Study of Sound Direction Evacuation

Wenhui Dong, Chunyu Yu, Mei Zhibin

Shenyang Fire Research Institute, China

ycyu01@aliyun.com

ABSTRACT

Nowadays, many buildings have exit signs which are used to guide occupancies to the exit when an emergency happens. However the assistance given by signage based on visual means may be reduced or totally ineffective in a smoke filled environment. And occupants may not be familiar with the building and its associated emergency egress routes and may have to rely on exit maps, markings, or signage to guide them to an exit or other means of evacuation. There are other limitations of signage-based visual means. Persons with visual disabilities will have difficulty with emergency information that relies on visual cues. Other weaknesses are that the illuminated exit signs may often compete with nearby bright lights or other visual elements. Exit signs may be inadvertently blocked from view due to renovations or remodeling of building.

Directional sound is a new kind of signage which can help occupants to pinpoint instantly where the sound is coming from and find the exit quickly. Used as a directional sound pattern, broadband sound can enable localization cues due to all binaural transfer function and precedence effect mechanisms. And broadband sound is distinctive from the audible sounds of bells and fire emergency voice speakers.

The fire alarm sounders and the fire emergency voice speakers are two important sounds in a fire emergency evacuation. So the compatibility of the directional sounders with fire alarm sounders and fire emergency voice speakers is very important in application. The three sound used in a fire emergency evacuation should work timesharingly and alternately.

Ambient sound levels may greatly affect the performance of the directional sounders, for the ambient sound may possibly have wide spectral range. A directional sound test room is built according to Annex B Directional test for sounders of the British standard BS PAS 41:2003[1] Directional Sounders – Requirements and tests. And tests were made to see the performance of different frequency distribution sounds used for evacuation direction under ambient sound levels.

KEYWORDS:

 evacuation ; directional sound technology ; broadband sound.
INTRODUCTION

In most buildings, exit routes are identified by visual means, exit signage. But the signage is easily obscured with even low level of smoke. Besides, exit can also be hard to find in visually cluttered areas, such as supermarkets and shopping malls. Many behavioral studies [2,3,4] have repeatedly shown that one of the most natural instincts in the event of a fire is people evacuate a building by the route through which they entered. This is rarely the quickest or most appropriate way. Many people fail to spot nearby exits and in some cases walk straight past visible fire exits.

Directional sound is a new technology which offers a solution to improve the exit signage for building occupants. This technology can help occupants to pinpoint instantly where the sound is coming from and relocate the exit. The technology was first proposed by professor Deborah Withington from University of Leeds. She performed numerous evacuation tests[5,6,7,8] involved scenarios such as with and without directional sound, evacuations with low visibility conditions created by use of theatrical smoke, and variety of room and complex corridor arrangements. In smoke-filled scenarios with little or no visibility of exit signs, directional sound demonstrated its benefit to provide cues that significantly reduced the time for subjects to find the nearest exit. Boer L C [9,10] designed a new sound signal on the basis of professor Deborah Withington’s work and proposed some evacuation tests in tunnel and ship environment.

The directional sound technology is widely used in many countries. NFPA72 National Fire Alarm Code of America[11] has provided guidance on installing and maintaining directional sounders from the 2007 Edition. And the BSI published the standards BS 8465-2005 Code of practice for design and installation of directional sounder evacuation systems[12] and BS PAS 41:2003 Directional Sounders – Requirements and tests[1].

THE PRINCIPLE OF SOUND DIRECTION EVACUATION

The ability to pinpoint the location of a sound source is based on the physics of sound and the physiology of the human hearing mechanism. The human brain processes a large amount of signals, some of which provide cues to the sound source’s location.

The horns, bells and loudspeakers installed in buildings to produce the alarm signal and voice messaging typically work at the same time to alert people to an imminent danger as wide an area as possible but give no information concerning the direction to, or location of, the nearest exits.

People are able to hear sound ranging from about 20Hz to 20000Hz. The primary localization cues are provided by interaural time differences, interaural intensity differences and head-related transfer function(HRTF). At lower frequencies the time delay between arriving sound signals is detectable. Interaural time difference is most evident in frequencies below about 1000Hz. At higher frequencies the loudness/intensity differences between the ears is more noticeable because of partial shielding of the more distant ear by the head. Interaural intensity differences are most evident for frequencies above 3000Hz. HRTF describes the transforming effect of the head, torso and external ear on sound as it travels from the sound source to the ear canals. The shape of the ear attenuates some frequencies and amplifies others like a filter. The HRTF changes depending on sound source location, providing an additional localization cue. And HRTF is most effective in the 5000Hz to 10000Hz range.

All of the above cues can be utilized simultaneously when the source signal is broadband sound containing a range of low and high frequencies. The combination of different cues provides reinforcement and redundancy of information to enhance the ability to locate the sound source. So the broadband sound is used as directional sound signal to help occupancy locate exit points and for guidance in complex evacuation routes in a large building. Directional sounders contain frequency content extending over almost all of the entire range discernible by the human ear. This wide band type of frequency content is often referred to as “white noise”.

Since the development of directional sound technology, numerous studies have been conducted that compare occupancy egress time assisted by directional sounders to egress time based on conventional visual signals and signage. These studies have yielded a large body of data that indicates that the use of directional sounders consistently results in a significant reduction of egress time.

TESTS OF LOUDSPEAKERS

As far as concerned, broadband sound is used in directional sound technology[11]. Theoretically, this sound should have a bandwidth ranging from about 20Hz to 20000Hz based on human hearing range. But in fact, few loudspeakers in the market are capable of presenting such a broadband sound and with acceptable
price. Also, the performance of these loudspeakers is uneven in current market. Used as a unit for directional sounder, the size of a loudspeaker is generally not bigger than 4 inches since a directional sounder with bigger size usually consumes more power and has aesthetic problems. So the effective range of the frequency bandwidth of the sounder is needed to be identified. The ability of producing broadband sound of the loudspeakers available in the market with the size below 4 inches is tested in an acoustical sound enclosure with an audio analyzer.

![Acoustical sound enclosure](image1)

Fig. 1. Acoustical sound enclosure

The results are showed in Table 1. The effective frequency range of most loudspeakers tested reaches 500-10000Hz, but not the broadband frequency range 20-20000Hz. Whether this effective frequency range good enough for localization needs to be tested.

| Number | Effective frequency range(Hz) | Size(inch) | Number | Effective frequency range(Hz) | Size(inch) |
|--------|-------------------------------|------------|--------|-------------------------------|------------|
| 1      | 500 ~ 10000                   | 4          | 10     | 1600 ~ 20000                  | 2          |
| 2      | 400 ~ 12620                   | 3          | 11     | 2000 ~ 16000                  | 2          |
| 3      | 2000 ~ 10000                  | 2          | 12     | 400 ~ 10000                   | 2          |
| 4      | 500 ~ 16000                   | 2.5        | 13     | 1600 ~ 16000                  | 2          |
| 5      | 1600 ~ 20000                  | 2.5        | 14     | 1600 ~ 5000                   | 2          |
| 6      | 400 ~ 10000                   | 1.5        | 15     | 1600 ~ 20000                  | 1          |
| 7      | 2000 ~ 16000                  | 1.5        | 16     | 1600 ~ 20000                  | 1          |
| 8      | 500 ~ 12620                   | 2          | 17     | 1800 ~ 14000                  | 1.5        |
| 9      | 2000 ~ 20000                  | 1.5        | 18     | 500 ~ 20000                   | 4          |

**Table 1. The effective frequency range of chosen loudspeakers**

**DIRECTIONAL SOUND TEST ROOM**

![Directional sound test room](image2)

Fig. 2. Directional sound test room

A directional sound test room is built according to Annex B Directional test for sounders of the British standard BS PAS 41:2003 Directional Sounders – Requirements and tests[1]. The performance of the directional sound signals will be tested in this room. The dimensions of the test room are shown in Fig.2. The room is geometric symmetry in order to provide acoustically symmetric condition around the subject.
Ambient sound levels may greatly affect the performance of the directional sounders, for the ambient sound may possibly have wide spectral range.

To test the localizing of a sound signal, test subjects with specified age distribution[1] will determine the location of bursts of sound from numerous possible positions. The test subjects should have normal hearing for their age.

36 full frequency sound boxes are placed in a circle with 10 degrees interval and 3 meters diameter around the subject. A digital audio signal is produced from a computer with sound card and transformed to a sound signal, which is amplified by a power amplifier before played by one of the sound boxes.

**DIRECTIONAL SOUND TEST**

Ten test subjects participated in the directional sound test. The age distribution is shown in Table 2.

| Age  | Number |
|------|--------|
| 18-27| 2      |
| 28-37| 4      |
| 38-47| 2      |
| 48-57| 1      |
| 58-67| 1      |

Fig. 3. Test subjects

Broadband sound with different frequency bandwidth is tested. Besides, pure tone signals are also tested for reference. The tested sound level is set 75dB. Appendix A to NFPA’s Fire Alarm Code[11] shows examples of what average ambient sound levels may be for different applications. But in China, the ambient sound levels of most possible applications may be higher. The fire alarm sound and fire emergency voice speaker sound should be at least 15dB higher than ambient sound levels. Besides, directional sound should be at least 15dB lower than the fire alarm sound considering the compatibility between the two sounds. So two ambient sound levels are considered in the tests. One is below 60dB, and the other is 75dB.

As in the test, 36 sound boxes are placed in a circle with 3 meters diameter around the subject. The circle is marked from 0° to 360°. Each sound box is placed in a position with specified degree.

Prior to commencing the tests, the subject needs to know:

1) Do not move head during the tests.

2) There are a number of different sounds to be played, and he or she will be require to identify the location of the sound.

3) Each sound will be played 10 times with each time from one random sound box. A gap of 5s is given between each sound and he or she has to make a decision on location in the 5s.

4) In the noise effect tests, a noise sound will be played continuously, while he or she will distinguish and tell the location of the directional sound signal.
For each sound, there are 100 test results. In each test, the direction pointed by the subject has a deviation with the sound box which gives the audible signal. And if the deviation is bigger than $5^\circ$, the percent correct number will diminish by one. The results are listed in Fig.4.

Background noise has some impact on the locating of the sound source. When the background noise level is closer to that of the test sound, pure tone sound patterns tend to be harder to locate, while broadband sound with bigger frequency range is still easier to pinpoint.

Besides, it’s easier to pinpoint the location of broadband sound, but the frequency bandwidth should be as wide as possible. According to the British standard BS PAS 41:2003, test subjects shall correctly identify the location of the sounder at least 75% of the time. In Fig.4, when ambient sound level is below 60dB, three sounds with bandwidth 0.02-20kHz, 0.3-16kHz, and 0.5-10kHz meet the above requirement. But when ambient sound level is 75dB, only two sounds with bandwidth 0.02-20kHz and 0.3-16kHz meet the requirement. More work should be done to choose the proper loudspeaker which can give more broadband effective frequency range.

Fig. 4. Results of the localization tests

COMPATIBILITY WITH FIRE ALARM SOUNDERs AND FIRE EMERGENCY VOICE SPEAKERS

The fire alarm sounders and the fire emergency voice speakers are two important sounds in a fire emergency evacuation. So the compatibilities of the directional sounders with fire alarm sounders or fire emergency voice speakers are very important in application.

The fire alarm sound can comfortably exceed most common background noises. And from the above test results, if the bandwidth of directional sound is broad enough, the percent correct can meet the requirement 75% of the standard BS PAS 41:2003 even if the background noise is louder. Fire alarm sound has a strong tonal content as opposed to the more even, broadband content of a directional sounder. DANIEL J [13] compares the spectrum of a typical fire alarm signal at a high setting with the spectrum of the directional sounder at a lower power setting. Although the fire alarm may have an overall A-weighted sound level 20 dBA or more higher than the overall A-weighted sound level of the directional signal, both sounds are audible.

But where directional sounders and voice evacuation systems employing speakers are utilized within the same occupancy the directional sounders can reduce the speech intelligibility of fire emergency voice speakers. So it is recommended [14] that when both systems are utilized in the same installation that the two systems are not operated simultaneously.

The fire alarm sound and fire emergency voice speaker sound should work timesharingly and alternately. And the time of each fire alarm may be 10s to 20s, and 10s to 30s for that of each fire emergency voice speaker. Considering the compatibilities of the three systems, the directional sounders should work the same time with fire alarm sounders with a lower overall A-weighted sound level, but timesharingly and alternately with fire emergency voice speakers.

DISCUSSION

The engineering application of directional sound technology will face some problems which will be discussed here.
Compared with the widely recognized fire alarm sound signal, the broadband sound may cause confusion to Chinese residents without training when an emergency happens. Occupants in buildings may do not know how to react when they hear the sound. So an enhancement with the addition of voice messaging is necessary. The voice message after the directional sound will tell occupants of what action to take when they approaching a directional sounder[9]. This message will allow them to react quickly and confidently without training or prior knowledge of this new evacuation signage.

Traditional fire alarm and voice evacuation system both give out sound signals when an emergency happens in buildings. The directional sound is an additional evacuation aid to be used, but not a replacement for the above two traditional systems.

The directional sounders should be installed at the exit. But sounders only at the exit may not provide directional sound loud enough to reach the majority of the occupants. Besides, in large, open areas, there may be multiple exits, but multiple directional sounders can cause interference with each other. So the installation of the directional sounders should be further investigated.

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