

3D Auditory Displays for Parking Assistance Systems

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ABSTRACT

The objective of this study was to investigate if 3D auditory displays could be used to enhance parking assistance systems (PAS). Objective measurements and estimations of workload were used to assess the benefits of different 3D auditory displays. In today's cars, PAS normally use a visual display together with simple sound signals to inform drivers of obstacles in close proximity. These systems rely heavily on the visual display, as the sound does not provide information about obstacles' location. This may cause the driver to lose focus on the surroundings and reduce situational awareness. Two user studies (during summer and winter) were conducted to compare three different systems. The baseline system corresponded to a system normally found in today's cars. The other systems were designed with a 3D auditory display, conveying information of where obstacles were located through sound. A visual display was also available. Both normal parking and parallel parking was conducted. Time taken for parking and the number of obstacles/curb hits were recorded. Participants answered a NASA TLX questionnaire after evaluating each PAS for estimation of their experienced workload. Most participants enjoyed the additional information provided by the 3D auditory displays. The winter trial showed a significant reduction in perceived effort when using a 3D auditory display compared to the baseline. The summer trial showed tendencies of higher mental demand and frustration with the baseline compared to the 3D auditory displays. The results suggest that 3D auditory displays can be appreciated and useful in difficult parking situations.

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INTRODUCTION

At first, Parking Assistance Systems (PAS) only used sound to inform the driver of obstacles behind the car. This evolved over time to include visual markers on a display and camera images. Today, PAS normally utilise both a visual indicator together with sound signals to provide the driver with proximity warnings for objects around the car while parking. In general, the sound signals are simple beeps with varying repetition rate depending on distance, and generally played from one or two locations within the car. This means that the driver needs to use visual information to find out where an obstacle is located. This increases the risk that the driver may accidentally hit an obstacle if moving slowly while focusing on the visual display, and it could also contribute to higher mental workload in order to maintain situational awareness. Sound can be an effective means of capturing attention [1, 2], so it may be wise to use 3D sound to guide the driver's attention to the closest obstacle.

Studies have shown that keeping congruence between the sound source location and the information provided is beneficial [3]. It is however important that the sounds are easy to locate in space. Therefore, several parameters such as frequency content and duration need to be taken into consideration [4, 5, 6, 7].

In analogy with visual displays, an auditory display is a device that provides information using sounds [8]. Commonly, auditory displays use simple alerts and notifications [9]. It is purely a way to inform a

user that something has happened which requires their attention. The amount of information provided through sound in these types of displays is very limited. By using 3D sound, more information can be conveyed to the user. The idea behind using 3D sound is to unload the visual modality, producing lower workload and increase the level of comfort.

This paper investigates the effect of two implementations of a 3D auditory display for parking assistance systems, compared to a generalised basic "factory" system similar to the ones used in today's series produced cars. Two trials were conducted, one during summer and one during winter. The winter trial was more difficult due to the mixed road surface (ice, snow and asphalt). In order to compare the different systems, parking and drive-off times were recorded as well as the number of times the participant hit obstacles such as "simulated" parked cars or the curb. In addition, a NASA TLX test [10, 11] was conducted after evaluation of each system. The NASA TLX questionnaire is based on ratings of 6 attributes, describing mental demand, physical demand, temporal demand, how well the participant performed, their effort to reach that degree of performance and frustration. The ratings are weighted based on relevance to the task, and then used to estimate the participant's overall workload.

The results show tendencies to benefits of using a 3D auditory display as a parking assistance system when the parking task is difficult. During the winter test, the 3D auditory display system required significantly less effort from the participants.

METHOD

Parking Assistance System Implementation

Information about obstacles around the car was extracted from 8 ultra-sound sensors located around the car. The system was designed to read sensor data and trigger sound signals based on the distances to identified obstacles. Three systems were designed that translated sensor information differently, 1) Baseline, 2) 3D Priority, 3) 3D All Active. The latter two were designed to create a 3D auditory display. An array of 8 loudspeakers was placed inside the car compartment, surrounding the driver. Due to space constraints, the distance between the driver and the loudspeakers varied depending on loudspeaker placement. In general, the loudspeakers in the rear were farther away than the front loudspeakers. The sensors were able to report distance from 30 cm to 60-150 cm depending on sensor placement. For all systems, the sound repetition rate varied depending on distance. The different threshold distances for each sensor can be observed in [Table 1](#). Closer obstacles generated a faster repetition rate than far obstacles. When an obstacle came within 30 cm from the sensor, the sound was changed to a constant tone.

Table 1. Repetition rates for the pulsed tones for the different sensor locations. See [Figure 1](#) for information about the locations of the sensors.

Distance Front (mm)		Distance Rear (mm)		Rate (Hz)
Inner (A)	Outer (B)	Inner (C)	Outer (D)	
300	300	300	300	4.0
350	330	420	330	2.0
370	370	580	370	1.3
500	420	780	420	1.0
550	450	900	450	0.8

The Baseline System

The *Baseline* system (see [Figure 1](#)) was designed to resemble PAS commonly used in today’s series production cars, where all front sensors trigger sound signals from the front left loudspeaker and all rear sensors trigger sound signals from the rear right loudspeaker. In this design, the sensor with the closest detection distance takes priority, meaning that front left and rear right loudspeaker never output sound simultaneously.

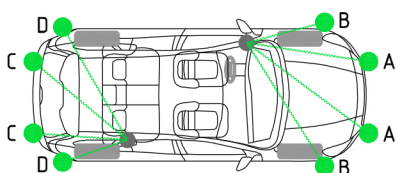


Figure 1. Standard “factory” design of a PAS, where front sensors are used to trigger sound from the front-left loudspeaker, and rear sensors are used to trigger sound from the rear-right loudspeaker. A/C are the inner front/rear sensors and B/D are the outer front/rear sensors. Refer to [Table 1](#) for their respective distance detection thresholds.

For the *Baseline* system, a pulsed sinusoidal tone with fundamental frequency of 527.3 Hz was used for the front sound and 386.7 Hz was used for the rear sound, see [Figure 5](#). The envelopes differ slightly between front and rear sounds, see [Figure 2](#). Both signals had a duration of about 125 ms. When an obstacle entered the “near-

zone” closer than 30 cm, a constant sinusoidal tone at 521.5 Hz was used in the front and a tone at 392.6 Hz was used in the rear, see [Figure 6](#).

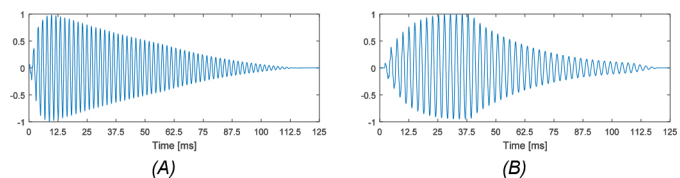


Figure 2. Time plots of the pulsed front (A) and rear (B) sounds for the Baseline version of PAS.

The 3D Auditory Display Systems

The other two cases, *3D Priority* and *3D All Active*, were based on a 3D auditory display approach; where each sensor triggered sound signals from a loudspeaker at the sensor’s corresponding location, see [Figure 3](#). The *3D All Active* system allowed any sensor that detected an obstacle to report it via its loudspeaker, meaning that multiple sound sources may be active at once. This created auditory information about obstacles surrounding the car. The *3D Priority* system was equal to the *3D All Active* system in all regards except that only the sensor reporting the closest distance to an obstacle was allowed to report the object’s location by the use of sound.

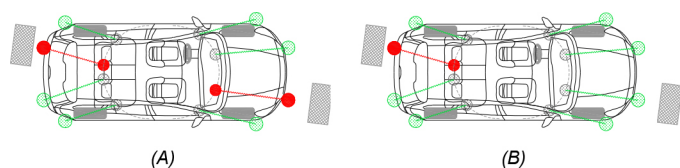


Figure 3. (A) 3D All Active version of the 3D auditory display, where each sensor detecting an obstacle triggered sound from their corresponding loudspeaker simultaneously. (B) 3D Priority version of the 3D auditory display, where the sensor detecting the closest obstacle triggered sound from the corresponding loudspeaker.

For both the 3D auditory display systems, for any frontal obstacles, a pulsed sound with a fundamental pitch of 586.8 Hz was used. The rear obstacle sound had a lower pitch than the front sound, at 263.8 Hz, see [Figure 7](#). The initial decay time was similar between the front and rear sounds, but the rear sound had a longer low amplitude tail, see [Figure 4](#). Similarly as the *Baseline* system, obstacles in close proximity to the car (< 30 cm) produced a constant tone. However, in the 3D auditory display systems, the tone was slightly more complex, including a richer overtone spectra compared to the *Baseline* sound. The front sound had a fundamental frequency of 522.2 Hz and a fundamental frequency of 393 Hz was used for the rear sound, see [Figure 8](#).

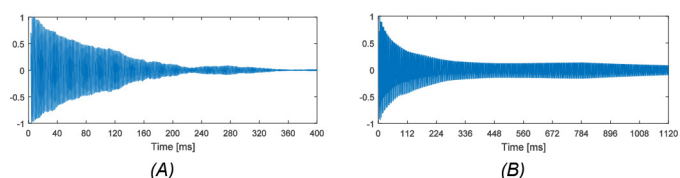


Figure 4. Time plots of the pulsed front (A) and rear (B) sounds for the 3D auditory display version of the parking assistance system.

Sound Design and Calibration

The *Baseline* system used sinusoidal beeps and tones, while the 3D auditory display systems had a more complex information sound, designed to be easier to locate than pure sinusoidal tones. The same sounds were used in both 3D auditory systems. The fundamental frequencies for the sounds can be seen in Table 2. One noticeable difference between the systems is the wider difference in fundamental frequency of the pulsed sound for the 3D auditory display systems compared to the *Baseline* system. They were designed in this way in order to enhance performance. Larger differences in frequency are easier to hear and should make it easier to distinguish sounds coming from the front from sounds coming from behind.

Table 2. Sound composition.

	Baseline	3D Auditory Display
Front Pulsed	527.3 Hz	586.8 Hz
Rear Pulsed	386.7 Hz	263.8 Hz
Difference	140.6 Hz	323.0 Hz
Front Constant	521.5 Hz	522.2 Hz
Rear Constant	392.6 Hz	393.0 Hz
Difference	128.9 Hz	129.2 Hz

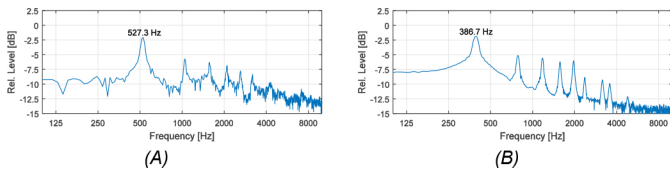


Figure 5. Spectra of the pulsed front (A) and rear (B) sounds used in the Baseline system.

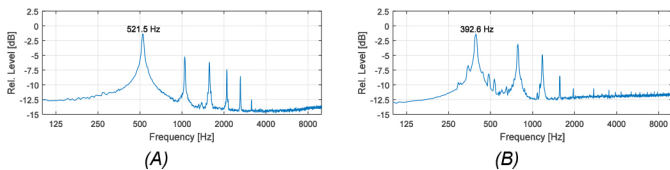


Figure 6. Spectra of the constant front (A) and rear (B) sounds used in the Baseline system.

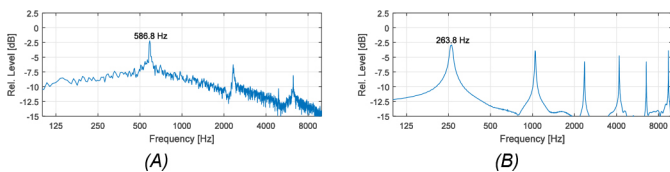


Figure 7. Spectra of the pulsed front (A) and rear (B) sounds used in the 3D Auditory Display systems.

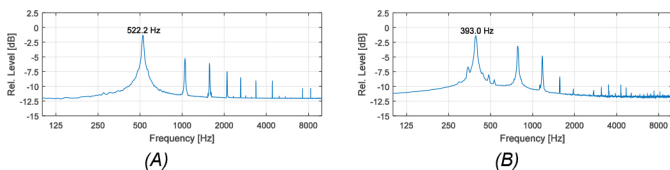


Figure 8. Spectra of the constant front (A) and rear (B) sounds used in the 3D Auditory Display systems.

The sound pressure levels for all signals were calibrated based on the background level inside the car when driving at low speeds (max 10 km/h). The background noise level was measured using an artificial head (Head Acoustics HMS IV). The background noise (mean value between left and right ear) was converted to effective masking threshold levels according to ISO-7731 [12]. The effective masking threshold levels can be observed in Figure 9.

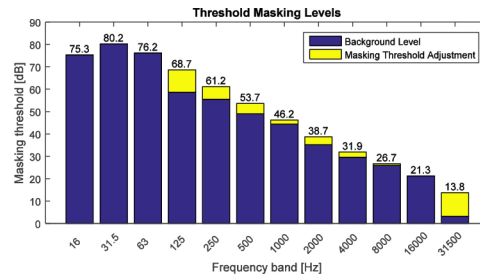


Figure 9. Effective masking threshold calculated from the background noise level when the car was running on idle.

The effective masked threshold (L_T) was calculated octave by octave, where the first octave band (16 Hz) is directly the same as the background noise level (L_N) in the same frequency band:

$$L_{T1,oct} = L_{N1,oct} \quad (1)$$

The other octave bands were calculated by:

$$L_{Ti,oct} = \max(L_{Ni,oct}, L_{T(i-1),oct} - 7.5 \text{ dB}) \quad (2)$$

The levels of the signals were adjusted to be 10 dB louder than the effective masking threshold level at the signal's most prominent octave band. The sound signal's sound pressure level was measured with one microphone positioned at ear level between the two front seats. Two octave bands were prominent for the sounds, 250 Hz and 500 Hz. Each sound, played from each loudspeaker, had the level adjusted to be 72 dB in the 250 Hz band or 64 dB in the 500 Hz band, depending on which octave band was most prominent for that specific sound and location. This made all sounds clearly audible.

USER STUDY

Two trials were conducted, one during summer and one during winter. The winter trial had the ground partially covered with snow and ice, compared to asphalt during summer. Two parking situations were designed: a regular parking spot and parallel parking. The sizes of the parking spots were 5×3 m and 6.4×2.3 m, respectively. Cardboard boxes were placed around the spots to simulate already parked cars. For the parallel parking, a curb was also in place. Refer to Figure 10 for an overview of the parking situations.