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ROUGHMAPS: A GENERIC PLATFORM TO SUPPORT SYMBOLIC MAP USE IN INDOOR ENVIRONMENTS

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RoughMaps: A Generic Platform to support Symbolic Map Use in Indoor Environments

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ABSTRACT
This research describes the design, implementation, and validation of a platform for managing contextually relevant symbolic maps for indoor positioning. The RoughMaps platform allows untrained users to upload and administer symbolic building maps and associated map meta-data for the purpose of indoor positioning. An associated API allows mobile application developers to retrieve map data for client-side use in their personalised and context-aware mobile applications; this API is validated through the implementation of an illustrative client-side Android mobile application.

In addition to introducing the RoughMaps platform as a generic means for storing and retrieving symbolic map data for the purpose of indoor positioning, this paper also outlines the results from a cognitive walkthrough that was conducted on the platform, and evaluates the positioning accuracy of the client and the performance scalability of the server. This is to our knowledge the first platform that focuses on both the use of symbolic maps and the reuse of existing infrastructure for the purpose of supporting indoor positioning on mobile devices.

Author Keywords
Indoor positioning; symbolic maps; client-side personalisation.

ACM Classification Keywords
D.2.13 [Software Engineering]: Reusable Software---reusable libraries, reuse models; H.5.2 [Information Interfaces and Presentation]: User Interfaces---evaluation/methodology, user-centered design.

1. INTRODUCTION

An important criteria for many mobile applications today is the ability to support personalised and context-aware information delivery. User positioning and the use of maps is essential for this purpose, and although satellite-based navigation has become the defacto standard for outdoor positioning, there remains no one consistent positioning technology for indoor environments, nor even a consistent approach in map representation when indoors. The RoughMaps platform is unique in that it has been designed to accommodate different positioning technologies and also to accommodate the use of symbolic maps, which are often not-to-scale, non-linear, and highly abstract in nature, containing only the most salient and most relevant features of a map, based on the immediate needs of a specific user.

Having some knowledge of one's geographical location is a fundamental requirement for many day-to-day activities. Today we make use of a multitude of navigational aids: street signs while driving or walking along public roads; directory listings and maps for the interior of large buildings; street directories for navigating across suburbs; and with increasing popularity, digital maps combined with GPS assistance for outdoor navigation. Each of these methods of navigation and positioning have their own advantages and disadvantages. When using a system for positioning (whether that be a map on a wall or an electronic device), it can be critical that the system operates with minimal distraction and effort - a utility as a means to an end. This leads to the need for symbolic maps.

This paper describes an implemented framework that allows building administrators to use a web interface to upload map and positioning information, as well as a web application programming interface (API) for client-side applications to retrieve the uploaded map information. A client application has also been developed; it uses the API to validate the intended functionality of the platform.

The aim of the research is to use symbolic maps for conveying positioning information to the user. This positioning information should be relevant to the context of the user, and based on any of a number of maps available for a single area. We expect the outcome of this research to provide users in unfamiliar environments with the ability to view their position and the position of nearby interests in an indoor environment.

This paper is structured as follows. In Section 2, we describe relevant past work that has been conducted in the areas of indoor positioning, positioning frameworks, and symbolic maps. In Section 3, we describe the RoughMaps platform, including details on the server, the administration interfaces, and the prototype client application used to validate the platform. In Section 4, we outline our evaluation results, focusing on a cognitive walkthrough of the system, as too the indoor positioning accuracy of the implemented Android client application, and performance scalability of the server. We then present our conclusions in Section 5.

2. RELATED WORK

This section outlines relevant past work that has been conducted in the areas of indoor positioning, positioning frameworks, and symbolic maps.

Indoor Positioning

There has been a considerable amount of research on indoor positioning, particularly focused on the technologies, infrastructure, and algorithms to support users in such contexts. Earlier research on indoor positioning (Golding and Lesh, 1999) has used an array of inexpensive sensors including accelerometers, magnetometers, temperature sensors and light sensors to generate low-accuracy positioning data, which was then parsed by a 'data cooking' module to create higher-accuracy position results. Further exploration of improving upon the raw data from indoor positioning sensors has been explored with algorithms for calibration-free WiFi positioning (Dong et al., 2009), infra-red proximity with accelerometers (Schindler, Metzger, and Starner, 2006), and foot-mounted inertial units (Woodman and Harle, 2008). These works all contribute to improving indoor positioning accuracy using different technologies; though do little by way of providing reusable generic positioning frameworks and integration of symbolic map use.

Higher positioning accuracy can be achieved using ultrasound (Harter et al., 2002; Priyantha, Chakraborty, and Balakrishnan, 2000; Hazas and Ward, 2003). Ultrasound technologies to date do however require specialised technology and modification to the existing infrastructure in order to function properly.

There has also been some past work on the use of existing infrastructure. Kim et al. (2009) looked at the 'fingerprint' of wireless frequencies and LaMarca et al. (2005) uses '802.11' radio frequencies to determine the position of users when indoors. In comparison, Quigley and West (2005) and Coyle et al. (2006) use Bluetooth technologies to focus on privacy-centric indoor positioning methods.

Positioning Frameworks

A number of positioning frameworks also exist; although their methods of using specific infrastructure and technology is relevant to this work, the frameworks do not focus on the use of symbolic indoor maps.

The work in 'BeaconPrint' (Hightower et al., 2005) for example describes algorithms for learning and recognising 'places' as opposed to geographical coordinate 'locations'; this is a similar concept to that which the RoughMaps platform aims to achieve, though the BeaconPrint system focuses only on identifying places (e.g. an entire building) and does not allow a finer grain of positioning for indoor environments within a particular place. In (Jose et al., 2001), an open architecture that allows location-based services to be discovered over the Internet is described. In comparison to RoughMaps, which focuses on providing contextually relevant map data, this work focuses on supporting location-based application discovery. Yet other research has focused on creating a framework for providing the mechanism for modelling people, sensors, devices, and places (Assad et al., 2007); though generic in its design, that framework does not focus specifically on symbolic map use in indoor environments.

Kargl and Bernauer (2005) outline in their COMPASS system, a positioning architecture that combines the output from different sensors to produce a probability distribution function describing the user's location as coordinates and corresponding symbolic location probabilities. In comparison to RoughMaps, where a user's indoor position is mapped to a graphical map, COMPASS returns symbolic locations in the form of simple textual strings that it receives from a webserver (e.g. "germany.ulm.university.main_building"). Another interesting method of representing a position is the 'W4 Model' (Castelli et al., 2007), where the position is recorded as a set of values 'who, what, where, and when'.

The 'Redpin' framework (Bolliger, 2008; Bolliger, Partridge, and Chu, 2009) is the result of research into modelling indoor positioning based on 'asynchronous interval labelling'. Using their 'Locator' algorithm, a location fingerprint for users can be determined. The positioning logic is performed server-side, and in comparison to RoughMaps, which focuses on using symbolic maps and providing an open interface for client-applications, the Redpin framework has its focus on indoor positioning using only radio frequencies.

The 'Yamamoto' toolkit on the other hand (Stahl and Haupert, 2006) looks at supporting geometric modelling of an indoor environment with a comprehensive administration tool for creating detailed three-dimensional maps, though does not lend itself well to supporting symbolic maps such as those that are hand-drawn.

Symbolic Maps

There has been little research into the use of symbolic maps for indoor positioning. Efforts from various researchers have, however, looked into a more general use of symbolic maps. One effort to use landmarks as a primary means of navigation in outdoor environments that lack GPS (Millonig and Schechtner, 2005) seems quite promising, though would need to be adapted and re-evaluated for an indoor environment.

Previous research has also looked at the difficulty involved with dynamic map modification (Reilly and Inkpen, 2004), automating the transformation of large-scale outdoor environments (Jones and Ware, 2005), and adding contextual values to maps as an ad-hoc process (Brem et al., 2010). We intend the RoughMaps platform to capitalise on the value of contextually relevant information by supporting users in defining and in using maps with symbolic elements of personal relevance.

Photographs of contextually relevant landmarks have also been used for navigational assistance (Bidwell and Lueg, 2004), as well as customised paths based on the mobility of the user (Tsetsos et al., 2005).

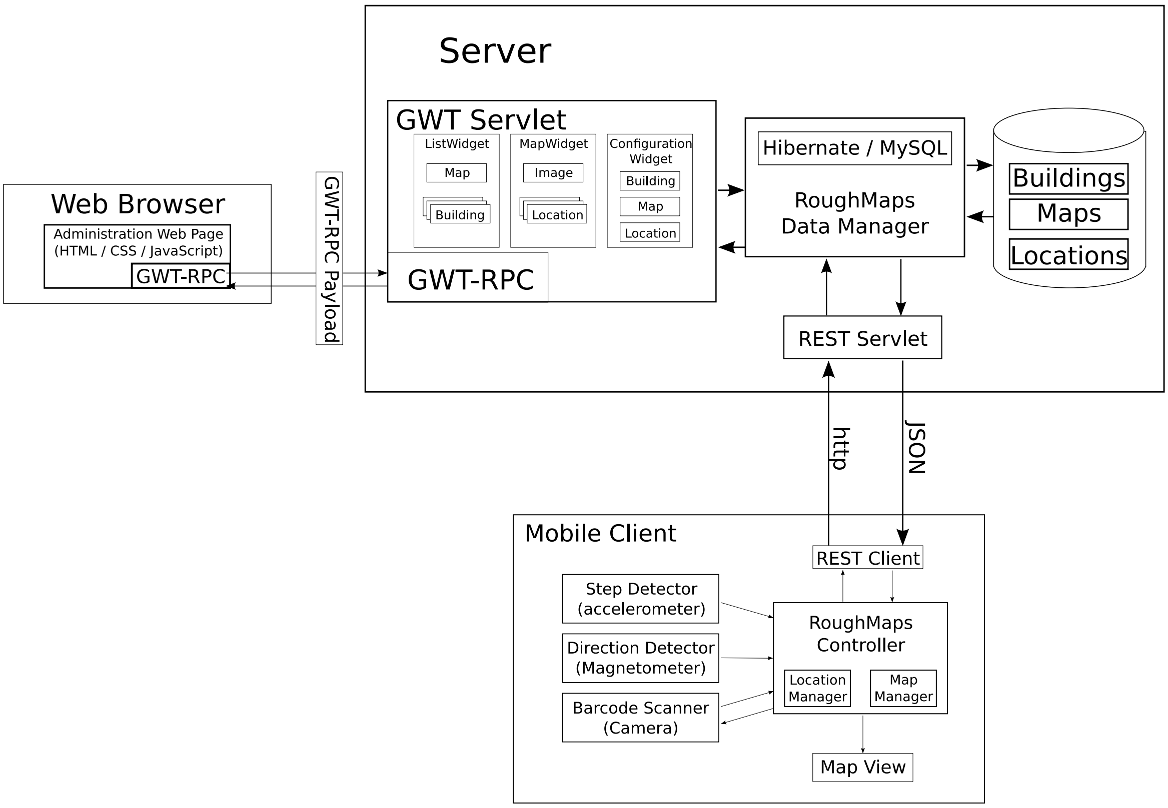

Figure 1. The RoughMaps platform architecture.

Another example of positioning in environments lacking GPS is the 'Navitime' software (Arikawa, Konomi, and Ohnishi, 2007), which provides a navigational system that uses WiFi signals for use in complex urban environments in Japan, where the many high-rise buildings can have a negative effect on GPS signal strength even when outdoors. The GUI presents contextually relevant information to the user in the form of symbols. Also explored in other work (Baus, Krüger, and Wahlster, 2002) is the variation of information displayed to the user based on the current user context.

Previous research looks toward supporting location modelling for symbolic maps for outdoor users; there does not appear to be much published work relating to positioning a user on these maps for indoor environments. In contrast to outdoor environments, we look at positioning and mapping methods using available indoor positioning infrastructure and with the aim of delivering symbolic maps contextually relevant to the user.

There has more recently been some early explorative work relating to indoor positioning and the use of symbolic maps (Gubi et al., 2010); the work described in our paper however covers that of a complete implementation that is supported also by evaluation and performance testing.

3. THE ROUGHMAPS PLATFORM

The RoughMaps platform aims to provide contextually relevant symbolic maps to end users. The components of the platform (see Figure 1) can be grouped into three main parts: the web application running on the server; the web administration interface also running on the server; and the client application that makes use of the RoughMaps client-API, running on a mobile device such as an Android smartphone.

With the focus of this work being to provide an open, generic, and reusable platform to support symbolic map use in indoor environments, some notable target markets for the platform include public buildings like museums, airports, libraries, and shopping malls. It can however also be noted, that the platform could additionally be used in a walled-garden configuration that would be more suitable for private business enterprise, in which indoor building maps should not be made available outside of an intranet.

Server

The RoughMaps platform stores all mapping information in an SQL database, and the database layer is accessed using the Hibernate[1] library. Hibernate is an object-relational mapping library for Java that provides mapping of object-oriented domain models to traditional relational databases. Using the Hibernate library allows one to create a database abstraction layer, which in turn simplifies the process of querying the database by allowing queries to be in POJO[2] notation.

GWT-RPC[3] servlets are provided for communication between the front-end (written in GWT) and the back-end server implementation. REST[4] servlets are provided for

[1] Hibernate, http://www.hibernate.org/.

[2] POJO: Plain Old Java Object.

[3] GWT-RPC: Google Web Toolkit - Remote Procedure Call.

[4] REST: Representational State Transfer.

client applications, allowing simple 'HTTP GET' requests for retrieving map and positioning information from the server (see Table 1).

URL Request	Information Retrieved
/roughmaps/building/list	All available buildings
/roughmaps/building/search/-30.40,150.67/4.5	Buildings within a '4.5km' range of the geo-coordinate '-30.40, 150.67'
/roughmaps/building/1	The building with ID '1'
/roughmaps/map/list/1	All maps associated with the building ID '1'
/roughmaps/map/3	The map with ID '3'
/roughmaps/location/list/3	All locations associated with the map ID '3'

Table 1. RoughMaps server REST requests.

A typical REST response (in this case for searching for buildings within a 4.5km radius) is shown below. The response is in JSON format.

```
Response: [{"name":"School of IT",
    "buildingId":1,"latitude":-33.888223,
    "longitude":151.194022},
    ...
```

Administration

The administration interface for the RoughMaps platform is written in Java using the GWT. Compilation of GWT Java code results in HTML/CSS/JavaScript; GWT is often used to create complex and intricate web applications using standard Java code. Communication with the server is performed using GWT-RPC, where actions in the GUI perform server requests to populate the interface with new information.

The administration interface (see Figure 2) is comprised of three primary components: the list widget (Figure 2A), which lists buildings and maps; the map widget (Figure 2B), which displays map data and existing positioning infrastructure; and the configuration widget (Figure 2C), which displays the editable fields for buildings, maps, and locations. The configuration widget loads when the user right clicks on the map, as shown in Figure 2D.

Client

The prototype client application is written in Java for the Android operating system. The primary purpose of the client implementation is to evaluate and confirm that the RoughMaps platform works for its intended purpose of providing the user with contextually relevant indoor symbolic map and user positioning information. Indoor positioning is, in the case of this prototype client, based on QR codes and the use of the accelerometer and compass sensors for the purpose of dead-reckoning. As can be seen in Figure 3, the client interface also consists of three primary components: the list view (Figure 3A, B), which lists buildings and maps that are automatically detected as being near the user's location (via GPS); the map view (Figure 3C), which displays maps and positioning infrastructure as well as the user's current position; and the preferences view (Figure 3D), allowing the user to change the step sensitivity and step distance of the pedometer. The server address can also be configured in the client-application; this is particularly relevant in cases where the RoughMaps platform is used in a walled-garden configuration, for example, as the primary mapping server for a single museum and its respective visitors (Figure 3D).

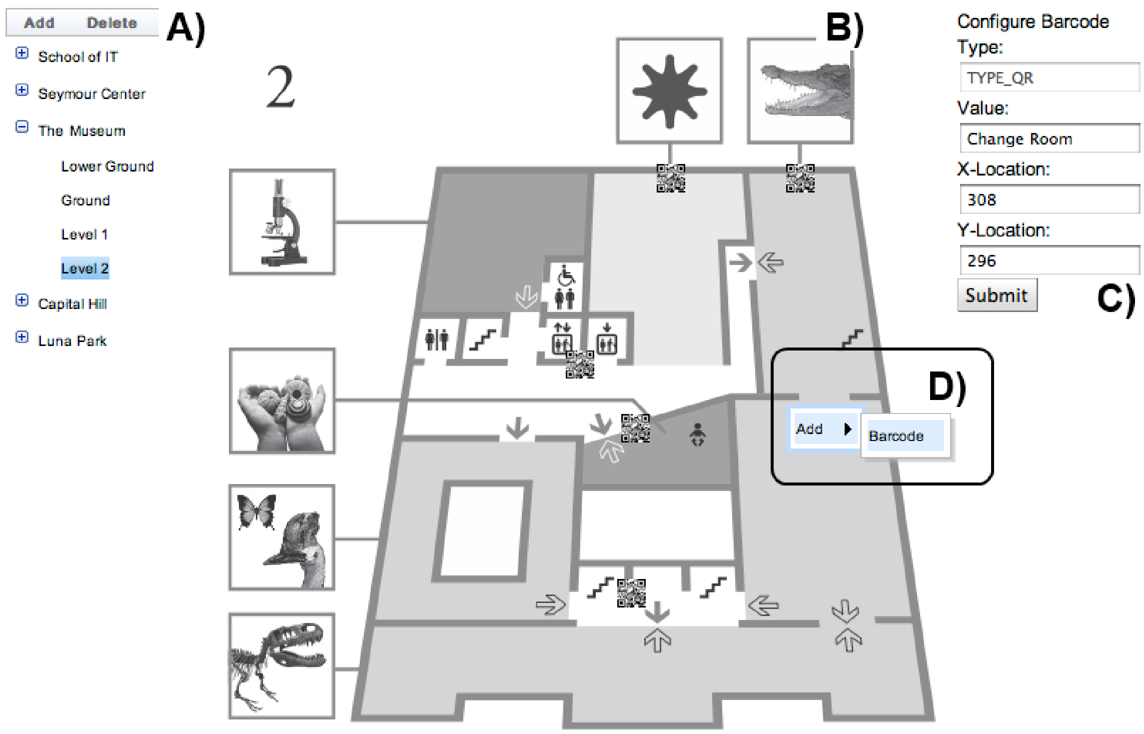

Figure 2. Administering a map.

Figure 3. The Android client user interface, showing: a list of nearby buildings (A), the list of maps associated with a building (B), the user positioned on the map (C), and some configuration options (D, E).

The Challenges Addressed by the RoughMaps platform

The challenges that this research addresses are described in the following sub-sections.

Infrastructure Reuse and Indoor Positioning

In order to demonstrate the RoughMaps platform, a prototype indoor positioning solution was required. The goal of our implementation was to minimise the need for additional infrastructure and to instead reuse the existing infrastructure in order to show, by way of example, how multiple indoor positioning technologies could be linked to the RoughMaps platform. In particular, in our prototype client smartphone application, we determine the indoor location of users via two complementary positioning approaches. The first approach uses barcodes such as QR codes to calculate the absolute position of the user. Secondly, we perform dead reckoning on the mobile client device using the inbuilt magnetometer (i.e. the digital compass, for determining direction) and accelerometer (i.e. gravity sensor, for detecting a user's footsteps) for calculating the user's position relative to the last scanned barcode. Dead-reckoning is typically considered to be useful over short distances, as any errors that occur with each user step are cumulative. Future implementations of the client application will also support map-matching, whereby the client application is able to map a user's location onto the areas of a map that are known to be traversable. The RoughMaps platform is not limited to just these two forms of indoor positioning technology; rather, the RoughMaps platform (see also Figure 2D) and prototype client application shows how the RoughMaps platform can be adapted to support any number of positioning technologies, including technologies such as WiFi and Bluetooth sensors.

Map Data Maintenance

The maintenance effort for building administrators is minimised by allowing map and positioning information to be administrated via a web interface. This reduces the necessity for 'perfection' in configuring the infrastructure locations for a map, as various configurations can be tested in real time to minimise the cost of errors and mistakes. This also allows fast setup times for new maps and locations.

Symbolic Maps

An indoor symbolic map is essentially an image that symbolically represents an indoor environment. Arguably, all maps are symbolic, but this work focuses on maps that show only the features relevant to the user. The seminal example of a symbolic map is the London Underground (see Figure 4A). Here a person is able to see where they can change over on train lines and the order of the train stations without the complication of representing the correct geographical distance between stations. An extreme case of a symbolic map is shown in Figure 4B, in which the map is distilled into a series of simple navigational cues associated with important locations.

Figure 4. Different types of symbolic map, showing the London Underground (A) and a series of visual cues (B).

The RoughMaps platform aims to support maps that vary in purpose, scale, and precision. It does this by allowing not-to-scale maps and positioning technology locations (e.g. QR codes) to be added to the platform via the administrative web interface.

These symbolic representations of an indoor environment are expected to vary based on the user's context. Map variations will also reflect the life span of a map in use, for example, professionally created maps will likely be available permanently, whereas hand drawn maps may be available or relevant only for a single visit or a day trip to a location (such as a museum). It is expected that some maps will also vary with time, e.g. consider a dinosaur exhibition that is replaced after 6 months with an exhibition on human evolution. In this case, the map outline may stay the same, with only the contextual information on the map changing; alternatively, the outline of room walls and exhibition content may both change. These are the types of symbolic maps that the RoughMaps platform is tasked to support.

4. EVALUATION

Our work has three main goals: 1. to design an architecture for managing symbolic maps for use in indoor positioning systems; 2. to implement this architecture server-side, including the relevant interfaces to administer the maps via a web browser; and 3. to create a mobile application that operates in conjunction with the RoughMaps server architecture.

Olsen (2007) suggests that the evaluation of an architecture or framework, like RoughMaps, should be based on demonstrating: a) that it can be implemented, and b) that it supports the applications that it was designed for. The first condition is met by the implemented mobile client application that makes use (via the REST requests outlined in Table 1) of the implemented RoughMaps platform. We test the second condition, i.e. that the RoughMaps platform supports the applications it was designed for, via a cognitive walk through of the client and the administrative interfaces, conducted by four programmers. Following the cognitive walkthrough, this evaluation section also analyses the positioning accuracy that can be achieved from a client application like our own, as well as the scalability of the RoughMaps server when multiple clients connect to it.

Cognitive Walkthrough

We evaluate the RoughMaps service by looking at the tasks which the platform aims to support. In particular, this section outlines two cognitive walkthroughs that were conducted to evaluate both the prototype client application interface and the administrative web interface. In particular, each task is broken down into a number of actions, and based on (Wharton et al., 1994), the following aspects of the interface were judged during the evaluation process:

- Will the user try to achieve the right effect?
- Will the user notice that the correct action is available?
- Will the user associate the correct action with the effect they are trying to achieve?
- If the correct action is performed, will the user see that progress is being made toward the solution of their task?

Procedure

The walkthroughs were conducted by a group of four programmers in the School of IT department, each familiar with smartphones and somewhat familiar with the RoughMaps platform. As a group, and with the above outlined questions in mind, the participants evaluated whether a new user to the RoughMaps platform would be likely to successfully complete the two tasks. The first task focused on the use of the client application, while the second task focused on the use of the web administration interface.

In the first task, the participants were requested to assume the role of a student looking to meet a particular researcher located in the School of IT building. Positioned just outside the building, the participants were required to use the client application to navigate from the ground floor to the researcher’s office in the Level 3 west wing of the building. In order to finish the task, the participants needed to complete nine actions (see Table 4). The mental model for the role that each participant was to assume, and which was provided before the start of the task, is shown in Table 2.

Concept	Reason
Have not been to the School of IT before.	This is the reason they need directions. It is a common occurrence, as students apply for enrolment in postgraduate studies or request assistance for subjects during ‘meeting hours’.
Are at the ground level entrance to the School of IT.	It is the main entrance to the School of IT.
Have been informed to use the “Level 1: Mary's Office - Step 1” and “Level 3: Mary's Office - Step 2” maps in RoughMaps to find their way to the office of the staff member.	This is a genuine task, and one that a person unfamiliar with the building may have to carry out.
Have not used the RoughMaps application before.	We are exploring the learnability of the interface.
Are familiar with the interface of the application.	The application has been designed to meet the Android UI conventions, and it is reasonable to assume that a person who owns a phone is familiar with its user interface standards.
Are aware that the RoughMaps application uses QR codes as a method of positioning.	This was part of the description of the application capabilities from the site where they acquired it.

Table 2. Mental model for subjects using the client application.

In the second task, the participants were requested to assume the role of a long-standing employee of a museum, who would like to use the RoughMaps administrative web service to set up some maps for visitors to the museum. Sitting in front of a computer with the RoughMaps website open, the participants were required to complete nine actions making up the task (see Table 5). The mental model that each subject assumed for the task is shown in Table 3.

Concept	Reason
Intimate knowledge of the museum building	The employee has worked at the museum for a number of years.
Well versed in the requirements of the visitors.	The museum employee answers questions and talks to visitors on a daily basis.
Has not used the RoughMaps administration before.	The maps have not been set up yet - they found out about the system.
Has references to existing maps they want to use.	They are aware of the museum resources, and know that the system requires the user to provide maps.
Knows the locations of positioning infrastructure through the building.	Again the user knows that the system requires the user to provide the locations of the positioning infrastructure on each map.

Table 3. Mental Model for subjects using the administrative web interface.

Data set

The map dataset that was used to evaluate the RoughMaps platform consisted of nine maps in total: four official symbolic (i.e. not-to-scale) maps of a museum, one to-scale map of the School of IT based on the building's architectural floor plans, and four hand drawn not-to-scale maps of the School of IT.

Results

Table 4 outlines the results of the cognitive walkthrough on the first task, while Table 5 outlines the results of the cognitive walkthrough conducted on the second task. The walkthroughs outline a number of findings relevant to improving both the RoughMaps administrative interface, as too the implemented client-side proof-of-concept mobile application. Whereas the results on the administrative interface are particularly relevant in determining how the existing platform can now best be improved, we envisage the results of the client-side application to be particularly relevant to third parties who will likely create their own mobile client implementations (similar to our own proof-of-concept mobile application).

Action	Result
1. Open the RoughMaps application.	Success.
2. Select the building titled 'School of IT'.	Success.
3. Select the map titled 'Level 1: Mary's Office – Step 1'.	UI needs improving, as many maps will likely confuse the user.
4. Scan the QR code at the building entrance.	Success.
5. Move to the elevator and take the elevator to level 3.	Success.
6. Select the map titled 'Level 3: Mary's Office – Step 2'.	Needs improving, as the user would assume this step to be automatic.
7. Scan the QR code at the elevator.	Success
8. Move to the door of the west wing of Level 3 and scan the QR code.	Needs improving, as this QR code was deemed redundant by users.
9. Navigate to Mary's office and scan the QR code there.	Success.

Table 4. Results of the Cognitive walkthrough for the client application.

In particular, with task one, it can be seen that the client application can be successfully used as a means for navigating the environment, selecting the right building, scanning barcodes, and moving about the indoor environment. However, the cognitive walkthrough outlined some areas requiring improvement with the client, primarily relating to the organisation and presentation of quite possibly many maps of a building, as too the ability of the prototype application to automatically guide the user to their destination without frequent input from the user.

In task two, it can be seen that the administrative interface can be successfully used to enter details about buildings/maps, and adding locations to the maps. The walkthrough also highlighted more generally the need for the interface to better guide and inform the user on the encompassed functionality, such as adding buildings and maps, and adding positioning technology locations on to the map.

Action	Result
1. Open the RoughMaps administration interface.	Success.
2. Click ‘Add’, ‘Building’.	UI needs improving, to inform users of this functionality.
3. Enter and save building details.	Success.
4. Select newly created building and click ‘Add’, ‘Map’.	UI needs improving, to inform users about this functionality.
5. Enter and save map details.	UI needs improving, to provide feedback for saving the map.
6. Expand the map list for the building and select the recently created map.	Success.
7. Double-click on the map to add a location.	UI needs improving, to inform new users of this functionality.
8. Select ‘Add’ then ‘Barcode’ from the menu.	Success.
9. Enter and save barcode details.	Success.

Table 5. Results of the Cognitive Walkthrough for the administration interface.

Positioning

In addition to the two cognitive walkthroughs that were conducted, we also evaluated the positioning accuracy of the system for a set of three different maps. This was achieved by walking along a given route twice for each particular map and then averaging the results. The maps are shown in Figure 5 and highlight the differing nature of map types that can be uploaded to the platform. In particular, Figure 5A, B, and C all represent the same route, though whereas Figure 5A is to-scale and based on a building floor plan, Figure 5B and C have been hand drawn by two separate users. Also note that the whole route is not shown in Figure 5B; this is because the user has, in this particular instance, zoomed into the map. Figure 5D shows an additional symbolic representation of the route in which the route is illustrated as a set of visual instruction steps rather than as a floor plan.

The results for each map are shown in Table 6, where it can be seen that the proof-of-concept client application had an average position error of 3.83m over a distance of 24m, , equating to an error per meter value of 15cm.

Map	Map scale	Average distance from final waypoint	Error per meter
A)	2	4m	16cm
B)	10	3.5m	14cm
C)	3	4m	16cm

Table 6. Position accuracy results. Note that the ‘map scale’ is a value used to convert a typical footstep distance into its corresponding value on the symbolic map.

From the two different positioning technologies that were used in the mobile application (i.e. QR codes and dead-reckoning based on the phone’s compass and accelerometer), QR codes (similar also to other technologies like barcodes and AR codes) were by their nature very accurate; albeit not as user friendly since they require explicit user actions to scan the codes. Past work has already shown that dead-reckoning, although more convenient to QR codes, becomes inaccurate as the distances travelled increases (Woodman and Harle, 2008). It is not the goal of this work to create algorithms to increase the individual positioning accuracy of systems when indoors, but rather to create the platform in which technologies like QR codes, and in the future also WiFi and Bluetooth, can all be easily integrated. To this end, the implemented client prototype successfully demonstrates that the infrastructure and architecture work effectively when the phone can provide reasonably accurate ways to establish the user’s location.

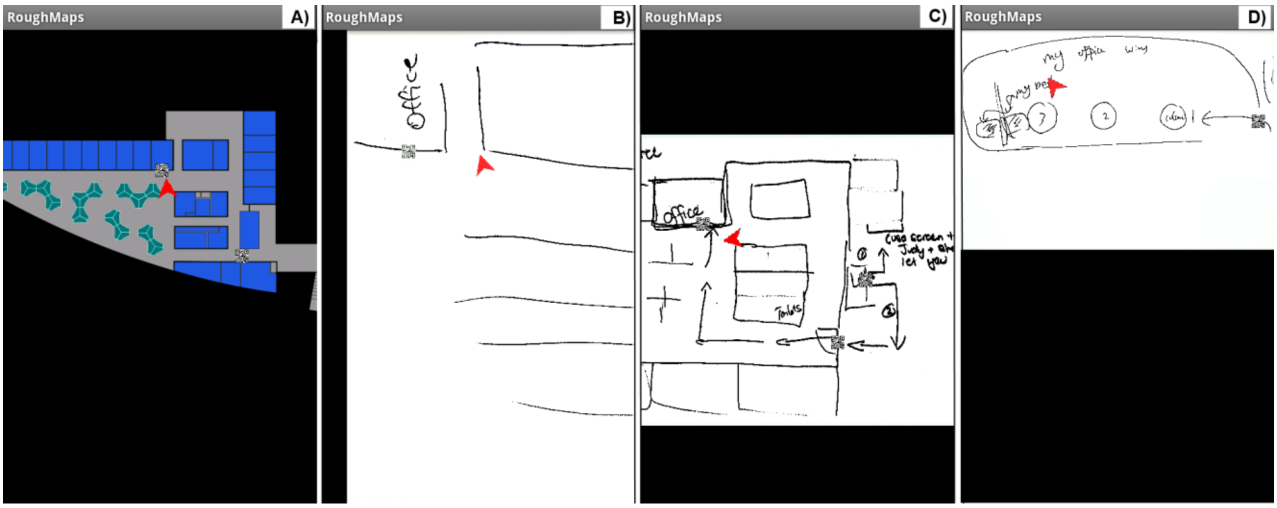

Figure 5. Symbolic maps used for route calculation during the positioning accuracy evaluation, showing a to-scale map (A), two hand-drawn maps (B, C), and a symbolic map based on a sequence of visual instructions (D).

Scalability

Evaluation of the scalability of the RoughMaps platform was performed using the Apache Benchmarking Tool[5]. With this tool, we measured the number of requests per second that the RoughMaps server is currently capable of handling. The hardware that was tested upon was an Intel Core 2 Quad 2.6GHz server with 3GB RAM and running Ubuntu 9.04.

We tested against the 'list all available buildings' URL REST Request (see Table 1), as this service tests the entire scope of a standard request - the HTTP request, a database query, and the HTTP response.

We found that the server responds exceptionally well to over 100 requests per second, which we found to be quite acceptable for a development system in its early phases.

5. CONCLUSIONS

In this paper, we present RoughMaps, a novel platform designed to support the administration and use of symbolic maps for the purpose of indoor positioning. This research looks at a new mechanism for managing arbitrary symbolic maps and for providing this information in a manner of contextual value to the user.

Key contributions of this work are the design, implementation, and evaluation of the RoughMaps platform. We also define the API in which client applications can interact with the platform, and validate the RoughMaps implementation by way of an illustrative client-side mobile application. The RoughMaps platform and client application are furthermore evaluated through a cognitive walkthrough, and the positioning accuracy of the client is also tested, as too is the scalability performance of the server.

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