZpz_i$, and TPe_i 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 formula (1), $term_1$ shows the expected time to reach and park in zone i, and $term_2$ shows the probability to reach zone i.

Example: in Fig. 2, the $Exp(rpr)$ of route rpr including zones $pz1, pz2, pz3$ can be calculated as following:

$$Exp(rpr) = 0.5 \cdot (2+1) + (1-0.5)(0.3 \cdot (7+1)) \\ +(1-0.5)(1-0.3)(0.2 \cdot (12+1)) = 3.61$$

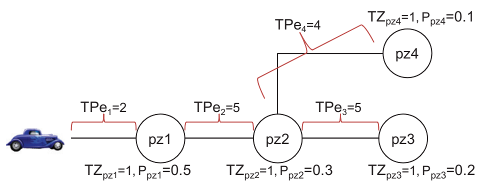

Figure 2. An Example of Parking Route

IV. Evaluation

To evaluate the proposed method, we conducted simulation reproducing the real structure of a large parking facility located at Nara, Japan. This structure is shown in Fig. 3. We also used traffic trace data collected in the facility. We measured parking waiting time in several contexts and analyzed the characteristics of the proposed and the compared methods.

A. Parking Simulator

Since we are trying to reproduce traffic in a parking facility, we needed to develop a new traffic simulator for that purpose. The simulator is based on a cellular automaton, and each cell corresponds to a 5m $\times$ 5m space that represents a space that a car occupies. All paths and parking spaces are represented by cells. A vehicle can move to one of neighboring 8-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 5m/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.

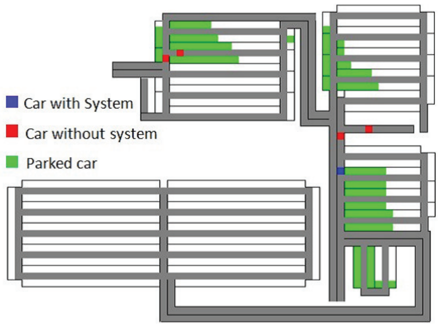

Figure 3. Screen shot of parking simulator

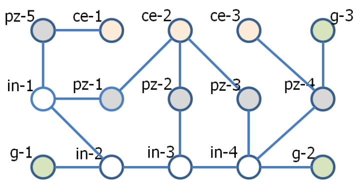

Figure 4. Graph representing simulated facility

B. Compared Methods

We compared our method with methods explained below.
Random Parking : Cars randomly select a target zone. If the car cannot park because the target zone is full, then the car will select the next target randomly.
Billboard Advertising Parking : Cars select the most popular vacant zone shown on the billboard as a target zone. If the car cannot park because the target zone is full, then the car selects the next target randomly.
Greedy Parking : 50% of cars select the highest popular zone as the target. Even if the target zone is full, the driver does not give up immediately. If a vacant space cannot be found after searching 5 zones, the driver selects the 2nd best popular zone as the next target.

C. Configuration of Simulation

We now explain the configurations in our simulation.
Driver Behavior Drivers are assumed to always park in the parking spaces that they find first, regardless of the guides provided by the navigation system. The parking time for each car is randomly set to 30, 60, or 90 minutes.
Structure of Parking Facility The graph representing the structure of the parking facility used in the experiments is shown in Fig. 4. ce, pz, in and g denote a store entrance, building, a parking zone, an intersection and a parking facility gate, respectively. The 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 walk time from the zone to the store building.

Method	Ave. Time(s)	Max. Time(s)
Penetration 100%	79	216
Penetration 10%(Equipped Car)	96	219
Penetration 10%(Not Equipped Car))	124	961
Random	121	1184
Billboard	109	997
Greedy	244	3964

Table I
RESULTS OF EXPERIMENT 1(EQUALIZED)

Method	Ave. Time(s)	Max. Time(s)
Penetration 100%	100	549
Penetration 10%(Equipped Car)	109	575
Penetration 10%(Not Equipped Car))	132	1193
Random	226	1792
Billboard	161	1716
Greedy	375	5834

Table II
RESULTS OF EXPERIMENT 1(IMBALANCE)

Penetration rate We investigated 2 cases shown below.

- *High(100%):* All cars search vacant space by following the recommended route by the proposed method.
- *Low(10%):* The cars equipped with the proposed method behave same as above. The rest use the billboard advertising parking method.

Proportions of cars entering each gate Two cases are investigated in the experiments.

- *Equalized:* Each of the gates is used by $1/3$ of cars.
- *Imbalanced:* 50% of cars use gate $g-3$. Each of other gates is used by 25% of cars.

D. Results of Simulation

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

1) Influence of Penetration Rate: We measured the parking waiting time by all methods in two different settings including equalized and imbalanced entrance. The results are shown in Table I and II. The cumulative distribution function of the results are shown in Fig.5 and 6. We can see that the parking waiting time with the proposed method is shorter than other methods. The average waiting time is shorter when the penetration rate is higher. In the both cases of equalized and imbalanced entrance, the result of high penetration case is better than the low penetration case. Especially, in the imbalanced case, the average parking waiting time is 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.

2) Influence of Topology of Facility: We compared 4 different configurations of the facility structure by changing

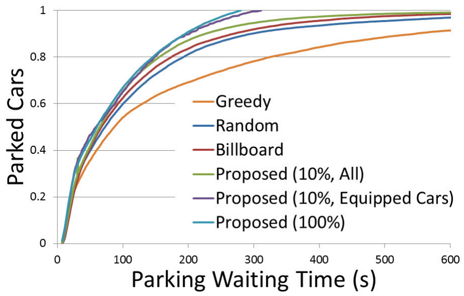

Figure 5. Influence of Penetration (Equalized)

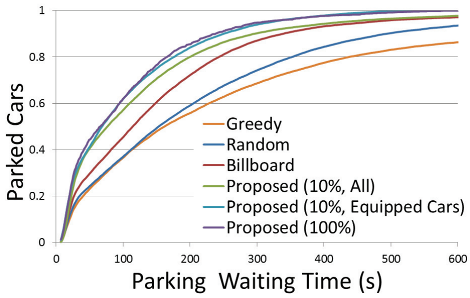

Figure 6. Influence of Penetration (Imbalance)

the capacity and graph of the original structure. The results are shown in Fig. 7.

- Map1: The original map (Fig.4), capacity 818.
- Map2: Zone pz-3 closed, capacity 697.
- Map3: Zone pz-5 and the store building entrance ce-1 closed, capacity 418.
- Map4: Zones pz-3, pz-5 and the store building entrance ce-1 closed, capacity 297.

We can see that the parking waiting time increases as the capacity and the number of zones in the parking facility increases. This is because we see more congestions in some 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 Random and Billboard methods decreased in case of the highest parking capacity. We consider those methods are capable to balance car flow somehow if parking facility is enough large.

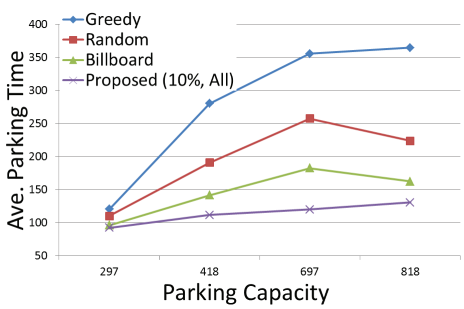

Figure 7. Influence of Parking Topology and Capacity

3) Influence of Search Length: Here, we investigate the influence of the search length of parking route that is performed in the vehicle part. We used the map with capacity of 818 cars, in 100% penetration rate and imbalanced entrance. We varied the search length from 2 to 6, and the result is shown in Fig. 8. The parking waiting time is 160s when the search length is 2, which is close to the billboard advertising method, since 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.

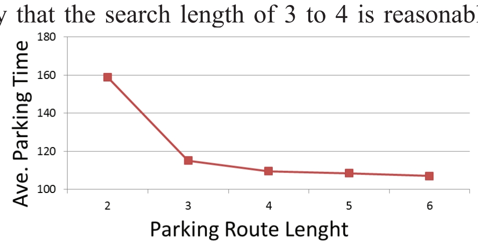

Figure 8. Influence of Route Length

V. Conclusion

In this paper, we proposed a navigation method which minimizes the parking waiting time in a large-sized parking facility. By simulation-based evaluation, we confirmed that the proposed method can reduce parking waiting time by 70% at maximum.

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