A Connected Work Zone Hazard Detection System for Highway Construction Workers

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Introduction

Due to proximity to high-speed traffic, highway construction safety has always been a great concern. From 2003 to 2015, 1571 deaths related to highway construction work were reported according to the Center for Disease Control and Prevention (CDC 2016). Previous studies have indicated that the unsafe behaviors of construction workers in addition to their lack of situation awareness is a major cause of many accidents at highway work zones. This research aims to design a hazard detection and prevention tool to ensure safety of worker operations at roadway work zones. The developed algorithm enables receiving real-time localization data of workers, passing connected and automated vehicles (CAVs) and construction equipment, detect potential unsafe proximities and provide real-time instructions to prevent detected proximity collision. Real-time trajectory and safety measures are visualized on Virginia Connected Corridors (VCC) Monitor, a custom web-based situational awareness tool. Also, the collected localization data is used for workers' activity recognition which helps to predict work-related movements.

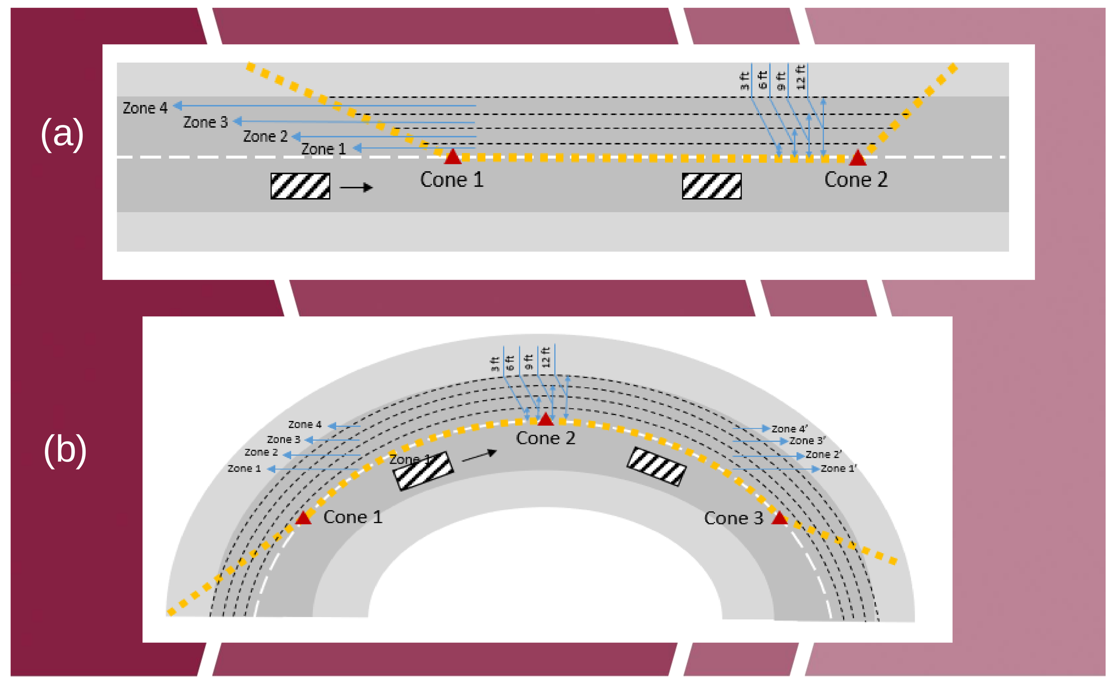

Figure 1. Work Zone Configuration and subzones separation for (a) Straight Section and (b)Curved Section

Methods

1. Proximity Hazards Identification

Safety zones with reasonable limits for workers, construction equipment and vehicles are designed. For workers-on-foot, 1 m and 1.5 m are adopted as diameters of the primary alert area and the warning area (Roofigari Esfahan, Wang et al. 2015) as shown in figure 2(a). Safety zones for equipment and CAV are based on design by Teizer and Cheng (Teizer and Cheng 2015), see figure 2(b). Key parameters for safety zone include velocity, width and length of equipment or vehicle, and friction coefficient of road surface. Since construction equipment can move in both forward and backward directions, and field-of-view can be limited under moving backward situation, the safety zone of equipment would be larger when it is reversing.

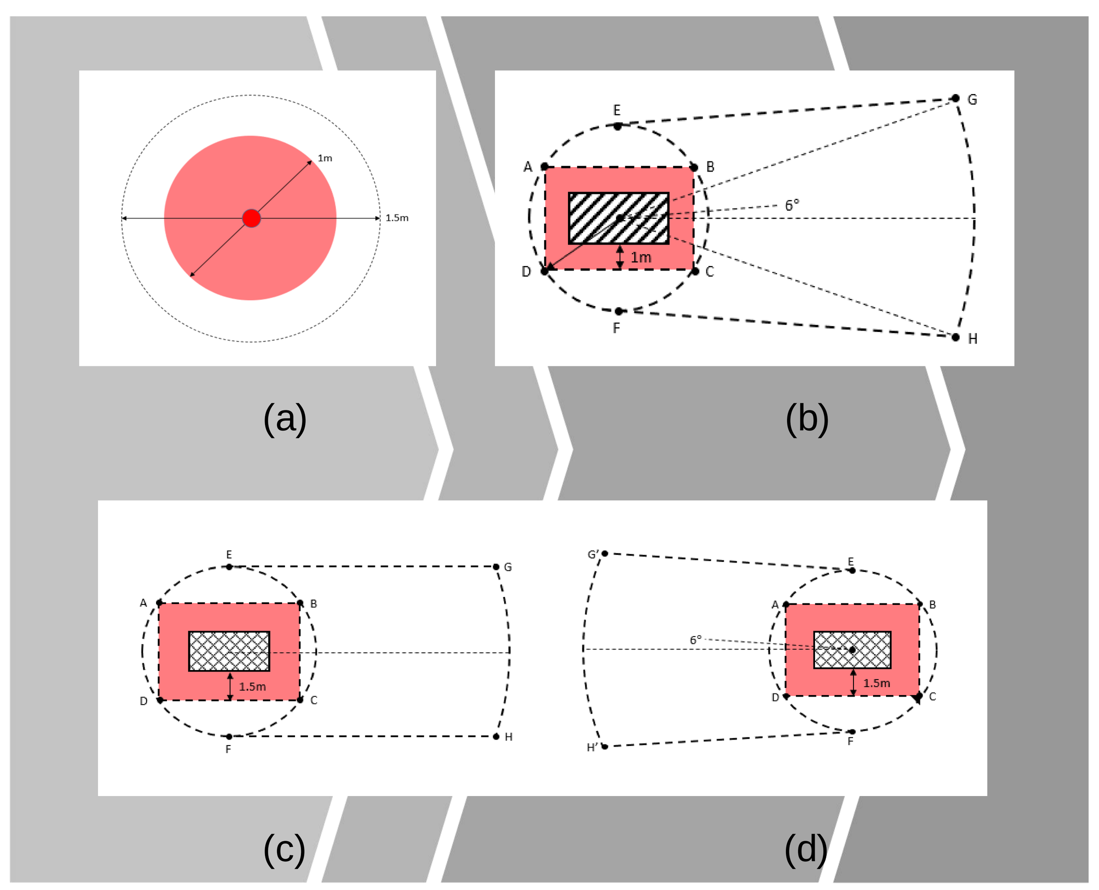

Figure 2. Safety zones for (a) Workers-on-foot , (b) CAV, (c) Construction Equipment in Moving Forward or (d)Backward direction.

For workers-on-foot in the work zone, considering that collision risk increases when they move closer to work zone border, 4 subzones of work zone are designed as shown in Figure 1. Safety zone area increase linearly from zone 4 to zone 1(the closest zone to border).

The hazard detection algorithm is developed to recognize the workers-on-foot's activities, detect hazardous proximities and provide a safe path to prevent the detected hazard. The recognition process depends on their speed, static situation and directions. The activities are categorized as jackhammering, walking, rolling, guiding and random movement. To facilitate data collection of workers and equipment, a database is generated. It contains information of various highway construction equipment and worker activities. The database it stored on VCC Monitor and the information is retrieved in real-time to be used for hazard detection in the algorithm. Ultra-wideband sensors are also used to collect location data of workers and equipment.

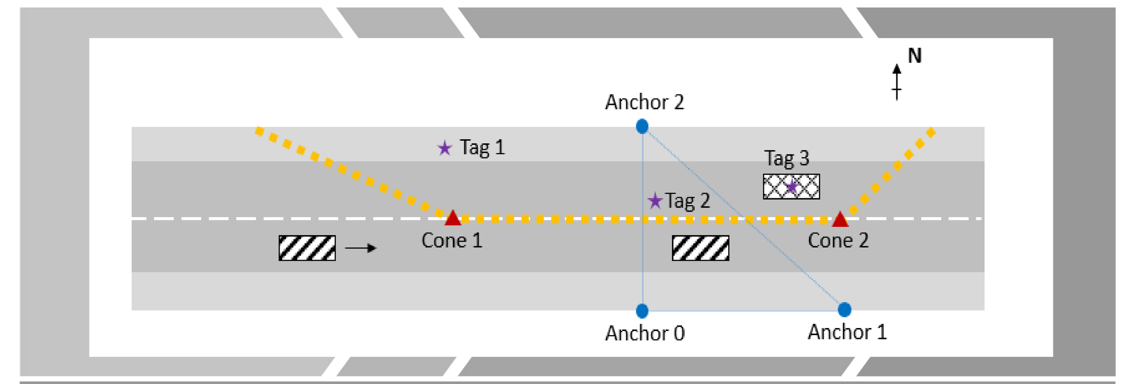

Figure 3. Experiment configuration

Experiment

A series of experiments were conducted at the Smart Roads at Virginia Tech Transportation Institute (VTTI) as shown in Figures 4 and 5(a). The experiments were conducted to collect initial data on both straight section and curved section. The work zone setting for the experiments is shown in Figure 3. Ultra-wideband sensors were embedded in hand-held equipment for tracking locations. Three sensors are programmed as anchors for data collection.

In total 7 tags were used in all experiments for workers-on-foot and/or equipment. The real-time location of each tag is shown on VCC monitor as shown in Figure 5(b). Equipment employed in these experiments include mower, mule, golf card and dump truck. All tags information was collected by anchors and sent to VCC server. Data generated by the on-board-equipment of Connected Vehicles was also collected and demonstrated on the website. The collected data was post-processed and used in the model to visualize trajectories and train activity recognition/hazard detection algorithms.

Result

A real-time work zone map is developed to present movement and proximity of various work zone actors on VCC monitor. Trajectory information as well as proximity representations of workers-on-foot, equipment and vehicle are overlaid on Google maps and displayed on VCC monitor as shown in Figures 6. Proximity Map shows warning area of each actor and displays warnings (presented in red when unsafe proximity is detected) when different actors' warning areas are intersected.

Figure 4. Work Zone Experiment on Smart Roads

Figure 5. Road Experiment with Equipment (a) and Tags Shown in VCC (b)

There are 49 data segments categorized in total: 3 are samples of jackhammering, 16 are walking, 10 are rolling (hand-held equipment which required regular moving), 14 are guiding (moving backward) and 6 are random movements. Supervised machine learning in MATLAB is used to train the model. The model with the highest accuracy was detected to be Ensemble Bagged Trees with 75.5% accuracy.

Future Work

A connected hazard detection system prototype for highway workers will be created in a follow-on study. Researchers will continue studying how to embed the developed system in a suitable wearable device for workers and alarm them properly. Compatibility with current personal protective equipment will be considered and the end goal of the future project will be a deployable product which can be put in real highway work zone environments by industry partners.

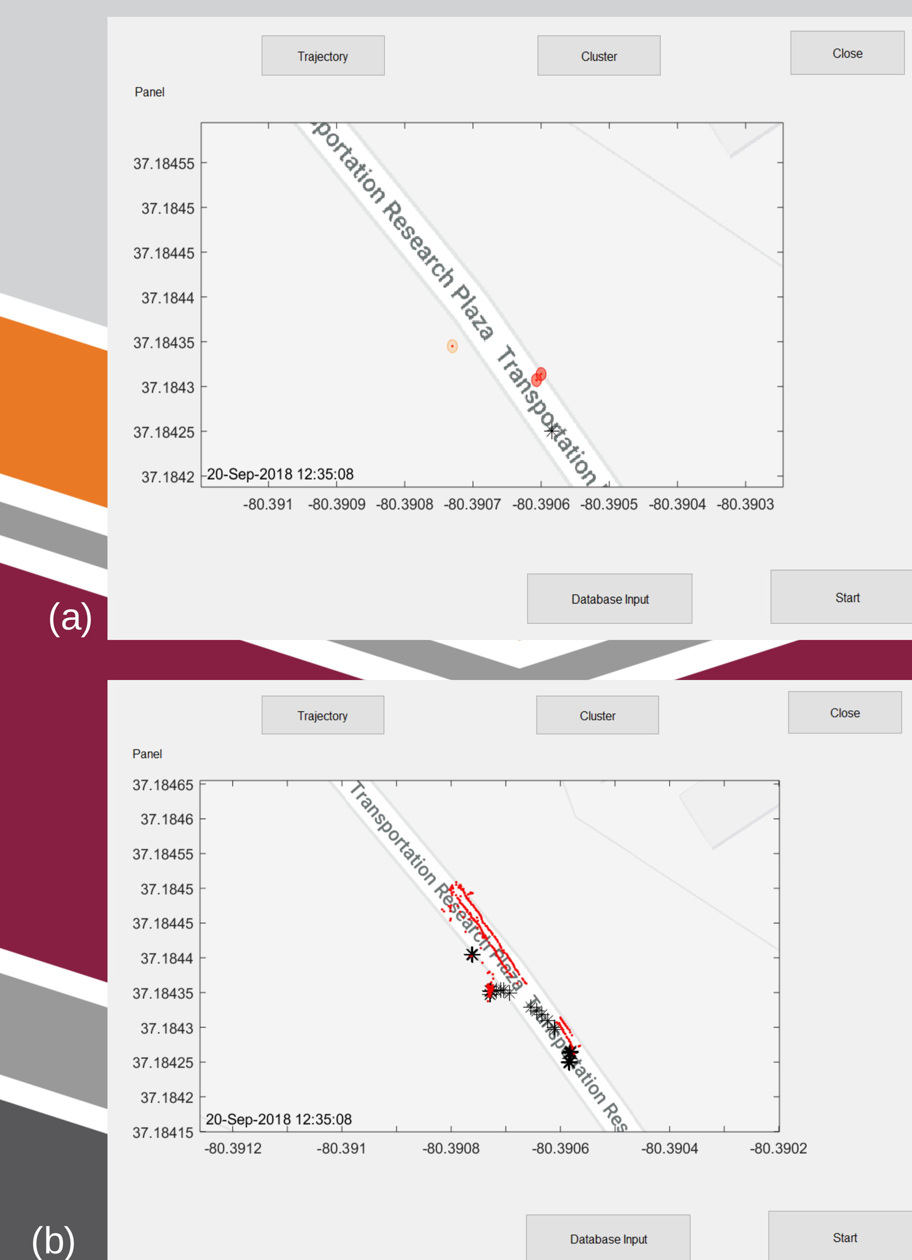

Figure 6. (a) Proximity Map Prototype and (b) Trajectory Map Prototype