EVALUATION OF A TRANSAURAL BEAMFORMER

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Abstract

Air traffic controllers listen to pilots' radio communications either by headphones or by loudspeakers. As air traffic increases, there is a tendency to use headphones to reduce the ambient noise level in the control room. Headphones are less disturbing for neighbouring controllers but may be uncomfortable to wear after long periods. This paper investigates the possibility of using an array of loudspeakers to focus sound at the controller and reduce the noise level at neighbouring positions.[1] *This may enable controllers to work without headphones for longer periods. Two prototype loudspeaker arrays were integrated with adjacent controller working positions and evaluated by nine air traffic controllers. Results of the qualitative assessment indicated that eight out of nine controllers were comfortable with the prototype system. The focused sound was clear and only one controller found sound from the neighbouring position a distraction.*

1 Introduction

Speech is still the main form of communication between air traffic controllers and pilots. On the controller side, this communication is monitored either by loudspeakers or by headphones. Too many voice communications over loudspeakers could be an auditory distraction for controllers at neighbouring working positions. Therefore, busier air traffic control (ATC) centres tend to use headsets to reduce ambient noise. However, headsets can be uncomfortable when used continuously. A possible solution to avoid the use of headsets has been developed [1] based on beamforming [2] and binaural stereo [3, 4, 5]. An initial version of a transaural beamformer [6] was evaluated in a laboratory environment without humans in the loop. Measurements indicated that the sound from a controller working position (CWP) was attenuated by 15 dB at a distance of one metre adjacent to the CWP. The question is whether this attenuation is sufficient to allow controllers to work without being distracted by their neighbours. Therefore, the aim of this study is to evaluate two adjacent transaural beamformers in a realistic operational environment with real air traffic controllers.

In section 2, a theoretical overview of the techniques of beamforming and transaural stereo is given. The prototype system is described in section 3. Section 4 and 5 discuss the method and the results of the qualitative evaluation and section 6 summarizes the main issues and gives an outlook about future intents.

2 Theory

2.1 Beamforming

Sound focusing is called beamforming in the literature and it is achieved by constructive superposition of sound waves. Sound waves that superimpose with equal phase add their amplitude. Hence, if the same sound signals from different loudspeakers coincide at the same time, the sound field at this point is amplified. The most

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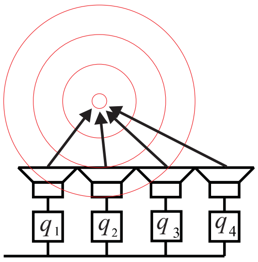

Figure 1: Delay & sum beamforming: A single signal is split to various loudspeaker signals. The loudspeaker signals have to meet at the focal point at the same time. To compensate for the different distances from the loudspeakers to the focal point, the signal is delayed with adjusted phase terms q_l.

efficient way of sound focusing, is a simple delay & sum beamformer [6]. It delays the loudspeaker signals such that they meet at the focal point at the same time, as sketched in Fig.1.

Fig. 2 shows the sound field of a 15 loudspeaker beamformer in three frequency bands. The greater the number of loudspeakers that are used, the greater is the sound amplification at the focal point. The width of the focal point depends on the wavelength and hence the frequency of the signal [7]. Fig. 2 only displays the sound field of one half of the horizontal plane and is referred to free field conditions. The radiation of an array of omnidirectional loudspeakers is concentric around the array axis, as depicted in Fig. 3. Due to reflections by walls, ceiling and floor, the sound pressure level (SPL) in a room will be stronger than in the free field. With a fifteen element array, the SPL of a room with 200 m^2 limiting surfaces can be approximated as 15 dB below the SPL at the focus spot [8]. To further reduce the room excitation one could:

- extend the array into the vertical plane in order to also manipulate the vertical radiation.
- use directive loudspeakers that mainly radiate into the frontal direction.
- place absorbers behind, under and above the array.

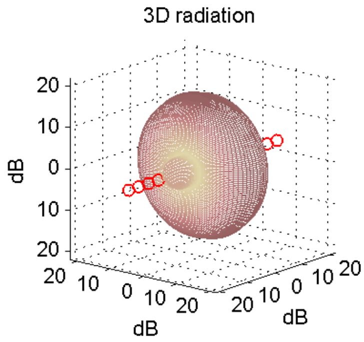

Figure 3: Three-dimesional beam pattern. The loudspeaker array is marked with red circles. For omnidirectional loudspeakers, the radiation of the array is concentric around the array axis.

Like the loudspeaker beamformer in reverse, a microphone beamformer can be directed at a certain point by delaying and summing the different microphone signals as depicted in Fig. 4. The advantage of a microphone beamformer is that it suppresses background noise as it can be focused to the controller directly. It therefore also reduces the feedback of the loudspeaker signals to the microphone. This feedback would appear as echo on the other side of the communication line. If the transfer functions from the loudspeakers to the microphones are known, the remaining feedback can be precalculated and subtracted from the microphone signals, such that the echo on the other end of the channel is cancelled. The proposed system (as described in section 3) has its loudspeaker and microphone arrays permanently installed on a CWP. Hence, the transfer functions are measured once and can then be used for the echo cancellation.

2.2 Transaural Stereo

It is important when air traffic controllers communicate with each other by intercom or telephone that they can still maintain communication with pilots at the same time. With headphones, one ear piece is often reserved for pilots and the other for controllers. In order to generate a similar effect with loudspeakers, transaural stereo is used to keep the two sound sources spatially separate. In the following, the concept of transaural stereo will briefly be reviewed. For more details

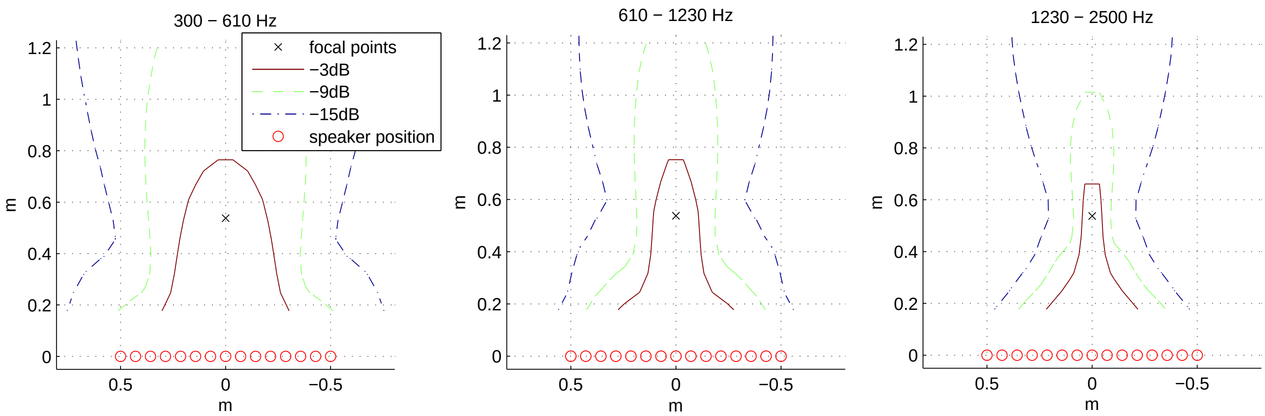

Figure 2: Sound field of a delay & sum beam in three frequency bands. The red circles mark the loudspeaker positions from the top view. The sound pressure level (SPL) is indicated by three level lines in 6 dB steps. The width of the sound spot (defined as the -3 dB line) depends on the frequency.

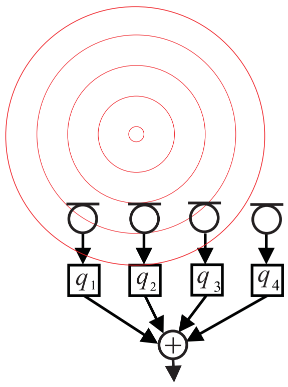

Figure 4: Microphone sum & delay beamformer: the different propagation times from the focal point to the microphones is compensated by the delays in q_m. Therefore, the signals arrive at the summation point in phase and are constructively superposed, hence amplified.

we refer the reader to [4, 6].

Humans with normal hearing abilities recognize the direction of incident sound due to interaural level differences (ILD) and interaural time differences (ITD) [3]. Simplified, sound from the right appears at the right ear first and louder, and weaker and later on the left ear. Such a pair of ear signals is called binaural. If a binaural signal is played back via headphones, the listener gets the impression of a realistic outside sound source in contrast to the in-head localization of simple headphone stereo.

A binaural signal can also be synthesized, if all the binaural information (ILD, ITD, reflections from pinna and shoulder etc.) is known. Measurements on a dummy head provide good average binaural information that fits well for a large variety of people. Synthesized binaural signals are used to generate virtual sound sources for headphone playback [5]. Loudspeaker playback would superpose additional binaural information that would degrade the spatial impression of the virtual sound source. In order to use loudspeakers, the influence of the propagation paths from the loudspeakers to the ears has to be compensated. In literature, this compensation is called cross talk cancellation and the method of playing back binaural signals with loudspeakers is called transaural stereo [4].

3 Apparatus

To evaluate the degree of disturbance between two neighbouring air traffic controllers, two identical transaural beamformers were integrated with two corresponding CWPs separated by 1.3 m. Each position consists of a standard screen with an array of fifteen loudspeakers mounted across the top and an array of four microphones across the bottom like sketched in Fig. 5. The loudspeaker array has a length of about one metre and the microphones are spaced every 9 cm. The controllers sat at a distance in the range 50 to 90 cm from the control screen. A simple webcam was positioned in the middle of the loudspeaker

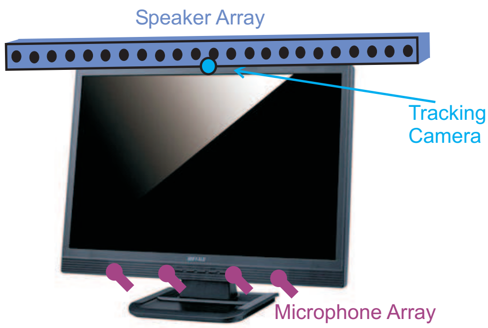

Figure 5: A fixed installation of the loudspeaker and microphone array at the CWP. A webcam tracks the position of the controller and adapts both (microphone and loudspeaker) beamformers to this position.

array to continuously track the position and orientation of the air traffic controller's head. From the tracking data, the positions of the ears are estimated and used as focal points for the transaural beamformer. The transaural beamforming signals are digitally processed on a PC before being converted to analogue and fed to the loudspeakers via 15 channels of an amplifier. A block diagram of the transaural beamformer is given in Fig. 6. Real loudspeakers only show omnidirectional radiation at low frequencies. The loudspeakers which were used for the prototype beamformers start to show directivity above 1700 Hz. For higher frequencies, the array radiates mainly into the frontal direction and does produce less ambient noise than ideal omnidirectional loudspeakers.

4 Method

Recordings of speech communication between pilots and air traffic controllers from previous real time simulations were edited to produce the effect of a high rate of speech (90%). The recordings contained male and female voices speaking English in a variety of foreign national accents. Two different recordings were used to play back through the loudspeaker array of each CWP. A controller was asked to initially adjust the volume of both loudspeaker arrays. This level was maintained for the duration of the evaluation. Then, pairs of controllers were asked to sit at the CWPs

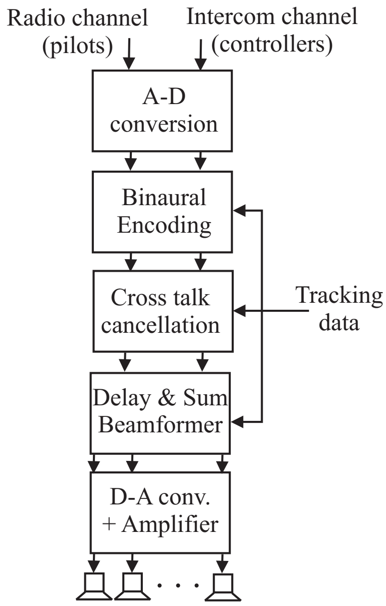

Figure 6: Block diagram of the transaural beamformer. The three blocks in the middle are performed on a PC. Additional hardware requirements are analogue/digital (A/D) converters and amplifiers.

and listen to the recordings for approximately fifteen minutes as if they were controlling traffic. Moving traffic from a simulator was displayed on the screens for authenticity but for simplicity was not correlated with the audio recordings. At the end of the session the sound source was moved to different positions and a second sound source was introduced by adjusting the transaural filters. Qualitative feedback was obtained by prompting their comments with a simple questionnaire. The questions were as follows:

1. Could you hear the communication from your neighbour's loudspeakers?

2. Do you feel disturbed by the loudspeaker signals of your neighbouring CWP?

3. Do you find it helpful to understand some of your neighbouring controller's conversation?

4. Does the headset-free communication setup improve your comfort?

5. Is the spatial separation between sources distinct enough to replace the channel sep-

Figure 7: In the laboratories of the Eurocontrol Experimental Centre in France, realistic control environments can be simulated. Within this simulation laboratory, nine pairs of subjects evaluated the transaural beamformers at two adjacent CWPs.

aration between pilots and controllers in the headphones?

6. Would a pilot's voice that moves along the same track as the aircraft be useful?

Questions 1 and 2 were dichotomous and could be answered with yes or no. Questions 3 to 6 were open-ended and were freely answered verbally.

5 Results

A total of eighteen subjects participated in the evaluation, nine controllers and nine ATC researchers working at the Eurocontrol Experimental Centre in France.

- All participants could hear the communication from the neighbouring loudspeaker array especially when their was a pause in their own CWP communication. In this case, some could even follow the meaning of the communication.

- One controller said sometimes it was not clear whether he was being addressed or his neighbour. The rest of the subjects did not feel disturbed by the neighbouring loudspeaker signals.

- Understanding some of the neighbouring conversation is only seen as helpful if sectors are adjoining and linked by traffic flow.

- There was general agreement that, in low levels of traffic, loudspeakers were preferred.

- All controllers detected changes in source position and thought it was important to spatially separate pilots from controllers when using telephone or intercom.

- The correlated movement of the pilot's voice with corresponding aircraft position on the screen is considered interesting to reduce visual search time.

It was observed that all controllers were comfortable with the sound level set initially by a single colleague.

6 Conclusion

Two transaural beamformers were installed at adjacent CWPs to evaluate how real air traffic controllers are affected by the neighbouring position. The main result is that eight out of nine controllers are comfortable with the system and do not feel disturbed by the loudspeaker signals of the neighbouring CWP. However, several controllers expressed reservations about the level of ambient noise if all CWPs in a busy centre were equipped with such a system.

Suggestions for future evaluations were to:

- have a large scale simulation with many transaural beamformer equipped CWPs.

- focus the controller's attention by performing realistic control tasks e.g. monitoring the radar screen, conflict detection and resolution, and issuing voice instructions to pilots.

- use more realistic quality of pilot audio by introducing noise equivalent to that experienced in a real aircraft cockpit.

7 Acknowledgments

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7.1 Copyright Statement