Presenting Evacuation Instructions on Mobile Devices by means of Location-Aware 3D Virtual Environments

Luca Chittaro
HCI Lab
Dept. of Math and Computer Science
University of Udine
Via delle Scienze, 206
33100 Udine, Italy
chittaro@dimi.uniud.it

Daniele Nadalutti
HCI Lab
Dept. of Math and Computer Science
University of Udine
Via delle Scienze, 206
33100 Udine, Italy
daniele.nadalutti@dimi.uniud.it

ABSTRACT

Natural and man-made disasters present the need to efficiently and effectively evacuate the people occupying the affected buildings. Providing appropriate evacuation instructions to the occupants of the building is a crucial aspect for the success of the evacuation. This paper presents an approach for giving evacuation instructions on mobile devices based on interactive location-aware 3D models of the building. User's position into the building is determined by using active short-range RFID technology. A preliminary user evaluation of the system has been carried out in the building of our Department.

Categories and Subject Descriptors

I.3.7 [**Computer Graphics**]: Three-Dimensional Graphics and Realism—*Interaction techniques*; H.5.2 [**Information Interfaces and Presentation**]: User Interfaces—*Graphical user interfaces (GUI), Evaluation/methodology*

General Terms

Design, Experimentation

Keywords

mobile devices, 3D models, emergencies, navigation instructions, RFID.

1. INTRODUCTION

Natural and man-made disasters present the need to efficiently and effectively evacuate the people occupying the affected buildings. Disasters involving buildings can be divided in two categories [15]: (i) *primary disasters* that directly damage buildings and can be natural as well as man-made (e.g., fires, bombings, chemical releases, earthquakes, floods, hurricanes), and (ii) *secondary disasters* that arise from primary disasters. For example, an earthquake could cause a structural fire, which may in turn burn out circuits resulting in a power failure.

In both cases, the occupants have to be evacuated as soon as possible (e.g., in case of fire) or immediately after the event (e.g., in case of earthquake). Considering the complexity of large buildings and the possibly high number of occupants, it is often difficult to organize a quick evacuation, especially when the building is seriously damaged, even if many evacuation strategies have been studied and some of them are widely accepted and possibly integrated into the architecture design of the buildings [12].

A mobile application that provides occupants with evacuation instructions would offer several advantages with respect to traditional techniques based on audio alarms and paper maps. The application can indeed be context-aware, providing the user with navigation instructions based on her position and the conditions of the building (e.g., avoiding the parts of the building that are unaccessible). Location-aware mobile applications can be even more useful for training purposes, e.g., users can autonomously train themselves in evacuating their workplace and their actions can be logged by the application for post-training analysis. Users can also be provided with different emergency simulations, learning evacuation paths for different scenarios by actually following them in the building. Moreover, people in a disaster are usually under stress and likely to be confused. Guiding users to the most appropriate emergency exit by presenting evacuation instructions in simple and effective ways is thus important to avoid misunderstandings and save lives. 3D models can be an interesting solution to exploit natural user's spatial abilities.

This paper proposes an approach based on a mobile 3D rendering engine [10] to interactively visualize a location-aware 3D model of the building augmented with visual evacuation instructions. User's position is determined by using active short-range RFID technology. The system provides also the user with the possibility of manually navigating the model for training purposes or when automatic positioning is not available.

2. RELATED WORK

Presentation of navigation instructions on mobile devices is a widely discussed topic in the literature. Most existing solutions are based on 2D maps [9], but alternative approaches have been studied, such as photos of the environment aug-

MobileHCI 2008, September 2-5, 2008, Amsterdam, the Netherlands.

mented with visual navigation aids (e.g., arrows) [5, 8]; 3D models [13, 7, 3, 11]; textual instructions; audio directions; route sketches [6]. Approaches based on audio directions do not require users to look at the screen of the mobile device during navigation, but, like textual instructions, they need long descriptions for giving directions (context must be explicitly described), increasing the cognitive workload of the user, and reducing the effectiveness of the approach [6]. Approaches based on 2D maps have the advantage of exploiting a well-known method for representing spatial information, but 3D models or augmented photos exploit natural users' spatial abilities because they provide users with the same visual cues they exploit in the real world (e.g., occlusion, size of the objects). Moreover, solutions based on 3D models might allow the user to train in navigating a building without being in it.

Müller et al. [9] present an approach based on augmented reality and 2D maps that requires minimal infrastructure investments. They place paper maps in different parts of the building, each map is identified by a unique marker and the application associates each marker to the position of the map in the building. Cameras in mobile devices are used as magic lenses: when the device is sweeped over a map of the building, the camera image of the map is augmented with the way to the user's destination (e.g., an office). The main advantage of this approach is that no tracking of the user is needed. However, the solution is not very suitable for emergency situations because it is not able to provide continuous real-time assistance to the user. Moreover, the employed paper maps are a shared resource and this can make it difficult to use them by more than one user at a time.

In recent years, a few attempts have been made at exploring the use of 3D graphics on mobile devices for navigation purposes. The first investigations were thought for outdoor environments [13, 7, 11, 3]. Later, some projects explored the use of 3D models for helping users in the navigation of indoor environments [1, 14, 4, 12].

Garcia Barbosa et al. [1, 14] developed a framework (based on the M3G standard) which allows users to load 3D models from a remote PC server, navigate them, find an optimal and collision-free path from one place to another, and obtain additional information on objects. They developed two applications based on that framework: a virtual rescue training for firefighters [1], and a 3D virtual tour application where multiple mobile clients navigate and interact with each other in a shared 3D model [14]. A significant limitation of the framework is the lack of automatic positioning: the user has to navigate the model manually. Moreover, displayed models are very simple and this could make it difficult for the users to visually match them with the real world.

Butz et al. [4] proposed a system that adapts the presentation based on technical limitations of the output media, accuracy of location information, and cognitive restrictions of the user. However, 3D models used in that project are very limited in terms of realism.

Pu and Zlatanova [12] list instead the requirements for a mobile system and a framework to manage evacuation of buildings using 3D models, but they do not implement it.

3. OUR PROPOSAL

To the best of our knowledge, our application is the first mobile system that uses location-aware 3D models of buildings for evacuation purposes, automatically updating the position and orientation of the viewpoint in the 3D model based on user's position in the real world. Paths are presented by means of bidimensional arrows projected on the floor, while emergency exits are highlighted by using spotlights (Figure 1).

3.1 Positioning

Our system uses RFID technology to determine user's position in the real building. No invasive infrastructure is required: RFID tags are very small and can be easily placed in any part of the building. In particular, we use Beacon RFID tags, i.e. active tags that send automatically a signal every specified amount of time. The specific tags we use have a range of about 4 meters and send their signal to the RFID reader every 500 milliseconds. The system knows the position of each tag in the building and computes user's position based on the detected tags and their distance from the reader. The distance of a tag from the reader is computed based on signal strength, that decreases exponentially with the increase of distance. When the signal strength associated to a tag is over a certain threshold, we assume that the user is very near that tag. If no tags are detected for a minute, the system warns that the viewpoint in the 3D model could be not in sync with the actual position of the user. As it is typical of navigators, there are some limitations in determining user's orientation. The system, indeed, computes user's orientation from her latest positions, so if the user turns without moving from her current position, the system is not able to recognize the change of orientation.

3.2 Visualization

The system computes the path between current user's position and the nearest emergency exit and highlights it by using a set of oriented arrows that are projected on the floor. The color of the arrows is automatically chosen to produce a good contrast with the floor, in order to help the user to perceive them easily. Emergency exits are highlighted by using spotlights [2]. In this way, the user can see them more clearly in the 3D model.

The system supports three navigation modes and the user can switch among them by pressing a button on the mobile device: (i) *manual*: the user manually navigates through the model by pressing the cursor keys of the mobile device, e.g., for training purposes when the user is not in the building or when there are no RFID tags available in the building, (ii) *automatic*: the position and the orientation of the viewpoint in the 3D model are computed by the system and then snapped to the evacuation path, and (iii) *mixed*: the position of the viewpoint is updated by the system, but the user can manually change the orientation.

The 3D model of the building augmented with evacuation instructions is displayed by using a custom X3D file viewer [10]. The model we used for the tests represents the building of our Department. It is made of 50.000 triangles, the size of the source file is 4.38 MB, with 100 kB of textures.

4. PRELIMINARY USER EVALUATION

4.1 Evaluation design

User evaluation was carried out in two phases. After the development of a first version of the system, we carried out a

Figure 1: A 3D model augmented with evacuation instructions. Paths are represented by arrows (left figure), while landmarks are highlighted by spotlights (right figure).

pilot test on two users. The first version of the system computed the position and the orientation of the viewpoint in the 3D model based only on the RFID positioning, without snapping them to the evacuation path. The pilot test highlighted that it was very difficult for users to match their position in the real world with the viewpoint in the 3D model because computed orientations were sometimes too inaccurate, leading to wrong and useless viewpoints in the 3D model (e.g., a viewpoint that is very close to a wall and looks at it) or even penetrates the structures of the building. This led us to implement a second version of the system that snaps computed viewpoint positions to the evacuation path. Moreover, in the second version the viewpoint is adjusted in such a way that at least one path arrow is visible in the 3D model when the user correctly follows the path in the real world.

In the second phase, we informally evaluated the new version of the system on 11 users (8 male and 3 female). Their age ranged from 20 to 26, averaging at 24.6. Five of them had never used a PDA or a car navigator before, while 3 of them had used a PDA before and 5 of them were familiar with car navigators.

The evaluation was organized in three steps: first, the users were provided with a brief explanation of the scenario of the evaluation (a fire emergency), then they used the system, and finally they were interviewed to get their opinions on the system.

In the first step, after getting profiling information (age, job, car navigator and PDA experience), we provided each user with a brief description of the task: reaching an emergency exit by following the visual navigation instructions provided by our system.

In the second step, users were taken to an office they were unfamiliar with and started using the system when they heard the sound of a fire alarm. The system was set in automatic navigation mode and the other possible navigation modes were disabled. The path started from the office and ended in an emergency exit that subjects did not a priori know. The path was not trivial: it was about 75 m long and contained 7 choice points along the way.

Users' position was logged by the system and, during the evaluation, users were followed from a distance. We counted the number of: (i) navigation errors (i.e., number of times the user made a wrong path choice), and (ii) stops (i.e., number of times the user stopped her walk).

Finally, subjects were interviewed, asking them to comment on the strengths and weaknesses of the system and to give suggestions about possible improvements.

The mobile device used in the evaluation was a Dell Axim X51v. Power saving features were disabled to provide maximum performance and to avoid turning off the backlight of the screen while users looked at it. The PDA was equipped with a 624 MHz CPU, 64 MB of main memory, an Intel 2700G graphics processor, and a Compact Flash RFID Reader.

4.2 Evaluation results

All subjects followed the path to the emergency exit without difficulty. Only one of them made a navigation error, but he was able to correct it. Four subjects stopped their walk once.

Several comments and suggestions emerged from the interviews. The aspect of the visual instructions that was found to be improvable concerned the indication of turns: 7 users proposed to change arrows that indicate turns with other types of arrows they found more effective. Three alternative visualizations of turns have been suggested: (i) changing the shape of the arrows, (ii) drawing an arrow in the center of the screen when the user has to turn, (iii) making the arrow blink. Three users suggested the use of audio instructions coupled with the visual ones, as it is typical of car navigators, but other 3 users said that audio instructions would be useless for them in case of evacuation. Four users found the refresh rate of the viewpoint unsatisfactory (this problem is not due to the rendering engine, but to the accuracy of the positioning and might be solved through a smoother interpolated animation). Two users suggested to add more landmarks to the 3D model (e.g., fire extinguishers).

5. CONCLUSIONS AND FUTURE WORK

This paper presented a mobile system that guides users in the evacuation of buildings. The informal evaluation was encouraging and showed that location-aware 3D models of buildings can be effectively used for presenting indoor navigation instructions. Our research is now proceeding in several directions. Firstly, we will formally compare the use of location-aware 3D models with location-aware 2D maps. Then, we will improve the computation of the evacuation path, allowing the user to avoid the parts of the building that are damaged or unaccessible. A very interesting solution to determine a safe path from user's position to an emergency exit is described in [16] and is based on a network of sensors that determines hazardous and safe areas of the building. Moreover, the use of a network of sensors can make navigation instructions dynamic: instructions can vary during the evacuation based on changes in the building (e.g., a part of the building can become unaccessible). Finally, we will consider the status of the battery of the mobile device to influence rendering accuracy and viewpoint updating frequency because the device should not run out of battery before the user reaches the emergency exit.

6. ACKNOWLEDGMENTS

Our research has been partially supported by the Italian Ministry of Education, University and Research (MIUR) under the PRIN 2005 project "Adaptive, Context-aware, Multimedia Guides on Mobile Devices".

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