Directed Audio Warning System for Reduction of Bus-Pedestrian Collisions

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Problem:

Collisions between buses and pedestrians often occur at intersections in cities where pedestrians and vehicles most frequently crisscross. These collisions are increasing as more pedestrians are distracted by their mobile devices, and bus drivers continue to be impeded by blind corners. Unfortunately, these accidents often result in injury and sometimes death, leaving transit agencies to deal with the tragic and sometimes expensive consequences. Is there an effective method to warn pedestrians of an impeding collision in order to reduce fatalities associated with these accidents?

These collisions only stand to increase in frequency, as increasing numbers of pedestrians choose to block off their surroundings with such devices as headphones, smartphones, and other electronic devices. This decrease in awareness of surroundings, particularly at a dense urban intersection, serves to magnify the likelihood that distracted pedestrians fail to notice a turning bus in their way.

In our increasingly litigious environment, the consequences of such incidents have become much more significant, as growing numbers of injured pedestrians choose to engage in a legal battle for compensation. The Southeastern Pennsylvania Transportation Authority (SEPTA), primary transit operator for Philadelphia and the fifth largest transit provider in the United States, estimates that over $40 million per year is spent on legal fees and compensatory awards directly stemming from bus-pedestrian collision instances. Thus, greater financial obligations from increasing numbers of bus-pedestrian collisions, though secondary in importance to the critical issue of pedestrian injury and life loss, impact the bottom lines of SEPTA and other cash-strapped transit agencies – making critical the development of any system or method that can reduce these collisions, saving lives and money in the process.

Approach:

Various bus transit operators have designed solutions that have reduced the number of bus-pedestrian collisions to some extent. However, our analysis shows that there are large areas for improvement in all the existing solutions, especially in detecting the pedestrian and emitting a warning signal. There are significant problems to the current systems that we are working to overcome in our proposed solution. The problems are as follows:

1. High costs. The cost of installation is at a price point beyond the reach of many cash-strapped transit agencies.
2. Complexity. These systems required complex retrofitting of the bus in order for successful installation, making changes difficult and increasing maintenance costs.
3. Lack of community support. Residents have complained about the additional beeping and warnings in cities already saturated with noise.

In this project, we propose a solution utilizing directed audio technology that is inexpensive, reliable, and non-disruptive to the surrounding environment.

Methodology:

We want to achieve a high directivity of sound, so that we can emit a targeted audio warning toward pedestrians without noisily disrupting the surroundings. A narrow beam of sound also has a startling effect on its target as compared to a regular, widely dispersing audio signal.

It is not feasible to achieve a high directivity if the warning is transmitted purely in the audible frequency domain (20 Hz – 20 kHz). The directivity of a wave increases with its frequency and length of its source. The frequency of audible waves is considerably low. Thus a very large speaker is required to achieve a high directivity for audible signals.

We thus emit ultrasonic waves at a higher frequency of 40 kHz. The nonlinearity of air acts as a mathematical transform on the wave (8). We have verified that if we transmit a Pulse Width Modulated audible signal with a center frequency of 40 kHz, the nonlinearity of air acts as a low-pass filter, demodulating it back to the audible domain with minimal distortion. This reproduced audible signal is much more directed as it is “carried” by the high frequency ultrasonic wave.

Findings:

The following plots illustrate the higher directivity of an ultrasonic speaker. We transmitted an audible signal through a regular speaker, and recorded the audible signal volume at various angles. The process was repeated with an ultrasonic speaker prototype we developed. The results show that the signal from ultrasonic speakers attenuates more rapidly at greater angles from normal. This proves its higher directionality.

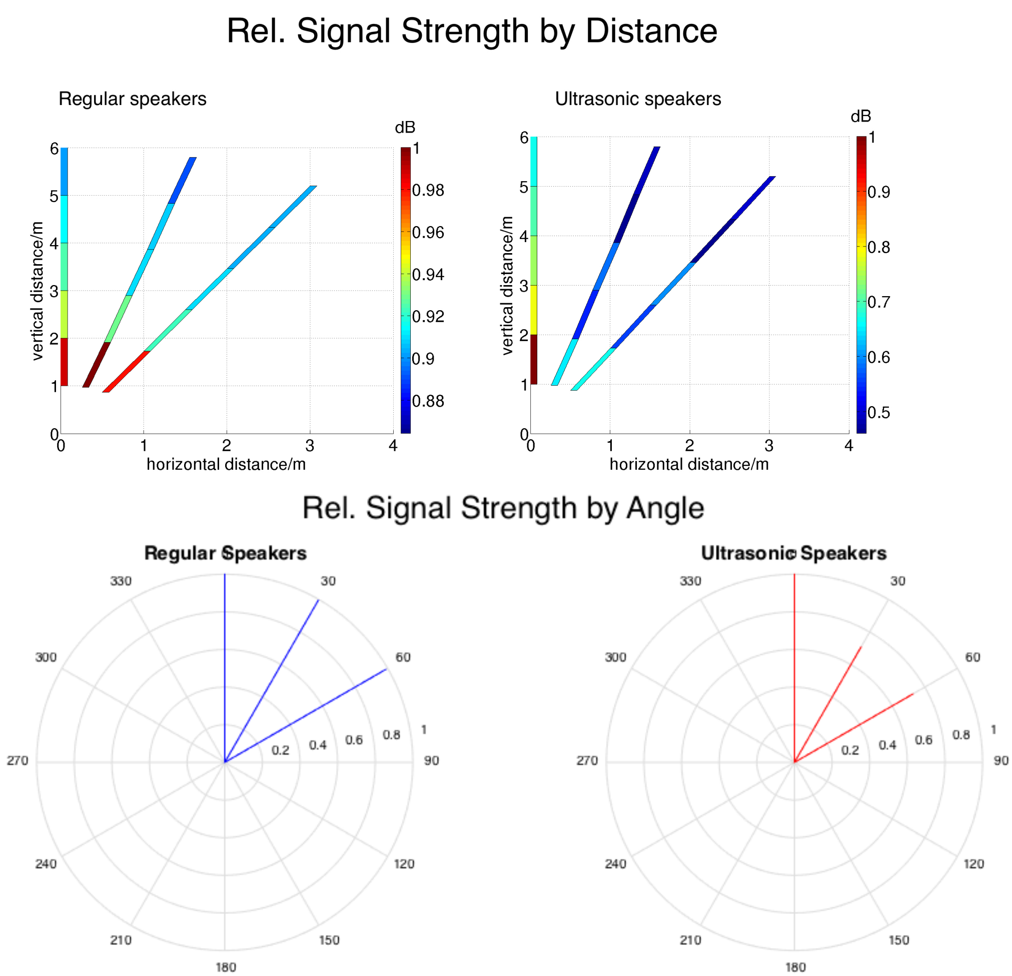

Figure 1: Comparison of relative signal strength at various angles for a regular speaker and an ultrasonic speaker

In one version of our speaker system, a sensor detects the position of a target person, and a motor swivels our directed speaker to face the target. To eliminate moving parts in our system, we are working to implement a phased array speaker, which would steer sound electronically.

A phased array speaker consists of an array of sound sources, with each consecutive element delayed increasingly. The effect of the constructive and destructive interference of sound would result in a maximum sound peaks at an angle from normal.

Consider the following simple illustration with just 2 sound sources. When the 2 sources have a uniform phase, the maximum is found right in its center. If the source on the right is delayed however, the wavelet peak from the left source travels further and meets a peak from the right source to right of the center.

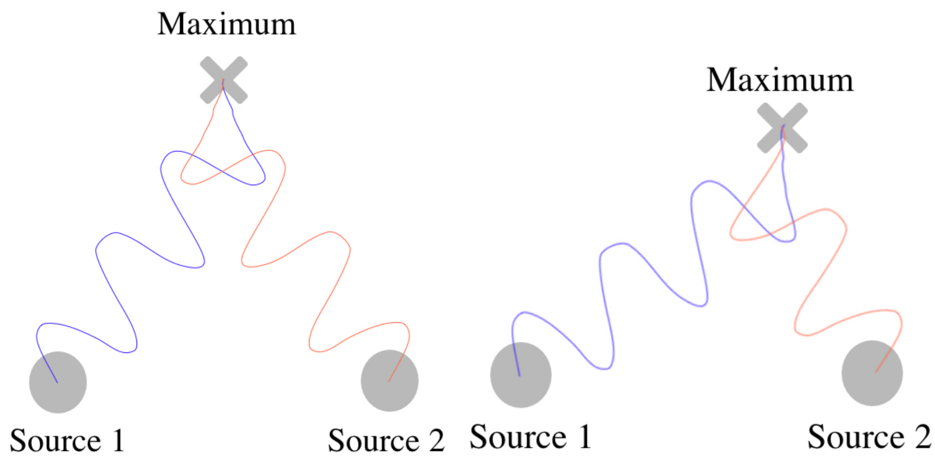

Figure 2: Position of maximum with uniform-phase sources and out-of-phase sources.

We employ this principle to steer the beam in our directional speaker, and have analyzed a model of the sound output to test its feasibility. The model results are based on an actual board configuration with 10 separate sound columns. The dimensions of the board are based on physical transducer sizes. The separation between transducer elements was reduced as much as possible to eliminate side grating lobes. Theoretically, based on the formula $\sin(\theta) = \frac{\lambda}{d}$, where θ is the angle between normal and line to the second maximum, and *d* is the separation between sound sources, if $d < \lambda$ then the grating lobes would be eliminated. The wavelength of an ultrasonic 40 kHz wave in air is about 8.5 mm. A limitation in the physical layout is the transducer diameter, which was 16.2 mm. We thus arranged the board such that the spacing between each speaker column is approximately half a transducer length:

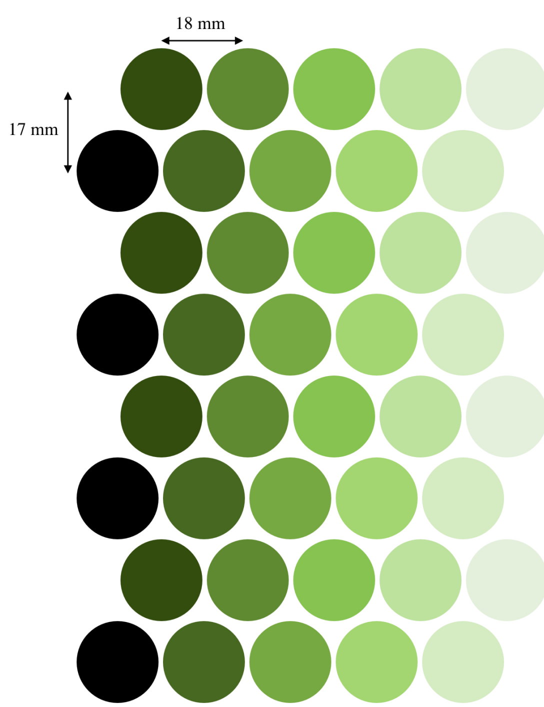

Figure 3: Transducer spacing for phased array speaker. Speakers with uniform phase are

the colored uniformly.

Conclusions:

Our overarching goal was to design a warning system that would reduce bus-pedestrian collision in a way that is effective, targeted and robust. The various experiments, simulation and prototyping we have done with the ultrasonic directional speaker provide a promising solution.

The prototype speaker we produced is low-cost. It consists of electronics and hardware that are cheap and readily available. The audible sound that is reproduced is also clear enough that a transmitted speech signal is discernible by a listener.

Recommendations:

We are currently pursuing potential collaborations with industry to produce a deployable prototype that can test the directed audio beam technology in the field. Such a collaboration is significant in many ways. First, it will integrate research in directed audio technology into an existing commercial system, allowing us to save development time and overhead. Second, this hybrid combination successfully addresses the flaws of previous systems. The integration of our directed audio beam will allow for minimal noise disruption to the urban environment, an important accomplishment that addresses the needs of community stakeholders. Additionally, the incorporation of our system will allow for lower unit costs, higher reliability, and a lower complexity than was previously possible with either of the two standalone systems. Continued funding should help realize the development of such a prototype.