WRITTEN ASSIGNMET 2: FINAL REVIEW

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Spatial Effects:
Simulation of Sound Source Motion

Introduction

Successful sound design requires an understanding of not only frequency and time but also space. In the application of film, sound effects may be required to move in space to accompany the movement of visual cues or to indicate motion off screen. It is possible to record these sounds by means of a Foley artist performing choreography around a stereo pair, dummy recording head or more complex microphone array; however this requires thorough planning the appropriate facilities and equipment. The ability to simulate this sound source motion in a convincing manner allows for greater flexibility in post-production. In terms of music, classical notions of performance and production are usually static in terms of the placement of instruments in space. More modern and experimental genres, on the other hand, are more open to dynamic spatial effects especially when it comes to synthesised sounds. An ability to simulate sound source motion can therefore be seen to have applications in music as well. The artist would require the ability to control various parameters that affect the output sound to allow him or her to showcase their talents and creativity. Another important field where simulated sound source motion is of great use is the gaming industry. Most computer games involve movement that may be at a very high pace and the real-time positioning of a sound source in space is important for the immersion of the player within the game environment. These are three key areas where simulated sound source motion can be employed to achieve a required spatial audio effect and which would benefit from software plugin that could facilitate this.

Problem Statement:

In various fields of sound design there is a need to simulate the motion of sound source in space and time.

To fulfil this need, it is proposed that a sound source motion simulation be implemented as a software plugin to be used with current industry standard audio editing software (e.g. Pro Tools 10) making it easily accessible for a wide range of creative applications. The proposed solution will have the ability to input the trajectory of the source motion in time and space and will offer a choice of output reproduction methods (e.g. headphones, stereo loudspeakers or 5.1 surround). Future work would also see the ability to react in real-time to changes in trajectory for the application of gaming or live music performance.

Specification

To achieve the required spatial audio effect of simulated sound source motion, an understanding of the acoustic principles of distance falloff and the Doppler Effect is required. Additionally, consideration needs to be made of the output reproduction method.

Distance Falloff

It is important to consider that when a sound source is located further away from the observer it will appear quieter when compared to when the sound source is near to the observer due to a reduced sound pressure.

In the free field, this is accounted for by the inverse distance law:

$$\frac{p_1}{p_2} = \frac{r_2}{r_1} \tag{1}$$

Where p is the sound pressure and r is the distance between sound source and observer at locations 1 and 2 as indicated.

This falloff must be modelled as the sound source moves relative to the observer in order for a realistic effect to be achieved.

The Doppler Effect

When we are considering a sound source in motion we must appreciated the shift in frequencies that occurs, known as the Doppler Effect. The Doppler Effect is present when there is a radial component to the relative motion between sound source and observer. The greater the radial velocity, the greater the shift in frequency heard by the observed.

For a stationary observer and moving sound source, the Doppler Effect is calculated using the mathematical formula:

$$f_d = f_s\left(1+\frac{v_s}{c}\right) \tag{2}$$

Where v_s is the he radial component of the relative velocity between the observer and sound source (see **Error! Reference source not found.**), c is the speed of sound, f_s is the frequency of the sound source and f_d is the apparent frequency of the sound source for the observer.

The sound source may produce a range of frequencies so we consider the coefficient of frequency change since all frequencies are affected linearly:

$$F = \frac{f_d}{f_s} \tag{3}$$

Where F is the coefficient of frequency change.

Reproduction Method

The proposed plugin will need to offer the option of tailoring the output for a number of reproduction methods. The simplest method is the stereo loudspeaker which would require a panning of the sound between the two speakers based on the angular location of the sound source relative to the observer. A surround sound array (e.g. 5.1) would require a more complex panning between all the speakers. Another important method to consider is reproduction over headphones. This would facilitate a binaural output meaning that a two channel output could be used to simulate human spatial hearing cues at each ear which would be achieved by convolution of the sound signal with Head Related Impulse Responses (HRIRs). A pair of HRIRs represents the impulse responses for a sound source in a given location as measured at the entrance to the right and left ear canals. Please refer to [1] for more information on binaural reproduction over headphones (see '6.3: 3D with Headphones').

Implementation

As a proof of concept, a MATLAB function (***moving_source.m***) has been shown to simulate the motion of a sound source to be reproduced over stereo loudspeakers and is based on the work of Zbigniew Koziel [4]. In this example, the sound source can be chosen to move in front of the listener from left to right or right to left (see Figure 2). The function takes a single channel input and creates a stereo panned two channel output with Doppler Effect

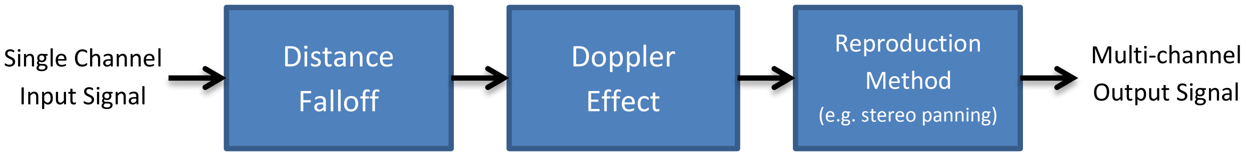

Figure 1. *Signal Flow of Sound Source Motion Simulation.*

and distance falloff based on the input parameters of: speed of sound source (in metres per second) and the distance offset of the observer from line of sound source motion (in metres). The signal flow can be seen in Figure 2.

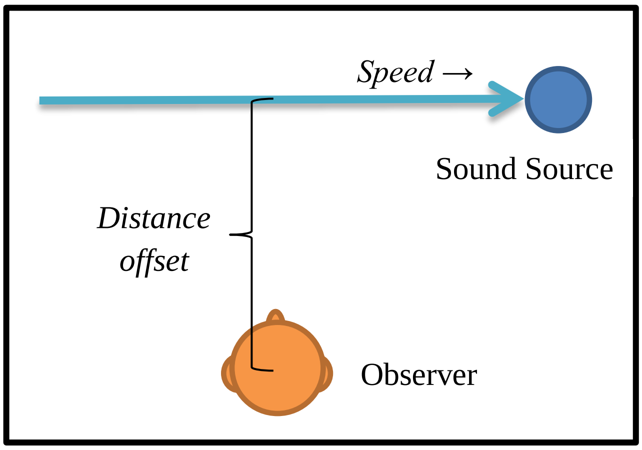

Figure 2. *Simulation configuration.*

While the sound source has a constant speed, its velocity relative to the observer is constantly changing due to change in location. This radial component is what it needed to account for the Doppler Effect and is found using trigonometry (see Figure 3).

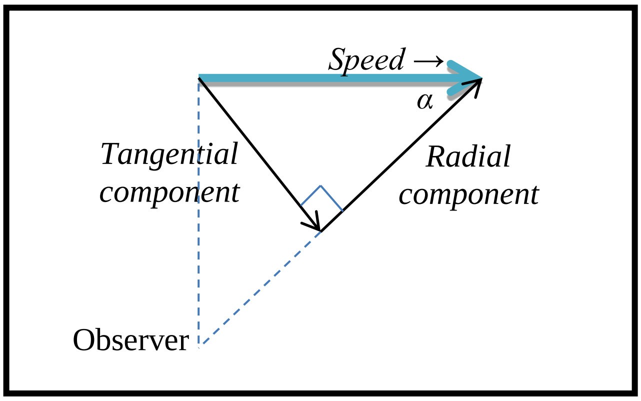

Figure 3. *Radial component of velocity of sound source relative to observer.*

Distance falloff is found by assuming that the input sound file represents a sound that is 1 metre away from the observer. Using Equation 1, the attenuation applied to the signal over time then becomes:

$$\boldsymbol{a} = \frac{\mathbf{1}}{\boldsymbol{d}} \tag{4}$$

Where ***a*** is the attenuation factor and ***d*** is the straight-line distance between sound source and observer as it follows its trajectory.

To utilise the two channel output, stereo panning is incorporated as the sound source moves from left to right or right to left in front of the observer. In this implementation, the sound is panned between extreme left and right as a function of the angle between the line joining the sound source and observer and the line of action of the sound source (labelled $\boldsymbol{\alpha}$ in Figure 3).

Evaluation

In order to evaluate that the proof of concept a wave file of an ambulance siren was input into the MATLAB function to verify that it provided an output as specified.

The same input was used during the development process to continually test by listening to the output audio to verify that it was behaving as desired. Once the proof of concept was complete the output signal was evaluated graphically.

Firstly the amplitudes of the left and right output signals were compared with each other and the input signal over time. Figure 4 shows the input and output waveforms. The sound source was simulated to be travelling in a straight line from left to right 10 metres in front of the observer at a velocity of 30 m/s.

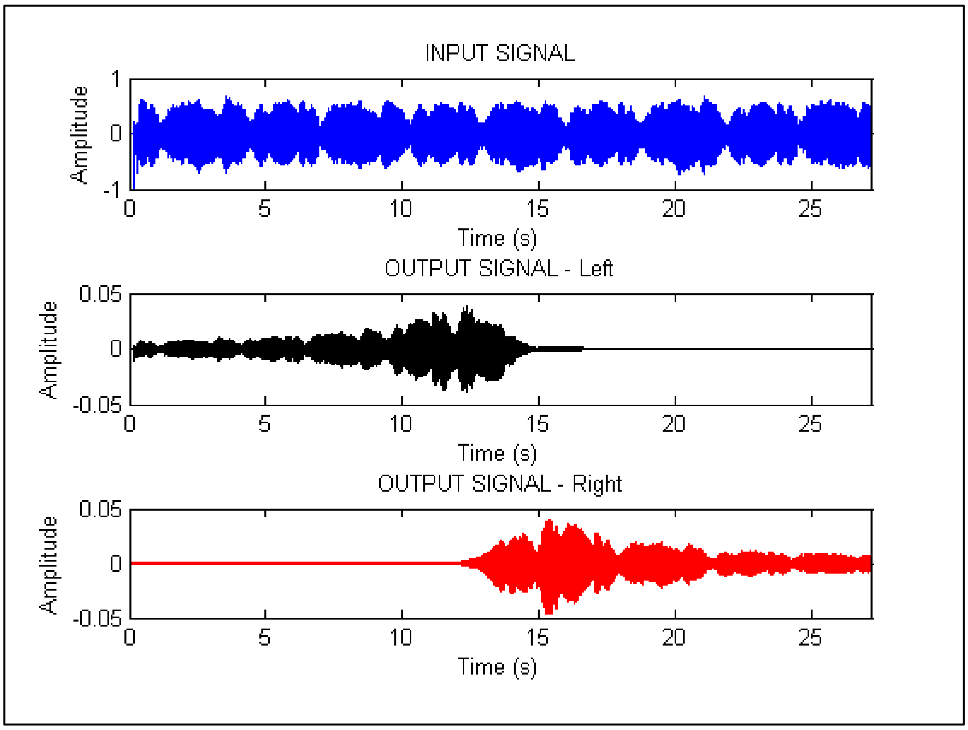

Figure 4. *Amplitude comparison of input and output audio for Siren input.*

The stereo panning is evident as the ambulance is simulated to move from left to right. It was not initially clear that the maximum loudness would be experienced at the central point so white noise was used as the input signal using the same velocity and minimum distance input parameters. Figure 5 clearly shows the effect of distance falloff. It can be seen by the summed left and right output signals (in green) that the signal is loudest when the ambulance is at its closest point as it passes in front of the observer.

Spectral analysis was used to verify that application of the Doppler Effect. For this evaluation, the clearest results were shown using a pure tone. Figure 6 and Figure 7 show the spectrogram of the left and right outputs respectively for a 1 kHz pure tone input for the same velocity and minimum distance input parameters. Both show the significant drop in frequency as the pure tone is simulated to pass the observer verifying the application of the

Doppler Effect. Since frequency is shifted higher as the sound source approaches and lower as the sound source recedes.

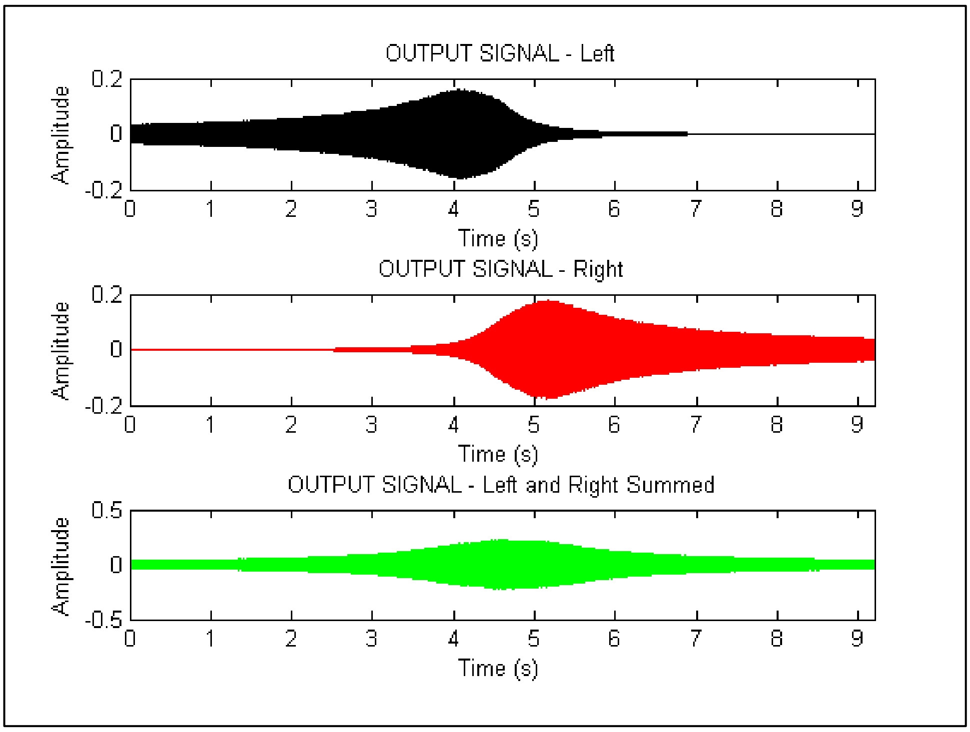

Figure 5. *Amplitude comparison of input and output audio for white noise input.*

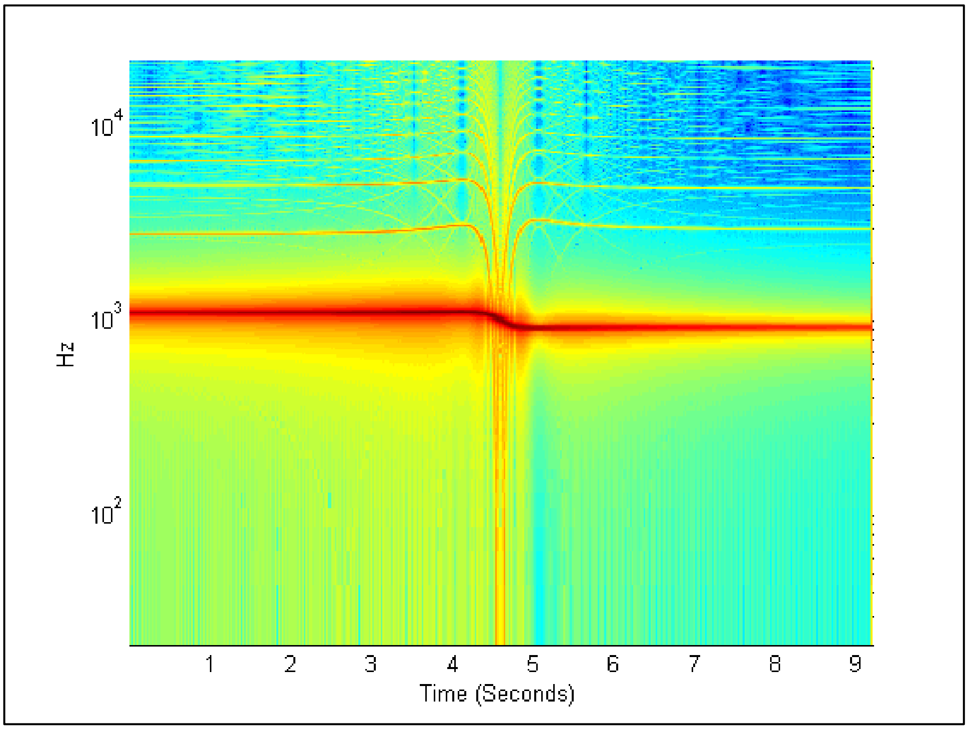

Figure 6. *Spectral analysis of the left output signal for a 1 kHz pure tone input.*

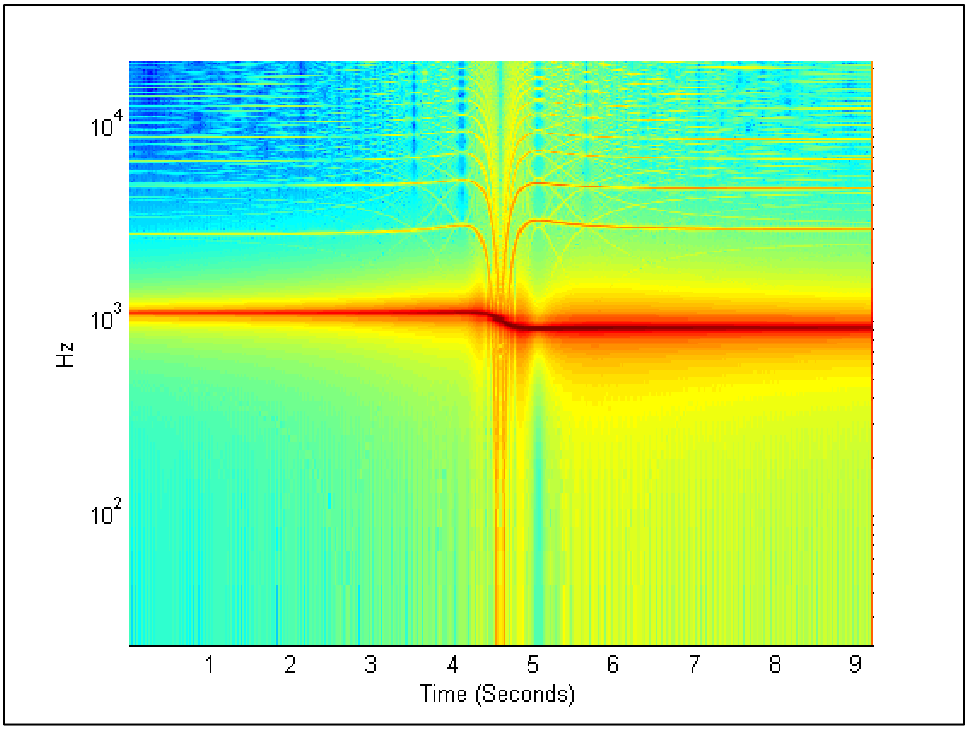

Figure 7. *Spectral analysis of the right output signal for a 1 kHz pure tone input.*

Limitations

There are a number of limitations to this proof of concept due to simplifications made. Firstly, considering the sound source to move in a straight line and at a constant speed removes the complex motion that may otherwise occur in reality. Secondly, the simulation is assumed to take place in the free field and there is therefore no attempt to incorporate any artificial reverberations. Additionally, since the simulation models the sound source as a simple point source there is no consideration of sound source directivity and any additional spatial cues to do with the size and shape of the source.

Validation

While it has been verified that the proof of concept performs as it was designed to is important to validate that it is in fact useful. For the proposed implementation, it is not essential for the simulated output sounds to be superior to those that could be achieved using recording techniques, since the main advantage of the solution is its ease of use and cost effectiveness due to reducing the time and equipment needs. It is, however, necessary that the output sounds are convincing and usable in a creative context. Consulting with sound designers in the areas of film, music and gaming would allow a better understanding of what they would look for in a sound source motion simulator and if they would choose to use one in the first place. When this is established, listening tests would be needed to ensure that the output audio is convincing to the expected audience. In the field of electronic music, the pursuit of realism may not be required. In this case, listening tests would attempt to validate people's preference for dynamic sounds as opposed to those that are stationary in space over time. It is important that these listening tests are conducted without bias; especially from those conducting the test. It is for this reason that double blind experiments are recommended.

Conclusion

Sound source motion can be simulated by modelling acoustic principles in order to produce a multichannel output for a range of reproduction methods as demonstrated by stereo output proof of concept. This paves the way for the development of a software plugin which will be more robust to accommodate complex trajectories and consider the dimensional characteristics and directivity of the sound source. It will additionally provide the option to select the output mode to suit a range of reproduction modes.

References

[1] U. Zölzer, ‘Spatial Effects’, *Digital Audio Effects (DAFX)*. John Wiley & Sons, Ltd, 2002.

[2] J. Blauert, Spatial Hearing: The Psychophysics of Human Sound Localization, MIT Press, 1983.

[3] M. Fowler, *Doppler Effect*, University of Virginia, http://galileo.phys.virginia.edu/classes/152.mf1i.spring02/DopplerEffect.pdf, 2009.

[4] Z. Koziel, *Traffic Noise Simulator*, MATLAB function, Acoustic Research Centre, University of Salford, 2009.