Acta Polytechnica CTU Proceedings **51**:29–35, 2024
`https://doi.org/10.14311/APP.2024.51.0029`

AUTONOMOUS DRIVING WITH A FOCUS ON HMI FOR PARALLEL PARKING MANEUVERS

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Abstract. Autonomous vehicles remain a major topic in the automotive industry today, including assistance systems, cooperative communication, and other aspects that lead to full vehicle autonomy. This paper investigates vehicle autonomy with a focus on parking assistance. Along with a review of parking assistants, the paper presents a prototype parking assistant with an alternative distance display. The parking assistant prototype, compared to parking without an assistant and conventional parking assistant, was tested in a real-world experiment of a within-subjects study design. The user experience of the proposed distance representation was obtained, and the results indicated that the prototype parking assistant with an alternative distance display helps less experienced drivers get a better idea of the distance from the obstacle.

Keywords: Parking assistance, in-car display, ADAS.

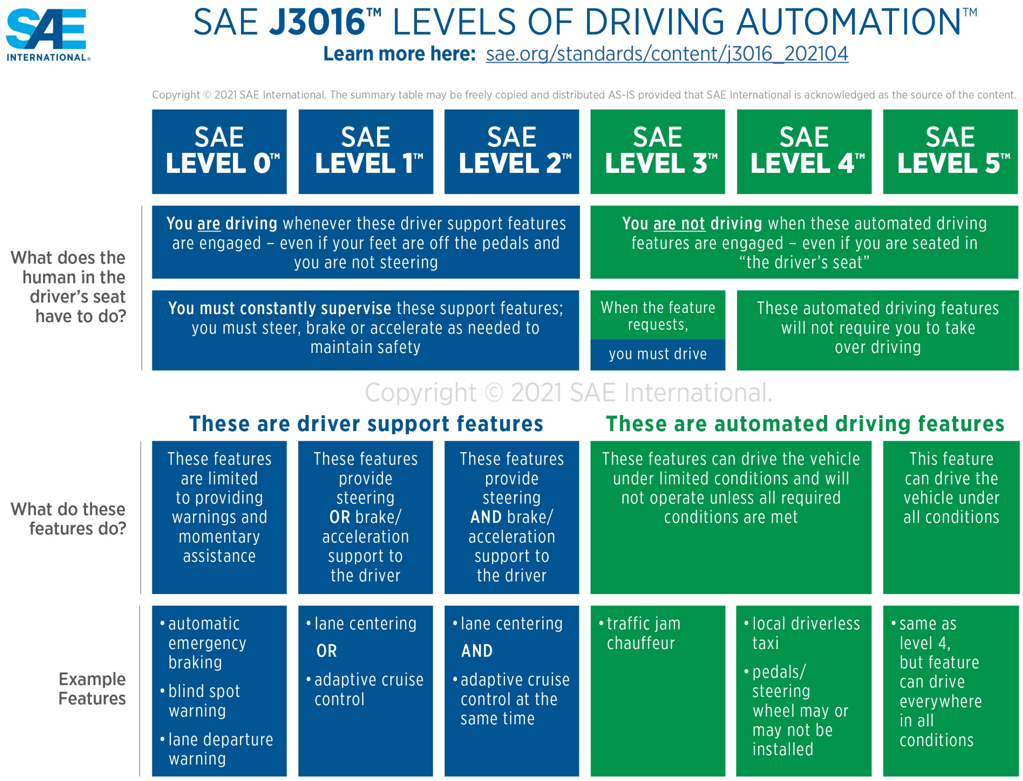
1. Introduction

Technology is evolving rapidly in the 21st century. The manufacturing, computer, and transport sectors are particularly affected. High-speed rail lines are being built. Traffic lights are being automated, and rail safety is being improved. The car industry is also moving forward with the development of autonomous vehicles. An autonomous vehicle can independently assess and respond to traffic scenarios without driver intervention. The Society of Automotive Engineers (SAE) has categorized vehicle autonomy into six levels (0–5), with increasing reliance on Advanced Driver Assistance Systems (ADAS) that must be fully reliable and cooperative [1]. The extent to which driver assistance systems are implemented varies depending on the level of autonomy. These consist of driving aids that maintain speed or keep the vehicle within the lane and assistants that aid in parking or ensure safe exit from the vehicle for passengers. Parking aids with a numerical distance display are widely available in the aftermarket. Therefore, an experiment was designed to test whether the alternative obstacle distance display is a suitable aid for the driver and can be used to park the vehicle closer to the obstacle than using the distance display with a color scale and audio signals. Tesla's numeric obstacle distance display is currently used with both the ultrasonic sensor and vision systems. The vision system replaces the ultrasonic sensors with cameras.

The autonomy of vehicles dates back to the early part of the last century [2]. The article says the first autonomous vehicle, controlled by a radio controller, traveled through the streets of New York City in 1925. As mentioned in [3], the subsequent development in this field was the autonomous vehicle built in 1956, guided by electromagnetic circuits embedded into the roadway. However, using it on the streets was too expensive, and the technology was limited to airport roads. An autonomous vehicle that required no modified infrastructure was introduced in 1995 [4, 5]. The test route was from Munich to Odense in Denmark, and the vehicle was in autonomous mode for 95 % of the journey. Following the introduction of GPS navigation systems and digital maps in 2000, there was a significant enhancement in research into vehicle autonomy, with technology giants such as Google beginning to develop autonomous vehicles.

2. Autonomous vehicles

Autonomous vehicles utilize sensors and cameras to collect real-time information about their surroundings [6]. The data is then evaluated by an on-board computer, which works alongside map data and interacts with surrounding vehicles and infrastructure. This system enables the vehicle to navigate roads and be conscious of potential obstructions within its immediate environment. The ultimate aim of this technology is to achieve autonomous operation without driver's intervention. However, attaining this objective demands prolonged effort and extensive research. Vehicle autonomy is distinguished into six levels. At present, autonomous vehicle development lies at Level 3. Google showcased a Level 3 autonomous vehicle capable of autonomously driving in specific suburban regions [7]. In the Czech Republic, cars with Level 2 autonomy can be purchased, offering a 'hands-off' mode in which the vehicle handles steering wheel rotation, acceleration, and braking. This category of autonomy encompasses Tesla's Autopilot [8] and Cadillac's Super Cruise system [9], amongst others. However, it is worth noting that the driver must pay full attention to the road.



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	SAE LEVEL 0™	SAE LEVEL 1™	SAE LEVEL 2™	SAE LEVEL 3™	SAE LEVEL 4™	SAE LEVEL 5™
What does the human in the driver's seat have to do?	**You are driving** whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering			**You are not driving** when these automated driving features are engaged – even if you are seated in "the driver's seat"		
	You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	
	These are driver support features			**These are automated driving features**		
What do these features do?	These features are limited to providing warnings and momentary assistance	These features provide steering **OR** brake/acceleration support to the driver	These features provide steering **AND** brake/acceleration support to the driver	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met		This feature can drive the vehicle under all conditions
Example Features	• automatic emergency braking • blind spot warning • lane departure warning	• lane centering **OR** • adaptive cruise control	• lane centering **AND** • adaptive cruise control at the same time	• traffic jam chauffeur	• local driverless taxi • pedals/steering wheel may or may not be installed	• same as level 4, but feature can drive everywhere in all conditions

Figure 1. Levels of autonomy [1].

According to SAE, the six autonomous driving levels can be divided into two groups (see Figure 1). Levels 0–2 are classified as driver-support systems, while levels 3–5 are classified as automated driving.

3. Parking assistance

Parking assistance has become a popular topic. As the number of vehicles on the road increases, parking areas reach their limit. Drivers often struggle to park their vehicles in designated spaces due to the narrow parking spaces. Therefore, vehicle manufacturers are focusing on the development of parking assistance, among other things.

Since 1933, car manufacturers have enhanced driver convenience in parking [10]. During that year, a car with a special wheel perpendicular to the vehicle's longitudinal axis was introduced to park effortlessly. Another notable innovation was Volkswagen's Futura model [11], which enabled all four wheels to pivot at a right angle, resulting in comfortable parking. In 2003, Toyota introduced the Prius equipped with the Intelligent Parking Assist system [12], shown in Figure 2. The car featured sonar sensors and cameras on both of its bumpers. When drivers decided to park the vehicle, they selected the appropriate parking space on the radio display. Once a space was selected, the car's system took control of the vehicle and parked it in the chosen space. Initially, there were issues concerning the recognition of pedestrians and particular objects such as a pram. Toyota was the only manufacturer to offer this system for three years until other manufacturers, including BMW and Ford, adopted the system in 2006.

Figure 2. Intelligent Parking Assist in Prius [13].

4. Ultrasonic sensors

The Prius's sonar sensors were replaced by ultrasonic sensors. This newer approach offers more sophistication regarding its integration into the vehicle's structure and ease of operation. Ultrasound is a mechanical wave with a frequency greater than 20 kHz [14]. The speed of ultrasound propagation relies on the density of the medium through which the waves travel. The velocity of ultrasound is the greatest in solids, reaching up to $3\,300\,\mathrm{m\,s^{-1}}$. Conversely, ultrasonic waves spread the slowest in gases at $345.7\,\mathrm{m\,s^{-1}}$. The propagation speed in liquids approximates $1482\,\mathrm{m\,s^{-1}}$ [15].

The speed of ultrasonic waves is contingent upon the density and bulk modulus of the medium they traverse. This relationship is well established and expressed by Equation (1).

$$v = \sqrt{\frac{K}{\rho}}, \tag{1}$$

where K is the bulk modulus and ρ is the density of the medium.

Ultrasonic sensors work based on calculating the speed at which the signal bounces off an obstacle [16]. The sensor consists of a transmitter and a receiver. The distance is determined by the transmitter sending an audio signal and triggering a time measurement. The transmitted signal propagates through the environment until it encounters an obstacle from which it bounces. The reflected signal then travels back to the sensor, which listens for the "echo". After the transmitted signal returns to the sensor, a distance calculation is performed. The sound propagates through the air at approximately $340\,\mathrm{m\,s^{-1}}$, which means that a one-centimeter wave travels in 2.94×10^{-5} seconds. Equation (2) shows the formula for calculating the distance.

$$d = \frac{t \cdot c}{2}, \tag{2}$$

where d is the calculated distance, t is the time taken for the ultrasound to return to the sensor, and c is the speed of sound propagation. The variable c depends on the environment in which the sound propagates.

The receiver is equipped with a piezoceramic sensor that can change its geometric shape based on the electrical signal, so it can be said that the piezoceramic converts mechanical energy into electrical energy [17].

4.1. USAGE OF ULTRASONIC SENSORS IN PARKING ASSISTANCE

4.1.1. BOSCH AUTOMATED PARKING SYSTEM

Sensors based on ultrasonic waves work in conjunction with a computer that analyses the proximity of objects in the vicinity of the vehicle. BOSCH states [18] that sensors are mounted on the sides of the vehicle to scan and map possible parking spaces. Once the assistant has confirmed that the space it has scanned is suitable for the car to park in, it sends a signal to the driver. Upon pressing a button, the assistant calculates the optimal route to the parking space, determining the required steering wheel turns and necessary maneuvers. Once the path is determined, the driver can relinquish control and guide the vehicle with gentle pressure on the accelerator and brake pedals. The assistant uses the electronic steering wheel control to guide the vehicle to the parking spot.

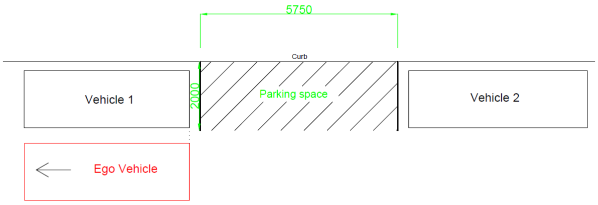

FIGURE 3. Parking scenario's scheme.

The driver remains in full control of the maneuvers and may cancel the operation anytime by touching the steering wheel. In addition, the assistant supervises the exit from the parking space and brings the vehicle to a safe position for the driver to proceed to the traffic.

4.1.2. VALEO AUTOMATIC PARKING

Valeo introduced the function Park4U in 2007 [19], which was implemented in the Volkswagen Touran. The parking maneuver is similar to the BOSCH system in the hands-free mode. Valeo states that once ultrasonic sensors have located a fitting parking space, the driver only needs to shift into the reverse gear, and the system takes control of the vehicle. The driver can interrupt the system's operation by touching the steering wheel. Additionally, in 2011, Valeo launched the Park4U Remote mobile application, which allows drivers to leave their vehicles and park them using their phones. This distinguishes it from the BOSCH parking assistant as it eliminates the need for the driver to remain inside the car to operate the brake and accelerator pedals.

5. EXPERIMENT

An experiment was designed to test the user experience using different HMI elements in parking assistants. Parking was done on a remote road with no surrounding traffic. The experiment aimed to determine if and which parking assistance could better help drivers while parking. A Suzuki Ignis was used for parking without a parking aid and with the prototype, and a Skoda Yeti was used for parking with a conventional parking assistant.

5.1. PARKING SPACE

For the purpose of the experiment, a parking space was created. The parking space was designed to conform to the dimensions specified in standard CSN 73 6056 [20]. The length of the parking space was 5 750 mm, and the depth was 2 000 mm, as illustrated in Figure 3, and Figure 4 shows the testing.

5.2. FIRST PARKING

Parking without parking assistance. Drivers were asked to park the vehicle using only the rear-view mirrors.

Figure 4. Parking scenario in real testing.

Figure 5. HMI in Skoda Yeti vehicle.

5.3. Second parking

The second method was parking the vehicle with the help of a parking assistant fitted to the car by the manufacturer. A 4-channel ultrasonic sensor system with a display of the distance to the obstacle on the radio display, paired with acoustic signals, was used. Human-Machine Interface, shown in Figure 5, informs the driver about the distance from the obstacle.

5.4. Third parking

Parking using the prototype parking assistant. The parking assistant, equipped with an ultrasonic sensor, responds to approaching an obstacle with an acoustic signal and displays the obstacle distance using colored LE Diodes and an OLED display that shows the distance in centimeters.

5.5. Implementation of prototype design

Before building the prototype parking assistant, a simulation of the circuit, shown in Figure 6, was performed in a virtual environment. The parking assistant consists of an ARDUINO microcomputer, acting as a control element. ARDUINO processes data from the ultrasonic sensor and calculates a distance from the obstacle. Based on the measured distance, particular LEDs are powered up. The connection of the LE Diodes requires a combination with a corresponding resistor. The value of the required resistance for each diode was determined using Ohm's law expressed by Equation (3). The microcomputer supplies the diode with a voltage of up to 5 V, and the current required for proper diode operation is 25 mA.

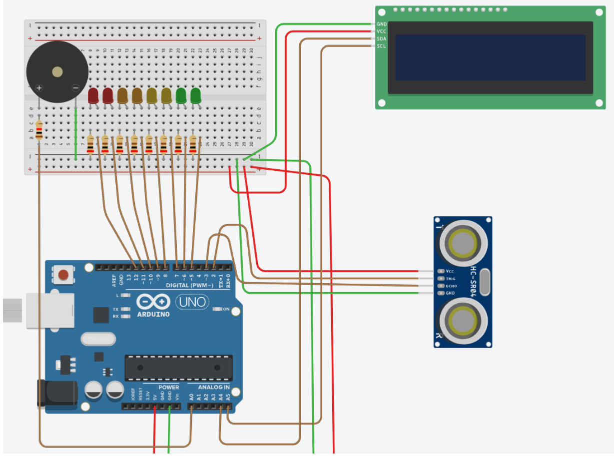

Figure 6. Virtual simulation of the prototype circuit.

$$R = \frac{U}{I} = \frac{5}{0.025} = 200\,\Omega \tag{3}$$

The circuit also includes a piezoelectric buzzer fitted with a 100 Ω resistor to reduce the volume.

The LEDs were wired to connect a selected 200 Ω resistor to the cathode. The positive pole of the LED is connected to the digital input of the ARDUINO UNO board. All eight LEDs were connected to pins 6 to 12, leaving the other pins available for other components. The piezoelectric buzzer was connected with a 100 Ω resistor on the positive pole to the analog input A0 and the negative pole to the GND pin on the breadboard. The TRIG and ECHO pins of the ultrasonic sensor were connected to digital pins 2 and 3, respectively. The positive and negative poles of the component were connected to the breadboard, which was connected to the ARDUINO.

In the next stage, an OLED display was added to the circuit to show the distance in centimeters measured by the ultrasonic sensor. The OLED display has four pins, which were connected as follows: the VDD pin was connected to the positive pole of the ARDUINO, the GND pin to the negative pole, the SCL pin to the analog pin A5, and the SDA pin to the analog pin A4 on the ARDUINO board as shown in virtual simulation in Figure 6.

The source code was created to ensure the correct functionality of all involved components. The distances at which the LE diodes light up and the buzzer sounds were defined in the code. The measured distance is also displayed in centimeter (cm) units on the OLED display. The first detection distance was set to 150 cm based on data collected from vehicles that had the parking assistant fitted by the manufacturer. The smallest permissible distance, so-called Full Tone, was set to 30 cm. All the LEDs light up at the full tone distance, and the buzzer provides an uninterrupted tone.

6. Results

In the experiment, the participants were asked to park the vehicle in all three ways. The time needed to park the car and the final distance from the obstacle were measured. The experiment was performed with 11 participants of different age groups and driving experience. Participants were also asked whether their vehicle had been equipped with parking assistance of any kind, see Table 1.

ID	Age	Km/Year	Parking Assistance
1	20	5000	Yes
2	20	1500	No
3	20	2500	Yes
4	21	600	No
5	20	3500	No
6	19	1500	Yes
7	50	9000	No
8	52	9000	No
9	47	38500	Yes
10	50	16500	Yes
11	53	21000	No

Table 1. Data table.

ID	Time	Distance
1	00:20,1	146
2	00:48,0	115
3	00:43,2	119
4	02:21,2	107
5	00:36,2	150
6	00:51,8	129
7	00:15,0	129
8	00:28,5	141
9	00:48,0	103.5
10	00:40,0	89
11	01:20,0	170
Mean Values	**00:47,2**	**127.14**

Table 2. Data without parking aid.

The results of parking without a parking assistant are shown in Table 2, and the results of parking with the conventional parking assistant are demonstrated in Table 3, indicating that the mean distance decreased by 33.23 centimeters compared to parking without a parking aid. However, the mean time needed for parking increased by 8.9 seconds.

The data collected shows that the mean value of the final distance from the obstacle gradually decreased with the use of parking assistance. In the third part of the experiment, the mean distance decreased even more, as seen in Table 4. The mean time needed for parking changed marginally compared to parking with a vehicle without a parking assistant. Still, compared to the mean time of parking with a conventional parking assistant, the mean time for parking with the prototype decreased by 8.8 seconds.

ID	Time	Distance
1	00:19,9	77
2	01:24,7	110
3	00:40,8	76
4	01:18,9	68
5	01:16,4	106
6	01:45,5	113
7	00:18,0	110
8	00:31,6	134
9	01:00,1	54
10	00:40,7	89
11	01:00,1	96
Mean Values	**00:56,1**	**93.91**

Table 3. Data with conventional parking assistant.

ID	Time	Distance
1	00:22,1	22
2	00:35,8	51
3	00:44,9	91
4	01:21,8	150
5	00:46,7	76
6	01:36,0	145
7	00:14,7	116
8	01:02,0	121
9	00:54,7	57
10	00:24,3	93
11	00:36,8	67
Mean Values	**00:47,3**	**89.91**

Table 4. Data with prototype parking assistant.

Using the prototype, the participants parked an average of 37.23 centimeters closer to the obstacle than using a car without parking assistance. This might have occurred because the drivers were comfortable with the numerical display of the distance. Driver ID 6, despite having a parking aid in his car, was able to park faster using only the rear-view mirrors. The reason for this may be that the parking aid can also be stressful for some drivers and can affect the driver's concentration when parking.

However, the mean values of the final distance show that the drivers were comfortable with the alternative distance display, resulting in a close approach. They were also able to park the vehicle more quickly than when using conventional parking assistance.

Figures 7 and 8 show the measured data during the experiment. In Figure 7, a greater parking distance from the obstacle can be observed for most participants when using rear-view mirrors. The distance was measured from the rear bumper of the parked vehicle to the nearest part of the obstacle to which the vehicle

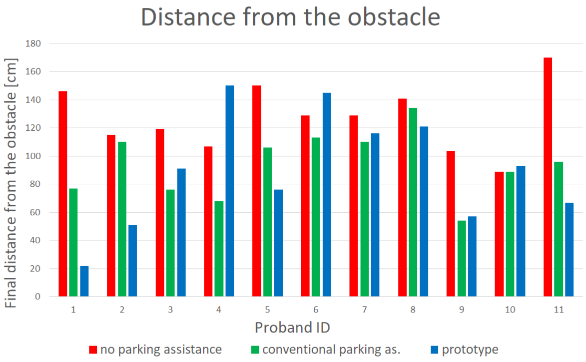

FIGURE 7. Comparison of distances from the obstacle.

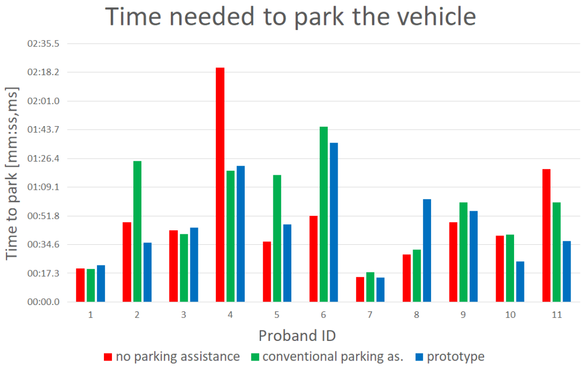

FIGURE 8. Comparison of the parking times.

was parked (a third-party parked vehicle). Figure 8 shows the time it took to park the car. The time was measured from the start of the parking maneuver to its completion when participants applied the parking brake. For participants ID 5 and 6, a notable increase in parking time can be observed, which can be explained by trying to park the vehicle as close as possible to the obstacle using the parking assistant. Therefore, the measured data show that both conventional and prototype parking assistance improve the driver's awareness of the proximity of the obstacle but increase the time required to park the vehicle. The parking aid prototype with an alternative distance display is better used on roads with less traffic.

7. CONCLUSION

This paper aimed to present the prototype parking assistant and verify whether the alternative distance display could be a suitable aid for drivers. It was explored that the assistant could help park the vehicle closer to the obstacle than when using the conventional parking assistant. The experimental results showed that the parking assistant with the alternative distance display gave drivers a better idea of the distance from the obstacle. Therefore, the data mean of the final distance to the obstacle was smaller than that of the other parking aids. The mean parking time was also the shortest when using the alternative distance display. For more experienced drivers, the numerical representation of distance from obstacles made a less significant difference than for those with less experience. The decreased time spent using the parking aids is also more evident for the less experienced and younger participants.

The authors believe that having a larger sample of participants would provide a more comprehensive analysis. This should be addressed in the forthcoming experiments. Furthermore, future research on parking assistants might also focus on analyzing drivers' subjective impressions of the user environment, semi-automatic and automatic parking assistants, and the strategy the system uses to park the vehicle in the parking spot.

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