Look at Me: Augmented Reality Pedestrian Warning System Using an In-vehicle Volumetric Head Up Display

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ABSTRACT
Current pedestrian collision warning systems use either auditory alarms or visual symbols to inform drivers. These traditional approaches cannot tell the driver where the detected pedestrians are located, which is critical for the driver to respond appropriately. To address this problem, we introduce a new driver interface taking advantage of a volumetric head-up display (HUD). In our experimental user study, sixteen participants drove a test vehicle in a parking lot while braking for crossing pedestrians using different interface designs on the HUD. Our results showed that spatial information provided by conformal graphics on the HUD resulted in not only better driver performance but also smoother braking behavior as compared to the baseline.

Author Keywords
Augmented reality (AR); pedestrian collision warning; head up display; depth perception; driver vehicle interface.

ACM Classification Keywords
H.1.2 User/Machine Systems: Human factors; H.5.1 Multimedia Information Systems: Artificial, augmented, and virtual realities; H.5.2 User Interfaces: Evaluation/methodology.

INTRODUCTION
Recent advances in sensor technology and pedestrian detection algorithms [2, 9] allow automakers to introduce pedestrian collision warning as an advanced driver assistant system (ADAS). Once pedestrians are detected in the vehicle's path, the warning is given to the driver typically through auditory alarms or simple visual symbols [17]. Since such warnings often lack spatial information, drivers need to further localize (i.e., recognize direction and distance of) approaching pedestrians for appropriate decision and reaction. This is a perfect opportunity to use AR in the vehicle; AR HUDs can overlay conformal graphics on top of the vehicle's path to notify the driver of the specific location of pedestrians.

Taking advantages of AR HUDs, we aim not only to guide drivers' attention for faster detection, but also to help them localize the threats earlier. Thus drivers can have more time to prepare for the appropriate reaction. In this paper, we introduce a novel interface design for pedestrian collision warning using a volumetric head up display and evaluate usability of the new interface.

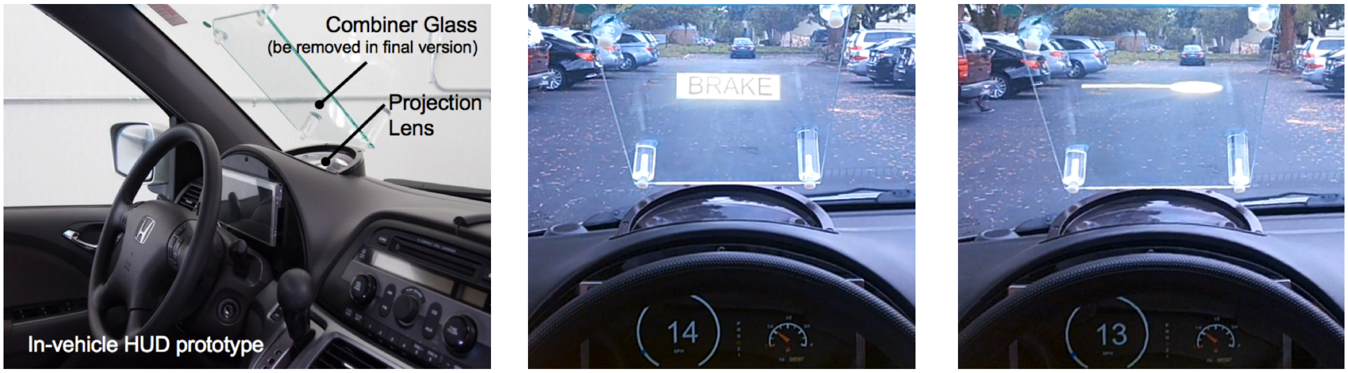
RELATED WORK
AR HUDs can support diverse use-cases by guiding drivers' attention to relevant environmental elements. Many researchers have shown the benefit of AR HUDs as promising driver vehicle interfaces that leverage currently available ADAS such as navigation aids, forward collision warning, blind spot warning, lane departure warning and left turn aid [1, 19, 12, 5, 22]. Regarding pedestrian collision warning, Pomarjanschi et al. showed that highlighting pedestrians with gaze-contingent cues helps reduce the number of collisions [18]. Lim et al. compared driver performance in pedestrian detection using two different types of video see-thru night vision displays [15]. However, most user studies have been conducted in driving simulators with either videotaped or virtual reality driving scenes, where ecologically valid color and depth perception are virtually impossible.

To support better localization, AR HUDs can further guide driver's attention in the third dimension of depth. Some user studies have quantified depth perception provided by different display technologies for AR HUDs: monoscopic, stereoscopic, multi-view and volumetric displays [11, 4, 21, 1]. Our previous work demonstrated that a volumetric display with dynamically adjustable focal plane outperformed a traditional monoscopic display [1]. However, the effects of depth perception on driving performance are yet to be fully understood.

Driver performance in pedestrian collision avoidance can be evaluated by detection performance (e.g., detection distance, reaction time), braking behavior (e.g., pedal

IUI'16, March 07-10, 2016, Sonoma, CA, USA
© 2016 ACM. ISBN 978-1-4503-4137-0/16/03...$15.00 DOI: http://dx.doi.org/10.1145/2856767.2856815

* This work was done when the first author was a research intern at Honda Research Institute USA.



(a) Test vehicle with a volumetric HUD **(b) Traditional warning** **(c) Virtual shadow**

Figure 1: Two interface designs implemented in the in-vehicle volumetric HUD prototype

response, maximum deceleration) and final outcome of vehicle measures (e.g., stopping distance, time to stop) [7, 14]. Braking behavior can be further modeled and characterized into normal or hard braking by analyzing deceleration profiles (changes in headway, speed and acceleration during braking maneuver) [6, 16].

EXPERIMENTAL USER STUDY

The main objective of this study is to answer two questions regarding pedestrian collision warning; (1) Can visual warnings on HUDs improve driver performance? (2) Can spatial information provided by AR HUDs change braking behavior? To answer those questions, we ran an experimental user study. Sixteen experienced drivers were asked to drive a test vehicle in a parking lot and brake for crossing pedestrians while using different interface designs for pedestrian collision warning. We designed a two factor repeated measures experiment, such that participants completed the driving tasks under each of six conditions: 3 interface designs (no warning, traditional warning - brake sign, and new warning - virtual shadow), and 2 levels of distance to the target pedestrians (near vs far). First we asked participants to drive without any warning signs for both distance conditions, which served as baseline. Then participants completed the rest of four experimental conditions. The order of interface design experienced was counterbalanced to minimize learning effects. We also randomized the location of road events and randomly added no event trials to minimize drivers' anticipation of pedestrian presence. During each driving trials, we time stamped location, velocity, and acceleration of the test vehicle for further analysis.

Apparatus

Volumetric Display and Depth Perception

We implemented design ideas on our in-vehicle volumetric HUD that can show computer graphics at variable depths from 8m to optical infinity with about 17° field of view (Figure 1.a). Volumetric displays form a visual representation of an object in a 3D space using multiple focal planes, as opposed to stereoscopic displays that simulate depth by presenting offset images to the left and right eye at a fixed focal plane [3]. Our volumetric display with time-multiplexed multi-focal planes can fast switch virtual images between far and near distance, creating a flicker-free appearance of the virtual objects rendered sequentially at different depths. This provides depth cues such as not only binocular disparity but also accurate accommodation, convergence and motion parallax without head or eye tracking. Since it projects computer graphics at the same focus distance of the target objects, drivers do not need to shift focus between virtual objects on the display and real objects in the scene. Therefore, it helps reduce perceptual (e.g., dual images and defocus blur) and safety issues caused by focal depth mismatch [8, 13, 20, 23, 24]. We believe 8m focus depth is reasonable for collision warning because we need to warn the driver in advance to avoid collision. For example, when we consider the generally accepted 2 second rule, the driver needs to be warned 13m ahead of the threat at 15mph. For any hazard occurring within 8m, a complementary auditory alarm could be more effective.

Pedestrian Localization

In this study, we used a wizard of Oz method to simulate pedestrian localization technology by experimental manipulation. We assumed our capability of detecting and localizing pedestrians (e.g., via V2P communication [10]). To simulate this, we pre-defined locations of pedestrians and a trigger point for pedestrians to emerge. When the test vehicle passed the pre-defined trigger point, a global positioning system (GPS) triggered the visual warning to appear. This was accomplished by an excellent quality real time kinematic GPS: OxTS RT4003 with less than 20 cm localization error. This event also transmitted to the (acted) actual pedestrian by a walkie-talkie. We sent the signal to the pedestrian about a half second in advance, considering the time delay of his reaction based on our pilot test and practice.

Interface Design

In the ***traditional warning***, a "BRAKE" sign is shown to notify drivers of presence of pedestrians in the vehicle's path (Figure 1.b). It was based on head up warnings currently available in some luxury cars. Regardless of distance to the target, the sign remains the same at the center of the display until the car stops.

In the new warning, a ***"virtual shadow"*** is shown to notify drivers of direction and distance of an approaching pedestrian (Figure 1.c). Inspired by actual shadows, the shadow is attached to the target pedestrian, appears larger as the car approaches and finally disappears when the car passes. The size of a virtual shadow is proportional to the typical size of pedestrians and the direction of tether tells from which direction the pedestrian is approaching.

Distance to the Target Pedestrians

We introduced two different levels of distances to the target pedestrians that might affect the driver's perceptual risk and yield different braking behaviors. The near targets appeared when the time to collision (TTC) was 2.5 sec. The 2.5 sec TTC was set to be short enough to induce last second hard braking and selected from referencing previous braking study literature [15]. We doubled the distance for the far targets to encourage timed-normal braking.

Driving Tasks

In our user study, we gave participants a realistic parking lot scenario where they are asked to drive with constant speed of 15 mph until they arrived at the pre-defined parking area designated for them. While driving they were asked to brake for any crossing pedestrians. The road events prompting drivers' reaction were always actual pedestrians. In visual warning conditions, drivers additionally saw computer graphics on the HUD.

Dependent Variables

To characterize driver braking behavior and performance, we analyzed deceleration profiles during each braking maneuver and defined dependent variables (Figure 2) such as car reaction time (T_{react}), braking time (T_{brake}), time to stop (T_{stop}), maximum deceleration (G_{max}) and stopping distance (D_{stop}). We defined car reaction time as the elapsed time between the onset of a stimulus (when the car passes pre-defined trigger line) and the beginning of the car's deceleration. Braking time was defined as time spent for decelerating. Reaction and braking time add up to equal time to stop. Braking behavior was characterized by the process measures including reaction time, braking time, and maximum deceleration. Faster reaction followed by longer braking time along with smaller maximum deceleration was considered smoother timed braking behavior. Driver performance in pedestrian collision avoidance was evaluated by the final outcome of vehicle measure, stopping distance or gap from the target when the car stopped.

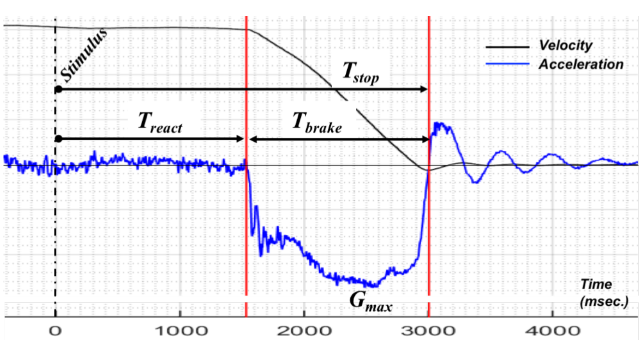


Figure 2. Dependent variables derived from deceleration profile

Results

We eliminated data from two participants who completely ignored the visual cues. Post-test interview revealed that they did not want to rely on technology, but rather believed in their own driving skill and experience. Therefore, we analyzed data from 14 participants using two-way repeated measure Analysis of Variance (ANOVA) to examine the effect of interface design and target distance. We found significant main and interaction effects on all five dependent variables, and performed post-hoc contrast tests for the planned comparisons. The results are summarized by mean and interaction plots (Figure 3).

Reaction, Braking Time and Time to Stop

Post-hoc tests (Figure 3. a and c) revealed that the virtual shadow reduced reaction time while increased braking time which resulted in the same level of time to stop compared to the baseline for both near and far targets. The traditional

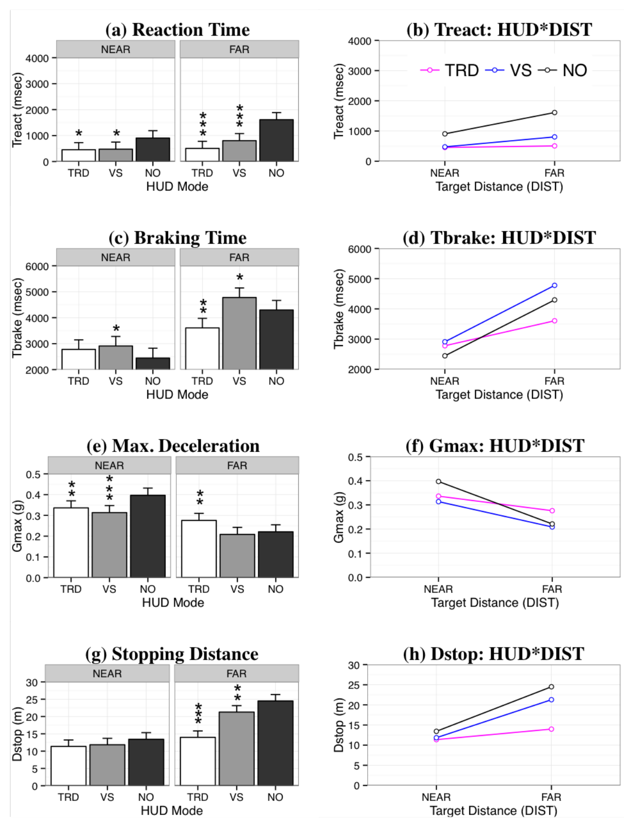


Figure 3. Driver Braking Behavior and Performance. Mean and interaction plots of data from 14 participants. Mean values are reported with 95% confidence intervals. Group differences are reported with *p-values* from the contrast tests compared to the baseline *('***' p < 0.001, '**' p < 0.01, '*' p < 0.05.)* TRD = Traditional warning, VS = Virtual Shadow, NO = No warning.

warning reduced both reaction time and braking time, which resulted in reduced time to stop. More interestingly, as shown in the interaction plot (Figure 3b), target distance did not affect reaction time when drivers used traditional warning.

Maximum Deceleration

Figure 3 (e) and (f) summarizes the post-hoc test results. For the near targets, both interface design reduced maximum deceleration. For the far targets, the traditional warning showed even higher maximum deceleration than the baseline.

Stopping Distance and Gap

For the far targets, both interface designs reduced stopping distance, which resulted in larger gaps leading up to the pedestrians. The interaction plot indicates drivers had similar stopping distances (i.e., traveled distances) regardless of target distance when their using the traditional warning.

DISCUSSION

In this study, we investigated the effect of visual warning presentation methods on drivers' performance and braking behavior in pedestrian collision avoidance. Before presenting any visual warning, we evaluated drivers' baseline performance when they did not have any warnings. In general, partial counterbalancing within the treatment conditions would limit internal validity of the study. However, we intended to run a pretest-posttest design where our main interest was behavioral changes while using warning systems compared to drivers' usual (intact) behavior. Therefore, we did post-hoc contrast tests for the planned comparisons focusing on mean differences in both performance and behavior compared to the baseline.

In terms of driver performance, both the traditional warning sign and the virtual shadow reduced stopping distances (or increased gaps from the pedestrian) for the far targets. This result suggests that visual warnings, whether they provide spatial information or not, improved driver's performance. For the near target we did not find any improvement.

In terms of braking behavior, both interface designs reduced reaction time implying that visual cues help with driver's faster detection. Interestingly traditional warnings caused even harder braking for the far target, which is not necessarily required to avoid collision. Actually drivers showed similar braking behavior regardless of target distance in response to the warning signs. This is probably because the sign lacks spatial information about approaching pedestrians. On the contrary, the virtual shadow resulted in smoother braking for both near and far targets. This result suggests that spatial information presented by conformal graphics resulted in smoother braking behavior. The trend is more obvious when we compare behavioral changes caused by target distance among three interface designs. For example, the interaction plots in Figure 3 (b) and (d) show the same differential effect of target distance between virtual shadow and no warning conditions where only stimuli for the driver were actual pedestrians. This implies that virtual shadows may provide the same level of depth cues as actual pedestrians.

CONCLUSION

In summary, this study suggests that pedestrian collision warning improves driver performance as compared to the baseline, regardless of cue presentation method. However, only conformal presentation of warning cues further results in smoother braking behavior by helping drivers' localization of pedestrians.

In this study, we introduced a novel interface design for pedestrian collision warning that casts virtual shadows of approaching objects that are immersed in the real world, taking advantage of our volumetric HUD. We also developed realistic driving scenarios and a test protocol for usability evaluation of pedestrian collision warning systems. This is one of the first usability evaluations of in-vehicle head up displays with 3D presentation capability. The proposed design and findings can be extended to other use-cases such as cross traffic alerts to avoid collision with vehicles backing up in parking lots, given that high performance object detection and localization technology is available.

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