On the Acoustics of Alleyways (#9190)

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Abstract

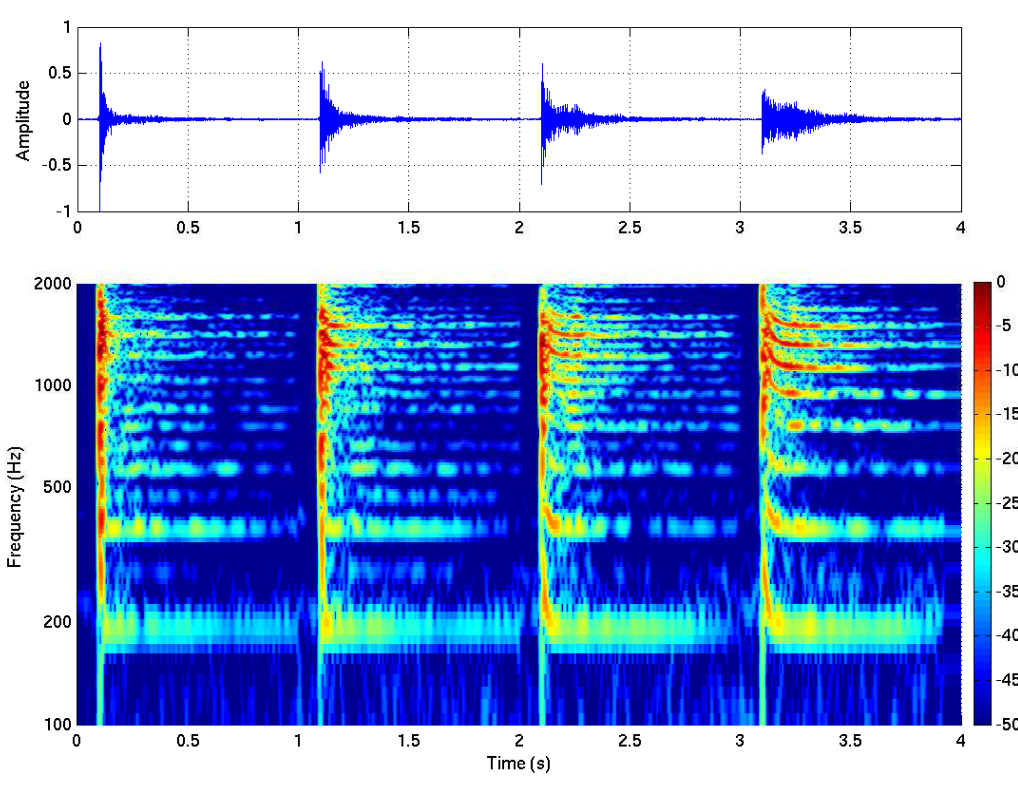
Alleyways bounded by flat, reflective, parallel walls and smooth concrete floors can produce impulse responses that are surprisingly rich in texture, featuring a long-lasting modulated tone and a changing timbre much like the sound of a didgeridoo. This work explores alleyway acoustics with acoustic measurements and presents a computational model based on the image method. Alleyway response spectrograms show spectral zeros rising in frequency with time, and a modulated tone lasting noticeably longer than the harmonic series associated with the distance between the walls. With slight canting of the walls and floors to produce the long lasting modulated tone, the image method model captures much of this behavior.

Measurements

Measurements were taken in 3 different alleyways in Palo Alto, CA using the following measurement setup.

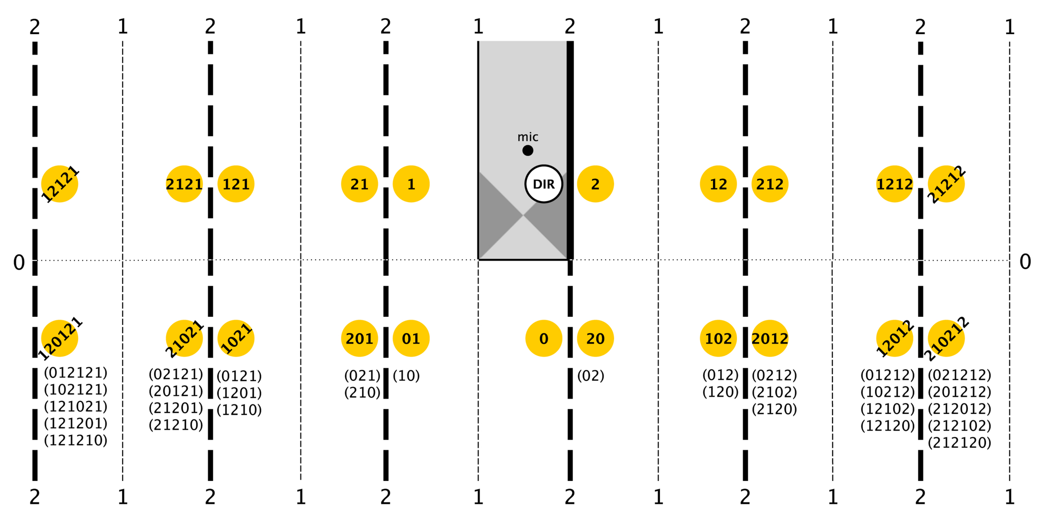
- 2 figure-8 microphones, 1 loudspeaker, balloons, orchestra whip
- several microphone/source positions
- tennis ball, string, measuring tape, level (to measure canting)

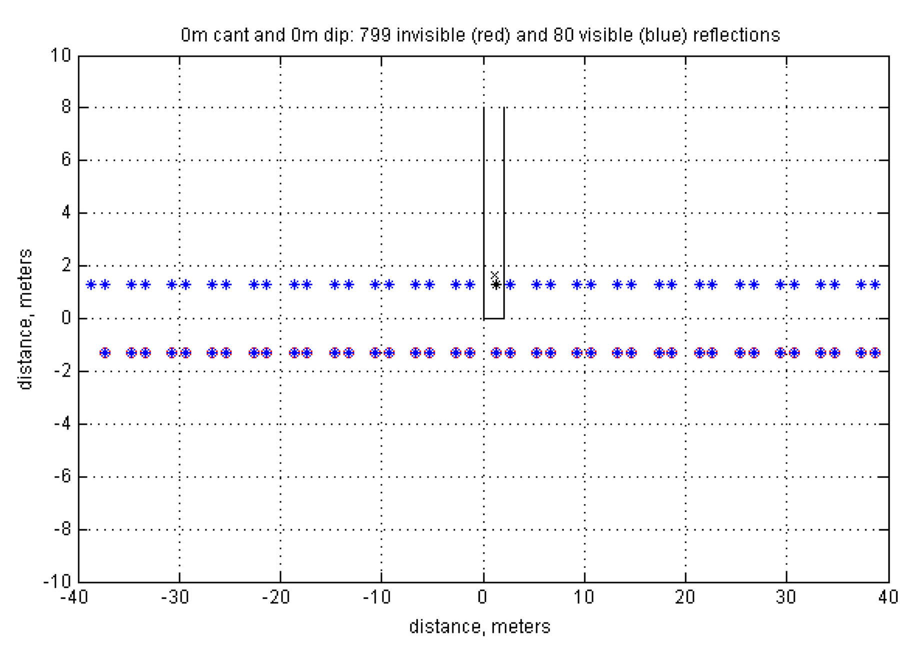
A series of measurements were taken with the speaker moving away from the microphone at 12' intervals.

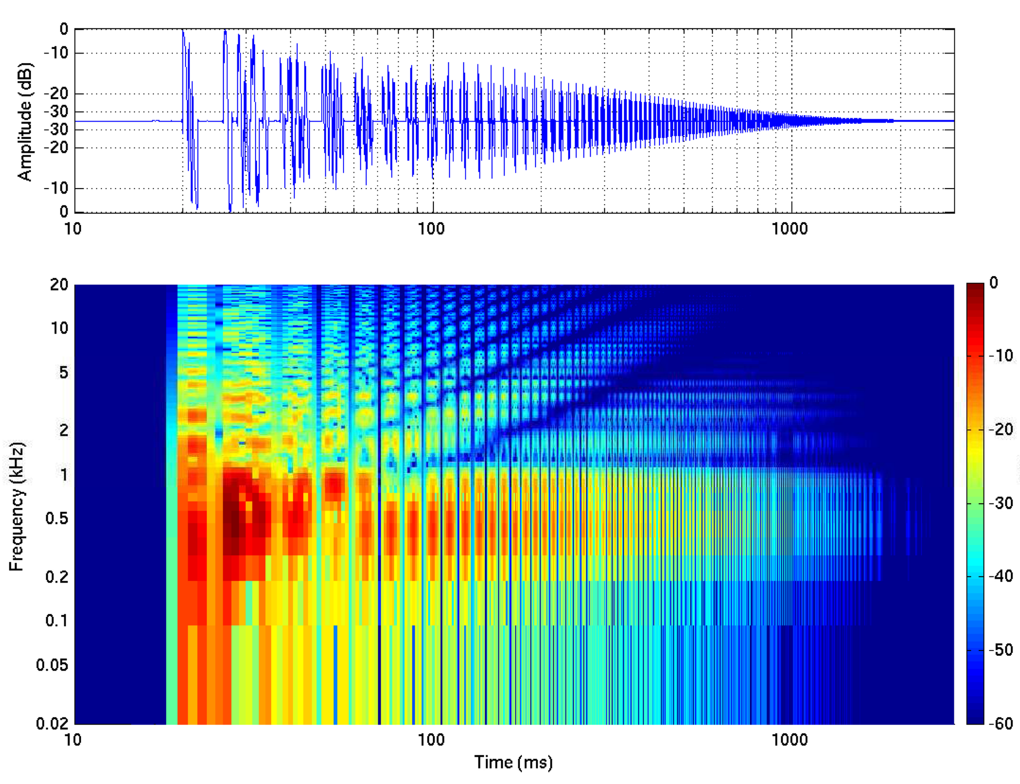


As the source moves away from the microphone, the low-order image sources are roughly the same distance to the listener as the original source, and the later arrivals become more separated in time, creating a downward chirp frequency response.

Model: Orthogonal Walls

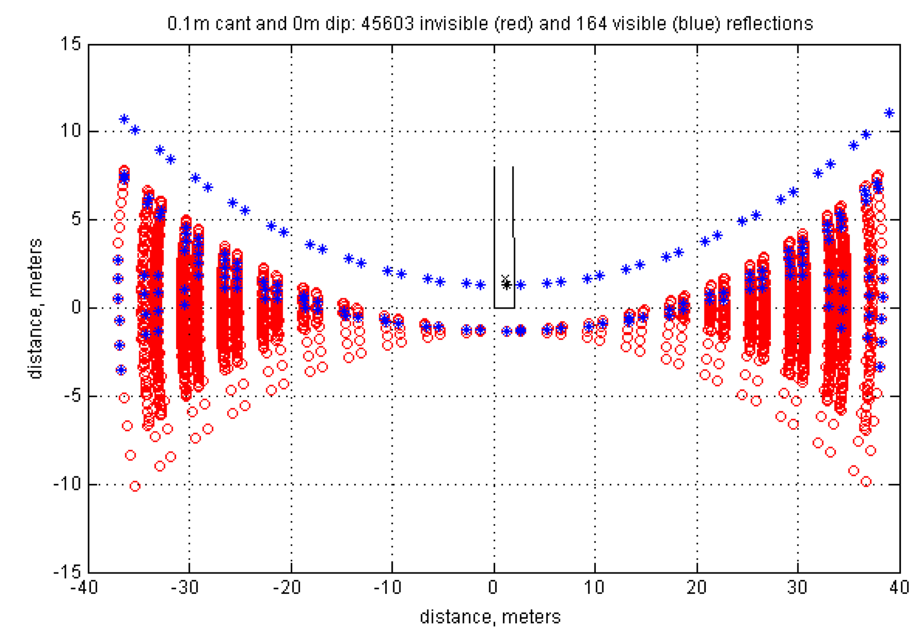






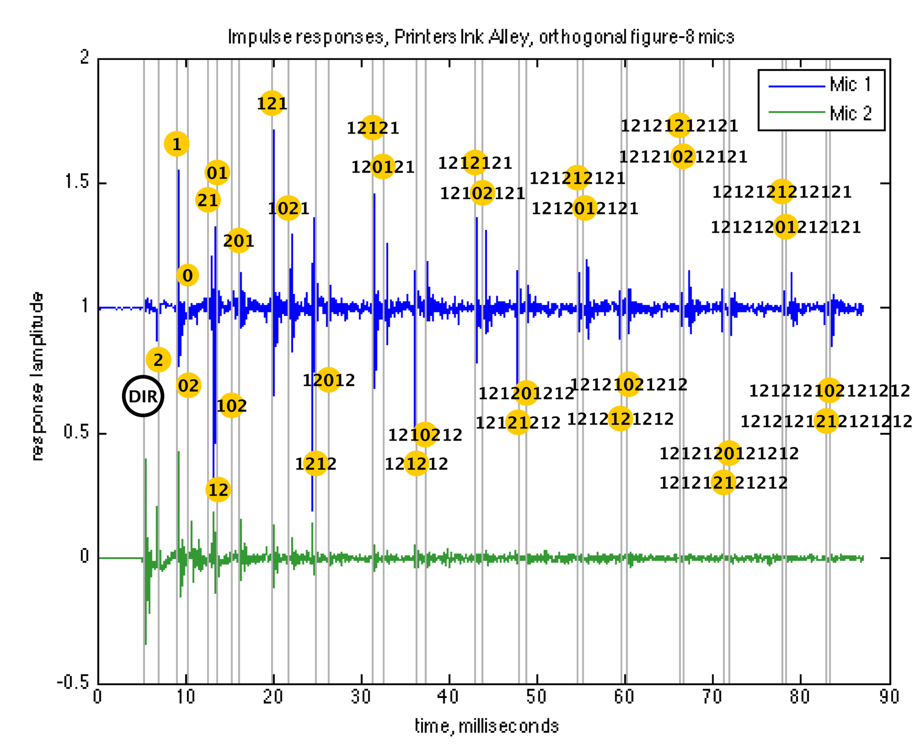
Differences in source-signal arrival times between the two rows are more pronounced at the beginning of the transient response than at the end, and produce a series of spectral zeros that increase in frequency with time during the impulse response onset.

Model: Canted Walls



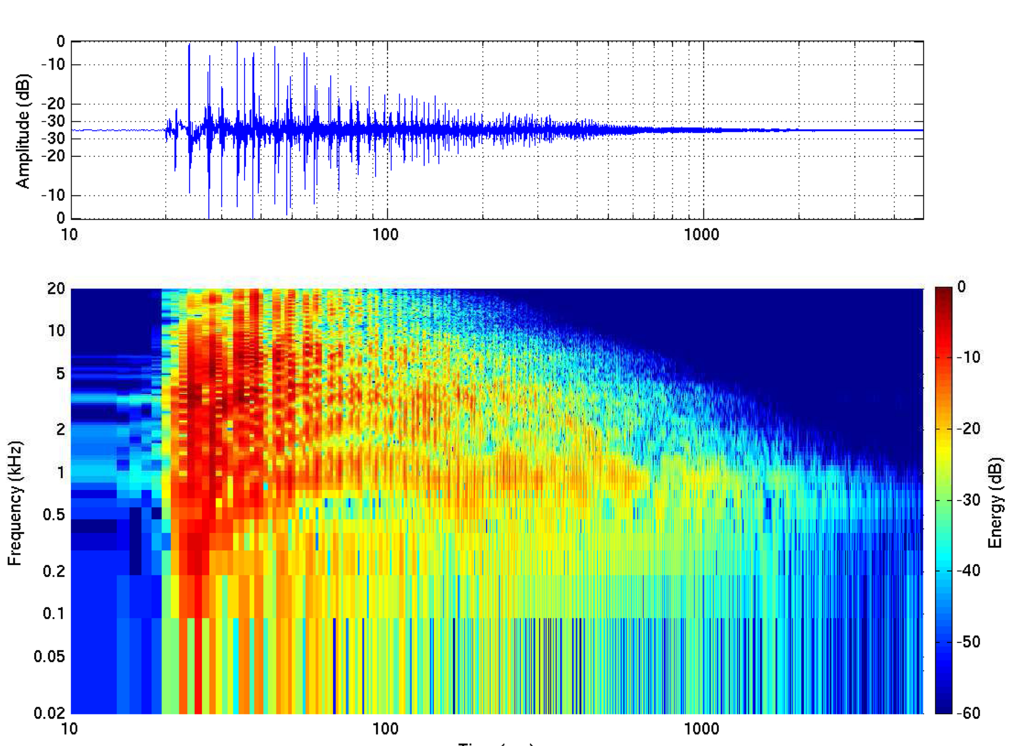
An alleyway with canted walls has neighborhoods of virtual sources, who generate modes that are closely related in frequency. This creates strong, slow amplitude modulation due to beating frequencies.

The degree of canting in the walls and dip in the floor exponentially increases the number of visible sources. The energy decay envelope of the impulse response is therefore more $\frac{1}{\sqrt{r}}$ than $\frac{1}{r}$.



In the early field, a decreasing relationship between arrival times of pairs of sources emerges, consisting of a source and its reflection through the ground. The orientation of our figure-8 microphone and speaker, both facing a wall, was key to matching our measurements to our model.

Analysis of Acoustic Features

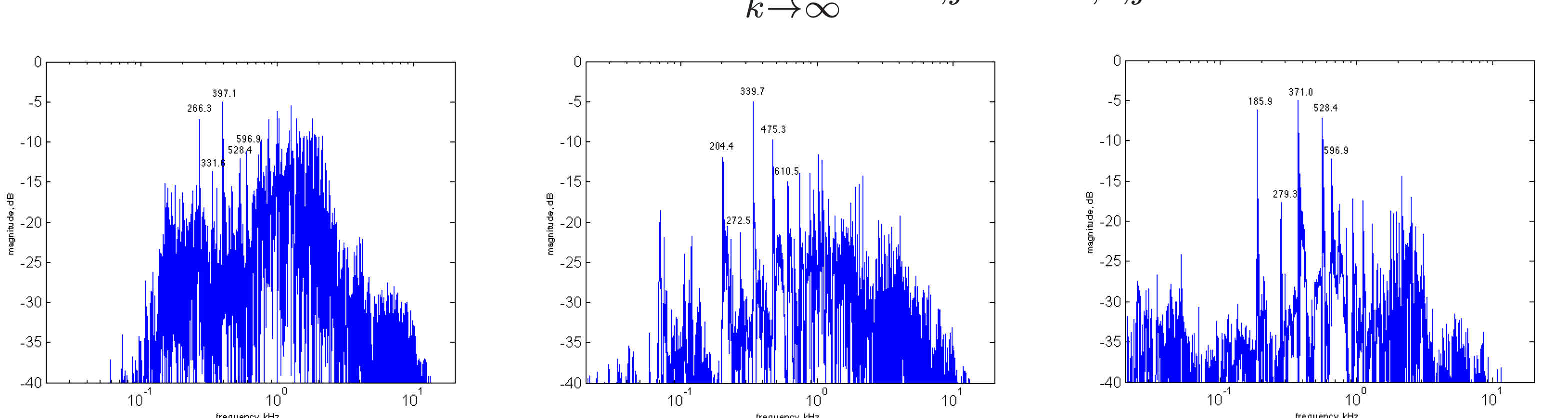


From this measured spectrogram, we observe the following:

- A rising frequency pattern at onset, followed by a downward frequency chirp
- Strong modes with shifting and neighboring center frequencies
- Independent amplitude modulation of modes in the late field, and slow decay of acoustic energy

1. Onset. Spectral zeros in the first 100 milliseconds show a rise over time, explained by the decreasing difference in image-source arrival times, leading to a rise in frequency regardless of the cant of the walls. With canted walls, the distance between this pair increases with order. This leads to the subsequent fall in frequency.

2. Modal analysis. The geometry of a given alleyway dictates its strongest modes, which are peaks in the FFT of the entire impulse response.



3. Decay. As reflection order and degree of wall canting and/or floor dip increases linearly, the number of visible sources increases exponentially. This causes energy to decay at a rate closer to $\frac{1}{\sqrt{r}}$ as opposed to $\frac{1}{r}$. These visible sources have closely-related modes which cause beating patterns to emerge.

For pairs of virtual sources **vs** reflected about the floor with order k and direct sound source **s**,

$$\lim_{k\to\infty} \frac{||\mathbf{vs}^k_{i,0,j} - \mathbf{s}||}{||\mathbf{vs}^k_{i,j} - \mathbf{s}||} = 1,$$

$$\lim_{k\to\infty} ||\mathbf{vs}^k_{i,j} - \mathbf{vs}^k_{i,0,j}|| = \infty.$$