Testing the Minimum Audible Movement Angle (MAMA) of 3-D sound in Virtual Audio Environments

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Introduction

The field of 3-D audio goes under many names. It's referred to as 3-D audio, virtual acoustics, binaural audio, or spatial audio. At its core, 3-D audio uses digital filters to simulate the acoustical properties of the real world. It models the acoustical effects of the head, the outer, and the inner ear using filters called Head-Related Transfer Functions (HRTF). It's a very multidisciplinary field which draws from acoustics, computer science, psychoacoustics, sound design, and psychology. When designing 3-D audio systems that can be used in the real world, it's important that the position and movement of a sound can be reliably reproduced and perceived. With that said, the resolution of these sound environments is imperfect. The CIPIC HRTF database produces sounds at 625 fixed angles opposed to the real world where a sound can come from any direction. This also impacts the degree with which moving sounds can be perceived. This is called the Minimum Audible Movement Angle or MAMA. Many factors can influence this value including the frequency and movement speed of the sound. We designed a study to test the effect of movement speed on MAMA for 3-D sound.

Motivation: Audio RESCUE

For a long time, audio research was reserved to computer musicians and people in academia. Recently, more emphasis has been placed on bringing audio tech into the real world to serve humanity. Dr. McMullen is a strong proponent of this with a passion for Human Centered Computing. Her study - Audio REScue aims to aid firefighter search and rescue with 3-D audio tech. To do this, we need to understand how firefighters perform S&R, how they communicate with each other, and how tech could improve the process. We also need to understand how 3-D sound movement is perceived and what speed works best for simulating all angles of movement if we're going to use it in a device.

So what do firefighters do?

Our first task was to research firefighter search and rescue and design a focus group for the Gainesville Fire Department. The focus group was to learn how GFD performs search and rescue and how technology could improve it. In general, a search and rescue operation is broken up into a size up, primary search, and secondary search. Size up includes observing the building and determining a course of action. A primary search includes entering the building, controlling the fire, and rescuing any people inside the building. A secondary search is performed after the fire is controlled to assess the damage and loss of life. In talking with GFD, we learned how firefighters generally communicate during this process. Searches are generally done in pairs, with all firefighters communicating through radio. In a room together, firefighters can also yell and use hand signals to communicate. They stressed that individual behavior is very dependent on the department and the person who's performing the search.

Previous Work

The next step was to learn about previous work on the minimum audible movement angle. In 1977, a study by Perrot and Musicant tested the effects of sound movement speed on the MAMA. They designed an experiment using stationary speakers and a speaker attached to a moving pole. The sound would either come from the moving speaker or the stationary one. The participant was blindfolded and asked whether the sound moved and how much it moved. The idea was to see how movement speed affected a person's ability to detect the movement of a sound. They rotated at speeds of 90, 180, and 360 degrees/sec. They found that the greater the velocity of movement, the less accurately the sound could be localized.

In 1988, Perrot and Tucker published a study to calculate the MAMA as a function of velocity and signal frequency. Using an experiment similar to Perrot and Musicant (1988), they confirmed that there's an inverse relationship between spatial resolution and the rate of travel meaning faster sounds are harder to locate. They also found that spatial resolution is optimal for signals below 1000 Hz and above 3000 Hz. Their testing conditions included frequencies between 500-3700 Hz and speeds between 8-128 degrees.

In 2019, Han and Chen conducted a study to further analyze the relationship between velocity, frequency, and MAMA. While the sounds in the first two studies were played on a system of loudspeakers, Han & Chen were the first to run this type of experiment in a virtual environment. The experiment was conducted by simulating the sounds with 3-D audio. Each listener wore headphones and heard a total of 18 testing conditions [= 6 frequencies (500 Hz, 730 Hz, 950 Hz, 1170 Hz, 1800 Hz and 2900 Hz) x 3 angular speeds (100/s, 150/s and 200/s). They found that MAMA is larger in VAE (Virtual Audio Environments) than REA (Real Audio Environments). They also found that after 1000Hz, the MAMA increases drastically.

Study Design

When designing our study, we used a mix of Han & Chen (2019) and Perrot & Musicant 's (1977) methodologies. Han & Chen created virtual moving sounds using an HRTF at different speeds and tested if the motion could be perceived. It considered what the MAMA was for different angular speeds but it didn't say how reliably the participants could locate a position. They also didn't consider low angular velocities (they only did 100°/s, 150°/s, 200°/s). In a situation where accuracy is very important, it's critical that we know how lower angular speeds affect perception of virtually created 3-D sound. This insight might allow us to create sounds movement that's audible and reliable. The Perrot & Musicant study (1977) measured the localization accuracy of moving sounds by playing noise from a speaker on a moving pole.

We designed a study similar to Han & Chen (2019) with localization in mind. In the experiment, 3-D sounds were simulated to move from different distances (near/far) at different speeds with real world background noise. Since we are testing multiple independent variables, this would require a factorial experimental design, meaning that each level of one independent variable is combined with each level of the others to produce all possible combinations. In the actual testing session, each listener would participate in a total of 145 testing conditions [= 6 angular speeds (10°/s, 20°/s, 40°/s, 80°/s, 160°/s, and 320°/s) x 2 distances (close field and far field) x 2 noise ratios (0% and 50%) x 6 angular movement distances (5°, 20°, 40°, 60°, 90°, and 120°)]. The sound was a triangle wave at 400Hz.

To create sounds of varying distances we leveraged spectral cues and the inverse square law of sound. Near field sounds (< 1m) have a low frequency attenuation due to head diffraction. Far field sounds (> 15m) have a high pass attenuation due to loss of energy traveling through the air. The inverse square law also says that for every doubling of distance, the intensity of a sound is reduced by 6dB. To simulate near field sounds, we exaggerated the effects of the ITD (interaural time difference) and IID (interaural intensity difference). To simulate far field sounds, we passed the signal through a lowpass filter at 900Hz and reduced the gain by 20dB.

While we didn't get a chance to connect the interface to the signal process during our time here, the lab plans to continue working on it when we're gone.

Acknowledgements

Thanks to Dr. Kyla McMullen, Armisha Roberts, and Dr. Juan Gilbert for having me in their lab/department for the summer. I learned a lot about real life coding and the impact technology can have on people's lives. Thanks to DREU and the CRA for accepting me and providing funding for this internship. Thanks to the University of Florida for hosting me this summer.

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