MIXED REALITY FOR EXPLORING URBAN ENVIRONMENTS

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Abstract: In this paper we propose the use of specific mobile system architecture for navigation in urban environments. The aim of this work is to evaluate how virtual and augmented reality interfaces can provide location and orientation-based services using different technologies. The virtual reality interface is entirely based on sensors to detect the location and orientation of the user while the augmented reality interface uses computer vision techniques to capture patterns from the real environment. The knowledge obtained from the evaluation of the virtual reality experience has been incorporated into the augmented reality interface. Some initial results in our experimental augmented reality navigation are presented.

1 INTRODUCTION

Navigating in urban environments is one of the most compelling challenges of wearable and ubiquitous computing. Recent advances in positioning technologies - as well as virtual reality (VR), augmented reality (AR) and user interfaces (UIs) - pose new challenges to researchers to create effective wearable navigation environments. Although a number of prototypes have been developed in the past few years there is no system that can provide a robust solution for unprepared urban navigation. There has been significant research in position and orientation navigation in urban environments. Experimental systems that have been designed range from simple location-based services to more complicated virtual and augmented reality interfaces.

An account of the user's cognitive environment is required to ensure that representations are not just delivered on technical but also usability criteria. A key concept for all mobile applications based upon location is the 'cognitive map' of the environment held in mental image form by the user. Studies have shown that cognitive maps have asymmetries (distances between points are different in different directions), that they are resolution-dependent (the greater the density of information the greater the distance between two points) and that they are alignment-dependent (distances are influenced by geographical orientation) (Tversky, 1981). Thus, calibration of application space concepts against the cognitive frame(s) of reference (FORs) is vital to usability. Reference frames can be divided into the egocentric (from the perspective of the perceiver) and the allocentric (from the perspective of some external framework) (Klatzky, 1998). End-users can have multiple egocentric and allocentric FORs and can transform between them without information loss (Miller and Allen, 2001). Scale by contrast is a framing control that selects and makes salient entities and relationships at a level of information content that the perceiver can cognitively manipulate. Whereas an observer establishes a 'viewing scale' dynamically, digital geographic representations must be drawn from a set of preconceived map scales. Inevitably, the cognitive fit with the current activity may not always be acceptable (Raper, 2000).

Alongside the user's cognitive abilities, understanding the spatio-temporal knowledge users have is vital for developing applications. This knowledge may be acquired through landmark recognition, path integration or scene recall, but will generally progress from declarative (landmark lists), to procedural (rules to integrate landmarks) to configurational knowledge (landmarks and their inter-relations) (Siegel and White, 1975). There are quite significant differences between these modes of knowledge, requiring distinct approaches to application support on a mobile device. Hence, research has been carried out on landmark saliency

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(Michon and Denis, 2001) and on the process of self-localisation (Sholl, 2002) in the context of navigation applications.

This work demonstrates that the cognitive value of landmarks is in preparation for the unfamiliar and that self-localisation proceeds by the establishment of rotations and translations of body coordinates with landmarks. Research has also been carried out on spatial language for direction-giving, showing, for example, those paths prepositions such as along and past is distance-dependent (Kray, 2001). These findings suggest that mobile applications need to help users add to their knowledge and use it in real navigation activities. Holl et al (Holl et al., 2003) illustrate the achievability of this aim by demonstrating that users who pre-trained for a new routing task in a VR environment made fewer errors than those who did not. This finding encourages us to develop navigational wayfinding and commentary support on mobile devices accessible to the customer.

The objectives of this research include a number of urban navigation issues ranging from mobile VR to mobile AR. The rest of the paper is structured as follows. In section 2, we present background work while in section 3 we describe the architecture of our mobile solution and explain briefly the major components. Sections 4 and 5 present the most significant design issues faced when building the VR interface, together with the evaluation of some initial results. In section 8, we present the initial results of the development towards a mobile AR interface that can be used as a tool to provide location and orientation-based services to the user. Finally, we present our future plans.

2 BACKGROUND WORK

There are a few location-based systems that have proposed how to navigate into urban environments. Campus Aware (Burrell, et al., 2002) demonstrated a location-sensitive college campus tour guide which allows users to annotate physical spaces with text notes. However, user-studies showed that navigation was not well supported. The ActiveCampus project (Griswold et al., 2004) tests whether wearable technology can be used to enhance the classroom and campus experience for a college student. The project also illustrates ActiveCampus Explorer, which provides location aware applications that could be used for navigation. The latest application is EZ NaviWalk, a pedestrian navigation service launched in Japan in October 2003 by KDDI (DTI, 2004) but in terms of visualisation it offers the 'standard' 2D map.

On the contrary, many VR prototypes have been designed for geo-visualisation and navigation. A good overview of the potentials and challenges for geographic visualisation has been previously documented (MacEachren et al., 1999). LAMP3D is a system for the location-aware presentation of VRML content on mobile devices applied in tourist mobile guides (Burigat and Chittaro, 2005). Although the system provides tourists with a 3D visualization of the environment they are exploring, synchronized with the physical world through the use of GPS data, there is no orientation information. For route guidance applications 3D City models have been demonstrated for mobile navigation (Kulju and Kaasinen, 2002) but studies pointed out the need for detailed modelling of the environment and additional route information. To enhance the visualisation and navigation, a combination of a 3D representation of a map with a digital map were previously presented in a single interface (Rakkolainen and Vainio, 2001, Laakso et al., 2003).

In terms of augmented reality navigation a few experimental systems have been presented. One of the first wearable navigation systems is MARS (Mobile Augmented Reality Systems) (Feiner et al, 1997) which aimed at exploring the synergy of two promising fields of user interface research: including AR and mobile computing. Thomas et al, (Thomas et al., 1998) proposed the use of a wearable AR system with a GPS and a digital compass as a new way of navigating into the environment. Moreover, the ANTS project (Romão et al., 2004) proposes an AR technological infrastructure that can be used to explore physical and natural structures, namely for environmental management purposes. Finally, Reitmayr, et al., (Reitmayr and Schmalstieg, 2004) demonstrated the use of AR for collaborative navigation and information browsing tasks in an urban environment.

Although the presented experimental systems focus on some of the issues involved in navigation, they can not deliver a functional system that can combine accessible interfaces; consumer devices; and web metaphors. The motivation of this research is to address the above issues. In addition, we compare potential solutions for detecting the user location and orientation in order to provide appropriate urban navigation applications and services. To achieve this we have designed a mobile platform based on both VR and AR interfaces. To understand in depth all the issues that relate to location and orientation-based services, first a VR interface was designed and tested as a navigation tool. Then we have incorporated the user feedback into an experimental AR interface. Both prototypes require the precise calculation of the user position and orientation for registration. The VR interface relies on a combination of GPS and digital compass while the AR interface is only dependent on detecting features belonging to the environment.

3 MOBILE PLATFORM

One of the motivations for this research was to investigate the technical issues behind virtual and augmented navigation. At present, we are modelling the 3D scene around the user and presenting it on both the VR and AR interfaces. A partner on the project the GeoInformation Group, Cambridge (GIG) - provides a unique and comprehensive set of data, in the form of the building height/type and footprint data, for the entire City of London. The urban 3D models are extruded up from Mastermap building footprints to heights, held in the GIG City heights database for the test sites in London, and textures are manually captured using a digital camera with five mega pixel accuracy. The project has also access to the unique building height/type dataset developed for London by GIG and in use with a range of public and private organisations, e.g. Greater London Authority. Based on this, a generic mobile platform for urban navigation applications and services is prototyped and the architecture is presented in Figure 1.

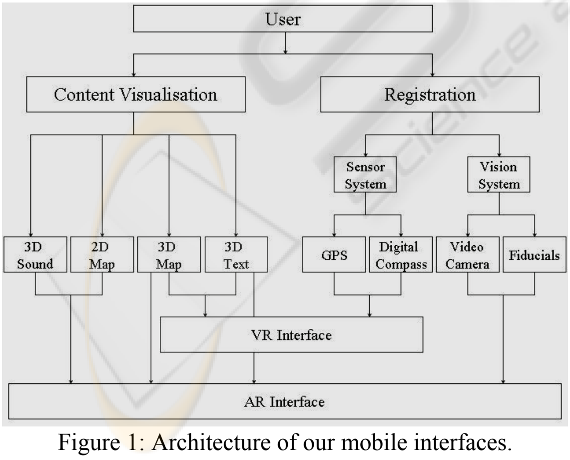

Figure 1: Architecture of our mobile interfaces.

Figure 1 illustrates how a user can navigate, using intelligent data retrieval, inside an urban environment, and what types of digital information, appropriately visualised, can be provided in the form of a service. Information visualisation techniques adopted depends on the digital content used during navigation. Registration, in this context, includes the two most significant pieces of information for calculating the user's location and orientation: a sensor system and a vision system which are used as input to the VR and AR interfaces. The VR interface uses GPS and digital compass information for locating and orientating the user. In terms of the content used for visualisation, the VR interface can present only 3D maps and textual information. On the other hand, the AR interface uses the calculated user's position and orientation coordinates from the vision methods to superimpose 2D and 3D maps and text, on the 'spatially aware' framework.

In terms of the software infrastructure used in this project, both interfaces are implemented based on Microsoft Visual C++ and Microsoft Foundation Classes (MFC). The graphics libraries used are based on OpenGL and VRML. Video operations are supported by the DirectX SDK (DirectShow libraries). Originally the mobile software prototype was tested on a mobile hardware prototype consisting of a Toshiba laptop computer (equipped with 2.0 GHz M-processor, 1GB RAM and a GeForce FXGo5200 graphics card), a Pharos GPS and a Logitech web-camera. Currently, we are in the process of porting the mobile platform to Personal Digital Assistants (PDAs). The final prototype will build on Mastermap data, stored in GML, with simple shading applied to the building outlines. The geographical models will acquire both the orientation information and the location through a client API on the mobile device, which will be sent to the server in the packet-based message transmitted over the used network. The server will build and render the scene graph associated with the location selected and return it to the client for portrayal.

4 VR NAVIGATION

Navigation within our virtual environment (the spatial 3D map) can take place in two modes: *automatic* and *manual*. In the automatic mode, GPS automatically feeds and updates the spatial 3D map with respect to the user's position in the real space. This mode is designed for intuitive navigation. In the manual mode, the control is fully with the user, and it was designed to provide alternative ways of navigating into areas where we cannot obtain a GPS signal. Also users might want to stop and observe parts of the environment – in which case control is left in their hands.

During navigation, there are minor modifications obtained continuously from the GPS to improve the accuracy, which results in minor adjustments in the camera position information. This creates a feeling of instability in user, which can be avoided by simply restricting minor positional adjustments. The immersion provided by GPS navigation is considered as pseudo-egocentric because fundamentally the camera is positioned at a height which does not represent a realistic scenario. If, however, the user switches to manual navigation, any perspective can be obtained, which is very helpful for decision-making purposes. While in a manual mode, any model can be explored and analysed, therefore additional enhancements of the graphical representation are of vital importance. An illustrative screenshot of a user testing our prototype in automatic mode is shown in Figure 2.

Figure 2: User's view during VR navigation.

One of the problems that quickly surfaced during the system evaluation is the viewing angle during navigation which can make it difficult to position the user. After a series of trial and error exercises, an altitude of fifty meters over the surface was finally adopted as adequate. In this way, the user can visualise a broader area plus the tops of the buildings, and acquire richer knowledge about their location, in the VR environment. The height information is hard-coded when the navigation is in the automatic mode because user testing (section 6) showed that it can be extremely useful in cases where a user tries to navigate between tall buildings, having low visibility.

5 PRELIMINARY EVALUATION

The aims of the evaluation of the VR prototype included assessment of the user experience with particular focus on interaction via movement, identification of specific usability issues with this type of interaction, and to stimulate suggestions regarding future directions for research and development. A 'thinking aloud' evaluation strategy was employed (Dix et al, 2004); this form of observation involves participants talking through the actions they are performing, and what they believe to be happening, whilst interacting with the system. This qualitative form of evaluation is highly appropriate for small numbers of participants testing prototype software: Dix et al (Dix et al, 2004) suggest that the majority of usability problems can be discovered from testing in this way.

The method used for the evaluation of our VR prototype was based on the Black Box technique which offers the advantage that it does not require the user to hold any low-level information about the design and implementation of the system. The user-testing took place at City University campus which includes building structures similar to the surrounding area with eight users in total (testing each one individually). For each test, the user followed a predetermined path represented by a highlighted line. Before the start of the walk, the GPS receiver was turned on and flow of data was guaranteed between it and the 'Registration' entity of the system. The navigational attributes that were qualitatively measured include the: *user perspective*, *movement with device* and *decision points*.

5.1 User Perspective

The main point of investigation, was to test whether the user can understand where they are located in the VR scene, in correspondence to the real world position. An examination of the initial orientation and level of immersion was also evaluated after minimum interaction with the application and understanding of the available options. The information that was obtained by the users was concerning mainly four topics including: *level-of-detail (LOD)*, *user-perspective*, *orientation* and *field-of-view (FOV)*.

Most of the participants agreed that the LOD is not sufficiently high for a prototype navigational application. Some concluded that texture based models would be a lot more appropriate but others expressed the opinion that more abstract, succinct annotations would help. Both groups of answers can fit in the same context, if all interactions could be visualised from more than one perspective. A suggested improvement was to add *geo-bookmarks* that would embed information about the nature of the structures or even the real world functionality.

As far as the 'user-perspective' attribute is concerned, each user expressed a different optimal solution. Some concluded that more than one perspective is required to fully comprehend their position and orientation. Both perspectives, the egocentric and the allocentric, are useful during navigation for different reasons (Liarokapis et al., 2005) and under different circumstances. During the initial registration, it would be more appropriate to view the model from an allocentric point of view (which would cover a larger area) and by minimising the LOD just to include annotations over buildings and roads. This proved easier to get some level of immersion with the system but not being directly exposed to particular information such as the structure of the buildings. An egocentric perspective is considered productive only when the user was in constant movement. When in movement, the VR interface retrieves many updates and the number of decision points is increased. Further studies should be made on how the system would assist an everyday user, but a variation on the user perspective is considered useful in most cases.

The orientation mechanism provided by the application consists of two parts. The first maintains the user's previous orientation whilst the second restores the camera to the predefined orientation. Some users preferred a tilt angle that points towards the ground over oblique viewing angles.

Furthermore, all participants appreciated the user-maintained FOV. They agreed that it should be wide enough to include as much information, on the screen, as possible. They added that in the primary viewing angle, there should be included recognisable landmarks that would aid the user comprehend the initial positioning. One mentioned that the orientation should stay constant between consecutive decision points, and hence should not be gesture-based. Most users agreed that the functionality of the VR interface provides a wide enough viewing angle able to recognise some of the surroundings even when positioned between groups of buildings with low detail level.

5.2 Movement with Device

The purpose of this stage was to explore how respondents interpreted their interaction with the device, whilst moving. The main characteristics include the *large number of updates*, as well as the *change of direction* followed by the user. These are mainly considered with the issues of making the navigation easier, the use of the most appropriate perspective, and the accuracy of the underlying system as well as the performance issues that drive the application. Some participants mentioned the lack of accurate direction waypoints that would assist route tracking. A potential solution is to consider the adoption of a user-focused FOV during navigation using a simple line on the surface of the model. However, this was considered partially inadequate because the user expects more guidance when reaching a decision point. Some participants suggested to use arrows on top of the route line which would be either visible for the whole duration of the movement or when a decision point was reached.

Moreover, it was positively suggested that the route line should be more distinct, minimising the probability of missing it while moving. Some expressed the opinion that the addition of recognisable landmarks would provide a clearer cognitive link between the VR environment and the real world scene. However, the outcomes of this method are useful only for registering the users in the scene and not for navigation purposes. A couple of participants included in their answers that the performance of the system was very satisfactory. The latency that the system supports is equal to the latency the H\W receiver obtains meaning that the performance of the application is solely dependent on the quality of operating hardware. The adaptation to a mobile operating system (i.e. PocketPC) would significantly increase the latency of the system. Moreover, opinions, about the accuracy of the system, differ. One of respondents was convinced that the accuracy, provided by the GPS receiver, was inside the acceptable boundaries, which reflected the GPS specifications supporting that the level of accuracy between urban canyons was reflecting the correspondence to reality, in a good manner. A second test subject revealed that the occlusion problem was in effect due to GPS inaccuracy reasons underlining that when the GPS position was not accurate enough, the possibility to miss the route line or any developed direction system increased. Both opinions are equally respected and highlighted the need for additional feedback.

5.3 Decision Points

The last stage is concerned with the decision points and the ability of the user to continue the interaction with the system when it reaches them. A brief analysis of the users' answers will try to name the current disadvantages as well as proposed solutions. As described previously, the user has the feeling of full freedom to move at any direction, without being restricted by any visualisation limitations of the computer-generated environment. Nonetheless, this intention may provide the exactly opposite result. The user may feel overwhelmed by the numerous options that may have and be confused about what action should take next. At this point, we have to take under consideration that most users do not have relevant experience in 3D navigational systems and after spending some time to understand the application functionality, they would enhance their ability to move in the VR environment. To access user responses more effectively we plan to perform more testing in the future.

Some users commented that when a decision point or an area close to it is reached, the application should be able to manipulate their perspective. This should help resolving more information about the current position as well as supporting the future decision making process. Another interesting point is that under ordinary circumstances, users should follow the predefined route. Nevertheless, in everyday situations the user may want to change route, in response to a new external requirement. Partially some of these requirements would be fulfilled if the user could manually add geo-bookmarks in the VR environment that would actually represent points in space with supplementary personal context. A well-proposed solution is to include avatars which would depict the actual position, orientation and simulation of the real situation. One participant suggested that a compass object on the screen would be of great assistance for navigational purposes. This opinion is very intriguing because it would help solve the occlusion problem, by pointing towards the final destination or waypoint. Besides, the adjustment of perspective would not be necessary because, except the predefined route line, the user may become capable of trusting a more abstract mechanism.

6 AR NAVIGATION

The AR interface is the alternative way of navigating in the urban environment using mobile systems. Unlike the VR interface which uses the hardware sensor solution (a GPS component and a digital compass), the AR interface uses a camera (with 1.3 megapixels) and computer vision techniques to calculate position and orientation. Based on the findings of the previous section and a previously developed prototypes (Liarokapis, 2005, Liarokapis et al., 2005), a high-level AR interface has been designed for outdoor use. The major difference with other existing AR interfaces, such as the ones described in (Feiner et al, 1997, Thomas et al., 1998, Reitmayr and Schmalstieg, 2004, Romão et al., 2004), is that our approach allows for the combination of four different types of navigational information: 3D maps, 2D maps, text and sound. In addition, two different modes of registration have been designed and experimented upon, based upon *fudicial* and feature *recognition*. The purpose for this was to understand two of the most important aspects of urban navigation: *wayfinding* and *commentary*. In the fiducial recognition mode, the outdoor environment needs to be populated with fiducials prior to the navigational experience. Fiducials are placed in points-of-interest (POIs) of the environment, such as corners of the buildings, ends of streets etc, and play a significant role in the decision making process. In our current implementation we have adopted ARToolKit's template matching algorithm (Kato and Billinghurst, 1999) for detecting marker cards and we try to extend it for natural feature detection. Features that we currently detect can come in different shapes, such as square, rectangular, parallelogram, trapezium and rhomb (Liarokapis, 2005).

Figure 3: AR navigation using fiducial recognition.

Figure 3, illustrates how virtual navigational tool (a 3D arrow and a 2D map) can be superimposed on one of the predefined decision points to aid navigation. However, user-studies for tour guide systems showed that visual information could sometimes distract the user (Burrell, et al., 2002) while audio information could be used to decrease the distraction in tour guide systems (Woodruff et al., 2001). With this in mind, we have introduced a spatially referenced sound into the interface, to be used simultaneously with the visual information. For each POI of our test case scenario, a pre-recorded sound file is assigned to the corresponding fiducial. As the user approaches one, commentary information can be spatially perceived; the closer the user the louder the volume of the commentary. Alternatively, in the feature recognition, the user is 'searching' to detect natural features of the real environment to serve as 'fiducial points' and POIs respectively. Distinctive natural features like door entrances, windows have been experimentally tested to see whether they can be used as 'natural markers'. Figure 6 shows the display a user navigating in City University's campus is presented with, to acquire location and orientation information using 'natural markers'.

Figure 4: Feature recognition (a) using window-based tracking (b) using door-based tracking.

As soon as the user turns the camera towards these predefined natural markers, audio-visual information (3D arrows, textual and auditory information) can be superimposed (Figure 4) on the real-scene imagery, thus satisfying some of the requirements identified in section 5. Depending on the end-user's preferences, a specific type of digital information may be selected to be superimposed. For example, for visual impaired people it may be preferred to use audio information rather than visual, or a combination of the two (Liarokapis, 2005). A comparison between the fiducial and the feature recognition modes is shown in Table 1.

Table 1: Fiducial vs feature recognition mode.

Recognition Mode	Range	Error	Robustness
Fiducial	*0.5 ~ 2 m*	*Low*	*High*
Feature	*2 ~ 10 m*	*High*	*Low*

In the feature recognition mode, the advantage is that the range of operation is much greater, thus it can be applied better when wayfinding is the focus of the navigation. However, the natural feature tracking algorithm, which is used in this scenario, does require improved accuracy of the position and orientation information, as it currently works with a high error. In contrast, the fiducial recgonition mode offers the advantage very low error during the tracking process (i.e. detecting fiducial points). However, the limited range of operation makes it more appropriate for commentary navigation modes rather than for wayfinding. Nevertheless, the combination of fiducial and feature recognition modes allows users to perceive both wayfinding and commentary navigation into urban environments.

7 CONCLUSIONS

Our prototype system illustrates two different ways of providing location-based services for navigation, through continuous use of position and orientation information. Users can navigate in urban environments using either a mobile VR or a mobile AR interface. Each system calculates the user's position and orientation using a different method. The VR interface relies on a combination of GPS and digital compass data whereas the AR interface is only dependent on detecting features of the immediate environment. In terms of information visualisation, the VR interface can only present 3D maps and textual information while the AR interface can, in addition, handle other relative geographical information, such as digitised maps and spatial auditory information. Work on both modes and interfaces is in progress and we also consider a hybrid approach, which aims to find a balance between the use of hardware sensors (GPS and digital compass) and software techniques (computer vision) to achieve the best registration results. In parallel, we are designing a spatial database to store our geo-referenced urban data, which will feed the client-side interfaces as well as routing algorithms, which we are developing to provide more services to mobile users. The next step in the project will be to port our platform to a PDA, which will be then followed by a thorough evaluation process, using both qualitative and quantitative methods.

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