Exploring the Mobile Interaction with Large Information Spaces within Mixed Reality Environments: A Grounded Theory Approach

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Abstract: Increasingly powerful mobile devices like the Apple iPhone allow users to access digital artifacts (e.g. media files) efficiently while being on the move. Although such devices are technically capable of browsing even large information spaces, their small form factors limit the efficient use of traditional user interfaces. Mapping an information space to the physical space and utilizing mobile devices as spatially aware displays allows for the physical navigation of the information space and therefore reduces complexity. However, previous research has not focused on how users actually interact with such immersive, dynamic representations of the information space in mobile settings. The paper contributes (1) a qualitative, exploratory study on the interaction design of such applications, (2) a theoretical foundation derived from the analysis of the study results based on grounded theory and (3) design implications for future applications.

1 Introduction

In the last few years, the capabilities of mobile devices have increased considerably. Devices such as Apple's iPhone allow users to access digital artifacts (e.g. media files) in a usable manner while being on the move. This fosters new opportunities for instance for knowledge workers who are required to navigate large information spaces (e.g. interlinked video collections) even in mobile settings. While novel mobile devices are basically capable of browsing these spaces, their small form factors and minimal screen real estate pose great challenges for user interface designers. When these large information spaces are for instance visualized as a graph-like structure in 2D and users are able to browse it on the mobile device with a zoomable user interface (comparable to a typical map application, which is available on most of today's mobile devices), users need to zoom and pan quite a lot to navigate the space and eventually will lose orientation at a certain point (this phenomenon is called *desert fog* [JF98]). Three dimensional visualizations allow for a denser information layout. At first sight, this increases the overall complexity. However, mapping the 3D virtual information space to the physical space and using the mobile device as a spatially aware display [Fit93] promises a decrease in model complexity, due to the possibility of navigating the information space physically. The mobile device is basically used as an “eye in the hand” and the virtual information space is visualized and mapped to the physical space using augmented reality technology (see e.g. [KM09]). Figure 1 shows a screenshot from a sample application from our lab, where a three dimensional graph-like information space is mapped to an office desk.

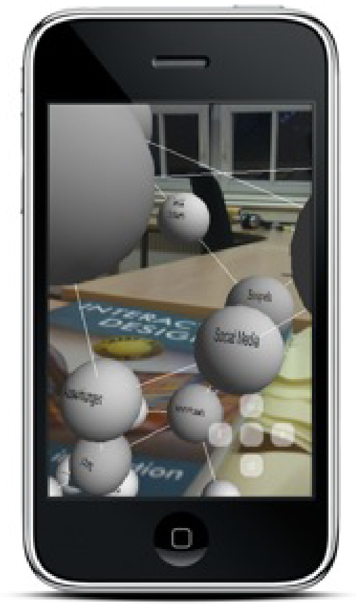

Figure 1: Example visualization of a large, graph-like information space which is mapped to the physical space. In this case, the graph resides on an office desk.

There have been various approaches which utilize a mobile device as a spatially aware display (or so-called *peephole* or *magic lens*) [Yee03, RE06, LVC07, RO08]. However, these were evaluated in lab settings and not in a real-world context, where they actually should be applied. This is particularly important since the information space is dynamically mapped to the physical space and its actual representation strongly depends on the highly dynamic situation. The community hence lacks a fundamental understanding of how users would actually interact with such an immersive representation of the information space in mobile settings.

The paper at hand contributes a qualitative, exploratory study on the interaction design of such applications. The study aimed at gaining deeper insight into (1) how users interact with such dynamic information spaces in mobile settings, (2) how the relationship between digital and physical space is perceived and (3) what the relevant theoretical dimensions for a proper interaction design are. Moreover, the paper contributes a theoretical foundation, based upon the study results, and shows how this can be used to derive design implications for future applications. The paper concludes with a summary and outlines potential future research directions.

2 Exploratory Study

The major aim of the study was to gain a deeper understanding of how users actually interact with large information spaces in mobile mixed reality environments. For this purpose, a qualitative, exploratory study with 12 participants was conducted. The data was analyzed using a grounded theory approach [GS67, SC90]. All of the participants were knowledge workers between 20 and 60 years of age (avg. 28) with different scientific backgrounds. They had to explore various information spaces in different settings: (1) in a typical workplace, (2) on the train and (3) outdoors. The information spaces were visualized as user interface mock ups of three dimensional graph-like inter-related information spaces on an Apple iPhone (cf. Fig. 1). The order of the settings and the data sets were counter-balanced to exclude any learning effects.

The participants were subdivided into a total of 4 samples. The basic idea hereby is that after each sample (i.e. a group of participants, here: 2-4 people) the observations are being coded. Afterwards, relevant codes (i.e. categories) are identified and related, irrelevant codes are removed and the study setup is (potentially) adapted to further explore relevant categories.

The participants were asked to think aloud. As additional sources, the participants were observed in the field and semi-structured interviews were conducted. During the interviews, the participants were given the possibility to sketch their ideas as UI paper prototypes. Both interviews and observations were coded on word-level. Each single-user session lasted about 1.5 hours.

The focus was to observe the participants' *interaction with* and *orientation within* the information spaces. In each setting, the participants were asked to navigate to certain points in the information space. Hence, it was highly interesting to see how they utilized the device as a spatially aware display to navigate to the targets (i.e. whether they walked towards it or for instance only used their arms or upper body). In the workplace and on the train, the participants were asked to perform the navigation tasks while sitting, as well as standing.

In some of the navigation tasks, the digital information spaces intentionally collided with the physical space. Figure 2 shows a picture taken from behind a participant. The information space he was asked to browse collided with a window while being on the train. In this case, it was interesting to see how he coped with the collision. Due to the limited space of interaction, he pulled his left shoulder back and focussed the device onto the window, imagining that the information space is *projected onto* the window's surface and therefore completely contained within the train and not outside.

3 Results

In the following, results of the study are presented. Moreover, selected design implications are outlined. The actual coding process is left out due to space limitations. The analysis of the observations and interviews revealed the following major categories:

Figure 2: Participant interacting with an information space on the train. The information space was deliberately placed near the window, colliding with the actual physical world.

Context The surroundings, as well as the user preferences have a large impact on how users interact with a dynamic information space in a mobile setting. The interaction depends i.a. on the *user's handedness* (e.g. a lefty is unlikely to explore the information space to the left hand side, since she can move more freely to the right hand side), on the *device orientation* (e.g. when in landscape mode, the device is preferably moved vertically) or on the provided *interaction space* and whether the user is *seated or standing*.

Input Modality When users are able to *walk* within the information space, the interaction is completely different compared to an interaction which is limited to the user's *hands*. When walking, the diameter of the information space is nearly unlimited and the space can be explored rather freely, as opposed to manual interaction with one or two hands, where the interaction space is limited by one's arm length.

Navigation Important sub-dimensions comprise a user's *viewport* and how a user perceives the information space: *user-centric* or *space-centric*. In case of a user-centric point of view, the user assumes that the space is centered around herself (and also moves with her), whereas a space-centric view implies that the centre of the information space is physically anchored. In the latter case, the centre of a room can for instance serve as the centre of the virtual information space. The user-centric view is comparable to Pederson's "egocentric perspective" [PS07] on the interaction with everyday objects, where the user as well serves as the centre of reference to all of the user's interactions.

Visualization The visualization influences how the user actually perceives the embedded information space. Key sub-dimensions here are: *level of abstraction*, *visual layout*, *information order/priority* (e.g. whether near information is more important or not) and *aesthetics* (e.g. colors, shapes and registration in the physical environment).

The inter-relationships of the sub-dimensions contained within these four categories allow to derive design implications for future applications. Again, due to the space limitations, only two implications in terms of interaction techniques are outlined exemplarily.

1. **Acquire'n'Zoom** Whether users are seated or standing implies how they navigate the information space. When e.g. standing, users utilize the movement of the upper body to position the mobile device (*target acquisition*) and afterwards, they walk towards the target (*target selection*). In contrast to this, when users are seated, they need to be able to navigate the information space in a similar way. Hence, they need to be able to acquire certain sub-areas of the information space and then zoom towards them while seated to continue browsing the information space.
2. **Grab'n'Rotate** The surroundings and particularly the provided interaction space have a huge impact on how freely users are able to interact with the information space. For instance on the train, the interaction space is rather limited. To overcome the constraints in spatial navigation, the reference point needs to be changed dynamically. In other words, an application shall afford the repositioning (e.g. the rotation or simply the movement) of the information space (in analogy to the mouse movement on a mouse pad, when the mouse reaches the border of the mouse pad). This is also a technique which can be applied to overcome collisions with the physical world (as it was e.g. the case in Fig. 2).

4 Summary and Future Work

The present paper contributes an exploratory study with 12 participants on the mobile interaction with large, dynamic information spaces in mixed reality environments. A theoretical foundation emerged from the study results and allows for the derivation of design implications for future applications. Two design implications in terms of interaction techniques were presented.

While the grounded theory approach revealed a sound theoretical foundation, future work shall address the further exploration of specific sub-dimensions. Particularly the navigation category showed that it is important how users perceive the information space: either user-centric or space-centric. The actual strengths and weaknesses of both approaches remain to be investigated. Moreover, it is highly interesting to investigate the effects of dynamic settings on the input modality dimension, e.g. how interactions need to be designed when users often switch from interaction spaces with a high degree of freedom (e.g. when walking) to ones with a lesser degree of freedom (e.g. when seated) and vice versa.

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