ABSTRACT: As a result of his research of the auralization, the author has developed a computer software named CODA. CODA is the software for the simulation of sound field in a room. It calculates the room impulse response, the paths of all sounds, and the frequency characteristics of the sound amplitude and phase for the particular point in space. It can also perform an area scan of the whole room and present the sound amplitude graphically. The room impulse response obtained by CODA can be convoluted with anechoic sounds and head-related transfer functions for later binaural presentation. CODA can perform the calculation for sound propagation in other materials, not only in the air. Also, CODA is not limited to hearing frequencies - it can also perform the calculation for ultrasound and infrasound frequencies. Thus, although specialized for architectural acoustics, CODA can be used for other applications such as hydroacoustics and simulation of medicine ultrasound.

Key words: computers, auralization, hydroacoustics

1 INTRODUCTION

Simulation is a powerful tool widely used in almost every area of engineering. By means of simulation one can save huge amounts of money, because it is possible to make changes and improvements of the product before its production. Modeling is type of simulation used for centuries, and the development of computers has enabled a more sophisticated type of simulation - computerized simulation. The simulation of sound with proper presentation of the results is called auralization [4]. During his research of auralization the author has developed a software tool named CODA for the simulation of sound. CODA analyzes the sound in a room, and presents results graphically. It can also export the data needed for convolution carried out by third-party software, and thus it can perform the auralization of a simulated room.

2 GENERAL CONCEPT OF AURALIZATION

There are two types of sound simulation: physical modeling and computerized simulation. Physical modeling is the older method, but lately, the more flexible and cheaper computerized simulation is becoming the dominant means of simulation. In physical modeling a simulated room is made in scale 1:5 or 1:10. Test signals, recorded in an anechoic chamber are reproduced in the simulated room, and then picked up by a microphone or an artificial listening head. Special microphones and speakers are used for the reproduction and reception of sound. Since the room is actually smaller, the test signals must be transformed to a higher frequency. The benefit of this method is that all wave phenomena are incorporated, because the simulation is carried out in the real world. Problems arise when slight changes must be made in the room to improve the acoustics. It is normally expensive,
because changes are made physically. Another problem is that downsized microphones and artificial listening heads are very expensive. Due to the transition of test signals, problems arise with air absorption - air absorption is generally higher for higher frequencies, and therefore it has to be compensated by additional drying of the air.

Fig. 1. General concept of auralization

Computerized auralization is a much more sophisticated tool. The general concept is shown in Fig. 1. The first step is the calculation of room impulse response (RIR), and the data for this calculation is obtained by the user’s input of wall properties, room geometry and source directivity data into the computer. There are several methods for the calculation of RIR. The most common methods are ray-tracing and mirror imaging, but these methods do not include wave-related phenomena, such as diffusion and diffraction. Solutions for these problems are the finite element and boundary element methods (FEM & BEM). Although more accurate, these methods are rarely used because of their complexity. After calculation, the program transforms RIR to binaural RIR (BRIR) for the convolution with the anechoically recorded test signal and the head related transfer functions (HRTF). The results can then be presented either binaurally, transaurally, or by multiple-loudspeaker array.

Binaural reproduction is the simplest way of presentation (it involves only a set of headphones), but it has several known disadvantages, such as in-head localization, back-front ambiguity and lack of head tracking. Transaural presentation has better tracking and localization but it requires more sophisticated equipment (two loudspeakers in an anechoic chamber, and crosstalk-cancellation filters). The best, but also the most complex method is multiple-loudspeaker array presentation in an anechoic chamber. A loudspeaker array usually consists of 20-50 loudspeakers, driven by signals from a multiple-channel convoler.

3 CODA

CODA is written for IBM PC compatible computers, based on a 80486 processor or higher. It requires the minimum of 4 MB of RAM. Since auralization is closely linked with architecture, CODA has been integrated in CAD software. The choice fell on AutoCAD for Windows because of its popularity, and because the use of AutoCAD import and export formats has been recommended for auralization software. The programming of CODA was
started in the LISP language [1], because its interpreter is part of AutoCAD software package. Very soon it became too slow for the complex and ever growing calculations involved in auralization. So CODA was translated to AutoCAD Development System (ADS) which is in its essence a library of AutoCAD functions for C language [2]. Even after that, the calculations were not carried out quickly enough. Therefore, proprietary procedures had to be written for all calculations. For the time being, the only ADS procedures used in CODA are those for screen input/output. In this way it was possible to combine the performance of C language with the ease of use, which makes this CAD software package widely accepted.

There are two ways of entering the room geometry. The first one is to load it from an existing CAD drawing, and the second one is to draw it manually. All objects in the room, such as sources, receivers, walls, etc., are defined as blocks. Each block has its geometrical data (position, orientation in space...) as well as its acoustic-related data. Sources and receivers are defined by their directivity characteristics (Fig. 2). Walls are defined by their absorption and diffusion properties.

![Fig. 2. Drawing of control room of Radio “Maribor” with directivity characteristics of sources and the receiver](image)

For the calculation of reflections CODA uses the mirror-image method, because it is simple, accurate and requires less calculation than other methods. The mirror-image method calculates reflections by mirroring the source across the wall. The sound that gets to the receiver seems to come from that virtual source. The same algorithm applies to the second and third order reflections. The source is first mirrored across the first wall, then the virtual source of the first-order reflection is mirrored across the second wall and the process continues.

When the program has determined the paths of valid reflections, it has to calculate the influence that the reflection will have on the sound amplitude and phase. The amplitude and phase of the sound changes also because of the sound propagation [5].

The mirror-image method has its disadvantages: it does not take into account the wave-related phenomena such as diffusion [3]. The principle of the calculation of diffuse reflection is shown in Fig. 3. The position of diffuse reflection theoretically can be anywhere on the
wall, but those closer to the specular reflection (which is the shortest way between the source and the receiver) are more likely to occur. The probability of the occurrence of diffuse reflection is governed by a normal distribution. After the calculation, every valid diffuse reflection gets its virtual source. It is further treated as any other reflection. If that reflection hits another diffuse wall, the procedure is repeated. The diffusion of the wall is defined by three parameters: diffusion coefficient, frequency range, and directivity characteristics.

CODA can analyze the room acoustics in two ways. It can analyze sound in the location of a particular listener, which is defined by its directivity characteristics. It can also produce an area scan. The frequency resolution for the first type of calculation can be adjusted by the user. It can vary from 1/3 of an octave to 1/100 of the hearing range. The user can also decide which reflections are to be taken into account during the calculation. After the calculation has been completed, the results are displayed in three windows. The first one represents the drawing of the simulated room, including all direct sounds and reflections, drawn in different colors (Fig. 4).
In the second window CODA displays amplitude and phase frequency characteristics at the position of the receiver (Fig. 5).

The precision of these characteristics is limited by the frequency resolution which was defined earlier. The third window contains the reflectogram - time diagram of direct sound and incoming reflections (Fig. 6). This window contains information for the second part of auralization – convolution.

If the user chooses the second type of sound analysis – area scan of the test room, CODA calculates the sound for every point in the room. The resolution of this area scan is variable, and the user can adjust it. When the calculation is done, CODA draws the test room and
displays the results in different colors (Fig. 7). This form of analysis usually refers to one frequency, but it is also possible to find the average value for a given frequency range.

Fig. 7. Area scan of analyzed room

The results of both types of calculation can be printed and saved on disk in both graphical and textual forms using the recommended formats - DWG and DXF formats, as well as proprietary formats which includes all calculation results.

4 CONCLUSION

CODA is a software for the computerized simulation of the sound field. It can perform the analysis of the sound in one point in the room, and it can also perform an area scan which gives the information about the amplitude of the sound in the whole room. When CODA analyzes the sound for one point in space it gives the following results: paths of all direct sounds and reflections, amplitude and phase frequency characteristics, and reflectogram of room impulse response. All data can be exported in a proper format for later convolution, which produces binaural sound, and completes the auralization process.

Therefore, it is obvious that CODA is optimized for use in architectural acoustics. However, since the frequency range in which CODA can perform calculation is not limited, and since the media in which sound propagates need not be necessary the air, CODA can be used in other applications too. CODA has already been used for the simulation of the propagation of ultrasound in human head during the surgery of a brain cancer. Due to the similarity of media and frequency range, CODA can be also used for hydroacoustic simulations.

4. REFERENCES
