Bringing the Smart City into the Car: Monitor, Predict, Control

David Eckhoff*, Daniel Zehe*, Jordan Ivanchev*, Alois Knoll**
*TUMCREATE, Singapur, **Technische Universität München
{firstname.lastname}@tum-create.edu.sg, knoll@in.tum.de

I. INTRODUCTION

The development of large cities towards Smart Cities will have a decisive influence on the mobility of the future. With a large number of ubiquitous sensors and actuators, Smart Cities can not only continuously monitor certain aspects of a city (such as traffic), but also take action based on this new level of knowledge. The underlying devices are often equipped with communication capabilities to allow for the central collection of large amounts of data, where it can then be processed. The actual 'smartness' of the city lies within the usage of this information, that is, how it can be used to improve existing processes as well as offer new services.

In today's road traffic, these Smart City mechanisms can already be observed. The car itself is used as a sensor that reports position and speed continuously to a server, which allows conclusions about the current traffic conditions on the roads. With a larger number of sensors, in this case, vehicles, this picture becomes more complete and, in turn, the system can also be controlled better. Ultimately, the efficiency and benefit of many services is highly dependent on the availability of data, data quality and associated predictability. Only if it is possible to reliably predict how the system will behave in the future based on the currently observed state, can a Smart City adapt to it in a timely manner. For example, if traffic conditions on a certain road can be predicted, traffic light signal phases could be optimized or alternative routes could be recommended even before congestion reaches a critical state. Technically speaking, this makes the Smart City a type of feedback-control-loop.

The challenges these systems face are manifold. The large amount of collected data raises concerns in terms of data protection, in particular the questions of who owns the data, who is allowed to process and store it, and how and to whom it is made available [1]. Considering a high level of pervasiveness of sensor systems and networks, it also has to be clear what is actually allowed to be measured or monitored. The design of Smart City systems must therefore always take privacy protection into account. Ideally, all deployed privacy protection mechanisms have no perceptible impact on the utility of the collected and presented information [2]. Additionally, even data that is not meant to be publicly available needs to be sufficiently anonymized so that in the case of a data leak consequences for the users can be minimized.

Another important challenge is how (and which) user devices can be integrated into the smart city. A smart phone offers many possibilities, however, coupling it directly with a vehicle can be critical as security issues can lead to accidents or even physical injury. Looking further into the future, a more direct integration of vehicles seems necessary to fully utilize potentials introduced by autonomous mobility, e.g., to control traffic flow without human interaction. Until then, presenting information to the driver is a challenge on its own, because even if drivers can be informed about a certain situation, it is not guaranteed that they will follow these recommendations.

A smart city application that faces all these challenges can be studied in Singapore, where it tries to alleviate the problem of parking space searching. In this article we describe the app's functionality and in particular its capabilities to predict the availability of parking spaces at the destination even before the trip starts [3]. Furthermore, the application assists in navigation, updates its prediction on the go, and recommends alternative car parks in the vicinity of the destination.

II. PARKING SPACE PREDICTION

In some parts of Singapore it can be difficult to find a car park within walking distance. In the vicinity of popular shopping centres, tourist hot spots or in the central business district, it is not uncommon for motorists to approach several car parks until they find one with available parking spaces. The main feature of the app is to optimize this process in order to minimize the amount of time spent by the individual to search for parking, while simultaneously reducing traffic volume by avoiding unnecessary trips.

Based on historical data of more than 1000 Singapore car parks, the current position of the driver, the entered destination and a calculated travel time, the app provides information on how many free parking spaces are available at the time of arrival in the selected car park. During the trip, this forecast is updated and recommendations for alternative car parks near the destination are given, should the original car park be fully occupied.

In order to enable this prediction and to achieve the highest possible accuracy, an artificial neural network is employed (see Figure 1). The prediction of car park availability is a rather direct problem, which allows the use of a conventional feed-forward neural network with only one hidden layer instead of using more complex deep learning methods. This neural network is trained using historical data for each car park. Training of the neural network is independent of user requests which makes the prediction during operation very fast, allowing tens of thousands requests to be processed simultaneously.

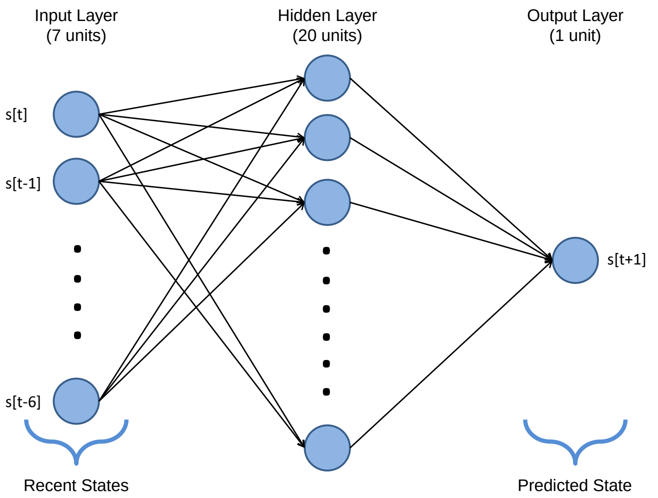


Fig. 1. Structure of the used neural network. Seven input states representing the car park utilization in the last one and a half hour are connected to twenty neurons in the hidden layer leading to a prediction of the car park availability.

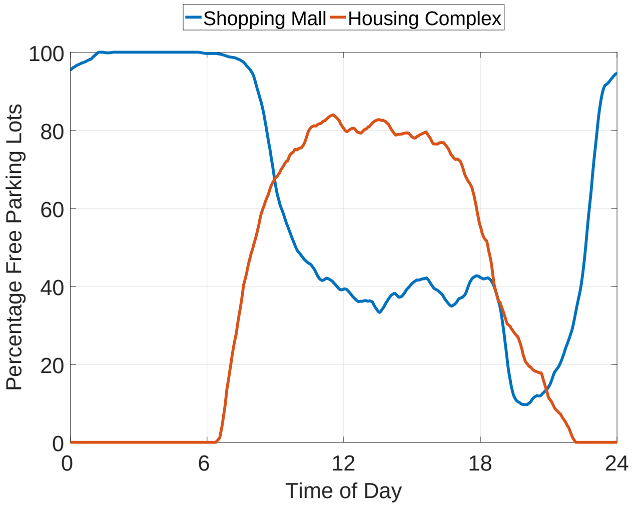


Fig. 2. The utilization of car parks differs based on the location and the type of usage. Car parks connected to residential buildings (red) show a much lower utilization during the day than car parks in the city centre (blue). The latter show a high demand in the morning hours and an additional peak in the late afternoon. The figure shows utilization during a weekday.

Figure 2 shows that car park-specific learning is necessary to make accurate predictions, since the utilization of different car parks is strongly dependent on their environment. A parking garage in a residential complex shows completely different temporal characteristics than a parking garage in the city centre. Although it is possible to group various parking lots, it reduces the prediction accuracy because the influence of population density, traffic volume and location-specific conditions is very pronounced. Figure 3 shows the prediction quality for a car park in the city centre and a lookahead time of 60 minutes. We observe that the neural network achieves sufficient accuracy. If the lookahead time is reduced to e.g. 30 minutes, the prediction accuracy further improves.

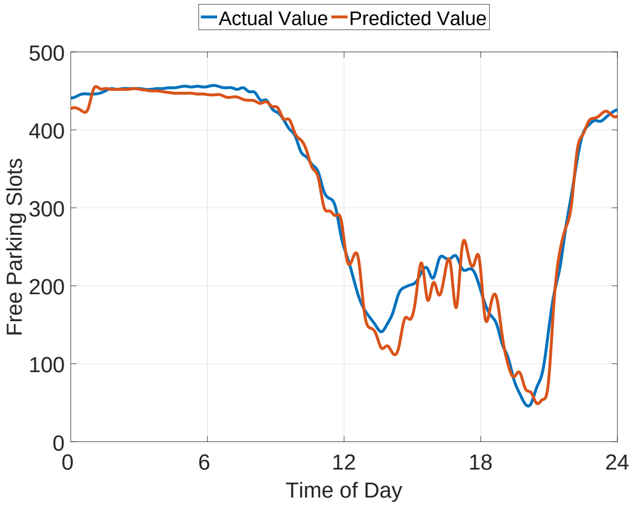


Fig. 3. Example for the prediction accuracy of a random car park. It can be seen that the neural network (red) can predict the general trends well. When the car park utilization fluctuates more strongly, the prediction may differ more from the real value (blue).

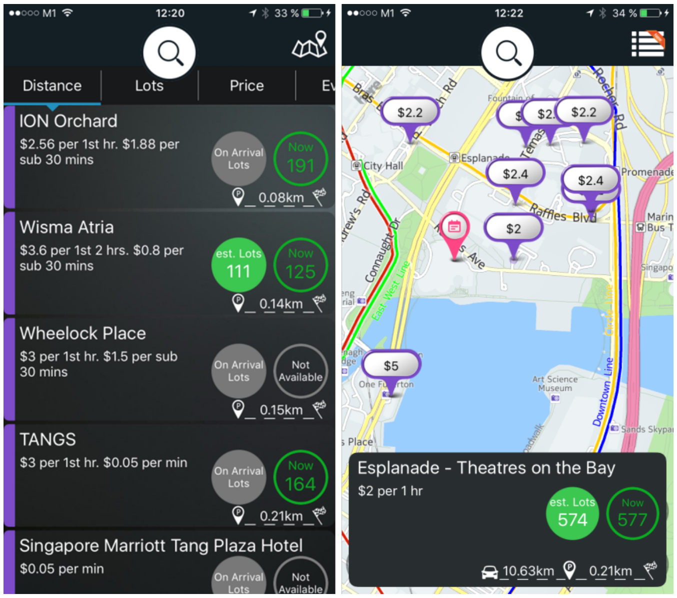
With regard to data protection, an application like this in itself is not problematic. Requests to the server can be encrypted and the response from the server cannot be used to determine the behaviour of other users. Storing historical data about car park utilization is also not a problem as it is publicly accessible information. In order to continue training the neural network during operation, only information about car park utilization and time stamps are required. User data is not necessary.

To increase the usability of the app, route planning has been integrated. The GUI includes available car parks, the predicted number of free parking spaces at the time of arrival and further information such as the parking fee. The user can interact with the app and select preferred car parks. Figure 4 shows the application's interface.

Through recommendations in the app, utilization of the car park as well as the traffic flow can be controlled to a certain extent. But instead of depriving the user of information (e.g., by hiding certain car parks) and thus reducing their trust in the service, certain incentives can be created. Parking fees or additional services, e.g. car washes, could be offered at discounted rates if the driver agrees to choose a car park slightly further away from their destination. In order to support new shopping areas, the selection of certain parking spaces could be combined with sales campaigns in adjacent shopping centres. The integration of ride and bike sharing services into the app offers further possibilities to influence the mobility of users.

III. OUTLOOK

Currently, the application is limited to connected car parks, i.e., it relies on the provision of live data by car park operators. If the idea is further developed in the sense of the Smart City by integrating vehicles also as sensors, this service could be expanded to also include information about on-street



ION Orchard
$2.56 per 1st hr. $1.88 per sub 30 mins
On Arrival Lots — Now 191 — 0.08km

Wisma Atria
$3.6 per 1st 2 hrs. $0.8 per sub 30 mins
est. Lots 111 — Now 125 — 0.14km

Wheelock Place
$3 per 1st hr. $1.5 per sub 30 mins
On Arrival Lots — Not Available — 0.15km

TANGS
$3 per 1st hr. $0.05 per min
On Arrival Lots — Now 164 — 0.21km

Singapore Marriott Tang Plaza Hotel
$0.05 per min
On Arrival Lots — Not Available

Esplanade - Theatres on the Bay
$2 per 1 hr
est. Lots 574 — Now 577
10.63km — 0.21km

Fig. 4. User interface of the application. The left pictures shows a list of car parks, their current availability and predictions. The right shows the map view with annotated parking fees.

parking [4]. While driving, vehicles could identify free parking spaces using camera systems (recognizing road signs) and distance measurement sensors to provide this information to the service. This would lead to a significant increase of coverage without additional investment costs.

Parking space information is only the beginning. Modern sensors in vehicles as well as in the infrastructure can provide additional knowledge that can be used for new services. These can then in turn be made an integral part of the driving and route-finding process of (autonomous) vehicles to not only meet the personal preferences of the driver (or passenger), but also to follow optimization targets specified by the service. Through comprehensive knowledge about the state of the traffic system, strategies could be applied that shift from a local optimum towards global improvement, i.e., individual vehicles choose a strategy which primarily serves the entirety of vehicles.

This does not necessarily lead to a (justifiable) personal disadvantage, since a city-wide coordination of traffic towards a desired optimization goal can be advantageous for all vehicles. For example, a route that seems like a detour could still have a shorter travel time through the use of intelligent traffic lights and if all vehicles coordinate in order to reduce congestion along the route [5]. Advantages do not need to be directly related to travel times, but can also include CO_2 emissions, noise, and urban heat generation [6], which in turn can increase the quality of life in the city. Improving the quality of life should anyway be the primary goal of the Smart City, and its entities, that is, humans and technology, must work together to achieve this goal. System-wide optimization cannot be reached without the help of ubiquitous sensors, actuators, communication and data analysis technologies, because even when humans pursue a common goal, they possess neither the necessary system-wide knowledge nor the required coordination.

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