Mobile Augmented Reality: Exploring Design and Prototyping Techniques

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ABSTRACT
As mobile devices are enhanced with more sensors, powerful embedded cameras, and increased processing power and features, new user experiences become possible. A good example is the recent emergence of Augmented Reality (AR) applications that are designed for personal use while people are on-the-go. However, designing effective and usable AR experiences for mobile devices poses challenges for the design process. In this paper we outline reasons why simulating a compelling, mobile AR experience with sufficient veracity for effective formative design is a challenge, and present our work on prototyping and evaluation techniques for mobile AR. An experiment within the context of an ongoing design project (Friend Radar) is presented along with resulting findings and guidelines. We reflect on the benefits and drawbacks of low, mixed and high fidelity prototypes for mobile AR by framing them into a set of analytic categories extracted from the existing literature on prototyping and design.

Author Keywords
Mobile; Mobile HCI Augmented Reality (AR); design; design process; prototyping; experiment; interview; methodology; service design.

ACM Classification Keywords
H.5.2. Information interfaces and presentation (e.g., HCI): User Interfaces, Prototyping.

INTRODUCTION
As mobile devices grow in power, capabilities and features, doors open for designers and engineers to create new experiences and applications. Augmented Reality (AR) applications are expanding in terms of function, not least because of the growing capture, sensor and location-sensing capabilities of emerging mobile devices. As a result, mobile AR applications are increasingly useful and appealing. Recent research suggests that mobile AR could be responsible for amassing an enormous amount of profit in advertising, games and applications in general as it becomes increasingly feasible and popular [12].

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Early experiments with mobile AR required considerable amounts of equipment in their creation [1, 29], equipment that arguably produced decrements in the user experience and therefore in the user's assessments of the benefits of such applications. By contrast, current smart-phones can easily support this type of experience in real world settings. In addition, utilizing GPS and integrated compasses, the combination of AR and location-enabled and positioning services [17, 15] means that it is now possible provide users with ways to use AR and gain easy access information about their surroundings while on-the-go.

Nevertheless, significant design challenges are posed by the ever-evolving hardware, features and capabilities of mobile devices and the services they utilize. While assessment of the usability of specific interface or interaction design features yield well to laboratory-based evaluation of static of minimally interactive mock-ups (e.g., is the target area large enough to be selected?, is the font readable and in what lighting conditions?, is the image occluding other content?), full service ecosystem design, such as those imagined for mobile AR applications do not yield so well to such methods. Therefore, designers are required to come up with new ways to convey their visions and test their concepts when designing new services, services that draw on real-time information from multiple sources using interaction methods that are often unfamiliar to users. To prototype the envisioned, fully-fledged service is obviously costly and will result in premature, often non-retractable, commitments within the service design; such premature commitments are precisely what iterative design and evaluation are aimed at circumventing. However, these are rarely applied to AR [28] and, to get useful feedback from users, it is necessary to create an experience that is 'realistic' or provocative enough of the envisioned scenario of use such that users are able to give meaningful and actionable feedback. Herein lies the tension we address in this paper: *how to create a user experience that is sufficiently "realistic" and provocative for users to envisage the final service experience and thus give meaningful and actionable feedback without building the whole service ecosystem?*

In this paper we illustrate our design methodology, through description of our approach to designing a mobile augmented reality application called Friend Radar. We utilized three different techniques to prototype our concept: (1) a low-fidelity prototype (i.e., mock-up and Wizard of

OZ); (2) a mixed-fidelity prototype using video and (3) a high-fidelity working prototype used on an actual smart phone. Using these three prototypes, we conducted a set of in-situ evaluation sessions, gathering feedback from users in real life scenarios. Our application focuses on allowing users to find whom of their friends are in the local vicinity by displaying icons and avatars overlaid on the current camera-rendered location, showing distance and direction in relation to the user.

Our contribution emerges from the findings on the use of the three different prototyping techniques for mobile AR. In particular, we detail the benefits and drawbacks of each approach and the settings, scenarios and phases of the design process (such as during early ideation or later stage evaluation) in which they may be best used.

BACKGROUND AND RELATED WORK

Recently, with the growing proliferation of smart-phones, mobile HCI researchers have been not only focusing on interface usability and user experience but also on tackling the growing design challenges that come along with new technologies and services [10, 28]. In particular, dealing (1) with the multiplicity of contexts, (2) the real world settings, (3) simulating real-time services or location-based services and (4) the newer features and modalities that mobile devices support, have been major challenges. To overcome these challenges, new techniques have emerged that cope with these issues, providing new design guidelines [9], prototyping [5] and evaluation techniques [30, 6].

Design Methodologies and Prototyping Techniques

In particular, motivated by the new form factor and usage paradigm that mobile devices afford, strong emphasis has been placed on how to effectively create prototypes that can be used to validate concepts at early stages and, preferably, during out of the lab field tests. This offers users a better perspective of how the system will be used thus resulting in better feedback for the design process. However, for mobile AR, given the tight coupling with context and, for visual-based AR, the real world view through the camera feed, simulating windows, menus and icons is not sufficient [5].

From the HCI and prototyping literature [31] and more recent mobile related experiments [5, 14, 18, 19, 32] two main prototyping approaches can be found: (1) low-fidelity and (2) high-fidelity prototypes. While the former are usually easily and quickly built, using mock-up and paper to simulate a working system (e.g., Wizard-of-Oz), the latter generally offer an experience closer to that of the final product, allowing users to interact with working software, at least to some extent. More recently, experiments have been trying to understand the value of the middle ground between these two approaches, using mixed-fidelity prototypes [22]. These aim at bridging the gap between low- and high-fidelity prototypes by introducing the flexibility of the former but still providing means to increase the degree of visual refinement or interactivity [22], adjusting the prototype to the desired goals.

Nevertheless, very few accounts of prototyping for mobile AR are available in the literature [8].

Mobile Augmented Reality Channels and Trends

Augmented reality and mixed reality are concepts that have been used around technology for more than 20 years [1,3, 20, 21, 25]. However, their coupling with mobile devices has only been made possible more recently with the advent of powerful smart-phones and new and smaller sensors (e.g., GPS, cameras). Consequently, cumbersome, intrusive equipment is no longer required to create these experiences. Moreover, as previous work has shown, augmented reality provides new affordances and visualization options that enhance experiences by providing additional information combined with the real world surroundings of the users [29, 1, 25, 15]. By placing virtual objects over reality users are provided access to information that is typically not available to them using their own senses [1]. Naturally, this gains further relevance with mobile technology as users move around and are able to explore what is around them freely within real world settings [2][25].

With technological advances in the field of sensors (e.g., GPS, Accelerometers, Gyroscopes, Cameras) a number of mobile AR trends have recently emerged. Visual-based AR is the most common trend and represents the majority of existing applications like Yelp's Monocle[1] or Layar[2]. With visual mobile AR, applications typically overlay additional information on top of what the smart-phone's camera captures, displaying a combination of the real world with added information on top of what is around the user. The majority of such applications are strongly based on location services, providing information on the user's surrounding [2]. Within these we can find a wide variety of services that are oriented mostly towards search, entertainment, gaming, daily life support applications, advertising and shopping.

The two other trends within mobile AR, far less popular and very much underexplored, make use of the additional feedback channels available on most smart-phones – haptics and sound [11, 33]. A traditional example is the common eyes-free turn-by-turn navigation system that uses speech to provide directions to its user. However, more recently, some research efforts have been combining the use of haptics and sound to augment reality at specific locations, providing context-awareness of additional information used both in gaming apps (e.g., treasure hunts) and commercial or advertising applications (e.g., play a jingle/song when close to a certain shop).

Challenges

However, despite the new opportunities they provide, these new features and capabilities now available on most smart-phones present new challenges, especially when creating such rich interactive experiences [5]. Specifically, AR on mobile devices is still very new and few guidelines or

[1] Yelp – http://www.yelp.com
[2] Layar – http://www.layar.com

documented accounts on how to design such rich experiences are available [5, 27]. Furthermore, despite the highly enthusiastic projections for its adoption in the near future, the majority of users, even savvy smart-phone aficionados are not aware of the existence of AR for mobile devices, nor what the concept means. Therefore, designers are faced with the challenge of how to test and validate their ideas at initial stages of the design process.

Although some reports on designing mobile AR can be found, most refer to highly complex settings and infrastructures, defined for very specific purposes [1, 1, 17, 15] or are strongly focused on the hardware constraints [4, 1]. Still, despite being a medium that serves as a window to the user's reality, amplifying actions or activities and changing the user's perception of the world, studies on design or from a user-centered perspective are scarce [5] and accounts on prototyping are almost non-existent [8]. As a consequence methods and techniques for the design of mobile AR are yet rarely studied or defined but increasingly needed.

THE FRIEND RADAR CONCEPT

The Friend Radar concept merges social networks, messaging tools and location-based services, and makes use of AR. Information is presented in a way that allows users access to friends' information without losing the current, local, physical context around them.

The Friend Radar concept draws data from existing technologies such as social networks like Facebook[3] and Google+[4], location based apps/services such as Foursquare[5] and similar check-in tools and previous experiments designed specifically for mobile devices like DodgeBall Social. However, the Friend Radar aims at enhancing the experience by providing an enriched visual display of friends overlaid on the users' surroundings. In particular it provides added affordances that allow users to see where friends are situated in relation to him/her and their distance. It also presents details such as preferred friends, directions where groups of friends are located and their availability meshed with the real world. In opposition to map-based radars, this AR based concept does not require users to translate two-dimensional views into their surroundings, which is especially relevant at non-familiar locations.

Our goals with this concept, in this initial stage, are to show friends' positions in relation to the user, including details such as proximity and availability. Friends' location and status can be retrieved from various sources (e.g., Messenger apps, Social networks) and their avatars configured, being overlaid over the locations to which the user is pointing his/her camera/device (Figures 3 and 4). In addition, tapping on a friend's icon displays his/her profile with information from the service they are using at that moment and allows for some types of communication (e.g., sending a message or alert) – Fig. 1. Overall, it merges the social network experience with the real world, enhancing it with additional, contextually relevant, information.

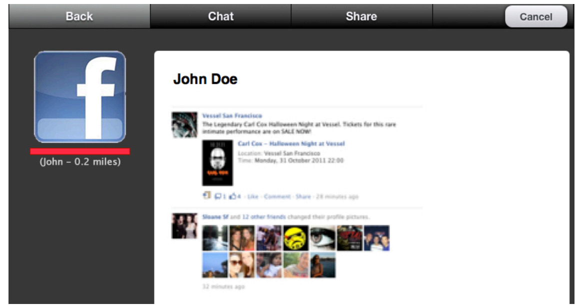

Figure 1. In addition to the AR interface, users can retrieve detailed information on distance and friends' activities.

Design Approach

The design process we are following is focused on users. Our aim is to understand the best way to provide users with realistic experiences at early stages of the design process and, from a methodological perspective, understand which are the best approaches to prototype for mobile AR. In an area that is growing so rapidly, it is crucial to understand what it means to prototype for mobile AR and to be able to create the experiences for end-users, without committing to costly development processes.

In particular, some of the techniques used for the initial design stages are based on previous experiments for mobile interaction design [6]. As suggested by recent literature, better results can be achieved while designing mobile interaction when immersing users within realistic scenarios, including prototypes and in-situ tests [6, 30, 24]. In order to do so for AR, our goal was to approach the design process by experimenting with different prototyping techniques and exploring the benefits and drawbacks of each.

PROTOYPES

Three different mocks/prototypes for the Friend Radar concept were created. To build these we used three significantly different approaches – low-, high- and mixed-fidelity - but following the same philosophy: to create a prototype as close to the real experience as possible in terms of form factor and weight. Our hypothesis was that each prototype would yield different advantages but, given the highly interactive nature and rich experience that mobile AR presents, best results would come from the higher fidelity prototypes.

Low-fidelity mocks

The lowest fidelity prototype used for this study was built using a dummy/non-functional device (e.g., a product design mockups that was created typically to illustrate a form factor design). The dummy phone mimicked a common Android device with a 3.5-inch screen (Figures 2 a) and b). In order to simulate the camera feed, the screen

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3 Facebook – http://www.facebook.com
4 Google+ - http://plus.google.com
5 Foursquare - https://foursquare.com/

was removed and a hole was cut on the back cover of the phone (the inside of the dummy phone is hollow). A transparent screen was placed on top of this hole to simulate the device's screen (e.g., reflection) and to allow users to easily use it as a touch input device, while maintaining the ability to see through (see Figure 2a). In addition, this screen was also used to allow for an easier use of the Wizard-of-Oz technique, where small icons were glued to the screen to simulate the augmented reality. For the moving avatars longer pieces of paper were used. This facilitated their movement by the "wizard" simulating the actual location-based interaction.

Figure 2. a) Low-fidelity mock. The see-through hole allows users to see what is behind the device, simulating the camera.

Figure 2. b) Low fidelity mock and used icons (right) next to an actual working device with the hi-fidelity prototype (left).

A small amount of clay was also added to the fake phone to slightly increase its weight and make it identical to an actual functioning device. The building process lasted approximately one hour, including the creation of the attachable icons (e.g., map, avatars) and weight add-ons.

Mixed-Fidelity Videos

For the second prototype, a mixed-fidelity prototyping approach was used, combining aspects from both low and high fidelity prototypes. In particular, for this case, and following the categories defined by McCurdy et al [22], the degree of visual and aesthetic fidelity was high while the interactivity remained low. Our hypothesis was that using video would be an adequate approach to simulate a realistic in-situ experience at a very early stage, as it allows simulating movement and including additional content over captured footage, displaying it directly on mobile devices.

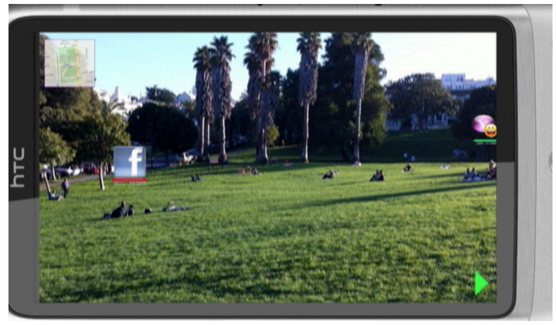

Figure 3. Video of the mixed-fi being played on a smart-phone.

To create the prototype, two different locations were selected. Videos were shot beforehand. For the first location, a public park with a few people sitting down and walking around was selected (Figure 3). The second set of videos was shot in a busy square with shops, buildings and people walking and standing in different areas (Figure 5). Both locations were selected because they represent places where friends usually meet-up, seek encounters and congregate. Each video had an approximate duration of 30 seconds and included light panning and some jitter to emulate a realistic usage scenario (i.e., scanning the area for friends).

Figure 4. High-fidelity prototype. The icons are overlaid on the camera feed and move with the phone's movement.

Once the videos were captured, they were edited and the friends' icons were overlaid using a video editing software. This process took around one hour for each of the videos. Icons were placed hovering above people's heads. Those placed over people that were walking followed that person around, simulating a connection between the person and the avatar (Figure 3). The videos were exported to a phone, used during the evaluation sessions.

High-Fidelity Prototype

The high-fidelity prototype was developed using the Android Development Kit. The prototype uses the camera feed, displaying it live and showing whatever the camera is capturing. On top of this feed, shown on full screen mode, a set of icons and avatars is also displayed on semi-fixed positions. Using the accelerometer and compass sensors, whenever the device is rotated, the icons and avatars will maintain their position in relation to the surrounding environment. They will be occluded when the device is not facing the icon's position. This offers an accurate rendering of mobile augmented reality (Figure 4).

In addition to the interactive view, this prototype also includes the possibility of interacting with some of the icons. Once an icon is tapped, a second screen displaying detailed information about that person will be shown (see Figure 1). The working prototype required approximately 2 working days to be fully developed. We note that the icons had already been designed for the previous prototypes.

EXPERIMENT

Our goal with this experiment was to assess the benefits and drawbacks for each approach–the low-fi, the mixed-fi and the high fidelity prototypes–evaluating the trade-offs and adequacy of each technique to different scenarios.

	Development Time	Skills and tools	Location Dependent
Low-Fidelity	30 minutes	Wizard of Oz	No
Mixed-Fidelity	1 hour (per location)	Video editing	Yes
High-Fidelity	2 Days	Programming knowledge	No

Table 1. Summary of requirements and development time for each prototyping approach.

When compared with storyboards or simply describing scenarios to users, we felt this in-situ approach, using artifacts that could be seen and touched by the users, would be much more beneficial to the design process. Accordingly, we set up a short experiment where we used all the prototypes for users to experiment in-situ, simulating a real life situation. As a result, we expected participants to (1) clearly understand the concept without any explanation; (2) detect some of the features presented through the prototype; (3) validate some of the idealized functionalities; (4) assess the concept's usability and (5) use it as an exploratory tool regarding users' expectations for such an application.

Evaluation Sessions

The experiment was conducted following a *guerrilla* approach [23]. The overall idea on this approach is to rely on methods that are not strict and can be easily adjusted to situations where costs (both financial and effort wise) have to be kept very low. It assumes that a simple scenario is set and, using a prototype, a set of quick tests with a small group of users take place, producing highly valuable results when compared to the effort the approach takes.

For our study, participants were approached directly, while relaxing or idling, at the same locations where the videos were shot. These locations were selected for all the three prototypes in order to avoid any bias that the location and environment could introduce into the study but also to fake reality. Participants were approached and were selected randomly. Each participant was invited to participate by one of the researchers while another researcher filmed the experiment.

A total of 24 users participated in these sessions and interacted with or visualized prototypes. Much in line with similar exploratory and detailed experiments, and field studies [24, 1, 16, 30], a group of 8 participants interacted with each type of prototype. Participants for each prototype were divided into two groups (one per location). Each session took around 1 hour, in addition to the time spent interacting with the prototypes and responding to the questionnaire (detailed on the following sections). No gratuities were provided and participants authorized the filming. The goals of the experiment were not explained beforehand.

For the low-fidelity prototype, participants were only explained what technique would be used and requested to imagine it as a functioning application. One of the researchers involved in this experiment played the Wizard and held the icons in front of the device at different locations, allowing the participant to see these icons whenever pointing the device at them.

For the video prototype, participants were only requested to visualize the prototype for the duration of the video. Each participant was handed the smart-phone immediately after one of the researchers had pressed play. Participants were also allowed to review the video again if so desired.

Finally, for the high-fidelity prototype, participants were handed the phone and requested to play and interact with an application that was being developed.

Once again, we emphasize that no explanation on the type of applications or its goals was provided to any user. We intentionally omitted this information to test how easy it would be for users to understand what they were doing based on the prototype alone.

Once finished interacting (or visualizing) the prototypes, participants were asked to provide their opinion through a short set of questions during a follow-up interview. Most sessions were filmed for additional analysis.

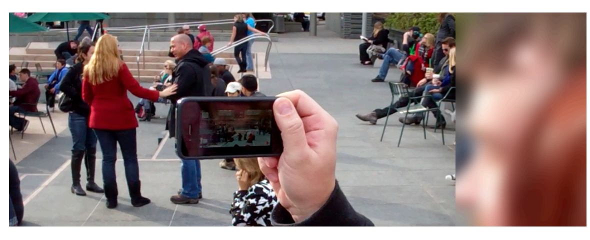

Figure 5. User testing the video (mixed-fidelity) prototype on a busy urban location.

Post-experiment

Follow-up interviews took place immediately after the participants used the prototypes. Tests lasted around 5 minutes for the low-fidelity prototypes, from 1 to 2 minutes for the video prototypes (depending on the number of times the participant watched the videos) and approximately 3 minutes for the high-fidelity prototypes. The interviews took from 5 to 10 minutes on the questionnaires and from

30 minutes to one hour for follow-up comments and discussion (here participants were allowed to freely explore the prototypes). The goal was to establish a comfortable conversational setting for participants from which we could gather data and understand their motivations and responses in as much detail as possible.

The majority of the questions were pre-defined on a script while others emerged during the interview and follow-up conversations. On the questionnaire, participants were requested to rate the prototypes and experiment using a 7-point Likert scale (1 – strongly disagree; 7 – strongly agree) with regards to realism, ability to convey the concept and easiness to understand. Again, the goal was to focus on each prototype's ability to convey a concept, its features and support early stage identification of issues and advantages. A set of questions regarding the application per se (e.g., user interest in using it, privacy) was also included.

RESULTS

Participants who interacted or visualized the prototypes were aged between 17 and 48 years. Their professions ranged from students (14), customer service representatives (2), teachers (2), attorneys (2), strategists (1), and financial advisors (1) to unemployed (2). From the 24 participants, only 5 stated not owning a smart-phone. Only three in 24 participants had any previous contact with AR applications while 6 knew what the expression meant and could explain what the concept was. Once again, the sample size for our study followed the standard for in-situ mobile evaluation available throughout the literature [24, 1, 28, 16, 30], allowing for rich, interactive and highly detailed sessions.

As expected, there are some significant differences between the three approaches. The following sections detail the results for each type of prototype.

Low-Fidelity Mocks

The low-fidelity mock-ups, using the dummy phone and the Wizard-of-Oz approach produced the poorest results. As shown on the chart on Figure 6, the majority of users had difficulties understanding the concept just by holding and panning the mock. Six out of 8 participants disagreed that it was easy to understand the goal of the app or what they were looking at. Interestingly, given that the Wizard promptly showed the avatars/icons whenever the participant pointed the phone to the right direction, 5 of the 8 participants stated that it was easy to understand how it would work, despite not comprehending the goal of the app or the content being shown.

Regarding the prototype's realism, all users were adamant that the prototype did not feel real or look real in any way, that it was clearly just an experiment and that should not be taken very seriously.

Finally, once the questionnaire had been completed, our concept for the applications was explained. After receiving the explanation, all participants understood the concept and application functionality, and all replied positively when enquired on whether they would use the app (Figure 9).

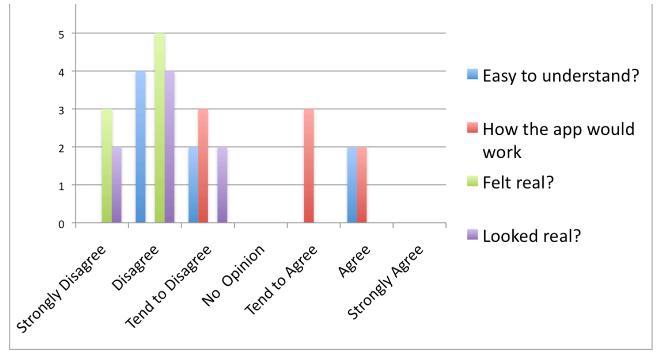

Figure 6. Results from the tests with the low-fidelity prototype. Users had trouble understanding the concept.

During the interviews that followed the tests, but prior to the explanation of the concept, most people did not understand the concept:

> "I just don't get it. I just see a fake phone and someone showing me pieces of paper."

There was one exception to this:

> "I get what is happening. As I move the phone different things are shown. I'm seeing on the device things that could or should be there but that I don't see by myself, right? I just don't know what those things are!"

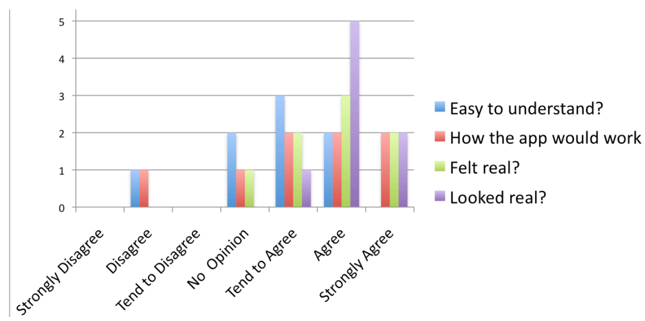

Figure 7. Results from the tests with the video prototype.

Mixed-Fidelity Videos

Results for the video (mixed-fidelity) prototypes can be seen on the chart (Figure 7). Five out 8 participants thought it was easy or very easy to understand the concept just by viewing the 30 seconds video. The majority also stated being able to understand how it would work (6 out of 8) and that the prototype felt and looked real (7 out of 8). Six out 8 users showed great interest in the concept and stated they would use the application. No further explanation on what the concept was or which features would be available was given before enquiring about participants' interest in the Friend Radar app.

From the post-test interviews, some of the participants, having understood both the concept and interaction mechanisms, mentioned:

"It would be cool to touch the icons and see something happen like showing that user's Facebook profile"

One participant had some trouble understanding the basic interactive features stating that:

"I think it works great to show how the app would work or look like but it's not the best way to see how I would use it."

In regards to the actual concept and their interest in the application, most users were excited about the possibility of using it. In particular, one user said:

"When will it be available? I would love to have this app!"

High-Fidelity Prototype

Surprisingly, results from the high-fidelity prototype were less positive than those from the mixed-fidelity prototype (Figure 8). Only half of the participants (4 out of 8) tended to agree, agreed or strongly agreed that the concept was easy to understand by interacting with or using the prototype. However, as shown on Figure 9 the majority of participants replied positively when asked if it was easy to understand how the application would work. On this question, only one participant (who never owned a smart-phone) strongly disagreed and another tended to disagree. With respect to realism, results were substantially better and the majority of users (6 out of 8) were positive about whether the prototype felt and looked real.

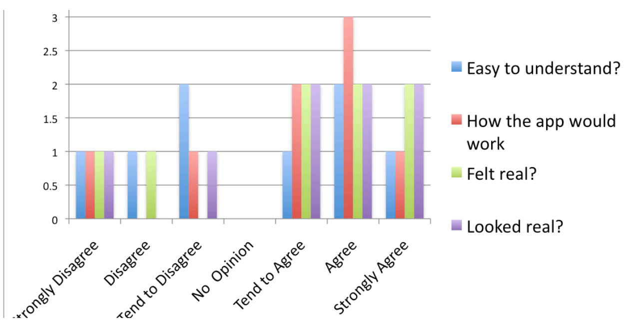

Figure 8. Results from the high-fidelity prototype tests.

During the interviews, some participants commented on the responsiveness and interactivity of the prototype:

"It's a bit slow and it doesn't do much. Is it this all it does?"

Another participant mentioned the icons were too small:

"It's difficult to hit the buttons on this tiny screen when they are always moving!"

Interest and acceptance

Once the questionnaire had been completed, the concept and features for each prototype were explained to participants. As noted above, when asked about whether they would be interested in using such an application post this explanation, people were largely positive (Figure 9).

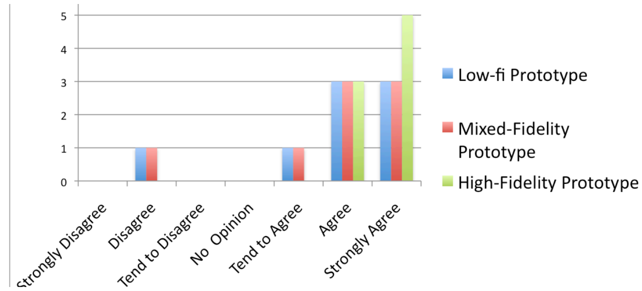

Figure 9. Results from the final question. The vast majority of participants stated being very interested or interested in using the Friend Radar application.

DISCUSSION

Our goal in this investigation was to explore the extent to which different kinds of prototype can be provocative and inspire a sense of an envisioned end-user experience in order to get feedback that would be valuable for the design process. The value of role-playing is well established but our concern was that for AR, effective props would be necessary to make the role-playing realistic and engaging enough to get useful feedback.

Each of the three prototyping techniques showed some potential benefits for application/service evaluation. Two in particular easily conveyed the idea that was being tested, without any explanation and to users who had no previous knowledge of what mobile AR means.

In analyzing our results, we derived a number of analytic categories–these were inspired in part from previous literature on prototyping and evaluation. We use these categories to reflect on users' reactions to our prototypes.

These categories are shown in Table 2, and are as follows:

- Probing – triggering users imagination in a provocative way and using the prototypes to explore new applications, concepts and usages for technology being studied [13, 26].
- Concept Validation – addressing the concept in general, the overall idea of the application and its goals, by presenting it to end-users and requesting their feedback.
- Feature Validation – validating the different features and functionalities that compose the application in more detail.
- Usability Testing – addressing interface usability issues and breakdowns and assessing efficiency and ease of use [23].
- User Experience Evaluation – understanding users' feelings, opinions, expectations, acceptance, pleasure and deeper emotions regarding the experience of use.

	Probing	Concept Validation	Feature Validation	Usability Testing	User Experience Evaluation
Low-Fidelity (Mock-ups and WOz)	Good for probing as it allows to easily add features.	Not very good to demonstrate the concept or interaction flow.	Difficult to demonstrate features but easy to include new ones in-situ.	Not great to test usability issues, but enough to validate icon size and readability.	Not adequate to evaluate more complex dimensions such as excitement, aesthetics, etc.
Mixed-Fidelity (Video)	Not great for probing as it is non-interactive and non-flexible.	Very good for concept validation as it shows features and interaction flow very easily.	Good for simple features. Difficult to demonstrate more complex features as it is non-interactive.	Not ideal for usability testing but still allows for the detection of some issues.	Good to assess some aspects of user experience (e.g., aesthetics, flow).
High-Fidelity (Functional Prototype)	Supports probing to some extent but does not allow for in-situ add-ons.	Good for concept validation mainly because it is interactive.	Good for feature validation as it allows users to explore them in detail.	Very good for usability testing as it supports interaction and functionality.	Good for experience evaluation, if care is taken to polish the interactivity.

Table 2. Summary of benefits and drawbacks from the different approaches.

Low-fidelity

Throughout the tests conducted with the low-fidelity mock-ups and using the Wizard-of-Oz technique, it became clear that there were significant challenges to applying this approach for such a rich and novel experience as augmented reality. Nevertheless, despite the difficulties in applying this technique in-situ (which, from our perspective might generalize to all mobile design in general), the low-fidelity prototype showed the greatest flexibility. The possibility of maneuvering the icons according to the situation, adapting features and behaviors on the fly had a positive impact on the study (Table 2). It's easy to update format yields very well to probing purposes as it is easy to quickly create new icons and add features on-the-fly. Although the prototype did not look or feel real, it allowed participants to understand how it would work (i.e., being aware that they would be able to see information added to the world through phone's). In addition, the low-fi approach benefits from being location independent (i.e., can be used at any location). Finally, the relatively easy building process is also a major advantage of this approach.

However, although low-fidelity prototypes are great tools for initial stages of design, for the particular case of mobile AR, as already mentioned, their evaluation and use during in-situ tests is both difficult to achieve and cumbersome. The process itself becomes distracting to users and detracts from the validity of the experiment, making it difficult to validate an unknown concept with end users. Moreover, it requires an additional person to act as the Wizard, further increasing the effort to experiment these prototypes on the field. Finally, as our results clearly show, the low-fidelity prototype provided the poorest results and was the least successful in conveying our idea and concept to participants and for the detection of some usability problems (see Figure 7 and Table 2).

Mixed-fidelity

The second approach used in this experiment, video based mixed-fidelity prototypes showed some interesting benefits. They provided a realistic way to convey the concept to users, even at very early stages. Results showed that users understood the concept without any previous explanation, even those without smart-phone and AR experience.

Crucial to these results was the ability to visualize the video prototypes on the same location where the videos were captured. This allows users with no experience or knowledge of AR applications to quickly grasp the idea and understand the concept (as shown in Table 2). An interesting finding that emerged from the experiment was that some of the participants started following the video movement (e.g., accompanying the pre-set panning from the captured footage), reenacting the actual scene, without any suggestion to do so. This leads us to believe that users quickly gain awareness of what is happening on the video and how the prototype would be used in real-life allowing the validation of the concept and simple features (Table 2).

Another benefit, which is common to other types of prototypes, especially when used in-situ, video for AR design promoted user participation and triggered their imagination for features and usages. When interviewed, several users suggested different usage possibilities for some of the icons and UI details as well as the app's goals (e.g., discovering what the others are wearing). The greatest advantage of this approach, however, is the degree of realism and level of fidelity it provides for the effort and time it takes to build. Simulating mobile AR with video is a quick process that requires no coding or programming knowledge yet has several benefits (Table 2).

Despite the positive results in terms of providing a good idea of the experience and showing users the concept of what is being designed, there were some shortcomings on using video as a prototype. In general, the majority of the experiment's participants felt the need to experience interactivity. Several participants tried to interact with the icons on the videos without any feedback in return, which caused some confusion and frustration. Moreover, it is possible that video prototypes require similar conditions when testing to those that were available when filming the initial videos. Further tests will be conducted to validate this hypothesis. However, although weather conditions were slightly different (e.g., sunny morning vs. grey afternoon) from video to test, both locations provided similar results. It is also noteworthy that some affordances and features are not easily perceived through video (e.g., the use of gestures) – see Table 2. Usability testing.

Overall, these results show that to make this approach more ecologically valid, further work is required, especially in regards to how interactive the prototypes are. As used, the video was clearly a very provocative experience that triggered users interest and clearly demonstrated the concept. However, some of the features and the lack of different affordances and interactivity were clearly a drawback and merit further research.

High-fidelity

From the three approaches, the high-fidelity prototype was expected to show the best results, as it is closest to an actual working application. Unsurprisingly, our test showed that this was, in fact, the best approach in terms of realism, feeling and looking real for the majority of users. In particular, the ability to immediately match the surroundings (including passers by) with what is being displayed is a determinant factor to support this result. Furthermore, the interactivity that can be achieved with a developed and functioning prototype is far greater than that which can be achieved with the two previous approaches, making it especially adequate to explore available features and assess user experience (Table 2). This also facilitates usability testing, as users are able to interact with the various elements of the user interface, allowing for the detection of functional and interaction issues (see Table 2). Finally, the ability to display the camera feed also makes this a location independent approach.

However, despite the clear advantages that creating a working prototype has over video or low-fidelity mock-ups, there are important drawbacks to this approach, very noticeable on our experiment's results. One of the main reasons behind these less than optimal results comes from the fact that, when users interact with an actual device and notice the live video feed, expectations are raised to much higher levels. Even when faced with a working set of features and a higher degree of interactivity, participants stated that the prototype did not look real merely because of the response time to some of their actions (e.g., tapping the icons) or because of the resolution of some of the icons. Some of the comments and reactions during these tests suggest that results from our questionnaire might not match reality, especially if compared to the other approaches. Future experiments will address this issue by presenting different approaches to the same participants at different stages of the design process.

The major drawback from this approach, however, is the effort and knowledge it required to be developed, in comparison with low-fi and mixed-fi prototypes. Moreover, the ability to update and adjust prototypes on the fly is also unavailable and new prototypes have to be developed for different platforms (i.e., iOS, Android, Windows Phone).

CONCLUSIONS AND FUTURE WORK

Mobile devices now afford extremely rich experiences that have yet to fulfill their full potential. Mobile Augmented Reality in particular is expected to have a significant impact on the mobile world, providing a new and exciting way to interact and observe the world.

However, currently, mobile AR is still barely known by most mobile device users and presents a difficult design challenge for developers and designers. The combination of sensors and the new interaction paradigm that combines the surrounding 'real world' context with interactive visual elements and real-time data sourcing and presentation, makes it especially difficult to test with users at early stages in the design process. Designers are required to come up with new ways to convey their visions and test their concepts when designing new services in order to get useful feedback from users. In this paper we have presented three forms of prototype for a social, mobile augmented reality application, the Friend Radar, and have evaluated user reception of those prototypes to assess their ability to convey a complex, novel interaction scenario. We presented results from an experiment that assessed three different, low time requirement prototyping approaches for mobile AR – embodied as a low, a mixed and a high-fidelity prototype.

Our results have shown that all possess strengths and weaknesses but, surprisingly, the mixed-fidelity approach is the one that seems to provide the best trade-off. Not only were users able to understand the concept that was being shown very quickly, but this approach also afforded the detection of usability and design issues, triggering users imagination at the same time. Naturally, this last factor is highly valuable as it allows designers to get feedback at a very early stage. This combined with the easiness to create the video prototypes demonstrated the value of this approach. That said, high-fidelity prototypes provide even more realistic experiences, and can, at early design stages, offer results that are similar to those offered by mixed-fidelity prototypes. However, users' expectations are raised to higher levels, requiring care with the fidelity of some of the features and the fluidity of the interactive elements.

These results provide a significant contribution to the mobile interaction design community, which, with the rapid evolution of mobile devices, will soon embrace the potential of mobile AR.

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