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An Immersive and Interactive Map Touring System Based on Traveler Conceptual Models

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SUMMARY Digital map systems can be categorized, based on the support they provide, into map navigation systems and map touring systems. Map navigation systems put more focus on helping travelers finding routes or directions instantly. By contrast, map touring systems such as Google Maps running on desktop computers are built to support users in developing their routes and survey knowledge before they go for travel. In this paper, traveler conceptual models are proposed as an interaction paradigm to enhance user immersion and interaction experience on map touring systems. A map touring system, MapXplorer, is also introduced as a proof of concept with its system design and implementation explained in detail. Twenty participants were invited to join the user study that investigates users' performance and preferences on navigation and exploration tasks. The results of experiments show that the proposed system surpasses traditional map touring systems on both navigation and exploration tasks for about 50 percent on average, and provides better user experience.
key words: *map navigation, street view, spatial cognition, touring system, traveler conceptual model*

1. Introduction

Digital maps are handy tools for travelers in wayfinding and also in understanding spatial information within unfamiliar environments. In wayfinding, travelers usually use map navigation systems to acquire route knowledge as they are on the go. For instance, while driving a vehicle or walking on a street, travelers can benefit from instant guidance given by GPS navigation systems or map systems on a mobile device to determine which way they should take on an intersection. *Map navigation system*, by definition, assists its users while they are in the middle of travel. Conversely, *map touring system* aids its users before they travel. If travelers do not have any map navigation systems, they can use map touring systems in advance as an alternative. However, it is not an instant process to understand spatial information while using map touring systems. Therefore, to ensure that their forthcoming travels are going to be fine, travelers need to spend more time to survey beforehand.

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1.1 Wayfinding in Unfamiliar Environments

Some previous studies investigated issues regarding human wayfinding behaviors in unfamiliar environments. Golledge *et al.* [1] introduced two types of environment learners: (1) *map learners*, who gather information from a conventional 2D map; and (2) *route learners*, who explore specific paths and gain spatial knowledge from a walk-through. They found that map learners tend to learn better than route learners. In addition, Münzer *et al.* [2] compared the incidental acquisition of spatial orientation knowledge via a pedestrian navigation assistance system with map-based wayfinding. They found that map users obtained better survey and route knowledge than users of navigation assistance systems. These two studies both implied the importance of survey knowledge in understanding unfamiliar environments.

Kim and Wohn [3] observed the driving performance and situation awareness in simulated driving environments. They investigated how map and augmented reality (AR) navigation paradigms affect productivity and safety. They found that AR navigation was more efficient and effective in route decision-making at complex decision points. However, AR navigation was less safe since it required more cognitive loads.

Parush and Berman [4] suggested the use of landmarks to support wayfinding in virtual environments. Kim *et al.* [5] included landmarks as navigation aids in their 3D virtual environment. The navigation tool was more helpful in finding detailed objects than finding highly represented objects. Chen *et al.* [6] constructed a system integrating a map with route videos to improve landmark and turn recognition. Users could then make better turn decisions in less time.

1.2 Map Touring Systems

In addition to traditional map of bird's-eye view, 360-degree imagery view that represents human's view has become popular recently. For instance, Google Street View [7] is introduced as a feature of Google Maps. This view depicts many landmarks for their positive impact in wayfinding [4]. Google Street View allows users to pick any location on Google Maps and experience street-level tour interactively. Many users thus benefit from this map touring system for their forthcoming navigation. Users can learn preferred routes and the spatial information provided by this system in advance before they travel.

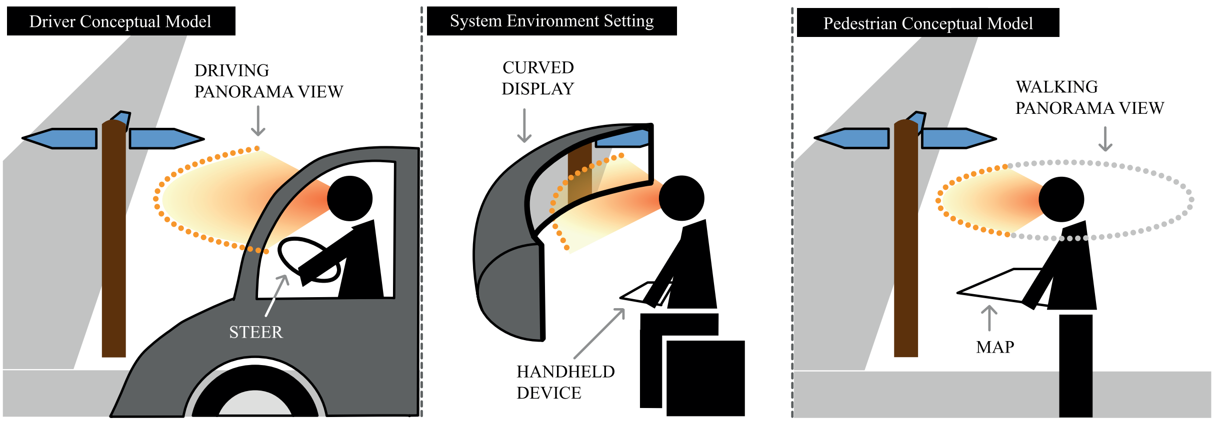

Fig. 1 Traveler conceptual models.

Several projects have been introduced to enhance immersive experience on map touring systems. The Earthwalk system (http://www.the-earthwalk.com) enables users to navigate the Google Earth using five footpads. Users can experience an immersive control of a huge map while walking on it. The Google Liquid Galaxy also allows users to control the Google Earth. It employs monitor displays arranged in a circle encompassing users to present an immersive flying experience while exploring the globe. The Kinoogle [8], an interface for Google Earth, has also been presented. It is operated with body and hand gestures with the assistance of Microsoft Kinect sensors.

By contrast, some research projects proposed natural interactions on map touring systems. Kim *et al.* [9] presented Google Earth control techniques on a tabletop display. Their system employed hand gesture and multi-touch instructions on the tabletop display. However, they did not include street view control in their system. Piovesana *et al.* [10] developed map touring system utilizing vertical and tabletop displays. They added a physical object on the tabletop display as tangible input. However, their system suffered from two difficulties: (1) position and orientation mapping from a virtual world back to the real world; and (2) panorama spotting when map scale is very limited. Moreover, their system was neither based on ego-centered reference frame (ERF) nor world-centered reference frame (WRF). Consequently, to get navigational awareness, two mental rotations are required: a circular rotation to bring WRF into a track-up alignment, and another rotation to line up object's point of view with the perspective of the users' forward view [11].

All previously mentioned related work have contributed in improving map touring systems. However, we argue that their ideas are not based on a well-defined interaction paradigm. Our research starts with a more fundamental approach in regard to the interaction paradigm. Section 2 of this paper comes with the description of traveler conceptual models as the base theory. Some previous studies regarding map cognition, spatial cognition, immersion, and natural interaction are also examined in this section to develop better map touring systems. In Sect. 3, a map touring system named MapXplorer is explained as a proof of concept. The system implementation focuses on how to build an immersive experience and natural interaction for supporting users' forthcoming navigation. Experiment methods and results are elaborated in Sect. 4 as evaluation. Finally, this paper provides some discussions in Sect. 5 followed by conclusions and future work in Sect. 6.

2. Traveler Conceptual Models

Conceptual models basically express the expectations that users have about a computer's behavior. They are approximations to objects or processes, which maintain some essential aspects of the original. These models are considered as the ways to model processes in cognitive psychology, and they can be classified into surrogates or metaphors [12]. Additionally, metaphor is considered helpful in teaching novices [13].

In this research, traveler conceptual models — the pedestrian and driver conceptual models — are used to develop more immersive feelings and natural interactions on map touring systems. As shown in Fig. 1, we incorporate behavior settings and characteristics of these models:

1. Having separate displays for map and street views,
2. Using a large display for the street view, and
3. Adapting a natural user interface mimicking drivers' steer and a metaphor of a map held by pedestrians.

The following subsections explain issues related to these settings and characteristics.

2.1 Mental Rotation Issues

Map touring systems on computers are commonly presented in a single monitor display. This configuration, however, gives mental rotation loads to the users during map exploration and navigation [11], [14]. To alleviate these problems, we argue that map views on map touring systems should apply both forward-up (in ERF) and north-up (in WRF) orientations as illustrated in Fig. 2. This design is coherent with

Fig. 2 Map orientations in proposed map touring systems.

Darken and Cevik's findings [14]. They confirmed that the forward-up orientation, which shows the forward direction on the top of the map, performs better in targeted search such as wayfinding tasks. By contrast, the north-up orientation, in which the north is on the top of the map, is preferred for primed search and naïve search [14] in map exploration tasks.

To enhance users' map and spatial cognitions further, two different displays are suggested in map touring systems. The existence of both views at the same time is necessary to support user map and spatial cognitions. By migrating the map view from monitor displays to handheld displays, user mental rotation load is reduced. Because the map view is displayed horizontally, vertical rotation to forward-up alignment is eliminated as well during cognitive operations [11]. However, the monitor displays should be only used for observing surrounding environment in accordance with current location pointed on the map view.

2.2 Immersion Aspect

Common map services in either computers or mobile devices often have to deal with space limitation. As a result, this kind of services cannot fully provide immersive feelings for the users. According to traveler conceptual models, enlarging the street view is essential to deliver immersion in map touring systems. Previous studies demonstrated that a large display allowed users to perform better on a spatial orientation task [15]. Moreover, a large display with a wide field-of-view benefited both male and female users in navigating a virtual environment [16].

The traveler conceptual models also suggest that it is better to use curved displays than flat ones. The curved displays, in fact, offer wider field-of-view whose characteristic is congruous with the panorama view encompassing the traveler. A curved display creates a sense of immersion and contributes to less frustration on search tasks [17].

2.3 Natural Interaction

In order to provide the users with smooth and natural interaction, map touring systems should incorporate direct manipulation controls through multi-touch, hand motion gestures, or both. The hand motion gestures basically embody the metaphor of drivers' steering behaviors. Additionally, multi-touch interaction reflects the pedestrians conducts while engaging with a map on their hand. As an example, pedestrians point their finger to a location on a map. By doing that, they expect to have an instant panoramic view on that particular location. By allowing direct touch as a map control, map touring systems can benefit from kinesthetic cue to optimize user spatial memory ability [18].

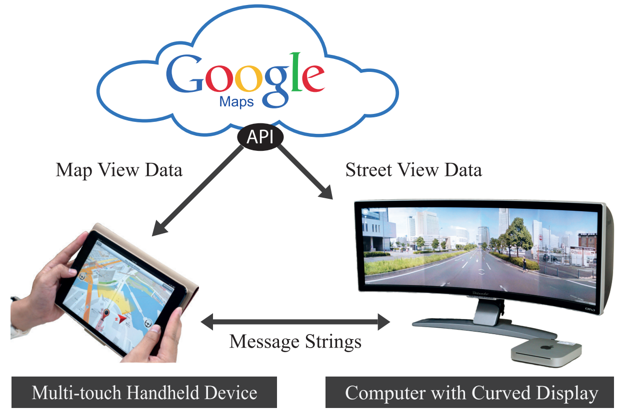

Fig. 3 MapXplorer system architecture.

3. MapXplorer

A map touring system called MapXplorer is implemented as a proof of concept. Being a realization of traveler conceptual models, MapXplorer runs on a pair of computers and handheld devices communicating with each other on a local network. Both devices retrieve map and street view data from Google Maps API (https://developers.google.com/maps/) through Internet connections. Figure 3 shows system architecture of MapXplorer.

3.1 Map View on Mobile Applications

MapXplorer is implemented based on traveler conceptual models combining driver and pedestrian behavior settings and characteristics. As shown in Fig. 1, the models suggest that map views should be on the users' hands rather than on monitor display. Hence, the map view is deployed on the handheld device.

As a prototype, the map view is specifically developed with Google Maps SDK for iOS (version 1.6.1). The SDK supports flat markers, which are drawn oriented against the map view's surface rather than the device's screen. As a result, the markers rotate when the map view is rotated, and change perspective when the map view is tilted. MapXplorer map view utilizes the markers to indicate both forward-up and north-up orientations as shown in Fig. 2. Both orientations appear together to optimize user performance in map localization [11].

With respect to the device's orientation, as the users rotate the map view, the forward-up ground overlay con-

Table 1 MapXplorer desktop-mobile communication protocol.

Flow	Occuring event	Strings to send
Desktop to Mobile	Street location is moved	{Latitude, longitude, bearing, number of path links} values
	Street image cannot be found	Notification message
	Intersection is notified	Notification message
Mobile to Desktop	Users assign new location	{Latitude, longitude, bearing} values
	Users rotate the map view	Bearing value
	Users adjust street pitch	Pitch value
	Users adjust street zoom	Zoom value
	Users release pitch control	"Reset" message
	Users request forward move	"Forward" message
	Users request backward move	"Backward" message
	Users request forward move to the nearest intersection	"Jump" message

sistently remains facing towards the map top side. On the contrary, the north-up or cardinal ground overlay always changes its rotation value when the map view is turned. As seen in Fig. 2 the north-up ground overlay can be deliberately adjusted to being in different angle or even parallel with the forward-up ground overlay.

3.2 Street View on Desktop Application

As illustrated in Fig. 1, the models suggest that street views should have wider field-of-view (FOV) to provide immersive feelings. Therefore, MapXplorer equips a street view with a 43-inch curved display (2880x900 pixels). The street view FOV can be conveniently adjusted by setting the zoom described in Sect. 3.4 via handheld devices.

As a prototype, the street view is specifically developed as a desktop application on OS X platform. The desktop application simply comprises WebKit, an open-source Web browser engine. The WebKit's engine loads PHP page from a web server hosted on a computer. The WebKit's window script object bridges the request communication between desktop application and Google Maps API. The primary functions for manipulating the street views are written in JavaScript inside PHP server-side code.

3.3 Desktop-Mobile Intercommunication

Desktop and mobile application on MapXplorer are practically linked via Bonjour socket connection. The socket connection becomes a media for transferring information string between these two platforms. As the users change the map location or orientation on the handheld device, the computer shows a congruent street view on curved display. Furthermore, when the users make forward or backward movement, the map view changes the location of forward-up and north-up markers accordingly. In summary, the detailed protocols are described in Table 1.

3.4 Control Interface

All controls in MapXplorer rely on the hand gestures upon

Table 2 MapXplorer controls list.

Gesture	Applied Control	
	Map View	**Street View**
Single-touch: Pan	Translate	-
Single-touch: Long press	Change Location	
Motion: Steer right	Rotate CCW	Heading right
Motion: Steer left	Rotate CW	Heading left
Device is laid down		
Multi-touch: Pinch in	Zoom out	-
Multi-touch: Pinch out	Zoom in	-
Multi-touch: Rotate	Rotate CW/CCW	Heading left/right
Multi-touch: Side pan	Move forward/Move backward	
Motion: Vertical shake	Move forward to nearest intersection	
Device is stood up		
Multi-touch: Pinch in	-	Zoom out
Multi-touch: Pinch out	-	Zoom in
Multi-touch: Side pan	-	Pitch street view

the handheld device. In particular, multi-touch gestures affect different controls depending on device orientation. For instance, side panning gesture performs forward or backward movement only while the device is laid down. The identical gesture performs upward or downward pitch control instead while the device is stood up. To activate side panning and motion control, user should put their both thumbs on the outer most side in device touch screen as shown in Fig. 4. Table 2 presents the further details of MapXplorer control configuration.

Eventually, not all controls are inspired from drivers' or pedestrian's behavior. Halasz and Moran [13] mentioned that an abstract conceptual model could be custom-made for fitting the user's reasoning about the system. As a result, MapXplorer applies side panning gesture controls, which are not representing any travelers' behavior. However, these controls are built based on users' control preference during pilot study, whose approach is similar to the previous research [19].

4. User Study and Result

MapXplorer system is expected to become a beneficial general-purpose tool for spatial exploration and future wayfinding. To verify this hypothesis, a user study was arranged to examine the system usability and user performance.

Twenty participants were invited to join the user study. Their ages ranged from 22 to 39, with a mean of 26. Twelve of the participants are male and 8 of them are female. These participants are university students coming from various departments. All of them have experiences of using Google Maps and Street View on computer. However, two of female participants did not have experience using multi-touch map application on the handheld device. Two other female participants said that they had never tried motion gesture control on handheld devices. This user study consists of

(a) (b) (c) (d)

Fig. 4 MapXplorer interaction controls: (a) Motion gesture for left steering; (b) Motion gesture for right steering; (c) Side panning for moving forward or backward when device is laid down; (d) Side panning for pitching up or down the street view when device is stood up.

Table 3 Narration example in navigation test.

You have just arrived at Taichung Train Station. You want to meet your friend. Your friend says: I will wait for you at a place described as follows:	
1	From the train station front gate (starting point), take the left path and move along to the North West.
2	As you meet some intersections, just pass them and go straight forward.
3	Until you find a red-brick building at a left corner. There are a lot of palm trees surround that building.
4	On that intersection, look at the right side.
5	You will see a 7-Eleven store. I will wait for you there.

two types of tests, which are navigation test and exploration test.

4.1 Navigation Test

In this test, narrated instructions were given to the participants. The instructions consisted of landmark clues and direction commands. The participants executed them accordingly to figure out the route and find the destination. The participants had to draw the route correctly on a printed map. Completion time was obtained according to how long the participants take to draw the route successfully.

Four tasks were used during this test. A pair of two tasks used the same location, but different narration on each. Although tasks are distinctive, all of them have similar complexity and difficulty. The complexity and difficulty factors include: 1) route length; 2) number of turns; 3) number of landmark; and 4) number of directions in the narration. Table 3 shows an example of narration in a task.

4.2 Exploration Test

In this test, the participants are assigned to find three landmarks in form of texts within three predefined areas. The landmark texts involved in this test is undetected inside the map and only available on the street view. Practically, the participants need to correspond the predefined areas on a printed map with the street view on the both systems. Afterwards, they need to draw circles indicating the specific location of the landmarks on the printed map and point out where the landmarks on the street view as well. Completion time was recorded according to the duration time of finding all inquired landmarks.

(a) (b)

Fig. 5 Test apparatus: (a) Using Google Maps; (b) Using MapXplorer.

Similar to navigation test, there are also four tasks in the exploration test. Two tasks use same location. For each task, similar complexity and difficulty were set based on landmark fame and saliency.

4.3 Test Scenario

At the beginning, the participants were given 10 minutes to practice MapXplorer system. Afterwards, the participants took navigation and exploration tests. User completion time was measured during these tests. The participants were asked to conduct the tests both on Google Maps (legacy system) and MapXplorer. Originally, the participants were told to use any way they liked to operate the legacy system on a computer Web browser. However, most of them decided to use half-and-half view, which puts the street view on the half-top and map view on the half-bottom. MapXplorer utilized a curved display as specified in Sect. 3.2 and a 7.85-inch iPad Mini (1024x768 pixels). Meanwhile, the legacy system utilized a 21-inch flat display (1440x900 pixels). The legacy system was not intended to use the same curved display because its height is too short for displaying the half-and-half view. This experiment apparatus overview is illustrated in Fig. 5.

Figure 6 shows the task order for each participant. In total, each participant should complete eight tasks. Task 1 to task 4 were navigation tests and task 5 to task 8 were exploration tests. To obtain a proper comparison, the tasks order were not randomized. Instead, they were conducted in

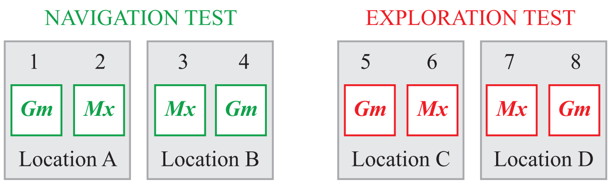

Fig. 6 Test scenario: *Gm* is Google Maps; *Mx* is MapXplorer.

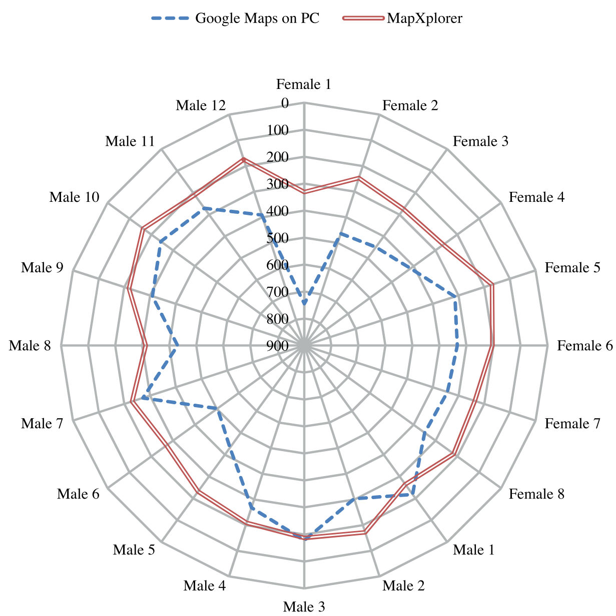

Fig. 7 Navigation test results.

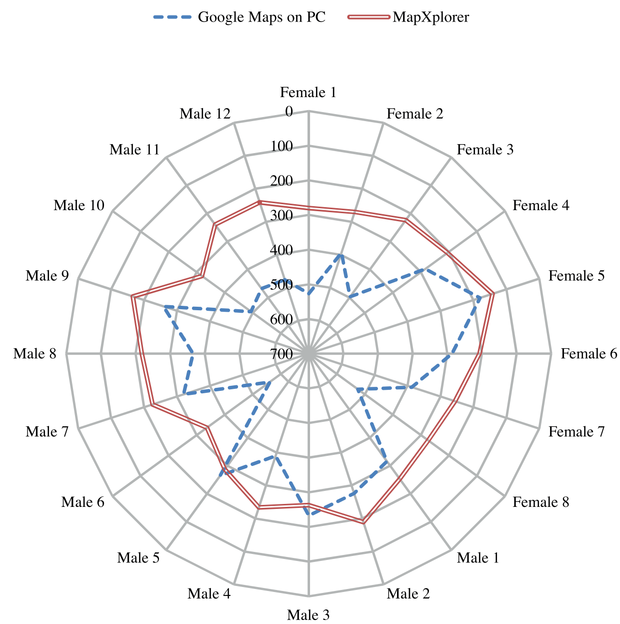

Fig. 8 Exploration test results.

the following specific order:

- Tasks 1, 4, 5, and 8 were executed using Google Maps on a computer desktop;
- Tasks 2, 3, 6, and 7 were carried out using MapXplorer system.

Due to some learning effects, it was possible that tasks 1 and 5, which used Google Maps, benefited the participants in accomplishing tasks 2 and 6, which used MapXplorer. Nevertheless, it was also potential that tasks 3 and 7, which used MapXplorer, availed the participants in finishing tasks 4 and 8, which used Google Maps. Thus, this specific order brought a fair setting.

4.4 Test Results

Figure 7 shows the average completion time in seconds for each participant in navigation test. The experiment results show that MapXplorer gives better performance than the legacy system in general. The average completion time of MapXplorer and legacy system of all participants is 234 seconds and 372 seconds, respectively. So, in average the participants performs 159% faster in the navigation test when using MapXplorer.

Figure 8 shows the average completion time in seconds for each participant in exploration test. The result still shows that MapXplorer gives better performance than the legacy system. In summary, the average completion time of MapXplorer and legacy system of all participants is 243 seconds and 363 seconds, respectively. So, in average the participants performs 149% faster in the exploration test when using MapXplorer.

4.5 Usability Evaluation

After the participants finished all the tasks, they were asked to fill a questionnaire as user feedback. The participants rated quality factors of both systems according to their experience. Using a 10-point Likert scale, average rating for each quality factor is shown in Fig. 9. In summary, MapXplorer is graded higher than the legacy system in all-quality factors, covering: 1) immersion; 2) geographical comprehension; 3) natural user interface; and 4) control ease. The legacy system earned 5.85 points on average, and MapXplorer received 7.98 points.

5. Discussion

Some conspicuous results were identified in the tests. For example, users 9 and 11 performed slightly better when using the legacy system during the navigation test. Users 11 and 13, moreover, performed marginally better when using the legacy system during the exploration test. It may be because they have already had more experiences in using Google Maps and Street View than other participants. These users stated that during the test, they conversely felt more comfortable using the legacy system than using the proposed system. It was also noticed that most of the participants were still unfamiliar with the new controls of MapXplorer. This is an indication that 10 minutes in the prelim-

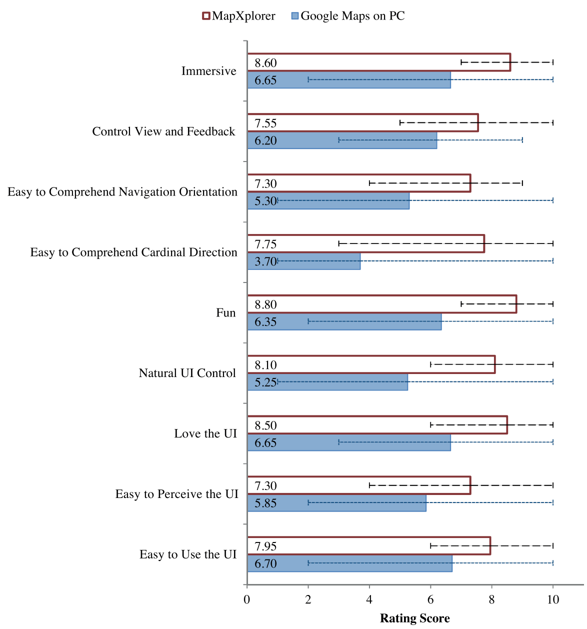

Fig. 9 Usability evaluation results using 10-point Likert scale.

inary test is perhaps insufficient.

The study found that during the exploration test, all participants benefited much from the map view on the handheld device. The participants performed location selection more conveniently and naturally using handheld devices than mouse pointers. However, the participants' gestures for location selection were various. Some of them selected a location by a long-press gesture, which had been already supported by the implementation. Nevertheless, some participants expected that similar execution could be done by a double-tap gesture. This gesture was perhaps influenced by double-click instructions on desktop computers.

By contrast, during the navigation test, it was observed that participants were less aware of the map view on the handheld device. The participants spent more times enjoying the street view on the curved display instead. During forward or backward movement, the participants likely used to treat the handheld device as a control rather than a map view instrument. The participants only looked at the map for localization, especially when they were on an intersection. Therefore, handheld display dimension (e.g., whether using phone or tablet) may not be a dominant factor in affecting user performance in the navigation tasks.

In addition, we observed how display aspect ratio and form factor affect participants' performance and preference while using MapXplorer for navigation and exploration tasks. Two different displays were compared: the flat display (1440x900 pixels) and the curved display (2880x900 pixels). In average, three-fourth of participants demonstrated better performance on the curved display. These participants preferred the curved display to the flat one due to its immersion aspect. Conversely, one-fourth of participants showed similar performance on both displays, but they were more familiar with map touring systems on flat display. They did not think that wider display was the key factor for finishing navigation or exploration task better. Some of them who lacks map and spatial cognitions skill even mentioned that too many things shown on the curved display made them confused.

6. Conclusions and Future Work

An immersive and interactive map touring system is proposed in this paper. The system is designed based on traveler conceptual models. It specifically adapts drivers and pedestrians wayfinding behaviors in unfamiliar environments as the conceptual models, which integrate the advantages of map cognitive studies and natural interaction design.

According to the experimental results, the proof of concept, MapXplorer, has secured positive feedback from the participants. In brief, MapXplorer surpasses the legacy Google Maps system in several quality factors, including immersion, natural user interface, and ease of control. The results also show that MapXplorer can improve user map and spatial cognitions. MapXplorer can support users in completing the tasks 1.5 times faster on average comparing with the legacy system.

The average task completion time of all users in using MapXplorer for both map exploration and navigation tasks is about 1.5 times faster than the legacy system.

We suggest further investigations and developments to the current research as follows:

- involving more precise cognition measurements by investigating user cognition load [20], attention and stress level [21] during map exploration and navigation; and
- employing larger curved displays, such asd Google Liquid Galaxy, and presenting optical flow cues [22] for delivering more immersive environment and better navigation performance.

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