CrashAlert: Enhancing Peripheral Alertness for Eyes-Busy Interaction while Walking

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ABSTRACT

Divided attention when people multi-task while walking (e.g. texting, web browsing) can lead to dangerous outcomes, such as colliding into obstacles or other people. To avoid such risks we introduce CrashAlert, a novel system that augments a mobile device with a depth camera to extend the user's peripheral awareness and to provide visual cues of the environment in a minimal footprint display on the device. CrashAlert aims at enhancing peripheral alertness with eyes-busy mobile interaction by giving distance and location information of obstacles in a users' path. We present the design and early feedback of CrashAlert. An initial study outside the lab environment showed that with CrashAlert users improve their handling of potential collisions without any loss in task performance. Participants reported an increased perception of safety and alertness. Our results suggest that low fidelity-visualizations (i.e. reduced ambient information) are easily understandable and glance-able, lowering the cost of accessing such information during mobile eyes-busy interaction.

ACM Classification: H5.2 [Information interfaces and presentation]: User Interfaces. - Graphical user interfaces.

Keywords: Eyes-busy interaction, obstacle avoidance, texting and walking, walking user interfaces.

INTRODUCTION

Mobile device users habitually multi-task (e.g. texting, browsing the web) while walking. Unfortunately, tasks that require a high degree of visual attention or *eyes-busy interaction* limit much of the user's peripheral vision. This practice has resulted in users tripping onto curbs, walking into traffic or deviating from their intended path [4,5,6,9]. In 2008, eyes-busy interaction while walking led to a twofold increase from the previous year, in emergency related accidents [6]. This has forced municipalities to consider safety policies that ban mobile device usage while walking [9]. Policy making aside, technological support for safer walking and multi-tasking is relatively unexplored.

In this paper, we introduce *CrashAlert*, a system that captures and displays information beyond the user's peripheral view, using a depth camera attached to a mobile device (Figure 1). CrashAlert has two components-it scans the environment for obstacles on the user's path, and alerts users about the position and distance of these obstacles in a minimal footprint display on the mobile screen. We implemented various visual mappings of the environment to keep CrashAlert's ambient display at a best minimum size.

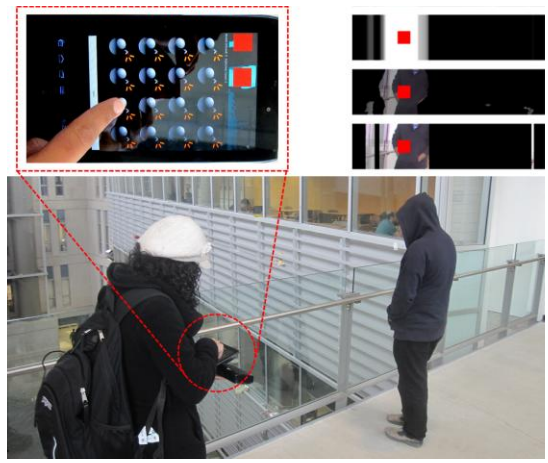

Figure 1 – CrashAlert senses environmental obstacles through a depth camera and informs the user of their positions in a minimalistic and configurable manner on the device's display. (bottom) User walking; (top-left) Peripheral objects displayed in an ambient and minimal manner; (top-right) Various visual transformations available in CrashAlert with an alert in red.

We studied the impact of CrashAlert in a collision-prone environment in the 'wild'. Eight participants walked through a cafeteria during busy hours. We provoked potential collisions unknown to the participants by having an 'actor' moving head-on or cutting-off the user. Participants were able to easily interpret our visual alerts, felt safer using CrashAlert even after a short period of use, and their performance was not affected by the visual augmentations. We also found that with CrashAlert users were more proactive in avoiding collisions.

The main contribution of this paper is a demonstration that augmenting a mobile device with additional sensors, such as a depth sensing camera along with a minimal-footprint visual display of the sensor's data can assist users in eyes-busy interaction while walking. This contribution comes in three parts: (1) a mobile system, CrashAlert, augmented with a depth sensing camera, (2) a set of visual transformations aimed at minimizing screen space and optimizing relevant information, and (3) a study of CrashAlert showing improved handling of potential collisions with no negative impact on task performance.

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RELATED WORK

We first report on the dangers of multi-tasking while in motion due to limited peripheral alertness and then briefly describe systems aimed at improving eyes-busy interaction while walking (such as walking and texting). CrashAlert's primary objective is in assisting users to avoid collisions while in motion and we therefore briefly report on assistive technologies designed for visually-impaired users.

Dangers of multi-tasking and walking

Field studies examining the effect of cell phone use on street crossing behavior have observed that pedestrians cross more slowly when conversing on a cell phone, are less likely to look at traffic before entering the roadway, and make more unsafe crossings compared to non-distracted pedestrians [4,7]. More recently, studies have shown that users can deviate significantly from their walking path when texting and walking [5] and hospital reports confirm an increased number of emergency incidences related to mult-tasking/texting while in motion [6]. Researchers have also controlled environmental factors (i.e. car speed, traffic density) in virtual reality settings and results confirm the negative effects of multi-tasking while walking [5]. The effects worsen with more demanding tasks: pedestrians are less likely to successfully cross a road and take more time to initiate a crossing when conversing on a cell phone than when listening to music.

These prior results have mainly guided the efforts of policy makers but also motivate the need for novel technological interventions. Furthermore, while VR studies can control many environmental conditions, we purposefully evaluated CrashAlert in the field to evaluate the potential risks and benefits of providing users with peripheral alertness.

Walking user interfaces

A new line of research in walking user interfaces [3] has emerged with the goal of studying and exploring methods to assist users with eyes-busy tasks while walking. Such interfaces have mainly concentrated on aiding users in being more efficient and accurate (therefore indirectly safer) with cognitively demanding tasks such as text-entry when mobile. Results suggest that audio feedback [1] can better guide touch-screen input while walking. To further aid users with text-entry in motion, researchers have introduced systems that automatically enlarge soft buttons when walking [3], systems for two-handed chorded keyboard input with a stylus [10], and novel adaptive methods that leverage a mobile device's tri-axis accelerometer to compensate for extraneous movement [2].

Relatively fewer technological interventions have been proposed to enhance *peripheral alertness* with eyes-busy tasks while walking. These are limited to directly displaying the video feed from the mobile's camera on the screen (i.e. WalkNGo) or with some limited processing to show on-coming vehicles. To the best of our knowledge CrashAlert is the first system to exploit transforming images from a depth camera to provide visually salient information onto a minimal footprint display.

Guidance systems for visually-impaired users

A number of commercially available (i.e. Sendero GPS, Trekker Breeze) and research-based systems [8] provide instructions to visually-impaired to assist with navigating and way-finding in common places. These systems rely on audio cues and recent results suggest that vibro-tactile cues can also be mapped in a spatial manner to guide users in navigating through environments [11]. While audio and haptic cues do not consume real-estate space on mobile screens, they are mostly presented serially by discretizing information about the environment. Prototypes closer in practice to ours process the mobile device's video feed from the environment and alert users about salient features, such as pedestrian crossings [12]. These systems rely on a fair amount of processing that may not be practical for real-time ambient feedback about out-of-periphery objects.

INFORMATIVE FIELD OBSERVATIONS

To better understand how users engage with mobile devices while on-the-go we observed people walk while interacting with their mobiles in a university cafeteria and at a shopping center. We recorded the holding angle of the device, the number of hands used, the number of steps taken before lifting their heads (to detect on-comers and obstacles), the type of obstacles they most commonly avoided, patterns in walking speed and how many steps they took while typing. Our data collection was limited to an indoor setting and it is probable that different outcomes would be obtained by collecting data from outdoor settings as well. However it constitutes a good basis for understanding some of the behavioral phenomenon taking place during eyes-busy interaction and walking. These observations led to the following considerations relevant for the design of a technical system aimed at helping users avoid collisions:

C1 – Collisions: people typically slowed down when reaching a crowded area or around obstacles on their route. In most cases the person multitasking while walking would be the cause of a collision and not the other passersby. Therefore, the system should help users avoid collisions located on their path, possibly highlighting the unexpected like people stopping or crossing in front of them.

C2 – Fallback to vision: Our observations showed that navigating and dodging obstacles and other people without lifting the head is a common practice. However, people fallback to vision in complex situations. Therefore, the system should identify such possible situations and notify users so they lift their heads and sort out the situation.

C3 – Tilt angles: Mobile device users hold their device at different angles, which is important when considering the capture mechanism for determining what lies in front of the user. The system should support a configurable or dynamic mechanism in order to meet different users' preferences.

DESIGN FRAMEWORK

The design of a peripheral alert system for eyes-busy interaction while walking is influenced by numerous factors including data capture methods, information presentation methods, and notification mechanisms. Environmental factors such as the lighting in the environment, the density (size of crowds), and the specific use context can also affect the design of such systems. However, for this first investigation we focus on the first three design factors.

Data capture methods

Data outside a user's periphery can be captured in a multitude of ways, but primarily through embedded sensors or video from the device. Such sensors can ideally capture information about on-comers and moving objects (cars, trucks, etc.), static objects (tables and chairs) or environment features (such as curbs, potholes, stairs). However there is also a limit to how much a user can process while simultaneously performing an eyes-busy task. Based on our observations users are primarily concerned about potential collisions directly in front of them. When faced with known environment features, such as stairways or walls, users generally stop walking.

Information presentation

The captured environment data needs to be presented in an ambient and non-intrusive manner to the user. Most ambient displays, however, are designed for public or larger displays than those used on mobile devices. This raises challenges in determining how best to present the salient peripheral information using a minimal screen footprint. Alternatives such as audio and haptic displays are also possible. However, audio is limited in noisy environments (unless the user is wearing ear phones) and in rendering spatial information [1]. Vibro-tactile displays also do not consume display space and can be rendered with some spatial information [11]. However, vibrotactile information is limited in providing context and detail information. Whereas ambient visual presentation consumes display space it also provides maximum flexibility in choosing appropriate renderings of the peripheral environment.

Notification mechanisms

When collisions are imminent, users should be notified of the severity through an alert. Various types of alerts are possible, including audio, haptic and visual. Since our primary modality for conveying peripheral information is through visual means we also provide visual alerts in our system.

CRASHALERT

Figure 2 presents CrashAlert, a system designed to provide users with ambient visualizations and visual alerts to help them avoid obstacles while multitasking on their mobile devices. CrashAlert uses both a depth and a normal camera attached to the device to capture a region in front of the user but outside their field-of-view. This slice of the image is processed and presented to the user on the mobile device.

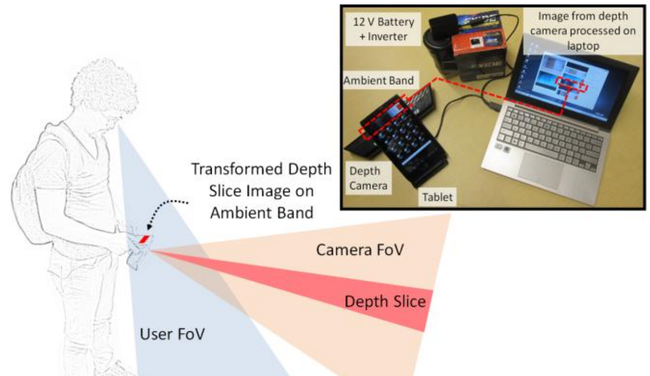

Figure 2 – (left) A depth sensing camera can assist in extending the user's limited peripheral view. Minimal processing on the slice of the depth image, or *Depth Slice*, can reveal salient information about the environment. Our implementation allows for an adjustable height and position for the Depth Slice. (inset) Hardware components in CrashAlert.

CrashAlert has three main components: an ambient visual band, visual alerts for near-by objects, and a depth slice. The ambient visualization seeks to convey a glance-able representation of the elements in front of the user (C1), so that they gain an awareness of elements outside their field-of-view. The visual alerts are generated from the depth image for objects that are as close as 2 meter away from the user. Their appearance (a bright red square in the position of collision, Fig 3) is easily noticeable by the user, causing them to raise their head to better cope with obstacles (C2). Finally, CrashAlert allows the user to define the region of the source images (depth slice) that better aligns with the front of the walking path according to the user's particular tilt when holding the mobile device (C3). In our implementation the position and size of the depth slice are configurable by the user in a settings screen.

For this early investigation of this design framework, we *captured data* by means of depth and video cameras affixed to the mobile device, to provide peripheral information from directly ahead of users. CrashAlert approaches *information presentation* through visual ambient cues. And finally *notifications* are in the shape of positioned visual alerts and could be augmented with vibro-tactile and audio feedback (which we leave for future work).

Depth Slice

Several alternatives exist for displaying information on CrashAlert's ambient band (discussed next). For example, the entire video image can be squashed onto a small portion of the display. This would make it difficult to identify objects of interest through lack of surrounding context. Alternatively, objects can be placed in a birds-eye radar view. This would lack the advantage of showing the type of obstacles, i.e. person, lamp post, etc. To provide context and details we instead selected a horizontal slice of the image, processed it, and scaled it to the size of the ambient band. With this the user gets a sense of the objects in their surroundings. By default we fixed the position of the depth slice to pick up information from the lower part of the scene as it could provide sufficient details to avoid many type of obstacles, i.e. walking users, curbs, columns, etc.

Ambient Band

The ambient band on CrashAlert displays a processed depth image and gives details in a minimalistic manner. Figure 3 presents four different ambient visualizations provided in our current implementation: (a) depth image (DI), (b) depth average columns (DAC), (c) depth mask (DM), and (d) columns mask (CM). The *depth* image is a histogram-based depth image that reduces the depth information (each pixel is a value between 0 and 10000) to a single byte (a value between 0 and 255), and paints then in a gradient from black to green (see figure 3a). The *depth average columns* image is obtained by applying a binary threshold to the depth image, and calculating the average value for each column of pixels; this average is then assigned to all the pixels in the column (see figure 3b). The *depth mask* uses the depth image as a mask on the image captured by the normal camera; this way it shows the full color version of the closest objects on a black background (see figure 3c). Finally, the *columns mask* image takes the 3b image and increases the value of each non-zero column to 1, this new image is used as a mask on the color image; this way it shows the closest objects plus their surroundings in the vertical dimension (see figure 3d).

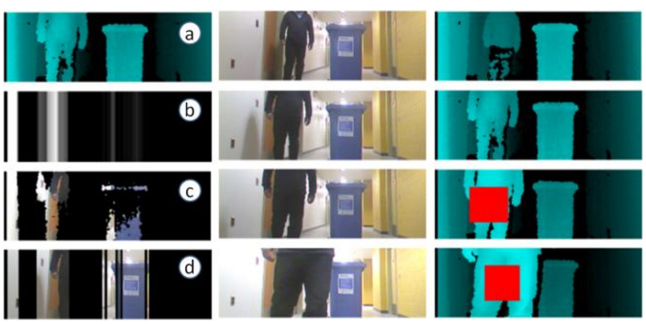

Figure 3 – (best seen in color) (left) Ambient band visualization based on given scene. (a) Depth Image (DI) shows reduced depth information; (b) Depth Average Columns (DAC) shows depth info as columns; (c) Depth Mask uses DI as a mask to a color picture of the same view; (d) Columns mask uses the DAC as a mask to a color picture of the same view. (middle) On-comer approaching. (right) Red alert appears as on-comer gets as close as 2m to the user.

Implementation Details

Hardware. CrashAlert is a prototype built with an Acer A100 7'' tablet computer[1], a laptop computer, and a Microsoft Kinect. The laptop is carried in a backpack together with a 12 volt battery to power up the Kinect in a mobile setting. The laptop receives images from the Kinect via USB, processes and transforms them, and sends them to the tablet via Bluetooth. The tablet receives images at a rate of approximately 10-11 frames per second.

Software. The laptop runs a .NET C# application which interfaces with the Kinect through the OpenNI.net[2] stack, processes the images with OpenCV[3] through the Emgu.CV[4] wrapper, and communicates them over Bluetooth with the 32feet.Net network library[5]. The tablet application is an Android 2.3.3 application with normal Bluetooth permissions.

EVALUATION AND USER FEEDBACK

Our experiment was designed to observe how users multitask in a naturalistic environment when using CrashAlert. We recruited university students who habitually text and walk. Eight volunteers (6 male, 2 female, mean age of 25.5 years) from various disciplines. We collected generic data about their own experiences walking and texting. All said they do this often, although they generally agreed that such practice is dangerous, with an average of over a dozen collisions reported in the last year.

We designed a within-subjects experiment in which participants were exposed to four conditions: (1) None or No feedback (None), (2) Camera alone (CA), (3) Depth Image (DI) and (4) Depth Image with Mask (DIM). Depth Image consisted of using the depth image or the depth columns as from Fig 3.a or 3.b. The Depth Mask was one of 3.c or 3.d. The camera was fixed at a 0º angle and participants were asked to keep the tablet horizontal. The depth slice covered the middle-low 2/5 of the depth and normal images.

Task and Procedure

We asked participants to focus on the goals of a whack-the-mole game, while walking through the university cafeteria. Each trip consisted of starting the walk at the near-by bookstore and looping around the entire food court. Participants were asked to walk as normally as possible while playing the game. Their objective was to tap on as many moles as possible during their trajectory. Each trial consisted of one loop around this path. Participants were asked to naturally avoid collisions with people and obstacles. We ensured that participants would face at least four collisions during each trial. This was achieved by asking an 'actor', unknown to the participant to provoke potential collisions. The 'actor' would cut the participants' path orthogonally, would stop right in front of them, would come toward them at a fast pace, or would walk with them but then immediately swerve in their lane. The experimenter recorded participants' behavior during any potential collision on paper.

[1] http://acer.us/ac/en/US/content/iconia-tab-a100

[2] http://www.openni.org/

[3] http://opencv.willowgarage.com/wiki/

[4] http://www.emgu.com

[5] http://inthehand.com/content/32feet.aspx

We captured the user's total walking time, the number of moles they 'hit', as well as the number of times they performed a 'dodge/slow down', a 'heads-up', a 'full stop', and a 'bump'. Each experiment lasted roughly half an hour. Each condition was done twice, resulting in 8 participants x 4 conditions x 2 trials = 64 trials in total. We also interviewed the participants between trials and at the end of the experiment, and collected data (5-step likert scale) about their perceived safety, efficiency, alertness, walking speed, understandability and glance-ability of each of the conditions. If a mole was not hit within 2.5 secs we recorded an error and the mole was shown as being destroyed.

Participants wore the backpack containing the battery pack to which the Kinect was connected. They were first explained the task and were briefly explained the visualizations. We did not inform them of the planned collisions and asked them to behave naturally while trying to hit moles in the game as efficiently as possible. Participants walked through the cafeteria as per the assigned path. They completed 2 trips around the path or trials per condition.

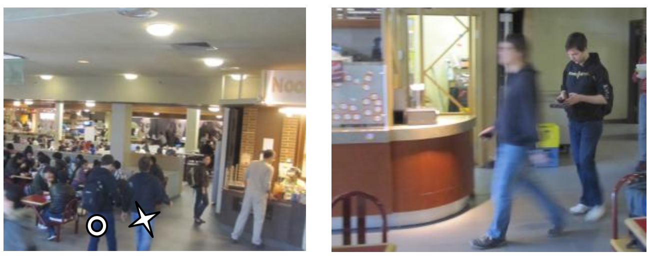

Figure 4 – (left) Experiment setting in university cafeteria. The participant is marked with circle and the 'actor' marked with a cross. (right) 'Actor' quickly swerves into the participant's path to provoke a collision; the latter is still engaged in the task with the aid of CrashAlert.

Quantitative Results and Discussion

Each trial lasted 130.5 seconds on average (stdev = 20.8) with an average number of 246.25 moles whacked per trial (stdev = 42.4), and an average error rate of 0.64% (moles missed, stdev = 1.37%). Moreover, participants whacked moles at an average rate of 1.91 moles/second (stdev = 0.04); and therefore the wide spread in the number of moles per trial is explained by the wide spread in completion time. There were no significant differences between techniques on number of moles hit or error rate.

For the total 64 trials we registered 721 instances of possible collisions with an average of 180.25 instances per condition (stdev = 8.84). Figure 5.left-top shows the percentage distribution of collision handling maneuvers (dodge/slow-down, heads up, stop before crash, near crashes) for each condition. The graph shows that using any visual feedback helped users maneuver through the possible collisions in a smoother way because they could slow down or perform a dodge based on the peripheral information. This better handling came at no cost in playing the game as shown in figure on error rates, Figure 5.left-bottom.

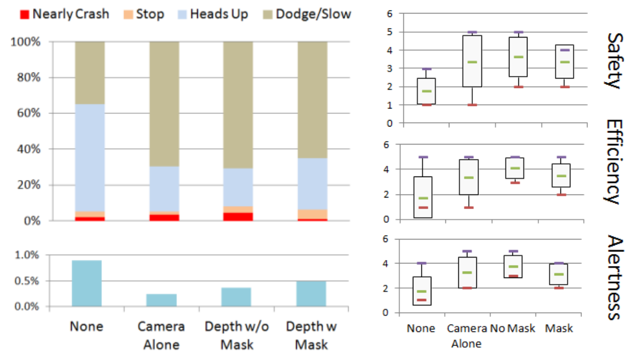

Figure 5 – (left-top) User navigation patterns broken down into % of total near crashes, full stops, heads-up and dodges. (left-bottom) No significant difference in error rates among techniques. (right) User rankings for their perception of Safety, Efficiency, and Alertness with each system.

Qualitative Results and Discussion

The post-experiment survey results (see figure 5.right) showed that, when using CrashAlert, there was a trend for participants feeling a higher degree of safety and alertness. Even though there was no real performance gain, participants perceived their task performance as being more efficient. Moreover, participants perceived the depth image visualizations as more understandable and glance-able compared to the depth mask condition.

We interviewed each participant after each condition and had a longer debriefing after the whole experiment. We coded their answer into 19 tags and 4 topics as shown in table 1. In this section we present the results around three of the topics resulting from our coding: abstraction, navigation and alert. The fourth topic concerns technical improvements which we describe in our discussion.

In terms of the *abstraction* level of the visualizations, participants said that even though the full raw video and the depth mask images provide higher levels of detail they were nonetheless harder to read, requiring more attention and generating more stress when executing the task (even though we did not find any significant impact in performance); for example P8 said "*I have to check the [color] image much more and longer*". In contrast, the images in the depth condition were found easier to read "at a glance". Depth images communicate information that would have taken longer to read in the color or mask conditions; for example P7 indicated that "*[with the depth image] I can see the [thin] veranda which I couldn't in the normal video*". Moreover, participants reported depth images as falling into the background to the point that some users were not sure whether they were using them.

Participants talked about the different ways that CrashAlert enhances their current *navigational* senses (sound, peripheral view and knowledge of the environment) beyond simply noticing and alerting about obstacles and potential collisions: (1) allows participants to walk toward the dark regions shown on the ambient band and (2) react to the alert.

Some participants found it useful to simply relax and follow the darker areas of the depth images, as they trusted that these areas would not have obstacles. In a different situation, when walking through a narrow and crowded corridor, a participant knew the person in front of her (shown with an alert due to proximity) was walking in the same direction and so she decided to follow the position of the alert to way-find through the crowd.

Finally, participants also noted that a system based only on alerts (no color, depth, or mask image) would already be an advantage compared to having nothing. Moreover, participants indicated the need for different *alert types*. One such type is alerts based on direction and speed; for example, participant 1 said "*I couldn't tell whether people where coming toward me or moving further away*". Another type of alert would be based on the type of object (static or moving object) and their related hazard estimation; for example P3 noted "*[I would like to see] a significance level indication of obstacles like how much danger if collision occurs*", and P5 said "*perhaps I could be alerted about different objects in different ways… moving people and static chairs require me to take action differently considering time and predictability*".

Topic	*Tags*
Alerts	Alert by direction (1), alert by type of object (5), no haptic (1), alert alone (4), alert by speed (1), sound (1).
Abstraction	Gradient easier to read (2), not sure of use (2), color/masks attention demanding (6), color/masks gives more details (1), depth image easier to read (2), depth image falls into the background (1).
Navigation	Navigating by using dark bands (3), navigating by following an alert (1), environmental knowledge (4), sound + peripheral view (2).
Improve…	More range (2), trust (3), frame-rate (3).

Table 1 – Themes emerging from our study based on 19 tags with number of instances in parentheses.

DISCUSSION

Our observations and user feedback support the use of CrashAlert for avoiding daily encountered obstacles in mobile eyes-busy interaction. Users were able to dodge passers-by or ensure reliable avoidance. We provide some general discussions about such forms of technology support, the limitations of our current system, and provide some recommendations to designers.

Technology to support eyes-busy interaction

Our initial goal was to allow users to feel and act safely with eyes-busy interaction while walking. Systems such as CrashAlert can provide such levels of support. Additional work is required to understand what features instill trust in the technology. Further exploration is also required to determine how safe such innovations can be for other non-users in the environment. Some possibilities include encouraging more heads-up with improved alerts (see next).

Further improvements

CrashAlert demonstrates the benefits of providing ambient peripheral awareness on mobile devices. We intend on further improving on limitations of our system

Improvements to the ambient display. CrashAlert was implemented and evaluated using a tablet device. Further exploration is needed to determine the ideal minimum size of the ambient display to show out-of-periphery information. One consideration is to provide a strip of LEDs on top of the display that can convey critical alerts through blinks. We also need to consider other ambient modalities, including the option to alert using vibrotactile, audio and combined vibrotactile+visual cues. Ideally these will also provide non-intrusive alertness in a minimalistic manner.

Dynamic selection of the depth slice. Our current implementation allowed users to configure the position and size of the depth slice. We envision a horizontal depth slice that is constantly scanning the environment and notifies users of the positions and locations of close objects.

Field-of-view. Participants requested slightly larger range from the depth camera. This is possible with wide angle lenses on the depth camera that can also capture information from the sides. Alternatives include having tiltable cameras pointing in different direction based on the tilt of the phone and walking direction. Additional sensors (i.e. sonar) could also be embedded, however with care as more information may not be easily interpreted.

Scene and situation analysis. CrashAlert could be enhanced with scene analysis to discriminate features such as potholes, stairs, railings, and alert users accordingly. Participants also commented on the need to inform them if people were moving toward or away from them, and their speed.

CONCLUSION

Eyes-busy interaction while walking can be dangerous. Very few technological interventions have been proposed for assisting users with this form of multi-tasking. We present CrashAlert, a mobile device augmented with a depth sensing camera that shows users out-of-periphery objects in their path while walking. CrashAlert processes the depth image in different ways, to show salient information of potential collisions, such as distance and position. The information is displayed on a minimal footprint ambient band on top of the device's display. In a study outside a lab environment felt safer multi-tasking and walking with our system and even used it to help navigate around the environment. There was also no negative impact on performance with the ambient band, showing that even minimal environment information outside the user's periphery can assist with eyes-busy tasks in motion. We describe a number of features that can improve the effectiveness of CrashAlert and direction for further investigations.

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