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DUMMY-HEAD RECORDING

MURRAY HODGSON

INSTITUTE OF SOUND AND VIBRATION RESEARCH

INTRODUCTION:

This paper summarizes the results of a pilot study evaluating the use of dummy-head stereophony for auditorium acoustic research carried out at Heriot-Watt University and reported in (1). For many years there has been considerable commercial and research interest in the development of a sound reproduction system that will accurately reproduce performances. Such a system would record the sound field at some location and replay it to a listener such that he perceives the identical psychoacoustic impressions as he would have perceived at the recording location.

Such an accurate reproduction system is of particular importance for research into the design of auditoria. In auditorium design it is necessary to know how to design the geometry and interior of the enclosure such that the highest listening quality results. This requires an understanding of the relationship between the acoustical characteristics of the hall as characterized by various acoustical parameters (eg. RT, energy fractions, correlation functions) and the psychoacoustic impressions that are perceived in that hall.

Beranek (2) was the first to investigate this relationship. More recently, other researchers have continued this work using techniques which overcome the shortcomings of Beranek's methods. Recordings are made of the same performance in various halls. Pairs of recordings are later replayed to subjects who are simply asked which performance they prefer. Using multivariate analysis, correlations between the results of the paired comparison tests and the acoustical characteristics of the auditoria are made. In this way are determined those acoustical parameters (and in what amounts) lead to high (and low) listening quality.

The attributes of the psychoacoustic impression perceived by a listener are: loudness, tonal quality, reverberance and the spatial attributes: direction, distance and spatiousness. An accurate reproduction system must accurately reproduce all of the above impressions. Monophonic, conventional (intensity and time-delay) stereophonic and quadraphonic sound reproduction systems are in wide use. However all these systems have serious shortcomings regarding the fidelity of their reproduction of psychoacoustic impressions; particularly spatial impressions. Only dummy-head stereophonic reproduction can accurately reproduce all impressions.

PSYCHOACOUSTIC PERCEPTION AND IMPLICATIONS FOR REPRODUCTION:

The fundamental assumption of psychoacoustics is that all such impressions are determined by the sound pressure signals that reaches the two eardrums of a listener. Further, identical eardrum signals result in identical psychoacoustic impressions. Thus the sound reproduction system must replay to the two eardrums of a listener exactly those signals that would have reached the eardrums at the recording position. In this case the subjective quality will be maintained. However, if on reproduction distorted signals reach the eardrums, incorrect impressions will result.

It is beyond the scope of this paper to discuss the details of psychoacoustic perception and the acoustics of the external hearing system. A more complete discussion is found in (1). Suffice it to say that the hearing system consists of two external ears separated by a diffracting object (the head) which produces differences in the spectra, levels, timesof arrival and phasesof signals of $f < 1500$ Hz arriving at the two eardrums. Further, each external ear acts as a complex directionally dependant filter to signals with $f > 4$ kHz. The characteristics of each eardrum signal and the interaural signal differences thus depend on the spectrum, loudness and spatial distribution of the field. This provides perceptual cues which the human hearing system can decode to determine the psychoacoustic characteristics of the sound field.

The acoustic characteristics of the human external hearing system are described by its free-field to eardrum transfer function for all angles of incidence; that is, the ratio of the sound pressure level received at the eardrum for sound incident at the incident-angle to the level received at the eardrum position in the free field. It is clear that a sound reproduction system will transmit signals without distortion if it consists of two separate transmission channels, each recording sounds and replaying them to the respective eardrums of a listener such that the free-field to eardrum transfer function of each channel is identical to that for the human external hearing system at all angles. One way to accomplish this is to record sounds at some reference position in the ears of a dummy head and to replay them to the same reference position in the listener's ears. For distortion-free transmission the dummy head must have identical acoustical characteristics to that of the subject. Also the reproduction system must have a flat response. These are the basic requirements for dummy-head stereophony.

DUMMY-HEAD REPRODUCTION SYSTEM DESIGN:

A dummy-head reproduction system consists of a dummy-head microphone, a tape recorder, replay equalizers and replay transducers. The dummy-head microphone is made up of a head and torso simulation with two external-ear simulators. Each external ear must contain a pinna flange, concha and an earcanal terminated by an impedance network. The correct positioning of the earcanal with respect to the concha is essential as is the position and orientation of the ears on the head. The dimensions and detail of the head, torso and external ears are made equal to the average adult human dimensions. The head and torso are usually made of fibre glass or plaster; the external ears are made of soft rubber. The impedance network is usually an accurate simulation of the average human eardrum impedance. However an accurate simulation is not necessary, as the earcanal termination impedance does not affect the directional discrimination of the ear. Any inaccuracy can be corrected by a suitable electronic filter.

Of fundamental importance is the choice of the reference position at which the microphones receive the signals. In order that all spatial information in the original sound field is reproduced, the reference position must be such that the variation of frequency response at the position is constant with source location. Any position in the earcanal between the eardrum and approximately 7 mm. inside the earcanal entrance is suitable. The most common choice of reference position is at the eardrum. However, this necessitates use of a coupler which combines the microphone and eardrum impedance network. The Zwislocki coupler is the best commercially available coupler incorporating a ½" B + K microphone and an impedance network that accurately simulates the average human eardrum impedance up to 7.5 kHz.

Recently, researchers have experimented with other microphone positions using a dummy head with an anechoic earcanal termination. In this way, they include the earcanals and eardrums of the listener in the transmission channels improving the accuracy of the transmission. In any case, the microphones used must have a flat response and high sensitivity. If a tape recorder is used in the system it may be necessary to equalize its non-linear phase response so that audible phase distortion is not introduced.

Two methods of replaying dummy-head recorded signals have been used - loudspeaker replay and headphone replay. With loudspeaker replay signals are replayed to a listener through two loudspeakers at several meters distance and at angles of about ±60° from the line of sight. Signals recorded in the left and right ears of the dummy head are replayed through the left and right loudspeaker respectively. Equalization filters must be inserted in each channel to compensate for the amplitude and phase distortion due to crosstalk between, for example, the left loudspeaker and the right ear, due to the listener's ear and to the non-flat loudspeaker response.

With headphone replay, perfect channel separation is achieved but equalization must be provided to compensate distortion produced by the headphone and the listener's ear and the coupling between them. Equalization is based on the average human ear. For loudspeaker replay the equalization holds only for one position of the listener's head with respect to the loudspeakers and, therefore, accurate head positioning is essential. Further, replay through loudspeakers must be done in an anechoic chamber to eliminate unwanted reflections. For headphone replay equalization holds only for one positioning of the headphones and therefore this must be standardized.

PERFORMANCE OF DUMMY HEAD SYSTEMS

A review of early work on dummy-head stereophony shows that the performance of even the earliest dummy head systems was significantly better than that of other existing systems. The fidelity of reproduction improved as dummy-head system designs improved, often following new findings regarding the mechanisms of psychoacoustic perception. However, even with the most advanced designs in existence, several reproduction faults are common. These faults concern the reproduction of spatial attributes of a sound field, the other attributes being relatively easy to reproduce. They are directional inaccuracies, front to back exchanges and in-head-localization.

Directional inaccuracies describe the lack of exact agreement between the perceived and actual direction of incidence of a sound. Such inaccuracies are particularly great for laterally incident sounds and for sounds incident in the plane of symmetry of the head. A more specific directional inaccuracy pertains to the elevation of an incident sound which is often perceived to be too high. The explanation for such faults is not exactly known but is probably partly due to the fact that the dummy head is based on the average human and is therefore never identical to any one listener's head.

A front/back exchange occurs when a sound incident from in front (back) of the dummy head is perceived to be in back (front) of the listener on replay. The most serious example of such a fault occurs with headphone replay of dummy-head signals when front to back exchanges often occur. A considerable amount of research has been carried out at various laboratories to solve this deficiency and achieve correct frontal positioning of sounds. The results of experiments made at Heriot-Watt University have suggested that the fault is caused by the poor response of dummy heads, and in particular their eardrum impedance simulations at high frequencies (8-15 kHz). This causes a loss of important frontal positioning perceptual cues. All known dummy heads are poor human simulations above about 8 kHz.

In-head-localization occurs when the impression of distance is destroyed and the sound is perceived to be inside the head. This fault is common with other reproduction systems and occurs with dummy-head reproduction when a crude dummy head is used or when inaccurate replay equalization is used.

Despite the above shortcomings, the quality of reproduction is most impressive with dummy-head stereophony, resulting in a listening experience that is startlingly true-to-original. The loudness, tonal colour, reverberance and spatiousness of a sound field are accurately reproduced. It is believed that improvement of the high frequency response of dummy-head systems will solve the existing problems of incorrect transmission of directional information and will, in particular, result in accurate front positioning. If this is accomplished, dummy-head stereophony will be a truly accurate method of reproducing sound fields.

REFERENCES

1. M. HODGSON 1978 Report submitted to the Science Research Council. Dummy-head stereophony for use in auditorium acoustic research.

2. L.L. BERANEK 1962 Music, Acoustics and Architecture. John Wiley and Sons, New York.

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THE SYNTHETIC SOUND FIELD AS A DESIGN TOOL IN THEATRE ACOUSTICS

Howard G. Latham
Heriot-Watt University, Edinburgh.

The synthetic sound field generates complex sound fields for subjective evaluation in an anechoic chamber. A range of different theatre acoustic conditions can be simulated by controlling the values of a number of physical variables. These variables include the sound pressure level of direct sound; the sound pressure level, delay time, direction and number of early reflections; the sound pressure level and decay time of reverberation; and the sound pressure level of ambient background noise. The advantage of sound field simulation over traditional design indices lies in its ability to evaluate subjectively the combined effects of any number of physical variables. The subjective effect of changesin the physical characteristics of simulated sound fields can be measured in terms of speech intelligibility and speech quality scales. Projects with difficult acoustic problems requiring evaluation of alternative solutions may benefit from practical application of the synthetic sound field.

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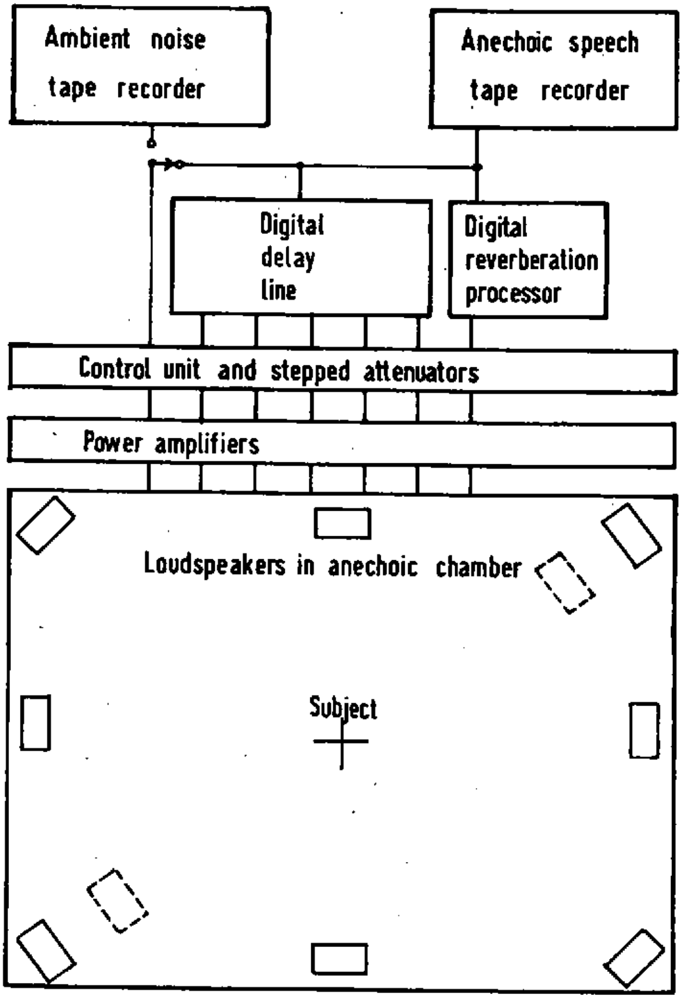

The synthetic sound field