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RESEARCH PAPER

One-Day Long Statistical Analysis of Parking Demand by Using Single-Camera Vacancy Detection

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Abstract: Many researches have focused on parking demand to gain information for traffic management recommendations and decision-making where real-world car park statistics is of great importance. This paper seeks to obtain one-day long statistical analysis of a multi-purpose off-street parking space in downtown Abu Dhabi, using a single-camera vacancy detection system. The proposed methodology to collect one-day long statistics uses pattern recognition to determine occupancy states based on visual features extracted from parking spots. This vacancy detection system has two major advantages. First, it relies on only few pixels compared with other methods, being able to cover more than 150 parking spots within a single camera frame. Second, the system works well in both nighttime and daytime – robust to changing light conditions. The accuracy is 99.9% for occupied spots and 97.9% for empty spots for this period of study. This study also proposes a better indication of parking demand when the park is near its full capacity, as the utilization rate does not capture the parking demand from the motorists who fail to find parking spaces.

Keywords: parking strategy, vacancy statistical analysis, one-day long monitor, parking demand indication

1 Introduction

Parking space management has become a more pressing issue due to growth in private vehicle ownership. On one hand, building too little parking space causes traffic congestion and spillover to other areas[1,2]. On the other hand, having too much parking space, underutilizes scarce land property, encourages people to own more private vehicles, and reverses the trend towards environmentally friendly transportation profile[3]. Real-world statistics is important for informed decision making. This paper seeks to obtain one-day long statistical analysis of a multi-purpose off-street parking space in downtown Abu Dhabi, using a single-camera vacancy detection system.

Many researches have looked into car parking activity to gain information for traffic management recommendations and decision-making. One of the vital information is demand for parking[4]. It is the "accumulation of vehicles parking at a given site at any associated point in time… This value should be the highest observed number of vehicles within the hour of observation[5]." Parking demand therefore indicates level of car park utilization over time. Adjusting size and number of car parks[6], assessing benefits and environmental cost[7], gauging effect of changes in policy, and projection of future need[8] all rely on this parking demand.

In particular, parking demand is first used as considerations for car park size. Currently, many off-street parking areas are based on information compiled by Institute of Transportation Engineers' Parking Generation. This book specifies the minimum parking demands for different land uses. However, the information collected is from single-use suburban locations[1]. As a result, little is known about profile of parking demand for mixed land use, which would in fact needs less space. Therefore, a low-cost and efficient method to obtain more relevant and accurate parking demand would be valuable in car park design.

Besides car park design, assessing parking demand of existing car parks is also useful for implementing policy changes. The most pertinent one is charging the right price for a parking space. The high parking demand with limited supply of parking spaces results in high price charged. However, while overcharging leads to underutilization, wasting public resources, undercharging leads to shortage of parking space. Getting the right price therefore helps to allocate the resources to those who most need it. A

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successful pricing system in San Francisco further optimizes pricing according to parking demands at different time and day-to-day situations [4]. Admittedly, exacting the optimal price for a product, which is previously not on the market, cannot rely on this parking demand alone. While it only presents the number of people who derive some utility from parking, parking demand information is necessarily used in complement with surveys to gauge the right number of customers who are willing to pay at a given price.

There are broadly two ways of evaluating this parking demand. First, it can be modeled based on simulation. The models range from convenient and simplistic ones to highly sophisticated simulations requiring large set of data[9]. In fact, studies have focused on various factors influencing the choice of one parking lot over another in predicting the demand. They include variables like walking distance, parking fees, the availability of parking space, and penalties fees of illegal parking[10,11]. Some models consider when motorists evaluate those factors with perceived cost and utility based on Possibility Theory[12]. Other models use machine-learning approach to determine current demand of parking facilities based on time parameters[13]. Regardless, these models need to be validated by real-world information. Second, the parking demand can be obtained from real-world statistics. Automated system such as smart parking systems[14] efficiently collect vital information on the parking activities[15]. The systems can be further categorized into intrusive and non-intrusive ways[16]. For example, wireless-based[17] or wired-based sensor[18] method require invasive procedures to install the complicated equipment. On the other hand, the non-intrusive ways such as microwave radar, passive acoustic array sensors, and passive infrared sensor are easier to install[14]. Nevertheless, they both are resource-intensive just for short-term data collection. Instead, preferable approaches should be centered on one-to-many detection in image-based detection system, which is inexpensive, flexible and non-intrusive.

In the vision-based field, a lot of research has focused on object detection. Bong et al used pixel detection with threshold to differentiate between cars and empty slots. Although this threshold value is non-adaptive to changing light conditions, he compensated this with edge detection[19]. Still, the method does not work well, when the cars-to-camera distance is high and the car images have few pixels. Fabian based his method on the homogeneity of the car pixel values, counting the number blocks containing pixels of similar homogeneity values[20]. Again, this requires highly detailed images with limited applications in a large-scale single-camera detection system. Our proposed method relies on fewer pixels, being able to cover more than 150 parking spots within a single camera frame.

There have also been attempts using machine learning to classify the parking states[21,22], but they are not robust to changing light conditions. By contrast, Huang developed a Bayesian framework detection method that is robust to changing in light conditions. This detailed study even modeled shadow from sunlight direction, based on U.S. Naval Observatory to anticipate the false recognition of shadow as black-colored vehicles [23]. However, this method is complicated, because although the shadow could be recognized as the car, it has uniform appearance. Measurement of randomness or spread of pixel values can account for this shadow problem. In addition, although the method achieved up to 99% accuracy[23], the method was only tested during daytime. Our proposed system, also achieved equally satisfactory result, whereas nighttime period was included.

There exist few cases of comprehensive empty slot recognition system that includes nighttime detection [24]. Macdonell and Lobo looked at nighttime but the whole picture frame consisted only five parking spots [25]. Another study in Japan tested a system using Fuzzy C-mean Classifier to identify the vacant parking spots with somewhat satisfactory results. The study collected one-day long data over two months[26], but the parking space was on a rooftop of a multi-story parking lot and contained less than 30 parking spots. As a result, the observed parking space does not accurately represent the parking space system and it has too few cars to obtain meaningful statistics.

While there have been little parking studies for one-day long period, the most comprehensive work is a study commissioned by Transport Department in Hong Kong, to estimate parking demand from 07:30 to 22:30 across almost 4000 parks[27]. The study found similarities in the shape of parking demand profile and there emerged categories of car parks corresponding to different types of land usage nearby. From this known demand pattern, the study then proposed predicting parking demand based on the surrounding land use of an interested car park. Although the method sufficed for its application, subcategories of car parks could emerge when parking demand is observed for the entirety of one-day period. Car parks with similar parking pattern in daytime may have different characteristics at nighttime. As a result, studies should not presuppose the dynamic time period of parking activities, but instead should rely on empirical data of a whole-day period.

Another limitation of current parking studies is relying only on utilization rate even when the park is near its full capacity. Utilization rate does represent parking demand when every motorist who wishes to park can park and consequently be recorded as a part of the total parking demand. However, when the car park is near its maximum capacity, not all motorists who wish to park can successfully secure the parking space. Assessing total parking demand from only the utilization rate inevitably excludes those unsuccessful parkers. One detailed study, in addition to