A NEW RENDERING METHOD OF MOVING SOUND WITH THE DOPPLER EFFECT

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ABSTRACT

This paper presents a new rendering method of a moving sound with the Doppler effect. In the conventional rendering method of moving sound, Head Related Impulse Responses (HRIRs) are simply changed according to the sound position. However, the Doppler effect cannot be added to a sound using this method. When a sound object moves with high speed, the pitch of a sound object should be controlled by some other rendering method. In our method, each HRIR is divided into two components, such as an initial delay and a main wave form. The two initial delays of both right and left ears are respectively recalculated based on relative speeds and a propagation path. These resultant initial delays are used in rendering. Thereby, the Doppler effect can be added automatically to a sound merely by setting the sound position in this algorithm. Details of this algorithm are discussed in this paper.

1. INTRODUCTION

In sound space around us, many sound sources are moving relative to a listener. It is therefore important to add a moving effect to a sound. When a sound moves at high speed, a listener can perceive a pitch shift of the sound, known as the Doppler effect. Conventionally, a sound source is convoluted with Head Related Impulse Responses (HRIRs) to display a static sound position. Furthermore, when HRIRs are changed according to a sound position, a perceived position of the sound source is moved. In this case, however, the Doppler effect is not added to the sound source. The pitch shift accompanying the Doppler effect must be added separately to an original sound source. Consequently, two-step rendering, such as a sound position and a pitch shift, is needed to express a moving sound.

This paper presents a novel rendering method of a moving sound with the Doppler effect. In our method, a sound position and the Doppler effect can be added to a sound source simultaneously when the relative sound position is simply changed. The algorithm is discussed in subsequent chapters.

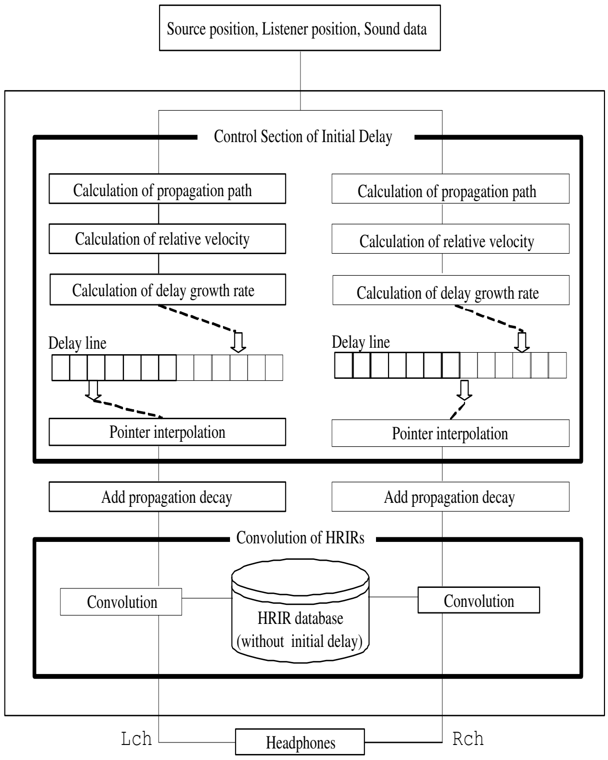
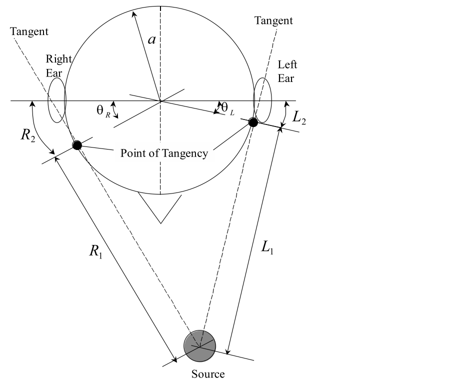


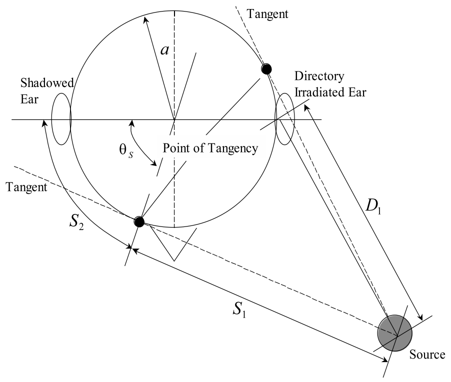
Figure 1: Rendering algorithm for moving sound

2. OUTLINE OF OUR ALGORITHM

The outline of our algorithm is shown in Fig. 1. In our method, the Doppler effect is added to each ear. Thereby, the arrival time of the sound wave of each ear is controlled (Fig. 1, upper box) and the initial delay of HRIR is unnecessary. In the bottom box of Fig. 1, HRIRs without initial delay were stored according to each direction. Afterwards, propagation decay is added; the sound source is convoluted with appropriate HRIRs without initial delay for the Doppler effect (bottom box).



(a) Both contact points of the tangent line are on the front side.



(b) One contact point of the tangent line is in front, but another is on the reverse side

Figure 2: Propagation path calculation method

3. RENDERING METHOD FOR THE DOPPLER EFFECT

3.1. Conventional Method

Smith [1] proposed a rendering method of the Doppler effect for a digital rendering. In this method, a propagation path of a sound is replaced with a delay line. A listener and a moving sound are treated respectively as a read pointer and a write pointer. A draly growth-rate $\dot{D}_t$ is defined to control pointers as

$$\dot{D}_t = -\frac{v_{ls} + v_{sl}}{c - v_{sl}}, \tag{1}$$

where c is the velocity of sound in the air, v_{ls} is the speed of motion of the listener to or from the sound source, v_{sl} is vice versa. The read pointer and the write pointer respectively increase as 1 and $1 - \dot{D}_t$. Thereby, the Doppler effect is added to a sound source.

3.2. Doppler Effect to Each Ear

This method to render the Doppler effect is extended to each ear in our method. Therefore, two $\dot{D}_t$ are defined for each ear, producing a binaural signal. The numerator of eq. (1) expresses the relative velocity between the listener and the sound source. The relative velocity v_r is obtained as

$$v_r = \frac{r_{n+1} - r_n}{\Delta t}, \tag{2}$$

where r_n is the length of a propagation path at the nth time, and Δt is the renewal interval of sound position. On the other hand, v_{sl} in the denominator of eq. (1) is calculated as the difference between $(n+1)$th and nth vector of the sound source toward the center position of the listener's head.

3.3. Calculation of the Propagation Path from the Source to Each Ear

Propagation path in eq. (2) must be calculated to decide v_r. Woodworth [2] proposed calculation method of propagation path, his method was divided into two cases, such as near and far from the listener. In that method, however, definitions of boundaries were not shown clearly in either case. Some extended methods have also been proposed [3, 4], but no method can express interaural time difference (ITD) changes according to distance.

Therefore, we used the following calculation method of the propagation path. Figure 2 portrays the proposed method. In this method, the sound-wave propagation path is treated as a diffraction path of a spherical wave. The spherical wave model can express changes of ITD according to distance.

3.4. HRIR without Initial Delay

As mentioned above, the initial delay of each HRIR is unnecessary because the arrival time of spherical wave to each ear has already been calculated. Therefore, each HRIR must be divided into two components: an initial delay and a main wave form. Figure 3 shows a cutting method of the initial delay. In this method, the HRIRs of all directions are upsampled eight times and a cross correlation function between neighbor positions is calculated. All HRIRs are shifted in the time domain so that maximum value of cross correlation is obtainable. Finally, the same initial delay is removed from all HRIRs so that HRIRs retain appropriate ITD information.

4. SIMULATION

Figure 4 shows a result of a simulation produced by our method. An original source (Fig. 4-(a)) is an octave noise with center frequency of 4 kHz. The simulation was of a

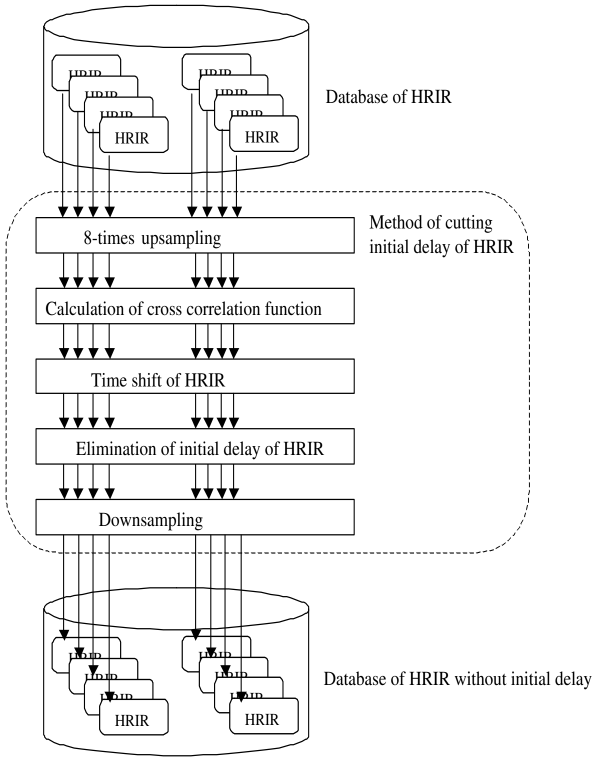
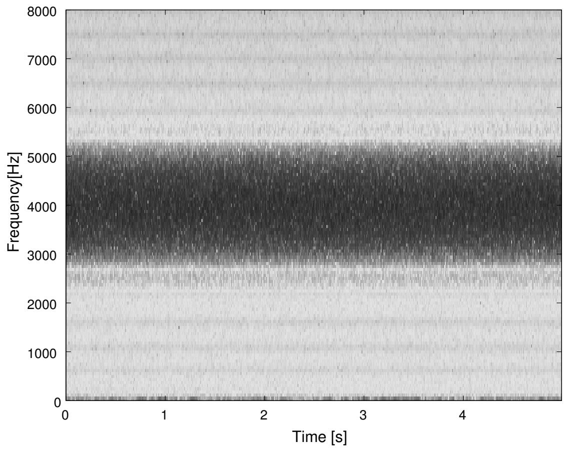
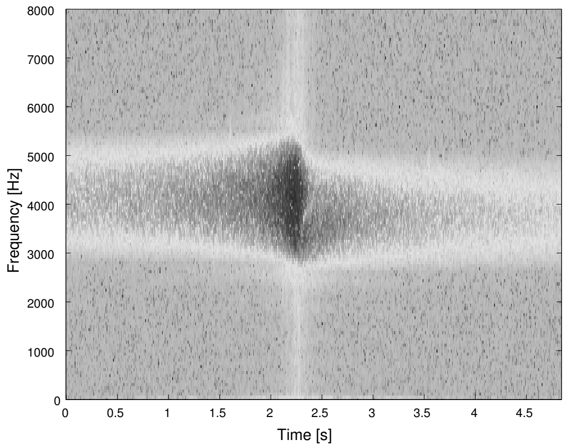


Figure 3: Cutting method of initial delay

sound source moving from front to back on the axis of 1.5 m of the left at 36 km/h. Figure 4-(b) shows a spectrogram of the left side ear of the simulation. It can be found that the pitch shift and propagation decay are added to the sound.



(a) Original sound



(b) Rendered sound with the Doppler effect

Figure 4: Spectrogram of rendering output

5. CONCLUSION

This paper presents a new rendering method of moving sound incorporating the Doppler effect. In this method, sound sources are convoluted with a HRIR without initial delay but with a calculated propagation delay from sound-source and listener positions. That is, only the sound position of each time is needed, but additional pitch shift rendering is not needed to realize the Doppler effect. The Doppler effect is then given automatically to each ear.

6. ACKNOWLEDGMENT

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7. REFERENCES

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