On the Comparative Effect of Snowfall, Accumulation, and Density on Speech Intelligibility

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***Abstract*--Sound is known to be altered in some manner by the acoustic characteristics of snow. However, the specific characteristics of snow, which actually affects the acoustical transfer characteristics, are not clearly understood. This transfer characteristics will be crucial in disaster prevention radio broadcasting systems that warn citizens working outdoors of potential natural disasters during the winter in regions with heavy snow. These systems use extremely high-output horn speakers to convey the warning messages to a large area. Accordingly, the purpose of this research is to clarify how the speech intelligibility will be influenced by the amount of snowfall, its accumulation, and the snow density. In this research, impulse response measurement outdoors is actually carried out during snowfall. We measured and compiled the transfer characteristics under several snow conditions, convolved these with test speech in order to simulate the transmitted speech quality during snow. We conducted a Japanese speech intelligibility test using these speech samples, and clarify the effect of each snow quality measure using multivariate analysis. As a result, it was found that although there is some influence of the amount of snowfall and density, the influence of the amount of snowfall becomes dominant as the distance between the loudspeaker and the listener (microphone) becomes large.**

I. Introduction

When it snows in the winter, we often feel that the acoustical environment, both indoors and outdoors, sounds more quiet than usual. This is because snow makes it harder for sounds, especially for relatively low-frequency range, to travel long distances. It is known that the transfer characteristics of sound change due to snow accumulation [1-3].

The influence of the above phenomenon on the speech intelligibility of warning messages played out from disaster prevention radio broadcasting systems can have dire results. These warning systems are being deployed by the Japanese government throughout Japan to warn citizens working outdoors of potential natural disasters, such as earthquakes, flash floods, or severe weather. The system consists of wireless receiver stations that receive audio warning clips, and extremely large output horn-type loudspeakers to play out the audio warning, normally read speech warning messages. In the event of a disaster, in order to obtain information from this warning system, we must rely on sound only. Thus, the influence of snow during winter may prevent the accurate communication of warning messages. Some large to mid-size cities in northern Japan are known to have a significant amount of snowfall, and so research is required in order to keep the citizens in these cities safe during winter.

In the previous study [4], it was found that the speech intelligibility deteriorated due to snowfall and snow accumulation. During these measurements, we became aware that the weight (density) of snow has a notable impact on the acoustical transfer characteristics. However, since we did not have a clear definition of snow quality at the time, we were not able to systematically determine its effect on intelligibility.

Therefore, in this study, in addition to the influence of the amount of snowfall and accumulation on speech intelligibility, we attempt to quantitatively define snow quality and clarify the influence of each factor on speech intelligibility.

II. Definition of Snow Quality

Differences in snow quality appear in the snow due to elements such as crystal structure, porosity, and moisture content and so on. In particular, the moisture content is related to snow dryness. In previous research, it was found that wetness/dryness of snow affects speech intelligibility significantly [4]. Snow dryness/wetness changes depending on the amount of moisture contained in the snow, as well as its weight. Therefore, it should be possible to quantify dryness/wetness of snow by measuring the density of the snow. In this study, the snow quality was quantified by the density, which can be measured by the mass of a pre-defined volume of snow. The density was normalized as the weight in grams per cubic centimeters.

III. Measurement of the Transfer Characteristics of Snow

A. Impulse Response Measurement

In this study, we will simulate the speech that travels to the subject during snowfall by convolving the measured transmission characteristics with the test speech. Transfer characteristics are measured by conducting an impulse response measurement experiment outdoors when there are snowfall and accumulation. Fig. 1 outlines the measurement procedure. Log-SS signals were played out from a loudspeaker during snowfall, recorded, digitized, Fourier-transformed, inverse filtering for the Log-SS signal is applied, inverse Fourier transformed, and then noise reduction is applied to obtain the impulse response. For noise reduction processing, synchronous averaging and band limitation was performed. The impulse response was measured for various combinations of the amount of snowfall, snow accumulation, snow density, and also for different distances between the loudspeakers and the microphone.

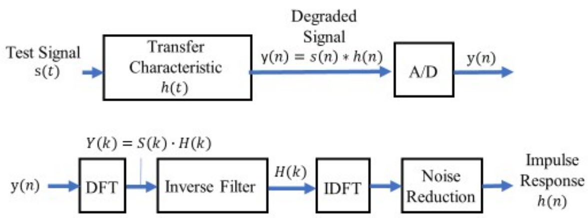

Fig 1. Outline of the measurement procedure

B. Measurement Method of Snowfall, Accumulation Density

In this study, we measured the amount of snow accumulation, snowfall, and density using a relatively simple method. Accumulation was calculated by measuring the height of accumulation at 10 measurement locations and calculating the average. Snowfall was measured by measuring the height at the above ten locations, and then calculating the average accumulation per hour at these locations. For the density, snow was put in a container with a constant capacity and the mass was measured 10 times, and the average value was calculated.

C. Measurement conditions

Since the impulse response measurement needs to be done outdoors during snowfall with as little noise as possible, all measurements were conducted inside the university campus in the very early mornings. Figure 2 shows the configuration of the equipment at the time of impulse response measurement, and Table 1 shows the equipment used. We used two PCs, one for playback, and one for recording. The loudspeakers, as well as the microphones, were placed 1.5 m above the snow accumulation. The microphones were placed 20 to 100 m from the loudspeaker in 20 m increments.

During the impulse response measurement, the snow accumulation amount, the snowfall amount, and the density were simultaneously measured. The snow conditions during each of the measurement trials are shown in Table 2. The impulse response measurement experiment was performed 7 times.

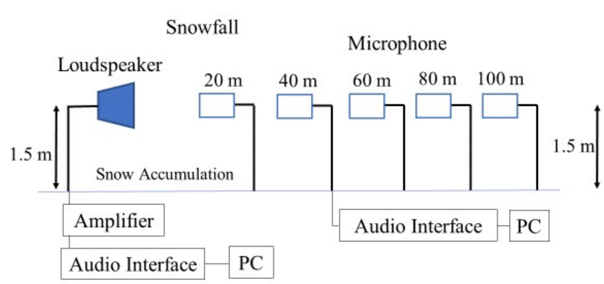

Fig 2. The configuration of the equipment

TABLE 1. EQUIPMENT USED

Microphone	BENETECH GM1356 2.2
Loudspeaker	BOSE MMS-1SP
Amplifier	BOSE 1705 II
Audio Interface	Roland UA-25 EX
	BEHRINGER UCA222
Recording PC	ASUS VivoBook X540LA
Playback PC	TOSHIBA Dynabook TB67/PG

TABLE 2. SNOW CONDITIONS IN EACH MEASUREMENT TRIAL

No.	Snowfall [cm/h]	Accumulation [cm]	Density [g/cm^3]
1	0	0	0
2	0.56	3.49	0.092
3	2.15	7.54	0.073
4	2.5	17.4	0.176
5	0.21	20.8	0.09
6	1.95	22.8	0.064
7	1.8	29.4	0.081

IV. EVALUATION OF SPEECH INTELLIGIBILITY

A. Japanese Version DRT (Diagnostic Rhyme Test)

The Japanese DRT is an intelligibility test method that allows a subject to listen to one word out of word pairs differing only in the beginning phoneme of Japanese words [5,6]. The listener selects which one of the word pairs they heard. In this test, to allow systematic evaluation per phonetic feature, consonants are divided into 6 features, 10 word-pairs per feature totaling 120 words are used. The test words were read by one male and one female speaker.

Eight subjects with normal hearing, all in their early twenties were employed to test the speech intelligibility in all seven snow conditions. The DRT word speech was convolved with impulse responses measured for the 7 measurements. The test sound was presented over headphones.

V. RESULT

A. DRT Evaluation Result

For reference, the speech intelligibility was evaluated with no snow accumulation (0 m) and no snowfall (0 cm/h). The result with no snow was 86% at 40 m distance between the loudspeaker and the microphone, 75% at 60 m, and 63% at 80 m. These results are not shown in the following Figures.

The relationship between snowfall and intelligibility is shown in Fig.3 and 4 for female and male speech, respectively. As shown, as the amount of snowfall increases, speech intelligibility generally decreases. The decrease is rather gradual, and there are also exceptions (especially above 2 cm/h, at which the intelligibility mostly increases). This obviously is because the snow falling between the loudspeaker and microphone attenuates the sound level. It should also be noted that the more distant the microphone to the speaker, the lower the intelligibility.

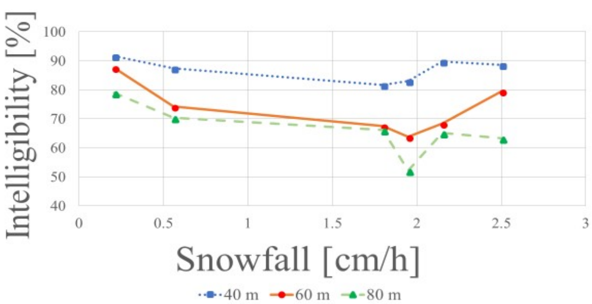

Fig 3. The relationship between snowfall and intelligibility of female speakers

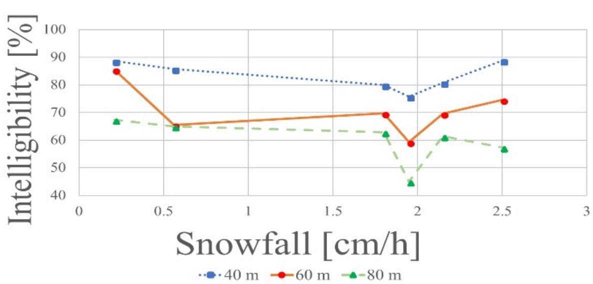

Fig 4. The relationship between snowfall and intelligibility of male speakers

Fig.5 and 6 show the relationship between snow accumulation and intelligibility for female and male speaker, respectively. There does seem to be some decrease in intelligibility with more accumulation, but the decrease is very gradual. Thus, compared to snowfall, the effect on intelligibility seems to be minor. Again, the more distant the microphone to the speaker, the lower the intelligibility becomes.

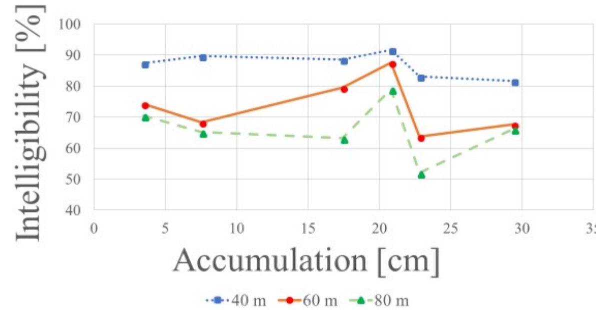

Fig 5. The relationship between accumulation and intelligibility of female speakers

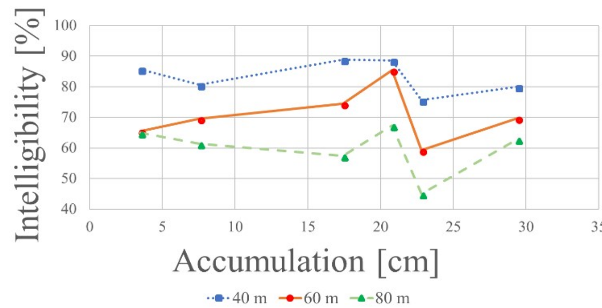

Fig 6. The relationship between accumulation and intelligibility of male speakers

Finally, the relationship between density and intelligibility is shown in Figs. 7 and 8 for female and male speakers, respectively. When the density is 60 m or more, the intelligibility decreases when the density is low, and intelligibility increases as the density increases.

It seems that sound is absorbed more by the porosity of snow with low density, and results in lower intelligibility. Thus, snow density shows a negative correlation with speech intelligibility.

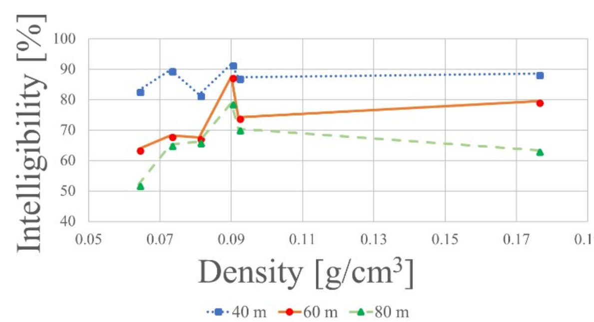

Fig 7. The relationship between density and intelligibility of female speakers

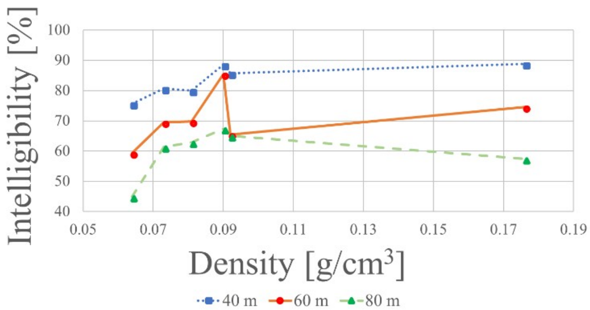

Fig 8. The relationship between density and intelligibility of male speakers

B. Multivariate Analysis

Multivariate analysis is used to quantitatively analyze the relative influence of snowfall, accumulation, and density. Multiple regression analysis is performed here. The contribution of each variable is indicated by obtaining the standard partial regression coefficient of each element.

The results of multiple regression analysis are shown in the Figs. 9 and 10 for female and male speakers, respectively.

As can be seen, the contribution of each factor is mixed at smaller distances between the loudspeaker and the microphone. However, at longer distances, the contribution of snowfall dominates over other factors. This was somewhat surprising since we expected all snow characteristics to affect the intelligibility in a similar manner. In fact, at a distance of 80 m, the contribution of snowfall is above 0.8 and 0.6 for female and male speech, respectively. This suggests that for locations that are far from the loudspeakers, snowfall should be closely monitored. If the snowfall exceeds a level at which speech intelligibility is severely affected, speech played out from the loudspeakers should be equalized to compensate for the effect of the snow, most likely an inverse filter that will try to cancel the transfer characteristics of snow during heavy snowfall.

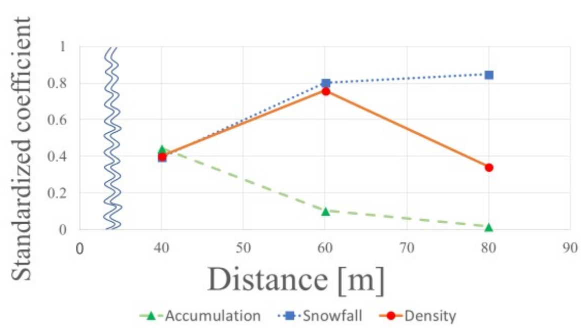

Fig 9. Multiple regression analysis of female speakers

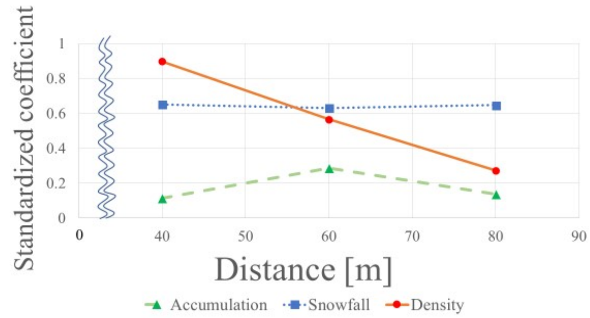

Fig 10. Multiple regression analysis of male speakers

VI. Conclusions

We analyzed the characteristics of snow that affects the speech intelligibility of speech warnings played out from disaster prevention radio broadcasting systems during snowfall. A speech intelligibility evaluation test was conducted by using speech convolved with the transfer characteristics during snowfall in order to clarify the influence of accumulation, snowfall, and density on intelligibility, respectively.

It was found that snow accumulation has a relatively small influence, and the amount of snowfall has the largest influence. Multivariate analysis showed that as the distance increased, the effect of snowfall increased, dominating the contribution to intelligibility.

We would like to measure and analyze the relationship between snowfall, accumulation, density, and intelligibility under more variant conditions.

Acknowledgment

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