A non-sensor solution for effective and inexpensive parking management: payment, reservation, and dynamic pricing

Shuguan Yang
Dept of Civil and Environmental Engineering
Carnegie Mellon University
Pittsburgh, PA 15213
shuguany@cmu.edu

Sean Qian
Dept of Civil and Environmental Engineering
Heinz College
Carnegie Mellon University
Pittsburgh, PA 15213
seanqian@cmu.edu

1 Project overview and background

1.1 Overview

In this project, a non-sensor based parking management system is proposed. Comparing to traditional on-street parking management schemes, the proposed system is more advantageous in the following ways: (1) Providing better estimates for accurate spot-by-spot real-time parking occupancy without deploying sensors; (2) Applying dynamic spot-by-spot parking rates based on both demand and supply. (3) Offering parking reservations via mobile or web applications; (4) Enabling convenient and flexible parking payment; and (5) Improving the efficiency of parking enforcement.

1.2 Introduction

The current on-street parking system is inefficient. Information regarding occupancies and violations are usually difficult to acquire, though various sensing technologies have been utilized in modern on-street parking management systems. Those parking management systems do not scale because most parking sensors are relatively unreliable subject to high expenses of installing and maintaining costs. Moreover, parking rates for on-street parking are usually fixed, which is essentially inefficient for system management as the actual parking demand can vary significantly from time to time. A flexible and dynamic price can ensure the most effective usage of parking resources in an efficient way.

To conquer the drawbacks of traditional parking and payment schemes, various studies regarding parking management have been conducted in recent years. Parking reservation schemes based on Internet are widely recognized and explored in literature[1, 2, 3, 4]. Some of them discussed the architecture of reservation systems and communication protocols. For example, Wang et al. [5] developed web- and smartphone-based reservation systems for parking lots, and Wang et al. [6] used short message systems in their reservation scheme. The hardware and software implementations of the reservation system were described in [7, 8]. Meanwhile, some other studies focused on policies of parking reservation. Liu et al. [1] analyzed the feasibility of expirable parking reservations, whereas Kaspi et al. [2, 9] explored vehicle sharing regulation via parking reservations, along with a case study using data from Capital Bikeshare in Washington D.C. [9]. Yan et al. [4] proposed a user-to-user parking spot trading system which requires the usage of mobile devices and availability is not guaranteed for reservations. Parking data of San Francisco downtown areas is used in the system evaluation.

In terms of real world implementations, more public and private garages start to accept online parking reservations, including airport, hotel, shopping parking as well as employee-only parking lots.

Most of the systems offer reservations as a daily, monthly or one-time pass, but spot-by-spot, fine-grained and real-time parking management is rare. For example, For the purpose of relieving congestion, Yosemite National Park launched a pilot program in June 2016 where visitors can reserve a guaranteed parking space for the whole weekend; DOT of New York City offers monthly municipal garage reservations. To our best knowledge, there is currently no report of public on-street parking with the reservation capability.

In addition, dynamic parking has also been studied to mitigate congestion and reduce parking cruising time. In recent years, they have been tested in pilot areas. The SFPark project of the city of San Francisco involves rate adjustment every month aiming for an optimal parking occupancy 60% -80%. The LA Express Park project also implemented dynamic pricing since August 2012. Seattle Department of Transportation is also installing new parking meters where prices are adjusted based on demand since 2014. Based on data collected from pilot areas, several studies are conducted with the focus on assessing the influence of dynamic pricing on parking choices and occupancies[10, 11]. Teodorovi et al. [12] analysed the optimal pricing scheme with the assumption that future traffic arrival patterns are known. Tsai et al. [13] introduced a pricing model to making reservation cost equivalent to the value of reduced cruising time. Qian et al. [14] proposed a dynamic pricing model for optimizing recurrent morning commute. Liu et al. [1] also incorporated dynamic pricing within the expirable parking reservation. Zheng et al.[15] considered both garage parking and on-street parking when formulating dynamic parking pricing.

In this document, the proposed on-street and off-street parking management scheme integrates novel technologies of payment methods, statistical modeling, dynamic pricing and big data analytics, intending to offer a more efficient, reliable and convenient parking system for both managers and users. The proposed parking management system brings convenience to the general public by providing real-time parking occupancy and pricing information, and allowing parkers to make parking reservations in advance that guarantee a spot. The system also features an incentive-based violation reporting scheme that can reduce the workload of parking enforcement patrolling and disincentive parking violations. Moreover, any dynamic pricing algorithms, such as [14], can be implemented to ensure parking occupancies within a targeted range.

Specifically, the proposed parking management system provides the following novel features:

1. **Online parking reservation**: Users are able to reserve for their desired parking location and time slot via mobile or web applications, by paying a fixed amount of premium fee. At the first time using the associated apps, users will be asked to register for an account with their credit card info and license plate number. Users can also store their frequent parking locations/time period to save time for future reservations. Similar to the scheme of dynamic airfare, current and future parking rates are adjusted from time to time based on the estimated parking demand and space availability. Users can check the rate information as well as estimated and predicted parking availabilities through those apps.

   As part of the optimal spots allocation, parking spots are not assigned to the parkers when making reservations. Rather, the specific spot information will not be sent to the parker until 15 min prior to his/her arrival via SMS or app notification. Also, parkers can look for their vehicle plate number on the display corresponding to the assigned parking spot in the reservation area.

   In the case a reserved parking spot be occupied by an unauthorized vehicle, the parker can take a photo and report violations through the apps. The system will immediately allocate another spot if possible, or the parker gets full refund plus additional compensations, such as future parking credit.

2. **Incentive-based violation reporting mechanism**: Such a mechanism is designed to enhance the efficiency of parking enforcement and minimize the duration of violated parking. For those parkers who find their reserved spots occupied by unpaid vehicles, they can report violation via the mobile/web app, so that they will either be assigned with another spot or be fully refunded plus additional parking credit. Moreover, for each parking spot, there is an associated indicator (such as an LED light) showing the current occupancy status, for instance, green as vacant, red as paid or reserved period coming soon. Thus, everyone, especially those looking for a vacant parking spot, would easily spot an unpaid and unauthorized vehicle. Everyone is fully incentivized to report such violations through mobile/web app, since they will get parking credit issued to their accounts and even a vacant

parking spot if the violated vehicle is towed away immediately. Upon receiving a violation report, the system will sent a violation alert message with the exact location and reported photo together to a nearby parking enforcement officer.

This incentive-based reporting mechanism utilizes crowd-sourcing to promptly detect parking violations, and turning the parking enforcement from inefficient cruising-based into efficient on-demand service. This can significantly lower the cost of parking enforcement and improve the system efficiency. If increased revenue from parking citations is received, then part of that revenue is given back to the violation reporters as parking credit. On the other hand, this mechanism also helps improve the accuracy of parking occupancy estimation.

3. **Pay as you park**: The system also allows the parkers to check out earlier than their scheduled (or reserved) session expiration time, and get partial refund. All reserved or non-reserved parkers who check out earlier have the option to check out via their mobile app or the kiosk. They will receive partial refund of the prorated parking fee, i.e 80% of the prorated parking fee for the remaining un-parked duration. Once the parker checks out, his/her spot will be marked available with the indicator turning green on immediately.

   This feature offers several advantages. First, it offers more flexibility for parkers when they pay for parking, and reduce their anxiety on overpaying or underpaying. Second, it improves the efficiency of on-street parking by increasing usage and reducing potential capacity waste. Third, it serves as another incentive for users to report real-time parking schedule to the system, which in turn increases the system efficiency, as well as improves the accuracy of parking occupancy estimation.

4. **Dynamic parking rate**: In order to keep the parking occupancy within an optimal targeted occupancy rate, such that 80% to 90% occupied of the entire parking area, parking rates are adjusted in real time based on the predicted parking demand. Parking demand prediction is determined by a number of factors including historical average demand, current real-time occupancy, and the number of existing and incoming reservations. In general, the parking rate goes up as the number of estimated available parking spots declines (or equivalently the predicted parking demand increases), and drops down once the amount of vacant spots is expected to be lower than the targeted occupancy rate.

   Users can check the current parking rate in the web/mobile apps, and they are charged for the parking rate at the time of their parking check-in. When a user make a reservation, he/she pays for the parking rate displayed at the time of reservation (as lock-in), and will not be impacted by future rate adjustments. Real-time parking rate is also displayed on a large digital display panel on-site, making it visible to all parkers, with or without reservations.

5. **Smart spots allocation**: To maximize the usage of parking resources, parking spots for reservations are not assigned until 15 minutes before the start of an actual parking session. Parking spots are allocated and monitored in real time to maximize the availability of vacant spots while fulfilling all reservations. Several factors are taken into considerations in this spot assignment process including: subsequent incoming reservations, non-reservation parking and violations, and predicted future parking demand. The mechanism of spot allocation is further explained in Section 3.3.

   When making reservations, parkers are not informed of their assigned spots until 15 minutes prior to their reserved parking session. At 15 minutes prior to the reserved parking session, the system determines a parking spot and inform the parker via push notification or SMS. Meanwhile, parkers can also look for their plate number displayed at each spot.

2 System Design and Components

In this section, we discuss the design of the proposed parking management system as well as its hardware components.

2.1 System Design

The design of the parking management system is described in Figure 1.

The web/mobile application handles user reservations and communicates with the parking server. The parking server will update spot assignments and price changes for the parking kiosk and the

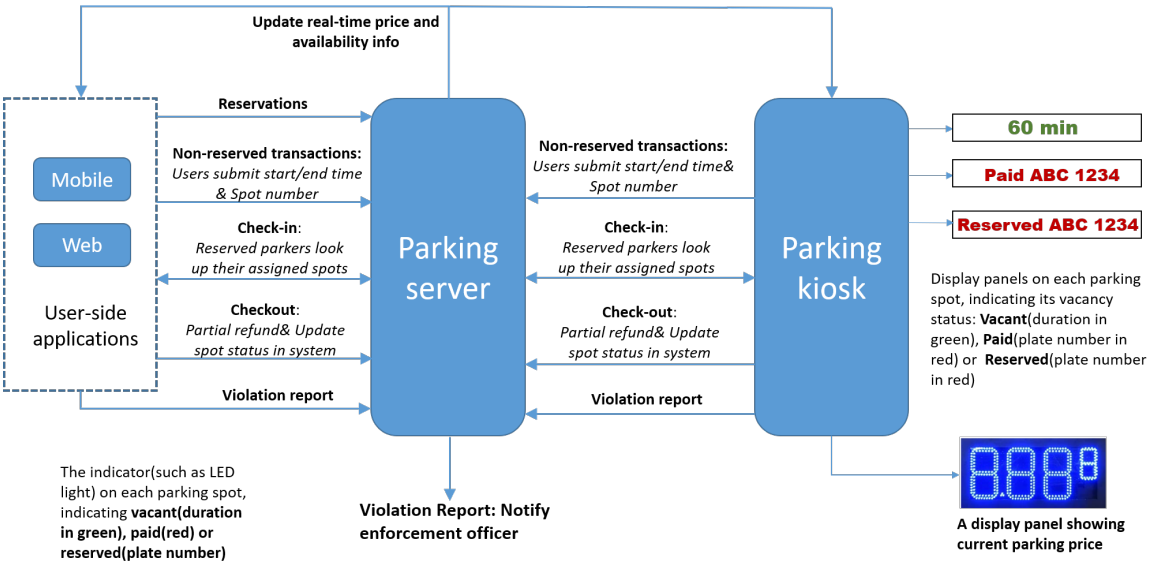

Figure 1: System design and information flow chart

web/mobile applications. The logic controller is connected to a parking kiosk, translating kiosk commands into electrical signals. In addition, the parking server processes all violation reports. It will notify the enforcement officer, issue refund to users, offer parking credit, and archive all records.

2.2 Parking kiosk

Similar to traditional on-street or off-street parking kiosks, the kiosk here features a user interface and a credit card reader. It uses the cellular network (i.e., LTE), wifi or cable, to communicate with the cloud-based parking server. A parkers enter his/her plate number and the spot number to pay for parking. For a parker with the reservation, he/she can use the kiosk to check-in and confirm the assigned spot on the kiosk. Also, anyone can report parking violation, and check current parking rates through the kiosk.

There is a large digits display (such as a LED panel) around the kiosk displaying real-time pricing information. Parking rates are visible to everyone including parkers passing by the kiosk.

Since the kiosk is mounted outdoor, it needs to be water/snow proof and with low-temperature endurance.

2.3 Vacancy and license plate display for individual parking spots

To display the current vacancy status, a red/green light indicator is installed next to each parking spot, such as a multi-color LED light or a small display pad. There are three types of occupancy status for each spot, represented by three display modes of the display respectively.

1. Vacant: If the spot is available for at least 15 minutes, the panel displays longest possible parking durations in green, e.g. 60 min. This display will be updated every few minutes, such as 1 minute or 5 minutes.
2. Paid (non-reservation): During a paid parking session for a 'walk-in' parker (i.e., no reservation), the panel displays the license plate number in red.
3. Reserved: 15 min before a reserved parking session starts, the panel displays the plate number of the reserved vehicle in red. The display changes back to vacant in green when the reserved period ends.

All the display panels are connected to a logic controller kit via wire, which is then connected to the parking kiosk via either cable, bluetooth or wifi.

2.4 Parking server

The parking server is set to handle all requests sent from parking kiosks as well as the mobile/web applications. It processes all payments and reservations, estimate/predict parking occupancy, dynamically set parking rates, and send updates to parking kiosks. It assigns spots for upcoming reservations and notify parkers via push notifications/emails/text messages. Whenever a violation is reported, the server notifies enforcement officers and handle refunds.

2.5 Mobile and web applications

The mobile and web application serves as a remote and portable "parking kiosk" for users. Users are able to create accounts, make or change reservations, pay for parking, check in/out parking sessions, extend current parking sessions, check real-time pricing and availability information, and report for parking violations.

Users need to register personal accounts for the first time they use the mobile or web app. The account will save their credit card info, license plate numbers and favorite parking locations for future convenience. Users select a parking location (or area) and enter desired parking duration when making reservations. For non-reserved (walk-in) parking, users simply enter the spot number and parking duration via their mobile app or the on-site kiosk (provided that the spot is available).

3 Descriptions of system functionalities

This section describes the process of parking and payment from the user perspective.

3.1 Reservations and payments

The proposed parking management system allows users to reserve a parking space for a specific time period, with an additional premium fee. The premium fee is not refundable unless the user does not find his reserved spot available (i.e. a parking violation). When making reservations, users choose their desired parking location (or area) and a period of time/date, but they cannot specify a parking spot. Spots are dynamically assigned by the parking server in order to maximize space usage, at the same time accommodating non-reserved (walk-in) parkers as much as possible.

Non-reserved users can park at any spot with the green light on, they can pay for parking using the app or the kiosk by entering the plate number and parking spot number. The maximum duration they are allowed to park is restricted by incoming reservations, and the duration is displayed for each parking lot. For example, if there are a reservation assigned to the spot 60 minutes later, then the walk-in user can only purchase for up to 45 minutes. Meanwhile, the system in real time modifies spot assignments to provide the longest possible duration for the current parkers.

3.2 Parking rates

Time-dependent parking rates, in conjunction with dynamic pricing schemes such as [14], will be used to target an optimal parking occupancy, for example, 80% to 90%.

For time-dependent parking rates, the time of day will be divided into several periods, each of which has a different base rate according to historical occupancy information. On top of that base rate, a dynamic pricing scheme will be implemented so that the real-time parking rates can be adjusted according to real-time and predicted occupancies.

Users who make parking reservations early pay the parking rate at the time of reservation (which is likely to be lower than real-time parking rate) plus an additional non-refundable premium fee. When an excessive amount of reservations are received for a certain period of time, parking rates for subsequent reservations will increase. However, the rate for non-reserved parkers may drop under the base rate if the real-time occupancy is significantly lower than usual.

3.3 Optimal spot assignments

As introduced in Section 4, the parking system adopts a dynamic spot assignment scheme. The reason for introducing such a scheme is to avoid 'fragmented' parking time slots, and maximum the duration of available spots. Without this scheme, reservations in combination with random 'walk-in' parkers will generate a fair amount short vacant time slots or fragments, such as 30 mins. Those time slots may not fit most parkers' demand, thus the parkers either have to come back and move their vehicle to make room for upcoming reservations, or they have to find a spot somewhere else. The proposed optimal spot assignment scheme incorporates subsequent reservations, non-reserved parking and violations information, iterate through options to extend the duration of a single vacant spot by merging fragmented time slots, while still satisfying existing reservations. As a result, this spot assignment reduces the inefficiency induced by the reservations and increases the revenue from the parking facility.

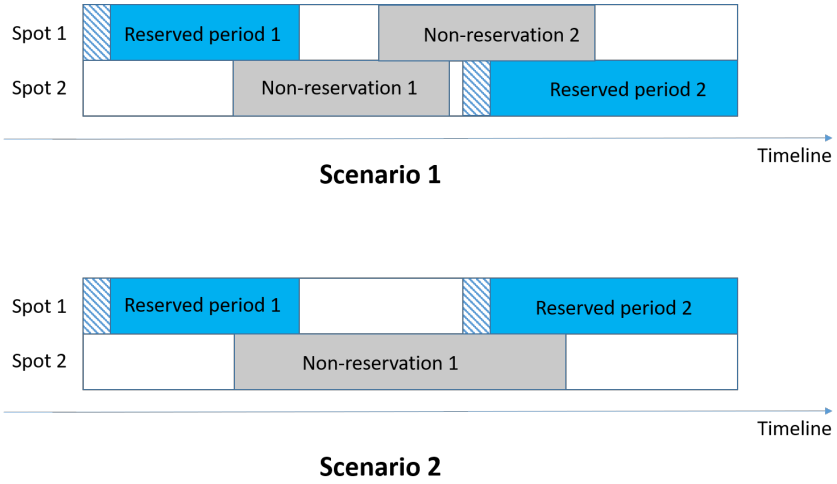

Figure 2: Demonstration of optimal spots assignment in a two-spot case. *Blue bars stand for reserved parking periods; diagonal striped periods stand for the 15-min period before the reservation that is required by this system; gray bars stand for 'walk-in' parking periods.*

The fundamental mechanism for the spot assignment can be demonstrated in a simple two-spot case. As illustrated in Fig 2, in the case when the system receives two parking reservations 1 and 2, with a time gap between the end of the first one and the start of the second. Without the optimal spot assignment, namely if parking spots of the reservations are determined at the time of reservation, they would either be assigned to the same spot or different ones, as shown in the two scenarios in the figure. Due to the uncertainty of subsequent reservations or "walk-in" parking sessions, neither of the two assignments are optimal for both scenarios. One would need to assignment spots for reservations in real time in order to best accommodate all possible scenarios in the future.

3.4 Incentive-based violation reporting

For parkers finding their reserved spots occupied by another vehicle, they can take a photo and report the violation via parking kiosk or their mobile/web app. A new parking spot will be assigned if possible, or they will get refund along with a parking credit for compensations. This triggers an alert notification sent to the enforcement officers. The parking credit is charged to the violated vehicle as part of their fine. The parking credit can be in the form of a promo code, and can be applied to any account of the users' discretion.

All spots that are currently vacant will be displayed in green on its display panel, and each reserved or paid parking spot has display of a license plate in red. In this way, any vehicle parked in a spot with green display is clearly unpaid parking. Anyone can report parking violations. Upon the validation by the enforcement officer, the reporter who has an account receives a parking credit.

Such a violation reporting scheme will significantly reduce the amount of parking violations as they will be reported and cited effectively. The scheme will reduce the patrolling frequency of enforcement officers.

4 User scenarios

In this section, several user scenarios are described to demonstrate the functionalities of the proposed system and how those functionalities are integrated.

4.1 Reserve and park

User A makes a parking reservation via his mobile app. If he is to use the system for the first time, he needs to register an account (with his up-to-date vehicle license plate number, and credit card info), fill in a time period of parking, and select the area of the parking spots. The earlier he submits the reservation request, the lower parking rate he is likely to pay. He needs to pay the additional amount of premium reservation fee to reserve this parking spot.

15 minutes prior to his reserved parking session, the spot ID will be assigned based on current and future parking occupancy, and the display panel if his assigned spot show his license plate number in red at that time. He will be informed of the spot ID via push notification on the phone or a text message, or he can check it using his phone app or at the parking kiosk upon arrival. Upon arrival, he uses the web/phone app or the kiosk to check in his reservation to start. He will also receive a notification when his parking session is about to expire (with the information of the spot being extensible or not, and if so, for how long) unless he leaves already.

If User A decides to leave 30 minutes earlier, he has the option to check out upon departure, by tapping checkout on the kiosk or on his web/phone application. As a result, he receives a refund of 50% of the parking fee of the unparked 30 minutes, and the spot is immediately displayed in green with the maximum available duration, available for any other parkers.

4.2 Non-reserved parking (walk-in)

User B wants to park but did not make a reservation. She can check the current parking rate on her mobile app. If she cruises around the parking area, she can also see the rate on the digital display connected to the parking kiosk (just like a gas station). She can choose one spot with a green display to "walk-in" park, and pay for parking on her mobile app or the kiosk by entering the spot number and the duration of her desired session (She will need an account if she pays via the web/mobile app). However, she cannot pay for more than the longest possible parking duration, constrained by the next parking reservation on this spot if any.

If User B decides to leave 30 minutes earlier, she has the option to check out upon departure, by tapping checkout on the kiosk or her web/phone application. As a result, she receives a refund of 70% of parking fee of the unparked 30 minutes, and the spot is immediately displayed in green with the maximum available duration, available for any other parkers.

4.3 Report a violation

If User C reserved a parking spot, but come to find out her spot is taken by another unauthorized vehicle, she can first park on any spot with a green display, and then take a photo to report for the violation, submit her new spot number via either her mobile app or the kiosk. The violated vehicle will receive a ticket and possibly be towed. If she parks without reporting the violation, then it is possible that she will be reported as a violation.

In case there is no available spot when the violation occurs, user C receives both parking fee and reservation fee refunded, as well as an additional parking credit as a compensation, which can be applied the next time she park. This credit comes from the citation to the violated vehicle.

For user D who walks by, if he sees a vehicle parking on a spot with the vacancy display in green or an occupied display with inconsistent license plate number, he can also report this violation via

his mobile app or the kiosk. He can receive a the parking credit after the violation is validated by an enforcement officer.

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