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A Study on Setting the Minimum and Maximum Distances for Distance Attenuation in MPEG-I Immersive Audio

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Abstract

In this paper, we introduce the minimum and maximum distance setting methods used in geometric distance attenuation processing, which is one of spatial sound reproduction methods. In general, sound attenuation by distance is inversely proportional to distance, that is 1/r law, but when the relative distance between the user and the audio object is very short or long, exceptional processing might be performed by setting the minimum distance or the maximum distance. While MPEG-I Immersive Audio's RM0 uses fixed values for the minimum and maximum distances, this study proposes effective methods for setting the distances considering the signal gain of an audio object. Proposed methods were verified through simulation of the proposed methods and experiments using RM0 renderer.

Keywords : MPEG-I Immersive Audio, object audio, 6DoF, distance attenuation

Ⅰ. Introduction

In MPEG, MPEG-I Immersive Audio standardization, a standard for reproducing spatial sound in a 6DoF(Degrees of Freedom) content environment, has been in progress since 2017[1], and RM0(Reference Model zero) has been selected and CE(Core Experiments) is in progress in 2022.

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Since the user can freely change the position in the 6DoF content environment, the relative distance and direction between the user and the audio object changes according to the user position. In order to reproduce a realistic spatial sound in the 6DoF content, it is necessary to reproduce various spatial sound effects such as direct sound, specular reflection sound, reverberant sound, diffracted sound, distance attenuation effect, doppler effect, etc. Among them, the distance attenuation effect, in which the sound becomes louder or smaller according to the relative distance, is one of the important factors for spatial sound reproduction.

In general, sound attenuation by distance is inversely proportional to distance, that is 1/r law, and MPEG-I Immersive Audio RM0 basically follows this law. While following the 1/r law, the sound signal becomes abnormally louder when the relative distance becomes too short, Conversely, the sound signal becomes very small and the user may not be able to hear it when the relative distance becomes too long. In that case, it is effective to set the gain of the audio signal to zero and not to perform rendering. For these reasons, when the relative distance between the user and the audio object is very short or long, an exceptional process might be performed by setting a minimum distance or a maximum distance respectively for effective processing.

In MPEG-I Immersive Audio RM0, the constant minimum distance value and maximum distance value are applied to all objects, which may not be effective considering the characteristics of each audio object. For example, a mosquito sound audible at close distance will not be audible at a distance of 10m, so a maximum distance of 10m might be sufficient. Conversely, since a thunder sound can be heard from several kilometers away, it would be appropriate to set the maximum distance to several kilometers.

In this paper, we propose a method of setting the minimum and maximum distances based on the loudness according to the relative distance, not setting constant values. This method calculates the distance at which the loudness of the audio object becomes the minimum or maximum threshold gain, and setting this distance as the minimum or maximum distance. For this, a reference distance, which is defined in MPEG-I Immersive Audio as a characteristic of an audio object, is used[2].

By setting a minimum distance according to the proposed method, it is possible to avoid increasing the signal gain beyond a certain threshold gain. And, by setting a maximum distance according to the proposed method, it is possible to prevent the audio object from becoming inactive even though the sound gain exceeds a certain threshold gain.

To verify the effect of the proposed method, simulations are conducted to compare the result of the proposed method with that of the RM0 method. In simulations, the results by both methods are generated using the RM0 renderer. From the comparison, the merits of the proposed method will be demonstrated.

The contents of this paper are as follows. Chapter 2 briefly introduces the concept of distance attenuation effect, minimum distance and maximum distance. Chapter 3 describes the method of setting the minimum and maximum distances in MPEG-I Immersive Audio RM0 and the simulation results accordingly. Chapter 4 describes the proposing minimum and maximum distance setting method with simulation and experimental rendering results. Finally, a conclusion is drawn in Chapter 5.

Ⅱ. Basic concept of geometrical distance attenuation

This chapter briefly explains the concept of geometrical distance attenuation effect, and also briefly explains the concept of minimum distance and maximum distance.

1. Basic concepts of geometrical distance attenuation effect

We can feel in our daily life that the sound becomes smaller as the distance of an audio object increases and the sound becomes louder as the distance of an audio object decreases. It is a phenomenon due to the geometric distance attenuation that the signal gain changes according to the relative distance between the user and the audio object[3].

Geometric distance attenuation is calculated using different formulas for audio source types, and follows the 1/r law for point sources. Figure 1 below shows the signal gain according to the relative distance, assuming $g(d_x)$ is the signal gain at distance d_x. If the relative distance is doubled, the gain of the signal is halved according to the 1/r law, and the energy is reduced by 6dB. Conversely, if the relative distance is reduced to 1/2, the signal gain is doubled and the energy is increased by 6dB[4][5].

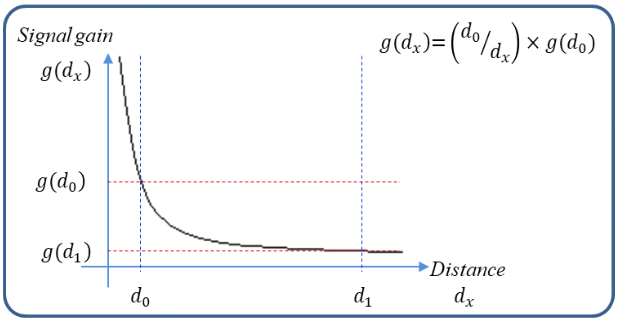


Fig. 1. Signal gain according to distance

In order to accurately calculate the gain of the audio signal according to the distance, a reference distance is helpful. In MPEG-I Immersive Audio, there is a parameter named reference distance as a characteristic of an audio object or channel, and at this distance, the gain of the audio object or channel becomes 0dB[2]. The following equation shows the equation for calculating the decibel scale signal gain according to the distance in MPEG-I Immersive Audio.

$$Gain\,[dB] = 20\log(reference\_distance/current\_distance) \quad (1)$$

In MPEG-I Immersive Audio, the gain of an audio object at the same distance has a different gain when the reference distance is different. For example, an audio object with a reference distance of 1m has a gain of 0dB at 1m and -6dB at 2m, but an audio object with a reference distance of 2m has a gain of 6dB at 1m, and 0dB at 2m. It is convenient to use the reference distance to reproduce realistic sounds by setting a small reference distance for sounds that could be heard at a short distance, such as mosquito sounds, and setting a large reference distance for sounds that could be heard from far away, such as thunder sounds.

2. Basic concepts of minimum distance

While a signal gain attenuates according to the 1/r law, if the relative distance is too close, the signal gain increases rapidly, which may cause clipping. In order to prevent this phenomenon, MPEG-I Immersive Audio uses the minimum distance concept as follows. “To prevent excessive distance gain when coming very close to a source, the distance attenuation curve from the core geometrical distance attenuation model is only applied from a certain threshold distance from the extent onwards. For distances within this threshold distance, the distance gain is kept constant to the value at the threshold distance”[6].

Figure 2 below shows the signal gain according to the distance for the case where the minimum distance is applied, assuming d_m is the minimum distance. When the distance is closer to d_m from the far side, the signal gain increases, but when it becomes smaller than d_m, the signal gain does not increase anymore according to the concept of the minimum distance.

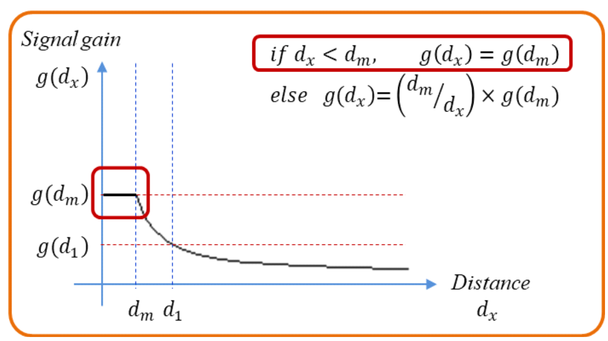


Fig. 2. Signal gain according to distance when minimum distance is considered

3. Basic concepts of maximum distance

While a signal gain attenuates according to the 1/r law, if the relative distance is too far, the signal gain decreases to an inaudible level, and the audio object might be regarded not to need to render. In order to effectively utilize this phenomenon in the renderer, MPEG-I Immersive Audio uses the maximum distance concept as follows. “To avoid the unnecessary rendering of sources that are essentially inaudible due to being very far away, the distance gain is linearly ramped down starting from a certain roll-off start distance, reaching zero at a certain roll-off end distance. Beyond this roll-off end distance, the source is essentially inactive"[6].

Figure 3 below shows the signal gain according to the distance for the case where the maximum distance is applied, assuming $g(d_x)$ is the signal gain at distance d_x and d_M is the maximum distance. When the distance is closer to from the near side, the signal gain decreases gradually, but when it becomes larger than d_M, the signal gain drops to zero according to the concept of the maximum distance.

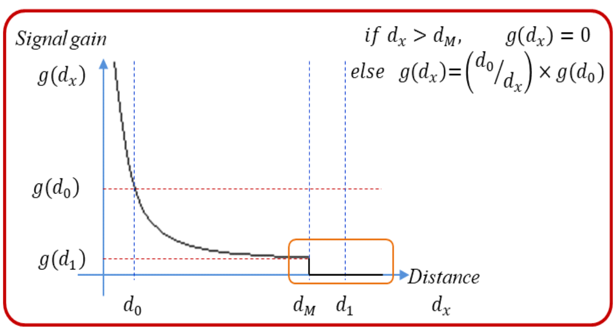


Fig. 3. Signal gain according to distance when maximum distance is considered

Ⅲ. Minimum distance and maximum distance at MPEG-I Immersive Audio RM0

1. Minimum distance at MPEG-I Immersive Audio RM0

In the MPEG-I WD(Working Draft), the minimum distance value is set to 0.2m for all audio objects as follows[6].

Name	Type	Value	Description
Distance_MinDistance	float	0.2	The minimum distance for the propagation delay and distance attenuation in meters

In this paper, the gain of the audio signal at the minimum distance was investigated with interest. In MPEG-I Immersive Audio, since the gain at a specific distance is calculated according to Equation (1), the gain at the minimum distance is calculated differently according to the reference distance. The Figure 4 below shows the signal gain as a function of distance for audio signals with different reference distances, and Table 1 shows the gain of the audio signal at the minimum distance. As can be seen from the following table, the larger the reference distance, the higher the signal gain at 0.2m, and the gain difference at 0.2m when the reference distance is 1m and 100m is up to 40dB.

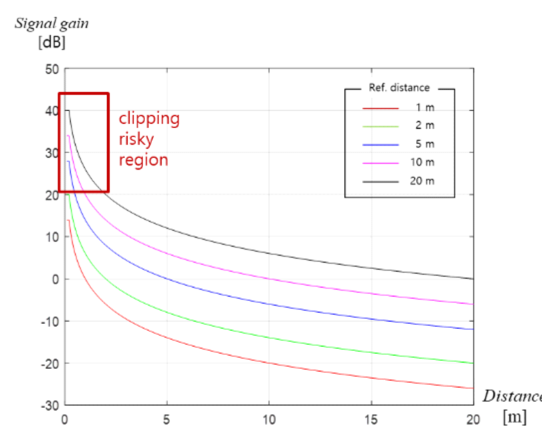


Fig. 4. Signal gains according to distance with different reference distances

Table 1. Signal gain at 0.2 m with different reference distances

reference distance of object [m]	1	2	5	10	20	50	100
signal gain at 0.2 m by RM0 [dB]	13.98	20.00	27.96	33.98	40.00	47.96	53.98

2. Maximum distance at MPEG-I Immersive Audio RM0

In the MPEG-I WD, the maximum distance value is set to 500m for all audio objects as follows[6].

Name	Type	Value	Description
Distance_MaxDistance	float	500	The maximum distance for the distance attenuation in meters

As with the previous minimum distance, this study investigated the gain of the audio signal at the maximum distance. The gain of the audio signal at the maximum distance is also changed by the reference distance, like the gain at the minimum distance. Figure 5 below shows the signal gain as a function of distance for audio signals with different reference distances, and Table 2 shows the gain of the audio signal at the maximum distance.

As can be seen in the Figure 5, all objects are inactivated at 500m, and the signal gains at 500m are different for each reference distance as shown in the Table 2. In the case of an audio object with a reference distance of 100m, it is inactivated at a gain of -14dB, which may not be proper in some cases.

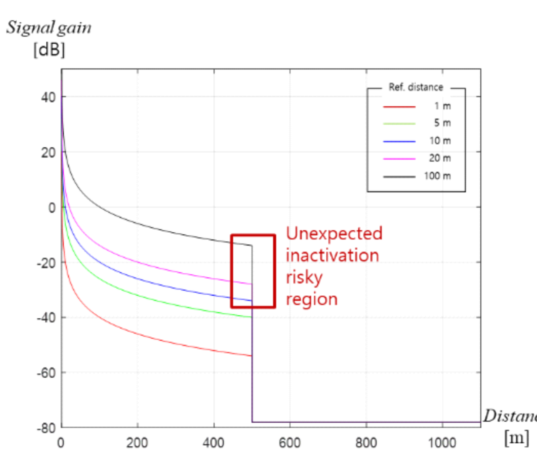


Fig. 5. Signal gains according to distance with different reference distances

Table 2. Signal gain at 500 m with different reference distances

reference distance of object [m]	1	2	5	10	20	50	100
signal gain at 500 m by RM0 [dB]	-54.0	-48.0	-40.00	-34.0	-28.0	-20.00	-14.0

Ⅳ. Proposed minimum distance and maximum distance setting method and experimental results

In this chapter, the proposed minimum and maximum distance setting methods and simulation and experimental results are described. In this paper, the minimum and maximum distances are set not based on the fixed distance, but based on the signal gain according to the distance of the audio object. This method calculates the distance at which the gain of the audio object signal becomes some minimum or maximum threshold gain, and sets this distance as the minimum or maximum distance. It is described in detail below in this chapter.

1. Proposed minimum distance setting method

We set the minimum distance based on the reference distance, which is one of the characteristic information of the object. For example, a method of setting the minimum distance, as in Equation (2) below, to be proportional to the reference distance may be used. Here, constant A is in relation with the reference distance, having a positive constant value.

$$minimum\_distance = reference\_distance / A \quad (2)$$

Substituting the above Equation 2 into Equation 1, the following Equation 3 can be obtained.

$$\begin{aligned} & Gain[dB]\ at\ minimum\_distance \\ & = 20\log\left\{reference\_distance/\left(\frac{reference\_distance}{A}\right)\right\} \quad (3) \\ & = 20\log\{A\} \end{aligned}$$

As shown in Equation 3, by setting the minimum distance as in Equation 2, the same gain is always obtained at the minimum distance. While the constant A could be set regarding the renderer's condition, A was set to 5 or

10 in the following simulations and experiments.

Table 3 compares the minimum distance between the RM0 method and the proposed method according to various reference distances. As can be seen from the Table 3, in the RM0 method, the minimum distance is a fixed value independent of the reference distance, and in the case of the proposed method, the minimum distance value is changed according to the reference distance.

Tables 4 compares the signal gain at a distance of 0.2 m between the RM0 and the proposed method, when the reference distance is different. As can be seen from the Table 4, in the RM0, the gain at 0.2m is changed according to the reference distance, but in the case of the proposed method, it has the same gain at 0.2m, except when A=10 and the reference distance is 1m, in which case, the distance is less than the minimum distance.

Figure 6 shows the signal gain graph according to the distance calculated using the proposed method for the minimum distance when the reference distance is different. As can be seen by comparing the Figure 4 and the Figure 6, in the RM0, as the minimum distance is fixed, the threshold gain is set differently depending on the reference distance, whereas in the proposed method, the minimum distance is changed according to the reference distance, the

Table 3. Comparison of minimum distances between the RM0 method and the proposed method according to reference distance

reference distance of object [m]	1	2	5	10	20	50	100
minimum distance by RM0 [m]	0.2	0.2	0.2	0.2	0.2	0.2	0.2
minimum distance by proposed method [m] (where A = 5)	0.2	0.4	1	2	4	10	20
minimum distance by proposed method [m] (where A = 10)	0.1	0.2	0.5	1	2	5	10

Table 4. Comparison of signal gains at 0.2 m between the RM0 method and the proposed method according to reference distance

reference distance of object [m]	1	2	5	10	20	50	100
signal gain by RM0 method [dB]	13.98	20.00	27.96	33.98	40.00	47.96	53.98
signal gain by proposed method [dB] (where A = 5)	13.98	13.98	13.98	13.98	13.98	13.98	13.98
signal gain by proposed method [dB] (where A = 10)	13.98	20.00	20.00	20.00	20.00	20.00	20.00

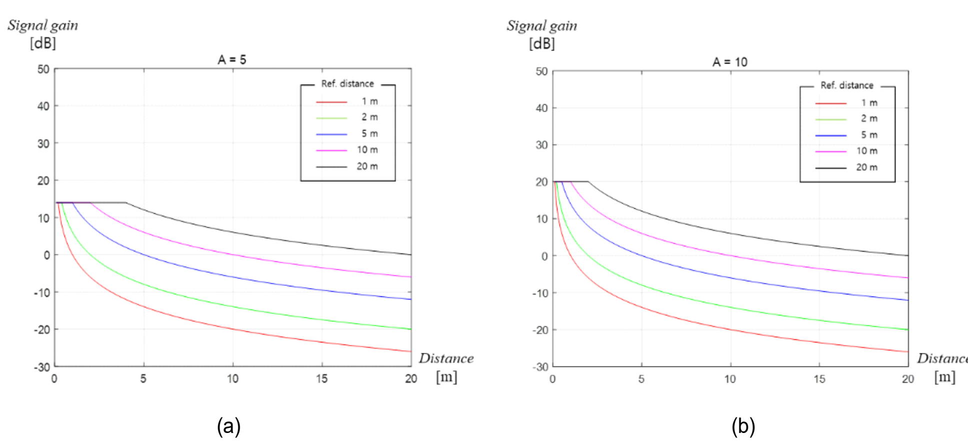


Fig. 6. Signal gain by the proposed method with different reference distances when A is set to (a) 5, and (b) 10

threshold gain is kept constant. Moreover, this threshold gain can be controlled through the control of the constant A value.

2. Experimental results of minimum distance

In order to check whether the proposed method works well, we had an experiment that recording the rendered audio signal when the distance is changed to 20, 10, 5, 1, 0.5, 0.2, 0.1m by using RM0 renderer and by using proposed method applied RM0 renderer, respectively.

The experiment was performed in the ‘Recreation’ scene, one of the MPEG-I Immersive Audio CfP(Call for Proposals) test scenes, and FoH-L object, which is one object of the scene, was used. Since the reference distance of FoH-L object is 10m, it is useful to check the signal gain change at a close distance. If the signal level of the source audio signal changes with time, it might be difficult to distinguish whether the change of signal level in the rendered signal is due to the signal level of the source audio signal itself or due to the rendering result. So, we changed the audio source signal of the FoH-L object to white noise with no difference in signal gain over time.

Figure 7 shows the rendering result signal of FoH-L object at various distance by using RM0 renderer and by using proposed method applied RM0 renderer, constant A was set to 10 and 5. As shown in Figure 7(a), since the minimum distance of RM0 is 0.2m, the signal gain increases until the distance decreases to 0.2m. The magnitude of signal at 0.2m is much larger than the magnitude at 10m. As shown in Figure 7(b), since the minimum distance according to the proposed method is 1m, the magnitude of signal increases until the distance decreases to 1m, and the magnitude is maintained even at 0.2m. This shows that the proposed method can effectively prevent the sound from becoming too loud at a close distance compared to the RM0.

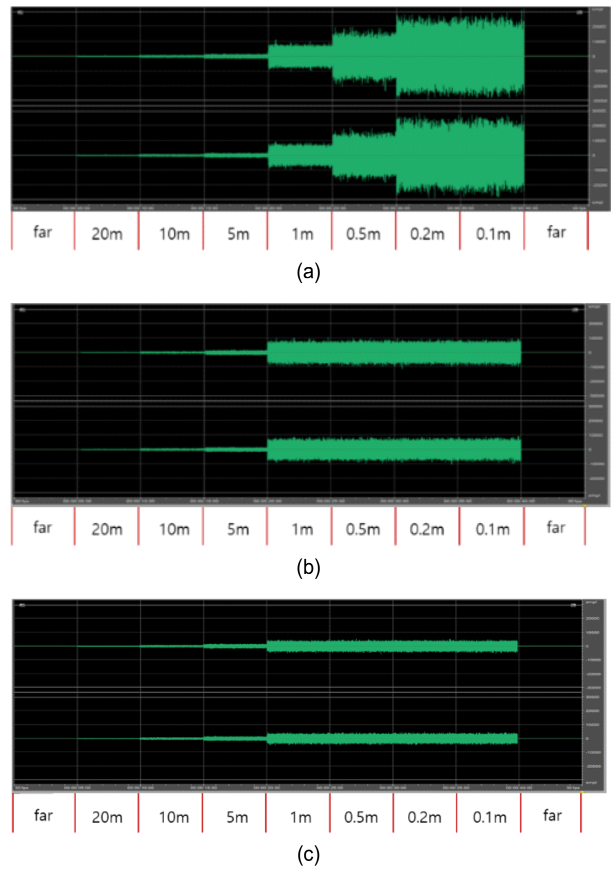


Fig. 7. Rendering result signal of FoH-L object at various distance (a) by using RM0 renderer, (b) by using proposed method applied RM0 renderer (A is set to 10), and (c) by using proposed method applied RM0 renderer (A is set to 5)

3. Proposed maximum distance setting method

We set the maximum distance based on the reference distance. For example, a method of setting the maximum distance, as in Equation (4) below, to be proportional to the reference distance may be used. Here, constant M is in relation with the reference distance, having a positive constant value.

$$maximum\_distance = reference\_distance \times M \tag{4}$$

Substituting the above Equation 4 into Equation 1, the following Equation 5 can be obtained.

$$\begin{aligned} & Gain\,[dB]\ at\ maximum\_distance \\ & = 20\log\{reference\_distance/(reference\_distance \times M)\} \\ & = 20\log\left\{\frac{1}{M}\right\} = -20\log\{M\} \end{aligned} \quad (5)$$

As shown in Equation 5, by setting the maximum distance as in Equation 4, the same gain is always obtained at the maximum distance. While the constant M could be set regarding the renderer's condition, M was set to 256 or 512 in the following simulations.

Table 5 compares the maximum distance between the RM0 method and the proposed method according to various reference distances. As can be seen from the Table 5, in the RM0 method, the maximum distance is a fixed value independent of the reference distance, and in the case of the proposed method, the maximum distance value is changed according to the reference distance.

Figure 8 shows the signal gain graph according to the distance calculated using the proposed method for the maximum distance when the reference distance is different. As can be seen by comparing the Figure 5 and the Figure 8, in the RM0, as the maximum distance is fixed, the threshold gain is set differently depending on the reference distance, whereas in the proposed method, the maximum distance is changed according to the reference distance, the threshold gain is kept constant. Moreover, this threshold gain can be controlled through the control of the constant M value.

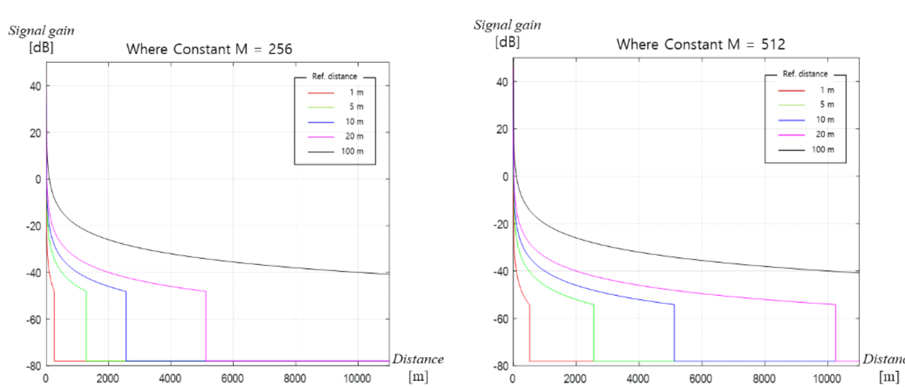
4. Experimental results of maximum distance

In order to check whether the proposed method works well, we had an experiment that recording the rendered audio signal when the distance is changed from 2,000m to 100m by using RM0 renderer and by using proposed method applied RM0 renderer, respectively.

The experiment was performed in the 'Battle' scene, one of the MPEG-I Immersive Audio test scenes, and 'Jet1', 'Jet2', 'Jet3' objects, which are some objects of the scene,

Table 5. Comparison of maximum distances between the RM0 method and the proposed method according to reference distance (*M* is set to 256 and 512, respectively)

reference distance of object [m]	1	2	5	10	20	50	100
maximum distance by RM0 [m]	500	500	500	500	500	500	500
maximum distance by proposed method [m] (where *M* is set to 256)	256	512	1,280	2,560	5,120	12,800	25,600
maximum distance by proposed method [m] (where *M* is set to 512)	512	1,024	2,560	5,120	10,240	25,600	51,200



(a) (b)

Fig. 8. Signal gain by the proposed method with different reference distances when *M* is set to (a) 256, and (b) 512

were used. Since the relative distance of these objects is changing 100 ~ 2,000m, it is useful to check the signal gain change at a far distance. The Figure 9 shows the movement path of the jet1 object in 3D space and the relative distance to the listener. 'Jet1', 'Jet2', and 'Jet3' sequentially pass through the same movement path, and this movement is repeated.

In the simulation of signal gain calculation according to the maximum distance, *M* values were set to 256 and 512. In that case, the maximum distance of the Jet1 object according to the proposed method would be 23,040m or 46,080m. This value is too large compared to the RM0 setting value of 500m, and is not suitable for comparison of rendering results according to the difference in maximum distance. For this reason, experiments were performed by setting the maximum distance to 1,000m, 2,000m and 23,040m.

Figure 10 shows the rendering result signal of Jet1, Jet2, Jet3 objects by using RM0 renderer, at which maximum distance is set to 500m, and by using proposed method applied RM0 renderer, at which maximum distance is set to 1,000m, 2,000m and 23,040m. When the maximum distance is set to 500m, a narrow silence region, in blue rectangle, is observed between Jet 1 and Jet 2, and also between jet 2 and Jet 3, as shown in Figure 10(a). This silence region is not observed when maximum distance is

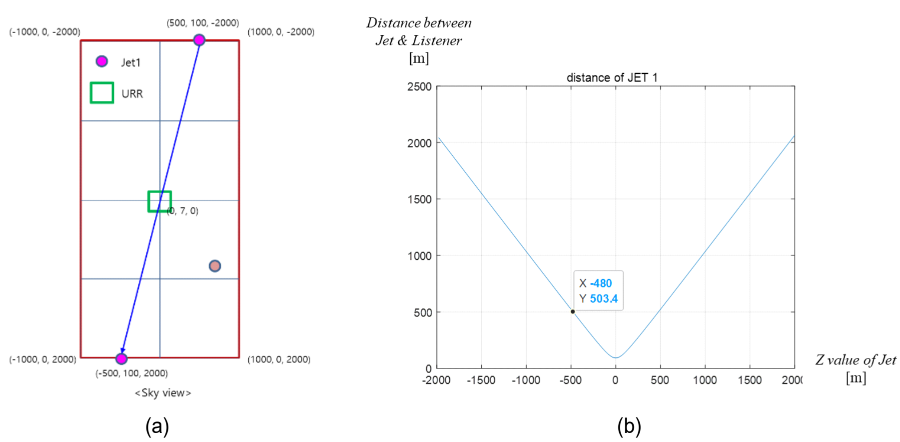


Fig. 9. (a) Travel path the Jet1 object and (b) the relative distance between Jet1 and listener according to the z axis value of Jet1 object

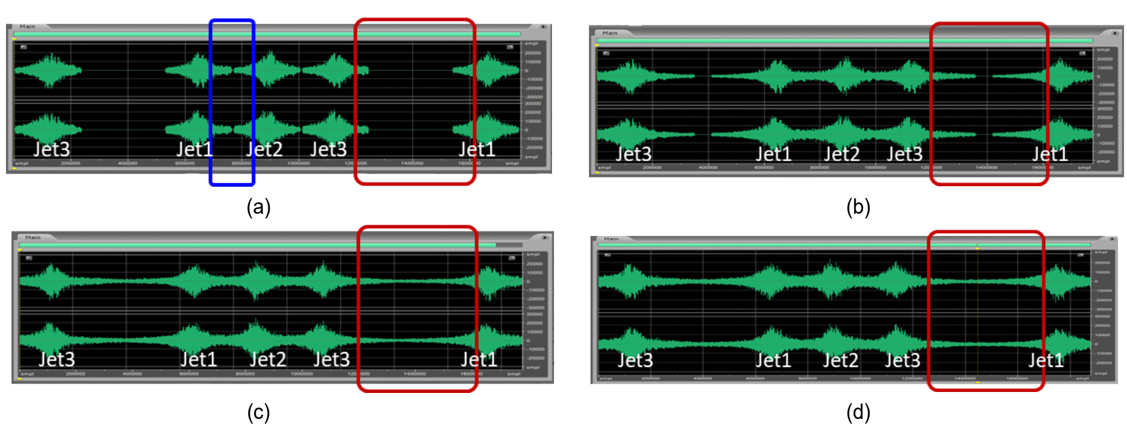


Fig. 10. Output signals where maximum distance is set to (a) 500m, (b) 1,000m, (c) 2,000m, and (d) 23,040m

set to 1,000m, 2,000m and 23,040m. Similarly, when the maximum distance is set to 500m, a wide silence region, in red rectangle, is observed between Jet 3 and Jet 1. When the maximum distance is set to 1,000m, in Figure 10(b), just a narrow silence region is observed, and when the maximum distance is set to 2,000m and 23,040m, the silence section is not observed at all.

The silence section that appears when the maximum distance is set to 500 is obviously due to the setting of the maximum distance. This is an example showing that an audible sound could be inactive when the maximum distance was set low, which does not meet the purpose of setting maximum distance. In Figure 10(c), even though it is set a maximum distance less than the maximum distance calculated by the proposed method, this silence section did not appear. This indicate that the proposed method can effectively prevent the audible sound from being inactivated.

V. Conclusions

In this paper, a study on the method of setting the minimum and maximum distances for geometric distance attenuation processing in the audio rendering method of 6DoF content was introduced.

In general, distance attenuation follows the 1/r law. But, when the relative distance between the user and the audio object is very short and long, exceptional processing might be performed by setting the minimum distance and the maximum distance respectively. While MPEG-I Immersive Audio's RM0 uses fixed values for the minimum distance and maximum distance, this study proposed effective methods for setting the distances considering the signal gain of the audio object.

The proposed method calculates the distance at which the signal gain of audio object becomes the minimum or maximum threshold gain, and sets this distance as the minimum or maximum distance. The proposed method can effectively prevent the sound from becoming too loud at a close distance compared to the RM0. And, the proposed method can effectively prevent the audible sound from being inactivated at a far distance. Moreover, threshold gain can be controlled through the control of the minimum distance constant A or maximum distance constant M value.

In order to verify the effectiveness of the proposed method, simulations were performed on the RM0 method and the proposed method to show the characteristics of the proposed method. And, the audio signal rendered by using the RM0 renderer was compared with the audio signal rendered by using the proposed method applied RM0 renderer. It was shown that the proposed method works effectively and is easily applicable to RM0.

Currently, MPEG-I Immersive Audio standardization is on the CE stage, and efforts are being made to improve the performance of RM0. We hope that this study will help the MPEG-I Immersive Audio standardization, and a high-quality 6DoF audio rendering technology standard will be established through various proposals and researches.

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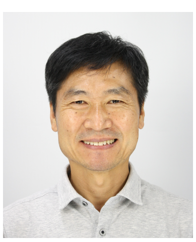

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