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Comparative Evaluation of Interfaces for Presenting Location-Based Information on Mobile Devices

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Abstract. Location-based information can now be easily accessed on mobile devices and is commonly presented in the form of lists of items, maps and more recently, augmented reality (AR). Each approach (list, map, AR) has its strengths and weaknesses. In this paper, we investigate the three approaches for searching and browsing location-based information, taking into account performance and users' perceptions of usability. Participants were issued with Android smartphones pre-loaded with a specific interface and performed a set of browsing and searching tasks. Results suggest that all three interfaces performed similarly for search tasks, but for browsing, the map performed worst. In terms of usability, participants appeared to rate the list better than the other interfaces for presentation location-based information.

Keywords: Augmented reality, maps, lists, user interfaces, evaluation, mobile information access

1 Introduction

Location-based information can now be easily accessed on mobile devices with the integration of features such as Global Positioning System (GPS) and wireless Internet capabilities. The information presented on mobile devices is commonly in the form of lists of items or on maps [5], mirroring that of desktop applications. However, the limited screen size in mobile devices and their mobile nature of use brings about a new set of challenges and opportunities for designers because visualizations that have been successfully employed in desktop applications may not be suitable for mobile devices [15]. In addition, the information needs of the mobile user are different from that of a desktop user as the mobile user is on the move [2, 6, 14]. For example, mobile users may require information based on the context that they are in (e.g. the train or bus schedule), gather information with a higher level goal (e.g. decide on a restaurant in the area that fulfills certain criteria) or obtaining information serendipitously (e.g. looking at the upcoming events in the area).

Recently, with the increasing capabilities of mobile devices, augmented reality [1] has emerged as a means to present information in location-based applications. Essentially, augmented reality (AR) interfaces superimpose location-based information over a live camera view of one's surroundings on the mobile device. By

doing so, the premise is that users are better able to understand one's environment by accessing this information. The growing interest surrounding AR has been spurred by easy-to-use applications such as LAYAR (<http://layar.com>), allowing users to experience AR from popular smartphone platforms.

With the live camera view showing the information available in the users' environment, AR interfaces may reduce the cognitive effort needed by the user to relate the information to the surroundings [11]. However, the camera view only focuses on a limited area, making it potentially difficult for users to orient themselves within the larger vicinity they are in. A list-based presentation, in contrast, is easy to understand and information is usually ranked according to some relevance criteria. It may however require more effort by the user to relate the information presented to the surroundings [5]. Finally, a map graphically displays information items according to their respective locations, allowing users to quickly grasp what is around them. A disadvantage is that map reading requires spatial awareness skills to orientate the map to one's surroundings [16].

Despite the diversity of presentation methods available for location-based information and their different strengths and weaknesses, a limited number of studies have been conducted to compare between them, to the best of our knowledge. For example, [20] compared a digital map interface with a physical map that includes AR features that superimposes content on the camera view. Findings suggested that the latter had a better performance. Further, [5] compared a map with a text-based interface for searching location-based information. Results were mixed as maps were not always the interface of choice among users. However, as yet, there have been no studies conducted to compare the three interfaces for presenting location-based information, namely, lists, maps and AR.

In this study, we fill this research gap by comparing the three approaches for searching and browsing location-based information. We take into account both task performance as well as users' perceptions of these interfaces. Our work is driven by the following research questions: (1) Which interface allows users to complete search and browsing tasks faster; and (2) Which interface for presenting location-based information is preferred by the user?

This paper is organized as follows. The next section gives an overview of related work. This will be followed by a description of the evaluation as well as the interfaces that were used. Next, results are presented. The paper ends by discussing the implications of the results, limitations as well as areas of future work.

2 Related work

List-based interfaces have been the starting point for displaying information on many mobile applications. Magitti [3] is a context-aware mobile recommender system designed to recommend locations of interest in a tourism setting. The primary interface is a list of recommended items that match a user's current profile and context. This list is updated whenever the context changes. A field evaluation suggests that the system was useful as a guide for recommending leisure activities. Next, CityFlocks [4] is a mobile application that provides location-based information

within a vicinity. A search interface is provided for information about places of interest. As in Magitti, results are presented as a list and ranked according to the likelihood of matching the searcher's interests. Findings from an evaluation showed that users found the content to be useful for navigating new environments.

Besides lists, maps provide an alternative presentation of location-based information on mobile devices. MobiTOP [13] offers a map-based interface for creating, sharing and seeking location-based content called annotations. Annotations are represented on a map by markers, and by selecting a marker, its associated content is displayed. In an evaluation of the application's usability in a geography field study setting, users reported to be satisfied with the map for information access as they were able to relate the information with the location. However, some found it difficult to view the map on small mobile screen. Next, SocialSearchBrowser [5] is a mobile application that uses a map to visualize location-based queries posted by its users. An evaluation was conducted to compare the application's map interface against a text-based version that presented queries in a list. Results were not conclusive, as of the 34 participants who took part, 16 participants preferred the map interface, 14 preferred the list, while four had no preference. Further, a more detailed analysis suggests that different interfaces are preferred in different situations, and that both options should be made available to users.

While AR interfaces have been developed and used over a number of years, it is only with the recent advent of well-equipped smartphones that they have now seen greater utilization. For example, the LOCUS project [18] presents the results of location-based searches using AR. A qualitative expert evaluation of the system suggests that LOCUS had an advantage over maps for displaying information because of the additional information that can be superimposed on objects being viewed, a feature which maps cannot offer. In a separate study, [17] compared a mobile AR map versus a standard mobile digital map to play a location-based game. Results were mixed in terms of usability as each interface type scored well on some constructs while doing poorly on others. Qualitative observations however suggest that the AR interface seem to encourage group discussion and public problem-solving.

In summary, evaluations for presenting location-based information tend to focus on one or at most two interface types (e.g. maps alone, or maps and AR). Further, such prior work usually involves small numbers of users (30 or less) and studies either performance measures or user perceptions. Thus, key contributions of our present research are that we investigate performance and perceptions across three different interfaces for presenting location-based information: lists, maps and AR.

3 Methodology

3.1 Interfaces Developed for the Study

Three interfaces – list, map and AR – were developed as separate mobile applications using the Android platform. These interfaces had a similar look and feel in order to maintain consistency across the applications. Furthermore, all three applications made use of the same location-based user-generated content from the MobiTOP [13]

system. Each interface was designed to display information items around the vicinity of the user. The application first obtains the current location of the user through GPS and queries the database for information that is nearby. Users can specify a search radius so that only information within it is retrieved. Further, each application allows users to search for information by keywords. The location-based information, also known as annotations, describes places of interest, and each contains a title, tags, description, location coordinates, one or more images of the location, as well as other metadata.

The list interface (Figure 1a) presents annotations with the nearest item at top of the list. Each list item shows the title, tags, description snippet, one image, date of contribution and the distance between the location of the annotation and the users' present location. Full details of the annotation can be viewed by tapping on it in the list. The map-based interface (Figure 1b) presents annotations as markers on a map. The user's current location is identified by a circle at the centre of the map, which can be navigated by panning and zooming. Tapping on a marker shows the corresponding annotation's full details. Finally, the third interface (Figure 1c) employs AR. Utilizing the browser interface provided by Wikitude API (<http://www.wikitude.org>), the interface displays nearby annotations by superimposing them over a live camera view. As users move around, the set of annotations displayed changes. Similar to other interfaces, users view an annotation's details by tapping on its marker.

3.2 Participants and Procedure

A total of 90 participants were recruited for the study. They comprised 47 females and 43 males between the ages of 17 and 39 and a mean age of 25. There was an equal mix of students and working adults. Participants primarily had Computer Science/Information Technology (47) and Engineering (27) backgrounds. The rest were from other disciplines such as banking and finance, construction, education, and marketing. Participants were frequent mobile phone users and a majority used their phones to share multimedia with their friends via social media services. Many were also frequent users of mapping and navigation services.

Participants were randomly divided into three groups of 30, with each using a specific interface. Each group performed the same set of tasks for browsing and searching. These tasks were modeled after typical information seeking activities that mobile users undertake [7] and involved real-world locations. At the same time, these tasks varied in their complexity of the information seeking process. The browsing task required participants to examine annotations via a particular interface to locate two places of interest (e.g. restaurants, buildings and shops). The searching task required participants to issue keyword searches then use a particular interface to locate two places of interest.

Each participant was provided with an Android smartphone pre-loaded with the assigned interface. All phones were of the same model to ensure a consistent experience. The researchers first introduced the study and the application. Participants also performed various familiarization activities. Following this, the study began and participants performed the searching and browsing tasks. Next, participants completed

a questionnaire that captured demographic data (reported earlier) and perceptions of their assigned application. Participants were also requested to provide qualitative comments about whether they liked their assigned interface.

Fig. 1. Interfaces used in the evaluation.

3.3 Measures

Measures covered two aspects. The first was the time taken to correctly complete the searching and browsing tasks. Each participant was accompanied by a researcher who recorded the completion time. As each searching and browsing task required the retrieval of two places of interest, the time taken was averaged, and these averages were used in subsequent analyses.

Secondly, participants' perceptions of the usability of the interfaces were also collected. Questions were rated on a scale of 1 (strongly disagree) to 5 (strongly agree) and consisted of the following constructs:

- Ease of use: the interface is perceived by the user as to not require a lot of effort to accomplish tasks [12].

- Learnability: the interface is easy for the user to learn and subsequently complete tasks [12].
- Efficiency: the interface enables the user to complete tasks quickly [19].
- Effectiveness: the interface enables the user to complete tasks accurately [19].
- Satisfaction: measures the degree to which the interface appeals to a user [9].

4 Results

4.1 Searching

Participants that used the map seemed to take the longest time ($M = 62.12s$, $SD = 33.13$) compared to those who used the list ($M = 48.26s$, $SD = 34.10$) and AR ($M = 53.38s$, $SD = 22.27$) interfaces. However, an ANOVA test suggested that these differences were non-significant.

In terms of perceptions, Table 1 presents the results of the various usability constructs. Separate ANOVA tests on the different constructs were conducted, and only ease of use yielded statistically significant differences across the interface types [$F(2, 87) = 4.02$, $p < 0.05$]. Post-hoc tests showed that the perceived ease of use for list and AR were significantly different, with the list interface performing better. There were no significant differences between list and map, or map and AR. Qualitative comments from participants appear to support our findings. Participants felt that using the list enabled them to “*locate the point of interest within a short span of time*”. Another who used AR highlighted that they found it “*hard to find the location*” especially if they were not familiar with the area.

The three interfaces performed equally for the other usability constructs. For example, most participants separately felt that they only needed a moderate amount of time to learn their respective interfaces as they were “*easy to learn even to a new user*”. All three interfaces were also reported to be efficient for locating information. For instance, a participant remarked that the list was a “*fast way to find information*”. In terms of effectiveness, the participants felt that relevant information was somewhat easy to obtain for all three interfaces. An AR participant commented that “*it did not require a lot of effort to complete the task accurately*”. Overall, participants were moderately satisfied with three interfaces for searching. For example, an AR participant remarked that the interface was a “*brilliant idea*”, while the list was “*simple and easy to use*”.

Table 1. Usability constructs results based on searching tasks for the different interfaces.

Constructs	List (N = 30)	Map (N = 30)	Augmented Reality (N = 30)
Ease of Use*	4.04 (0.57)	3.94 (0.55)	3.64 (0.55)
Learnability	4.44 (0.51)	4.33 (0.58)	4.10 (0.64)
Efficiency	4.08 (0.53)	4.01 (0.66)	3.80 (0.65)
Effectiveness	3.84 (0.61)	3.89 (0.71)	3.54 (0.77)
Satisfaction	3.69 (0.61)	3.73 (0.70)	3.57 (0.70)

* Statistically significant differences between the three interfaces

4.2 Browsing

For browsing, participants who used the map again took the longest time to complete the tasks ($M = 76.89s$, $SD = 46.61$) than the list ($M = 32.87s$, $SD = 20.59$) and AR ($M = 49.52s$, $SD = 33.45$) interfaces. This time, there were significant differences in time taken [$F(2, 87) = 11.97$, $p < 0.001$]. Post-hoc tests indicated that there were significant differences between map and list, and map and AR.

Table 2 lists results for the perceptions of the usability constructs for the browsing tasks. Participants who used the list found that it was easier to use than those who had used the map or AR. These differences were statistically significant [$F(2, 87) = 4.83$, $p < 0.05$]. Post-hoc results indicated differences between list and augmented reality interfaces. AR Participants commented that it was “*inconvenient to hold the phone and move around*” while almost all of those using the list interface had remarks with “*easy to use*” or its variants. There were no significant differences between list and map, or map and AR.

Table 2. Usability constructs results based on browsing tasks for the different interfaces.

Constructs	List (N = 30)	Map (N = 30)	Augmented Reality (N = 30)
Ease of Use*	4.06 (0.59)	3.86 (0.58)	3.61 (0.53)
Learnability	4.50 (0.52)	4.29 (0.62)	4.12 (0.65)
Efficiency*	4.14 (0.69)	3.81 (0.78)	3.72 (0.61)
Effectiveness	3.90 (0.61)	3.86 (0.74)	3.58 (0.74)
Satisfaction	3.77 (0.62)	3.63 (0.71)	3.57 (0.69)

* Statistically significant differences between the three interfaces

Unlike for searching, differences in perceptions of efficiency were also statistically significant [$F(2, 87) = 3.52$, $p < 0.05$]. Specifically, post-hoc tests suggest that the list was perceived to be faster for task completion than AR. There were no significant differences between list and map, or map and AR. This could be due to the fact that the participants who had used AR found it difficult to browse through the annotations especially when there were “*too many results and the pins (on the screen) overlapped one another*”. In contrast, the list interface provided “*fast response*” times possibly because it required the least graphically intensive among the interfaces.

Beyond these, the three interfaces performed similarly for the other usability constructs with respect to browsing. Put differently, participants found the interfaces easy to learn, and moderately effective in task completion. Participants were also relatively satisfied with their assigned interfaces.

5 Discussion and Conclusion

To reiterate, the objective of our work was to compare users’ performance and perceptions of three interfaces for searching and browsing location-based information on mobile devices. Our study yielded the following findings.

First, for searching, performance was similar across all three interfaces but for browsing, the map performed significantly worse than the list and AR interfaces. A key difference between the two tasks could have contributed to this finding. Specifically, the search tasks had an implicit assumption that participants had at least a vague idea of what they were looking for through the issuance of keyword queries. The queries effectively served as a filter to remove non-relevant annotations, thus leading to a less cluttered interface. This gave participants a better chance of ascertaining which annotations could fulfill the tasks' requirements. In contrast, the browsing tasks required more exploration of annotations for successful completion. Without the ability to execute keyword queries, participants had to manually sift through the annotations on their respective interfaces to determine which were relevant. Here, the list interface provided comparatively more informational cues than the map or AR interfaces, and hence likely contributed to the better performance. The AR interface presented markers without any other information, but because only markers associated with the current view were displayed, this indirectly served as a filtering mechanism, and participants could deduce which annotations were likely to be relevant by panning to a particular direction. The map however gave the fewest number of cues since all markers surrounding the participants' current location were presented, hence requiring the most time to complete the tasks.

Second, given the performance results, it was unsurprising that the list was rated best in terms of ease of use for search and browsing by participants. What was interesting however was that the AR interface was always ranked last despite its better performance when compared to the map. This divergence between perception and reality could be attributed to the relative newness of the AR concept in comparison to lists and maps, and the effort needed to use the interface. For the latter, participants had to physically move and hold up the mobile device in order to view the annotations [17]. This could be uncomfortable as fatigue could eventually set in. This pattern of results was also similar to the perception of efficiency for completing the browsing tasks. Again, the list ranked higher in terms of efficiency because participant had more informational cues than the map or AR interfaces. However, the map ranked higher in efficiency when compared to AR likely because the former was a more familiar concept. As a result, participants felt that the map was "*not cluttered*", and was therefore easier to locate annotations of interest. This perception arose because participants could easily zoom and pan within the map to reduce the number of annotations presented. While the AR interface had similar features, participants did not seem to use them as adeptly.

Third, although the list interface appears to have a slight edge over the other interfaces for presenting location-based information, the results when taken as a whole, are inconclusive. For example, while the list appears appropriate for browsing tasks, this advantage disappears for searching. In many information seeking situations, a combination of browsing and searching would be used [10]. Thus when these tasks are interleaved, the advantages of the list may become diffused. Further, differences between learnability, effectiveness and satisfaction were non-significant. This suggests that in the short term, users may find the list interface easier to use and more efficient, but as users learn to use the various interfaces, this usability perception gap may narrow.

Put differently, it appears that each of the interfaces have complementary affordances to meet the needs of users [5, 8]. Consequently, designers may consider incorporating combinations of the three interfaces in location-based applications. For instance, a list could provide an overview of the information within a vicinity, while an AR interface could help orientate a user by superimposing the information on the live camera view. Further, several design issues should be considered when integrating the interfaces:

- Enable users to select their default interface of choice for browsing and searching to cater to individual differences. Additionally, allow users to switch between interfaces easily to suit the task at hand.
- Map and AR interfaces should provide more informational cues to help users better discern relevant information around them. This is challenging given limited screen sizes but one approach is to embed information on the markers themselves. For instance, stronger hues on a marker could indicate more relevant content. The use of shapes and sizes could also be explored.
- To help manage information overload, filtering mechanisms need to be put in place, especially for map and AR interfaces. These should go beyond a coarse approach such as setting a limit for up to N nearest items to be displayed. Instead, techniques that consider a user's context should be included as well.

Despite the insights uncovered, there are some shortcomings that could be addressed in future work. First, our study was cross-sectional in nature and may favor familiar interfaces such as the list. A study that involves longer-term repeated use would be helpful in validating our findings. Second, participants' familiarity of the study's vicinities could be a factor in task completion time. Future work could involve a greater number of locations, both familiar and unfamiliar, for better comparison of results. Finally, individual differences such as spatial ability and experience with different interfaces should be investigated to attain a better understanding of the strengths and weaknesses of each user interface.

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