A Blind Mobility Aid Modeled After Echolocation of Bats

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***Abstract*—A new model of a mobility aid for the blind was designed using microprocessor and ultrasonic devices. This mobility aid was evaluated based on psychophysical experiments. In this model, a downswept FM ultrasound signal is emitted from a transmitting array with broad directional characteristics in order to detect obstacles. The ultrasound reflections from the obstacles are picked up by a two-channel receiver. The frequency of the emitted ultrasound is swept from 70 to 40 kHz within 1 ms, so it has almost the same characteristics as the ultrasound a bat produces for echolocation. The frequency of the reflected ultrasound wave is down converted by about 50:1 by using a microcomputer with A/D and D/A converters. These audible waves are then presented binaurally through earphones. In this method obstacles may be perceived as localized sound images corresponding to the direction and the size of the obstacles. From the results of psychophysical experiments, it was found that downswept FM ultrasound was superior for the recognition of small obstacles compared to other ultrasonic schemes. With it a blind person can recognize a 1-mm-diameter wire. It was also proved that the blind could discriminate between several obstacles at the same time without any virtual images. This mobility aid, modeled after the bat's echolocation system, is very effective at detecting small obstacles placed in front of the head.**

I. Introduction

During the last two decades, about 30 models of blind mobility aids have been developed, and some of them are in practical use [1]. The Sonic-torch [2], Sonospec, Pathsounder [3], Mowat Sensor [4], Nottingham Obstacle Detector [5], and Laser-Cane [6] are called clear path indicators or obstacle detectors because the blind can only know whether there is an obstacle in the path ahead [7]. These devices are used to search for obstacles in front of a blind person, and they operate in a manner similar to a flashlight, which has very narrow directivity. Sonicguide, however, is called an environment sensor because is has wide directivity enabling it to search for several obstacles at the same time [8]. Discrimination experiments have been done by Kay. However, there are still some problems to be solved in this latter device such as low spatial resolution and the perception of simultaneous virtual images. This used slower frequency sweeps over 250 ms, so its operation is different from the aid described here.

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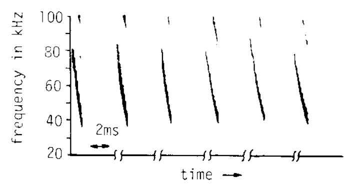

Fig. 1. Typical time spectrum pattern of FM bat's orientational ultrasonic.

Some species of bats have the ability to detect tiny obstacles and flying insects by using ultrasound echolocation. The bat echolocation mechanism is not completely understood, but according to current knowledge, it has been shown that the bat's inner ear mechanism has a function similar to that of a human. There are certain characteristics such as a high Q resonance at certain frequencies in the basilar membrane where the bat's hearing system differs from that of humans [9], [10]. However, it is expected that the same echolocation function may be elicited in the human auditory system.

Since most bats transmit downswept frequency-modulated (FM) ultrasound for their echolocation as shown in Fig. 1, this downswept FM sound probably has advantages in detecting and recognizing obstacles [11], [12]. In this paper, we describe the design of a new mobility aid device modeled after the bat's echolocation system. An investigation of the role played by the downswept FM sound to detect and recognize obstacles is also described.

II. Mobility Aid Device

Our mobility aid device consists of a microcomputer board with three channels of D/A conversion and two channels of A/D conversion. ROM (16 kbytes), RAM (16 kbytes), one ultrasonic transmitter, two ultrasonic receivers, and two earphones are shown in Fig. 2. Each element is made of CMOS to make the power dissipation as low as possible. The device can be driven by four rechargeable batteries. A photograph of the device is shown in Fig. 3.

The downswept FM ultrasound is emitted from a transmitter with broad directional characteristics, and the reflected ultrasound signals are picked up from obstacles by a two-channel receiver. The signals picked up are amplified and filtered. The frequency of the emitted ultrasound

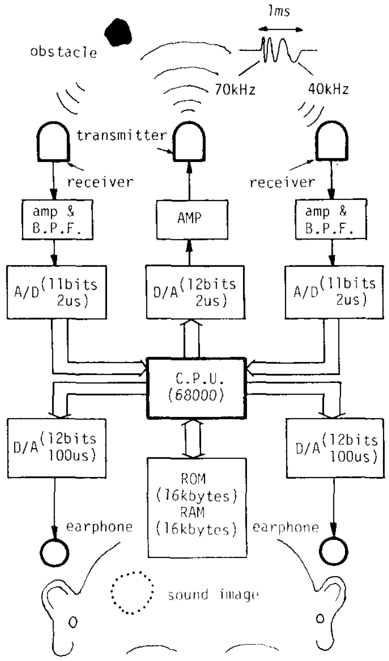

Fig. 2. Block diagram of our mobility aid device.

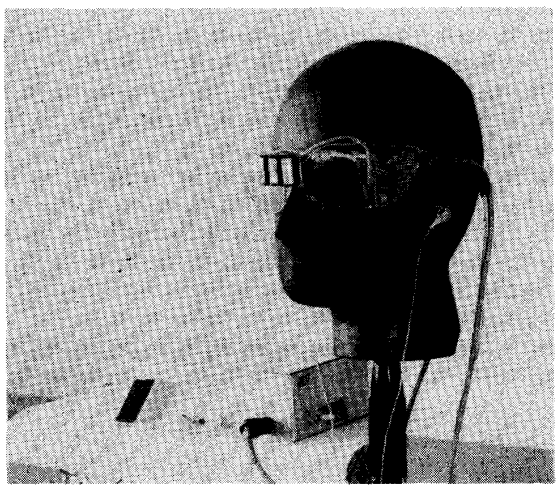

Fig. 3. Photograph of the device.

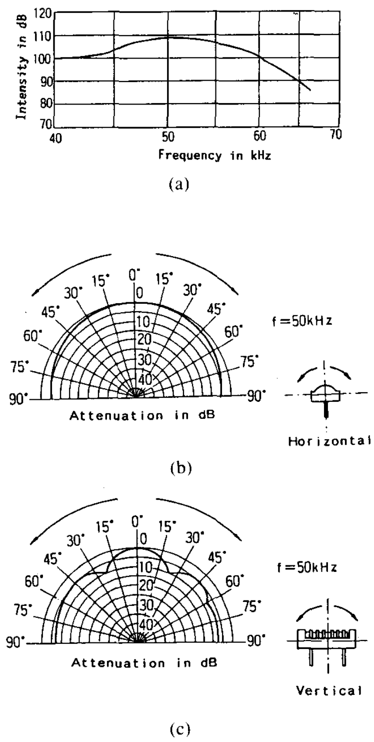

Fig. 4. (a) Frequency characteristics of ultrasonic transducer. (b) Horizontal and (c) vertical directivity of ultrasonic transducer.

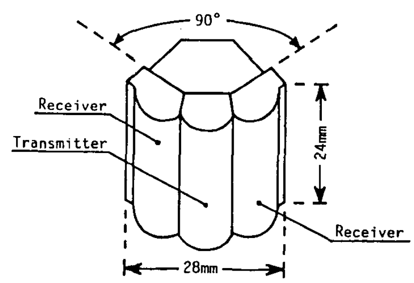

Fig. 5. Arrangement of the transducers.

signals sweeps downward from 70 to 40 kHz within 1 ms, so it has almost the same characteristics as the ultrasound signal a bat produces for echolocation.

The detected signals consist of 8192 sampling points and are stored into RAM through an A/D converter with 11-bit resolution during a 2-μs sampling period. These data are then downconverted into an audible signal through a two-channel D/A converter in 100 μs with 12-bit resolution. The refected ultrasound wave now lies in the frequency range of 800 to 1400 Hz where the auditory sensitivity is just below the most sensitive range of human hearing and the frequency difference limen is small. These audible waves are presented to both ears through earphones. In this method, obstacles may be perceived as localized sound images corresponding to the direction and the size of the obstacles.

The transmitter and the receivers were designed by Matsushita Electronic Components Co., Ltd., and these devices have a very wide frequency range and broad directivity as shown in Fig. 4.

These transducers are fixed in the center of the frame on a pair of eyeglasses, and the two receivers face orthogonal directions as shown in Fig. 5. Fig 6(a) shows the relative intensities of the reflected sound plotted as a function of the angle from a pole moved on a circular path 1 m in front of the receivers. Fig. 6(b) shows the arrival time difference of the reflected sounds between the two receivers as a function of the direction of the pole. Inten-

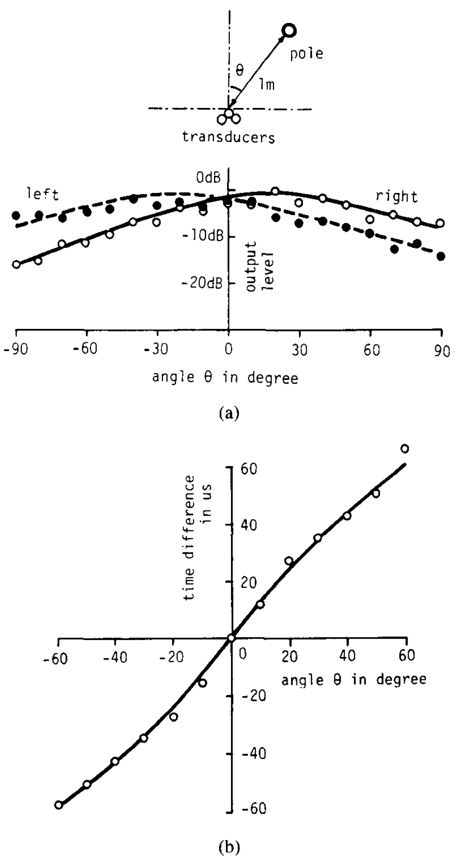

Fig. 6. (a) Relative intensities of the reflected sound as a function of the direction of the pole. (b) Arrival time difference of the reflected sounds between two receivers as a function of the directions of the pole.

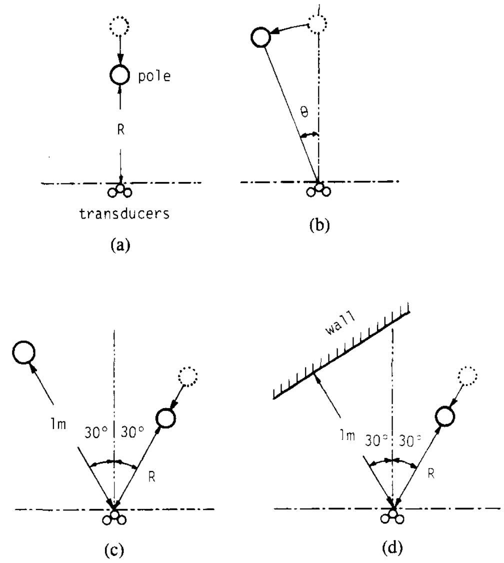

Fig. 7. Arrangements of obstacles and transducers for psychophysical experiment of the discrimination ability of poles.

sity and time differences produce a sound image inside the head through binaural sound perception that changes depending on the direction of obstacle, although auditory localization based on sound intensity differences is best made in a higher range than the output produced by the device.

III. Evaluation Method for Discrimination Between Two Objects

The ability of subjects to perceive an object was evaluated by following two experiments. Two normal-hearing subjects participated in these experiments. The subjects ranged in age from 24 to 29 years and had hearing thresholds better than 10 dB HL from 125 to 4000 Hz. The threshold was taken as the geometric mean of the two subjects. In the experiments, a pole 70 cm high was placed in front of the observer as shown in Fig. 7(a) and (b). The pole was made of acrylic material. The diameter of the pole was reduced from 20 to 2 mm incrementally.

Experiment 1

The distance R was made large. The pole was then moved continually closer until it could just be perceived [see Fig. 7(a)]. The pole was moved manually and slowly to prevent nondevice stimuli from affecting the judgment. The order of diameter presentation went from the largest to smallest.

Experiment 2

The angle θ from the front of the observer was changed until the pole was just perceived to be at a different direction [see Fig. 7(b)].

Next, the ability of a subject to discriminate between two objects was evaluated by the following three experiments. In the experiments, two other kinds of ultrasound signals were used besides the downswept FM signal to determine the most suitable. These consisted of a 50-kHz constant frequency (CF) with 1-ms duration and an upswept FM signal from 40 to 70 kHz with 1-ms duration. Each subject was tested using all these signals in the order of CF, upswept, and downswept FM signals. The various frequency variations with time are shown in Fig. 8.

In the third and fourth experiments, two poles 70 cm high were placed in front of the observer at an inclination of 60° [see Fig. 7(c)]. The diameter of the right pole was 30 mm, and during the course of each experiment, the diameter of the left was reduced from 30 to 3 mm.

Experiment 3

The distance R was changed until both poles were perceived to be at the same distance.

Experiment 4

R was changed until the two objects could just be perceived as being separate.

In the last experiment, the left pole was replaced by a

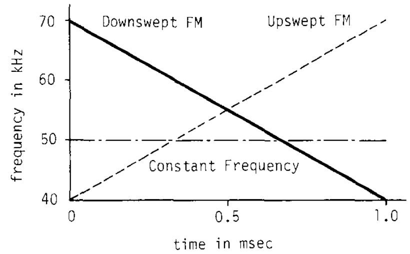

Fig. 8. Time spectrum patterns of three orientational sounds used for the psychophysical experiment.

steel plate perpendicular to the line between the plate and observer [see Fig. 7(d)]. The plate was 153 cm high by 124 cm wide. In the course of this experiment, the diameter of the right pole was reduced from 30 to 3 mm.

Experiment 5

R was made large. The pole was then moved closer until it could just be perceived.

IV. Experimental Results and Discussions

In experiment 1, the R at which the pole could just be perceived increased in proportion to the diameter of the pole, as shown in Fig. 9. In experiment 2, the θ at which the pole could be perceived at a different direction from the front of the observer decreased in inverse proportion to the diameter of the pole, as shown in Fig. 10.

In experiment 3, the R at which the two poles were perceived to be at the same distance increased markedly when the diameter of the left pole became less than 2 mm, as shown in Fig. 11. This result means that obstacles placed at the same distance were perceived at almost the same distance if the size difference between two obstacles was not too large. This phenomenon was found in the cases of upswept FM sound and CF sound as well as downswept FM sound.

In experiment 4, the R at which two poles were perceived to be individually separated was about 117 cm for both cases of FM sound and about 130 cm for the case of CF sound, as shown in Fig. 12. This means that FM sound is more advantageous to discriminate multiple obstacles than CF sound. The distance did not depend so much on the difference in the diameters of the poles; furthermore, no difference was found between upswept FM and downswept FM.

In experiment 5, where the plate was substituted for the pole, the R at which the pole was perceived as a separate object was about 113 cm in the case of FM sound and 93 cm in the case of CF sound. There was no difference for the case of upswept and downswept FM when the diameter of the pole was more than 10 mm, as shown in Fig. 13. FM sound appears to be superior to CF sound for the perception of obstacles. Downswept FM was, however, found to be better than upswept FM when the diameter of the pole was less than 5 mm. Downswept FM sound is

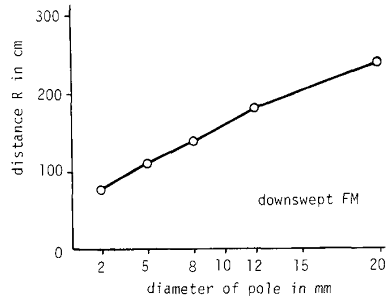

Fig. 9. Distance (R) at which the pole could be perceived at the different direction from the front of the observer.

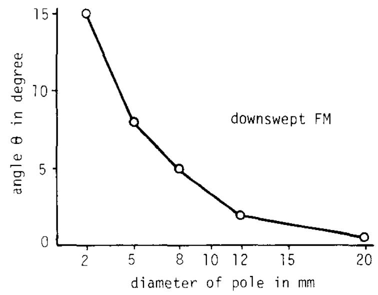

Fig. 10. Angle (θ) at which the pole could be perceived at a different direction from the front of the observer.

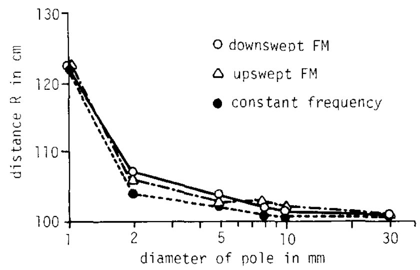

Fig. 11. Distance (R) of the right pole at which two poles were perceived to be at the same distance as a function of the diameter of the left pole.

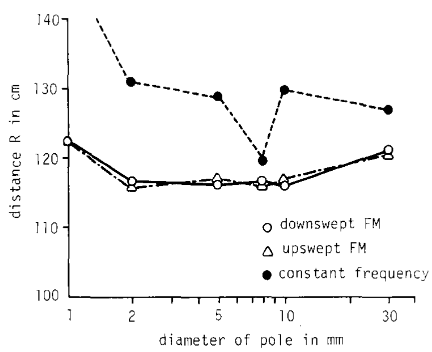

Fig. 12. Distance (R) of the right pole at which two poles were perceived to be individually separated as a function of the diameter of the left pole.

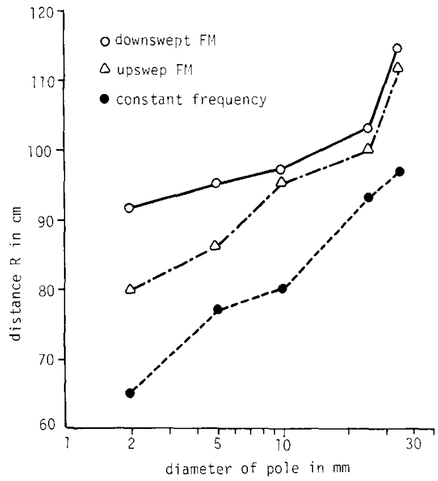

Fig. 13. Distance (R) at which the pole was perceived as a separate object as a function of the diameter of the pole.

most effective for the perception of small obstacles placed near a wall.

Temporal masking may explain why the downswept FM was more effective in all cases. Sounds that occur earlier are not easily masked by later sounds due to temporal masking. With downswept FM, the high-frequency sounds occur first, and these sounds are important to detect smaller objects. Whether this speculation is true or not, our mobility aid modeled after the bat's echolocation system seems to be effective in detecting small objects placed in front of the head.

The test used to evaluate the scheme is of a limited and preliminary nature. Although the package combined with a microcomputer board and battery pack for the device is relatively large, this device can be made in an inconspicuous package and can incorporate cosmetic features. The ears are not completely closed with the earphones for this device, so as to not prevent the user from making use of other naturally occurring sounds to aid mobility. The presently evaluated device has to be used with a cane or a guide dog and is only part of the mobility task. The essence of mobility is the motion of a person, either body movement through walking or head movements to localize sounds. The ultimate test will be the ability of the device to provide the information needed by the blind pedestrians in the real world in which the mobility task is ordinarily performed.

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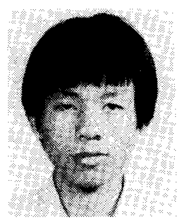

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