Exploring Requirements for Tools to Support a Pervasive In-Building Navigation Application

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ABSTRACT
Our research is concerned with the development of a mobile and pervasive application for in-building navigation that can effectively support visitors to complex building architectures, such as institutions, where they are limited to using traditional static signage or asking building occupants for directions. However, although limitations persist in such environments compared to outdoor locations, where applications such as Google Maps are accessible cross-device and provide users with navigational knowledge prior to arrival as well as en-route, on-going research and advances in pervasive systems are enabling new possibilities and changing how users receive in-building navigation support. In this paper, we present requirements for a set of tools that support the development of such an application based on insights gained from five separate formative user studies with 39 participants and also by reviewing other available tools.

Categories and Subject Descriptors
D.2.1 **[Software]**: Requirements – Tools; H.5.2 **[Information Systems]**: User Interfaces – Graphical User Interfaces (GUI); I.3.7 **[Computing Methodologies]**: Three-Dimensional Graphics and Realism – Virtual Reality

General Terms
Algorithms, Design, Experimentation

Keywords
Indoor navigation, pervasive application, mobile phones, 3D fly-through, game engines.

1. INTRODUCTION
Visitors in complex building architectures can often face difficulties finding their way and typically seek out assistance from traditional signage or asking others (e.g. receptionist, building occupants). Certainly the support available is limited in comparison to outdoor locations. Applications such as Google Maps and GPS services accessible via different devices allow users to gain navigational knowledge of a location prior to arrival as well as receive en-route guidance (e.g. viewing a Google Map on a mobile phone). Advances in pervasive systems, however, are enabling new possibilities and changing the way in which users receive navigation support within complex in-building locations.

This paper presents a set of requirements for tools that would support the development of an in-building navigation application by reviewing available tools and also from insights and feedback gained from five separate formative user studies involving 39 participants in the Infolab21 building at Lancaster University (summarized in section 4 and detailed in [9]). We investigated the utility of a prototype application that would support in-building navigation known as the Hermes2 Person Locator. This application was developed using a range of tools such as:

- An open-source toolkit known as GtkRadiant to develop a 3D model of the Infolab21 building and the Quake 3 game engine to render the model (figure 1) and generate fly-throughs as navigation content.
- The Hermes2 system, which includes a deployment of digital situated displays and a component-based architecture approach, as well as an experimental web-based approach, which supports the development of extensible applications.

Figure 1 – Infolab21 reception area rendered with Quake 3

The Hermes2 Person Locator application encompasses the use of personal mobile phones, a kiosk display, the Hermes2 situated displays and navigational content such as 3D fly-throughs, digital 2D maps and graphical arrows as dynamic signage. We explored user attitudes toward viewing localized navigational content at the beginning of their task (e.g. a task would involve locating a lecturer), whether it would be useful to download content to a mobile phone to view along the route and also receive additional support from graphical arrows showing on the Hermes2 displays.

To demonstrate the functionality of the Hermes2 Person Locator application, consider the following scenario:

James decides to wander to the Infolab21 building to see his first year tutor for some advice regarding his JAVA programming module. He remembers that his tutor's name is Dr. Simon Lock but does not remember his office or contact number. He approaches the reception desk and finds that the receptionist has left a note saying "Back in 10 minutes". Beside the desk however, he notices a kiosk display is labeled "Need help with directions?" James decides to use this display and finds Simon on a list of lecturers. He is then presented with a screen which enables him to view and download a digital 2D map and a 3D fly-through of the route he needs to take from his current location to Simon's office. The display also shows Simon's status message "In the office till 2pm". James decides to view the fly-through on the kiosk display and download (using Bluetooth) a video of the fly-through to his mobile phone. James also chooses to request graphical arrows to show on situated displays along his route. After making a selection from a collection of uniquely colored arrows, James then confirms on the display that he is happy for a notification message to be sent to Simon that a visitor is on his way. He then begins to walk towards Simon's office following the 3D fly-through he downloaded to his mobile phone. Simon receives the notification message sent by the system and gets up to set his door ajar. As James walks towards Simon's office he also comes across a digital display showing a semi-transparent graphical arrow, which he had selected, pointing towards his destination. Beneath the arrow he notices that other, non-navigation specific information is being displayed. At this point he decides to stop following the fly-through on his phone and simply follow the arrows on the displays and successfully finds Simon's office.

We proceed in this paper to describe related tools which support application development to support navigation in Section 2. Section 3 briefly discusses the tools that we have used to develop the Hermes2 Person Locator, including their benefits and shortcomings. Section 4 presents a summary of the five formative user studies carried out. In section 5 we propose requirements for a set of tools to support in-building navigation using insights based on our user studies as well as through consideration of other available tools. Finally, section 6 summarizes the paper with concluding remarks.

2. OVERVIEW OF RELATED TOOLS

A range of research studies have investigated the utility of tools that would support the development of mobile and pervasive applications for navigation. An early example of this is the Cyberguide [1] system which utilized an architecture that consists of a collection of independent software components (which would provide services, for example, the Navigator service uses positioning modules to chart the location and orientation of a user within the environment) to function as a tour guide in both an indoor and outdoor context. This component-based approach allowed the system to be an extensible tool as further services can be added through rapid prototyping or modified causing minimal impact to the rest of the system.

Kray et al. [3] describe the design of a pervasive navigation system known as GAUDI, consisting of a grid of autonomous digital displays connected to a navigation server, designed to support public navigation using signage for temporary events (e.g. in a University campus) that might require displays to be re-located and information displayed to be adaptive. Each display unit determines its location using sensors or through an administrator. The server supports operations such as the definition of the global route network (through use of a graph consisting of nodes, edges, etc.), calculation of routes (by the A* algorithm) and description and generation of the display interfaces.

Navigation support applications have also encompassed the use of tools to develop 3D representations of an environment. An example of a powerful tool is Yamamoto (Yet Another Map Modelling Tool) [6, 8] which is a map modelling toolkit that can produce a full schematic 3D model of a building (including structural elements such as walls, doors, stairs, etc.) as well as a routing algorithm.

Alternatively, tools such as game engines have been a cost effective solution to model a 3D environment (e.g. virtual museums [5]) as well as explore how users carry out navigation tasks. However, there is limited research in how such tools can be used to dynamically generate navigational content (e.g. user routes through the use of a location model), mainly due to computational limitations. In contrast, tools such as X3D [7], a rendering engine which is the successor to VRML (Virtual Reality Modeling Language), offer more flexibility for developers. For instance, Chittaro and Nadalutti [2] explored the use of the X3D engine to present a 3D model of a building on a mobile phone with evacuation instructions during an emergency. The mobile devices communicated with short-range RFID tags placed in the environment to establish the user's position. Two informal user evaluations revealed positive attitudes towards the system in providing navigational assistance.

3. OUR APPROACH

To develop the Hermes2 Person Locator application prototype for in-building navigation support, we utilized tools such as GtkRadiant and the Quake 3 game engine to develop a 3D model of a specific region of the Infolab21 building (for purposes of our user studies) and also the Hermes2 system. The following subsections describe our experiences using such tools including their benefits and shortcomings.

3.1 Development of the 3D Model

The 3D model of the Infolab21 building was developed by following a floor plan of the building created as part of a research project in the Computing Department. We used a toolkit known as GtkRadiant (figure 2) to develop the model mainly due to its open-source nature which allows flexibility in terms of bug-fixes, updates, etc. The toolkit allows the creation of 3D polygon structures as well as the application of photographic textures, thus allowing the 3D model to appear highly salient in terms of form, colour and appearance.

We used photographs that were taken inside Infolab21, such as of doors, ceiling, carpeting, etc. Door numbers for each office were also enlarged in order to make them clearly identifiable. A completed model was then compiled using GtkRadiant and rendered with the Quake 3 game engine, which required a patch to hide the normal in-game user interface information (as well as the weapon) such as the health bar, ammunition, etc.

As part of our formative user studies, we investigated how the Person Locator application could provide users with navigation support by presenting a 3D visualization of their route from their current location to the destination. Hence, the 3D fly-throughs were developed, which were essentially video recordings of the Quake 3 character walking from one location to another. This was done by using GameCam, an in-game recording software.

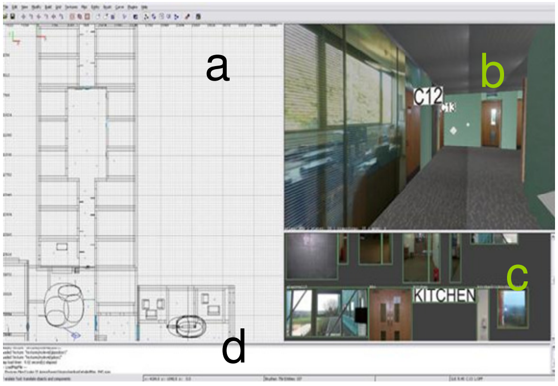

Figure 2 – the GtkRadiant development environment showing (a) model construction area (b) preview area (c) texture collection and (d) console window

3.1.1 Benefits and shortcomings

Using an open-source toolkit such as GtkRadiant and a game engine such as Quake 3 offered a cost-effective means of constructing a salient 3D model of the Infolab21 building to investigate whether users would find this type of content useful for navigation. However, the labor involved during development was relatively high (approximately 30 to 40 hours). Consequently, labor would increase significantly for buildings that are larger and far more complex. The time spent can of course, be reduced by lowering the detail of the environment (e.g. limiting the use of photographic textures).

Modelling a 3D environment enabled us to enhance user navigation by, for example, enlarging signage such as office door numbers. Generating video-based fly-throughs also allows this type of content to be viewable on any device (e.g. mobile phone, Hermes2 displays) which supports video playback. However, computational limitations were apparent as the routes cannot be dynamically generated from a location model. Thus, a more advanced tool such as Yamamoto would be suitable to accomplish this. Furthermore, as the routes were presented as continuous media, any form of interaction with the 3D environment (e.g. looking around) was restricted apart from using pause and play.

3.2 The Hermes2 System

The Hermes2 system currently consists of a deployment of 40 digital displays across two corridors (see figures 3 and 4) in the Computing Department of the Infolab21 building at Lancaster University. The system was initially designed to support a messaging application that adapts the idea of sticking a note on a door saying "Gone for coffee…" and enable awareness in the work environment. There are currently two versions of the approach for developing Hermes2 software, both of which were used to develop two separate versions of the graphical user interface for the Hermes2 Person Locator application prototype.

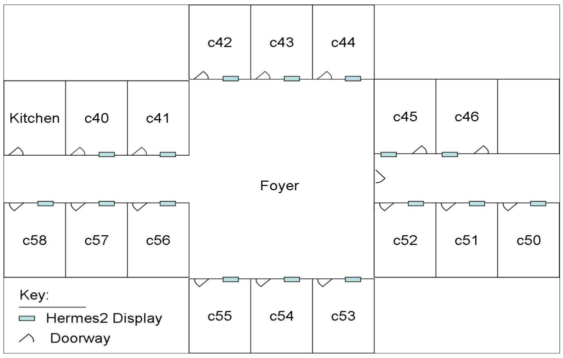

Figure 3 – layout of a specific region of the Computing Department in Infolab showing offices (c42, c43, etc.) and the Hermes2 displays situated adjacent to doorways

The first approach is Java-based and is based on a middleware that provides services such as access to software components as well as configuration information. It follows a pervasive, component-based and highly customizable design where developers can safely add or modify existing software components. The second, and more experimental, approach is AJAX-based and programmable in ASP.NET combined with C# for server side functionality. Similar to the first approach, it follows a pervasive and customizable design where, for instance, the graphical user interface of a developed application can be viewed on different types of devices (e.g. on a home computer as well as the Hermes2 displays), by using a web-browser.

Figure 4 – example of the Hermes2 display deployment environment in the Computing Department

3.2.1 Benefits and shortcomings

The Java-based implementation approach using the Hermes2 system is highly extensible as it allows developers to safely add or modify existing components (similar to the Cyberguide system's component-based approach). This approach also enables developers to access various hardware components such as modems, Bluetooth receivers, etc. However, we faced limitations with this approach, for instance, with rapid prototyping as the process of compilation and packaging to deploy and test components was time consuming (e.g. to test a modification the component would need to be packaged, uploaded to the server and the application would need to be restarted). Thus, due to such limitations and further unresolved bugs we developed a standalone GUI that would run on the Kiosk display for three of the five formative user studies (studies 1, 2 and 4, summarized in Section 4 and detailed in [9]).

The web-based approach enabled us to rapid prototype more effectively as applications can be run and debugged instantly by launching it from the development environment. Thus, we developed a second version of the Hermes2 Person Locator GUI that was able to run on the Hermes2 displays as well as the Kiosk display, by using a web-browser, for our fifth formative study. However, some limitations are apparent from a deployment point of view. It is difficult to trace errors once an application is developed using this approach. This is because the web-browser running the application is itself an independent application and can cause errors that are difficult to trace or handle (e.g. a browser crash during interaction). Furthermore, being web-based, access to hardware components (e.g. a Bluetooth receiver) is limited.

4. SUMMARY OF USER STUDIES

To explore the utility of a prototype application (i.e. the Hermes2 Person Locator) that would support in-building navigation we carried out five formative user studies with 39 participants in total. During each study we observed what appeared useful as well as ineffective in order to design each subsequent study. Table 1 below presents an overview of the conducted studies.

Table 1. Overview of the five formative user studies

#	Objective	Users
1	Exploring the utility of mobile phones and viewing 2D and/or 3D navigation content	8 (4m, 4f)
2	Follow-on study to the first study	6 (3m, 3f)
3	Questionnaire study – exploring whether Hermes2 display owners are willing to share personal information about their door displays to support navigation	12 (8f, 4m)
4	Exploring the combined use of mobile phone and situated displays for navigation	10 (5m, 5f)
5	Exploring user attitudes toward the use of dynamic signage	3 (1f, 2m)

4.1 Studies 1 & 2

The first user study was conducted in August 2008 with eight participants (4 male, 4 female) with an average age of 23.4 years. We investigated user attitudes toward viewing navigational content such as 3D fly-throughs and/or a digital 2D map and whether users would find it useful to download this type of content to a mobile device to view whilst en-route.

A second, follow-on user study was conducted in January 2009 with six users (3m, 3f) with an average age of 22.5 years. This was done as we encountered limitations in terms of mobile phone use during the first study. Thus, in this study we encouraged users to download the 3D fly-through and/or the digital 2D map to a mobile phone.

4.2 Study 3

A questionnaire-based study was carried out in March 2009 to explore whether Hermes2 display owners were willing to provide information (e.g. a message set on their display such as "Out for coffee…) as well as allow their display to show navigation-related content (e.g. a graphical arrow) to assist visitors in finding their way. The questionnaires were issued to twelve participants (4 male, 8 female) composed of academic and administrative staff as well as researchers with an average age of 32.4 years.

4.3 Study 4

This user study was carried out in March 2009 and focused on exploring whether users would find it useful to use a combination of mobile phones and situated displays to view navigational content along their route. The study involved ten users (5 male, 5 female) with an average age of 24 years.

4.4 Study 5

A fifth formative user study was carried out in July 2009 with three users (1 female, 2 male) with an average age of 23.3 years. We further investigated the utility of the Hermes2 displays for navigation support, that is, by exploring whether users would find it useful to personalize (by sketching a symbol) and view a graphical directional arrow along their route.

5. PROPOSED REQUIREMENTS

The requirements proposed for a set of tools that would support the development of an in-building navigation application are based on the insights and feedback gained from five separate formative user studies (detailed in [9]) and also by considering available tools described in section 2 of this paper.

5.1 Dynamic Navigation Support

An in-building navigation application must be able to dynamically support the user throughout their route, for example through use of a location model and a routing algorithm such as A* or Dijkstra which would provide localized and updated navigation information. The importance of a location model is discussed in [4], where it is argued that it is an essential factor in the design and implementation of location-aware systems. Furthermore, in our fifth formative study two users stated that they would like to use the Hermes2 displays whilst en-route to view localized navigational content (e.g. a 3D fly-through) in case they are disoriented.

Our experiences in using GtkRadiant and the Quake 3 game engine to develop a 3D model of the Infolab21 building proved to be somewhat limiting for this type of support. As the fly-throughs presented to users of their entire route on the Hermes2 Person Locator application were pre-recorded, tools such as Yamamoto or the GAUDI system would be a more effective solution. These tools provide a routing algorithm to compute a user's route based on a location model and present navigation content such as 3D visualizations (Yamamoto) and signage-based support (GAUDI), thus making them also highly relevant as alternative tools to be used in the development process of the Hermes2 Person Locator application.

Using the X3D rendering engine would also be another approach in showing dynamic visualization of the user's route. This was explored in [2] by Chittaro and Nadalutti where the visualization was presented on a mobile phone and users were directed through use of projected arrows. Communication with RFID tags in the environment would allow the user's route to become automatically updated, thus also matching the user's movement in the physical environment. In contrast, as the 3D fly-throughs used as part of the Hermes2 Person Locator application were presented as continuous media (i.e. videos) users were required to use pause and play on a mobile phone to match movement in the physical environment.

It is possible however, to introduce a certain degree of dynamic route generation by using pre-recorded fly-through videos. This would involve creating a set of recordings which only visualize user movement from one strategic location to another (e.g. only between two offices). Each recorded file can then be assigned a tag and once a user specifies a destination, the navigation application would then play a set of recordings which match each consecutive strategic location that a user must pass through. In this case a routing algorithm such as A* would be required to calculate the user's path. However, while this would be more suitable for a more simplistic in-building environment, a larger and more complex environment would cause issues as the set of recorded videos would escalate to excessive numbers.

5.2 Cross-device Application Approach

To ensure that a user is supported throughout their route, a mobile and pervasive navigation application and its content must be accessible cross-device. This could account for a situated display deployment (e.g. the Hermes2 display deployment in the Infolab21 building) which does not cover all areas of the building, thus requiring support from other devices (e.g. a mobile phone). In our fifth formative study, all three users confirmed that a mobile device showing navigational content would be useful in areas without situated displays.

The Hermes2 system enabled us to develop the Hermes2 Person Locator graphical user interface to be accessible cross-device (although limitations were faced using the Java-based approach, as discussed in section 3.2.1). For instance, the GUI can be shown on a kiosk display that users can access upon entrance to the building and also on other digital displays in the environment along their route.

Similarly the 3D fly-through videos presented to users visualizing their route are also accessible cross-device, for example, any device that supports video-playback functionality such as a mobile phone. This would allow users to "possess" the route whilst they are walking to the destination. Our formative studies (1, 2 and 4) showed that after viewing a 3D fly-through on the kiosk display, a total of eight users who downloaded the fly-through to a mobile phone commented that they felt secure along their route, thus confirming the utility of the cross-device nature of the fly-throughs.

However, as some devices may not support specific file formats, an approach to this issue could involve developing a library of commonly used formats for each 3D fly-through.

5.3 Adaptive Application Approach

A mobile and pervasive in-building navigation application must adapt to the user's needs as well as the environmental properties, for example, the application must not be tailored around the ideal location to show signage nor assume an ideal level of realism for presenting a 3D visualization of a user's route.

Currently the Hermes2 displays are situated adjacent to office doors and thus, any navigational signage would require the user to look to the side. In the fifth user study we found that all three users had different preferences and one user commented:

"I think seeing them on the side is slightly awkward, probably for two reasons. One, when you're walking straight, you don't tend to look, you know, laterally to either side… People tend to look forward or down slightly… What would probably be more kind of ergonomic, although slightly difficult, would be to have them on the floor somehow so you can simply glance down and see where you're going and you won't run into people…"

A pervasive navigation application might achieve this by for example, showing projections of graphical arrows on the floor as signage.

We also found from two of our studies (studies 2 and 4) that at least three users faced issues with a particular region of the Infolab21 building where objects such as furniture in the physical environment weren't represented in the 3D fly-throughs. One user in particular stopped walking because of this while following the fly-through on a mobile phone. Thus, the high level of realism that was used in the 3D model raised user expectations for all objects in the physical environment to be represented. To avoid such issues and to also follow a more adaptive approach, a navigational application should present users with the option to choose between different levels of realism (i.e. low, medium and high). In this case, using tools such as GtkRadiant and a rendering engine such as Quake 3 are more suitable as they allow texture manipulation whereas tools such as Yamamoto or X3D do not follow texture-heavy model rendering.

6. CONCLUSIONS

The key contribution of the work presented in this paper is a set of requirements for tools that would support the development of a mobile and pervasive in-building navigation application, based on insights gained from a range of formative user studies in the Infolab21 building and also by considering other available tools. In our studies we explored the utility of a navigation application known as the Hermes2 Person Locator, developed using a range of tools such as GtkRadiant and the Quake 3 game engine to model and render a 3D representation of a specific region of Infolab21 and also by using dynamic door displays.

The next step in our research is to explore the utility of different types of tools, such as Yamamoto, X3D and GAUDI, in order to improve the Hermes2 Person Locator application prototype to include, for example, a location model coupled with a routing algorithm (e.g. A* or Dijkstra) that would dynamically generate navigational information. Using such tools could also introduce a higher level of interactivity (e.g. using projected arrows in the 3D visualization of a user's route) in contrast to the 3D fly-throughs presented as continuous media.

7. ACKNOWLEDGMENTS

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