Exploring the Design Space of Smart Horizons

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ABSTRACT
This paper explores the design space of Smart Horizons – mobile applications offering to look at virtual representations of the user's visible surroundings. We conducted an outdoor field study with a fully implemented spatially aware restaurant finder service, in which participants accessed points of interest (POI) virtually attached to nearby buildings. The overall finding was that all orientation-aware visualizations of the nearby environment were highly preferable to a conventional orientation-agnostic presentation. Based on the participants' comparative judgments after using the system prototype, first design recommendations along the dimensions of perspective, field of view and realism are provided. Further research directions are proposed.

Categories and Subject Descriptors
H5.m. Information interfaces and presentation (e.g., HCI): User Interfaces, Evaluation Methodology.

General Terms
Design, Experimentation, Human Factors

Keywords
Field study, human-computer interaction, mobile spatial interaction

1. INTRODUCTION
The idea of combining geo-spatial information with mobile communication technology is gaining rapidly increasing interest in academia and industry alike. Thus, the continuously improving capabilities of mobile phones to determine their position and 3D-orientation have started inspiring the HCI community to realize new applications and interaction modes. As a result, currently the area of "Mobile Spatial Interaction" (MSI; http://msi.ftw.at) is established as a new and promising research field of its own. First steps into this direction go back to the early 1990's when Egenhofer [3] proposed visionary spatial information appliances, such as the *Smart Horizon,* enabling users to look beyond their current field of view.

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Starting from there, we have conceived Point-to-Discover (p2d) as a reference project demonstrating and evaluating the feasibility and attractiveness of Egenhofer's concepts. To anticipate the upcoming embedment of spatial sensing in mass-market mobile devices (e.g. the Nokia Navigator phone appearing in Q3 2008), we have built a combined sensor board (GPS, compass, and 3D accelerometers) attached to a Java-enabled phone, communicating with it over Bluetooth. The measured location and orientation is processed at a server-side platform, hosting an environment block model and geo-referenced services. By means of spatial selection algorithms, the system determines the objects and points of interests (POI) a user can see in his environment.

As an example application, we have implemented a mobile restaurant service for the inner city district of Vienna (Austria) enabling people to walk through an area of about 3 km² with approximately 1000 POI and to get recommendations about restaurants in their vicinity (see http://p2d.ftw.at for further descriptions of the project and prototypes). This paper describes a field study addressing some fundamental questions for the design of Smart Horizons. In particular, the role of perspective, field of view, and abstraction, regarding perceived ease of access to nearby POI is evaluated. The results strongly support an orientation-aware approach for applications to access nearby POI.

2. CONCEPTUAL DESIGN QUESTIONS
We were inspired by the successful 'flight-mode' visualization style of today's car navigation systems. The bird's eye view, visualizing the situation ahead from a 45° perspective, facilitates an efficient match of digital information with the driver's view. It blanks out the backwards situation, which is task-irrelevant, and makes closer parts of the road more prominent than farther away ones. For the design of a Smart Horizon system for pedestrians to access nearby POI, however, it is crucial to know whether the basic principles of car navigation systems can simply be reused, or whether they need to be adapted. This leads to three related questions concerning perspective, field of view and degree of abstraction.

2.1 Perspective
Conceptually, users could be confronted from several perspectives with virtual representations of their visible environment and their nearby POI. In their proper sense, Smart Horizons are sort of 'egocentric', i.e. they show virtual information from the user's own horizontal perspective (see designs 4-6 in Figure 1). On the other hand, a more elevated perspective could provide a better overview of the surroundings. This could either be realized by the bird's eye perspective mentioned above (designs 2-3) or a vertical view, as known from traditional maps (design 1).

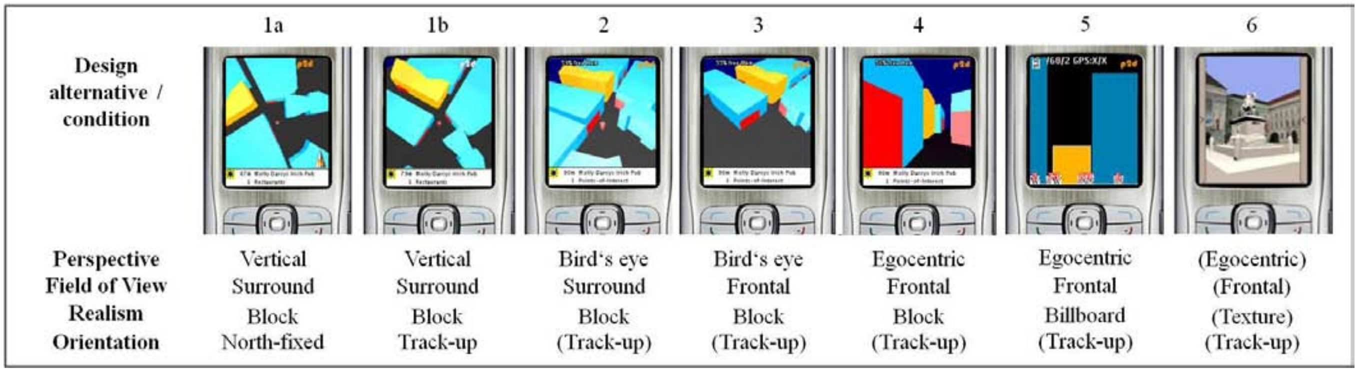

Figure 1. Different conceptual realizations of Smart Horizons and their properties regarding orientation-awareness, perspective, field of view, and abstraction. See further information on the applications in http://p2d.ftw.at/applications.html. The brackets indicate that these aspects were not investigated during the promenade, but only in the interviews.

Early studies with mobile location-agnostic 3D map visualizations for pedestrian navigation suggest a better orientation with an elevated perspective [5]. We aimed at validating these findings for spatially-aware POI access.

2.2 Field of View

The advantage of showing only the situation in front of the user is intuitively convincing for navigation tasks, but not necessarily for wider pedestrian application scenarios. During city exploration, a frontal field of view, even with 180° azimuth would imply quick and possibly confusing changes on the visual display, with buildings suddenly disappearing as one turns around. This leads to the second basic question, i.e. whether a frontal view (see designs 3-6) or a surround view (design 1-2) are more suitable for the access of nearby POI.

2.3 Realism

As opposed to navigation, accessing nearby POI is intrinsically related to the surrounding environmental objects, such as buildings or mountains. Here the question arises how to visualize these objects on a mobile device screen. Whereas highly realistic representations of course have strong advantages for matching reality with its virtual representation, a reduction to only the salient properties may however potentially be more adequate in terms of usability, due to typical limitations of mobile devices like screen size and resolutions, as well as reflections by sunlight. Furthermore, at least in the near future, simplified representations will provide a much better functional performance (e.g. lower latency and higher power consumption).

The concrete visualization concepts that we developed to compare the degrees of realism were: a simple panoramic view displaying the 2D silhouettes of buildings in the user's current field of view ('billboards', see design 5), plain 2.5D block models (the building footprint with a height value; see designs 1-4), and detailed 3D building models with textured facades (design 6).

2.4 The Role of Orientation-Awareness

Smart Horizons rely on the alignment with the user's orientation. Psychological experiments [6], as well as user studies on virtual reality navigation and mobile indoor navigation [2,4] have shown that aligning the map with the actual direction ('track-up') supports users more than an orientation-agnostic display ('north-fixed').

Rantanen et al. [8] explored a location- and orientation-aware messaging application, with regard to its potential for social interactions. In our study we wanted to validate the benefits of orientation-awareness for the access of nearby POI. For this purpose, we specifically compared two visually identical versions of the vertical perspective visualization in Figure 1: north-fixed (i.e., the baseline condition, design 1a) versus track-up (design 1b)

3. METHOD

A field study was designed to gather responses from users interacting with a fully implemented spatially aware system in a real-world environment. 14 subjects, 7 female and 7 male, were recruited based on public announcements and the test person database of our research institution. The subjects were aged between 20 and 48 (mean = 29.9 and median = 29.5).

Also other variables such as professional status were varied to account as much as possible for the broad target group of future users. Only two users (14%) regularly accessed the internet with their mobile, which reflects the still strong focus on voice services in Austria. 12 participants (86%) were residents of Vienna and estimated after the test to be familiar with 24% of the restaurants.

Four factors were defined, according to the outlined conceptual design questions: perspective (3 factor levels), field of view (2), realism (3), and orientation-awareness (2). Following a repeated measures design, every participant was confronted individually with all conditions in experimental test sessions (i.e. promenades in our case). While 36 theoretical conditions would have been necessary for a proper orthogonal factor design, only 7 conditions were specified (as depicted in Figure 1).

Apart from the infeasibility of including all combinations in a repeated measures test setup, many of the factor combinations are impossible or impractical. First, without orientation-awareness, only the vertical perspective makes sense, but not the bird's eye and egocentric views. Second, the 2D-billboard representation is only useful for the egocentric view, but not for the bird's eye and vertical perspectives. The same is valid for the combination of a vertical perspective with a frontal field of view. Finally, due to their elaborateness, fully functional texture designs (design 6) could only be implemented for the egocentric perspective.

A route of about 2 km length through the inner city of Vienna was defined. Along the route, seven points were specified to evaluate the seven design alternatives. According to a classification of terrain types for pedestrian use cases [9], three of the positions were falling into the category ‘low-density urban terrain’ and four into ‘urban environment’, respectively. The number of the POIs available at each of the positions varied between five and twelve (nine on average). In order to avoid learning and preference effects, as well as biases by the respective terrain and POI characteristics, the allocation of conditions to positions and the walking direction was systematically varied between subjects.

The procedure consisted of a briefing, the promenade along the seven positions, and an interview. Each of the seven test situations during the promenade was preceded by a learning phase at the respectively previous location to get accustomed to the user interface. Then, the subjects were confronted with four tasks. Two of them required the subjects to identify real world information based on the virtual information in the Smart Horizon (direction virtual to real, e.g., “You would like to drink a cup of tea. Use your Smart Horizon to browse through the restaurants and cafés and identify your preferred one. Please show me where it is in reality by pointing at it!”).

Conversely, the other two tasks required the identification of the virtual counterpart of a real-world object (direction real to virtual, e.g., “You are interested in THIS restaurant. Please use your Smart Horizon to find out its opening hours!”). For the historical scenario of the textured version (design 6), the tasks were adapted accordingly.

After each situation, the subjects had to rate the ease or difficulty of accomplishing the two task types. This procedure was repeated for the remaining test situations. In order to avoid a potential bias by inaccurate positioning, the task instructions were only given once the GPS device had been updated and nearby buildings and POI were shown by the Smart Horizon.

In a final interview, the subjects were explicitly confronted with all four conceptual design questions. They were asked to rank the design alternatives relevant for each question of interest, concerning the ease of accessing nearby POI. For example, they had to state which field of view alternative they preferred (frontal or surround). The tests were recorded by video, in order to enable detailed capture of the user behavior and statements, as well as the environmental context.

4. RESULTS

In this section, the experiences from the promenade and the interviews are presented. Due to its differing, culturally-related application scenario, the textured version (design 6) was only considered in the analysis of the interview, which was directed towards the subjects’ generalized reflections on the design questions. For the statistical analysis of mean differences, Wilcoxon tests were calculated. Occasional system failures prevented us from analyzing all data from all 14 subjects (missing data is indicated by the d.f. values in the test descriptions below). Figure 2 depicts the rating results for the six designs investigated during the promenade.

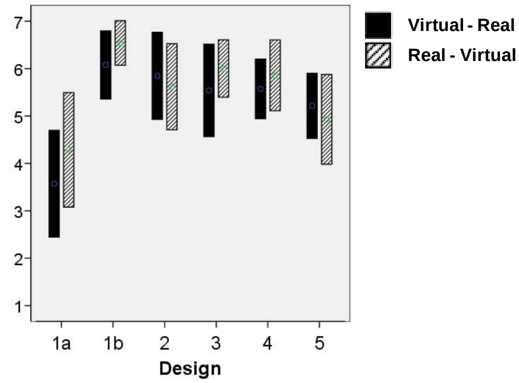

Figure 2: Rating results for the six investigated designs during the promenade, regarding the ‘ease of access’ in both directions (virtual to real and real to virtual). Error bars represent 95% confidence intervals.

The north-fixed style (design 1a) was characterized as more difficult than the track-up style (design 1b) when accessing nearby POI. The difference with regard to ease of access is highly significant for the identification from virtual to real ($Z=-3.2$, d.f.=13, $p<.001$), as well as from real to virtual ($Z=-2.842$, d.f.=12, $p<.004$). The users often spontaneously expressed their discontent with the north-fixed version. No strong differences are observable between any of the Smart Horizons (designs 2-5).

During the interview, the alternatives for the four design questions had to be ranked, which has led to the results illustrated in Figure 3. Again, the track-up condition of the vertical view was strongly preferred to its north-fixed counterpart ($Z=-3,204$, d.f.=13, $p<.001$). Concerning perspective, there is a clear trend for the preference of the bird’s eye perspective. The difference to the egocentric perspective is significant ($Z=-2.11$, d.f.=13, $p<.05$), but not to the vertical perspective ($Z=-1.7$, d.f.=13, $p<.09$).

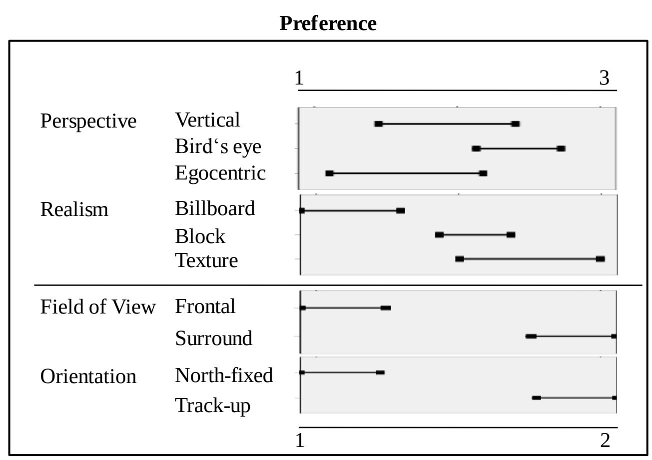

Figure 3: Mean preference ranks for the design questions, as obtained from the ranking during the interviews (upper part: 3=always ranked best, lower part: 2=always ranked best). Error bars represent 95% confidence intervals.

According to the user comments, the egocentric perspective did not provide enough overview of the situation, and if a building was close to a user, the impression of a wall covering the whole mobile screen could be even "scary" according to one of the participants. The bird's-eye-view better accomplished the need for overview, while doing a better job in indicating the direction one is looking to in a given situation.

With respect to the field of view, subjects clearly preferred the surround to the frontal alternative ($Z=-3.05$, $d.f.=13$, $p<.01$). The version with the least realism (i.e., the 2D billboards) was clearly disproved by the users. It was ranked significantly lower than the block representation ($Z=-2.89$, $d.f.=12$, $p<.01$) and the most realistic version, the textures ($Z=-2,54$, $d.f.=12$, $p<.05$). However, it is noteworthy that the textures were not significantly preferred to the block representations ($Z=-1.97$, $d.f.=12$, $p<.197$).

5. CONCLUSIONS

We conducted the first field study on the access of nearby POI with a fully functional and scalable 3D spatially-aware mobile service. We found that all orientation-aware visualizations of the user's surroundings were preferable to orientation-agnostic, north-fixed displays. This result nicely corroborates findings from other areas of research, especially experimental psychology [6], as well as mobile and desktop VR navigation research [2,4].

It is notable that during the promenade, the 'ease of access' ratings did not differ within the orientation-aware combined versions of Smart Horizons, which implies that the factors of interest (perspective, field of view, and realism) did not yield robust enough results to be measurable with the given small sample and factor combinations. Nevertheless, based on participants' clear judgments in the final interview, some first recommendations can be provided.

First, the user should view the virtual representation of the users' surroundings from an elevated perspective, rather than from an egocentric, first-person perspective. Second, regarding field of view, all nearby objects and POI around the user should be presented, not only those related to the user's actual field of view. Finally, with respect to the degree of realism, the display of 3D block models is preferable to 2D billboard representations. Plain and untextured 2.5D blocks appear to accommodate the requirements of nearby POI access already in a satisfactory way, and they are not necessarily surpassed by highly elaborated textured building models.

Our methodology aimed at gaining robust and valid preference results by confronting users with a deployed mobile spatial service that features previously uninvestigated visualization techniques, such as orientation-aware panoramic billboard views and various forms of 2.5D and 3D building models. Replication studies should face the challenge of stepping beyond preference data gathering, by developing objective measures for constructs such as 'ease of nearby POI access' and 'learnability of nearby POI access methods', while not constraining the spontaneous exploration behavior.

Further experimental research is required to explore the opportunities and limitations of fully textured 3D graphics on spatially-aware mobile phones. Here, it is important to determine the salient features that should be added to plain 2.5D block representations to optimize nearby POI access. Of course, the long tradition of map design, as well as new forms of 2D and 3D mobile map design [5,1] should be strongly considered here.

Beyond virtual graphical representation, research should increasingly address design and usability aspects of mobile augmented reality, driven by the ability of new mass market mobile phones to overlay the camera image with additional virtual information. Future studies should step beyond comparative usability and design questions, by evaluating the general usefulness of Smart Horizons in different application contexts, such as tourism information, maintenance work or pedestrian navigation.

6. ACKNOWLEDGEMENTS

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