APPLICATION NOTE

About this document

Content

This document is the second of three application notes on spatial hearing and binaural measurement technology. It provides information on the differences between conventional measurement microphone recordings and artificial head recordings, and lists some advantages of binaural recording technology. The last chapter describes the development of an artificial head measurement system with simplified external geometry.

Target group

This document is intended for acousticians who are interested in the aurally-accurate recording of sound signals and want to learn more about binaural recording technology.

Questions?

Do you have any questions? Your feedback is appreciated!
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Binaural recording using an artificial head

Summary

The aim of binaural recording is to capture a sound situation holistically. When listening to a binaural recording, the listeners should be able to "immerse" themselves in the sound situation and perceive it as if they were in an original sound field. To achieve this, the recording must include interaural differences and changes caused by the human body (see Application Note „Spatial hearing").

When recording with a conventional measurement microphone, however, all this information is missing. The measuring microphone records all sounds in the same way - regardless of the direction from which they are received. For this reason, the ear cannot locate or select sound sources when listening to a microphone recording.

In contrast, a binaural recording contains all information that is important for binaural signal processing. A binaural recording can be made using an artificial head, for example. An artificial head measurement system consists of an artificial head with one microphone each in the right and left ear canal.

1. Comparison of microphone recordings and artificial head recordings

Deficits of microphone recordings

In principle, recordings made with a single measuring microphone do not allow for directional transmission, since the sound pressure is a direction-independent scalar. Thus, due to the lack of directional and frequency-dependent coding by the outer ear[1], measuring microphones do not provide information that can be sensibly evaluated by the human ear. Recordings made with stereo microphones at least allow the transmission of level and/or delay differences, but do not reproduce the changes that occur in the sound field due to the listener's physiology. Especially in complex noise situations with several sound sources from different directions, conventional measurement technology produces recordings that can no longer be adequately analyzed by the human sense of hearing (compared to the original sound situation). Due to the lack of spatial separation of the noise sources, the brain is not able to separate the individual sound sources and it is more difficult to concentrate on individual sound sources. However, if the artificial head is in a sound field, it modifies the sound waves like a human before they are recorded by the microphones. And the information needed for binaural hearing is integrated into the recording.

Comparison of microphone recordings and artificial head recordings

Figure 1 illustrates the difference between the two recording modes. In the example shown, a measuring microphone and an artificial head each record two spoken phrases. The phrases are spoken simultaneously by two different persons. One person stands to the left of the recording sensor and the other to the right of it. In the upper illustration, the phrases have been mixed as in a microphone recording. In the lower illustration, the phrases have been separated according to direction, as in an artificial head recording, so that the observer can concentrate on a single phrase and understand it.

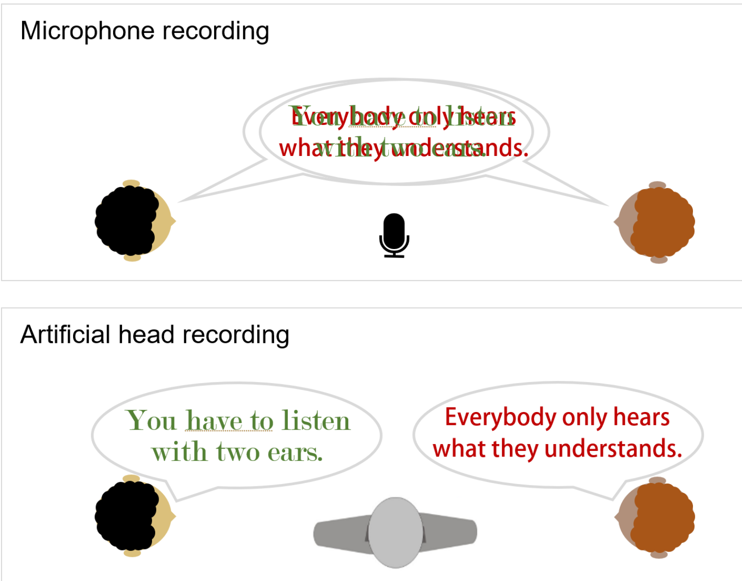

Figure 1: Visualization of a measuring microphone recording (upper illustration) and a binaural recording (lower illustration)

[1] In the following, the term 'outer ear' refers to a summary of all acoustically effective parameters consisting of the upper body, shoulders, head, auricle, and ear canal.

Figure 2 illustrates the difference by means of a basic level analysis. The recording was made with a sound source moved around both an artificial head and a conventional measuring microphone. With the artificial head recording (green and red curves), the level changes (it is higher on the side facing the ear and lower on the side turning away from the ear). The level of the microphone recording (blue curve) remains unchanged during the entire measurement.

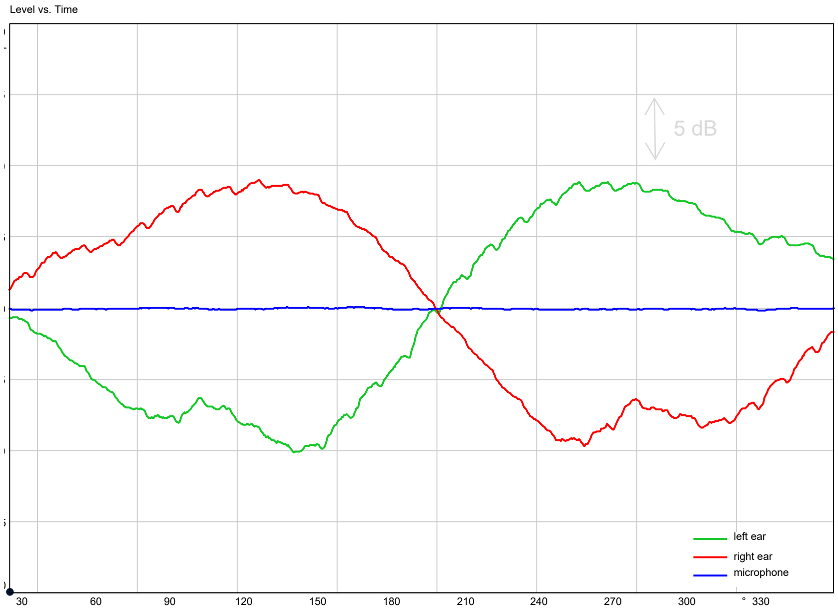

Figure 2: Comparison of an artificial head recording and a microphone recording

Recording complex sound situations

Particularly complex sound situations with many different sound sources can only be recorded and re-perceived correctly with the help of binaural sensors. The noise components of the overall noise, which only have a low power-density spectrum, hardly change the overall level. Nevertheless, it is precisely these noise components that may be perceived as very disturbing. A conventional microphone recording, however, cannot properly reproduce this complex sound situation. In such a recording without directional information it may happen that the quieter sound components are masked by louder ones. In this case, the noise component that was perceived as disturbing in the original sound field is no longer audible when listening to the corresponding recording.

Such a complex sound situation exists, for example, in a vehicle cabin. Here, in addition to the power train, ancillary components also contribute to the overall noise. The individual sounds of these ancillary components sometimes have a very low level. Nevertheless, these sounds may be perceived as disturbing due to the noise patterns they contain. In order to detect and analyze such disturbing noise, the recording of the sound situation must contain the disturbing noise pattern.

Example: vehicle interior sound

The following example of a vehicle interior recording of an idling noise (IC engine) and an artificially introduced disturbing noise shows the difference between a measuring microphone recording and an artificial head recording. The disturbing noise is only audible during playback of the artificial head recording (with the left ear). It is barely audible when listening to the measuring microphone recording. In addition, when listening to the binaural recording, the direction of the disturbing noise can be determined. Also, the detection and investigation of the disturbing noise by means of technical measurement analyses is only possible with the artificial head recording (see figure 3).

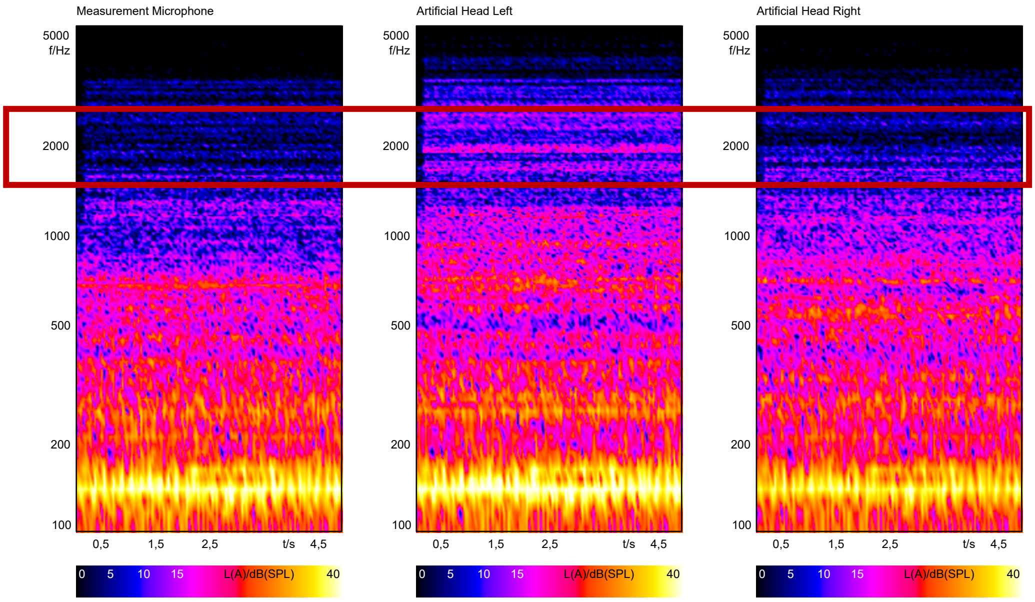

Figure 3: Time-dependent frequency analysis (FFT) of the idling noise of a combustion motor with disturbing noise around 2000 Hz; left: recording with measuring microphone, center: left artificial head channel, right: right artificial head channel

2. Advantages of artificial head recordings

Faithful reproduction of sound events

The aim of measurements by means of an artificial head is to record, transfer and faithfully reproduce sound events at the human eardrums. In contrast to a measuring microphone, an artificial head measurement system with a transfer function comparable to the human sense of hearing changes the sound field differently depending on the direction of the sound source. A binaural recording therefore contains, for example, the interaural delay and level differences that are necessary for sound source localization.

Hearing as an analyzer

With the help of binaural recordings and aurally-accurate playback, sound events can be recorded and played back in such a way that listeners hear them as if they had been present in the original sound field. This allows for a valid perceptual evaluation of the recorded sound signals. The human sense of hearing with its high resolution in frequency and time is included in the analysis of the sounds. In addition, due to the compatibility with conventional measurement technology[2], an instrumental, analytical investigation of the sound events can be realized at the same time.

Summary

Using an artificial head measurement system during recording enables a complete spatial imaging of a sound field and a realistic auditory impression that cannot be achieved by recording with a conventional measuring microphone.

[2] Compatibility with conventional measurement technology is achieved by means of recording equalization; see Application Note „Equalization of artificial head recordings“.

Advantages of binaural measurement technology

- Integration of the sense of hearing in the measurement chain or analysis
- Use of the binaural signal processing of the human sense of hearing (e.g., separation of sound sources and suppression of noise)
- Aurally-accurate, digital conservation of sound events
- More evaluators compared to the in-situ evaluation; all participants evaluate an identical sound situation
- Documentation of interaural delay and level differences

3. Development of an artificial head measurement system

Introduction

Every person hears best with their own ears. In everyday life, the changes caused by one's own auricles can easily be translated into corresponding information about the position of the sound source. When listening to an artificial head recording, however, one hears with someone else's ears, so to speak, namely with those of the artificial head. In order for the sound source localization to work well here, too, the external shape of the artificial head needs to fulfil certain conditions. The changes that the artificial head imprints on the sounds must allow as many people as possible to interpret them correctly. The shape of the artificial head must therefore be designed in such a way that as many people as possible can hear with its ears nearly as well as with their own ears.

Requirements of an artificial head measurement system

In order to ensure aurally-accurate recording and playback, an artificial head measurement system needs to meet the following requirements:

- The directional pattern of the artificial head corresponds to the average directional pattern of humans.
- The inherent noise of the microphones is not perceptible, thus allowing listening tests in the range of the hearing threshold.
- The dynamic range extends to the human threshold of pain in order to detect any level peaks correctly.
- The lower and upper cut-off frequency of the system include the audible frequency range.
- The system can be calibrated and is compatible with conventional acoustic sensors (for specific sound field situations).

Average head-related transfer function

When designing artificial heads, the first question that arises is what criteria should be used to design the artificial head geometry. Sometimes, head-related transfer functions among individual test subjects differ significantly. Therefore, when developing an artificial head measurement system, a head geometry needs to be found that provides good reproduction properties for as many test subjects as possible. The measured head-related transfer functions of individual subjects cannot simply be averaged to obtain an average directional pattern for an artificial head microphone. Such simple averaging bears the risk that important minima and maxima are averaged out. For this reason, a suitable physical-structure-averaging method must be used to determine an average head-related transfer function.

First artificial head measurement system

The first HEAD acoustics artificial head measurement system included a head and auricle replica whose outer, acoustically effective geometry was shaped according to individual templates (HEAD Measurement System, HMS I, see Figure 4). The head and auricle replicas were taken from two different persons (head replica from one person, ear replica from another person). When selecting the person for the ear replica, care was taken to ensure that the auricles of this person had as good a match as possible to the average transfer function previously determined using the structure average method. Given the fact that the complex structure of the head and the auricle defy precise description, this artificial head measurement system could only be calibrated starting at the microphone diaphragm.

Figure 4: HEAD Measurement System, HMS I

Model for the head-related transfer function

Investigations into the human head-related transfer function carried out in the context of Prof. Genuit's dissertation[3] showed that the directional pattern of the outer ear can be significantly defined by a few parameters of the outer geometry. It was possible to determine a mathematical model of the head-related transfer function based on a number of simplifications of the outer geometry of the outer ear. This gave rise to the idea of developing an artificial head measurement system featuring a simplified outer geometry (for a prototype, see Figure 5).

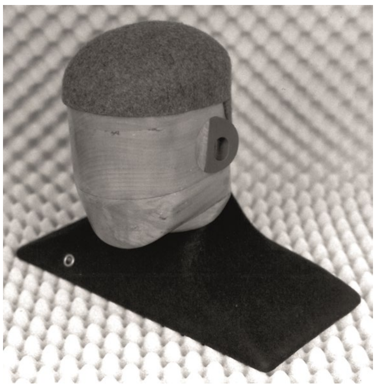

Figure 5: Prototype with simplified outer geometry

[3] Genuit: Ein Modell zur Beschreibung von Außenohrübertragungseigenschaften, Dissertationsschrift, 1984 (A model for describing head-related transfer function properties, PhD thesis, 1984)

Artificial head with simplified geometry

As a result, a calibratable artificial head measurement system with mathematically describable geometry was developed as a serial product (see Figure 6) which complied with the existing ANSI standard S3.36 for artificial heads.

Figure 6: First serial artificial head with mathematically describable geometry (HMS II)

This geometry changes the sound field in the same way as a person with average external geometry does. This is an advantage, as these artificial heads no longer represent just one individual person, but the mean value of many people. HMS II and all its successors up to HMS V therefore physically feature an average representative head-related transfer function.

Transfer function of an artificial head

Figure 7 shows the transfer functions of the right ear of an HMS III. Pseudo-random noise measurements were gradually determined at different positions of the horizontal plane in an anechoic chamber (vertical sound incidence angle $\delta = 0°$, horizontal sound incidence angle φ incremented from 0°–360° plotted on the X-axis).

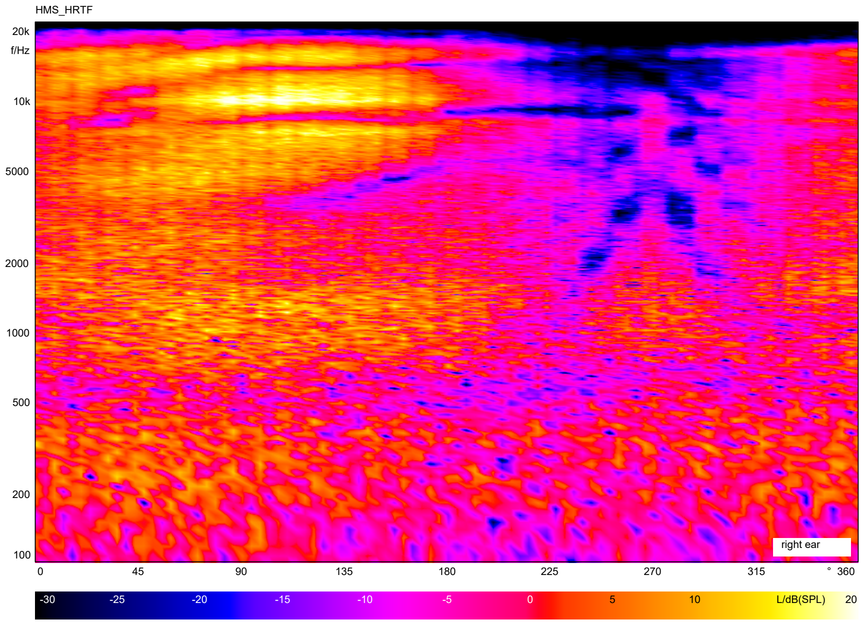

Figure 7: Transfer functions of the right ear of an HMS III in the horizontal plane

➞ *Proceed to the third application note on binaural recording technology*