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STEREOPHONIC PRESENTATION OF INFORMATION : SPACE SIMULATION UNDER HEADPHONES

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ABSTRACT - A system was developed for stereophonic presentation of information (3-D sound) over high-fidelity headphones. The purpose was to reduce the pilot's response time to a localized threat. Physical parameters permitting the localization of sound are reviewed. The technique used to collect a subject's acoustic filtering characteristics is also described. Space simulation of a monophonic sound is presented, the purpose being that the sound be heard as coming from a given point in space. The first steps of a physical validation of the synthesis are presented.

The acquisition of auditory information by a fighter pilot could be optimized by use of a three dimensional spatial presentation of sound messages (3-D sound) either simple warnings given by the machine to the pilot, or real conversations between two team-mates of the same patrol. Concretely, the idea is to send over headphones a sound or a word which seems to come from the direction of the sound source, even if it is originally inaudible.

The purpose is to reduce the pilot's response time.

Sound restitution over headphones is very familiar to people listening to walkmans. However, it has several flaws: sounds are localized "inside the head" ; the sound image moves along with the subject's head, and sound localization is imprecise. The purpose of this investigation was to develop a method for the processing of a sound signal, so that it could be perceived over headphones as coming from a given direction in space.

Principles of 3D sound

Simulation can be divided into three functions (fig.1)

* Sound illustration

The sound illustrator associates a specific sound to each type of information to be transduced.

* Orientation

From aircraft, threat and pilot's head positions, the orienter calculates the coordinates of the point in space where the sound signal has to be located.

Fig.1 Principle of 3D sound

*** Binaural processing**

The binaural processor may be considered as a generator of auditory sensory illusions of localization. From a simple signal (mono) provided by the sound illustrator, it creates two signals (stereo), one for each ear, so that the listener can localize the sound in the "real" three dimensional space, at the position determined by the orienter.

Physical parameters for sound localization [1, 2]

*** Time delay**

Being some distance apart, the two human ears are not struck by a sound at the very same instant. This interaural time is shorter than 700 μ s.

*** Spectral differences**

The head and the trunk diffract the sound wave. Pinnae filter frequencies, with more or less efficiency depending on the incident direction of sounds. This filtering effect depends on the geometric shape of pinnae and is, therefore, an individual characteristic.

*** Head rotation motions**

It has been shown that the listener's head makes small movements, more or less consciously, to improve sound localization, both horizontally and vertically. Their efficiency is probably real in cases when front-rear is undetermined, when interaural time is null. By turning his head, the listener suppresses the confusion.

The proposed hypothesis is that any information relative to sound localization is contained in the form of sound pressure signals arriving in ear canals.

Measurement of head related transfer functions (HRTF) of a subject

The purpose was to measure the interference of the head in the acoustic field, in order to simulate the action of the head on any sound signal. The HRTF is then defined as the ratio of the Fourier transform of the sound pressure signal in the ear canal of the head to the Fourier transform of the sound pressure signal at the same place, the head being absent.

The implementation of this type of measurement has already been described [3, 4, 5]. Our technique was derived from the work of these other researchers.

The sound excitation with a recurrence of 1 Hz was generated by wide-band (200 Hz, 15 kHz) electrodynamic loud speaker, with a diameter of 7 cm, mounted in a closed chamber ($14 \times 9 \times 8 \text{ cm}^3$). The electrical excitation lasted 20 μ s at 40 V amplitude and provided a sound impulse of 3 Pa lasting approximately 80 μ s. The sound signal was time invariant and therefore required only two simultaneous channels of measure, one for each ear.

Miniature Hi-Fi microphones (Sennheiser KE 4) were inserted into a subject's ear canals. Microphones were inserted into custom earmold shells, made from impressions taken for each subject. The earmold shells occluded the ear canals. No stapedian reflex occurred, considering its latency and low recurrence of excitation [6].

Measurements were made in the horizontal plane, at the height of the ear. The loudspeaker was rotated around the subject's head (1.15 m radius, 10° increment) the subject being still. The head position was controlled by the subject himself : a video system composed of two cameras and a video screen continuously displayed front and side views of the head. Approximately 10 minutes were required to make measurements over 360° .

The measurement had to be accomplished in free field. As we had no anechoic chamber we used a filtering technique using a time window of 5 ms to separate the incident wave from reflected waves. A time average (over 8 impulses) was obtained using a synchronization signal. A two-channel Spectral Dynamics SD 380 FFT analyzer was used for data acquisition, including two 12 bit AD converters and simultaneous sampling at 48 kHz per channel. Means are then transferred onto a microcomputer. Measurements show an excellent coherence function between 200 Hz and 15 kHz.

Head transfer functions obtained with a strong impulse signal (3 Pa, 80 μ s) were tested on a human head in an anechoic chamber to verify that they were the same as those that would be obtained under the same conditions, using a weak and much longer signal (Schroeder signal [7], 70 dB, 20 ms).

As an example, figure 2 shows a series of 36 transfer functions of the left ear of a Neumann artificial head, recorded over the entire horizontal plane by steps of 10° . These curves are only valid up to 16 kHz.

Fig. 2 - Transfer function - Neumann artificial head - Left ear

Space simulation of a sound by filtering

The purpose was to filter a sound signal so that it was perceived over headphones as coming from a predetermined direction.

A simple method was used :

- once the HRTFs had been measured, the headphones transfer function used for sound restitution was measured.

- The impulse response of the ratio of these two transfer functions (Head/Headphones) was calculated over 512 points using the inverse Fourier transform. 256 Points (5 ms) were sufficient for the impulse response of the ears, but more points were necessary to compensate for headphones.

- the product of the convolution of the signal to be filtered by the impulse response has to be calculated off-line.

Validation

Validation consisted in taking a sound signal and directing it toward the subject's ears either over a loudspeaker placed anywhere in the room at a know spot, or over headphones. In both cases the result must be the same :

- If the "result" is the sound pressure in subject's ear canals the validation is an acoustic validation. If pressures generated by the loudspeaker and the head phones are the same, acoustic measurements and calculations are validated.

- If the "result" is the sound source localization perceived by the listener, the valid is a psychoacoustic validation [8].

There, we are limiting ourselves to a physical validation in an ideal case :

- the subject is replaced by an artificial head (fixed microphones and very good signal/noise ratio - head still).
- HRTF is measured for a single position. This position is maintained throughout the entire validation.
- The test message is sent to the loudspeaker and measured in the ear.
- the stereo headphones are placed on the artificial head and are not removed until the end of validation.
- the headphones transfer function is measured.
- the test message is digitally filtered, sent over headphones and measured in the ear.

The use of this protocol suppressed problems of repetitive positioning of headphones on the head and microphones in ear canals.

Time responses were compared. In the upper part, figure 3 shows a sound pressure signal transduced by a loudspeaker placed to face the left ear of the artificial head, and measured in the ear canal. The lower part of the figure shows the signal emitted by headphones and also measured in the ear canal. Signal configurations are very similar, and simulation seems satisfactory.

Fig. 3 - Comparison, in time domain, between signal to be obtained (loudspeaker presented stimulus) and signal obtained by synthesis (headphones presented stimulus).

Conclusion

Extension of measurement to all locations in space is under preparation. A psychoacoustic validation will be initiated when we have a real-time processor. The filtering achieved by this processor will have to be able to be modified as a function of the listener's head position information. The sound image can then be stabilized in coordinates independent from the listener.

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