Designing Exocentric Pedestrian Navigation for AR Head Mounted Displays

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Abstract
Augmented reality (AR) is gradually becoming used for navigation in urban environments, allowing users to see instructions in their physical environment. However, viewing this information through a smartphone's screen is not ideal, as it can cause users to become inattentive to their surroundings. AR head-mounted displays (HMD) have the potential to overcome this issue by integrating navigational information into the user's field of view (FOV). While work has explored the design of turn-by-turn egocentric AR navigation interfaces, little work has explored the design of exocentric interfaces, which provide the user with an overview of their desired route. In response to this, we examined the impact of three different exocentric AR map displays on pedestrian navigation performance and user experience. Our work highlights pedestrian safety concerns and provides design implications for future AR HMD pedestrian navigation interfaces.

Author Keywords
Wayfinding; Pedestrian navigation; Exocentric navigation; Maps; Head mounted display; Augmented reality; Virtual reality

CCS Concepts
•Human-centered computing → Human computer interaction (HCI);

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Introduction

With an ideal technical configuration for running AR [7], a community of more than five billion users [29] and a growing number of open-source frameworks, AR-enabled smartphones are more than just an interim technology. They have been widely used as an apparatus for AR pedestrian navigation applications [6]. However, due to traffic density in urban areas, pedestrians need to be attentive to their surroundings. Engagement with handheld devices may expose them to higher risks of road accidents [15]. Therefore, the *handheld-AR* view is intended to be used only while stationary, as suggested in the instructions for the Google Maps Live View AR feature [3]. Furthermore, walking around while viewing an augmented real-world through a smartphone's camera feed may cause social embarrassment and could make other people feel uncomfortable [6, 8].

In contrast, AR HMDs integrate synthetic imagery into the user's FOV, and as a result allow them to retain awareness of the environment [5]. However, there are still many technical hurdles to be overcome before AR HMDs can progress from novelty to ubiquity, such as registration accuracy, human-like FOV, smaller form factor, and a semantic understanding of the real world [5, 18]. For those reasons, the design of navigation interfaces for AR HMDs is relatively under-explored compared to that of handheld AR.

From a review of literature, we found that research efforts in AR HMD pedestrian navigation have utilised the AR view to provide users with egocentric turn-by-turn guidance [23, 4]. The directional cues embedded in the real world reduces the abstraction of the conventional map and helps users quickly locate themselves in unfamiliar settings [26]. However, to be effective a navigation system also needs to provide users with an exocentric spatial layout of the environment, such as a map. Because egocentric and exocentric spatial information helps to address different navigation tasks, and both are useful at different times [30]. Much of previous work [21, 11, 1] that focused on exocentric navigation interfaces have projected an interface at a distance from the user's eyes in an attempt to maximise the overlay FOV and ensure readability [24]. However, this might lead to divided attention from the real world and inattentional blindness.

In addressing problems related to pedestrian's awareness of their surroundings, we could consider a map overlaid on the street to offer the users both local guidance and a bird's-eye view of the environment, as seen in one of the prototypes of Google Live View [12]. Alternatively, a map could take the form of a hand-based interface [17], which is similar to the activity of reading a physical paper map and therefore facilitates a familiar experience. Besides, the hand movement could induce users to safely reference the map on demand, since we hypothesise that the pedestrians would not walk with a seemingly unnatural pose of holding an empty hand in front.

To understand the implications of such interfaces on pedestrian navigation and user experience, we trialled three different AR map displays with 18 participants. As AR is still a developing technology, we overcame the technical limitations of current AR HMDs by conducting the study in a VR environment. This method of VR testing is becoming common practice for navigation [28, 27] and AR [16] studies, as it allows researchers and designers to overcome technical limitations and rapidly test their designs in a controlled environment. Performance data and user feedback collected from participants during the study were interpreted along with observations to provide implications for the design of future AR HMD navigation interfaces.

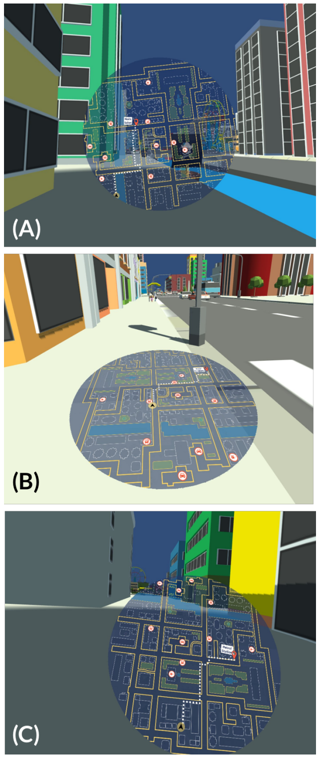

Figure 1: AR navigation displays: (A) Map Up Front; (B) Map On Street; and (C) Map On Hand

VR Prototype

The VR prototype was created using the Unity Game Engine. To simulate the urban environment, we constructed a city out of low-poly 3D models downloaded from the Unity Asset Store [2]. The virtual environment had all the necessary infrastructure of roads, buildings, and greenery. It also featured pedestrian and car traffic through the Unity Navigation System. Idle and animated urban dwellers were placed around the city along with ambient city sounds (such as people talking and car horns). Altogether, their presence was to imitate critical aspects of a living city.

Interface Design

For reading ergonomics, the map's design was a simplified version of the city's orthographic view. Visual emphasis was given to the road network and location markers (e.g. bus stops, car parks, and helicopter pads). A dotted line represented the travel route for each scenario. The map resembled a futuristic translucent interface that allowed the users to see through it. The fidelity of the map decreased at runtime because of the trade-off between render quality and performance; therefore, we slightly increased its size.

In terms of map position, the *Map Up Front* was displayed vertically in front of the user (Figure 1A). The *Map On Street* formed a 12° angle with the street (Figure 1B). Both of them were placed inside the user's immersive line of sight but at a comfortable distance to prevent eye strain. The *Map On Hand* was anchored to the right-hand controller, which means it was only visible when users moved their right hand into their FOV (Figure 1C).

The current location of the user ("*You Are Here*") was represented as a black arrow, and the facing direction was indicated by the pointer of the arrow. In this study, one of the map settings was automatic first-person alignment, in which the map would automatically rotate to align to the user's forward direction. As pointed out by Levine [22], this alignment would facilitate perspective transformation and therefore reduce user's cognitive workload in matching map information with the real world.

Several studies suggest that the map should be shown upon request to reduce distraction and improve navigation performance [11, 21]. Therefore, in addition to the map view, we developed a minimal arrow view to provide users with travel directions.

Interaction Design

In our study, we used an Oculus Quest[1] for its compact form factor and high performance. Participants could switch between the map view and the arrow view by pressing a button on the right-hand controller. Virtual navigation was a combination of the first-person perspective and the use of joysticks to walk and turn. Despite its ease of use, this locomotion scheme can cause sensory conflicts which may lead to simulator sickness [14]. The first participant joining our pilot study could not finish one interface trial. To minimise the user's discomfort, we reduced vection by slowing down the user's speed and kept it constant throughout the experiment. We also asked participants to wear acupressure wrist bands[2] to help mitigate potentially uncomfortable sensations caused by motion sickness [20]. These were worn five to ten minutes before the start of the first trial. We also instructed participants to sit down rather than stand up while using the VR prototype.

Study Design

This study was carried out following the ethical approval granted by the University of Sydney (ID 2018/125).

[1] Oculus Quest - https://www.oculus.com/quest
[2] Sea-Band - https://www.sea-band.com

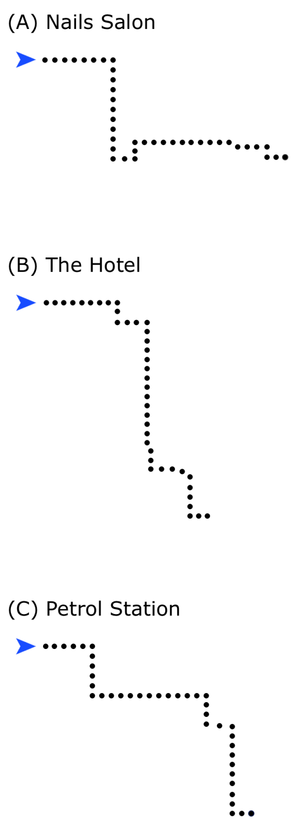

Figure 2: Route design

Map Display	Navigate to...	Search for...
(A) Up Front	Nails Salon	Bus Stop
(B) On Street	The Hotel	Helicopter Pad
(C) On Hand	Petrol Station	Car Park

Table 1: Experimental tasks used for each map display

Preliminary Study
When the prototype was fully functional, a pilot study was conducted with 5 participants. The feedback we received from the preliminary study further informed the design of the virtual environment. At first, our virtual urban environment contained just the essential infrastructure such as roads, buildings, and greenery, but it lacked people, traffic, and urban noises. As a result, some participants exhibited careless navigation behaviors such as unlawfully crossing the roads or walking on the street instead of the footpath. Therefore, the virtual environment was updated to include pedestrians, cars, and ambient noise to make the urban environment feel populated and to help deter pedestrians from taking shortcuts.

Experimental Tasks
Informed by the work of Reichenbacher [25] on elementary spatial user actions, we designed two tasks: (1) Navigating to a destination and (2) Searching for a particular place. The first task aimed to test aspects of Orientation, *"Which direction am I heading towards?"*, Localisation *"Where am I?"*, and Navigation *"How do I get there?"*. The second task aimed to test the aspect of Search *"Where is the nearest coffee shop?"*. To reduce learning effects, in every interface trial the participant navigated to different destinations and looked for different places (Table 1). The three travel routes were designed to have the same distance and the same number of turning points and street crossings (Figure 2).

Procedure
The study took up to 75 minutes in total. Trialling each map interface took about three to five minutes. To minimise ordering effects, we randomised the order of interfaces using the balanced Latin Square. Participants were instructed to wear Sea-Bands and sit down on the chair throughout the experiment. At the beginning of the study, participants learned to use Oculus Quest controllers to navigate and had a short VR practice session. Before every interface trial, participants received verbal and written instruction for the first task. They were also made aware of a second task of which instruction would be given from the application interface. After every trial, participants filled out two standard questionnaires and a general feedback form. Upon completing all the trials, participants were interviewed about their experiences.

Measurement
To measure how efficiently the participants used the prototype to complete the tasks, we recorded performance data including Successful completion, Completion time, and Errors. For task 1, there was an additional metric of Map usage time (total time the map was activated during the journey). The data were extracted from Android Debug Bridge logs, screen recordings of the VR scenes, and video recordings of the study. For overall evaluation of the prototype, we employed the System Usability Scale [9] and NASA Task Load Index [13]. Lastly, to gain insights into user behaviour, we analysed qualitative responses including the verbal comments given during the trial, the written responses in the General Feedback section (post-trial), and the concluding semi-structured interview (post-study).

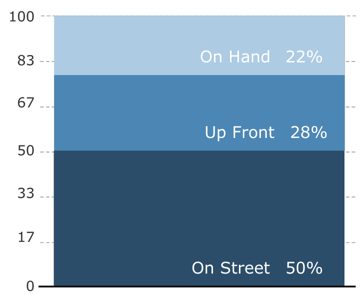

Figure 3: User preferences for map displays (N = 18)

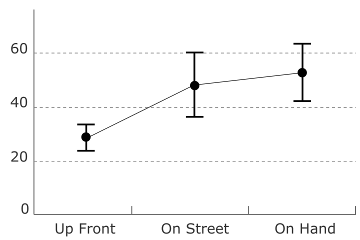

Figure 4: Simple line mean of location search time (Confidence level: 95)

	Mean Diff	Sig.
A-B	-20.056	.027
A-C	-24.556	.001

Table 2: Post hoc analysis with a Bonferroni adjustment: (A) Map Up Front, (B) Map On Street, (C) Map On Hand (Confidence level: 95)

User Study

There were 18 participants (9 females, 9 males) aged from 18-35 years old. All participants, except for one, indicated that they had little to no exposure to VR technology before the study. All of them were familiar with digital navigation applications such as Google Maps and had a minimum education level of a high school diploma.

Results

Some participants experienced motion sickness in the first interface trial, but the discomfort decreased in the subsequent trials. All participants completed the tasks successfully without any errors. We performed one-way repeated measures analysis of variance (ANOVA) for all other metrics to determine whether different map displays elicited any statistically significant differences (Table 3). Only Location Search time was followed up with a post hoc analysis with a Bonferroni adjustment to find exactly where the differences occurred. In post-study interviews, nine participants expressed their preferences for the prototype of Map On Street, five participants favoured the Map Up Front, and four participants chose the Map On Hand (Figure 3).

Map-based Navigation

There was a strong user preference for the Map On Street, even though there were no significant changes in system usability ratings or perceived workload among the three displays (Table 3). The majority of the participants liked how this map was positioned in a way that did not obstruct the view (P12) *"It was not covering anything that I would want to see"* and how they could have it open all the time (P18) *"I can see the map without much effort"*. The main reason for the preference could be that information displayed in the lower visual field is typically not interfering with the main view. Several projection-based AR studies supporting navigation with an arrow overlaid on the pathway found that

Measures	*F(2, 34)*	*p-value*
Navigation time	0.987	.383
Map usage	3.324	.066
SUS score	2.582	.090
NASA TLX score	1.831	.176
Location search time	6.917	.003

Table 3: Summary of quantitative data analysis (Since the p-value is heavily dependent on the sample size, in the results we also reported F value and effect size)

it led to a significantly higher ability of users to observe real-world points of interest [10, 19]. Nevertheless, some participants in our study found the map diverting their attention as they had to look down physically. Additionally, the relatively large map and the amount of spatial information shown might hinder users from seeing obstacles such as street potholes.

The Map Up Front, when being used en route, drew participants' attention away from the surroundings and obstructed the front view. Its usage, though not statistically significant, was less compared to the other two maps. Many participants pointed out that the size and position of the map made it very distracting (P7) *"I couldn't avoid looking at it"*, obtrusive (P5) *"The map was too big I couldn't see what exactly is happening in front of me"* and inconvenient (P7) *"I had to stop or keep walking in an open area"*. The semi-transparency was helpful to some degree; nonetheless, the map still prevented the participants from giving adequate attention to the road ahead (P12) *"Even though it is transparent, I did not really look past the map"*. There was only one participant (P1) who commented that this upfront display was what he had expected to see.

Regarding the Map On Hand, the main issue experienced by the majority of users was the unfamiliarity with this type of display, (P6) *"I did not know straight away that I could use the controller to bring it up"*. Conversely, other participants enjoyed having the control towards the position of the map and found it safer when the map did not get into their field of vision (P2) *"It did not get into my view until I wanted to look at it"*. The satisfaction of these participants suggested that we could look into the possibility of flexible placement of the interface in three-dimensional space to best accommodate the user's personal preferences, requirements of the surroundings, and the tasks at hand.

Location Searching

We found the Map Up Front ideal for stationary use as it took statistically significant less time for the participants to find a location (Figure 4) compared to the Map On Street ($p = .027$) and the Map On Hand ($p = .001$) (Table 2). The result of the Map On Street could be explained by participants needing to look from an oblique angle onto the display. As for the Map On Hand, its relatively new position seemed to affect the participant's ability to browse places of interest.

Limitations

The travel routes were relatively simple and may not reflect the complexity of real city environments. The long study time may have also caused participants to experience some fatigue, affecting their performance. Despite this, the majority of participants reported a high level of immersion and exhibited normal navigation behaviors as they do in real life. However, VR is not a complete replacement of real-life experimental testing as there is a limit to the extent reality can be mimicked. Two participants compared the prototype with video games because of the animated graphics of buildings and objects. Therefore, as AR continues to advance, real world field studies are essential to validate the results.

Implications

This section presents three design implications of the study.

(1) *Situational map displays*: Different spatial tasks require different map displays. For tasks that involve reading or searching for information on a map, an upfront display has higher readability and will increase user performance. Meanwhile, if the task is to navigate, displaying spatial information on the street may be a better option as it alleviates the problems of distraction.

(2) *Designing for safety*: Retaining the pedestrian's situation awareness of the surroundings should be criteria to evaluate different design choices. Apart from oncoming traffic, obstacles in the street, such as litter, debris, and potholes, are also particular hazards to avoid. Thus, future work should consider this when displaying spatial information in the lower part of a user's visual field.

(3) *Avoid over-simplifying the interface*: The directional arrow view was designed to reduce the users' cognitive load. However, the lack of information may lead to users experiencing anxiety (e.g. not knowing the upcoming turns and estimated travel time). Therefore, it is important to find the right balance of information on screen.

Conclusion and Future Work

In this study, we simulated an AR HMD pedestrian navigation interface in a fully immersive virtual environment. The system explored the impact of different map displays on navigation performance and user experience. The research offers design recommendations for AR HMD pedestrian navigation interfaces and adds to existing knowledge of using VR to understand pedestrian behaviours. The results suggest that an important future direction is towards the design of adaptive AR navigational interfaces that change based on individual needs, situation, and capabilities.

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