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Paper

Mobile Navigation Services with Augmented Reality

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In this study, we combine augmented reality (AR) with the technique of assisted global positioning system to construct a guiding system of AR and design the guiding graphs metaphorically, so that the system interface operation is used more intuitively. We further investigate the availability of the system, and present an empirical study to statistically show that the guiding system of AR significantly outperforms that of plane map in terms of the finishing time of mission and correctness. Finally, according to the results of questionnaire of the system availability, we induct six essential factors influencing the guiding system availability of AR, namely guiding service usability factor, user esthetics of design factor, guiding service technique factor, guiding service creativity factor, guiding service entertainment factor, and guiding service practicality factor. The results of the study could be extended to other related studies. In terms of task completion time and accuracy rate, AR navigation is obviously better than the two plane map navigation modes. The users can find the direction of the destination within 7 s on average, and the accuracy rate is as high as 97.73%. © 2017 Institute of Electrical Engineers of Japan. Published by John Wiley & Sons, Inc.

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1. Introduction

Augmented reality (AR) has been developed for almost 10 years now. Compared to virtual reality (VR), which uses computers to create a simulated world, AR incorporates the real world to enhance the information display and interactive experience in the real world. AR is used extensively, and various related technologies and devices have been developed, including projection, sensor, lens, and screen. With the development of mobile communication technology, apps that integrate AR have attracted wide attention. This study aims to combine AR with the mobile navigation service. As smart phones have become common in daily lives, the AR function in smart phones can bring users a smooth and realistic interactive experience.

In the development of AR, technologies such as ultrasonic, long-range laser, global positioning system (GPS), tri-frequency radio wave, and visual image have been used for outdoor positioning and tracking, thus enhancing the effect of AR. However, when using AR to improve the disarrayed street scenes in an urban area or in the navigation of urban street buildings with overlapping signboards in three-dimensional (3D) scenes, there are still technical bottlenecks to be overcome. For example, ultrasonic positioning suffers from severe disturbance when used outdoors, and its transmission range is short. Laser positioning is too costly, and full scan is difficult. Tri-frequency radio wave positioning has minimal interference but requires high accuracy for image registration. As the scale of street signboards is rather small, shops need to install independent three-point location transmitters for accurate positioning. The accuracy of the QR code recognition method can reach 100% under objective conditions and the cost is very low. It is free from environmental disturbance as long as it can be read by a machine. However, although the QR code recognition method has great accuracy and convenience, its application to the display of street scenes may have the problem of visual disturbance with too many QR codes; it does not improve disarrayed street scenes.

Based on the above discussion, this study attempts to use a human–machine interface design to overcome the above-mentioned defects in traditional navigation applications. AR is used to provide an interactive interface for users and improve the effect of urban navigation or other navigation services. Metaphorical elements are added by icon design, so as to make the interface operation more intuitive. In addition, this study adopts assisted-GPS (AGPS) to enhance the timely effectiveness of positioning. The difference between AGPS and GPS is that the AGPS can use both the signals of mobile phone bases and GPS satellite signals to accelerate the positioning process. These modes enable the system to guide the users to the destinations accurately.

This study uses an iPhone for experiments. Based on the built-in digital compass and AGPS, this study adds the AR navigation system, which allows users to find out the important landmarks and tourist attractions in the cities and displays relevant information about the destination. The navigation icons guide the users to reach the destination correctly. The metaphorical icons change in sizes and angles to allow the users to know the distance and direction to the destination.

The popularization of wireless network and development of mobile communication technology have led to people's dependence on mobile devices. When exploring new locations, people can learn only the objects in the physical space but are unable to explore the physical space by virtual space. Therefore, this study aims to use AR technology to design a mobile navigation service, which is displayed by graphical presentation on an iPhone. The users can superpose the indicative metaphorical icons in real space. The integration of virtuality and reality can enhance the effect of mobile navigation service.

The human–machine interface design considers the defects in traditional navigation application and superposes the digital information on the images of real space, thus allowing users to explore their cognized spatial information. The users will observe unnoticed elements in space and perceive the meanings of new

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indicative symbols. When the users are using the new indicative guide, the metaphorical icons can enhance the users' identification and interaction with the place as well as their cognition of landscapes in the navigation environment. Specifically, the purposes of this study can be described below:

1. To develop a mobile navigation service system with AR function based on iPhone;
2. To evaluate and explore the usability of the mobile navigation service system.
3. To design and apply the AR interface.

The proposed system is summarized as follows: The GPS and magnetic data acquisition first extract the GPS coordinates and the magnetic declination of the current user's location information on the mobile device. Then the users send the information to a server through HTTP. Next, the server uses Google GIS to find the user's location information. Then, the range query processing queries the location database to obtain the location information of the nearby buildings and destination of the user. Finally, the view management gives a view plane of the mobile device by overlaying each icon on the corresponding building and the direction of the user's destination.

Our main focus is on practical values and hardware cost to design our algorithm in mobile devices. With our approach implemented into a practical mobile app, the generic mobile devices are able to effectively use AR navigation without expensive visual rendering hardware and embedded sensors. We present two major parts of the contributions of this paper, namely AR view management and location database query processing. In contrast to traditional approaches [1–3], the proposed algorithm addresses more critical issues in AR view management and location data query processing as follows. First, it is difficult to find the destination because icons corresponding to uninteresting points occlude the destination on the view plane of the mobile device. Second, the icons overlap and mislabel the objects when there are many points of interest (POIs) near the user's destination. Third, it is a very difficult problem to maintain a desired spatial relationship of icons corresponding to the object on the view plane of the mobile device. Fourth, it is difficult to decide how many icons are to be displayed on the view plane of the mobile device such that these icons can be well arranged without any overlap and destination hidden. Fifth, it is hard for the users to have precise direction and distance to the destination. Finally, it is complicated for a server to immediately and precisely provide location information for processing the spatial query as the user is moving. Therefore, the proposed method provides novel and effective solutions for AR navigation from a data query layer to an AR representation layer, which prior works have not addressed.

2. Related Works

2.1. AR background Azuma defined the AR as a variance in VR. In VR, the users are immersed in a virtual environment created by a computer, and they cannot see the surroundings in reality when in VR. On the other hand, AR enables users to see the virtual objects overlapped in real environment and enhances the reality instead of replacing the reality [4]. Azuma [4] proposed three necessary attributes of AR:

1. It combines reality with virtuality.
2. It is real-time interaction.
3. It must be in 3D space.

AR is a hybrid environment combined with real, creative, and media environments. Such a new technology plays an important role in human technological application and innovation. It has been applied to various fields, including military, medicine, engineering design, robotics, maintenance and repair, consumer design, learning, entertainment, educational entertainment, and psychotherapy [4].

The earliest AR system could be traced back to the late 1960. Sutherland *et al.* built a 3D head-mounted display equipment with mechanical tracking. This equipment was worn to project the information generated by the computer and real objects on the laboratory wall. In the 1970s, many studies were conducted on computer graphics, especially interactive computer graphics, and the development of tracking technology brought opportunities for computer simulation.

Afterward, AR began to be integrated. The originality and popularization of science fiction brought new development to AR. Licklider proposed the innovative concept concerning co-development of human and computer; this concept was mentioned in the Cyberpunk science fictions in the 1980s. The film 'Terminator' was the best example of presenting the above-mentioned concept in the entertainment industry.

Despite its popularity, research on AR from the 1980s to the 1990s was carried out only in a few institutions, such as Armstrong Laboratory, Massachusetts Institute of Technology (MIT), Ames Research Center of NASA, University of North Carolina, and the Man–Machine Interface Laboratory of the University of Washington. AR refers to the situation where 'the user wears a transparent display equipment on head which can fuse the scene of the real world with the computer-generated image directly; it is still a special VR in essence' [5]. However, VR differs from AR according to the degree of fusion. AR provides a composite landscape; the scene that is perceived by the users contains both reality and virtuality. VR is a totally immersive environment, where the users' vision, hearing, and perception must be completely under the control of the VR system. The system must build a completely artificial world covering various input processes of the users. This is a very complex topic.

For AR, the integration of the real scene can enhance the effect of perception. The AR system has two major elements. One is the object of real scene, which is complex and cannot be completely simulated by a computer. Its fundamental purpose is to enhance the execution effect of tasks in the real world. The other one is the composite interaction between reality and virtuality.

2.2. AR applications AR has been applied extensively in medicine, entertainment, military, education and study, communication apparatuses, and so on. In recent years, it is even applied to peoples' daily lives. Bimber [6] applied AR on mobile phones, allowing the interaction with the real environment to be set by the mobile phones directly. Bimber predicted that ~50% of mobile phones could take pictures by the end of 2005. In comparison to traditional PC with head-mounted display, using mobile phones as a platform has greater potential in applications. Interactive guide may bring convenience to museums and tourism.

The projection enables two or more persons in the same space [7] to perceive the interactive change simultaneously. The projected target is unrestricted, and the smooth processing of the picture is still implemented by program operation on uneven surface and angled background. The projection not only allows multiple persons to enjoy the immersion effect but also eliminates the consideration of irregular surface of the projected object. The integration with the real environment is a great progress of the projection mode.

This is a case of applying AR on interior mechanism configuration in industrial design [8]. The design theme was the desktop electronic alarm clock configuration design. After observing the existing alarm clock designs, Kumar found that most of the shapes resulted from the configuration of the internal structure. Therefore, in the process of concept design, changing the configuration would be helpful to design new shapes. Kumar tried to create a configuration design system that allows the users to implement configuration design in AR. The system construction aimed to discuss whether the technical assistance of AR could be enhanced in the phase of configuration design so that users could carry out design activity more conveniently.

Andersen studied children's digital chess game and observed an interesting interaction between virtuality and reality. The design template displays a 3D battle board. It is the test version of a game built with AR, characterized by using Lego blocks on physical and digital boards. In addition, in the subject of the AR battle version game, the design concept, physical environment, and interface of the game can be drawn and described by qualitative research on the game. The evaluation of child users proved the assumption that the concept is feasible and can be further developed, though it should be improved. When children face a mixture of a computer game and a board (chessboard) game, they will encounter the experience and expectation of two games. This situation can be observed from the changes in animation required by children who would expect animation games to contain a large amount of changes but do not expect board games to have changes because they are static.

The Magic Book developed by Billinghurst *et al.* is the first case of applying AR to education. It is a real book that allows the readers to switch between reality, AR, and VR. The book can be read independently and also used with a head-mounted display to see the 3D AR scenes on the pages. After pressing the start button, the readers can enter the scene and explore the views as first person. More than one reader can participate in reading, and the readers looking at the AR scene would appear as a miniature virtual character in the scenes. The readers can see the virtual objects in full scale in the AR environment. Billinghurst *et al.* reported positive feedbacks on the two products that are based on AR. They also described the operation of lens and its development in the Magic Book interface so as to enhance its switching between VR and AR scenes [9].

Billinghurst *et al.* marked virtual objects as real physical objects, and the users could control virtual objects to interact with real objects. The features of real objects can be changed by using this technology, such as painting different colors, materials, or creating other objects. The scenes could be simulated as desired, and modified repeatedly [10].

3. Proposed Method

3.1. Mobile navigation service In this paper, we develop a mobile navigation service that allows the users to see real scenes through camera lenses in AR navigation. The virtual icons are superposed on the real scenes to guide the users to the destination. The network is combined with GPS for dual positioning. This study intended to improve the existing service of current mobile phones and introduce value-added service items. The service function, content, and interface are planned based on the design principle of a small screen user interface.

We used Objective-C to compose the mobile navigation system and used an iPhone as the display device. The real exteriors were observed through the camera lens, and the virtual icons were superposed on the real scene to guide the user to the destination. The virtual icons were designed metaphorically so that the user can be led to the destination more intuitively.

3.2. System architecture This mobile navigation system provides a system suitable for mobile devices, and it integrates AR, metaphorically designed icons, and AGPS, allowing the users to reach the destination easily by using the system. The proposed mobile navigation system is built by Objective-C and is operated on iPhone. The users need to connect the phone to a wireless network or a 3G network to operate the system. The flowchart of AR navigation is shown in Fig. 1.

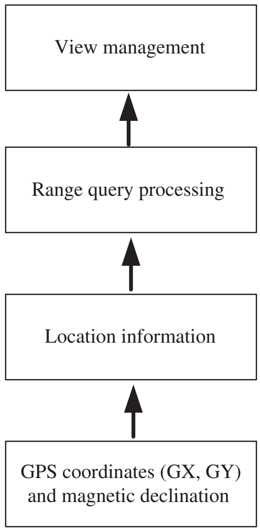

Fig. 1. Information flow

The information items include department websites and administrative units. The simple picture configuration and few buttons facilitate the users to become familiar with the operation quickly. The navigation picture contains AR icons and site information buttons. The main content of site information can be selected by pressing the site information button. The main content is divided into an upper and a lower part; the upper part is the main content of the site information and the lower part is the site button. The site information content is updated via network instantly.

3.3. UI design and view management In order to ensure user-friendliness, the design of the system interface considers the following features: design for mobile users, consistency, provision of feedback, using metaphor, using icons to clarify concepts, proximity, similarity, and providing appropriate text. We describe the interface planning for AR navigation as follows:

1. Consistency: interface configuration, operating mode, and color planning are consistent.
2. Providing feedback: correct icons and text feedback are given in correct directions.
3. Using metaphor: metaphorical icons and narrative descriptions let the user know the meanings of functions more easily.
4. Using icons to clarity concepts: metaphorical icons further clarity the navigation concept.
5. Providing appropriate text: the system uses concise and understandable text description.

To simplify our method for easy understanding, we present all techniques in our campus. Prior works [2,11] always adopt a fixed distance radius to determine the number of icons displayed on the view plane of the mobile device. However, this leads to hiding of the user's destination, and the icons overlap when there are many points of interest near the current user's location. Therefore, we propose a method to properly arrange every icon on a view plane of a mobile device. The view management provides a layout of the view plane to arrange the icon position, icon size, and icon layer on the mobile device. In terms of the GPS coordinates of each object in a real 3D scene, we can estimate the distance of each object in the 3D scene. With the estimation of the distance between the objects and current user's location in the 3D scene, we give each icon a weight to determine whether the icons are included on the view plane of the mobile device or not. That is, the nearest objects yield larger weights than farther objects. To avoid the consequential occlusion of the icons and hiding the destination, we depend on the weight of each icon to adjust its position and size on the view plane of the mobile device. In addition, we use the magnetic declination of the user's mobile device to determine which objects appear in the camera's field of view. Therefore, in light of the weight of each icon and the magnetic declination, we can precisely determine the number of icons displayed on the view plane of the mobile device.

Basically, our approach labels the icon at the close center of the corresponding building. If the building is out of the camera's field of view, the icon is not shown up on the view plane of the mobile device. The icons added later do not occlude existing icons on the view plane of the mobile device. Our method adjusts the size and position of the corresponding icon in terms of the distance from the current location of the user to that of building. That is, the nearest building is labeled with the larger size of an icon, while the icon cannot overlap other icons or other buildings. If the icons are overlapped because of the high density of the buildings, our method adjusts the position and size of the overlapped icons and moves them to other parts of the corresponding buildings on the view plane of the mobile device. If the overlapped icons still appear on the view plane of the mobile device, we move the overlapped icons outside or near the corresponding buildings by adding an arrow connecting each other. Therefore, the icons do not overlap and occlude the destination.

Additionally, to get to the destination fast, AR messages inform the user about the direction and distance to the destination on the view plane of the mobile device. Specifically, the user first gives the proposed system a destination. Next, by querying the location database, we can find the location information of the destination. If the destination is out of the camera's field of view, the AR messages inform the user about the direction and distance to the destination. If the building of destination is in the camera's field of view, our method moves other occluded icons away the destination to prevent occlusion. We also add an arrow connecting the occluded icon to the corresponding buildings to avoid label ambiguity.

For example, we would like to get to the College of Information. Figure 2 shows that our approach can properly label each icon corresponding to the objects of the camera's field of view. Figure 2 also demonstrates that the AR message of the destination is at the lower right corner of the view plane and the mark of the destination is on the icon of the College of Information. However, Fig. 2(a) shows the occlusion and the overlap occurring on two icons because the two corresponding buildings are too close in the view plane of the mobile device. Figure 2(b) shows that our approach separates these two icons and adds an arrow connecting the occluded icon and the corresponding building of the College of Language. Based on the real evaluation of the proposed method in our campus, the distance from the current user's location to the destination is about 200 m under the low density of the POIs in the field of view and, otherwise, is about 100 m under the high density of the POIs.

Fig. 2. Snapshot of the view plane under the navigation to College of Information in our campus. (a) The overlap over two icons and the destination hidden by an uninterested icon. (b) The position adjustment of the overlapped icons by using the proposed view management

3.4. Location database query processing

In this paper, we propose location-aware range query (LARQ) based on the concept of range query to recognize the belonging region to process user queries. The range queries are location-dependent queries to locate interested objects within a specified distance around current user's location. For example, the user can query all toilets around any current location within 100 m. In LARQ, all moving users periodically upload their locations to a server through HTTP. The server monitors the location change of each user. If any user is out of its query region, the server updates his/her query region.

We present the information flow of our proposed method in a bottom-up concept of layers such that the information gradually becomes more specific for AR navigation from a low layer to a high layer as shown in Fig. 1. The GPS and magnetic data layer extract the GPS coordinates (GX, GY) and the magnetic declination from GPS sensors and magnetometer sensors, respectively, on the mobile device. Then, the users send the GPS coordinates (GX, GY) and the magnetic declination to the server through HTTP. In the location information layer, we use Google Map API to geocode the coordinates (GX, GY) into location information (i.e. address) and iOS CLLocationManager to extract the magnetic declination (i.e. orientation) on the mobile device. The range query processing layer provides the location information of the nearby buildings and the destination of the user. The view management layer renders a view plane of the mobile device by overlaying each icon on the corresponding building.

To simplify our method for easy understanding, we present all techniques in our campus. Although it is a small region with limited geographical features, this makes it an ideal case study. More importantly, the proposed method can be applied to the

Table I. Descriptive information of buildings in the location database

ID	Category	Name	GX	GY	Declination	Icon	Website
C	College	College of Information	120.683669	24.149588	4.05°W, 208–242°		http://cids.nutc.edu.tw/
...	...	...	...	...	...	...	...

Table II. Geographic information of vertices in the location database

Vertex ID	GX	GY
1	120.682279	24.152334
2	120.684709	24.151521
...	...	...

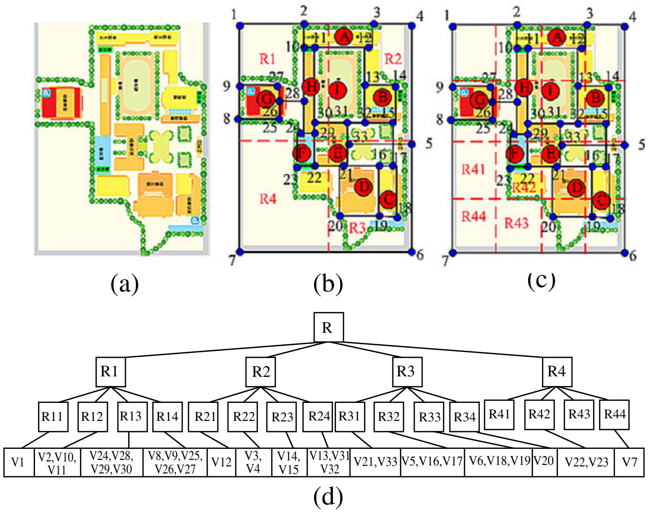

Fig. 3. R-tree representation of our campus in the location database. (a) Original map of our campus. (b) First-level representation of the decomposition of the map. (c) Second-level representation of the decomposition of the map. (d) R-tree data structure in the location database

general cases for large-region navigation. We use vertices to represent points, a path to express a way, and a rectangle to express a region of the building in the location database. The table of the building information consists of some attributes such as ID, Category, Name, GPS coordinates, magnetic declination, icon, and website to describe the location information of the building in the location database, where the magnetic declination is extracted from a magnetometer based on the default user's location of the front door at our campus. For example, Table I shows one of descriptive information for the building of the College of Information in the location database. On the other hand, the table of the vertex information is composed of some attributes such as Vertex ID and the GPS coordinates to describe the vertex of the map in the location database. For example, Table II and Fig. 3(b) demonstrate the vertex information of our campus in the location database. In addition, the table of the path information is composed of some attributes such as Vertex ID, Name, and start and end vertices to describe roads or streets in the location database. For example, Table III and Fig. 3(a) present the path information of the first avenue of the NTCUST (National Taichung University of Science and Technology) campus in the location database. Finally, the table of the rectangle region of the building information has VERTEX ID and GPS coordinates of vertices to describe the regions of buildings, grass lands, parking spaces, and so on. Table IV and Fig. 3(a) depict the vertex information of the region of the building of the College of Information in the location database.

We adopt an R-tree [12] for spatial data access with indexing building locations in the location database. The R-tree is a rooted tree in which every node of a subdivision of a root corresponds to a region. The leaf nodes of a subdivision of the region represent the vertices of the buildings. Specifically, we store the location objects in the R-tree such that we use nearest neighbor

Table III. Descriptive information of paths in the location database

ID	Name	Start Vertex	End Vertex
1	First Avenue of NTCUST	5	33
...	...	...	...

Table IV. Vertex geographic data on the rectangle region of the building for College of Information in the location database

Vertex ID	GX	GY
16	120.683610	24.149749
17	120.683857	24.149603
18	120.683653	24.149211
19	120.683352	24.149299

search [3,12] to traverse the R-tree to find the results for queries. We aggregate the nearby objects as a rectangular region, and attach them in the leaves of the R-tree. These rectangles are not intersecting. A query is only at one rectangle and does not intersect any of the contained objects. Figure 3(d) shows the R-tree representation of our campus in the location database. The computational complexity of a search in the R-tree is $O(\log_4 N)$, where N is the number of decomposed regions.

As Fig. 3 shows, we adopt the R-tree to decompose the map of our campus into two levels. Figure 3(a) illustrates the original map of our campus. Figures 3(b) and (c) depict the first-level and the second-level decompositions of the map at our campus, respectively. Black lines and blue points represent the paths and vertices, respectively, and the red circle is ID of the building as shown in Fig. 3(b) and (c). Figure 3(d) demonstrates the R-tree representation of our campus in the location database. The indexing in the R-tree can facilitate location data storage and search in the location database such that users can easily access spatial data over the client-server network environment.

3.5. Demonstration of mobile AR navigation service

Figure 4 shows the context of AR navigation for NTCUST. A user is heading toward the destination, guided by iPhone. First, this system is started, the screen displays the camera mode, and the user uses the phone to observe the environment to look for the direction and location of destination. The picture combines real scene with virtual icons, and the virtual icons guide the user

Fig. 4. Demonstration of mobile navigation services

Table V. Icon design

Category	Icon						
Dormitory	 Boys' dormitory	 Girls' dormitory					
College	 College of Language	 College of Information	 College of Design	 College of Business	 Executive Building		
Recreation	 Table tennis room	 Tennis court	 Track field	 Volleyball court	 Basketball court	 Gymnasium	 Library
Living	 ATM	 Public telephone	 Men's toilet	 Women's toilet			

to the destination. The user presses the department information button to view the target information. The picture is switched to the department information page, and the information of the site is displayed. The user can select the information page of nearby sites.

3.6. Icon design

The icons are designed metaphorically, and the types are classified by colors, as shown in Table V. Yellow represents dormitories, including those for men and women. Green represents colleges, including the College of Chinese, College of Information, College of Business, College of Design, and the Executive Building. Blue represents recreational facilities, including table tennis room, tennis court, track field, volleyball courts, basketball courts, gymnasium, and library. Red represents livelihood items, including ATM, public telephone, men's and women's toilets.

4. Experimental Results

4.1. Experimental setup

In this section, our proposed method, i.e. AR group, is compared with six methods, namely plane map navigation group with plain text, plane map navigation group with text and icons, and navigation applications with AR such as Mata [2], MAPSCOPE [13], Guan [14], and Grasset [20]. The real scenes are combined with virtual objects. The users look at the real scenes using the camera mode of the smart phone, while virtual icons are superposed for navigation. The AR group is where the users are guided by the virtual icons to the destination, and the user can press the department information button to switch to the corresponding page. On the other hand, the plane map with text group is where the mobile phone-based plane map and text are used for navigation. In addition, the plane map with text and icons group is where the mobile phone-based plane map and text and icons are used for navigation. MAPSCOPE is a popular navigation APP with AR on Apple store in which it uses Google Places API to locate POIs near your current location. On the other hand, Mata proposed a state-of-the-art augmented-reality system to provide navigation facilities, the generation of itineraries, and service delivery. After surveying the whole papers of IEEE VR and ISMAR from 2010 to 2016, we finally selected two more related works [13,14] as compared to the proposed approach in the comparisons. Guan *et al.* [14] proposed a recognition-driven 3D navigation that labels POIs by using the feature database composed of image patches with features, registered location, and orientation information from buildings and grounds. For comparison, we build such an image patch database under the buildings and the grounds of our campus. These images are taken at different distances from the scenes with various viewing angles, and they are then partitioned into smaller patches. There are totally 974 images as a 640 × 480 size and 276 616 patches in the database. Therefore, the database can aid POI navigation for users by estimating the location and orientation of the users' captured images on mobile devices. On the other hand, Grasset *et al.* [20] presented an image-based algorithm that provides POI navigation by determining the optimal places and size of labels by using a visual saliency algorithm with edge analysis to identify potentially important image regions and geometric constraints taken from users' scenes on the mobile device.

The subjects were pedestrians near our campus selected by random sampling. There were 49 subjects, who were divided into seven groups: the plane map with plain text group, the plane map with text and icon group, the AR group, the Mata group, the MAPSCOPE group, the Guan group, and the Grasset group. Each group had 7 subjects, totaling 49 subjects. Among these 49 subjects in the experiment, there are 45 valid samples. As the phone screen is small, in order to control the experiment properly and to exclude other influencing variables, a one-to-one experiment was conducted, meaning that only one person was tested at a time. The participants were informed of the factors excluded from evaluation before the experiment, and then the service was briefly introduced. In order to control the experimental time effectively and to guarantee the accuracy of operation, the operating mode and task flow were explained before the experiment so as to shorten the experimental time.

Males account for 57.8%, and females account for 42.2%. The ratio of male to female is about 6 : 4. In terms of age, those in the age group 16–20 accounts for 28.9%, the group 21–25 accounts for 44.4%, the group 26–30 accounts for 17.8%, and the group of 31 and above accounts for 8.9%. It is observed that the samples are mostly 16–30 years old. Most of the participants have had experience in mobile navigation (53.3%), while 46.7% have no prior experience. It is observed that the samples are evenly distributed. In the participant list, the ratio of students of NTCUST to the first-time visiting guests of NTCUST is about 2 : 8. In addition, for the task of navigation testing, the distance between a start point and the destination was about 200 m. The participants were asked to indicate the site location assigned by the task. The operation screen was observed throughout the experiment, in order to control the experiment process, remind the participants of the tasks, or help in troubleshooting. When the participants had questions or comments, the researcher could offer assistance or

Table VI. Reliability statistics of questionnaire items

Dimension	Cronbach's α value	Number of items
Technicality	0.798	4
Usability	0.858	4
Innovation	0.802	3
Applicability	0.861	4
Design esthetics	0.821	3
Entertainment	0.841	3
Intention to use	0.849	2
Total	0.946	23

take notes immediately. After using the system, the participants were asked to fill out the acceptance questionnaire according to their experiences. The scores were tallied immediately, and the researcher interviewed the participants concerning the items with low scores. The opinions and suggestions of the participants were collected to identify the affecting factors.

4.2. Questionnaire design The acceptance of mobile navigation service was evaluated for the seven experimental groups. The measurement was based on a Likert 5-point scale, ranging from 1 (strongly disagree) to 5 (strongly agree). This questionnaire integrated some usability evaluation dimensions proposed by prior works, and selected appropriate dimensions. The usability evaluation operation definition and quality elements summarized by this study are as follows:

1. Technicality: navigation effectiveness of AR, accuracy of positioning, and system stability [15].
2. Usability: ease of use, easy operation learning, and easy task completion [16].
3. Innovation: innovative AR function, innovative positioning function, and innovative navigation function [17].
4. Applicability: usability of AR, usability of navigation function, usability of positioning, and real-time interaction of system [18].
5. Visual appearance: real exteriors quality, visual appearance of AR small icons, and visual appearance of user interface.
6. Entertainment: entertainment of using system, entertainment of value-added service, and entertainment of AR interaction [19].

4.3. Performance analysis Most of the participants were not students of NTCUST and were unfamiliar with the campus environment. In the experimental process, the participants were required to complete the navigation tasks of this experiment by using the navigation service function of the proposed system. The participants were required to fill out an evaluation questionnaire after the experiment. In order to confirm the stability and effectiveness of the questionnaire, all the items and results were collected for reliability analysis. As shown in Table VI, the reliability coefficient is 0.944, indicating a high consistency as it is very close to 1. The Cronbach's-α value of the overall questionnaire items and dimensions was 0.7–1, indicating high reliability.

4.4. Efficiency analysis Table VII shows that the AR group and the AR-based methods are better than two plane map groups since AR can guide the users to their destinations fast under some small areas that cannot be navigated by the traditional map or the online map. Table VII also shows that the AR group takes less time to reach the destination as compared to other AR-based methods such as Mata, MAPSCOPE, Guan, and Grasset, since they take much time to analyze the image features for placing labels on the users' captured images. Instead of image-based navigation, our scheme determines the place and the size of labels by using the motion sensors of the mobile device, such as a GPS sensor and a magnetometer, to obtain the current users' location and orientation information. Without huge time complexity for obtaining the knowledge of the current users' scenes, our mechanism is faster than other methods.

Table VII. Descriptive statistics of average time

Group	Number	Average (s)	Standard deviation (s)	Standard error (s)
AR group	7	6.787	0.4523	0.4087
Plane map with text group	7	10.791	0.6561	0.5929
Plane map with text and icons group	7	9.082	0.7606	0.6875
Mata	7	7.836	0.7826	0.5296
MAPSCOPE	7	8.692	0.8423	0.6381
Grasset	7	7.253	0.6237	0.481
Guan	7	8.917	0.8783	0.608

4.5. Accuracy Tables VII and VIII show that our method can immediately and precisely guide the user to his/her destination. This is because the proposed view management can prevent the icon occlusion of the destination on the view plane of the mobile device. In addition, the proposed location data structure can speed up data search to facilitate real-time and precise icon representation on the view plane of the mobile device.

More importantly, Table VIII demonstrates that the AR group and the AR-based methods are superior to two plane map groups since the users can precisely reach their destinations with virtual navigation objects on real scenes. Table VIII also shows that the AR group outperforms Mata, MAPSCOPE, Guan, and Grasset since the image-based algorithms always suffer from feature recognition errors due to the presence of many buildings, device motion, and other moving objects such as cars and walking people in the captured users' images. Grasset surpasses Guan since Grasset optimizes the layout of labels in the view management to prevent the overlap of the labels in the users' view plane. In contrast to Grasset, our view management uses the motion sensors of the mobile device to consider the orientation of the current users' location for the label placing, so that the AR group can avoid the feature recognition errors from the captured users' images.

4.6. Usability analysis The usability evaluation questionnaire was based on a Likert 5-point scale, ranging from 1 (strongly disagree) to 5 (strongly agree), with 3 denoting no opinion. Among the questionnaire dimensions, the average means of AR-related items are over 4, which is better than that of the plane map group. According to the result, the participants have generally accepted the proposed mobile navigation system. In terms of descriptive statistics, the average value of 'navigation service usability factor' is the highest, at 4.295, and the average value of 'navigation service practicability factor' is 4.127. The average values of various items are shown in Table IX.

5. Conclusion

In this paper, we metaphorically designed an AR navigation system and tested whether the navigation mode has a positive effect on the users. The experimental groups included the plane map and plain text group, the plane map and text and icon group,

Table VIII. Descriptive statistics of task accuracy rate

Group	Number	Average	Standard deviation	Standard error	95% confidence interval of average	
					Lower bound	Upper bound
AR group	7	0.977	0.251	2.267	92.87	102.59
Plane map with text group	7	0.573	0.839	7.583	41.07	73.60
Plane map with text and icons group	7	0.708	0.799	7.220	55.32	86.28
Mata	7	0.8577	0.415	5.294	76.81	91.84
MAPSCOPE	7	0.7819	0.611	6.192	64.33	87.72
Grasset	7	0.896	0.293	3.697	89.31	98.28
Guan	7	0.872	0.394	4.475	79.58	93.04

Table IX. Averages of various factors

Factor	Average	Order
Navigation service usability factor	4.295	1
User design esthetics factor	3.943	5
Navigation service technicality factor	3.99	4
Navigation service innovation factor	4.06	3
Navigation service entertainment factor	3.94	6
Navigation service practicability factor	4.127	2

the AR group, the Mata group, the MAPSCOPE group, the Guan group, and the Grasset group. The results indicated that in the plane map navigation mode, the participants needed to compare the surrounding with the images or text to identify the location and direction. This process is time consuming and has a high error rate. On the contrary, in the AR navigation mode, the users can know the correct direction and location immediately under the guidance of virtual icons without the need to identify the surrounding. The process is efficient and the error rate is low. Therefore, the AR combined with reality and virtuality can accelerate the users' identification, and the real-time interaction enables the users to identify the current location immediately.

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