DAMIAN MURPHY

Hearing the world

Will and Deni McIntyre/SPL

In your GCSE science course you will learn about how sound waves are affected by their surroundings as they travel. Engineers are using this understanding to develop highly-realistic sound systems for films, music systems and computer games. The same ideas can help people with eyesight and hearing problems. Damian Murphy of York University describes how this is done.

GCSE key words
Sound waves
Reflection
Diffraction

Stereophonic sound has been around for over 30 years, and multi-speaker techniques are now commonplace in cinema sound systems, home cinema and DVD systems. They give a more 'immersive' feel to the sounds you hear. Your PC may have surround-sound enhancements for games and other entertainment software. This 'three-dimensional audio' can also be produced using standard headphones or stereo speakers together with precise measurements of the detailed physical characteristics of a person's head and ears.

For accurate surround-sound two things need to be taken into account. First, the environment in which it is heard — a room, a corridor, the middle of a field — affects the quality of a sound, and we need to be able to understand and recreate this. Second, our hearing system is designed to give us information about where a sound is coming from. This is a basic survival mechanism enabling us to run away from sounds associated with danger (e.g. a stampeding woolly mammoth, or an approaching fast car). Our sense of direction is very finely tuned, and for convincing surround-sound we need to know more about how our ears give us this directional information.

IMPULSE RESPONSE OF A ROOM

The size, shape and materials of a room all play a part in the quality of any sound heard within it. Imagine a gun being fired inside a large room or hall. This short, sharp and very loud event causes variations in the air pressure (known as **compressions** and **rarefactions**) that are transmitted through the air itself, spreading out into the room in every direction — a **sound wave**.

Figure 1 shows how a sound wave travels across a room. When it strikes objects in the room, it is

around us

partially **absorbed** and partially **reflected.** There may also be **diffraction** effects, where the sound bends round an object or passes through a gap (such as an open door), resulting in further spreading of the original sound wave. It is because of diffraction that we can hear through an open door or window. Very quickly (within 100 ms) the sound from our gunshot has spread through the room, having been reflected, absorbed and diffracted, resulting in a very complex and random pattern of sound.

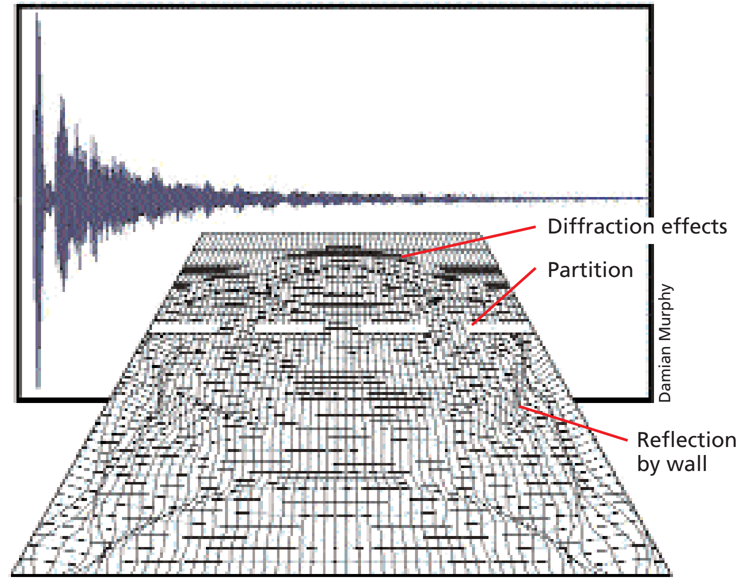

Figure 2 *A sound wave caused by the computer equivalent of a gunshot propagating through a mesh structure that is designed to simulate a room. Notice the reflections at the boundaries and the diffraction effects in the partitioned area, caused by gaps in the dividing wall. In the background is a typical room impulse response obtained from such a model.*

MEASURING SOUND

The example of a gunshot sound is used because it contains all the audio frequencies in which we are interested at equal amplitudes. We can describe the complex way the room affects this sound using a single measurement called the **impulse response.** We measure the variation in air pressure using a microphone (or just by listening to the sound) at a point in the room. We can examine how each frequency has been changed by its interactions with the room.

The impulse response itself is not very interesting to listen to. It lasts anywhere between 0.1 and 10 seconds depending on the size of the room and how reflective the surfaces are, and sounds like a click with a prolonged and decaying tail. This decaying part of the impulse response is due to the **reverberation** present in the room and is the characteristic ‘hanging on’ quality of a sound that can be heard once the sound source itself has become silent. Reverberation can, for example, be heard quite clearly in an empty church. It is possible to take this very boring sound and combine it electronically with any other sound — for example, a piece of music. We can make the music sound as though it is coming from inside any particular space, as long as we know the impulse response of that environment.

The impulse response of a room can be measured directly, but for most applications it is more practical to calculate an approximation using an acoustic model. Figure 2 (above) shows how the acoustics of a room can be modelled using a computer simulation.

● Most pop music vocal recordings take place in small rooms or booths yet the results we hear on a CD have a very different acoustic characteristic. What do they sound like? Why do you think this is?

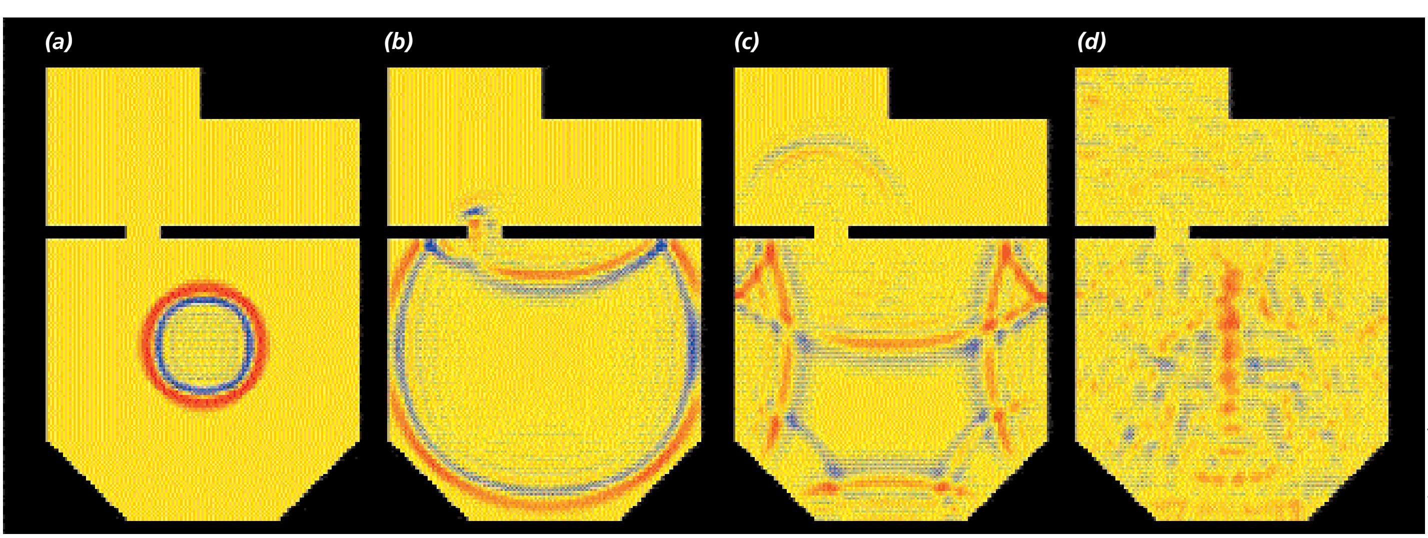

Figure 1 (a) *A sound wave spreads out into the room.* ***(b)*** *It is partly reflected and partly absorbed by the walls.* ***(c)*** *It is diffracted as it passes through a doorway into the room beyond.* ***(d)*** *After a while, both rooms are filled with a random jumble of low-amplitude sound waves.*

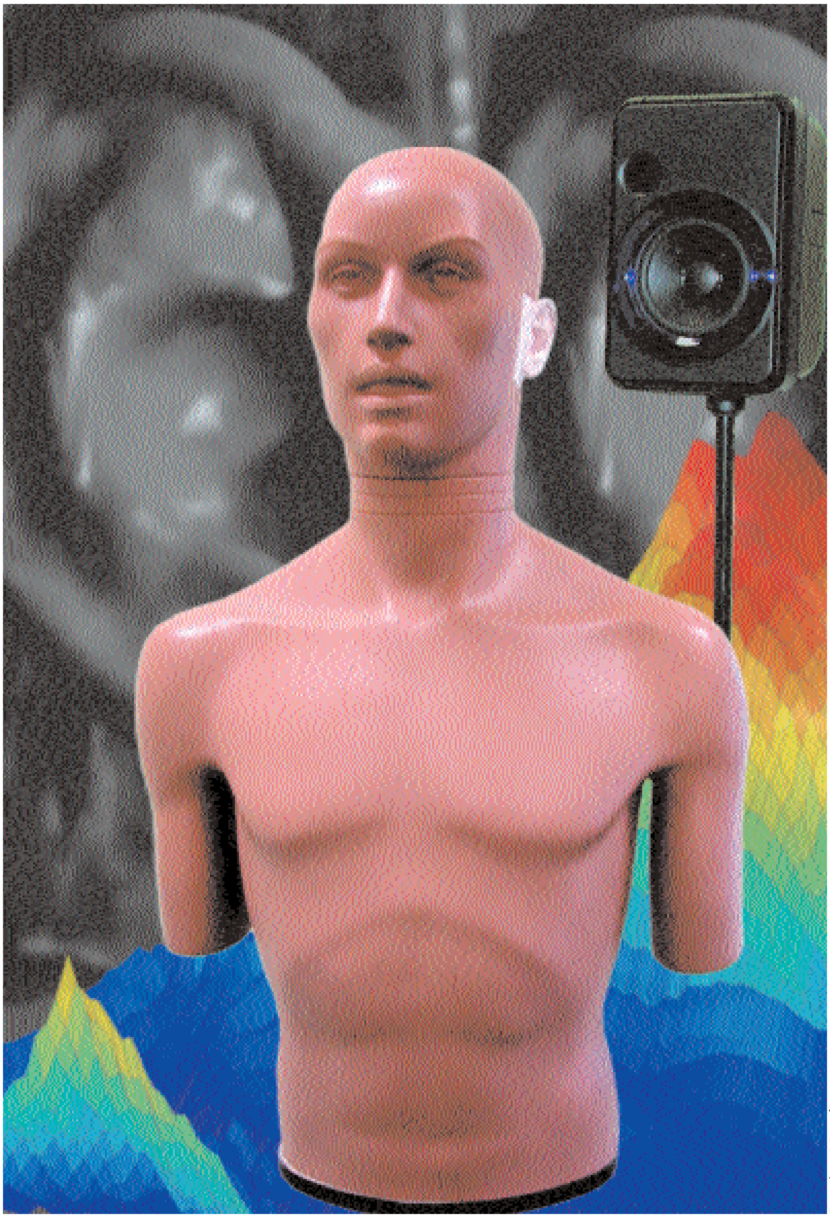

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Figure 3 *A mannequin and speaker used in the measurement of the head-related impulse response. A dummy is often used because it stays still when the measurements are being made. In the background is a three-dimensional graph of the measured head-related impulse responses showing how frequencies vary with the direction of the sound, and also a model of the outer ear.*

Some owls have one ear higher than the other. This is thought to give them a better three-dimensional picture of the sounds around them in a dark wood.

● Next time you go to the cinema, listen carefully to the sound you hear around you. What can you hear from each set of speakers? How good is the surround-sound effect?

IMPULSE RESPONSE OF THE EAR

Just as the room around us affects the sounds we hear, so does the shape and structure of our head, but on a much smaller scale.

A sound coming to us from one side arrives at one ear slightly before the other and its amplitude is different at each ear. Sound waves diffract around the head, and undergo minute reflections in the pinnae (the fleshy parts of the outer ears). This alters the frequency content of the sound that reaches the ear-

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Damian Murphy with the mannequin head.

drums and is how we know which direction the sound has come from.

Every person's head affects sounds in its own way because we all have heads and outer ears of different sizes and shapes.

If we measure the room impulse response at the entrance to the listener's ears we can find out how sounds are affected by both the room and the listener's head and ears. It can be electronically combined with any audio source. A sound can then be placed at any position in a three-dimensional virtual space around the listener's head, and reproduced using only headphones (or stereo speakers) (see Figure 3).

THE GOAL

Sound research can be valuable in producing aids for both visually and hearing-impaired people, for example:

- improved hearing-aids;
- audio guides for popular tourist attractions;
- computer interfaces that translate visual information into a virtual surround-sound space by placing 'audio icons' around the listener's head.

The ultimate scientific goal in surround-sound is to electronically generate a complex three-dimensional acoustic world that is indistinguishable from what we normally hear around us. As well as work with the visually impaired, this technology has applications in music composition, sound reproduction, art, architectural design, cinema, telecommunications, user-interface design, television and gaming entertainment. The result is accurate, exciting surround-sound effects.

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