10 Sensors for Parking Occupancy Detection

KOUROSH KHOSHELHAM

Abstract

This chapter provides an overview of sensor technologies and methodologies for determining the occupancy of parking spaces. It covers a range of sensors including active and passive sensors that can be installed overhead, in or on the ground in both indoor and outdoor environments. The chapter also provides a comparison of sensors, and discusses considerations for sensor selection and open challenges in parking occupancy detection.

Keywords

Magnetic, ultrasonic, infrared, radar, RFID, camera, visible light, inductive loop, piezoelectric

10.1 Introduction

The fast increasing urban population is presenting new challenges for the transport infrastructure in large cities. With more vehicles on the roads, parking spaces in busy city districts become scarce and harder to find. Consequently, drivers spend more time cruising for a parking space. This contributes to traffic congestion, increased fuel consumption, and increased carbon emissions. Frustrated drivers cruising for a parking space pose a risk to the safety of other road users, especially cyclists and pedestrians.

Many large cities across the world have realized the need for smart parking solutions that help the drivers find a parking space faster and more conveniently. Examples of smart parking solutions piloted in large cities include SFpark[1] in San Francisco, and Park and Joy[2] in Hamburg and several other cities in Germany. A main component of smart parking solutions are sensors for detecting the occupancy of parking spaces, both on and off street. This chapter provides an overview of various sensor technologies for parking occupancy detection. We first review the concept of smart parking, and then discuss parking occupancy detection sensors, with a focus on sensors that are installed in the environment

[1] `https://bit.ly/399SLA6` – San Francisco Municipal Transportation Agency, May 2018
[2] `https://bit.ly/3971NgW` – Smart City Hub, 23 March 2017

https://doi.org/10.34727/2021/isbn.978-3-85448-045-7_10

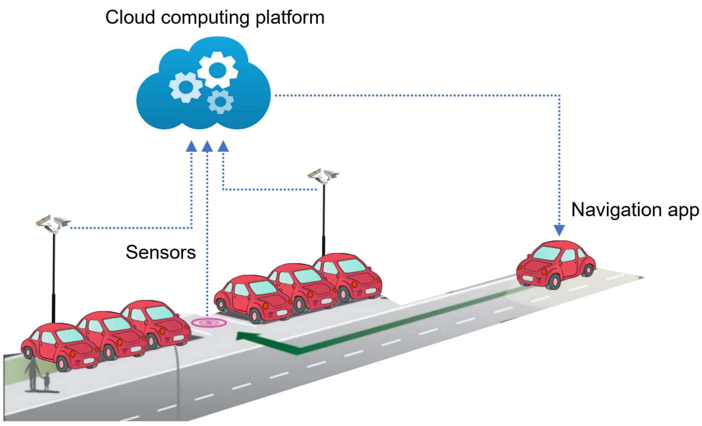

Figure 10.1: Smart parking concept. Source of background: `https://bit.ly/3varaXm` (© Deutsche Telekom, 2014).

(rather than on a mobile platform). Finally, we provide a comparison of different sensor technologies, and discuss considerations for sensor selection and open challenges in parking occupancy detection.

10.2 Smart Parking Concept

The basic concept of smart parking is illustrated in Figure 10.1. Sensors installed overhead, in or on the ground sense the occupancy of parking spaces and transmit the data in real time to a cloud computing platform via short range or long range communication devices. The cloud computing platform collects, stores and analyzes the data from all sensors and provides real-time parking availability and price information to mobile and web applications. Analysis of the data collected across different locations and at different times can provide other valuable information such as occupancy patterns, spatial-temporal variations, and correlation with events. The application component of the system enables the driver to find the nearest parking space on a map interface, book the parking space, and provides navigation guidance to reach it. In the following, we focus on the sensor component of smart parking systems.

10.3 Parking Occupancy Detection Sensors

A wide variety of parking sensors are available and have been used for parking occupancy detection. These sensors can be classified according to their installation platform. Mobile sensors are installed on a mobile platform such as a vehicle, or on a smartphone carried by the user. Fixed sensors are installed in the environment and serve as a sensing infrastructure. Fixed sensors can be further classified to overhead sensors, in-ground sensors and surface-mount sensors which can be glued to the surface. In this chapter, we focus mainly on fixed sensors that are installed in the environment. Mobile sensors are less practical for two main reasons. First, the data collected by a mobile sensor is more complex and the detection is more challenging. For example, in ParkNet (Mathur et al., 2010) where GPS and ultrasound sensors installed on the passenger side of taxi cabs were used to detect parked vehicles, generating an accurate parking occupancy map proved to be a challenge due to the complexity of determining the location and spatial extent of parking spaces. Second, parking occupancy detection using mobile sensors usually requires a crowd-sourcing approach which involves location sharing and raises privacy concerns. When parking availability information is crowd-sourced users may choose not to share their information (free riders) or deliberately disseminate false information to keep other drivers away from particular parking spaces for their own benefit (selfish liars) (Kokolaki et al., 2013).

To select the right type of parking sensor for a particular setting several criteria must be taken into consideration. Detection accuracy is perhaps the most important criterion for the selection of a parking sensor. It is defined as the proportion of correct detections in all detection results. Ideally, a parking sensor should be highly accurate, meaning that it always detects the occupancy or vacancy of a parking space correctly. Another important criterion for the selection of a parking sensor is reliability, which specifies how consistently the sensor performs under different environmental conditions. For example, a highly accurate sensor in normal conditions might completely fail in a rainy or snowy day or in a noisy environment, and is therefore rendered unreliable. In addition to accuracy and reliability, cost is another important factor when selecting a parking sensor. Sensors that can sense multiple parking spaces concurrently usually incur lower installation costs as fewer sensors will be needed to monitor a large parking lot. Sensors that are inexpensive to install might incur high maintenance costs. For example, sensors that wear out quickly, such as contact sensors, or sensors with a high power consumption, such as active sensors that emit sound or electromagnetic waves, are more expensive to maintain.

10.3.1 Magnetic Sensors

Magnetic sensors are passive sensors that measure the earth's magnetic field along three orthogonal axes. A magnetic sensor can detect the presence of a vehicle by measuring the distortion in the magnetic field caused by the vehicle. A simple detection algorithm based on magnetic measurements is to apply a threshold to changes of the magnetic field strength with respect to reference measurements made in a vacant parking space. In practice, however, the distortion of the magnetic field varies for different types of vehicles. Even for the same vehicle the distortion in the magnetic field can vary from one point to another under the vehicle. To reduce detection errors caused by these variations, more advanced algorithms based on machine learning can be used. However, these algorithms are more computationally complex and require more data, higher sampling rates, and more computing resources, resulting in higher power consumption and faster battery drainage.

Magnetic sensors can be used in both indoor and outdoor parking spaces. In-ground and surface-mount installations are more common for magnetic sensors as these sensors have a limited range and can detect a vehicle only within a short distance. The main advantage of magnetic sensors are their low cost and low power consumption. Magnetic sensors in the market can be as cheap as $1 per unit and typically have a battery life of up to 10 years[3]. The disadvantage of magnetic sensors is their short measurement range and susceptibility to other sources of magnetic interference. The short measurement range, typically 1 meter, means that vehicles with high clearance from the ground such as trucks, vans and SUVs might be difficult to detect. Magnetic interference can be caused by overhead power lines or other passing vehicles. Another important point to consider is that modern electric vehicles are made of lightweight material, such as carbon fiber and aluminum, which may be difficult, if at all possible, to detect by magnetic sensors.

Overall, magnetic sensors are moderately accurate but are less reliable due to their short range and susceptibility to magnetic interferences. On the positive side, they are inexpensive, consume little power, and have a long battery life, resulting in low installation and maintenance costs.

10.3.2 Ultrasonic Sensors

Ultrasonic sensors are active sensors that use sound waves to measure distance to an object. An ultrasonic sensor emits ultra-high frequency (above 20 KHz) sound waves and detects the returned wave reflected off the surface of an object. By measuring the round-trip time, and assuming a constant velocity for the sound wave, the distance to the object is determined. An ultrasonic sensor can detect the presence of a vehicle by measuring the distance to the latter. A simple detection algorithm compares the measured distance to a reference distance representing a vacant parking space. A parked vehicle is detected if the absolute difference between the measured distance and the reference is larger than a distance threshold for a period of time longer than a time threshold.

Ultrasonic sensors are usually installed overhead and are more suitable for indoor parking lots because environmental conditions such as wind, rain, snow, and fog can influence ultrasonic distance measurements. Sound velocity also

[3] https://www.pnicorp.com/placepod/

varies with humidity and air temperature resulting in inaccurate distance measurements. High frequency noise, e.g., generated by a whistle or the hissing of compressed air in pneumatic devices, and multipath effects where sound waves bounce off multiple surfaces, can also influence the performance of ultrasonic sensors. Acoustic sensors that use lower frequency sound waves (below 20 KHz) are more sensitive to ambient noise and are less common for parking occupancy detection.

The detection accuracy and reliability of ultrasonic sensors are generally considered high especially for sensors installed in indoor environments. Commercial products are claimed to achieve detection accuracies up to 99.9 %[4]. However, ultrasonic sensors are relatively expensive with prices ranging from $20 to $100 per unit. They also have a moderate power consumption and require regular maintenance.

10.3.3 Infrared Ranging Sensors

Infrared ranging sensors use a similar sensing principle to ultrasonic sensors except they use infrared light instead of sound waves. The sensor emits pulses of infrared light and measures the returned light reflected off the object surface. Infrared ranging is based on either the intensity or the time of flight of the returned light. Intensity-based infrared ranging is sensitive to the reflectivity of the object surface and is therefore less reliable. Time-of-flight infrared sensors emit infrared laser light and measure the round trip time of flight of the returned light which is then converted to a distance measurement. Similar to ultrasonic sensors, detection of a parked vehicle is based on the comparison of the measured distance to a reference distance representing the absence of any vehicle.

Infrared ranging sensors can be installed overhead or on the ground[5]. However, they are generally prone to interference by ambient light and are therefore more suitable for indoor parking lots. Time-of-flight infrared sensors are less sensitive to ambient light, but broad daylight will still likely hamper the performance of an infrared sensor installed overhead in an outdoor setting. Environmental conditions such as rain and snow and obstruction by leaves or trash also influence the performance of infrared ranging especially for sensors installed on the ground.

Overall, infrared ranging sensors are considered moderately accurate but less reliable due to their sensitivity to environmental conditions. They are also relatively expensive, have a moderate power consumption and require regular maintenance.

[4] https://bit.ly/3vNN3Om

[5] https://www.nedapidentification.com/products/sensit/sensit-ir/

10.3.4 Radar Sensors

Radar, short for radio detection and ranging, is very similar to infrared ranging except it uses low frequency radio waves to make distance measurements. The radar sensor emits short pulses of low frequency radio waves, typically between 15-20 GHz, and detects the returned pulses reflected off the object surface. The distance measurement is based on the time of flight of the returned pulse. The presence of a vehicle is detected by comparing the measured distance with a reference distance representing the vacant parking space.

The main advantage of radar over infrared and ultrasonic ranging is that low frequency radio waves (corresponding to a wavelength of 1.5 to 2 cm) are not affected by small particles in the air. As such, radar sensors can operate in different weather conditions such as wind, rain, fog, humidity, and even light snow. This makes radar a reliable sensor for parking occupancy detection in both indoor and outdoor parking lots. Radar sensors can be installed overhead, in, or on the ground, although in-ground and surface-mount installations are more common[6].

Radar sensors provide high accuracy and high reliability in parking occupancy detection. However, they are more expensive and consume more power as compared to infrared sensors. Therefore, installation and maintenance costs of radar sensors are relatively high.

10.3.5 RFID Sensors

RFID, short for radio frequency identification, is a technology for the transmission of small packets of data using radio waves. It consists of a tag and a reader. For parking occupancy detection, the RFID tag is installed on the vehicle and stores information about the vehicle such as the make, model and registration details. When the vehicle is within the range of a reader installed in a parking space, the reader detects the tag, reads the data stored in it, identifies the vehicle, and determines whether it is parked in the parking space.

RFID readers can be installed in both indoor and outdoor parking spaces. Overhead installation is the common choice for RFID readers. The main disadvantage of RFID technology for parking occupancy detection is that it requires RFID tags installed on all vehicles. This is expensive and its implementation is logistically complex. An argument in favor of RFID sensors for smart parking systems is that in some cities many vehicles are already equipped with RFID tags for electronic toll collection (ETC)[7], which can be used for parking occupancy detection as well.

[6] https://www.asmag.com/suppliers/productcontent.aspx?co=nhr&id=34962
[7] https://en.wikipedia.org/wiki/E-TAG

RFID sensors can provide accurate and reliable parking occupancy information. However, installing RFID tags on vehicles and readers in parking spaces is complex and expensive. RFID tags have a low power consumption and a relatively long battery life of 3 to 5 years. Nonetheless, the maintenance cost of RFID sensors for smart parking solutions is relatively high due to maintenance needs for both tags on the vehicles and readers in the parking spaces.

10.3.6 Cameras

Imagery captured by cameras overlooking parking spaces can also be used to detect vehicles and determine the occupancy of parking spaces. This is commonly done by training a machine learning model using a set of training images and applying the trained model to the captured imagery to detect vehicles and parking spaces in real time. Determining the occupancy of parking spaces is significantly simplified if the field of view of the camera is fixed. With a fixed camera, an image can be manually segmented to delineate the parking spaces in a pre-processing step and the segmentation will remain valid for all the images as long as the field of view of the camera remains unchanged. In effect, this will reduce the vehicle detection task to a simpler image classification task. The trained model is applied to each sub-image corresponding to a parking segment and classifies it into one of two categories: vehicle or vacant. Using state of the art deep learning methods and convolutional neural networks the classification of sub-images can achieve accuracies as high as 99 % (Valipour et al., 2016; Acharya et al., 2018). An example of parking occupancy detection by classifying image segments is shown in Figure 10.2.

Figure 10.2: Image-based parking occupancy detection.

Cameras are often installed overhead and can be used in both indoor and outdoor parking lots. Image-based parking occupancy detection provides high accuracy at low cost, since cameras are relatively inexpensive and one camera can monitor multiple parking spaces. However, as passive sensors cameras are dependent on ambient light or a separate light source. Another important limitation is that the image-based approach is not a typical plug-and-play solution as the machine learning model needs to be trained on the images captured at the specific setup to achieve optimal performance. Also, to improve robustness to environmental conditions, the machine learning model must be trained on images captured in various lighting and weather conditions (e.g. rain, snow, fog, and low light). To overcome this limitation, recent works have studied the feasibility of transfer learning, where a machine learning model trained on a generic public dataset such as PKLot (de Almeida et al., 2015) is applied to images captured in a specific parking setting. Acharya et al. (2018) showed that this approach performs reasonably well but the achieved accuracy of 97 % is slightly lower than that of a model trained on images of the same parking setting (99 %).

Image-based parking occupancy detection provides high detection accuracy with moderate reliability due to its susceptibility to lighting and poor weather conditions. Cameras are relatively inexpensive to install and maintain. Also, in many cases pre-existing networks of surveillance cameras can be leveraged for parking occupancy detection.

10.3.7 Visible Light Sensors

Visible light sensors measure the intensity of ambient light in the environment. To detect the occupancy of a parking space the sensor must be installed at a point where the light is obscured by a parked vehicle. This results in a reduced light intensity measured by the sensor, which is the basis for the detection of a parked vehicle.

Visible light sensors can be installed on the ground in both indoor and outdoor parking lots. However, vehicle detection by visible light sensing is easily influenced by the lighting conditions and any changes in the intensity of ambient light can result in detection errors. Transient light sources, such as headlights of other vehicles, and shadow cast by other objects can also seriously hamper the performance of visible light sensors for parking occupancy detection.

Overall, visible light sensors are considered inaccurate and unreliable, and despite their low installation and maintenance costs their use for parking occupancy detection is not common.

10.3.8 Contact Sensors

Contact sensors include pneumatic road tubes, inductive loop detectors, and piezoelectric sensors. These sensors generate a signal when they come in contact with a vehicle's tires. A pneumatic tube generates a burst of air pressure when pressed, which is converted to an electrical signal. An inductive loop contains an inductive element and an electronics unit, which can measure a decrease in the inductance of the loop caused by a passing vehicle. A piezoelectric sensor generates a voltage when subjected to pressure, which is proportional to the pressure or the weight of the vehicle. Contact sensors are designed for moving vehicles and are mainly used for monitoring traffic flow. However, if installed properly, they are capable of detecting the occupancy of parking spaces as well.

Contact sensors are installed on the ground and are more common for outdoor usage. Piezoelectric sensors can be placed under the asphalt surface as the load can be transferred through asphalt to the sensor.[8] Contact sensors are generally considered highly reliable as they perform well under different environmental conditions. New piezoelectric sensors can precisely measure the weight and determine the class of the vehicle. On the downside, contact sensors wear out quickly and require repair and maintenance regularly. Also, piezoelectric sensors are known to be sensitive to the temperature of the ground surface (Burnos et al., 2007).

Overall, contact sensors are accurate and reliable as their performance is not influenced by the environmental conditions. They are, however, expensive to install and maintain as they wear out quickly and require regular repair and maintenance.

10.3.9 Multi-sensor Parking Occupancy Detection

Different sensors have different strengths and limitations. When the strengths and limitations of two or more sensors are complementary, it makes perfect sense to fuse their data to overcome the limitations and achieve better results. For example, an active sensor used for parking occupancy detection may be more accurate and reliable but require more power or regular maintenance. In contrast, a passive sensor may be less accurate or less reliable but require little maintenance. Combining such sensors with complementary properties can result in high detection accuracy and reliability as well as low maintenance costs. Multi-sensor systems that take advantage of the complementary properties of different sensors have the potential to maximize the detection accuracy and reliability while minimizing the costs by reducing computational requirements and power consumption.

[8] `http://diamondtraffic.com/product/Roadtrax-BL`

While several combinations of parking occupancy sensors are feasible, a common choice is the integration of magnetic and radar sensors.[9] The magnetic sensor has a very low power consumption but it is prone to magnetic interference. The radar sensor, on the other hand, is accurate and reliable, but also power hungry. In a typical fusion approach, the magnetic sensor samples the magnetic field strength continuously to detect changes that might indicate the presence of a parked vehicle. Once a change in the magnetic field strength is detected, the radar sensor emits a pulse to measure the distance accurately and reaffirm the detection result with high confidence. In this way, the integrated magnetic-radar sensor can detect parked vehicles accurately and reliably while minimizing the power consumption.

Multi-sensor approaches to parking occupancy detection generally achieve high detection accuracies with high reliability. Multi-sensor systems are, however, relatively expensive to install and require regular maintenance.

10.4 Comparison, Considerations and Open Challenges

Table 10.1 provides a summary and comparison of parking occupancy sensors in terms of accuracy, reliability, installation cost and maintenance cost. Ideally, a parking occupancy sensor should provide high detection accuracy with high reliability, and can be installed and maintained at low cost. While none of the existing technologies meet all the above requirements, multi-sensor systems, ultrasonic sensors, and cameras seem more promising. However, when selecting a sensor for parking occupancy detection, it is important to take into consideration the application environment, whether it is outdoors or indoors, as well as environmental factors, such as noise, lighting and different weather conditions.

Table 10.1: Comparison of parking occupancy detection sensors.

Sensor	Accuracy	Reliability	Installation cost	Maintenance cost
Magnetic	Moderate	Low	Low	Low
Ultrasonic	High	Moderate	High	Moderate
Infrared	Moderate	Low	High	Moderate
Radar	High	High	High	High
RFID	High	High	High	High
Camera	High	Moderate	Low	Low
Visible light	Low	Low	Low	Low
Contact	High	High	High	High
Multi-sensor	High	High	High	Moderate

[9] `https://bit.ly/3s9obOm` – Bosch, 2020

Despite the advances in parking occupancy detection a few challenges still remain. The first challenge is the lack of a comprehensive quantitative comparison and benchmarking of the accuracy and reliability of parking occupancy sensors. Different sensors have been tested in different settings on sample sets of different sizes. This makes it difficult to compare and benchmark the performance of different parking occupancy detection sensors. Another challenge is the detection of improper parking, e.g., when a vehicle is not parked within the marked lines of a parking space, or illegal parking, e.g., in a disabled parking zone. Most existing sensors are only capable of detecting the presence of a vehicle in a marked parking space, but cannot detect the event where a vehicle is parked improperly or illegally. A third challenge is the recognition of different vehicle types, which can be useful for pricing or identification of improper/illegal parking (e.g., a car parked in a bus zone). Except for the RFID technology, where the reader can read the vehicle make, model and registration information from the tag, for the other sensors accurate recognition of vehicle types remains an open challenge.

Bibliography

Acharya, D., Yan, W., and Khoshelham, K. (2018). Real-time image-based parking occupancy detection using deep learning. In Peters, S. and Khoshelham, K., editors, *Proceedings of Research@Locate18*, volume 2087, pages 33–40. CEUR Workshop Proceedings.

Burnos, P., Gajda, J., Piwowar, P., Sroka, R., Stencel, M., and T., Z. (2007). Measurements of road traffic parameters using inductive loops and piezoelectric sensors. *Metrology and Measurement Systems*, 14(2):187–203.

de Almeida, P. R., Oliveira, L. S., Britto, A. S., Silva, E. J., and Koerich, A. L. (2015). PKLot – a robust dataset for parking lot classification. *Expert Systems with Applications*, 42(11):4937–4949.

Kokolaki, E., Kollias, G., Papadaki, M., Karaliopoulos, M., and Stavrakakis, I. (2013). Opportunistically-assisted parking search: A story of free riders, selfish liars and bona fide mules. In *2013 10th Annual Conference on Wireless On-demand Network Systems and Services (WONS)*, pages 17–24.

Mathur, S., Jin, T., Kasturirangan, N., Chandrasekaran, J., Xue, W., Gruteser, M., and Trappe, W. (2010). Parknet: Drive-by sensing of road-side parking statistics. In *Proceedings of the 8th International Conference on Mobile Systems, Applications, and Services*, MobiSys '10, page 123–136. Association for Computing Machinery.

Valipour, S., Siam, M., Stroulia, E., and Jagersand, M. (2016). Parking-stall vacancy indicator system, based on deep convolutional neural networks. In *2016 IEEE 3rd World Forum on Internet of Things (WF-IoT)*, pages 655–660.