Pedestrian Collision Warning for SEPTA Buses

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January 24, 2014

Abstract

We propose to research the problem of detecting and preventing imminent collisions between buses and pedestrians. GPS and inertial sensor measurements will be fused to analyze bus motion, and other sensors, such as laser scanners, will detect pedestrians in danger. Appropriate algorithms will be developed to anticipate collisions, and warn the driver and pedestrians through various channels. One particular channel under investigation is a directional speaker, projecting an audio warning from the bus towards the pedestrian.

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1 INTRODUCTION

1.1 Motivation

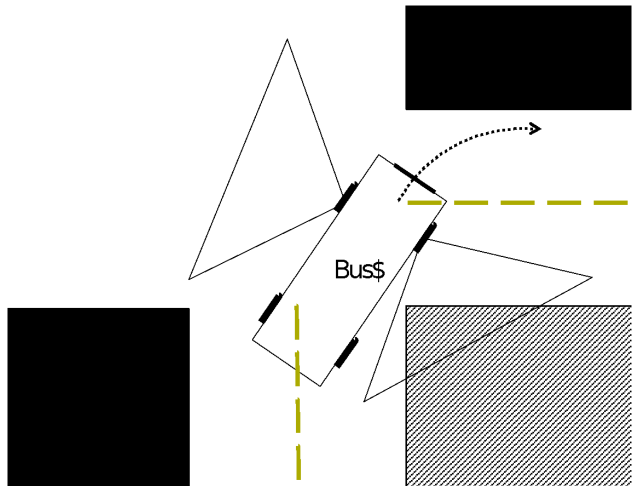

Figure 1: Diagram of turning bus, with danger zone highlighted

Fatal bus and pedestrian collisions have seen a sharp uptick in the last decade. While the causes for such an increase are varied, one primary driver of the trend is the rise of a phenomenon known as "distracted walking," which occurs when pedestrians are distracted from the primary task of walking by such devices as iPods, cell phones, and other forms of electronics.[1,2] Such behavior is likely to further cause pedestrian inattentiveness, potentially accounting for a significant portion of the increased number of bus pedestrian accidents seen in the past decade. As reported by SEPTA and other transportation authorities, most of these accidents happen while buses are turning at intersections, especially in dense urban areas, where pedestrian, automobile, and other forms of traffic are heavy - precisely the type of intersection where vigilance and attention to one's surroundings is absolutely critical.

The increase in the frequency of bus and pedestrian collisions has resulted in dire financial consequences for SEPTA and similar transit agencies across the country, mostly in the form of personal injury lawsuits from pedestrians that have been killed or injured as a result of these collisions. It is estimated that such claims cost SEPTA over $40 million per year in compensation and legal fees - and without some attempt at remediation, such incidents may only become more commonplace as time goes on.[3]

Thus, the financial losses from increased collisions, though secondary to the critical issue of pedestrian life loss, are nonetheless important to SEPTA and other cash-strapped agencies as they are forced to contend with ever-shrinking budgets and the costly realities of maintaining aging and decaying transportation infrastructure - making critical the development of a system which can prevent such accidents from occurring. Such a system will have the dual effects of saving lives and reducing the amount of money lost each year due to personal injury claims and legal costs.

The intention of our solution is to target and eliminate one of the primary sources of these collisions: pedestrian and/or driver inattention.

Current solutions use repeating audio warnings to alert pedestrians and bus operators (see Section 1.3). They attach to the steering column for turn detection (which requires extra devices installed on the vehicle steering system) and broadcast message alerts with no consideration of the actual situation, resulting in two negative outcomes: first, a need to disassemble the inner workings of the bus for system installation, increasing costs and inconvenience to the transit operator, and second, the imposing of an excessive amount of disturbances to the surrounding environment. Such a system, though perhaps effective, may prove challenging to introduce to transit systems and may enervate transit systems with onerous maintenance procedures. Additionally, the increased environmental agitation of the system could result in community pushback, with members of the community preferring the lack of disturbance to the collective benefits that such a system might provide.

As a part of our investigation and research into an optimal warning system that minimizes environmental disturbance while increasing operational simplicity, we will investigate various types of sensors for use in pedestrian detection and propose efficient warning approaches for bus operators and pedestrians.

1.2 Design Constraints

Several desired outcomes and metrics drive our system design.

- Accuracy of bus turning motion: We fuse sensor data from GPS and IMU sensors to determine when the bus is turning a corner, as this is the time of highest danger for pedestrians. It is important that this detection is robust, with very few false negatives.

- Comparison of sensors and algorithms: We will evaluate different sensors and methods of fusing input from multiple channels to determine the best way of detecting pedestrians in danger of being hit by the bus.

- Independence of the system: Most commercial solutions to this problem require extensive modifications to the bus, usually by disassembling the steering column in order to install turn detection sensors. This is invasive, expensive, and requires taking each bus off of its route for some amount of time. As any commuter will tell you, SEPTA can hardly afford to take more buses off the road!

1.3 Related Work

An example of a bus warning system currently in use can be found in the Cleveland metropolitan area. RTA, the regional transit agency responsible for managing Cleveland's bus system, recently installed the system in 400 buses at a cost of $600,000 ($1,500 per bus unit), all of which was paid for using existing federal stimulus money.[4] The system is directly wired into the steering shaft, and is activated when a rotation occurs that is greater than 45 degrees in either direction.

Several companies, such as Brigade Electronics,[5] sell passive sensing systems that can detect pedestrians or cars in the driver's blind spots. The system sold by Brigade consists of ultrasonic sensors and it warns the driver (but not the pedestrians). It also does not have the capacity to detect when the bus is turning.

2 METHODOLOGY

2.1 Technologies Used

2.1.1 Motion tracking

GPS signals and onboard IMUs (Gyroscope and Accelerometer) will be integrated to analyze the bus motion during turning. These sensors together with the computational component require no modification of the basic vehicle structure (reducing installation costs), while presenting actual motion information for crisis prediction. Various sensor technologies, such as laser detectors, sound detectors and conventional cameras, will be evaluated to provide better detection and distance estimation of nearby pedestrians.

2.1.2 Collision warnings

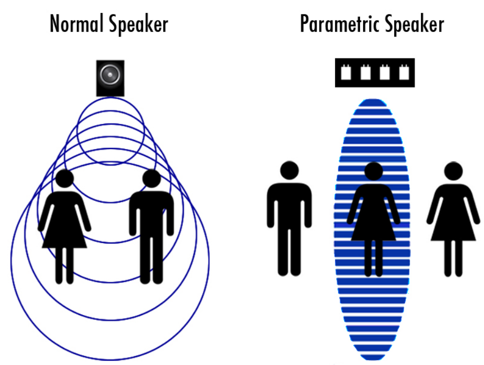

Figure 2: Sound projection of normal speaker vs. directional speaker

Once we have designed an optimal system for situation data collection, proper mapping and planning algorithms will be studied to estimate collisions and to trigger warning messages. We will develop a parametric speaker system for audio alerts, which combines an array of small ultrasonic speakers (Figure 4) to create a highly directional beam of audio (Figure 3). This directional beam can reach only a specific errant pedestrian without creating excess audio disturbance to surrounding areas - and is, in essence, a sound wave laser. Several systems, including one under in-house development, are currently being evaluated.

We are also aware that the needs of pedestrians vary, and want to ensure that our system can reach the broadest group of pedestrians possible, including blind, deaf, and otherwise disabled pedestrians. Thus, non-audio warning messages may also be delivered to disabled pedestrians through other channels; some examples, under detailed study, include flashing lights and bursts of air.

Finally, to complement the pedestrian warning system, we recommend instituting an additional training component for all transit bus drivers that encourages drivers to increase awareness of their surroundings.

3 PROGRESS

3.1 Project Status

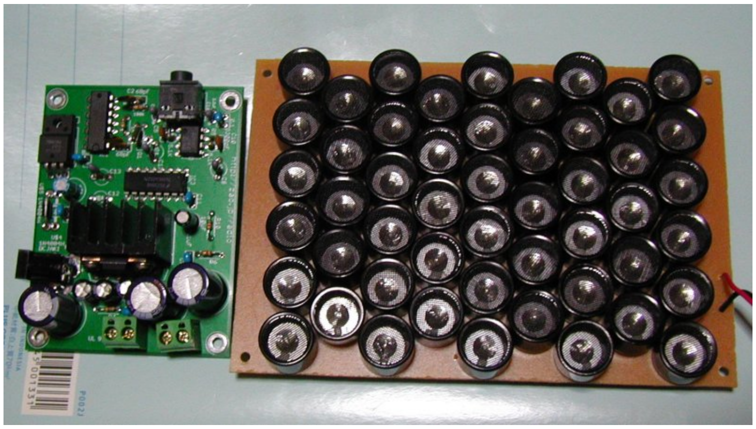

Figure 3: Parametric speaker kit

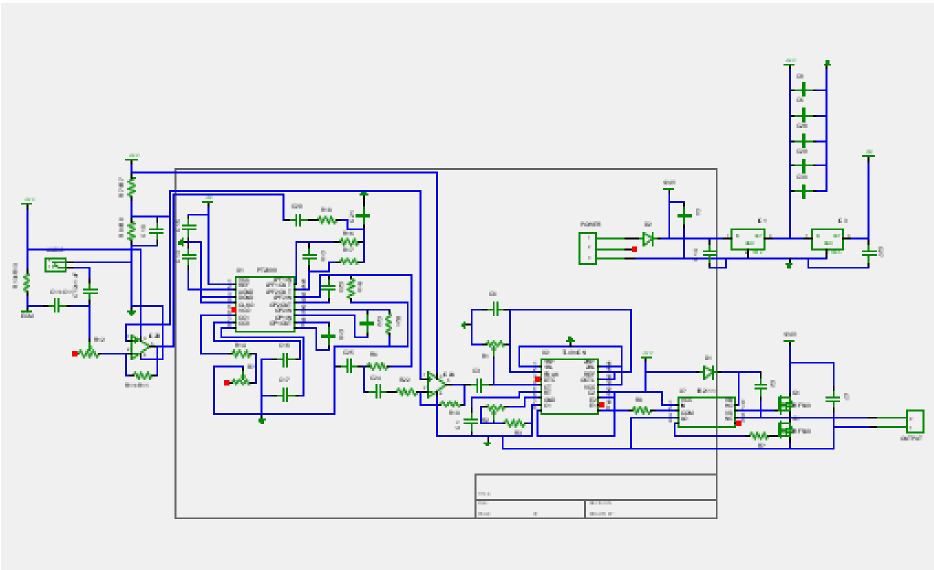

Figure 4: Parametric speaker DSP circuit diagram

The project is in the prototyping and testing stage. Previous generations of graduate students have built and performed preliminary testing with a sensor platform including IMU

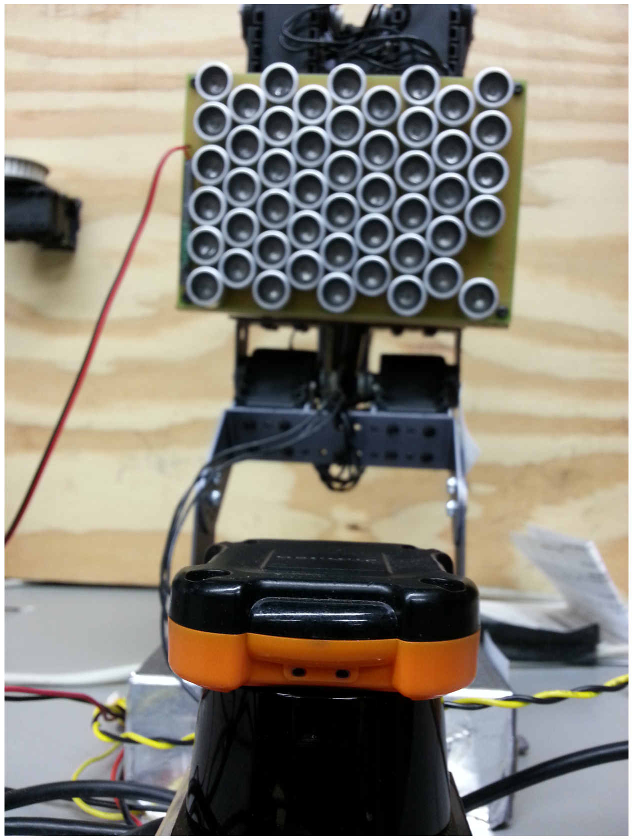

Figure 5: Testing setup with laser rangefinder and auto-targeting speaker

(inertial measurement unit) and GPS, to track the bus motion along its route. By correlating with Google Maps data and the planned bus routes, the system can correct for measurement noise and accurately sound the alarm only when the bus is entering a turn.

Figures 3 and 4 show the prototype parametric speaker kit and its circuit diagram. We are evaluating several different parametric speaker designs, including the Holosonics Audio Spotlight and the Soundlazer, among others. For now, we have the test-bench setup shown in Figure 5, with a Hokuyo UTM-30LX sensor and a parametric speaker kit mounted on a swivel base made of Dynamixel servomotors, which allows us to evaluate the system's human detection and directed sound projection capabilities. At this point the computation is driven by a normal laptop computer, but in the near future this will be replaced with an embedded single board computer.

3.2 Future Work

There is plenty of work remaining to make the system viable to be used in the intended public transit safety application. All parts of the system (bus tracking, pedestrian detection, and active warning) must be optimized for the environment in which they will be used.

The parametric speaker design relies on nonlinearities in the air medium to deliver the warning in the human audible range, and as such, there is a fair amount of distortion that must be corrected in software preprocessing. One way to do this is to decide on several pre-recorded messages (such as "Bus arriving! Please move to the sidewalk!") and use machine learning techniques to optimize the system parameters for the optimal reproduction of those specific messages. Since we do not need to synthesize arbitrary speech or play back high-bandwidth sound such as music, optimizing for specific phrases may be very effective. In addition, a relatively high level of ultrasonic power is necessary to make the warning audible outside, above the ambient noise of the Philadelphia urban landscape, so experiments will need to be done to ensure that pedestrians in the danger zone can clearly hear the speaker output. Also, we do not anticipate safety concerns due to ultrasonic exposure, but we will need to collect data on this point to ensure that the environment is safe for pedestrians.

The current system has sensors to track the bus movement along its route and detect when it is initiating a turn. We also have the parametric speaker to broadcast the audio warning. However, one key component is missing which sits in between the aforementioned components: human detection. When the bus is rounding a corner, we can clearly identify the danger zone as in Figure 1. But we need to know where the pedestrians are in order to effectively target the directional audio warning. This will be done by scanning the area using a laser rangefinder (for example, a Hokuyo UTM-30LX). Using the same IMU sensors that track the bus motion, we can correct for the egomotion of the bus and hopefully avoid projecting sound towards stationary, inanimate objects. Initial testing with a laser rangefinder has confirmed the possibility of human detection, as well as the possibility of calibration and customization of the laser's range; additional controlled testing will be required to ensure that the results of such detection are consistent by location and environment.

Once our prototype system is fully tested, safety-verified and working, we will need to integrate it into the public transit system. This requires that the system is fully self-contained, runs on a power source available from the bus, and is reliable enough to operate all day on the bus route, requiring a minimum of maintenance even when the buses are off-duty, since the SEPTA personnel working on the buses have other responsibilities and will not be trained in embedded system repair. So the last phase of the research project will be refining the embedded system design, and working with SEPTA to design the power budget and the final location of the sensing, computation, and output components on the bus itself.

4 CONCLUSION

In conclusion, we are in the process of implementing a full-stack embedded solution for delivering audio warning to pedestrians in danger of being hit by SEPTA buses. The objectives of our system are to be low-cost, reliable and easy to implement without major modification of the public transit infrastructure in Philadelphia. Research continues into improving the function of the parametric speaker, using a laser rangefinder to detect pedestrians from a moving vehicle, and systems integration with the goal of eventually installing the system for use on a bus.

4.1 Acknowledgements

Daniel D. Lee Dr. Lee is the T-SET UPenn co-director, director of the GRASP robotics laboratory and a Professor of Electrical and Systems Engineering at the University of Pennsylvania. His research focuses on understanding the general principles that biological systems use to process and organize information, and on applying that knowledge to build better artificial sensorimotor systems. He is currently a member of Team THOR, a Track A team in the DARPA Robotics Challenge, and previously was the team leader for the Ben Franklin Racing Team, the only Track B team to finish the 2007 DARPA Urban Challenge, and team leader of the UPenn team for the MAGIC 2010 challenge, which won second place. He is also the recipient of the NSF CAREER award for Biologically Inspired Learning Algorithms for Artificial Sensorimotor Systems, 2004-2010.

Camillo J. Taylor Dr. Taylor is an Associate Professor in the Computer and Information Science Department at the University of Pennsylvania. His research interests lie primarily in the fields of Computer Vision and Robotics and include: reconstruction of 3D models from images, vision-guided robot navigation and smart camera networks. He received an NSF CAREER award in 1998 and the Lindback Minority Junior Faculty Award in 2001.

Students We also acknowledge the following Penn students who developed the testbench sensing platform and gathered data in previous years: ESE students Yida Zhang, Rahul Bhan, Nikhil Karnik, Jordan Parker, Vaibhav Wardhen, and CIS student Thomas Boutin.

References

[1] J. L. Nasar and D. Troyer, "Pedestrian injuries due to mobile phone use in public places.," *Accident; analysis and prevention*, vol. 57, pp. 91–5, Aug. 2013.

[2] D. C. Schwebel, D. Stavrinos, K. W. Byington, T. Davis, E. E. O'Neal, and D. de Jong, "Distraction and pedestrian safety: how talking on the phone, texting, and listening to music impact crossing the street.," *Accident; analysis and prevention*, vol. 45, pp. 266–71, Mar. 2012.

[3] C. Karnash and O. Liebermann, "8 Charged With Faking Injuries After Minor SEPTA Accident In 2009," Oct. 2012.

[4] K. Farkas, "RTA to install an audible system on buses to warn pedestrians at crosswalks," Oct. 2009.

[5] B. Electronics, "Sensing Danger."

[6] S. Jang, D. Suh, and S. Chang, "Shadow Sound System Embodied with Directional Ultrasonic Speaker," pp. 3–5, 2013.

[7] F. J. Pompei, *Sound From Ultrasound: The Parametric Array as an Audible Sound Source*. PhD thesis, Massachusetts Institute of Technology, 2002.

[8] B. Kazunori, "Ultrasonic Directive Speaker," *Elektor magazine*, Mar. 2011.