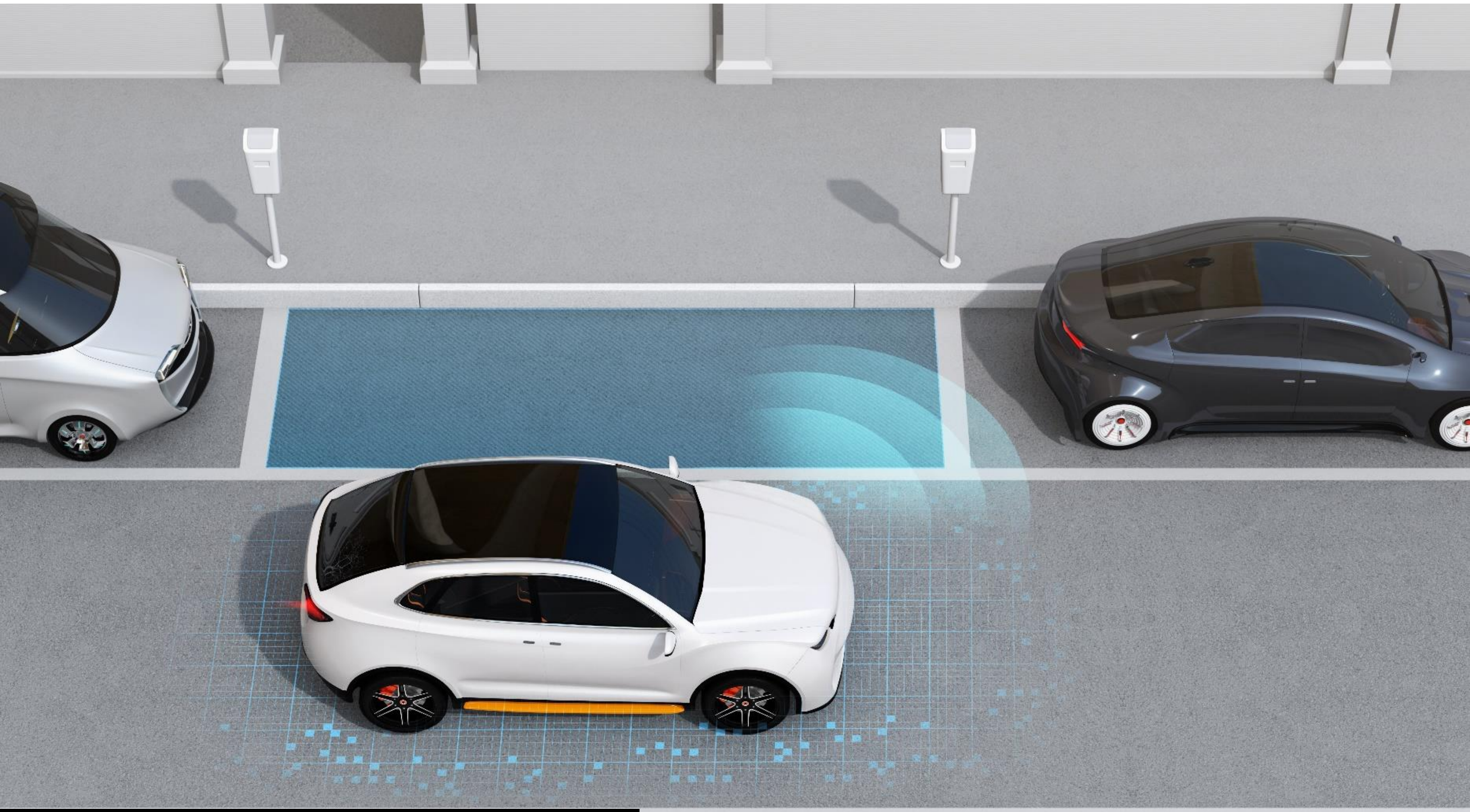
Automated Valet Parking:
Sensing Technology Challenges and Solutions



APPLICATION NOTE

At first glance, automated valet parking (AVP) may seem like a basic, simple function to develop and implement. Countless cars are being parked every day, the speed limit in parking lots is quite low – the average speed in parking lots often varies between 10 and 20 km/h – and the task of parking is relatively straightforward. Such typical tasks associated with valet parking include dropping the passenger and driver off at the entrance of a destination, steering left or right to engage in an alley, identifying a free parking space, and backing up in this parking space. Still, developing a reliable, automated valet parking system proves to be quite challenging. In the following pages, we will explore these challenges and look at use cases and the sensing technologies involved to resolve such challenges.

Challenges

In AVP, in addition to achieving its primary tasks, the vehicle must be able to guide itself through complex infrastructures and to safely react to unpredictable situations, all of this in variable environmental conditions.

Challenging Infrastructures

A prime example of challenging parking infrastructure is the spiral pathway used by a car when changing levels in an indoor parking lot. The numerous bumper marks and car paint scuffs routinely found on their concrete walls testify to the challenge of this driving situation induced because of the short distance between the wall and the vehicle and the low number of surrounding objects available for our brain to use as a distance or size reference.

Figure 1 – Spiral pathway in an underground parking lot

As well, exiting an indoor parking lot on a bright sunny day may turn out to be difficult as strong lighting contrasts reduce the visibility ahead.

Also, some areas only have parallel parking spots, which can be troublesome for drivers who are unfamiliar with this.

Figure 2 –Parking exit with changing light conditions

Figure 3 – Narrow parallel parking

An Unpredictable Environment

Parking lots are unpredictable environments where vehicles and pedestrians can emerge unexpectedly. Navigating them may prove stressful, especially for the inexperienced driver. With time, however, these tasks appear much more straightforward and require less concentration as the driver improves his skills and gains experience.

An AVP system must be able to quickly react to unpredictable events. Automated systems, like drivers, also need to build their own “instinct,” which requires a significant amount of training.

Figure 4 – Parking lots are complex, unpredictable environments

Challenging Environmental Conditions

Parking in harsh weather conditions is a burden that users will expect the AVP solution to resolve, after dropping all passengers off at the door. This is challenging both for autonomous systems and humans. In situations where there is rain, snow, or fog, the visibility is reduced, making it harder to see objects ahead of time and react to various situations. In addition, the sensors can be covered with water droplets or snow, resulting in decreased performance. Also, the appearance of the pavement changes, being either wet or covered with snow, which makes the control of the vehicle itself even more challenging.

Figure 5 – Reduced visibility due to snow

Considering that lives are at risk, we expect that automated systems will outperform human drivers. Vehicles equipped with automated valet parking must be able to navigate through challenging infrastructures, react to unpredictable events, and remain reliable throughout changing environmental conditions, which requires very sophisticated hardware and software.

Autonomous Valet Parking Implementations

Today, many passenger cars have park assist systems that help the driver during the parking process. Such systems require that the driver navigates the vehicle through the parking lot while the system locates a vacant space. Once a parking space has been identified, the driver may leave the steering control to the system but must keep control of the speed of the vehicle and the braking system. In the automated valet parking context, the vehicle needs to be able to execute its core function as well as to react to events coming from the outer environment without requiring human intervention. In these conditions, AVP becomes so complex that some companies developing AVP are looking into adapting the infrastructures and even creating specific robotic platforms as a first step to fully automated valet parking. For example, Bosch/Daimler has adapted an underground lot with external sensors to facilitate the navigation of a vehicle to a parking space[1], while Stanley Robotics has created a robotic platform to move the vehicles in a reserved parking area[2].

Detection Systems: Use Cases for AVP

The challenges presented above highlight many typical AVP use cases and key related system requirements. The system must detect vulnerable road users such as pedestrians at sufficient range, perform well with short-range detection to execute the parking maneuver, and remain functional in adverse weather conditions. The next section dives deeper into these use case examples and the different technologies that are best adapted for each of them.

Vulnerable Road User (VRU) Detection

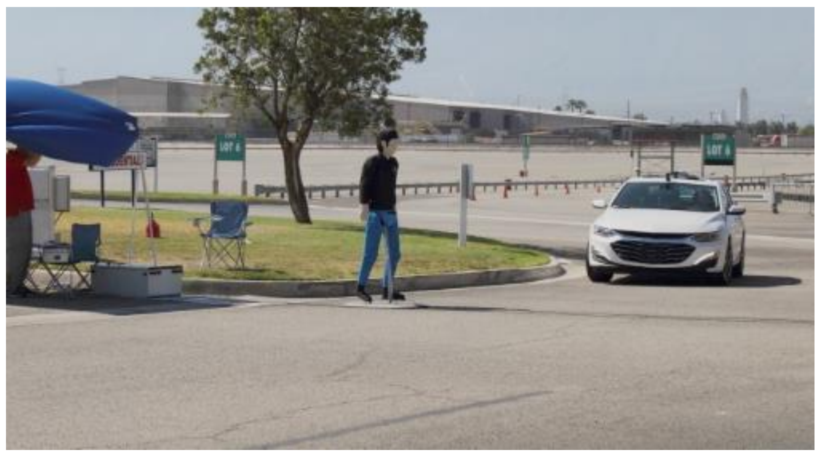


Figure 6 – Testing of pedestrian detection systems (source: AAA)

In a parking lot, pedestrian behaviors are difficult to predict and may require an abrupt reaction from the AVP system. The system must be able to detect pedestrians at up to 20 m for predictable behaviors and be highly reliable at shorter ranges (from 0 to 10 m) to account for unpredictable behaviors. At a speed of 20 km/h, if we consider a comfortable braking deceleration, it will take about 10 m to bring the vehicle to a full stop, to which a security factor must be added to enable the initial identification of the pedestrian.

AEB (Automatic Emergency Braking) systems deployed today relate to detecting VRUs in a similar fashion as the AVP scenario. Most of the time, AEB systems use cameras and radars. The camera is mainly used for pedestrian classification, which contributes to predicting the movement of the pedestrian, whereas radar is used to detect an object and determine its distance. The American Automobile Association (AAA) has conducted a series of tests related to AEB and the results with current systems were generally disappointing: at a speed of 30 km/h, the vehicles struck the adult pedestrian (EURO NCAP dummy) 60% of the time. The results were even worse with a child pedestrian (EURO NCAP dummy), who ended up being struck by the vehicle 89% of the time[3].

Although the speed of these AEB tests was greater than the typical speed for AVP, their results demonstrate the challenges related to reliable VRU detection. Part of this difficulty is related to the pedestrian's composition and

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1 https://specials-images.forbesimg.com/imageserve/5d36e64c95e0230008f64b79/960x0.jpg?fit=scale

2 https://www.vinci-airports.com/en/news/innovation-vinci-airports-and-stanley-robotics-continue-their-collaboration-and-extend-number

3 Automatic Emergency Braking With Pedestrian Detection; AAA, Oct. 2019. https://www.aaa.com/AAA/common/aar/files/Research-Report-Pedestrian-Detection.pdf?cjevent=6f45a9e15fef11ea811d04520a240613&utm_medium=affiliate&cmp=AFC_membership_na_prospecting_affiliate_MWG

their lateral movements, which are challenging for radar systems. Hence, the addition of LiDAR to the AEB and AVP system sensor suite is expected to contribute to enhancing both pedestrian detection quality and reliability[4].

Accurate Short-Range Detection

Achieving reliable short-range detection is crucial to execute parking maneuvers around cramped infrastructures, narrow parking spaces, and surrounding vehicles. For parallel parking, in some countries or States, a vehicle must be parked within 30 to 45 cm from the curb. If the sensors are not accurate enough, the result could be a vehicle that is parked much too far from the curb or, conversely, runs over it.

Figure 7 – Curbside parking can prove challenging for many drivers

Furthermore, parking spaces are sometimes bordered by pillars and pedestrian zones delineated by borders. Inaccurate short-range detection may result in damaging both the vehicle and the infrastructure. AVP systems must avoid overdriving concrete parking lot stops and be able to differentiate them from speed bumps, which are common in parking lots and do not require a complete stop.

In light of the above, the sensors used must enable close detection with a strong level of confidence.

Figure 8 – Damaged pillars

Figure 9 – Parking lot stops

Ultrasonic sensors (sonars) are often used for short-range detection, being affordable and easy to integrate with the vehicle design due to their small size. However, because this technology uses sound signals which are more sensitive to the outside environment, some situations can prove more challenging for sonars. For example, curved areas might cause the sonar signal to be thrown off (Figure 10), and even wind could blow away and fade the signal.

4 https://newsroom.aaa.com/2019/10/aaa-warns-pedestrian-detection-systems-dont-work-when-needed-most/

Camera sensors also face challenges for short-range detection. For example, when light and color contrasts are lower, it can then be very difficult to differentiate between a speed bump on which the color has run off and the road surface (Figure 11), which could lead the vehicle to maintain its speed across the bump.

Figure 10 – Curved curb throws off the ultrasonic signal

Figure 11 – Paint faded on speed bump

With radars, a low resolution can make detection less accurate at short range. Furthermore, a confined environment with closed walls such as underground parking lots can create interference and make it difficult for radars to accurately detect objects at short range.

For LiDAR, part of the difficulty lies with narrow beam divergence, which is designed for longer-range detection. This results in high saturation on short-range detection, which reduces the accuracy of the measurements. This may also impact the scene coverage, depending on the resolution of the sensor. Having narrow beam divergence leaves gaps between the LiDAR signal lines, which could result in small objects such as parking stoppers going undetected. Some LiDARs are optimized for short range and have features such as adapted power emission, avoiding short-range saturation, and are also designed with broader beam divergence enabling less false-negative detections.

Performance in Adverse Weather Conditions

For flawless performance in diverse environmental conditions, the AVP system must be able to recognize these different environmental conditions and adapt its driving behavior accordingly. In many cases, a lower speed may be required since the visibility will be reduced and, in some cases, the stopping distance will be greater, such as with rain and snow which affect the friction coefficient between the road and the tires. For an overall AVP system to perform well in these conditions and generate the correct instructions, the sensors and the perception system also need to work together consistently.

For light-based sensors like LiDARs and cameras, fog and rain are amongst the most challenging environmental conditions to operate in. Their effects on these sensors are relatively similar to the ones experienced by human vision.

Figure 12 – Reduced visibility due to fog

As fog is composed of very small particles of water, its impact on visibility can be explained mainly by the absorption of energy and the scattering of light. Rain will have a higher impact than fog, with physical particles accumulating on the surfaces such as the road and the vehicles, changing their reflectivity, and with water droplets on the sensor lens obstructing the emitted and received light. These negatively impact the system's level of confidence to detect the objects, to determine their distances, and to identify their nature.

Radars, in contrast, perform well in most adverse weather conditions, especially in fog and light rain. Radars are somewhat affected by heavy rain (>~25 mm/h)[5], although less than light-based sensors. Nevertheless, even in less demanding environments, radars alone do not provide enough information to ensure safe autonomous driving, as explained in the use cases discussed.

For perception systems, the overall difficulty is to achieve algorithms that perform efficiently both in optimal and in adverse weather conditions. Datasets that include all types of scenarios in all weather conditions are required, as the images and the data received from the sensors for a given scenario will be altered by environmental conditions.

As reported in a recently published research paper entitled *"Weather Influence and Classification with Automotive LiDAR Sensors*[6]*"*, addressing the challenges of adverse weather not only requires addressing high sensory requirements; it is also *"[…] of utmost importance to know potential degradation of different sensor types and mitigate their impact. To develop a truly autonomous vehicle, it needs to recognize system boundaries without external intervention and react accordingly to master all environmental impairments."*

Conclusion

According to the Insurance Institute for Highway Safety, about one in five car accidents occurs in parking lots and garages, despite common features such as speed bumps, narrow lanes, and slow speed limits[7]. Parking lots are challenging both for human drivers and for autonomous systems due to the infrastructure, unpredictable

5 https://dense247.eu/fileadmin/user_upload/PDF/1805_DENSE_A4_factsheet_v1.2.pdf
6 https://arxiv.org/pdf/1906.07675.pdf

environment, and changing environmental conditions. Hence, developing AVP systems prove to be complex projects that require significant investment. The use cases presented above are concrete examples that illustrate the need to leverage various sensing technologies that are complementary and can offer redundancy to cover all possible situations.

In order to weigh sensor modalities optimally in various scenarios, it is important to reliably classify available sensors' performance against each scenario. In the sensor suite for AVP, camera technology stands out for identifying various features, radar for its performance in adverse weather conditions, and short-range LiDAR for its good accuracy on short-range and small object detections. A fusion of sensor modalities and exceptional perception technology are necessary to not only enable AVP but all future ADAS and AD driving applications.

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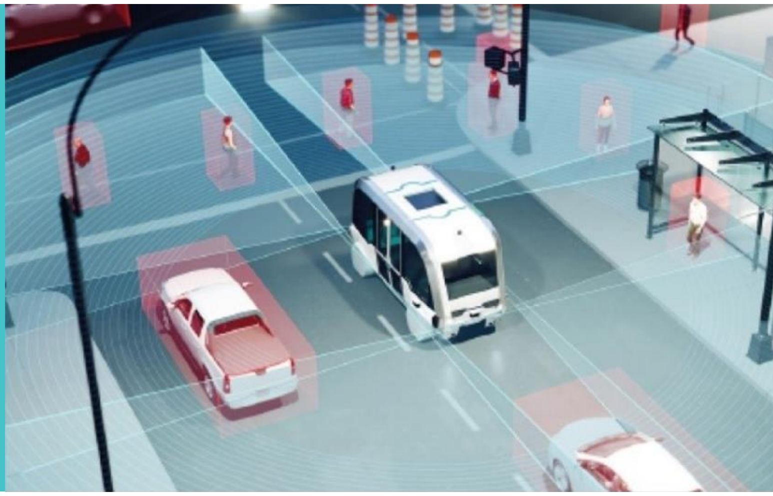
[7] https://rates.ca/resources/car-accidents-parking-lots-fault

About LeddarTech

LeddarTech is a leader in environmental sensing solutions for autonomous vehicles and advanced driver assistance systems. Founded in 2007, LeddarTech has evolved to become a comprehensive end-to-end environmental sensing company by enabling customers to solve critical sensing and perception challenges across the entire value chain of the automotive and mobility market segments with its LeddarVision™ sensor-fusion and perception platform. LeddarTech delivers a cost-effective, scalable, and versatile LiDAR development solution to Tier 1-2 automotive system integrators that enables them to develop automotive-grade solid-state LiDARs based on the foundation of the LeddarEngine™. LeddarTech has 14 generations of solid-state LiDARs based on the LeddarEngine™ platform operating 24/7 in harsh environments. This platform is actively deployed in autonomous shuttles, trucks, buses, delivery vehicles, smart cities/factories, and robotaxi applications. The company is responsible for several innovations in cutting-edge automotive and mobility remote-sensing applications, with over 80 patented technologies (granted or pending) enhancing ADAS and autonomous driving capabilities.

For more information: sales@leddartech.com



LeddarTech®

CANADA – USA – AUSTRIA – FRANCE – GERMANY – ITALY – ISRAEL – HONG KONG – CHINA

Head Office
4535, boulevard Wilfrid-Hamel, Suite 240
Québec (Québec) G1P 2J7, Canada
leddartech.com

Phone: + 1-418-653-9000
Toll-free: + 1-855-865-9900