PSYCHOLOGY

Obstacle Detection using Ambient or Self-generated Noise

OBJECT ranging can be achieved by humans using the sound reflected or scattered from obstacles. For a range of wave-lengths short compared with the size of its surfaces, and long compared with the size of the irregularities in these surfaces, specular reflexion will be obtained and an acoustic image of the sound source will be formed analogous to an optical image. In many situations, however, such as the approach of an external corner, an acoustic image may not be audible from the observer's position. In these cases sound scattered from the edges and irregularities may, or frequently may not, give the necessary warning. Such signals are, however, weak compared with those of the acoustic image with which we are chiefly concerned.

In the neighbourhood of such an obstacle, sound reaches the ears of an observer both directly and by reflexion from the obstacle, as if originating from the acoustic image. Interference between these signals introduces a series of maxima and minima into the frequency spectrum, the spacings of which depend on the path difference. A sound of broad bandwidth develops a characteristic tone the pitch of which becomes higher as the obstacle is approached[1–3]. This tone is not normally perceived as such; blind subjects generally claim to 'feel' the presence of an obstacle directly[4]. It is, however, readily perceivable under laboratory conditions.

Blind people are reputed to find difficulty in negotiating obstacles in the immediate vicinity of intense noise sources[5]. There would appear to be several reasons for this difficulty.

First, people accustomed to using self-generated noises such as their own footsteps may find such noises masked and be unaware that reflexion of the extraneous noise itself could give them the information that they require.

For people who normally make use of the ambient noise, there are some further causes of difficulty when the source is nearby. The depth of modulation of the spectrum as they approach an obstacle will depend on the relative amplitude of the direct and reflected waves. For large source distances and high reflexion coefficients, these will be nearly equal and the depth of modulation will be high. Nearby sources, however, in which the ratio of the path lengths is large may give modulation depths below threshold.

The pitch itself may also be very different from that obtaining for a distant source so that, for example, while maintaining a parallel course with a wall they would hear a changing pitch. Naturally, this could lead to the disorientation of the observer. Moreover, when the source lies between the observer and the obstacle, it can be seen that the pitch will be determined predominantly by the position of the source and very little by the position of the observer. This is, however, unimportant in practice as the reflecting surface would not be considered as an obstacle until the source of sound itself had been negotiated.

The main object of this article is to point out the potential importance of rates of change of pitch in giving additional ranging information, enabling several ambiguities to be overcome. The first of these is the occurrence of octave mismatches when this type of signal is matched in pitch to a sine wave, indicating the possibility of more than one estimate for the distance. The second arises when the source of sound lies at an angle remote from the normal to the reflecting surface, giving a higher value of pitch than for angles near the normal ($f = \frac{c}{2x \cos \theta}$ where c is the velocity of sound, x the distance of the observer's ear from the plane of the reflecting surface, and θ the angle between the source of sound and the normal to the surface).

In both cases, if pitch is defined in the musical sense of log frequency, it can be seen that the rate of change of pitch with movement of the observer, $\frac{\mathrm{d}f/f}{\mathrm{d}s}$, will lead to unique evaluation of the distance of the obstacle in the direction of motion. Specifically, $\frac{\mathrm{d}f/f}{\mathrm{d}s} = -\frac{1}{s}$ regardless of the angle of approach; so that the motion required to change the pitch by a given small amount is a direct measure of obstacle distance. This will, of course, be true only if the distance of the source from the surface is large compared with that of the observer. For distances that are comparable, the expression for the path difference is more complex; but, as before, the rates of change can be calculated by differentiating this. Despite the apparent complexity of this expression, the rate of change of pitch tends toward the simple value given above as the obstacle is approached.

It would seem then that, although a blind man must inevitably encounter difficulty and disorientation in the neighbourhood of a sound source, nevertheless if he is prepared to carry on his original course the appropriate ranging information will reappear and become more definite and more accurate as he gets nearer to the obstacle.

At higher speeds of travel, greater distances will be covered before the observer can come to a halt. The higher speeds, however, will also lead to greater rates of change of pitch with respect to time or conversely to a greater distance at which a predetermined rate of change is achieved.

As the rate of change of pitch is proportional to velocity, and inversely proportional to distance in the direction of motion, it follows that once a certain critical value of rate of change of pitch has been reached, the observer, whatever his velocity, will have a constant time, T, before collision if he maintains this velocity. An experiment of Leonard and Wycherley[6] gave stopping distances proportional to speed up to 5 m.p.h., at about 1 ft./m.p.h. (0·7 ft./ft./sec). The critical value for rate of change for this subject would therefore be about 2 octaves/sec, giving him 0·7 sec before collision if he takes no avoiding action or, assuming uniform retardation, 1·4 sec to stop.

The human auditory system is likely to be particularly sensitive to rates of change of this order, as they lie well within the range of rates encountered in the rise and fall of the formant frequencies of speech. It is interesting to note that, in the case of the cat, cortical neurones have been found that respond only to certain ranges of changing pitch[7]. Although the frequencies are much higher than can be perceived by humans, the rates of change concerned are comparable (1–5 octaves/sec).

Furthermore, most subjects have expressed the opinion that the pitch of this type of signal is much more readily perceived when it is changing.

It would appear that our auditory system and possibly those of some animals are well suited to the problems of detection and avoidance of obstacles.

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[1] Wood, A., *Acoustics*, 200 (Blackie, London, 1940).

[2] Cotzin, M., and Dallenbach, K. M., *Amer. J. Psychol.*, **63**, 485 (1950).

[3] Bassett, I. G., and Eastwood, E. J., *J. Acoustical Soc. Amer.*, **36**, 911 (1964).

[4] Supa, M., Cotzin, M., and Dallenbach, K. M., *Amer. J. Psychol.*, **57**, 133 (1944).

[5] Leonard, J. A., and Carpenter, A., *Amer. Found. Blind Bull.*, **4**, 70 (1964).

[6] Leonard, J. A., and Wycherley, R. (personal communication).

[7] Whitfield, I. C., and Evans, E. F., *J. Neurophysiol.*, **28**, 655 (1965).