Listening Decision Aid Simulator for Whistle Sound-Related Collision Accidents

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Key words: listening decision aid, collision accident, whistles sound, spatial transfer coefficient, three-dimensional sound

ABSTRACT

This paper describes Listening Decision Aid Simulator (LDAS) to provide a decision-supporting tool that can reproduce real-like listening situations focused on the duty officer's two ears. The sound propagation mechanism from a whistle to listener's two ears is established at first, and the spatial transfer coefficients of a bridge door are measured at training vessel. Then, the construction works with the spatial transfer coefficients and its evaluation experiments with five collision accidents are carried out. As results from tests, the five cases can be judge by LDAS; it led to the insight of practical use of LDAS as one of the decision supporting system in collision accidents.

1. Introduction

On 14 April 1912, M/V 'Titanic' foundered and safety standards in the shipbuilding changed forever. Soon after the tragedy, the International Maritime Organization (IMO) was established. The IMO prompted the first Safety Of Life At Sea (SOLAS) conference. Then, the SOLAS chapter V is revised with several relevant resolutions in July 2000. The Sound Reception System (SRS) is one of the new equipments recommended by those resolutions. Collision avoidance is surely the most important part at sea traffic. Especially, the traffic routes located in the west-southern coastal area in Korea are frequently in danger of being collision accident. These areas are surrounded with many islands, and fog and bad weather reduce visibility frequently. It is resulted in the form of sound blind sectors at which Sound Pressure Level (SPL) of whistle sound is decrease rapidly. The essential works to prevent accidents in these areas are finding locations, which are highly sensitive sea routes to marine accidents, and then investigating listening phenomena by duty officers on the watch.

The use of Sound Reception System (SRS) also can be considering as one of useful anti-accident equipment. SRS is acoustical electronic navigational aids to enable the officer on the watch to hear outside sound signals inside a totally enclosed bridge in order to perform the lookout function as required in the International Regulations for Preventing Collisions at Sea, 1972. The general requirements for the SRS are recommended by resolution A.694 (17). Even though SRS have high quality amplifier and direction finding sensors, it does not catch the ship's sound signal in the area of sound blind sectors, in spite of the sound source is located in the near side. The sound blind sectors, thus, are one of the inherent causes to whistle sound-related collision accidents.

The more important factors related with collision accidents in restricted visibility are to find the truth of blasting whistle sound by vessels concerned. But the decision works of that truth are difficult because the truth is only relies on the statements of duty officers. As shown in the decision letters of Korea Maritime Safety Tribunal (KMST, 2001), many collision accidents cannot judge the truth of blasting whistle sound with full confidence. Moreover, recently, collision accidents are increasing rapidly after the fisheries agreements both of Korea-China and Korea-Japan. If a collision accident is occur between multi nations, and if cannot decide the truth of blasting whistle sound, then the case may progress into Low Intensity Conflict (LIC).

Thus, a judge supporting system to decide the truth of blasting whistle sound is surly required coping with new maritime circumstances in the world.

2. Theoretical Background

The whistle sound, blasted by a ship, propagated into the air and the bridge door, then listen to a duty officer as shown in Figure 1. During this propagation, acoustical characteristics such as Sound Pressure Level (SPL), frequency, delay time, so on, will be change according to weather and surrounded constructions. The influence factors in the propagations are absorptions, reflections, and deflections.

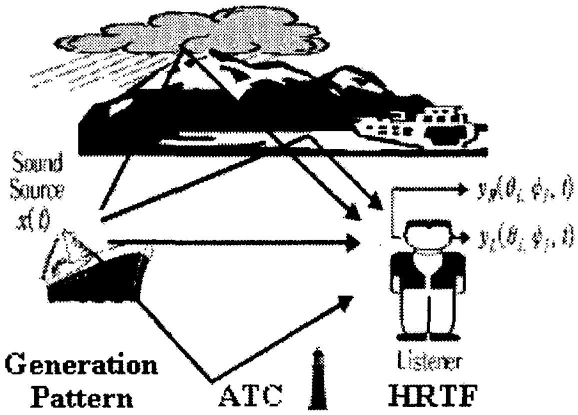


Figure 1 Sound propagation routes from a whistle to duty officer's two ears.

The theoretical relationships between a whistle sound and listener's two ears can be expanding as single-input two-output system. The two output signal from duty officer's two ears, $y_L(\theta_i,\varphi_j,t)$ and $y_R(\theta_i,\varphi_j,t)$ are defined as

$$\begin{aligned} y_L(\theta_i,\varphi_j,t) &= gp(\theta_R,\varphi_R,t)[(x(t)*h_L(\theta_i,\varphi_j,t-\tau_{L0})\alpha_{L0}+x(t)*h_L(\theta_i,\varphi_j,t-\tau_{L1})\alpha_{L1}+....+x(t)*h_L(\theta_i,\varphi_j,t-\tau_{Lk})\alpha_{Lk}+....] \\ y_R(\theta_i,\varphi_j,t) &= gp(\theta_R,\varphi_R,t)[x(t)*h_R(\theta_i,\varphi_j,t-\tau_{R0})\alpha_{R0}+x(t)*h_R(\theta_i,\varphi_j,t-\tau_{R1})\alpha_{R1}+....+x(t)*h_R(\theta_i,\varphi_j,t-\tau_{Rk})\alpha_{Rk}+....] \end{aligned} \tag{1}$$

where $x(t)$: input signal at time t, θ_i: bearing angles along with horizontal plane divided into I spaces $i=1,2,3,\Lambda,I$, φ_j: altitude angles along with vertical plane divided into J spaces $j=1,2,3,\Lambda,J$, $gp(\theta_R,\varphi_R,t)$: directional characteristics of a whistle at the relative bearing θ_R and φ_R, $h_L(\theta_i,\varphi_j,t)$ and $h_R(\theta_i,\varphi_j,t)$: Head Related-Transfer Function (HRTF) for the left ear and the right ear, respectively, τ_{Lk}: delay time with Kth order at L's sound path, α_{Lk}: attenuation coefficients with Kth order at L's sound path, $\alpha=\alpha_A+\alpha_F+\alpha_D$: combination of coefficients with air α_A, fog α_F, and bridge door α_D.

The expansion of Eq.(1) into z-domain is given by

$$\begin{aligned} Y_L(\theta_i,\varphi_j,z) &= GP(\theta_R,\varphi_R,z)H_L(\theta_i,\varphi_j,z)\sum\alpha_{Lijk}z^{-nLijk} \\ Y_R(\theta_i,\varphi_j,z) &= GP(\theta_R,\varphi_R,z)H_R(\theta_i,\varphi_j,z)\sum\alpha_{Rijk}z^{-nRijk} \end{aligned} \tag{2}$$

Note that $Y_L(\theta_i,\varphi_j,z)$ and $Y_R(\theta_i,\varphi_j,z)$ can be express as the production of each right side terms in Eq.(2). It means that the two outputs at given conditions can be obtain if we get the right side terms with high accuracy. The fictitious meaning of each right side terms, $GP(\theta_R,\varphi_R,z)$, $H_L(\theta_i,\varphi_j,z)$, $H_R(\theta_i,\varphi_j,z)$, $\sum\alpha_{Lijk}z^{-nLijk}$, and $\sum\alpha_{Rijk}z^{-nRijk}$, are displayed in Figure 2.

3. Acoustical Transfer Coefficients

3.1 Generation Pattern of Whistle

The directional characteristics of a whistle, $GP(\theta_R,\varphi_R,z)$ in Eq.(2), relies on the relative angle positions between the directions of a whistle and a listener's head. Further, the values of $GP(\theta_R,\varphi_R,z)$ are depending on the type of whistle concerned. The international technical details of sound signal appliances is indicated in USCG (2004) Annex III as 'The sound pressure level of a directional whistle shall be not more than 4 dB below the prescribed sound pressure level on the axis at any direction in the horizontal plane within ±45 degrees of the axis. The sound pressure level at any other direction in the horizontal plane shall be not more than 10 dB below the prescribed sound pressure level on the axis, so that the range in any direction will be at least half the range on the forward axis.'

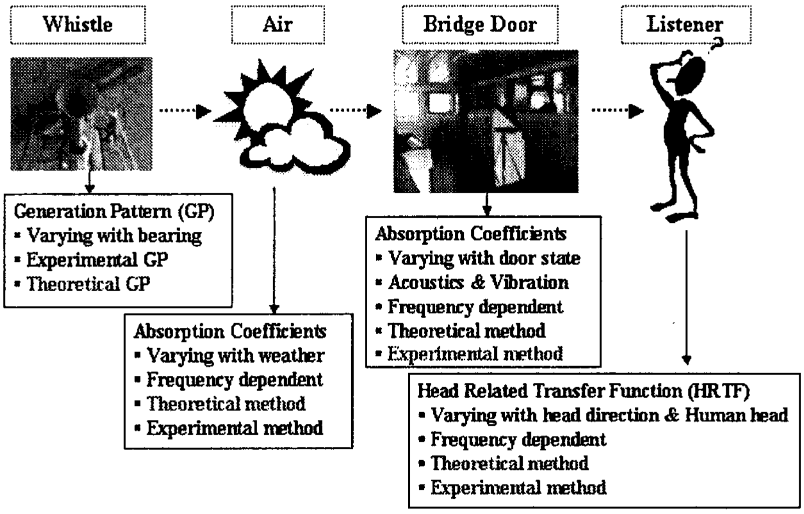


Figure 2 Sound transfer factors and its implementation methodology.

In this work, the technical requirements to a whistle sound, as mentioned above, are adopted to calculate $GP(\theta_R, \varphi_R)$ with assumption $\varphi_R = 0$. The approximation values having real parts only in z-domain are given by

$$GP(\theta_R) = \left|\cos(\frac{\theta_R}{2}) \times \alpha_{\min}\right| + \alpha_{\max}, 0 \le \theta \le 2\pi \quad (3)$$

where $\alpha_{\min}$: attenuation value within ±45 degrees, $\alpha_{\max}$: attenuation value except ±45 degrees.

The calculation result with $\alpha_{\min} = 0.1$ and $\alpha_{\max} = 0.9$ is shown in Figure 3. This figure is represented by polar-plot in $0 \le \theta_R \pi 360$.

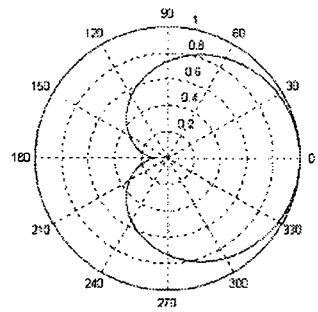


Figure 3 Polar-plot of $GP(\theta_R)$, $0 \le \theta_R \pi 360$ with $\alpha_{\min} = 0.1$, and $\alpha_{\max} = 0.9$.

3.2 Spatial Transfer Coefficients

The attenuation coefficients, α_A, α_F, and α_D, are expressed as $\alpha = \alpha_A + \alpha_F + \alpha_D$, we call it Spatial Transfer Coefficient (STC) in this work. In case of α_A and α_F, the attenuation coefficients are collected from previously reported tables by Knudsen & Harris (A.D.Pierce, 1994; L.L.Beranek, 1996). The transfer coefficients for α_D are measured with different conditions such as: door open, door half close, and door close. In this experiment, the acoustic measurement equipment B&K 2260D is used. Figure 4 shows experimental procedures. The measurement experiments are carried out on the bride of T/S 'SAENURI'.

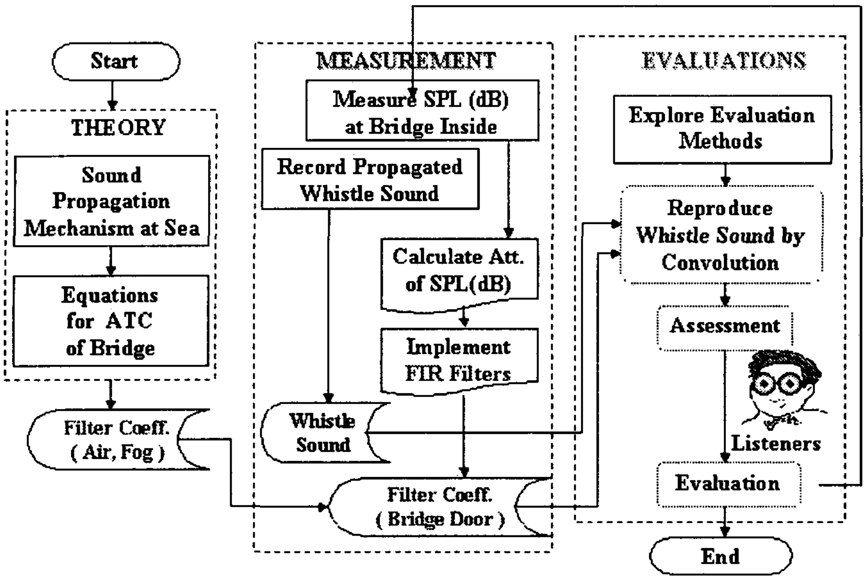


Figure 4 Flow-chart of STC measurements and evaluations of bridge door.

The measurement results of a whistle sound are shown in Figure 5. These results are measured at each door conditions, open, half-open, and close, and displayed as frequency (Hz) versus SPL(dB).

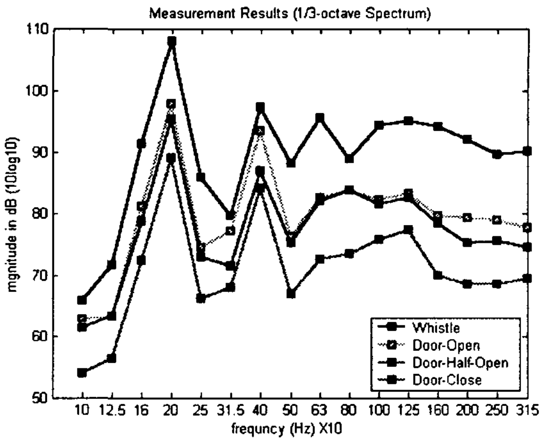


Figure 5 Measurement results of the bridge door with various door conditions.

Here, the values of SPL in Figure 5 are measured by means of

$$SPL_{rd} = SPL_{r} - SPL_{rREF} = 10\log_{10}\left(\frac{1}{4\pi r^2} + \frac{4}{k_R}\right) - 10\log_{10}\left(\frac{1}{4\pi r_{REF}{}^2} + \frac{4}{k_R}\right) \qquad (4)$$

Thus, the attenuation values of STC given by

$$\alpha_{rd} = 10^{0.1 SPL_{rd}(r)} \qquad (5)$$

After obtain the coefficients of STC, FIR (Finite Impulse Response) filters are implemented by the method of frequency sampling-based FIR Filter (IEEE Press, 1979) given by

$$h(n) = \frac{1}{2\pi}\int H(\omega) e^{j\omega n} d\omega = \frac{\omega_0}{\pi}\sin c\left(\frac{\omega_0}{\pi} n\right) \qquad (6)$$

The impulse response $h(n)$ has infinite sequences of numbers due to SINC functions. To cope with that problem, applied Hamming window given by

$$w[k+1] = 0.54 - 0.46\cos(2\pi \frac{k}{n-1}), k = 0,...,n-1 \quad (7)$$

3.3 HRTF

In this work, the pair of Head Related-Transfer Function (HRTF), $H_L(\theta_i,\varphi_j)$ and $H_R(\theta_i,\varphi_j)$ are used HRTF database, which is developed by the authors (YIM J.B., 1994; YIM J.B., 1996). This HRTF database is constructed from many head-related functions of Korean peoples.

3.4 3D Sound Reproductions

At first, the generation pattern $GP(\theta_R)$ and FIR filters $FIR(\theta_i)$ are applied to monaural whistle signal $x(n)$, and obtained $T(\theta_i,m)$ given by

$$T(\theta_i,m) = GP(\theta_R)\sum_{n=0}^{N-1} FIR(\theta_i,n)x(m-n) \quad (8)$$

where N : the number of FIR filter taps, m : the length of sequences.

Again, the calculation results of Eq.(8) are applied into Eq.(9)

$$\begin{aligned} O_L(\theta_i,\varphi_j,m) &= \sum_{n=0}^{N-1} H_L(\theta_i,\varphi_j,n)T(\theta_i,m-n) \\ O_R(\theta_i,\varphi_j,m) &= \sum_{n=0}^{N-1} H_R(\theta_i,\varphi_j,n)T(\theta_i,m-n) \end{aligned} \quad (9)$$

Then, $O_L(\theta_i,\varphi_j)$ and $O_R(\theta_i,\varphi_j)$ are to be the left ear signal and right ear signal to reproduce real-like sound field environments as mentioned in Figure 1. Because the pair of $O_L(\theta_i,\varphi_j)$ and $O_R(\theta_i,\varphi_j)$ have the directional information of HRTF pairs, $H_L(\theta_i,\varphi_j)$ and $H_R(\theta_i,\varphi_j)$, the convolution results by Eq.(9) also have that information. It is the basic theory of 3D sound reproduction.

4. Implementation of LDAS

4.1 System Construction

The Listening Decision Aid System (LDAS) consists of three main modules and five sub-modules. The implementation works are carried out using MATLAB GUI functions based on the Windows XP and PC environments. Figure 6 shows LDAS design procedures.

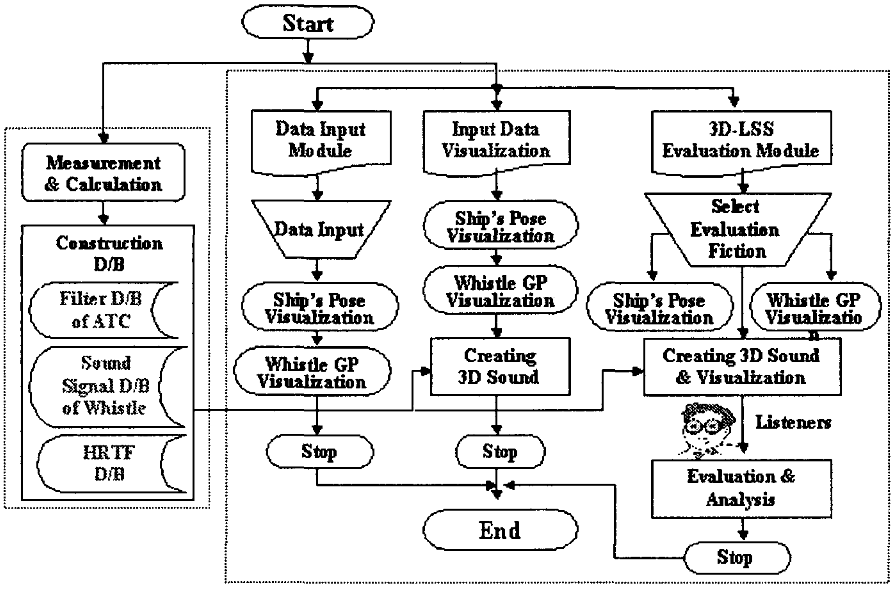


Figure 6 Flow-chart of LDAS design procedures.

The operation results of LDAS are shown in Figure 7, and the brief key functions of LDAS are summarized as followings:

Data Input Module

The function of this module (Figure 7a) is to collect the twelve casualty data such as: the first recognized position each other, the ship's length, the location of duty officer (bridge inside, bridge wing), door states (open, half-open, close), weather (clear, foggy), own ship's course and speed, other ship's course and speed, relative bearing of other ship's, and distance between two ships. Soon after entering the twelve data; the two ship's pose and the polar-plot of directional attenuation values of the whistle sound blasted by other ship are displayed on the small windows immediately. Thus, the user can check the entering data using graphics easily.

Sound Visualization Module

The function of this module (Figure 7b) is to visualize reproduced 3D sound. Using headphones, the user can hear the 3D sound repeatedly, and can compare with original whistle sound blasted by other ship.

Situation Evaluation Module

The function of this module (Figure 7c) is to provide various evaluation works for many casualty environments. This module consists of detailed five sub-modules as followings:

Original Sound Generation: It is to generate the original whistle sound of other ship.

Distance Related Sound Generation: It is to evaluate listening sound environments according to the two ship's distances from maximum mile to minimum mile with arbitrary given distance spaces.

Own Ship's Heading Related Sound Generation: It is to evaluate listening sound environments according to the change of own ship's heading with given space angles.

Other Ship's Heading Related Sound Generation: It is to evaluate listening sound environments according to the change of other ship's heading with given space angles.

Officer's Heading Related Sound Generation: It is to evaluate listening sound environments according to the change of duty officer's lookout direction with given space angles.

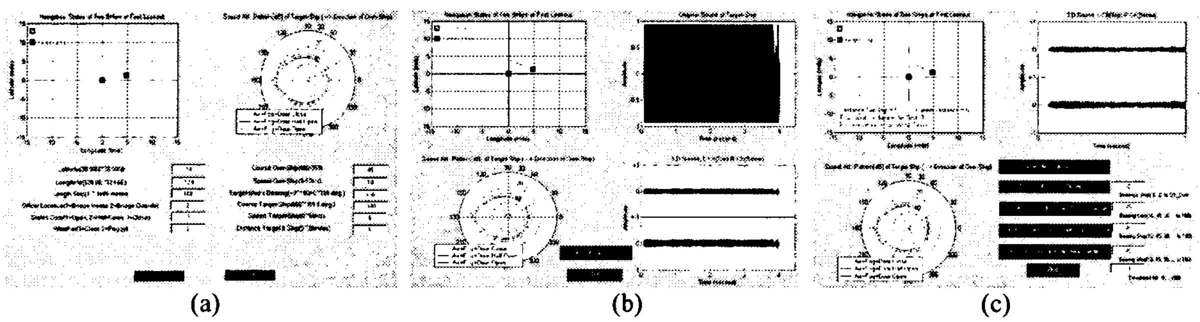


Figure 7 Operation results of three main modules in LDAS. (a) Data Input Module. (b) Sound Visualization Module. (c) Situation Evaluation Module.

4.2 LDAS Evaluation

Figure 8 shows the evaluation procedures by psychological assessment tests. In the evaluation experiments, the five important cases of collision accidents with restricted visibility by fog are compiled, and twelve data are arranged as numerical numbers as shown in Table 1.

Five subjects are participated in the psychological tests, and listen to the 3D sounds at given conditions, and then ask the relative loudness of 3D sounds comparing with the original sounds. The values of relative loudness are measured by six scales as shown in the upper right side in Figure 8, and the tests are repeated to take average values. The six scales means as followings:

Scale 0 = Can not heard any sound
Scale 1 = Much lower than the original sound
Scale 2 = Lower loudness than the original sound
Scale 3 = Same but less loudness than the original sound
Scale 4 = Almost same loudness as the original sound
Scale 5 = Quite equivalent loudness as the original sound

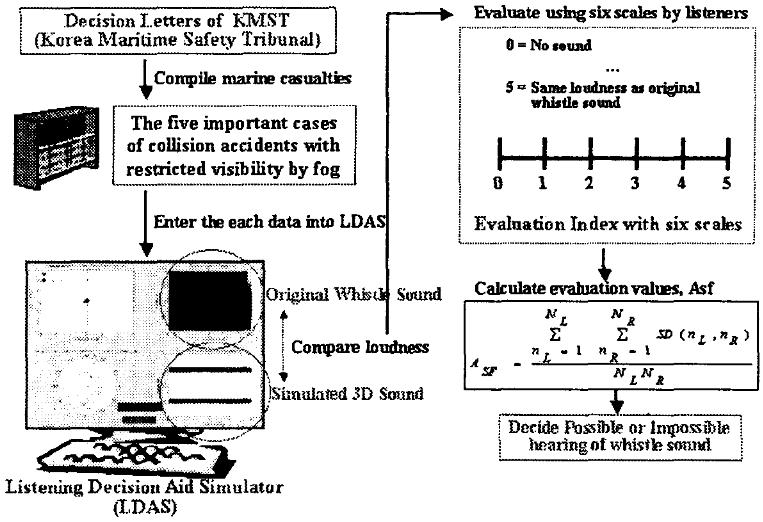


Figure 8 Evaluation procedures by psychological assessments.

Table 1 Five casualty cases of whistle sound-related collision accidents from 2002 to 2003 in Korea

Case	Tonnage		Related data at the first recognized position each other										
	A	B	Y	M	D	RB	D	CA	SA	WA	CA	SB	WB
1	1,957	2,864	2003	3	21	+18	5.0	54	11.0	0	265	12.2	0
2	8	7	2002	5	18	0	0.5	220	10.0	0	80	0.0	0
3	199	11,314	2002	8	4	-10	8.0	315	10.5	0	156	13.2	0
4	4,066	N/A	2003	6	22	0	2.5	87	11.5	0	270	10.0	0
5	5	5	2003	5	21	N/A	3.0	165	2.0	0	270	10.0	0

Ref.: A=Own ship, B=Other ship, Y=Year, M=Month, D=Day, RB=Relative bearing (deg.) between A and B, D=Distance (mile) between A and B, CA/CB=Ship's course (deg.) of A/B, SA/SB=ship's speed (kts) of A/B, WA/WB=Blasting whistle sound (0=none, 1=blasting)

The evaluation results by psychological assessments are represented as numerical index given by

$$A_{SF} = \frac{\sum_{n_L=1}^{N_L} \sum_{n_R=1}^{N_R} SD(n_L, n_R)}{N_L N_R} \quad (10)$$

where N_L : number of subjects, N_R : number of test repetition, SD : scales by subject n_L in n_R repetition.

4.3 Evaluation Results

The evaluation results of LDAS for the five cases in Table 1 are shown in Figure 9. The decision results using A_{SF} are summarized as followings:

Case 1: Impossible hearing whistle sound at this conditions due to A_{SF} =1.2.

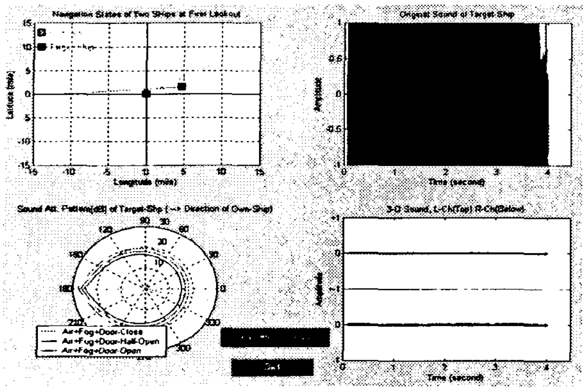
Case 2: Possible hearing whistle sound at this conditions due to A_{SF} =4.0.

Case 3: Impossible hearing whistle sound at this conditions due to A_{SF} =0.8. If the relative distance between two ships is less tan 4.0miles, then, it can be heard as A_{SF} =3.0.

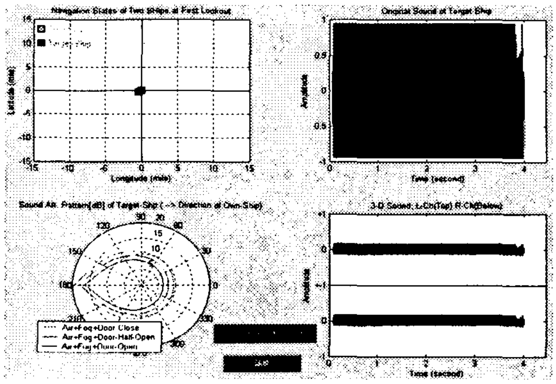
Case 4: Possible hearing whistle sound at this conditions due to A_{SF} =3.2.

Case 5: Possible hearing whistle sound at this conditions due to A_{SF} =2.7

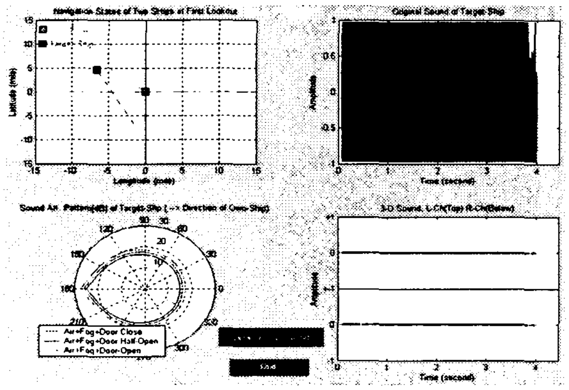
Note that the results, mentioned above, are not only comes from the evaluation by A_{SF} but also comes with the analysis of displayed graphics such as directional features of whistle, and the pose of both ships.



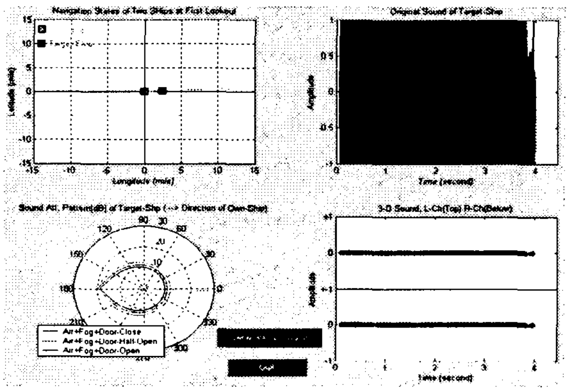
(a) A_{SF} =1.2 (Impossible Listening)



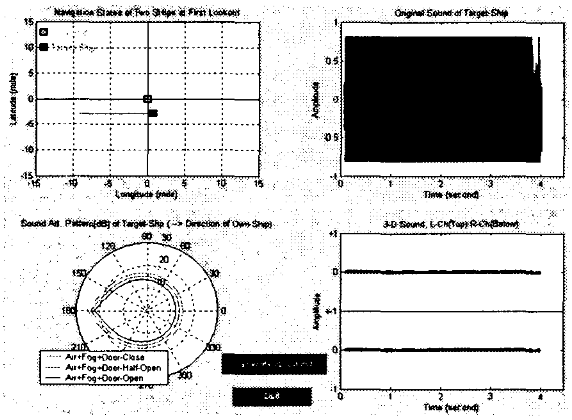
(b) A_{SF} =4.0 (Possible Listening)



(c) A_{SF} =0.8 (Impossible Listening)



(d) A_{SF} =3.2 (Possible Listening)



(e) A_{SF} =2.7 (Possible Listening)

Figure 9 Evaluation results for the five casualty cases. (a) Case 1. (b) Case 2. (c) Case 3. (d) Case 4. (e) Case 5.

5. Conclusions

Through the study, conclusions are made as followings;

(1) The theoretical background for the sound propagation mechanism from a whistle to listener's two ears is established.

(2) The reproduction mechanism of three-dimensional sound with spatial filters is explored.

(3) The implementation method of spatial transfer filters is proposed using frequency sampling-based FIR filter.

(4) The technical measurements method of Spatial Transfer Coefficients (STC) for ship's bridge door are

proposed and verified using psychological assessments by subjects.

(5) Listening Decision Aid System (LDAS) for whistle sound-related collision accidents is developed and verified through the evaluation experiments by five important cases.

Thus, it is clearly known that the LDAS can be use as one of the decision supporting system in the judgment of marine casualty.

Further, high accuracy STCs for all of existence ships in the world are needed to construct full-mission supporting systems. However it is impossible to obtain the all of STCs. One of the substitute methods is to use structural STC, which is a method using constructional shape of a bridge. This work is under proceeding now.

Acknowledgements

This work was supported by grant No.R05-2004-000-10760-0 from Ministry of Science & Technology, Korea.

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