Comparative Assessment of Mobile Navigation Applications using 2D Maps and Augmented Reality Interfaces

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***Abstract*—So far, 2D map-based navigation applications on mobile platforms have been dominating the market. However, with the rise of augmented reality technology, a new type of interface is introduced to the navigation applications. To this end, two mobile navigation applications having different interaction styles were developed for a task of navigation in Istanbul Technical University campus. The first application offers navigation within a 2D digital map view and the second application is an augmented reality browser, which provides navigation by displaying waypoints onto the phone's camera view. The aim of this study is to investigate how efficient these two different interfaces are in the tasks of navigation and exploring the campus area. In line with this purpose, a user experience test was conducted in the field and the results show that both interfaces have their own pros and cons, but they both accomplish their navigation duties with success.**

***Keywords*–user experience; augmented reality browser; mobile navigation.**

I. INTRODUCTION

Mobile navigation applications are essential for people to figure out how to get from one point to another in any environment without getting lost. Teevan et al. [1] stated that the most common reason for performing a local search was to get directions to their target location (52%), followed by the desire to go somewhere (43%), to get a phone number of a place (28%) and to choose a specific place to visit (21%). Therefore, the main focus should not only be given to show the right path with as much clear directions as possible but also to take the elements of exploration and discovery into account. Another important factor in the development process is the type of user interaction with the application. Different interaction types may create different effects on the degree of exploration of the environment and user's satisfaction while using the application, both of which are needs to be investigated constituting the main aim of this study.

We chose to implement two different interfaces, each of which has different interaction style. The proof-of-concept system is proposed as a campus guide application to be used within the vicinity of Istanbul Technical University (ITU) [2]. The first application offers navigation functionality and features to explore the area, whose interface design was inspired from the existing Google Maps [3] application. The second application is an Augmented Reality (AR) browser application, which displays the buildings in the campus onto the live camera view of the smartphone as Points Of Interests (POI) and provides navigation by displaying arrows as waypoints directing the user to any destination. By conducting user experience tests, as well as the travel duration, the usability of these two interfaces and efficiency of these two guidance approaches were investigated.

The structure of the paper is as follows: In Section II, related researches and their differences with this study are presented. In Section III, the design and implementation details of the algorithms and applications are introduced. In Section IV, setup of the user experiments is presented, and the results are discussed. Lastly, in Section V the paper is concluded by presenting the main outcome of this study and the future work ideas.

II. LITERATURE REVIEW

The navigation applications allow people to find their route and explore their surroundings easily and quickly in the places they have not visited before without losing too much time [4]. Especially universities with huge campuses welcomes thousands of new students and visitors every year, and to help people find their route without getting lost, most of the universities have guidance signs located at different points around the campus. However, this kind of guidance causes extra burden for the people because they first have to spend time and energy to find those signs. To overcome this issue, different mobile solutions were developed, which are easier for the people to get access [5][6][7].

In order to get more help and benefit from the navigation applications, the interaction styles of applications plays an important role. By using advantages of recent technologies, navigation applications can provide rich contents to the users. Most of the existing mobile navigation applications use 2D map interface, which presents interactive items overlayed onto the map to provide information. This kind of interface allows user to see their surroundings from a bird's-eye view [7].

On the other hand, AR browsers offer a different kind of interactivity. The technology of AR carries the experience with the real world to a higher level by allowing to see more than what actually exists by combining the real world with the virtual data provided. AR combines the real physical world view with various media contents such as images, 3D models, animations and sounds in order to enhance the perception of the user among the environment or the objects. The media content related with real world locations and displayed onto the camera view of the phones make the users feel as if the objects really exist on those locations, which provides opportunity for the people to enhance their perception and get to know better about surroundings [8][9][10]. Another reason of usage of augmented reality in navigation applications is that AR provides a location-aware interface [9]. Since the study of Feiner et. al. [11], mobile AR applications have been one of the attractive research topics in academia and they showed that AR technology can guide the people to explore an area or a city which are not familiar to them.

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In AR browser applications, as location-based AR applications, POIs are displayed onto the camera view by using information balloons or any other media content [4]. These applications use phone's camera, GPS, compass and other sensors to relate the digital content with the real world objects in order to provide much detailed information about that location[12][13]. There are couple of commercial AR applications available, such as, Wikitude [14], Layar [15] and Junaio [16], each of which enables displaying POIs on the camera view.

Comparison of user experience in using AR browser and 2D digital map applications has been discussed in some studies. Lee [13] proposed to use a 2D digital map, an AR browser and panoramic photographs interfaces to inform the tourists about the original view of the buildings which were damaged by an earthquake in Chirstchurch city. The user experience tests conducted in this study showed that 2D digital map interface was commonly used for browsing and finding the point of interests. Another application developed by Mulloni et. al. [18] provided a 2D digital map interface together with an AR browser interface within an application having a switching mode between them to offer navigation service. The results of user experience test of this study showed that AR browser interface was mostly used at crossings of the route where users tried to decide, which direction they need to turn, whereas they used 2D digital map interface mostly when they walked straight. In a similar study [17], three different applications, one with a 2D map interface developed using Google Maps Application Program Interface (API), another one with an AR browser interface and the last one with the combination of these two interfaces, were compared in terms of user experience for a navigation task. Results of this study showed that when AR browser interface was used, arriving at the destination took longer because of the obstacles on the route. The drawback of this system was that the route planning options in this interface was limited. Another outcome of this study was that using the AR browser interface user found shorter routes between two locations compared to that when using the 2D map because in the map those routes were either covered by trees or not included in the satellite images.

What distinguishes our study from the ones in the literature is the way of providing navigation service. To be more specific, AR interfaces in the literature borrowed either the 2D digital map interfaces for navigation purpose or only showed points of interests and expected the users to walk towards them. However, in our study, AR browser interface not only shows the point of interests but also it displays arrows as waypoints to guide the users their destination.

III. Proposed Navigation Applications

The shortest path between a selected source and target location is displayed to the users in both applications. Moreover, to help users to explore the campus, a search functionality is also implemented together with displaying buildings as groups, such as academic buildings, sport facilities, etc.

A. *Finding the Shortest Path for Navigation*

In both applications, the shortest path offered to the user is calculated by using Dijkstra's shortest path algorithm. For the implementation of this algorithm Liang's [19] method is used as a reference. The algorithm uses a weighted graph which includes nodes, edges and weights of each edges. The graph was created using Google Earth [20] software. To define nodes of the graph, pins are put onto the campus image for every building in the campus, and walkable areas between the buildings. Afterwards, the edges are specified and distance between each nodes are defined as the weights of the edges. A small part of the graph is shown in Figure 1, where the red lines show edges and the walkable paths for the users.

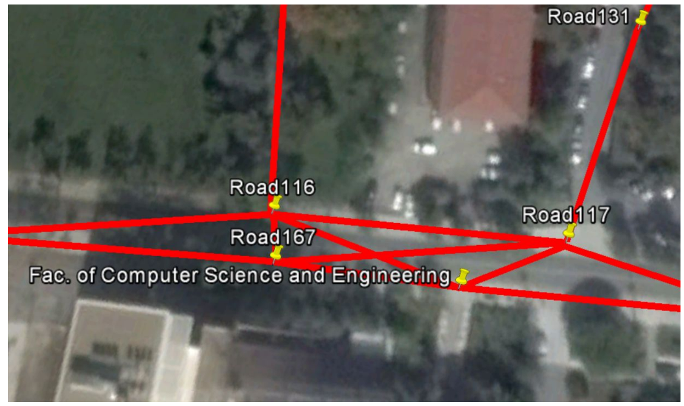


Figure 1. Representation of nodes and edges in the graph created in Google Earth program

The nodes are stored in an array with their descriptions and the edges are stored using an integer array, which has the index of the source node, followed by the index of the target node and the distance between the nodes as weights of the edges. The nodes created in Google Earth were exported and then parsed to extract and store the name, latitude and longitude information of each node to be used to construct these arrays. By using the coordinates of nodes, distance between two nodes are calculated using *Haversine Formula* [21] and then stored as weight of the edges. Haversine formula as defined in (1a)-(1f) gives us the distance between two coordinates $pos1(lat1, long1)$ and $pos2(lat2, long2)$. It presumes a spherical Earth with radius 6376.5 (1a). In order to convert $lat1, long1$ and $lat2, long2$ from degrees, minutes, and seconds to radians, each value is multiplied by $\pi/180$. It calculates the changes in latitude and longitude as in (1b) and (1c) respectively. Next, it uses (1d), (1e), (1f) to calculate the great-circle distance between two points, that is, the shortest distance over the earth's surface.

$$
\begin{aligned}
&R = earth'sradius = 6376.5, && \text{(1a)}\\
&\Delta lat = lat2.\pi/180 - lat1.\pi/180, && \text{(1b)}\\
&\Delta long = long2.\pi/180 - long1.\pi/180, && \text{(1c)}\\
&a = \sin^2(\Delta lat/2) + \cos(lat1). && \text{(1d)}\\
&.\cos(lat2).\sin^2(\Delta long/2), &&\\
&c = 2.\arcsin(\sqrt{a}), && \text{(1e)}\\
&d = R.c && \text{(1f)}
\end{aligned}
$$

where,

- lat : Latitude
- $long$: Longitude
- Δlat : change in latitude
- $\Delta long$: change in longitude
- a : the square of the half of the straight line distance between two points
- c : the great circle distance in radians
- d : distance

All the edges in this graph are bidirectional. Therefore, when an edge is defined as from A to B, another edge is also needed to be defined as from B to A. When the user wants to get to a target from his/her current position, finding the source node requires an extra calculation because user's position is defined with the corresponding GPS data and it may not be the same with any of the nodes in the graph. Therefore, when the user wants to walk or drive from his/her current position to a target destination, the source node in the algorithm is chosen by finding the closest node to the user's position. In order to find the closest node to the user's position, distance between user's position and all the nodes are again calculated using Haversine Formula.

After constructing the graph and specifying the node that is closest to the user, Dijkstra's algorithm [19] was implemented to find the shortest path from a source node to a target node. The shortest path between two nodes is defined as the path with the minimum total weights. The algorithm is known as a single-source shortest path algorithm because it finds the shortest path from the source node to all the other nodes. The pseudo code of the Dijkstra's Shortest Path Algorithm is shown in Figure 2.

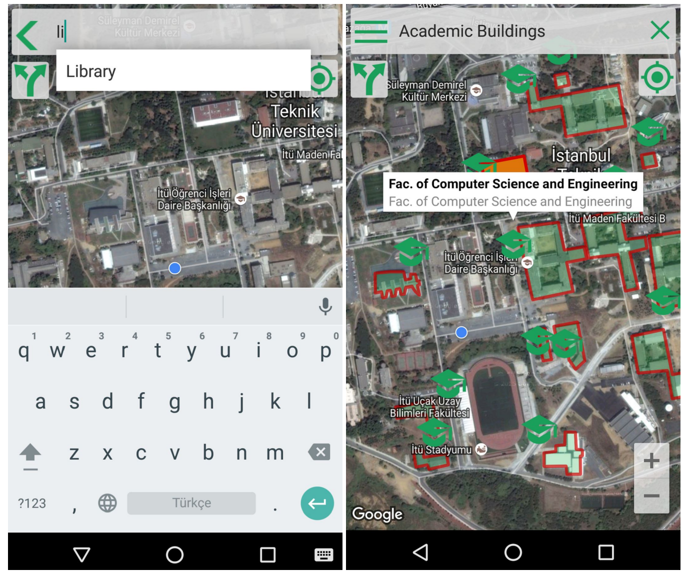
function SHORTESTPATH(source)
  Let V denote the set of vertices in the graph and v denotes any of the vertices in V;
  Let T be a set that contains the vertices whose paths to source are known;
  Initially T contains source vertex with cost[source] = 0;
  while $sizeof\ T \leq n$ **do**
    find v in V - T with the smallest cost[u] + w(u,v) value among all u in T;
    add v to T and set cost[v] = cost[u] + w(u,v);
  end while
end function

Figure 2. The pseudo code of the Dijkstra's Shortest Path Algorithm.

The algorithm returns the nodes of the path from source to destination node that were used to display route information in the applications [19]. The intermediate nodes are used to show waypoints in AR browser application and used to draw the path in the 2D digital map application.

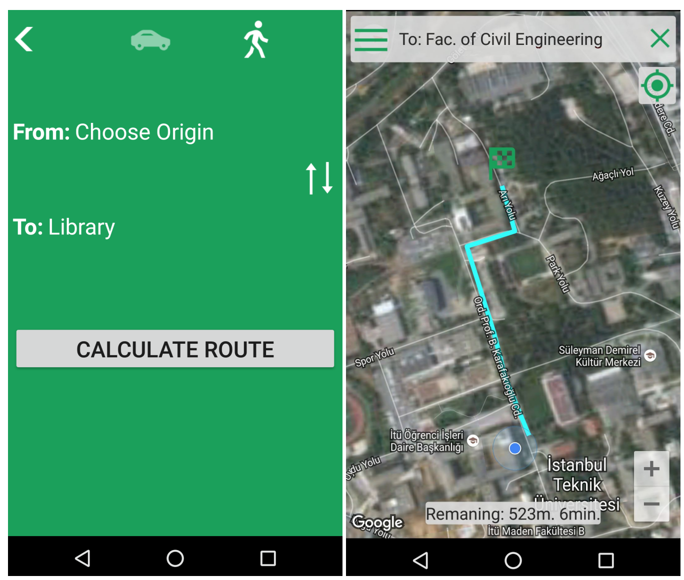
B. Navigation Application with a 2D Digital Map Interface

This application was developed as an effort to provide navigation service and also other informative features to help the new visitors easily adapt themselves to the ITU campus. Users can search a building and get detailed information about it (Figure 3a). The 2D map interface shows the user location with a blue dot, which is updated on the map as the user moves. Moreover, on this blue dot a small arrow shows which direction the user is currently looking at. Users can also view the buildings in groups, such as academic buildings, sports facilities, dormitories etc. (Figure 3b). User can choose source and destination locations (Figure 4a) and follow the highlighted path to the destination (Figure 4b). Zoom and map orientation controls are also available in the interface.



(a) **Search places** function (b) Displaying buildings in groups

Figure 3. 2D map interface

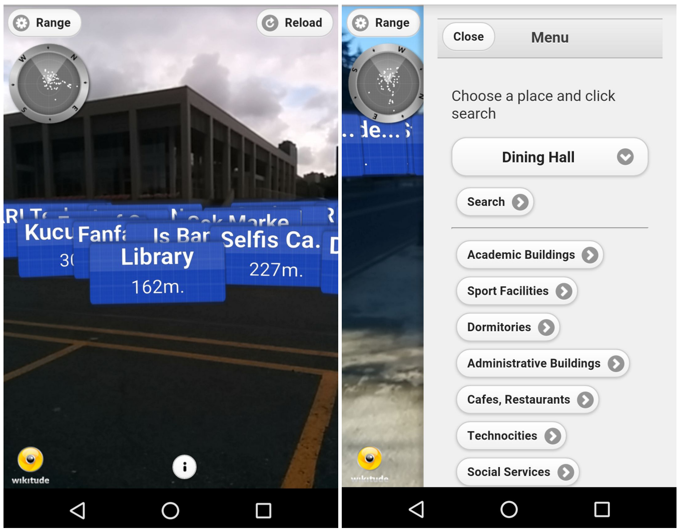


(a) Navigation menu (b) Route information

Figure 4. Shortest route to a destination

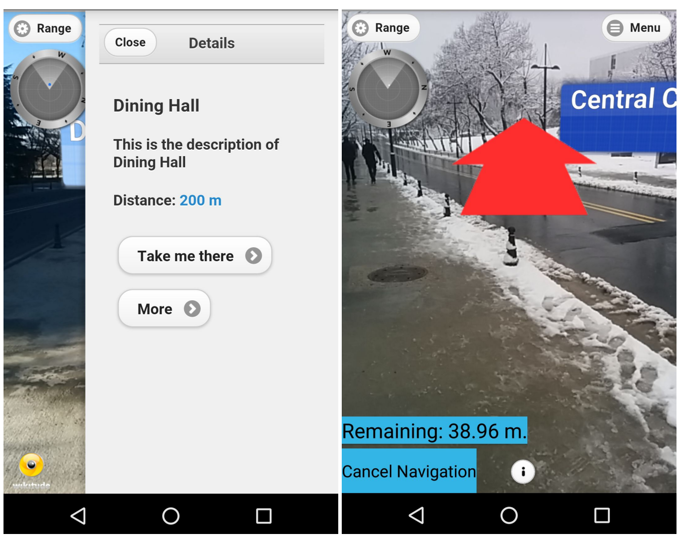
C. Navigation Application with an AR Browser Interface

POIs are presented to the user by blue boxes overlayed onto the phone's camera. POIs were defined as the buildings in the campus. The distance information between the user and the buildings are also presented. Users can also perceive their orientation to the buildings by using the radar component (Figure 5a). The features of displaying buildings in groups and searching a building from a dropdown list is also available in this application (Figure 5b). Moreover, users are free to define a range parameters to see the POIs that are located only within that range. This feature is useful if the user prefers to see only the buildings that are close to current location. A user can select any POI to see the detailed information about the building as in Figure 6a.



(a) POIs representation (b) Searh menu

Figure 5. AR browser application interface



(a) Detailed builging information (b) Target and waypoint representation

Figure 6. AR browser navigation interface

Since this interface uses the camera of the phone, the route information is provided using a first-person view. The route is displayed to the user as a series of waypoints represented by red arrows (Figure 6b). Once the user gets close enough to the first waypoint, the next one appears and user is directed to the second, and so on. If the new visible waypoint is not in the field of vision of the user, s/he gets directed with a small green arrow to the new waypoint (Figure 7).

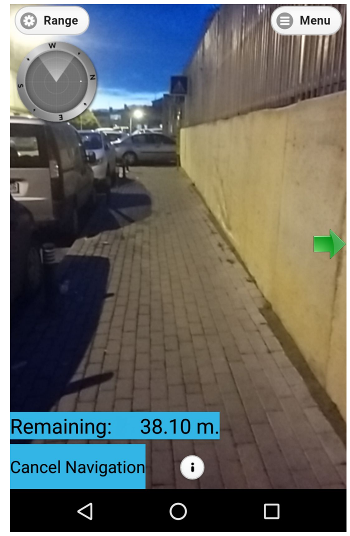


Figure 7. Arrow directing to the new waypoint

IV. Experiments and Results

A. Hardware and Software Settings

Both applications were developed for Android smartphones and tested with a Nexus 5 mobile device. The application with 2D digital map interface was developed using Google Maps API [22]. By using this API, Google's map is integrated into the application and GPS sensor data was fetched. For the application with AR browser interface Wikitude Software Development Kit (SDK) [23]was used. By using this SDK, any type of information can be easily augmented onto the camera view of the smarthphones. Coordinates, names and descriptions of POIs were arranged and uploaded to a web service. The application only requests this data when it is first started and parses the data to overlay the POI's information onto the camera view as shown in (Figure 5a).

B. Experimental Conditions

The user experience tests were conducted with two groups of participants consisting of 5 people each (3 female, 7 male) from ages 23 to 37. They were asked to follow predefined routes unfamiliar to them. Two successive routes were defined. First group of the participants were asked to follow the first route (699 meters) with the 2D map interface and the second route (307 meters) with the AR browser interface. Conversely, second group of the participants were asked to follow the first route with the AR browser interface and the second route with the 2D map interface. By doing this, the potential effect of task familiarity on the results was intended to be eliminated. The participants were instructed to think aloud during the tests. After each route was completed, the participants were asked to fill out two questionnaires about the interface they used. The first questionnaire was called NASA TLX [24] form, which consisted of six questions with a Likert scale of 1 to 21 (1: the lowest, 21: the highest). It is applied to the participants to obtain information about how much mental, physical, temporal and psychological work load they felt for the given task. The second questionnaire was the Post Study System Usability Questionnaire (PSSUQ) [25], which had 19 questions and measured the overall user satisfaction with the applications, usefulness of the applications, information quality and interface quality of the applications.

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C. Results

According to the demographic information about the users, none of them used an AR application before, whereas all of them used a 2D digital map application. Overall time spent by the two groups with the two interfaces are summarized in Table I. It is apparent that no matter which route was used, 2D digital map interface took less time to arrive to the destination than the AR browser interface.

TABLE I. MEAN ROUTE COMPLETION TIMES.

Group #	Route 1 (699 m.)	Route 2 (307 m.)
Group 1	with AR 13 min.	with 2D map 7.4 min.
Group 2	with 2D map 7.4 min.	with AR 8.2 min.

The results of NASA TLX questionnaire in Figure 8 showed that the application with the 2D map interface demanded less mental workload than the AR application. The probable reason for a difference of 2.3 points was that the participants used their intuition more with the AR interface to find the target. The application with the 2D map interface demanded less physical workload (4.8/21) than the application with the AR browser interface (12.6/21) since they needed to hold the phone always at the eye level to see the arrow and other information. Moreover, it was found out that AR browser interface caused negative feelings such as 12.9% more stress, irritation etc. because of the low stabilization of the arrow caused by hand movements and frequent GPS signal fluctuations. In terms of temporal worload, which was about how much time pressure the users felt due to the given tasks and whether the interfaces put the users in rush or not, the 2D map interface was evaluated higher by 2.2 points since some of the participants missed the route updates and then rushed to get on the previous route in order to not extend the distance towards the target. The results also show that the participants spent less effort to achieve the tasks with the 2D digital map interface (7/21) compared to the AR browser interface (9.5/21) since with the 2D application some of the participants looked the route only couple of times especially when they got close to the turning points, but with the AR application participants were always in the interaction with the application. Lastly, participants evaluated themselves more successful with the 2D digital map interface, since they arrived to the target location easier using the 2D digital map interface compared to their performance with the AR browser interface.

The results of PSSUQ is presented in Figure 9. In terms of user satisfaction, PSSUQ results showed that the 2D digital map interface (71.1% of user satisfaction) is better than AR browser interface (56.2% of user satisfaction). The reason that the users were less satisfied with the AR browser interface was due to the longer task completion times and the amount of the frustration they felt with the interface. In terms of interface quality, 2D digital map interface was considered simpler than the AR browser interface, which resulted in the 8.6% difference in the interface quality scores of the two interfaces. Moreover, 2D digital map interface was scored as 71% in terms of usefulness while AR browser interface was scored as 56% because the 2D digital map interface was easier to learn because it looked more familiar and usual than the AR browser interface, and also it was considered as more effective in the navigation tasks the participants fulfilled. Considering the information quality scores, because of the color choices (for some participants) and the low stabilization of the arrows the participants experienced with the AR browser interface, the 2D digital map interface was preferred. However, the radar feature of the AR browser interface was found useful by the participants since it helped them to stay on the right path during the navigation and also to get back on the right path when they got lost.

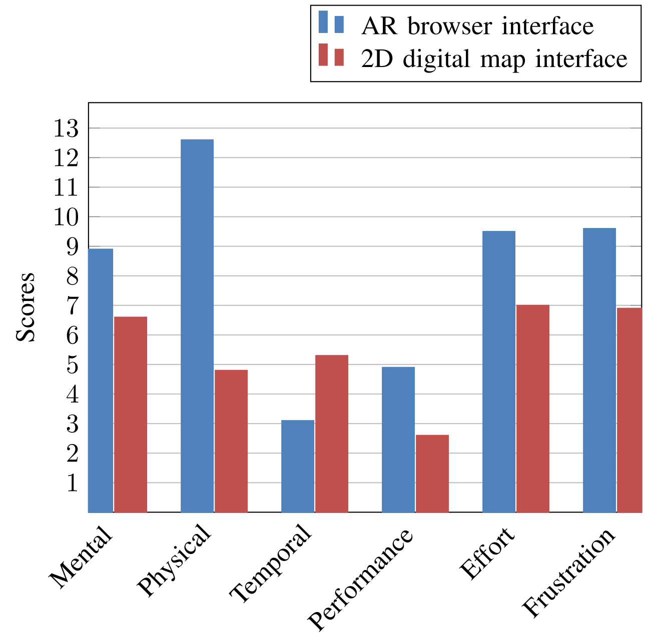

Figure 8. NASA TLX questionnaire results.

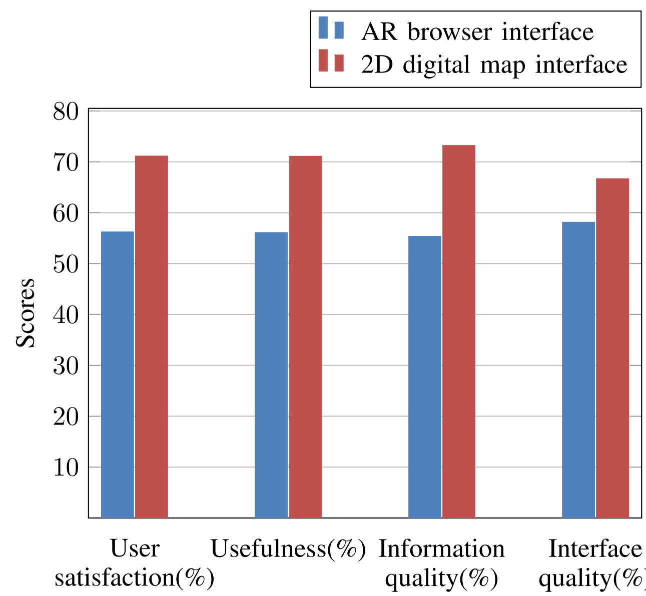

Figure 9. PSSUQ results.

Seven participants stated that they would prefer 2D digital map interface, whereas, three participants stated that the AR browser interface would be their choice. Moreover, four of the participants suggested that the combination of these two interfaces would be more useful. A seven degree scale (1: the highest, 7: the lowest) was provided to the participants to evaluate the degree of exploration they felt with the two interfaces. The answers showed that the 2D digital map interface helped

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them more to explore the area while walking and the average degree of exploration score given to 2D digital map interface was 4.3, whereas, average degree of exploration score of AR browser interface was 5.4 since using the AR application, users were regularly focusing on the arrow and keeping their eyes on the screen almost all the time. Moreover, the search places feature was mentioned as more useful in the AR browser interface especially when the POIs was overlapping.

Besides these questionnaires the thoughts of the participants stated during the experiments were also examined. At the beginning of the navigation task, each participant tried to orient him/herself to the map according to the direction that they are facing to. Some of the participants mentioned that radar component in the AR browser interface was helpful for finding the initial orientation. They also stated that the arrow, which shows the orientation of the user in the 2D digital map interface appeared and disappeared too much, which caused confusion about the direction to be followed. Moreover, participants stated that they had to look at the arrow all the time, which was tiring and might pose danger while walking. The blue boxes showing the target POI were mentioned as useful especially when they had difficulty to decide towards which direction they needed to walk. Most of the participants found the 2D digital map interface more helpful to get to know the environment and the route. However, when the GPS signal shows the user's location wrongly even for a moment, some of the participants got confused and felt anxious. In conclusion, all of the participants stated that the combination of these two interfaces would be more effective for a navigation task.

V. Conclusion and Future Work

In this study, two different mobile navigation interfaces were compared in terms of user experience by conducting an experiment using a navigation scenario. The results of the experiment revealed the advantages and disadvantages of both interfaces. Specifically, using 2D digital map interface participants spent less time to arrive to target locations. Moreover, in terms of physical and mental workload, the 2D digital map interface was less demanding. User satisfaction was found to be higher with the 2D digital map interface since the participants found it simple and functional for the given tasks. The radar component in the AR browser interface was considered useful for orientation and locating the target point.

As a future work, the combination of these two interfaces will be implemented, which was actually suggested by some of the participants. With this new interface, displaying the point of interests according to users' preference will be also provided. It is also thought to be a useful research that an AR application similar to the one in this study can be implemented in optical head-mounted displays, such as, Google Glass or Samsung Gear VR, and tested with the users in order to observe people's behaviour and usability of these type of devices in navigation tasks.

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