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A Study of User Interface in Augmented Reality Wayfinding Applications

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Abstract

Wayfinding is a pervasive activity in our daily life. Generally, wayfinding is defined as a process that people navigate themselves from one place to another place in physical space. For finding destiny, we need to know the context of the physical environment. There are many tools can help us to achieve this aim, such as printed maps, guideposts, navigation systems, and so on. Those universally applied tools normally show our surroundings in a two-dimensional plane, but human perception of the environment is based on a three-dimensional form. With the development of technology, novel navigational tools have come out and gradually being used in people's daily lives. Wayfinding applications based on augmented reality (AR) technique are one example of the novel tools. Rather than simulating and integrating physical space knowledge in a 2D interface, AR technique overlays navigational information onto the human perception of the real world seamlessly. However, guiding instruction can be present in plenty of ways. We have noticed that the way in which existing AR navigation systems presenting information varies widely, and we are interested in the difference of performance from diverse AR guidance representations.

This research discusses factors of AR wayfinding system user interface and aims to output a set of design principles in regard of system efficiency, which can be used as a reference or further discussion about this topic. Furthermore, we construct three AR guidance models to evaluate our principles by analysing the performance of the models and user feedback.

Declaration

I declare that this thesis is my own work and has not been submitted in any form for another degree or diploma at any university or other institute of tertiary education. Information derived from the work of others has been acknowledged.

Name: Miao Wang

Date: 11/16/2019

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Chapter 1 Introduction

1.1 Background and Motivation

The following is an informal anecdote by the author, which forms a significant part of the author's personal motivation for this work.

When I first explored Monash University Clayton campus two years ago, I took a copy of the campus map (Figure 1) with me. But I was not familiar with every path's name at all, it was so hard for me to find my classroom. In the end, I got the location of my classroom by asking others. At that time, I did not realise that the map itself has some limitations, but I attributed my loss to the unfamiliarity with the new environment. However, at the beginning of every semester, there always are some new students who ask for help about wayfinding, although they can access the map as well. Then I realised that being lost in a campus is not an accidental problem for me, but a common obstacle for many students. After we realised this issue, we started to think why the map cannot help users find their destination quickly? And how to improve the wayfinding problem? After a fundamental research, we had found that there are multiple ways to achieve wayfinding task, including traditional 2D graphical maps, digital maps such as Google Map are also widely used. Apart from that, AR navigation system has attracted our attention.

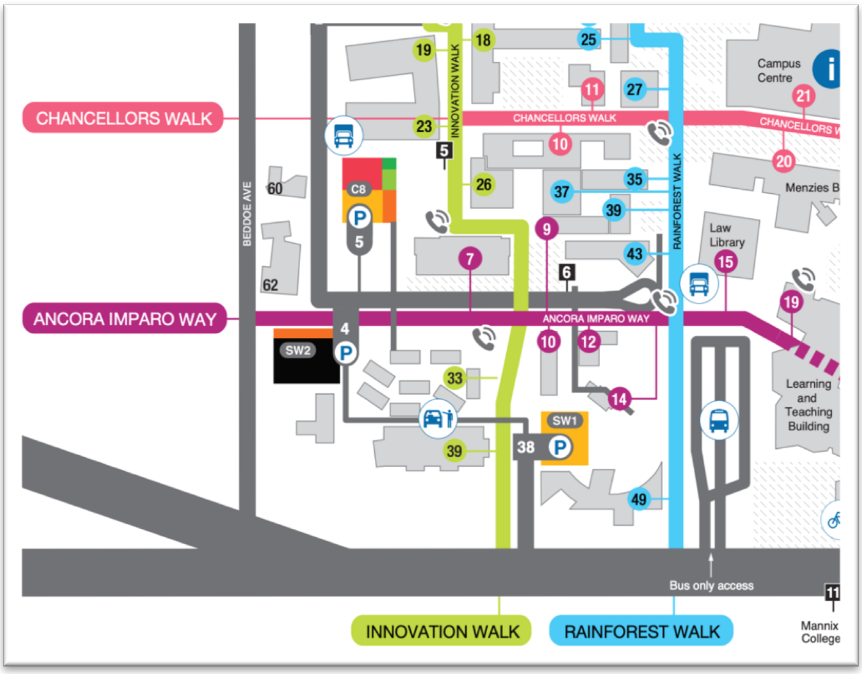

Figure 1: Monash University clayton campus map.

As a traditional method, printed maps are ubiquitous for providing aids in positioning and navigation. Even though this tool is highly acceptable in public and widely used, there are still some limitations that can be improved. For example, time for processing and receive information from a 2D map is long. When we first arrive a new place, we may do not know the context at all. Firstly, we need to find guidepost on the road or nameplates on buildings and search them over the map to recognise where there are on the map. Then we need to explore a bit more about the environment, find another object near to us, and figure out the direction we face. Next, we need to look for the destiny on the map, and plan a route connecting the current site and the destination. Finally, we can find destination by moving along the route we produced. These steps are common processes when we read and understand a map.

Currently, in our daily life, the most popular navigation tool is mobile applications (Panko, 2019). Those applications simplify the process which people used to conduct when we use a traditional static map. For instance, applications calculate and recommend optimal paths for passengers. And they track passengers' position and orientation, so that pedestrians or drivers can only go forward along with the solution provided by the digital maps. But usually, they do not perform appropriately among architectures with a complex interrelated structure or within a building. In addition, the way of context visualisation has not changed much compared with paper maps.

AR technology fundamentally changes the way how navigation information is presented. According to Lee and Billinghurst (2007), the first augmented reality project turned up at more than fifty years ago. Sutherland (1968) got an illusion of 3-dimensional view from a 2-dimensional graph through the instrumentality of a head-mounted display. Since it emerged, lots of computer scientists attempted to put the novel human-computer interaction method in the use of navigation (Al Delail et al, 2013; Morrison et al, 2009; Narzt et al, 2003). Based on a scene of the real world, users also get computer-generated messages from AR application. Therefore, user do not need to compare an independent tool with the real world anymore, and this way of data representation eliminates the process of transforming knowledge from 2D plane.

However, so far the majority of AR experts focus on the technical challenges both in hardware and data management. The understanding of how to create effective user interfaces in immersive environments is underexplored. A birth of new technology always brings new demands of interface design of interactive systems (Medina, 2009). Some studies introduced their achievement related to interface design, but most of them compactly described the problems they met and how they deal with those problems (Narzt et al., 2003; Morrison et al., 2009). There is a vacancy of systematically analysing the efficiency of interface design. Therefore, apart from employing the AR technique with positioning and navigation techniques, we propose a comprehensive study in the user interface design of augmented reality wayfinding application for filling the gap.

1.2 Research question and aims

Our main research question is: ***How to design the user interface to make AR navigation systems more efficient?*** We split the main question and start to address it with a few sub-questions:

- What aspects and elements of the user interface influence the efficiency of AR wayfinding system?
- How do they affect system efficiency?
- Is there any relationship between different potential elements?

This project is originally proposed for contributing to a campus AR wayfinding system, so our main target users are pedestrians in an organization-sized scope. Out of security and permissions considerations, we implement our prototypes and conduct studies in a virtual reality environment which is built in Unity, rather than a real campus environment.

Our research objectives are:

- Propose a guideline for AR wayfinding user interface design which can help developer building an efficient user interface of AR navigation.

- Based on the guideline we proposed, design a group of prototypes that may perform navigation instruction well.

- Design an experiment to verify prototypes performance.

- Analysis and visualize experimental data, evaluate the prototype and the guideline.

1.3 Outline

This thesis is structured as follows:

- Chapter 2 discusses our findings from extensive literature, which are related to wayfinding, augmented reality, and general user interface design principles. After that, our original guideline for AR wayfinding user interface design is exhibited at the end of this chapter.
- Chapter 3 demonstrates which methodology we adapted in our research and how we designed our research program.

- Chapter 4 shows the process of prototype design and the how we implemented them with considering the experiment environment. Moreover, this chapter also describes our experiment design in detail.

- Chapter 5 illustrates the process of user study and the knowledge we generated from the experimental data. It also summarises prototype evaluation from users' feedback.

- Chapter 6 presents research outcomes and contributions, and it also states the limitations of this research and our future work to improve the limitations.

Chapter 2 Literature Review

This chapter summarises the knowledge we have got from plenty of literature. First, we have demonstrated the importance of user interface design, then we discussed how different elements affect the interface performance. The research gap is exhibited when we display the current context of AR wayfinding applications. In the end, an original AR wayfinding guideline is displayed, which is produced by a set of the including filtering, grouping and integrating various elements discussed in this chapter.

2.1 Importance of User Interface Design

Hackos and Redish (1998) defined the interface as a part of products that user can see and interact with. Usually, one application is designed to achieve one or a small set of related tasks, and the logic for processing the tasks always be hidden behind the interface. Users only care about how skimpily their operations are and how friendly the output is displayed. As a consequence, interface design plays a significant role in customer satisfaction. As well as navigation applications, interface design in this field an independent discipline to be explored, and Hodson et al (2015) supported that some designers isolate design part alone with the whole project of navigation.

There are many case studies about physical wayfinding systems, but the challenges of emerging AR wayfinding systems are different from the existing projects. Previous principles may not be adequately compatible with a novel AR application. Therefore, design principles for AR wayfinding need to be formulated exclusively.

In general, the design is consisted of two main concepts, as Hashimoto and Clayton (2009) introduced, they are content and form. Content is the information that the system tries to convey, and the form is how the system presents the content. As for user interface design for AR wayfinding application, the content is navigational instructions, and the form is augmented reality application. In order to gain a comprehensive understanding of this topic, we have read a wide range of literature that are about wayfinding, general design principles and current development status of AR navigations.

2.2 Wayfinding in Traditional and Popular tools

Wayfinding is ubiquitous for everyone (Golledge, 2003). All the information that guide you to somewhere else, or help you identify where you are, is some kind of geographical information. The map is the most traditional way of displaying geographical data. In the field of geo-visualisation, Kraak and Ormeling (2013) define map as an interface for visualising geospatial information, which refers to the position and other attributes of objects in the world, like magnitude, distance, and direction. Maps were mainly recorded on papers, boards, or stones. In 1980, the proliferation of on-screen maps has enriched the use-pattern of geographical information (Kraak and Ormeling, 2013). Generally, we call the designation of those new patterns as geographical information system (GIS). GIS provides the capability to manipulate user custom information and facilitate data analysis.

2.2.1 Development of Traditional Maps

The map is an essential tool for us, and the use of maps can be traced back to a long history ("History of maps and cartography", 2019). The earliest maps are created totally based on human experience and observation. In those days, inaccuracy was inevitable. Another problem is that the time cost of geographical data acquisition and cartography is hard to compress; on the other hand, building renewal becomes more frequent.

Later, the application of satellites simplified environment detection and achieved a great improvement in accuracy (Kraak & Ormeling, 2013). Then, the popularization of computers has enhanced productivity in cartography. So far, revolutions appeared both in map presentation and drawing, but we still regard those maps as traditional maps. Traditional maps, in this article, refer to maps are only presented statically, regardless of the medium. Traditional map designers simulate objects in real worlds as models in a two-dimensional graph. Besides positions, map structure also exhibits a distribution of points, size of objects, and distance among items. Figure 1 shows an example of a normal 2-dimensonal map interface. The main task of traditional cartography focusses on transcribing real location phenomena and relationships among objects in reality. Dots, lines, shapes and colours are structured to imitate different areas and spaces. (Jones, 2014). Well-designed symbols based on convention could accelerate the user understanding correspondence between real objects and their alternatives. (Jones, 2014)

A shortcoming of static maps is about the efficiency of information transformation. In general, users need some time to figure out the orientation and the environment they are in (Ishikawa et al., 2008). Figure 2 demonstrates a process of understanding maps. User first need to perceive surroundings to understand their context and directions. Then they need plan a route on their own.

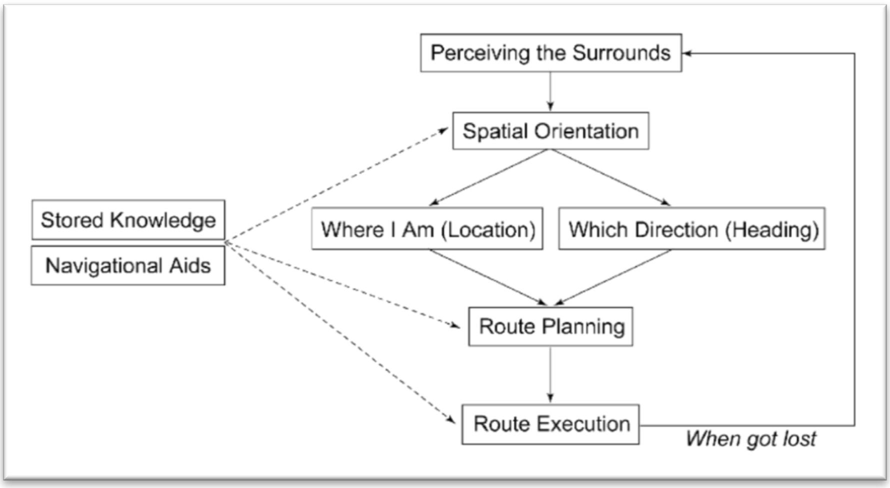

Figure 2: adapted from the Process of identifying 2-D Maps (Ishikawa et al., 2008)

2.2.2 Pervasive Digital maps

Current electronic devices have expanded the capability of maps dramatically (Blatt, 2013). Existing digital maps not only improve user experience by means of animated user interface and three-dimensional presentation, the more important character is that it also provides data analysis and navigational assistance. Recent popular maps, such as google map (Figure 3), they store position phenomena and road condition, then according to custom input, dynamically analysis and recommend optimal paths to user. In addition, those digital maps also track users' position, navigate them to destination. Vilar et al (2014) defined wayfinding as the process of users moving to the destination. A lot of application contributing to wayfinding tasks are available on the market, such as Google Map (Google Maps, 2019) and Lost On Campus ("Lost

On Campus – StudentVIP", 2019). The interfaces of those two digital maps are exhibited in Figure 3.

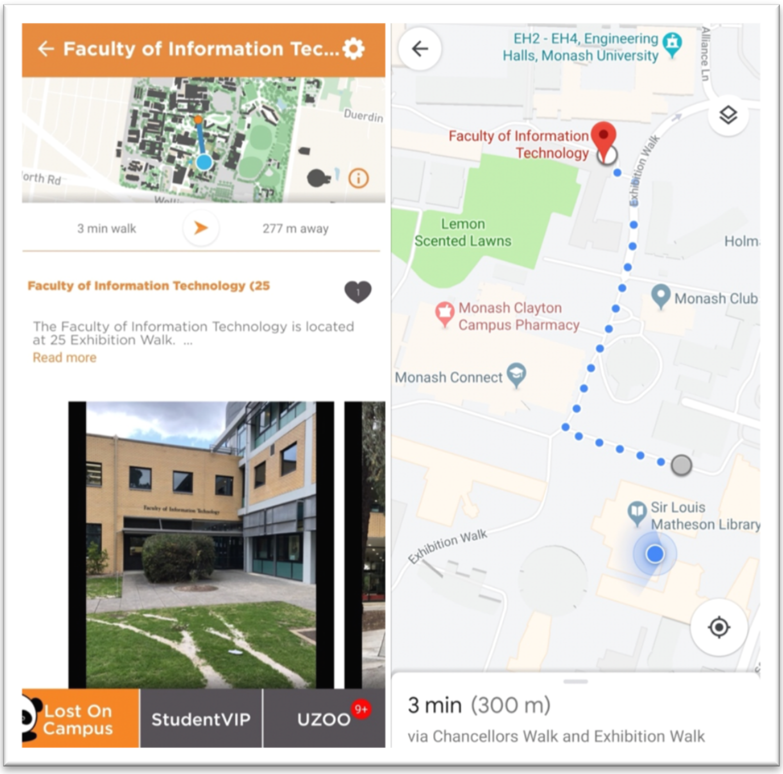

Figure 3: Mobile Map interfaces of Lost on Campus (left) and Google Map(right)

However, these electronic maps did not satisfy users for too long. Plenty of digital maps draw support from global positioning system (GPS) (Xu and Xu, 201). Those applications cannot perform well within buildings or in a small area with dense and complex buildings (Baus et al, 2005; June et al, 2017). In addition, the perform of positioning accuracy is influenced by weather and other external factors as well (Al Delail et al, 2013). Pervasive on-screen maps work properly when they guide users to a building, but it may have problems to declare how should we get in the architecture and where is the laboratory we want to arrive.

As for guidance visualisation, users need new wayfinding systems which are more accurate and clearer in instructions. Many people call for a new model of maps. Tyner (2014) said that user expect to observe everything from a map, but current maps do not provide everything for users like photographs. Montello (2002) also states that "maps do not present the world directly and transparently". (p283) Applications of AR in wayfinding are ground-breaking attempts to grant maps ability to "present everything".

2.2.3 Navigational Tool Design Principles

Section 2.2.1 and 2.2.2 demonstrated some criteria about wayfinding tools, including accuracy, legibility, productivity, and navigational assistance. In this section, we focus on its visualisation design principles, and the whole thesis does not involve any discussion about positioning technique later.

Hodson et al. (2015) claimed that wayfinding systems should provide appropriateness, simplicity and information consistency to assist user instantly understanding the unfamiliar environment.

Appropriateness

To improve the appropriateness of wayfinding, we need to keep the interface clean and concise. At the same time, landmarks and path should be highly accessible. Regarding the wayfinding application, the contrast between real-world objects and instruction elements should be noticeable. If computer-generated guidance is too obvious, it may influence users' observation through the interface. If the guidance symbol is not strong enough, the system efficiency and user satisfaction may decrease accordingly. As a result, balancing contrast is a critical aspect of our criteria. To make a fixed-sized output device adapt to the different amount of data, the system should allow users to zoom the interface in different levels (Dillemuth, 2005).

Legibility

Legibility is how simple for users to get to understand. Different from visual contrast to make elements in the map easy to be seen, easy to be understood is another part. As we discussed in section 2.1.1, how user understand symbols depends on their knowledge and experience (Jone, 2014). A set of legible marks can advance the efficiency and effectiveness of navigation information. For wayfinding applications, legibility mainly depends on the visualisation of navigation directive. The shape of the symbol should be easy to understand or be commonly employed already. The need for corresponding text should be considered as well.

Consistency

Information consistency asks that related date are presented in the same style. For instance, Figure 4 shows an example of AR navigation system. As it displays, Mulloni's project (2011) sticks a continuous instruction set at the bottom of the screen. Although the pattern of navigation information changed on the main display, the colour and the shape of symbols are consistent, and the lower part showed instructions consistently.

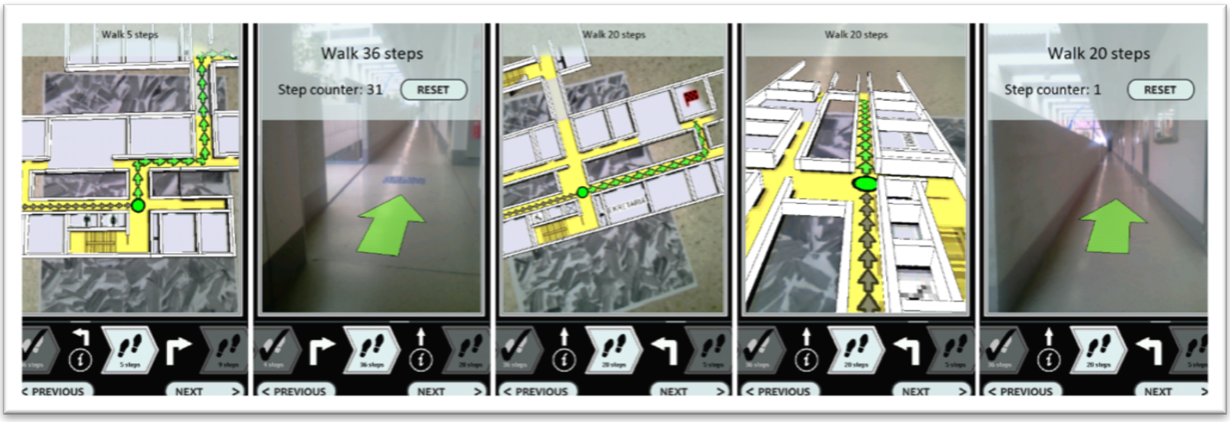

Figure 4: Screenshots of an AR navigation application (Mulloni et al., 2011)

2.3 General Design Principles

After reviewing the basic concepts of navigational information, we have learnt that general design elements make a significant contribution to system expression of location information. In this section, we review back to a broader range of researches and studies about design principles and laws to build a theoritical foundation for user interface design. First, well study general design principles of data presentation. Then, we discuss design principles for interactive system user interface forms in regard to visual perception, usability and operability, and aesthetics.

2.3.1 Universal Design Elements

Common elements for universal design are lines, shapes, colours, figures and texture. Those elements are the carriers of data, and they determine user perception from a cognitive perspective. And the harmony of elements makes a great contribution to aesthetics.

Line

Line is the basic elements in design (Hashimoto and Clayton, 2009). It has several attributes, such as curve or straight, thin or thick, visual or implied, and direction. Line is a crucial element in any kind of navigation platform. Hashimoto and Clayton (2009) claimed that diagonal lines imply a sense of motion, because when we are moving forward, our body always leans forward. Lines rotated in different degrees give us different perception. For example, in Figure 5, we cannot capture any direction information form picture a. But in picture b and c, we set the vertical lines in a tilt angle, then we can percept a direction easily. The width of the line narrows from near to far, which gives this two-dimensional line a sense of tilt in three-dimensional space. Regardless of a sense of three-dimensional space, solid lines and dashed lines show different visual effects. Taking Figure 3 as an example, the dotted line in Google map looks like a trail of a stop motion animation, which presents a feeling of movement. And the full line in the left screen offers an available solution to go to the destination, which lacks a sense of guidance.

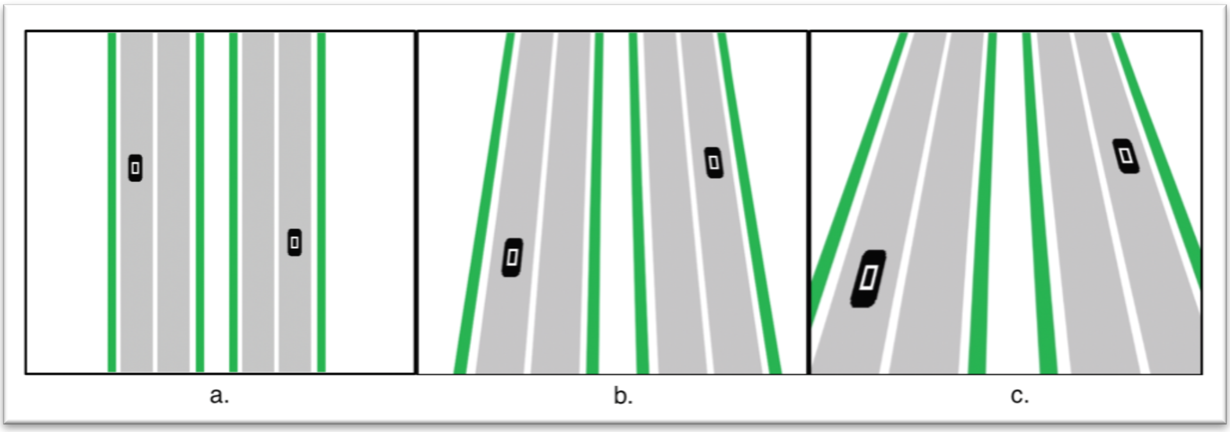

Figure 5: Lines are rotated in different degrees

Shape

Shape is another essential element in navigation design. Comparing AR wayfinding interface (Mulloni et al., 2011) in Figure 4 with that in Google Map which presented in Figure 3, both direction indicator and basic elements in implied navigation line are in a shape of arrow. Based on experience, the arrow is the most intuitive representation of the orientations. The fundamental elements in the AR wayfinding interface are easier to be understood than dots and wide-angle sector in Figure 3.

Colour

Colours consists an indispensable part of wayfinding interface. Colour is one of the simple and efficient means to achieve visual contrast, which is explained later. And is the most powerful component to present emotions in visual communication (Sears & Jacko, 2009). In addition, the colour is a requisite factor to evaluate aesthetically pleasing productions. The following picture shows an interior design product included in Wayfinding Design in the Public Environment (Hodson & Images Publishing Group, 2015). Colours are used to identify different rooms and navigational lines. Solid lines clearly demonstrate which space and corridors are accessible.

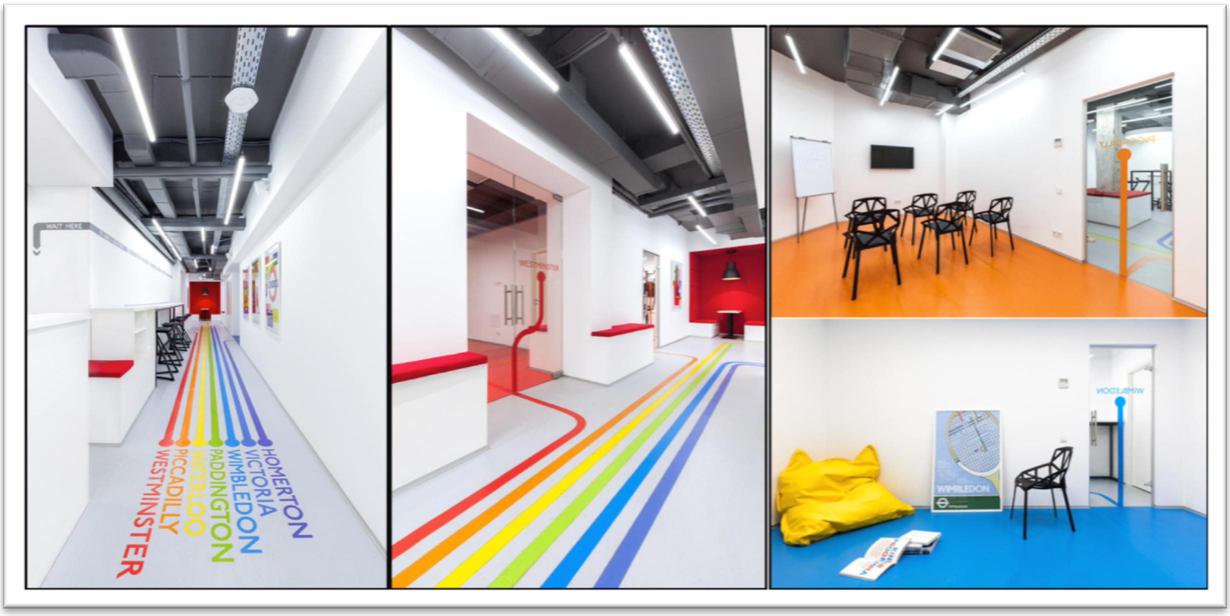

Figure 6: Emil Dervish's Interior Design for a Language School in Kiev Downtown ("Emil Dervish Creates Subway-Inspired Interior for Underhub Language School — urdesignmag", 2019)

Others

Figures are often used to express distances in wayfinding applications. For instance, "3 min walk" and "36 steps" in Figure 4, both of them describe the distance to destination. Since the size of popular AR devices are small, like mobile phones, textures are not involved in our interface design considerations.

2.3.2 Interactive System Design Principles

Ideally, users expect that the system can help them achieve their goals efficiently and quickly. The way in which user use and operate the interface have largely affected user satisfactions. There are plenty of user interface principles have been widely used, such as 10 Usability Heuristics for User Interface Design from Nielson (2013), and The Eight Golden Rules of Interface Design from Shneiderman et al (2016). In this part, we describe a set of popular principles that applicable for most interactive systems.

Easy to learn

User want to quickly understand what interactions the interface expects in order for the system to undertake specific tasks as quickly as possible. First, the system should use the languages that users familiar with (Nielson, 2013) to keep consistent with the real world. Consistency is a strong contributor to learnability ("The 4 Golden Rules of UI Design ", 2019). In addition, if the system consists of multiple fragments, each fragment should also maintain design consistency (Shneiderman et al., 2016). For instance, messages in different fragments should in same size and colour.

The interface should be clear and apply contrast to highlight parts which user should focus on. Contrast gives rise to figure-ground perceptions ("How Figure-Ground Perception Helps Us Distinguish Scenes", 2019). In the wayfinding applications, if the navigation information is not obvious enough, the system usability may be greatly reduced. Taking advantage of a reasonable combinations of colours and sizes to data is an effective means of achieving contrast ("The Principle of Figure-Ground", 2019).

Different with constructing contrast of navigation information from background, we should group related components together. Gestalt laws of proximity explains (Koffka, 2013) that when objects are too close, our brains would consider them as a whole. On the other hand, irrelevant elements should be separated on the interface.

Error control and notification

Errors made by users should be prevented (Shneiderman et al., 2016; Nielson, 2013). This principle requires us to check if the user input is valid before submitting a request. To prevent invalid data, the interface can limit the data format entered by the user as much as possible. If any errors happened, solution should be notified to user, and the wrong action should be withdrawn easily (Shneiderman et al., 2016).

Aside from error notification, system also needs to provide response when the request is successfully executed ("The 4 Golden Rules of UI Design ", 2019), or shows user process instance state when it takes time to execute. Those informative feedback helps user keep in control. When the user does not receive timely feedback, they may initiate repeated requests multiple times, which may increase the load on the server.

Minimize user workload

The system should save settings and parameters that may be reused, in order to avoid enter same input frequently. In addition, for simplify user interaction, the system should limit the number of choices (Foltz, 1998). Otherwise, excessive information may make decision making harder, and may violate the principle of concision. The hint of wayfinding application is that the system should offer a small number of optimal solutions.

2.4 Immersive Visualisation

Augmented reality (AR) is one of the prominent technologies that have potential to break through limitations of current solution for location-based service (Al Delail et al, 2013; Morrison et al, 2009; Narzt et al, 2003). In 1997, Azuma defined Augmented reality as “a variation of virtual reality (VR)”. Both VR and AR are kinds of immersive technologies (Chandler et al, 2015). VR completely immerses users into a virtual environment, but AR brings participants into a semi-virtual world, which supplements virtual objects onto real-world views (Azuma, 1997). In this section, we discuss how immersive visualisation can be used to improve wayfinding.

2.4.1 Virtual Reality

Jerald (2015) defined virtual reality (VR) as a virtual environment generated by computers. When users are immersive in the virtual environment, they can interact with the virtual world, just like they do it in the physical world. This method of human-computer interaction is new and interesting, so it has made notable progress in the commercial market. For instance, as the emergence and development of various head-mounted displays, VR films and VR video games are becoming common to the public in the current entertainment industry. Another parament character of VR is that we can simulate some tasks in the VR environment which are impractical in the real world (Bliss, 1997). Such as it also benefits many industries like military training, engineering analysis, flight simulation and so on (Jerald, 2015).

Advantages and Limitations of VR navigation

In addition to its amusement and virtuality, the high efficiency of VR performance contributes to its popularity as well. Bliss et al. (1997) applied VR to wayfinding training and tested the performance of VR navigation by comparing with work of blueprint map and non-guidance. Figure 7 shows the building structure and the VR user interface. They divided participants into three groups. All groups needed to rehearse a fire rescue after a navigation training. One group of firefighters learned the rescue environment from schematic diagrams; another group learned it by a virtual reality system which simulates the real building structure; the other one had no training before the rehearsal. In the beginning, researchers assumed that the VR training group might get the best achievement in the rescue task. But the actual result showed no difference between the VR group and the blueprint map group, and both of them performed better than no-training firefighters.

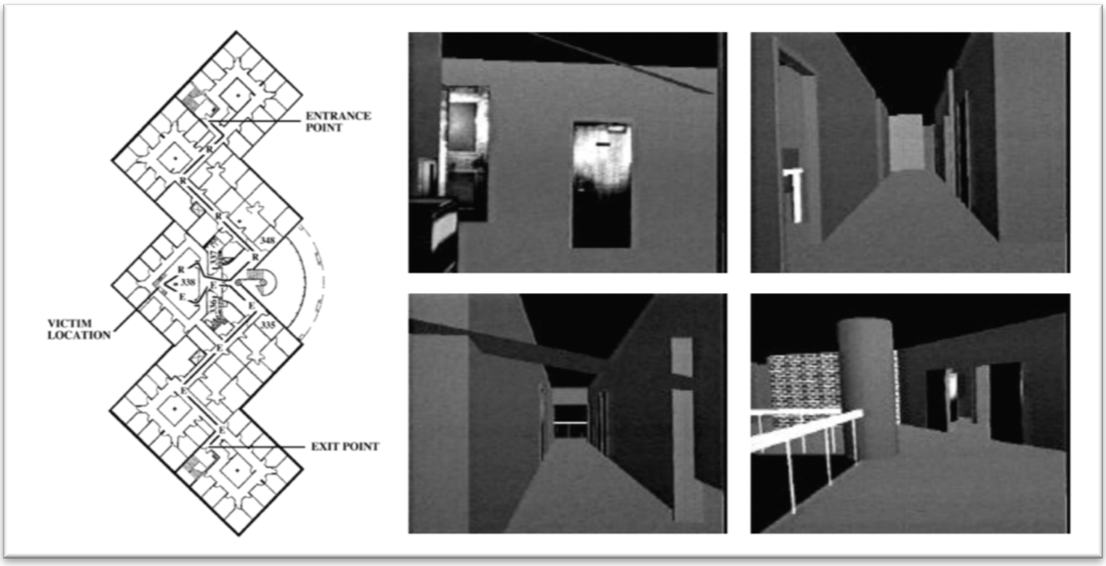

Figure 7: Schematic Diagram(left) and VR Navigation Interface in project of Bliss et al. (1997)

Although the experimental results did not meet expectations, Bliss et al. (1997) were still optimistic about efficiency and prospects of VR. Because they thought participants are more familiar with aids from schematic diagrams. If they have as much understanding of virtual reality as that of blueprint maps, the result may alter. Apart from helps participants understanding unfamiliar circumstances, VR also helps researchers observing how people behave in possible situations (Conroy, 2011).

However, the limitation of VR in navigation is that the virtual world is totally independent of our physical world. Users need to switch between separate spaces when they learn or apply knowledge. Then Mixed Reality came into being and filled the gap between the two words.

2.4.2 Augmented Reality

Milgram and Kishino (1994) defined Mixed Reality (MR) as an environment that emerges virtual space and the real world. As the following picture shows, Augmented Reality is closer to the physical environment. Augmented reality has the potential to change our experience from different senses, such as visual sense, tactile sense, auditory sense, etc (Azuma et al, 2001). But within this literature review, we only consider the application of AR in the field of wayfinding.

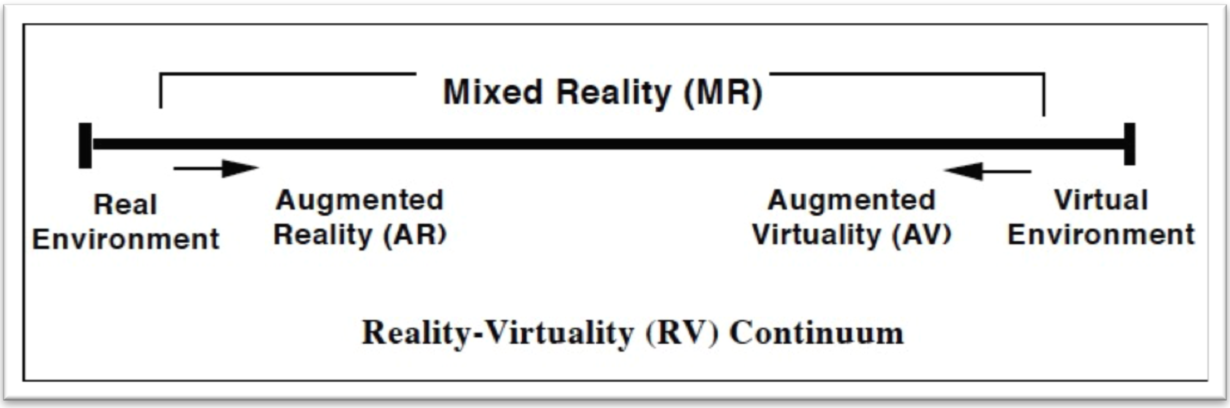

Figure 8: Reality-Virtuality Continuum (Milgram and Kishino, 1994)

AR Visual Displays

To design a good interface, besides functions provided by the product, developer also need to deeply understand both technology as well as user experience (Hackos and Redish,1998). Many wide design principles are derived from studies of human perception (Ware, 2012). Gestalt Psychology (Koffka, 2013) summarized a group of principles which describe the law of human perception and behaviours, and it has promoted the development of design science (Chang et al., 2002; Graham, 2008). Apart from visual cognition of an output device, interfaces also provide patterns of interaction with users. Therefore, the difference among hardware devices may affect user experience and then influence the user interface performance.

There are three AR visual displays, video see-through, optical see-through and projective displays (Van & Poelman, 2007). Video see-through captures real world scene by cameras and overlay additional information on the video of environment. Optical see-through lets user observe real world itself through half-trans-parent mirrors, and computer-generated data is reflected by the mirrors to users' eyes (Rolland & Fuchs, 2000). Project display adds digital data directly on real world entities by a projective device (Van & Poelman, 2007).

Van and Poelman (2007) also came up with another way to categorize AR visual display which is based on the position of device. Head-worn displays are equipment attached to users' head. Hand held displays are more portable and flexible to move, and literally, can be held in hands. Special displays are statically placed in the environment and are not portable. Table 1 shows a comparison of different AR visual displays. Besides, Gabbard et al. (2014) summarized the characters of head-up displays. Head- up displays are placed in a proper visual range of participants and are not fixed by wearing it on the head. These devices are suitable for drivers.

Positioning	Head-worn				Hand-held	Spatial		
Technique	**Retinal**	**Optical**	**Video**	**Projective**	**All**	**Video**	**Optical**	**Projective**
Mobile	+	+	+	+	+	−	−	−
Outdoor use	+	±	±	−	±	−	−	−
Interaction	+	+	+	+	+	Remote	−	−
Multi-user	+	+	+	+	+	−	Limited	Limited
Brightness	+	−	+	Limited	+	+	Limited	Limited
Contrast	+	−	+	Limited	+	+	Limited	Limited
Resolution	Growing	Growing	Growing	Growing	Limited	Limited	+	+
Field-of-view	Growing	Limited	Limited	Growing	Limited	Limited	+	+
Full-colour	+	+	+	+	+	+	+	+
Stereoscopic	+	+	+	+	−	−	+	+
Dynamic refocus (eye strain)	+	−	−	+	−	−	+	+
Occlusion	±	±	+	Limited	±	+	Limited	Limited
Power economy	+	−	−	−	−	−	−	−
Opportunities	Future dominance	Current dominance			Realistic, mass-market	Cheap, off-the-shelf	Tuning, ergonomy	
Drawbacks		Tuning, tracking	Delays	Retro-reflective material	Processor, memory limits	No see-through metaphor	Clipping	Clipping, shadows

Figure 9: Comparison of visual AR Displays (Van & Poelman, 2007)

In addition to the differences in displays themselves, there are also huge difference in the performance of various gestures (Budhiraja, 2013). The study of gestures is a new challenge that immersive visualization brings to the interface. According to the mobility of wayfinding takes, we do not pay attention to spatial displays and head-up displays, which is inapplicable for pedestrians. However, Figure 9 provide a valuable reference about how to evaluate an immersive visualisation interface performance.

AR Application Development Guideline

Except for learning experience from research programs, we also get knowledge from a few mature technology companies. Both Google CCL and Apple Inc. generalized their principles for developing AR application. Google CCL (" Augmented Reality Design Guidelines", 2019) sketches 4 considerations, including Environment, User, Content and Interaction. Environmental principle indicates that the size of digital data should fit in the real world. User principle reminds us to pay attention to users' safety and comfort. Content principle asks developers to make virtual objects as realistic as possible. In addition, the interaction principle let us consider all senses such as vision, hearing, haptic feedback and so on. Apple Inc. ("Augmented Reality - System Capabilities - iOS - Human Interface Guidelines - Apple Developer", 2019) also emphasise the importance of user comfort, and it explains more about computer-human communication. The communication principle reminds developers to notice that there are particular ways to present hint in 3D environment which can improve user experience of communication. As Figure 10 displays, the circle around the cube which contains arrows tells users the trend of its rotation. Compare with a text label, the 3D hint is more interactive.

Those guidelines are designed for AR application development, rather than user interface only. We filtered principles related to user interface design and contribute to explore how to design user interface to achieve the overall design aim.

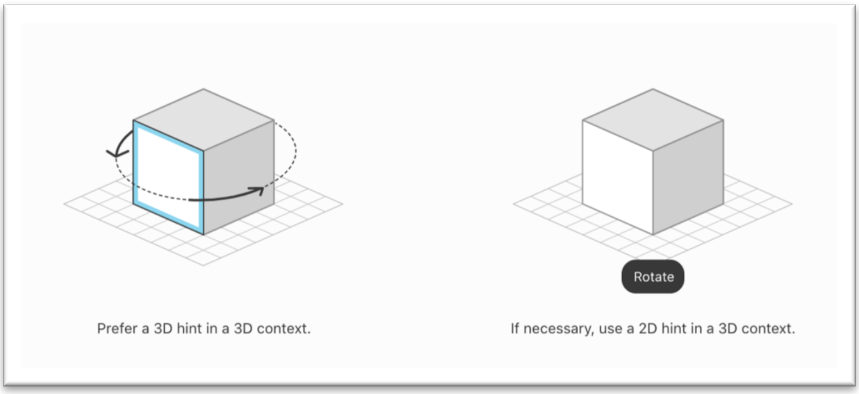

Figure 10: Hints in 2D and 3D environment

2.4.3 Related Work in AR navigation

AR assists users to explore geographical information intuitively by augmenting computer-generated data onto context in which users are inlaid (Grasset et al, 2011). AR navigation system can present invisible information through its interface, which improves users' perception of surroundings. In this section, we display how others apply AR in wayfinding tasks.

Reviewing back to existing AR navigation project, we found various patterns of AR interface. Morrison et al. (2009) conducted a user study about a location-based game. Some participants were in virtue of a traditional 2D map, and others used Maplens (Figure 11), which is an AR mobile navigation system. Maplens user used a mobile phone to scan a printed map without any marker, then Maplens identified the graphics and analysed geographic information. Then the system queried location related information from a hypermedia database and displayed them on screen in multiple media format, such as photos. One problem they showed was that icons and labels were very dense on the interface. They settled this issue by providing a freeze function. The role of freeze function was spread out icons on the screen to improve user clicking accuracy. This AR application focused more on the improvement of interaction among users, but not fully reflected the potential of AR in the field of navigation. Because it still relied on paper maps. Nevertheless, it clearly presented their issue and solution in AR interface.

Figure 11: Maplens Interface (Morrison et al., 2009)

Narzt et al. (2003) implemented a navigation interface that applied AR technique in video and 3-D graphs. They created the AR visualisation for drivers and pedestrians as INSTAR. They decorated a live video stream by a navigation arrow. As Figure 12 illustrates, the arrow starts from current lane the participant on, and bend to the next path toward the destination. Besides the length of the arrow, they highlight it by a bright colour to reduce confusion with the live video stream. The authors concluded the most intuitional advantage of the AR interface was a decrease in the ambiguity of navigational instructions. In this paper, they detailed exhibited the tools and process they used to generate the AR-view and expected more pint-sized device as a desired output equipment. As for the user interface, they protruded guidance information to make it obvious but did not discuss more user experience of different data displaying methods.

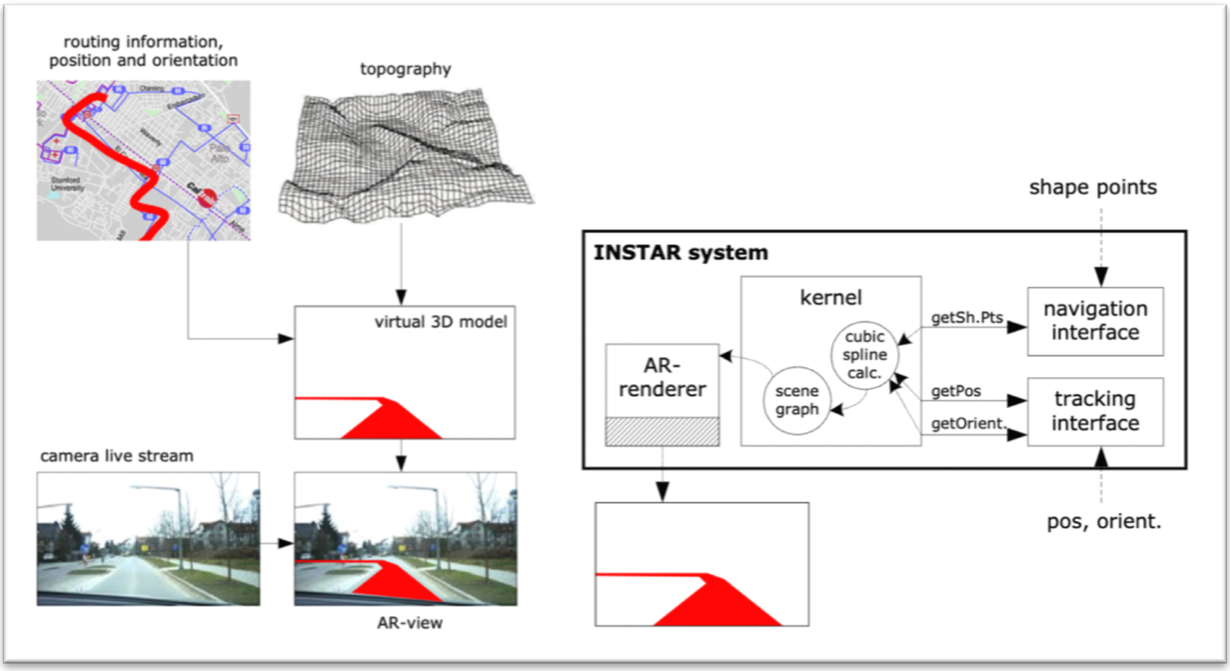

Figure 12 Instruction Generating Process of INSTAR (Narzt et al., 2003)

Gabbard et al. (2014) implemented another AR navigation system for drivers(Figure 13). They used a see-though head-up display supplement graphics on screen. This project investigated in challenges of user perception and cognitions. They raised a problem that colour perception is a huge challenge of optical see-through displays.

Figure 13: a see-through AR wayfinding interface used by Gabbard et al (2014)

Mulloni et al. (2011) developed an indoor AR navigation project, which is presented in Figure 4. They stated that a large number of investigations in AR navigation paid more attention to the accuracy of localisation, and their work would contribute to the user interface of sparse localisation indoor navigation. They decrease the position deviation with the aid of stabled info-points. Those fixed posts provide precise location information. As figure 8 shows, there are two parts of the interface. Lower part consistently presents a set of expected actions step by step. And the content of upper part alters in accordance with the object that user scanning. When the users point to the camera at a paper map, the screen shows a 3-D model of the building structure and a route leading to the destination. When users turn the lens to the real environment, the main window may overlay an instructional arrow on the real-time video stream. The authors illustrated several considerations about interface design, including simplify minimize user input, adapting user failure and activities. In the conclusion part, the authors verified that AR technique provides value to navigation tasks and emphasised the positive influence of info-points. Besides, they admitted that the interface was not mature enough to avoid user frustration and other usability issues.

In summary, the above research focuses more on technology implementation and only applied a single display mode. They did not analyse the possibility of different AR interfaces for navigation as a whole. They all proved that AR can by employed in wayfinding, and AR wayfinding is more user friendly (Mulloni et al., 2011). In addition, AR wayfinding support other functions, such as collaboration and interactions (Morrison et al., 2009). But the efficiency of user interfaces of AR navigation has not been discussed comprehensively.

Looking through the related literature, we found that there is a vacancy in user interface design study of wayfinding in augmented reality. Most of existing literature of augmented reality wayfinding projects employed only one pattern of display and emphasised their contribution on technique implementation (Van & Poelman, 2007) or optimal algorithm (Julier et al., 2000). Some expert demonstrated their challenges and solutions in regard to interface design, but their considerations were with respect to general interface design principles, and challenges about features peculiar to AR, such as performance of displays and gestures, were not reflected (Mulloni et al., 2011). Few studies focus on interface design about unique attributed of immersive visualisations. However, there is no universally applicable best interface, because the optimal choice of interactive mode depends upon the task of system (Budhiraja, 2013). And few studies focus on particular one specific problem in AR, such as occlusion (Livingston et al., 2003; Dey & Sandor, 2014).

2.5 Summary Guidelines for AR Wayfinding User Interface

After reading a broad range of literature, we selected and grouped those considerations which may devote to AR wayfinding user interface performance. Then we selected a group of essential criteria and infer our own summary guidelines for AR wayfinding user interface, and evaluate the significance based on literature we read. The guidelines are showen in Table 1. The Origin column shows where the related principle has been discussed before. We believe this table constitutes an important contribution of this thesis, by bringing together the observations from a wide variety of related work in a single place.

Principle	Description	Origin (section number)
cooperate with information from the real world	AR helps user gain more data than what they can get from the physical context. All data overlaid on the real-world scene should not affect observation to the real world.	2.4.2 2.4.3
compatible with the environment	Virtual objects should be realistic. The size of virtual data should match to the physical environment.	2.4.2

fit with users' perception	Computer-generated data should be noticeable (distinct from the real world). Computer-generated data should be placed at somewhere that user can see them easily (adapt to different viewing angles, distances).	2.3.1 2.2.3
error prevention and correction	The interface should provide enough information to minimise errors made by users; When users miss instructions, the system should display notifications.	2.3.2
comfort and safety	The system does not cause physical discomfort such as dizziness, weightlessness and so on. Virtual objects should not affect users' inspection of real road conditions.	2.4.2
aesthetic and minimalist design	Simplify data representation. Avoid overloading and clutter.	2.2.3 2.4.3
legibility	Navigational information should be understood by users easily. Try to let user understand and use it without the help of documentation.	2.2.3
visibility of progress status	System should provide useful feedback within a reasonable time, let users know what is going on? What happened? Where are they?	2.3.2
adaptive to body movements	Guidance should be changed dynamically when users are moving. navigational information should be update in time.	2.4.2
consistency and standards	Users should be able to see navigational data all the time. The presentation of navigational guidance should not be changed in any condition.	2.2.3 2.3.2

Table 1: a guideline for AR wayfinding user interface