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Bluetooth-controlled Parking System Based on WiFi Positioning Technology

Hsin-Chuan Chen,[1] Rong-San Lin,[2*] Chiou-Jye Huang,[3**] Lidan Tian,[1] Xining Su,[1] and Haikun Yu[1]

[1]School of Computer Engineering, University of Electronic Science and Technology of China, Zhongshan Institute, Zhongshan 528402, China
[2]Department of Computer Science and Information Engineering, Southern Taiwan University of Science and Technology, Tainan 71005, Taiwan
[3]Department of Data Science and Big Data Analytics, Providence University, Taichung 43301, Taiwan

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Nowadays, modern parking systems are developing towards automatic vehicle identification. Since the applications of mobile WiFi and Bluetooth signals are very popular and mature, in this paper, we propose an intelligent parking management system based on the technologies of WiFi positioning and Bluetooth control to manage vehicles entering or exiting a parking lot. Only a dedicated app for the parking lot needs to be installed on a user's mobile phone. When the user is driving near the parking lot, the mobile phone can send the vehicle ID via a Bluetooth signal after WiFi positioning to communicate with the Bluetooth sensor module of the roadside unit (RSU) of the parking lot. Then the RSU end can automatically identify the vehicle. Owing to its convenience, practicability, and low cost, such a parking system using Bluetooth identification based on WiFi positioning is worth popularizing.

1. Introduction

For operational convenience and intelligent management, a developing trend for modern parking lots is to perform the automatic identification of vehicles. Automatic vehicle identification (AVI), such as through license plate recognition, increases the safety, security, and supervision of a system by using hands-free access technologies, providing comfort and convenience for drivers entering or exiting a parking area.(1,2) However, such a parking system has a higher cost due to more equipment required, and its identification rate is not 100% because image recognition is easily affected by many environmental factors such as license plate defacement, light, and the angle of imaging.(3,4) Some image processing technologies can be used to enhance the performance of parking systems using license plate recognition. For example, a lightweight and high-performance multi-angle license plate character recognition model was proposed to reduce the complexity and computational complexity of traditional license plate recognition, whose identification rate was as high as 84.5%.(5) Alternatively, an automated car parking system that deploys a robust vehicle and face detector combined with a

*Corresponding author: e-mail: rslin@stust.edu.tw
**Corresponding author: e-mail: cjh1007@pu.edu.tw
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set of face recognition algorithms was proposed by Mahmood *et al.* to improve the efficiency of system management.(6) Two optical sensors, with the length between them varied between about 3.9 and 5.54 m in accordance with the length of the vehicle, were placed on the sides of a passageway to distinguish whether a vehicle was moving through the passageway.(7) Therefore, such a sensing technology can also be applied to a parking system. In the Electronic Toll Collection (ETC) system of freeways using E-tag IDs,(8,9) the RFID reader at the roadside unit (RSU) end can automatically identify a vehicle by reading a passive E-tag pasted on the vehicle windshield. If an active E-tag is used to achieve a larger working range, it is necessary to install an on-board unit (OBU) device with a transmitter and battery in the vehicle.(10) However, if this method is applied to a parking system, people may be concerned that the high-power RF radiation from an RF station installed near their homes will harm human health.(11) Moreover, the RF band used by the ETC system partially overlaps with that presently used for mobile communication, which may cause interference when using mobile phones, and the system cost is still high.(12) Because of its low implementation cost, safety, and easy operation, an IR-based parking system(13) using IR communication is suitable for small and medium-size parking lots. However, sunlight or fluorescent light easily disturbs IR communication. Moreover, an OBU device must be installed on the windshield of the vehicle when an RSU system adopts IR communication.(14) An IR parking system using a split transmitter/receiver (TX/RX) installation on an RSU end has been proposed, where the TX and RX modules of the RSU end and the OBU device were placed facing upward and downward, respectively. This system not only reduced the impact of sunlight on the receiver module of the OBU device, but also reduced the signal interference caused by two neighboring vehicles in the sensing zone.(15)

Recently, the mobile phone has become a necessary and important communication tool, and it supports versatile communication styles such as WiFi and Bluetooth. As reported in this paper, we have attempted to build an intelligent and convenient parking management system that uses a mobile phone instead of an OBU device to check whether a vehicle has arrived near a parking lot through WiFi positioning, and then communicates with the Bluetooth sensor module of the RSU system. Therefore, the vehicle can be automatically identified through Bluetooth communication. This paper is organized as follows. Section 2 describes the basics of WiFi positioning technology. Section 3 introduces the proposed Bluetooth-controlled parking system based on WiFi positioning. Section 4 illustrates the implementation of the proposed parking system and provides experimental results. Finally, Sect. 5 summarizes the features and performance of the proposed parking system.

2. WiFi Positioning Technology

GPS, a commonly used radio navigation and positioning technology,(16–18) receives information from satellites to provide accurate geographic locations, vehicle speeds, and time information anywhere in the world. GPS has more precise positioning information than other methods; however, it cannot work in an indoor or underground environment without satellite signals, and it has a start-up delay and high power consumption. Owing to the rapid development of mobile phones, WiFi positioning(19) has become an important technology for retrieving position information.

2.1 Basic concepts

In the WiFi network shown in Fig. 1, each wireless access point (AP) has a unique MAC address in the world. When the mobile device turns on the WiFi function, it can scan and collect the surrounding AP signals. Regardless of whether the AP is encrypted or not, connected or not, or has a low received signal strength indication (RSSI) level, the mobile device can obtain the MAC address broadcast by the AP.(20) The mobile device sends the data that can indicate the AP to the location server, and then the server calculates the geographic position of the device according to the location and RSSI of each AP and returns it to the user's device. To obtain higher position accuracy in an indoor environment, the widely used positioning approach called the position fingerprint algorithm(21,22) is employed as an estimator that collects the received RSSI measurements to generate location fingerprints and then computes the most likely position of the user. This approach requires few hardware resources and has a low computation cost.

2.2 Distance estimation

The RSSI level is used to measure the distance between the transmitter and the receiver in wireless communication, and it is inversely proportional to the distance. The power at the receiver end P_R (i.e., the RSSI level) in dBm is given by the following formula:(23)

$$RSSI = P_R = -10\eta \log_{10} D + P_1, \tag{1}$$

where P_1 is the power of a signal measured at 1 m distance as a reference and η denotes a factor depending on the environment. Therefore, the sensing distance D can be estimated by

$$D = 10^{\frac{P_1 - P_R}{10\eta}} = 10^{\frac{P_1 - RSSI}{10\eta}}. \tag{2}$$

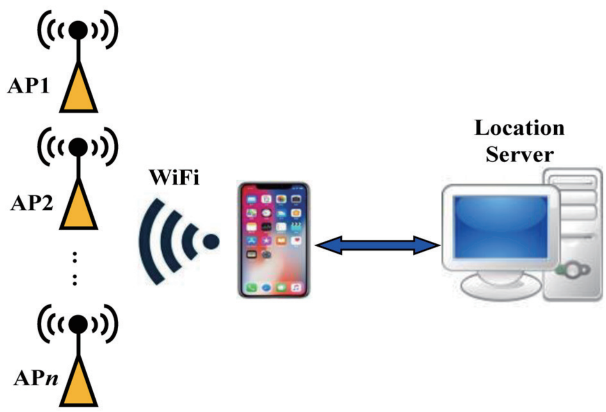

Fig. 1. (Color online) Basic structure of WiFi positioning.

In the system proposed in this paper, when the vehicle approaches the parking lot, the distance from the parking lot is estimated from the RSSI level while finding the WiFi service set identification (SSID) of the parking lot, so as to determine whether the vehicle can start an identification operation with the RSU equipment through Bluetooth communication.

2.3 Comparison

Table 1 shows a comparison of WiFi positioning and GPS positioning in terms of the environment, accuracy, power consumption, and cost.(24) Although the accuracy of WiFi positioning is lower than that of GPS positioning in open areas, it has the advantages of not being limited to an outdoor environment and a low cost. In addition, for low-power mobile devices, the power consumption of WiFi positioning is less than that of GPS positioning.

3. Proposed Parking System

To build a parking system without an OBU device on the vehicle, we use a mobile phone to replace the OBU device, which can find the location of the vehicle by WiFi positioning and communicate with the RSU equipment through Bluetooth signals to control the parking fence. The design details of this proposed parking system will be described in the following subsections.

3.1 Architecture

Figure 2 shows a schematic diagram of the overall architecture of the proposed Bluetooth-controlled parking system based on WiFi positioning,(25) where the mobile phone is placed in the vehicle to replace the conventional OBU device. The RSU equipment is composed of five parts as shown in Fig. 3,(25) where an embedded system platform is used as the main controller of the RSU equipment, which can communicate with the WiFi router and Bluetooth sensor module and control the parking fence and CCD camera. In addition to providing the SSID of the parking lot as part of WiFi positioning, the WiFi router can also be used as a communication device inside the parking lot. Moreover, the Bluetooth sensor module shown in Fig. 4 consists of a Bluetooth chip with a built-in Bluetooth transceiver, an antenna pad, and USB/UART ports,(26) and it is used to identify the vehicle ID. At present, Bluetooth 4.x operates in the 2.4 GHz band(27) and uses the technology of Gaussian frequency shift keying (GFSK) modulation,(28) with very low power consumption in the running mode and standby mode. For the further monitoring of vehicles that enter or leave the parking lot, an auxiliary CCD camera is used to take photos of the vehicles.

Table 1
Comparison between WiFi positioning and GPS positioning.

Positioning method	Environment	Accuracy	Power consumption	Cost
WiFi	Indoor/Outdoor	Medium	Low	Medium
GPS	Outdoor	High	High	High

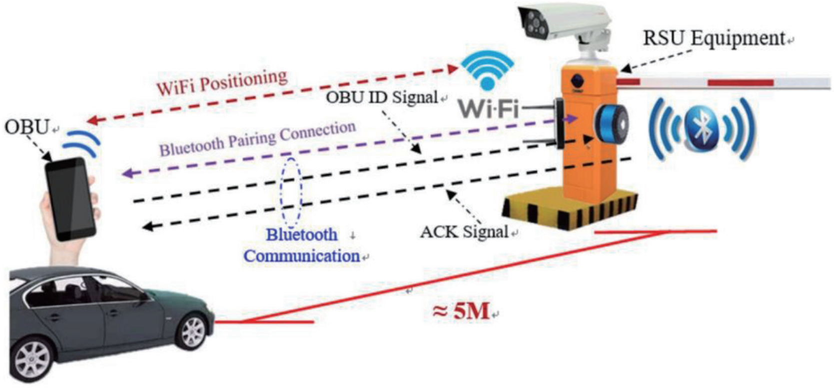

Fig. 2. (Color online) Schematic diagram of proposed parking system.

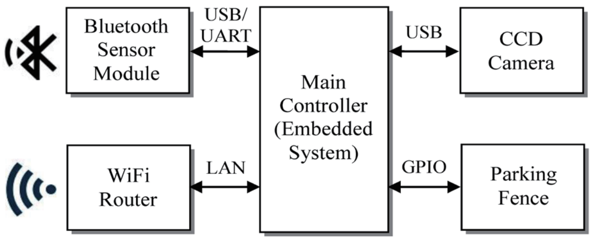

Fig. 3. Structure of RSU equipment.

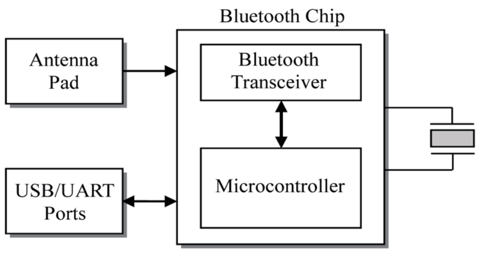

Fig. 4. Structure of Bluetooth sensor module.

3.2 Principle

According to the illustration of Fig. 2, the operation flowchart of the proposed parking system can be divided into two parts: those of the mobile phone app and the RSU equipment, as shown in Figs. 5 and 6, respectively. The operation details(25) are described as follows.

1. Firstly, the user's mobile phone needs to install the dedicated app for the parking lot, and the phone must be placed in the vehicle when the user drives it.
2. When the vehicle arrives near the entrance/exit of the parking lot, the mobile phone automatically searches for the SSID signal sent by the WiFi router of the parking lot.
3. When the mobile phone finds the SSID from the WiFi router of the parking lot but does not need to connect with the router, the distance from the parking lot is estimated according to the RSSI signal to determine whether the vehicle has been close to the parking lot.
4. If the vehicle is about 5 m from the parking lot, then the app of the mobile phone requests a pairing connection with the RSU equipment of the parking lot through Bluetooth communication.
5. If the connection is successful, the app will automatically send the identification (ID) code of the vehicle.
6. When the RSU equipment receives the ID code, it checks whether the ID code exists in the database of the parking lot.

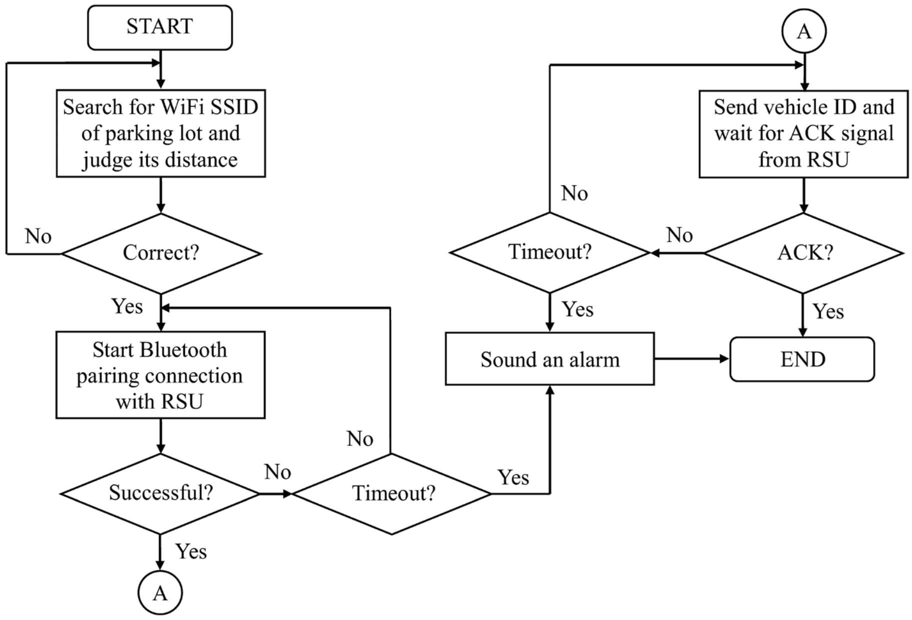

Fig. 5. Operation flowchart of mobile phone's app.

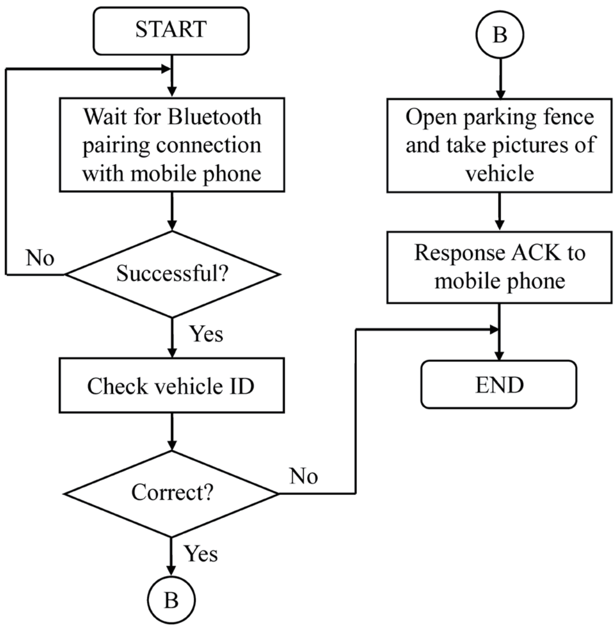

Fig. 6. Operation flowchart of RSU equipment.

7. If the ID code exists in the database, the RSU equipment opens the parking fence and takes a photo of the vehicle to assist the system management.
8. At the same time, an acknowledgment (ACK) signal is sent back to the mobile phone to ensure the correct handshaking between the mobile phone and the RSU equipment via Bluetooth communication.

9. If the phone does not receive the ACK signal or the verification fails, the app will repeatedly send the ID signal to request verification until timeout.

3.3 Protection against erroneous operation

When the user leaves the vehicle with his/her mobile phone and walks around the entrance/exit of the parking lot, the mobile phone app still detects the SSID from the WiFi router of the parking lot, which may cause erroneous operation of the system. To avoid this situation, the app can check whether the built-in Bluetooth device of the vehicle has been found to detect whether the mobile phone is placed in the vehicle. For example, if the vehicle is equipped with an audio device with Bluetooth transmission, then this equipment is set as the default Bluetooth device by the dedicated app of the parking lot, which is used to detect whether the mobile phone is still in the vehicle. When the user carries the mobile phone into the vehicle, the application will automatically query whether to find the audio device. If requested, it will start to work as an OBU device. Once the mobile phone is removed from the vehicle, the app does not find the audio equipment at its Bluetooth device list and it will immediately stop finding the SSID of the WiFi router in the parking lot. In contrast, if the mobile phone is brought into the vehicle, the app starts again.

3.4 Benefits

Conventional parking systems, such as those using IR communication or an active RFID tag, require an OBU device to be installed in vehicles. People may complain that the installation of the OBU device will adversely affect the aesthetic feeling of the vehicle interior, and the power supply of the OBU device is also a problem. The proposed parking system adopts a mobile phone with the installed dedicated app as an alternative to the OBU device, which makes it more convenient for people to use. Bluetooth communication between the mobile phone and the RSU equipment is realized only when the vehicle has approached near the parking lot through WiFi positioning. This will help reduce the power consumption of the mobile phone, as well as the power consumption of the RSU equipment since it does not need to send an induced signal regularly. Moreover, the overall cost of the proposed parking system is lower than that using other identification methods.

4. Experimental Results

In our experiment, a Linux-based embedded system module, Raspberry Pi Model B (Pi_3B+),[29] was used as the main controller. It adopts an ARM Cortex-A53 processor, which is a 1.4 GHz 64-bit quad-core processor, and provides versatile interfaces such as GPIO, USB, SPI, I2C, and LAN. Since the Pi_3B+ has its own on-board Bluetooth chip controlled by a UART port to support a low-power communication function of Bluetooth 4.2/BLE, no extra Bluetooth dongle is required in the RSU equipment of the proposed parking system. A 450 Mbps TL-WR886N wireless router[30] was used to create a WiFi SSID of the parking lot, which can cover a range of about 100 m.

4.1 App development

A dedicated app was developed for the parking lot, and it was implemented by using Java on the Android-based operating system of the mobile phone. The functions of this app shown in Fig. 7 include user management, WiFi positioning, and Bluetooth communication, and Fig. 8 shows the main page of the completed app.[25]

4.2 Technical details of WiFi positioning

SSID search and distance estimation are two important issues for realizing the WiFi positioning function on a mobile phone, and thus this subsection introduces some related technical details of the Android system as follows. Firstly, location permission can be added dynamically by using the ActivityCompat.requestPermissions() function. That is because if Android 6.0 or above does not dynamically add permissions, the search result of the WiFi list will be empty. Therefore, a thread is defined to constantly notify Android Handler to update the list. When Handler receives the message, it instantiates the WifiManager API (Application Program Interface), which is used to manage all aspects of WiFi connectivity, and the WiFi list is obtained by the WifiManager.getScanResults() function to complete the SSID search.

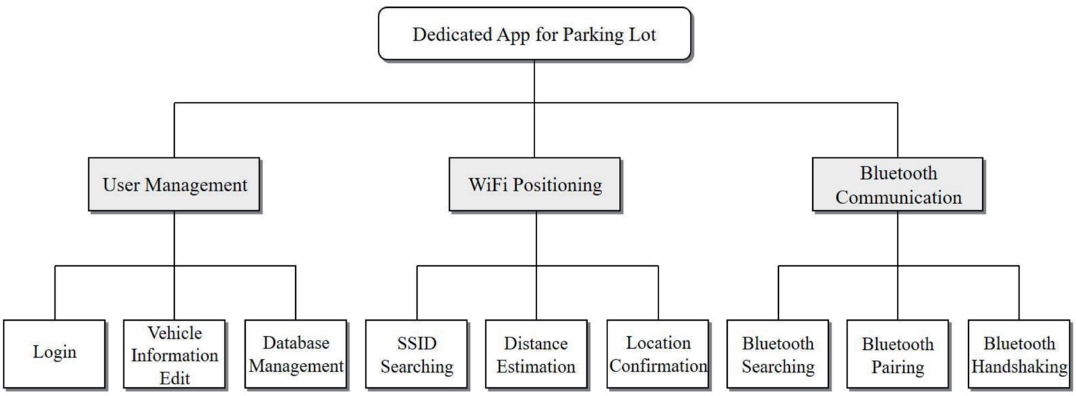

Fig. 7. Functional architecture of app.

Fig. 8. (Color online) Main page of app provided by parking lot.

Furthermore, the distance is estimated by a self-built function, which calculates the distance through Eq. (2) according to the RSSI signal strength corresponding to the SSID of the parking lot. Finally, the app checks whether the vehicle is close to the desired sensing range of the parking lot.

4.3 Measurement for identification rate

According to the measurement results shown in Table 2,[25] we found that the WiFi strength received by the mobile phone in the vehicle decreased with increasing distance from the WiFi router. Although a distance of 10 or 15 m is still within the sensing range of the Bluetooth signal, the identification rate of vehicle IDs is not optimal; moreover, these distances are expected to be too far to satisfy the actual application of a parking lot. When the chosen sensing distance is 5 m, the WiFi strength is −50 dBm and the Bluetooth signal can be detected, and thus the identification rate will reach 100%.

4.4 Estimation of power consumption

From the perspective of power consumption in Bluetooth communication, the Bluetooth power consumption of the mobile phone is about 60 mW for each pairing, data transmission, and reception between the mobile phone and the RSU equipment, while the RSU equipment consumes slightly more power than the mobile phone. As shown in Fig. 9, within a distance of

Table 2
Measurement results.

Distance (m)	WiFi strength (dBm)	Bluetooth detection	Identification rate (%)
1	−35	√	100
5	−50	√	100
10	−54	√	90
15	−60	√	20
20	−63	×	0

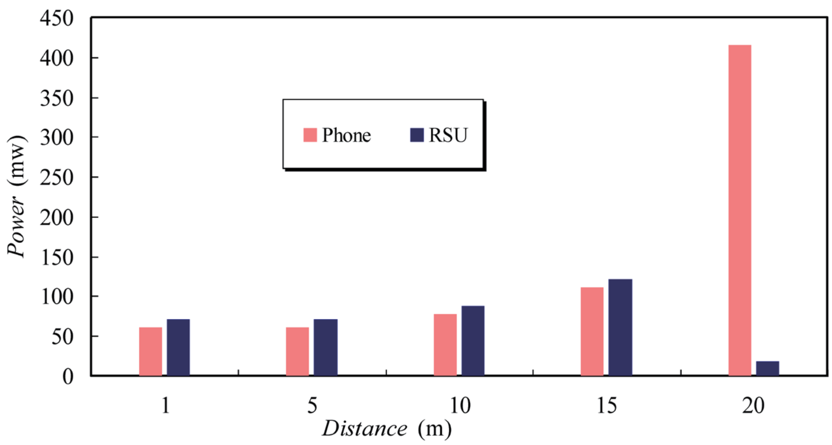

Fig. 9. (Color online) Power consumption for Bluetooth communication.

5 m, only one Bluetooth communication is required for correct identification. However, the identification rate decreases with increasing distance. Since the mobile phone and the RSU equipment require frequent Bluetooth handshaking, but do not need re-pairing, the Bluetooth power consumption will also increase. When the distance reaches 20 m, because the mobile phone and the RSU equipment cannot connect with each other, the mobile phone will ask for a pairing connection many times until timeout; therefore, the Bluetooth power consumption will increase greatly. However, the RSU equipment only consumes a small amount of Bluetooth standby power.

5. Conclusions

On the basis of WiFi positioning and Bluetooth control of the mobile phone, an innovative and intelligent parking system without an OBU device that makes it more convenient for people to drive in and out of a parking lot is proposed in this paper. The experimental results showed that the RSU equipment had a high identification rate at a distance of 5 m. Since the mobile phone starts to communicate with the RSU equipment through Bluetooth communication after WiFi positioning, the power consumption of the mobile phone and RSU equipment is reduced. Moreover, the proposed parking system has low hardware complexity compared with the other parking systems, making it suitable for indoor and outdoor parking lots.

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