Auditory Signal Design for Automatic Number Plate Recognition System

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ABSTRACT

This paper focuses on the design of an auditory signal for the Automatic Number Plate Recognition system of Dutch national police. The auditory signal is designed to alert police officers of suspicious cars in their proximity, communicating priority level and location of the suspicious car and taking into account the auditory environment of the police car. Design goals are formulated and corresponding design principles are applied and tested. Conclusions are drawn and discussed and recommendations for future work are made.

Author Keywords

Audio design; Auditory signal design; Localization, Automatic number plate recognition plate system; Dutch national police

ACM Classification Keywords

H.5.2 User Interfaces > Auditory (non-speech) feedback

H.5.5 Sound and Music Computing > Signal analysis, synthesis, and processing

INTRODUCTION

The Dutch national police are currently experimenting with a system to aid identifying suspicious cars, in order to apprehend criminals or other persons of interest. This Automatic Number Plate Recognition (ANPR) system uses two roof-mounted cameras to read the licence plates of all cars in scanning range of a police car. Subsequently, the licence plate numbers are compared to a police database, to determine whether the car or its registered owner is of interest for the police. In that case, the police officers receive visual and auditory feedback.

There are several causes why a car can be of interest for the police, e.g., a stolen vehicle, or a suspended license plate. The former case is of higher priority than the latter case. Internal communication with the Dutch national police resulted in a selection of four priority levels for ANPR signals.

The ANPR system interrupts officers during their current task. According to priority level, the officers themselves decide whether to respond to this suspicious car or carry on with their current activity. In order to make this decision, the signal of the ANPR system should be intuitive, concise and informative.

This paper focuses on the design of an auditory signal of the ANPR system that is effective in the auditory environment of the police officer.

PROBLEM SITUATION

In the current system, police officers always receive the same alarm sound. For several reasons, this is not an optimal solution. First, the alarm sound does not differentiate between causes with a high or low priority. Second, the current activity of police officers is not taken into account. The alarm sound does not differentiate between causes with a higher or lower priority compared to the current activity. Consequently, police officers always have to examine the screen to decide on whether to take action (e.g., [4]). Third, the alarm sound does not differentiate between parked and moving cars. In the latter case, police officers have the opportunity to take action immediately. Fourth and finally, the alarm sound does not convey a sense of direction. Two frontal loudspeakers produce the monophonic alarm sound. Thus, the centre of the car is perceived as spatial location of the sound. In case of multiple lanes of traffic, police officers first have to examine the dashboard monitor to know on which side of the car they should look. This process often takes too long to be able to take immediate action.

THE AUDITORY ENVIRONMENT

In addition to visually monitoring the environment, police officers continuously monitor incoming radio messages. On the one hand, they listen if a message is directed at them (i.e., being assigned to a call). On the other hand, they listen in on messages intended for colleagues to stay informed on their whereabouts and duties. The amount of messages may vary from once every 10 minutes to 30 messages in 5

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minutes. Typically, the driver wears an earpiece in his/her left ear. In case of duo surveillance, the co-driver wears an earpiece in his/her right ear. Additionally, messages can be played through the car's loudspeakers.

At high driving speeds there are two main sources of car sounds: rumbling engine sounds, and wind sounds caused by the non-aerodynamic light bar. In case of emergency, the combination of a loud siren with the car sounds makes it nearly impossible for police officers to talk with each other. Consequently, police officers crank the volume of their earpieces, which in turn leads to complaints about fatigue in the long run.

When analysing the engine and wind sound, it can be concluded that these sounds are most intense below 200Hz. Wind noise is also present in the range between 200Hz and 7000Hz, but in much lower intensity.

DESIGN GOALS

The sounds designed for the ANPR-system should be intuitive, concise and informative in the auditory environment of the police officer. Therefore, the following five design goals are formulated.

1. The signal should be distinctly audible in the auditory environment of the police car.
2. The signal should convey the priority level of the suspicious car.
3. The signal should convey the location of the suspicious car in respect to the police car.
4. The signal should convey the direction of movement of the suspicious car in respect to the police car.
5. The signal should distinguish stationary cars from moving cars.

USERS

Although based on generalisations, some common characteristic can be attributed to the personality of police officers, such as acceptance of hierarchy and strong leadership, a preference for conciseness, and a need for clarity in procedures and protocol [1, 2]. These characteristics can be used to determine the main concepts the signal should convey: dependable, commanding, concise and assertive. In turn, these main concepts can be translated to acoustical properties, as shown in Table 1.

Main concept	Acoustical properties
Commanding, concise, assertive	Staccato, short attack, short decay
Dependable, assertive	Muffled or low pitched
Commanding, assertive	Some grittiness
Commanding, concise, assertive	Short sounds

Table 1: acoustical properties and corresponding main concepts

DESIGN

Selecting frequency range

As mentioned earlier, the auditory environment includes engine and wind noise, which are most intense below 200Hz. Therefore, any designed sound should have a frequency higher then 200Hz for better audibility. Selecting a certain frequency range also affects the user's ability to pinpoint the location of where the sound originated. The accuracy of localization is dependent on frequency and angle of the sound [6]. Full frontal sounds have a broader localizable frequency range than sounds at an angle. As Figure 1 illustrates, the frequency range at which a sound is localizable for the most angles are the frequencies below 1000Hz and between 2800Hz and 4000Hz. Considering the requirements for the auditory environment (design goal 1) and localization (design goals 3 & 4), the designed signal should predominantly use frequencies in the ranges of 200Hz to 1000Hz and 2800Hz to 4000Hz.

Message composition

The message conveyed by the designed signal is composed of three elements, which communicate the following message: *"This is the ANPR-system, there is a suspicious car over there"*. These elements, namely identification (design goal 1), priority level (design goal 2), and location (design goals 3 & 4), will be discussed next.

Identifying the ANPR-system

Identification of (and a call for attention to) the ANPR-system aims to provide a frame of reference for the police officers. In this case, a header sound is designed. This header is a sound, prior to the sound notifying priority and location. Its goal is to prepare the users for a confined number of possible notifications. Therefore, it directs the user's attention to the upcoming task of choosing whether to respond or ignore the upcoming notification of a suspicious car.

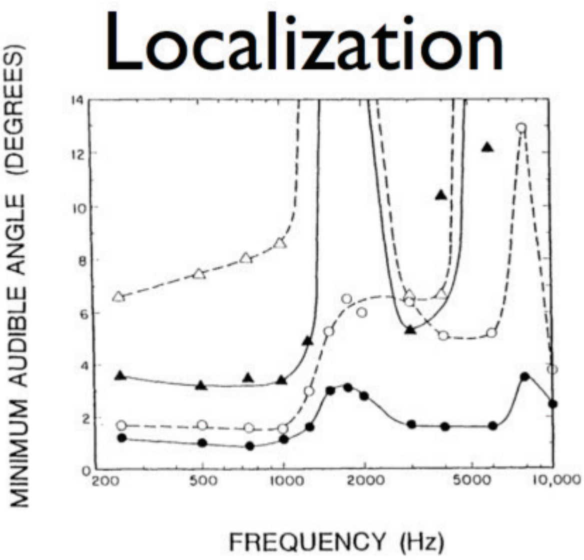

Figure 1: The minimum audible angle between successive pulses of a tone as a function of the frequency of the tone and the azimuth of the source (●=0°; ○=30°; ▲=60°; △=75°). Adapted from [6]

The design of the ANPR header sound is based on the Dutch pronunciation of the abbreviation ANPR and therefore consists of four separate phonemes. As the waveform in Figure 2 shows the letters A and N blend into each other, where the letters P and R are more self-contained.

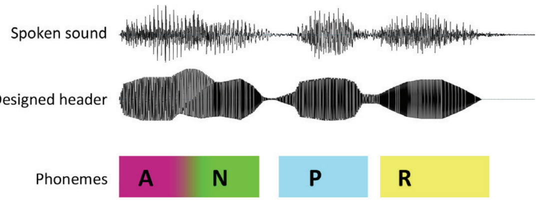

Figure 2: Header waveform and phonemes

The designed header coheres to the iamb of the spoken sound, but it does not cohere to the pitch because of the frequency space covered earlier. The total duration of the header is 400ms instead of the 1000ms the spoken sound. This duration is made shorter, because the speed at which the car travels requires a fast response time. The sound is composed of simple sine waves with a base frequency of 300Hz and its 2^{nd}, 3^{rd} and 4^{th} harmonic.

Priority level

After the header sound, the signal continues by communicating the priority level. This priority level sound consists of a combination of two 200ms long sounds, one with a base frequency of 300Hz, and one with a base frequency of 220Hz. Harmonics are used to increase pitch robustness [5], and to reduce potential masking effects by other sound sources. Taking into account the frequency range for optimal localization described earlier, both signals contain the 2nd, 3rd, 9th, and 10th harmonics. These two sounds are used in conjunction with the following two principles to convey the four priority levels.

1) Texture of the signal. Two of the main concepts that appeal to the users are assertive and commanding. This is translated to the texture of the signal. A more gritty texture, meaning short, jagged fluctuations in the volume of the harmonics, of the signal will be perceived as a more assertive and commanding signal. Therefore as the priority of the signal increases the grittiness also increases.

This alone cannot be enough to distinguish the priority levels because it works by comparison. When two sounds are played one after another, it is easy to say which is grittier, but without a comparative context, other cues must be implemented to obtain a clear distinction.

2) Meter of the signal. The meter refers to the number of beats in a bar of music, and determines how a repetitive pattern (rhythm) occurs. Often, but not always, a rhythm with a 2/4 meter is experienced as more lively, erratic and jittery then a 4/4 beat. Therefore the chosen meters for the priorities 4, 3, 2 and 1 are 4/4, 3/4, 2/4, and 1/4, respectively. By combining the high and low pitched sounds and the time signature, the final priority level sounds were created as visualised in Figure 3.

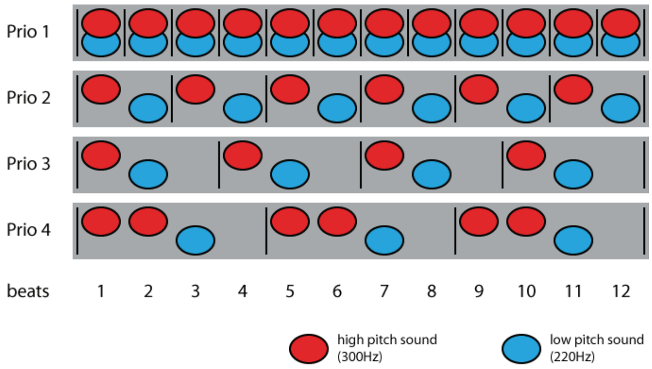

Figure 3: sequences of sounds for each priority level sound.

Localization

As specified in the design goals the location and direction of movement of the suspicious car should be communicated by the signal (design goals 3 & 4). Three principles are used to address this localization and spatiality in accordance with the aforementioned frequency range.

1) Sound origin. Installing multiple speakers inside the police car provides an opportunity for spatiality, by differing the volume (and applying subtle timing changes) between the speakers. This gives the impression of sound coming from the left, right, front, back or anywhere in between. Alternatively, spatiality may be obtained through binaural techniques by mounting two speakers at each seat's headrest (e.g., [3]).

2) Volume. Changes in sound volume can be used to convey changes in distance between a listener and a moving source [9]. In the current design, a lower volume indicates that the suspicious car is further away. This volume drop is only applied behind the car, because detecting a car at great distance in front of the police car then would lead to a signal with a volume too low to determine the priority (or even too low to notice). Figure 4 shows the location of the volume drop.

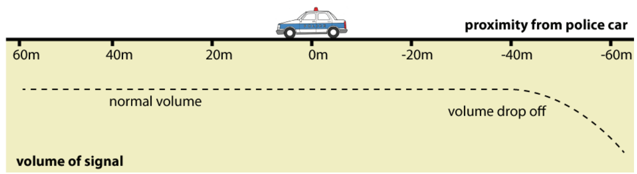

Figure 4: Location of volume drop off.

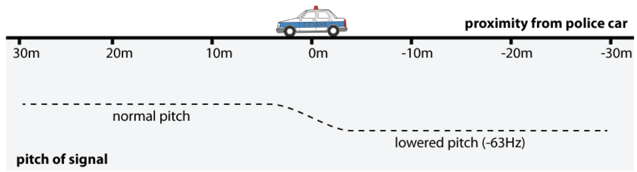

Figure 5: Location of pitch change.

3) Doppler like effect. The third localization cue is a Doppler like effect that occurs when a suspicious car passes the police car (or vice versa). If the suspicious car is located behind the police car the pitch of the signal will be noticeable lower (63Hz) then when it is in front of the police car. If the two cars pass each other a Doppler effect is quite noticeable in the signal. Figure 5 shows the location of this pitch change in respect to the police car.

Stationary versus moving cars

It is beneficial for a police officer to distinguish moving cars from stationary cars in order to quickly identify the suspicious car. Therefore the signal for stationary cars differs from the sound for moving cars (design goal 5). A low tone (base frequency 100Hz and 2nd, 3rd, 9th and 10th harmonic, duration 600ms) is chosen to signal the officer that the car is stationary. Although the base frequency is outside the preferred frequency range, the lower and longer tone is chosen to evoke a sense of mass and immovability. When a stationary suspicious car is detected, the signal starts the same as that of a moving car, i.e., a header followed by a priority level sound. But at the point the suspicious car is next to the police car, the low tone sound is played either at the left or the right speakers. This indicates that the suspicious car is parked (or otherwise stationary) to the direct left or right of the police car.

TESTING

The designed signal is tested in three different ways to measure the recognizability and learnability of the priority level sound and effectiveness of the localization.

Test 1: recognizability of priority levels

A first-time user should be able to determine the priority level of the four sounds. Therefore, this test aims to answer the question: *Is the priority level intuitively recognizable?* Five participants used headphones to listen to the priority level sounds in random order, and where given the task to arrange the four sounds in order of perceived priority. They were allowed to listen to the sounds again if they wanted to. The results of this test (see Table 2) show that none of the participants perceived all priority levels as they where designed. Prio1 and Prio2 are swapped in half of the results. This makes them intuitively ineffective. Prio3 and Prio4 are swapped in all but one case. This could make them intuitively effective, but just not in the way they were designed. Furthermore, the results show no confusion between Prio1 & Prio2 on the one hand, and Prio3 & Prio4 on the other hand. Overall, this test shows that the two principles used in designing the priority level sounds do not seem to work as intended.

Test 2: learnability of priority level sounds

This test addresses the question: *Once primed with the reference sounds, are the priority level sounds distinguishable by the participants?* In order to test this, five other participants used headphones to listen to the four priority sounds, and were told to which priority they belonged as a reference. They listened to these four sounds twice in random order. Participants were instructed to identify each of these eight sounds. Participants were not allowed to replay the sounds, nor were they allowed to revisit their previous answers. The results are shown in Table 3.

In this test 36 of 40 priority level sounds were identified correctly over all participants after they were primed with the reference sounds. So, it can be concluded that in 90% of the cases, the priority level sounds are correctly distinguished once they are familiar with the sounds.

Participant	Prio1	Prio2	Prio3	Prio4
A	2	1	4	3
B	1	2	4	3
C	2	1	4	3
D	1	2	4	3
E	2	1	3	4

Table 2: Results recognizability test. Designed priority order versus intuitively perceived priority order.

Participant	Correctly identified	Incorrectly identified
F	5	3
G	8	0
H	8	0
I	8	0
J	7	1

Table 3: Results learnability test.

Scenario	Description
1	Car moving in the same direction, appearing in front right of the police car. The car is overtaken by the police car and finally appears alongside the police car on the right.
2	Car moving in the oncoming direction. Appears from a side street in front left of the police car.
3	Car parked in a row of cars on the right side of the police car.
4	Car moving in the same direction. Changing lanes and appearing directly in front of the police car.

Table 4: Test scenarios for testing effectiveness of localization.

Participant	Sce1	Sce2	Sce3	Sce4
A	-1	v	x	v
B	v	-1	x	x
C	v	v	-1	v
D	v	v	x	v
E	v	-1	-1	v

Table 5: Results localization scenario test. (v = correctly identified; -1 = identified an adjacent car; x = incorrectly identified)

Test 3: effectiveness of localization

This test aims to answer the question: *Are the designed localization cues effective in identifying suspicious cars?* Four scenarios with suspicious cars were designed and represented as short film clips, see Table 4. Each film clip featured the same footage, including environmental sound, of a driving car filmed from the point of view of the driver. Signal sounds with localization cues were added to each clip.

Five participants, the same as in test 1, were instructed that a sound would indicate a specific moving or stationary car. Their task was to point at this car on the screen. Participants were allowed to watch the video clip again if desired. The results are shown in Table 5. As the results show, 11 of 20 cases were identified successful, and 5 cases where off by one car. Thus, in 55% of the cases the localization was accurate, and in 80% of the cases it was accurate within a margin of one car.

A notable result can be seen in scenario 3, where none of the participants identified the car correctly. Two of the participants identified the parked car in front of the car that was pointed at; the other three participants identified moving cars.

CONCLUSION[1]

To achieve the design goals, the final design of the signal sound for the ANPR-system consists of a header sound and a priority level sound. Signal localization cues are applied to draw attention to the correct position.

Test 1 shows that the priority level of the signal is not intuitively recognizable. An explanation for this could be that the meter was not perceived in the intended way. One thing that was not taken into account in the design was the perceptual rhythmic and melodic accents that can be heard in sequences of sounds. Povel & Essens [7] (rhythmic) and Van Egmond et al.[8] (melodic) show that in a grouping of three or more tones, the first and last tone receive an accent. This could explain the ineffectiveness of priority level 4 sound because it may have been perceived as a 2/4 instead of a 4/4 meter, as illustrated in figure 6. A similar perceptual issue occurs in the priority level 1 sound. Because there are no accents, no meter is evoked.

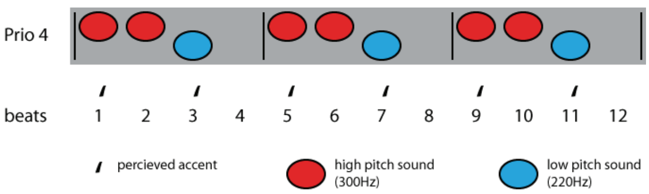

Figure 6: perceived accents in priority level sound 4.

Although the priority level sounds are ineffective in intuitively conveying their priority, test 2 shows that they are clearly distinguishable once the user is familiar with the priority level sounds. Next, test 3 shows that the localization principles applied to the signal were successful in drawing the attention to a particular car. Therefore, this design seems an effective starting point for further research, and to add a new functionality to the ANPR-system.

[1] The second and the third author were involved in the study after the experiments were conducted, in order to give the paper a theoretical framing and for the interpretation of the results.

FUTURE WORK

A first point of improvement would be a better design of the priority level sounds in which the rhythmic and melodic accents are properly applied. This will hopefully increase the intuitive recognizability and help officers in determining the priority level.

Although this study focused on the design of an auditory signal for the ANPR-system, it would be beneficial to broaden the scope. The designed sound should be seen as one element of the interface that consists of more elements that work together in achieving the same goal. Visual devices like dashboard monitors or even integrating visuals in the windscreen may increase the efficiency of the ANPR-system. In this study we employed the method of scenario based testing, using video clips. A next step would be to test the sound design in a natural setting.

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