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RoughMaps

A Generic Platform to support Symbolic Map Use in Indoor Environments

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***Abstract*— An important feature for many applications is the ability to support personalised and context-aware information delivery. User positioning and the use of maps are essential for this purpose. The RoughMaps platform accommodates the use of symbolic maps, which are often not-to-scale, non-linear, highly abstract in nature, and which often contain only the most salient and most relevant features of a map based on the immediate needs of a given user. This work describes the design, implementation, and validation of the RoughMaps research platform, for managing and retrieving contextually relevant symbolic maps for indoor positioning. This is to our knowledge one of the first platforms that focuses on the use of symbolic maps to support indoor positioning in personalised and context-aware mobile applications.**

Keywords— Indoor positioning, symbolic maps, mobile computing, personalization.

I. Introduction

An important feature 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 de-facto 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 research platform is unique in that it has been designed to accommodate for the use of symbolic maps, which are often not-to-scale, non-linear, highly abstract in nature, and which often contain only the most salient and most relevant features of a map based on the immediate needs of a given user.

This paper describes the design, implementation, and validation of a research platform for managing and retrieving contextually relevant symbolic maps for indoor positioning. The RoughMaps platform allows untrained users to upload and administer symbolic building maps and related map meta-data for the purpose of indoor positioning. An associated web application programming interface (API) allows mobile application developers to retrieve map data for client-side use in their personalised and context-aware mobile applications.

In addition to introducing the RoughMaps research platform, this work summarises our evaluation of the platform by way of a cognitive walkthrough of the interfaces used to upload maps and meta-data to the server, and by way of a simple client-side smartphone application that integrates dead-reckoning and QR positioning techniques to validate the platform's API for accessing and retrieving symbolic map data.

Building upon previous work [12], the aim of this research is to provide a platform upon which the use of symbolic maps for conveying positioning information to users of personalised and context aware applications can be investigated. 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 building or area. In addition, the platform is expected to become a resource upon which a growing number of personalised and context-aware applications can leverage symbolic maps to provide users in unfamiliar environments with the ability to view their position and the position of relevant nearby interests in indoor environments.

This paper is structured as follows. In Section II, we describe our motivation for symbolic maps and the need for a research platform to evaluate the use of symbolic maps in practice. In Section III, we outline relevant past work that has been conducted in the areas of indoor positioning technologies, positioning frameworks, and symbolic maps. In Section IV, 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 V, we outline our evaluation results, which focus primarily on a cognitive walkthrough of the platform. We then present our conclusions and directions for future work in Section VI.

II. Motivation

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, maps, and indoor signs for navigating the interior of large buildings; street directories for navigating across suburbs; and with increasing popularity also digital maps on electronic devices like smartphones. These navigational aids each have

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their own advantages and disadvantages, and this is also dependent on the intended purpose and person for which the aid is needed. Often the best suited representation of a user's geographical location is not the most geographically to scale, but rather that which symbolises those features in an environment that are most relevant or salient to the user at hand. Often, as is the case with many hand-drawn maps, the best representation will in fact only be useful for one person, i.e. the person for which it was specifically created, and only for a constrained period of time. Such a map will typically include a combination of different categories of spatial knowledge, including landmark, route, and survey knowledge [34]. This is where the notion of a "rough map" arises, i.e. a map that has been created in an approximating (or rough) manner by end users, often for near-immediate use of the map by others. Such maps may be as simple as the hand-drawn representations in Fig. 1A and B, or geometrically representative like that in Fig. 4, or as extensive as that shown in Fig. 1C.

A. Symbolic Maps

[26] define a 'map' to be the representation of a part of space containing a set of connected places that are related to each other by spatial transformation rules (e.g. transformation rules that map three-dimensional space onto a geometrically accurate two-dimensional space). Although many maps are represented to scale, this is not always the case, and [21] outlines a number of classifications for spatial relations that can be used for Geographic Information Systems (GIS), including both qualitative relations (e.g. topological, mereological, mereotopological, and ordinal relations; see [21] and [13] for a detailed discussion of these terms) and quantitative relations (e.g. distal, angular, and special relations). In comparison to the quantitative relations, which are inherently graded concepts relying on continuous or discrete measures, qualitative relations abstract away from those measures by collapsing 'indistinguishable' values into an equivalence class [8].

One example of a qualitative spatial map is the topological map, which is often used to simplify geographical maps, with only the vital information remaining and all unnecessary detail removed. They have often been studied in cognitive theories of space, to represent incomplete knowledge of space, qualitative representation of metrical information, and connectivity relations among landmarks [31]. As [13] outlines, the inclusions of qualitative models of space are "expected to allow the next generation of GIS to at least partially bridge the gap between rigid computational models of space and less rigid users that freely navigate between quantitative and qualitative and between low-level and high-level conceptions of space". It is these qualitative representations of space, and in particular symbolic maps that our work focuses on.

In this work, an indoor symbolic map represents a map 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 Fig. 1C), which [24] outlines to be both iconic and symbolic in nature

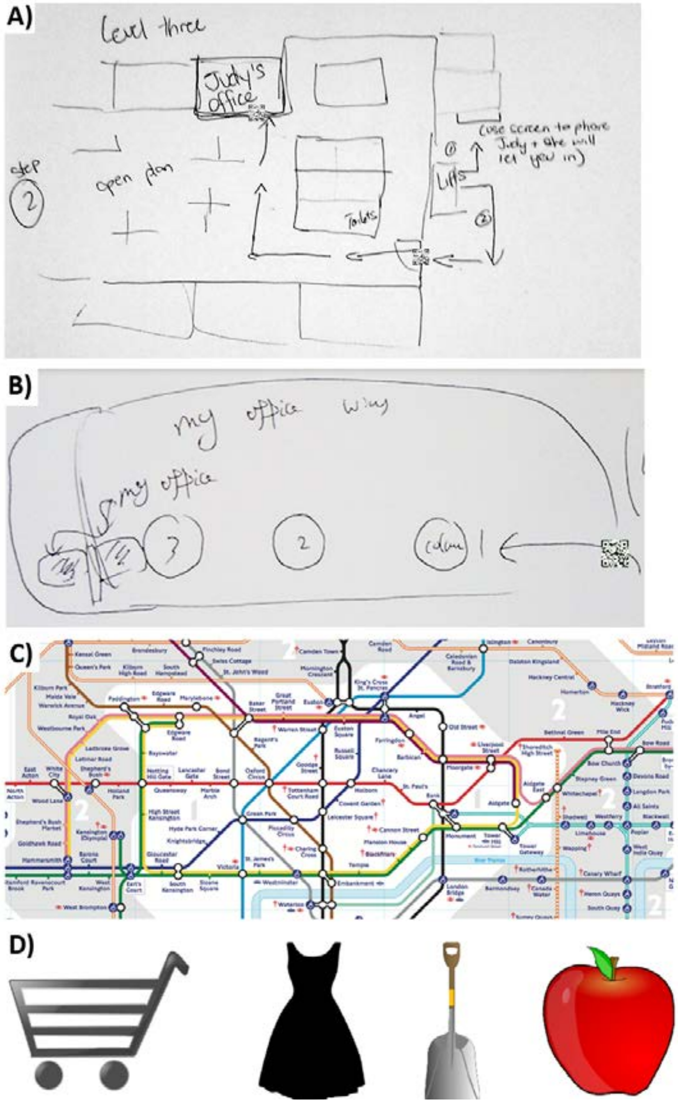

Figure 1. Different types of symbolic map, showing hand-drawn maps (A, B), the London Underground (C), and a series of visual symbolic cues (D).

(i.e. in its use of straight uni-dimensional lines to stand for the fragmented route of the tracks). In that map, a person is able to see train line interchanges and the order of the train stations without the complication of representing the correct geographical distance between stations. Another example of a symbolic map is the familiar hand-drawn map (Fig. 1A and B), outlining the instructions and salient objects that a user should follow in order to reach a particular destination. An extreme case of a symbolic map is shown in Fig. 1D, in which the map is distilled into a series of simple navigational cues that may be associated with important locations.

B. The Case for Symbolic Maps

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. Symbolic maps are found in a plenitude of domains such as museums, airports, and shopping centres (incl. individual shops). These maps are best suited to the places in which they have been specifically designed for, and also for the specific audience that they have been designed for. These characteristics also make symbolic maps an ideal target for personalisation.

The representation of an indoor environment can vary greatly depending on the context in which it is created and used. For example, consider a static museum map that has been professionally created and that is available to visitors of the museum (Fig. 4), versus a hand-drawn map that has been created for a specific purpose and with a specific person in mind (Fig. 1A).

Some factors that affect the method and style of the type of maps in the RoughMaps platform include:

- The intended purpose for which the map is created: For example consider a map designed for a public tour, or for visiting a friend, or for finding the bathroom.
- The intended person (or people) for whom the map is created: For example consider maps created for colleagues, friends, family, or customers.
- The expected duration for which the map will be useful: For example consider professionally created maps that are made available permanently, versus hand-drawn maps that may be available or relevant only for a single visit or a day trip to a particular location (e.g. an office room), before being disposed.

A symbolic platform like RoughMaps also opens up the possibility for multiple maps to be provided for any given location. This enables scenarios in which, for example, maps representing different museum tours be uploaded, either by a museum representative, or by a casual visitor to the museum (i.e. crowd-sourced).

III. RELATED WORK

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

A. 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 [11] 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 [10], magnetic anomaly-based positioning [15], infra-red proximity with accelerometers [32], and foot-mounted inertial units [36]. 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 ([14], [28], [16]). 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. [20] looked at the 'fingerprint' of wireless frequencies and [22] uses '802.11' radio frequencies to determine the position of users when indoors. In comparison, [29] and [9] use Bluetooth technologies to focus on privacy-centric indoor positioning methods.

B. 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 wide variability in map types that are representative of symbolic indoor maps.

The work in 'BeaconPrint' [17] 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 [18], 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 [1]; though generic in its design, that framework does not focus specifically on symbolic map use in indoor environments.

[19] 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' [7], where the position is recorded as a set of values 'who, what, where, and when'.

Another relevant framework, 'Redpin' ([4] and [5]), is the result of research into indoor positioning based on 'asynchronous interval labelling'. This framework allows for room-level accuracy using location fingerprints based on radio frequency technology. The 'Yamamoto' toolkit on the other hand [33] 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.

'IndoorAtlas' (www.indooratlas.com) [15] and 'Indoor Google Maps' (maps.google.com/starthere/) are two additional positioning frameworks that allow users to upload floor plans. These platforms require the floor plans to be mapped onto aerial images of the building, and so do not cater for symbolic maps that are not-to-scale, abstract in nature, and that may be designed with a variety of specific uses in mind.

C. Symbolic Maps

Most of the past work into symbolic map use for indoor positioning has come from the field of robotics, in which robots use a variety of different sensors (including laser range finders, ultrasonic transducers, infrared, tactile, camera, compass, and proprioception sensors) to create and then autonomously navigate building representations [23]. That field of work focuses on the use of sophisticated modelling equipment to create highly accurate geographical floor plan representations that are then often distilled into topological and symbolic maps, rather than the provisioning mechanism that allows for the use of symbolic indoor maps by end users of personalised mobile applications.

Other efforts have in comparison looked more generally at the use and viability of symbolic maps. [25] for example provide a guideline on the use of landmarks as a primary means of navigation in outdoor environments that lack GPS, and [3] also provide results on a study into landmark based navigation, in which participants are shown textual and photographical content on landmarks to guide them along a path. Also explored in other work is the variation of information displayed to the user, based on the current user context [2].

Yet other research into symbolic maps has looked into the ability for map morphing to help users relate maps with significant spatial and schematic differences [30], and adding contextual values to maps as an ad-hoc process [6]. 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.

IV. THE ROUGHMAPS PLATFORM

Building upon our previous work [12], the RoughMaps platform aims to provide contextually relevant symbolic maps to end users. The components of the platform (see Fig. 2) 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 accessible outside of an intranet.

A. Administration

The RoughMaps web administration interface is where maps are uploaded to the RoughMaps server. These maps need not necessarily have a high level of detail, but rather be designed with a specific understanding of the target user in

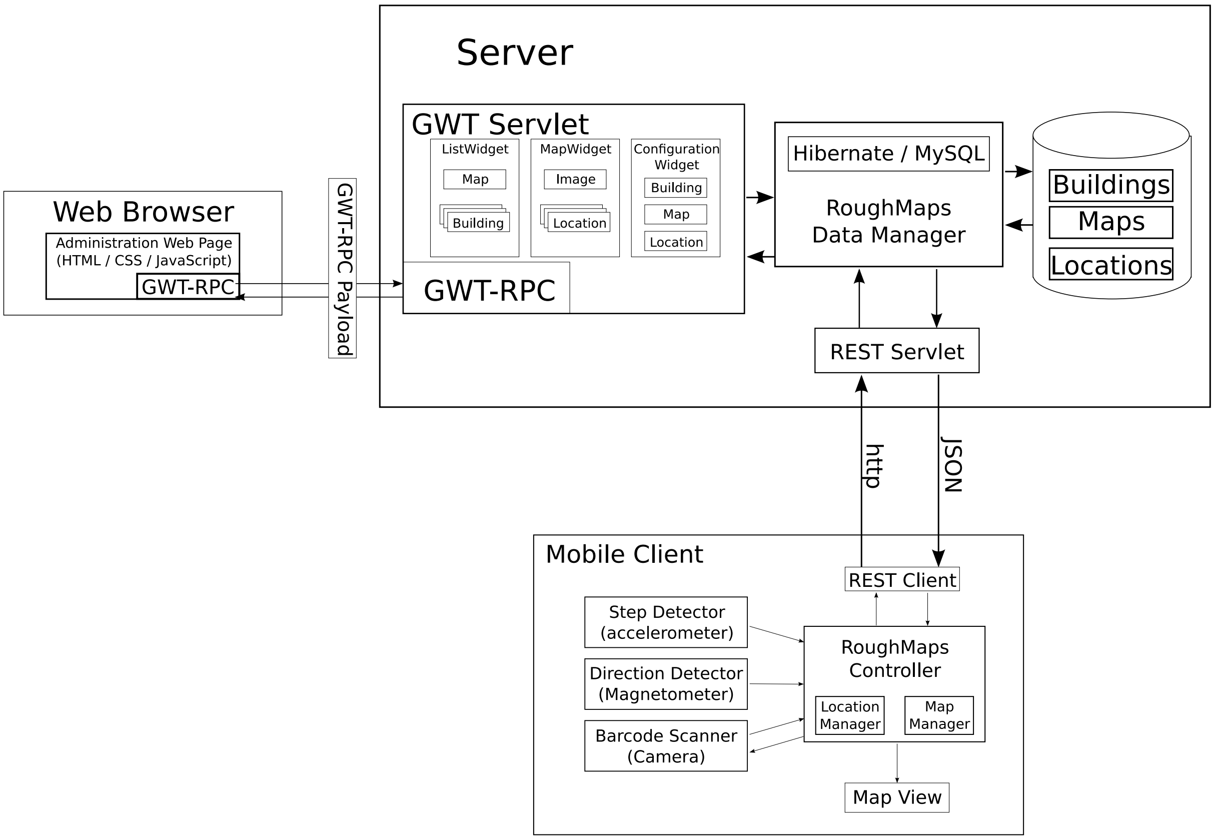

Figure 2. The RoughMaps platform architecture.

mind. For example, whereas a fire warden would require a map with sufficient detail to locate all of the people within a building, a visitor to a building may only need to know how to get to the desk of a person they want to visit.

The administration interface allows a user of the RoughMaps platform to define a building by its name, its geo-coordinates, and the maps that the building contains by clicking on the 'Add' button in Fig. 4A (see also Fig. 3A and B). Once the maps have been uploaded, locations representing positioning infrastructure in the building can also be placed on the map (e.g. QR codes). This information is saved to the RoughMaps database, such that client devices can then retrieve it.

The administration interface (see Fig. 4) is comprised of three primary components: the list widget (Fig. 4A), which lists buildings and maps; the map widget (Fig. 4B), which displays map data and existing positioning infrastructure; and the configuration widget (Fig. 4C), which displays the editable fields for buildings, maps, and locations when the user right-clicks on the map (Fig. 4D).

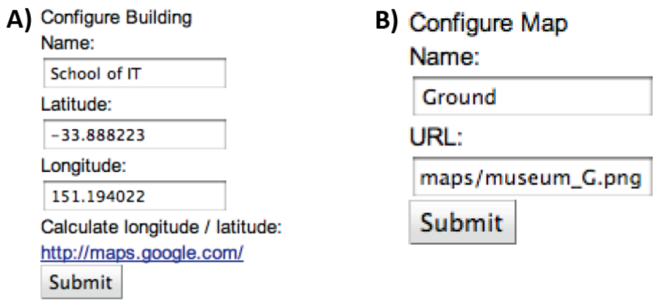

Figure 3. Configuration of (A) a building and (B) a building's map(s).

The administration interface for the RoughMaps platform is written in Java using the GWT, and communication with the server is performed using the Google Web Toolkit Remote Procedure Call (GWT-RPC).

B. Server

In order to provide access to the information stored in the RoughMaps SQL database, the underlying server provides two sets of servlets. GWT-RPC servlets are provided for communication between the front-end (written in GWT) and the back-end server implementation. REST (Representational State Transfer) servlets are provided for client applications, allowing simple 'HTTP GET' requests (by essentially any device connected to the Internet) for retrieving map and positioning information from the server (see Table 1).

TABLE I. ROUGHMAPS SERVER REST REQUESTS

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'

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},
    ...
```

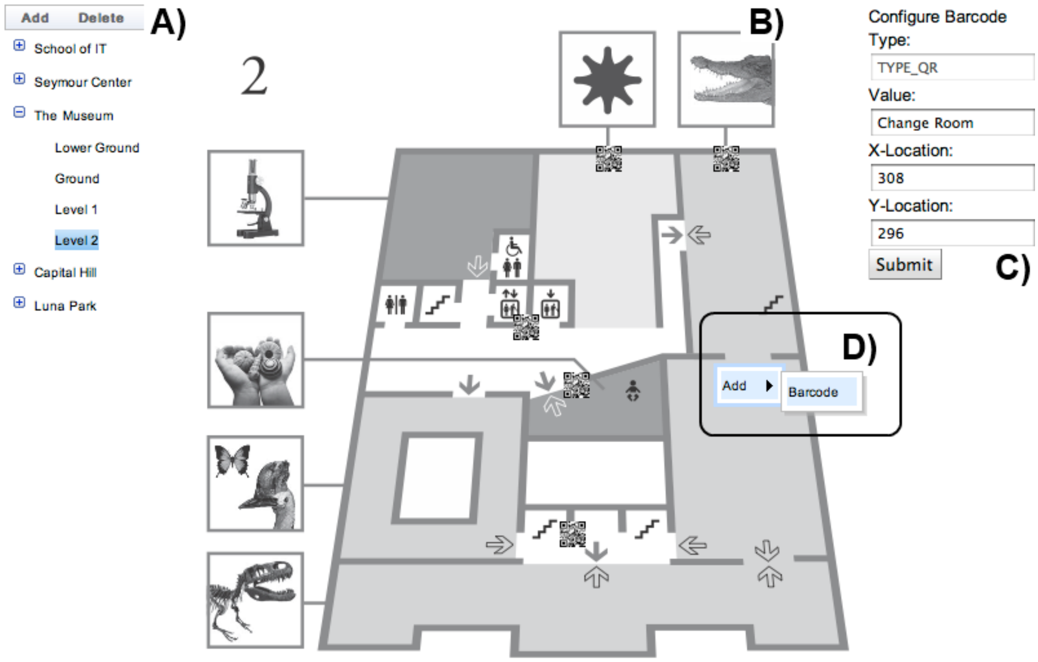

Figure 4. Administering a map.

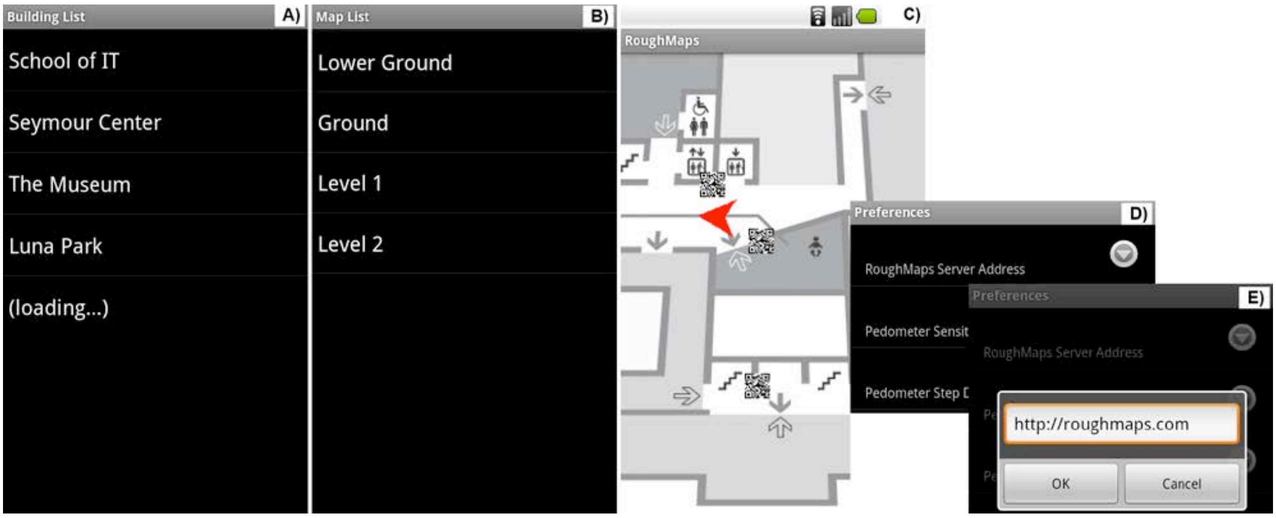

Figure 5. The Android client user interface, showing: a list of nearby buildings (A), the list of maps associated with a building (B), the user positioned on the map (C), and some configuration options (D, E).

C. Client

As described above, client devices communicate with the RoughMaps server via REST servlets in the form of http get requests. In order to evaluate and validate the platform, a client application was developed for the Android operating system. This client application utilises all of the available technical aspects of the platform, allowing the user to retrieve and use the information on the server.

On first starting the client application, the user is presented with a list of buildings that are automatically detected as being nearby to the user's location (via GPS/Cellular) and displayed based on their associated name (Fig. 5A). The user can then select a building for which to display a list of available maps (Fig. 5B). Each map has a name associated with it, and the user can at this point select a particular map to be displayed (Fig. 5C). In addition to showing the map and positioning infrastructure, the map view also shows a red arrow representing both the position and orientation of the device. As the user turns or moves around, they can see their position update on the map according to the supported infrastructure in the environment and the map. The user can also navigate the map using a variety of standard gestures such as scrolling the map via a drag gesture, pinching to zoom in and out, and double-tap to zoom in a fixed amount. Fig. 5D shows the preferences view, which allows 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 might be used in a walled-garden configuration, for example, as the primary mapping server for a single museum and its respective visitors (Fig. 5E).

Indoor positioning in the client application is based on two complementary positioning approaches. The first approach uses QR codes (also known as matrix or 2D barcodes) to calculate the absolute position of the user (Fig. 6). A range of barcode scanning applications are available for smartphones, and the one used in our client implementation is from ZXing[1]. Applications that generate QR codes for a specific value (such as 'Entryway' or 'http://chai.it.usyd.edu.au/') are also available in abundance; the only requirement being to print the QR codes out and place them somewhere in the building.

Figure 6. Scanning the QR Code for 'http://chai.it.usyd.edu.au'.

The second approach is based on the dead reckoning technique. This is achieved 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 QR code. Dead-reckoning is typically considered to be useful over short distances, as any errors that occur with each user step are cumulative. This approach to indoor positioning was chosen simply as a means to evaluate the platform. The platform is however not tied to a particular indoor positioning technique, and it has in fact been designed such that other technologies be supported with relative ease. In particular, and as described in the administration section above, the RoughMaps platform allows a map administrator to add positioning technologies like QR codes (or WiFi, Bluetooth, IR, or other) as points on the map.

[1] ZXing Barcode Scanner, http://code.google.com/p/zxing/

Then, as these new locations are added to a map, the clients that are retrieving the information from the RoughMaps server can retrieve and use the positions of this new technology as they support it.

V. EVALUATION

This work has three main goals: 1. to design a platform for managing and retrieving contextually relevant symbolic maps for use in indoor positioning systems; 2. to implement this platform 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.

[27] outlines the difficulties in evaluating complex system architectures and toolkits - and particularly those that are used 'off-the-desktop' (e.g. consider indoor positioning and navigation) - compared to traditional desktop computing systems. In this section, we evaluate the RoughMaps platform by demonstrating that it meets its requirements (verification) and that it also fulfils its intended purpose of supporting the users and applications that it was designed for (validation). The first condition is met by the successful implementation of the mobile client application, which makes use of the RoughMaps platform via the REST requests outlined in Table 1. We test the second condition, i.e. that the RoughMaps platform supports the applications it was designed for, via a cognitive walkthrough of the client and the administrative interfaces. 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.

A. *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. As outlined in [35], the cognitive walkthrough is a usability inspection method that focuses on evaluating a design for ease of learning. It is often called an expert analysis technique because the participants are usability experts rather than end users. Using this usability method, each task was broken down into a number of actions, and based on the process outlined in [35], the following aspects of the interface were then judged:

- 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?

1) *Map Data Set*

The map dataset that was used to evaluate the RoughMaps platform consisted of nine maps in total: four symbolic (i.e. not-to-scale) maps that are in use by an actual museum, one to-scale map of the School of IT based on the building's architectural floor plan, and four hand-drawn symbolic maps of the School of IT, similar to those shown in Fig. 7.

2) *Procedure*

The cognitive walkthroughs were conducted by a group of four researchers from the School of IT, 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.

TABLE II. MENTAL MODEL FOR SUBJECTS USING THE CLIENT APPLICATION

Concept	**Reason**
You have not been to the School of IT before.	This is the reason the user needs directions. It is a common occurrence, as students apply for enrolment in postgraduate studies or request assistance for subjects during 'meeting hours'.
You are at the ground level entrance to the School of IT.	It is the main entrance to the School of IT.
You 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 your 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.
You have not used the RoughMaps application before.	We are exploring the learnability of the interface.
You 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.
You 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 the user acquired it.

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 another nine actions (see Table 5).

The mental model that each subject assumed for this second task is shown in Table 3.

TABLE III. MENTAL MODEL FOR SUBJECTS USING THE ADMINISTRATIVE WEB INTERFACE

Concept	Reason
You have intimate knowledge of the museum building.	The employee has worked at the museum for a number of years.
You are well versed in the requirements of the visitors.	The museum employee answers questions and talks to visitors on a daily basis.
You have not used the RoughMaps administration interface before.	The maps have not been set up yet – the employee just found out about the system.
You have references to existing maps you want to use.	The employee is aware of the museum resources, and knows that the system requires the user to provide maps.
You know the locations of positioning infrastructure throughout the building.	Again, the employee knows that the system requires the user to provide the locations of the positioning infrastructure on each map.

3) 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. These results were relevant in determining how the existing prototype platform and service for client-side applications could best be improved.

TABLE IV. RESULTS OF THE COGNITIVE WALKTHROUGH FOR THE CLIENT 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 (i.e. upon exiting the elevator).
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.

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, QR codes, 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 too 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 more generally highlighted the need for the interface to better guide and inform new users on the encompassed functionality, such as adding buildings and maps, and adding positioning technology locations onto the map.

TABLE V. RESULTS OF THE COGNITIVE WALKTHROUGH FOR THE ADMINISTRATION INTERFACE

Action	Result
1. Open the RoughMaps administration interface.	Success.
2. Click 'Add', 'Building'.	UI needs improving, to better inform new users of this functionality.
3. Enter and save building details.	Success.
4. Select newly created building and click 'Add', 'Map'.	UI needs improving, to better inform new users of this functionality.
5. Enter and save map details.	UI needs improving, to provide feedback on maps that have been saved.
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 better inform new users of this functionality.
8. Select 'Add' then 'Barcode' from the menu.	Success.
9. Enter and save barcode details.	Success.

B. *Positioning Accuracy*

In addition to the two cognitive walkthroughs that were conducted, we also performed a small evaluation of the positioning accuracy of the system for a set of four 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 Fig. 7 and highlight the differing nature of map types that can be uploaded to the platform. In particular, Fig. 7A, B, C, and D all represent the same route, though whereas Fig. 7A is to-scale and based on a building floor plan, Fig. 7B, C, and D have all been separately hand-drawn and are not-to-scale. Note that the whole route is not shown in Fig. 7B; this is because the user has in this particular instance zoomed into the map. Note further that Fig. 7D is a 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 4.13m over a distance of 24m, equating to an error per meter value of 17cm.

TABLE VI. POSITION ACCURACY RESULTS.

Map	Map scale[a]	Average distance from final waypoint	Error per meter
A)	2	4m	16cm
B)	10	3.5m	14cm
C)	3	4m	16cm
D)	3	5m	20cm

a. 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 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 than QR codes, becomes inaccurate as the distance travelled increases [36]. 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 other technologies like WiFi and Bluetooth, can all be easily integrated. To this end, the implemented client prototype successfully demonstrates that the infrastructure and platform work effectively when the phone can provide reasonably accurate ways to establish the user's location.

C. *Scalability*

Evaluation of the scalability of the RoughMaps platform was performed using the Apache Benchmarking Tool. 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 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 is quite acceptable for a system in its early development phase.

VI. CONCLUSIONS AND FUTURE WORK

In this paper, we present RoughMaps, a novel research platform designed to support the administration and use of symbolic maps for the purpose of indoor positioning in personalised and context aware applications. 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. The platform is expected to also become an essential tool for the continued study of symbolic maps and their relevance and importance in personalised and context-aware mobile applications.

Future work will now focus on extending the platform to account for multiple user types so that the platform can distinguish between different users and user groups (e.g. building administrators versus casual users), and testing the system with end users.

Key contributions of this work are the design, implementation, and validation of the RoughMaps platform. We outline the API in which client applications can interact with the platform, and evaluate the RoughMaps implementation by way of an illustrative client-side mobile application and two cognitive walkthrough usability inspections. The positioning accuracy of the client prototype is also tested, as too the scalability performance of the RoughMaps server.

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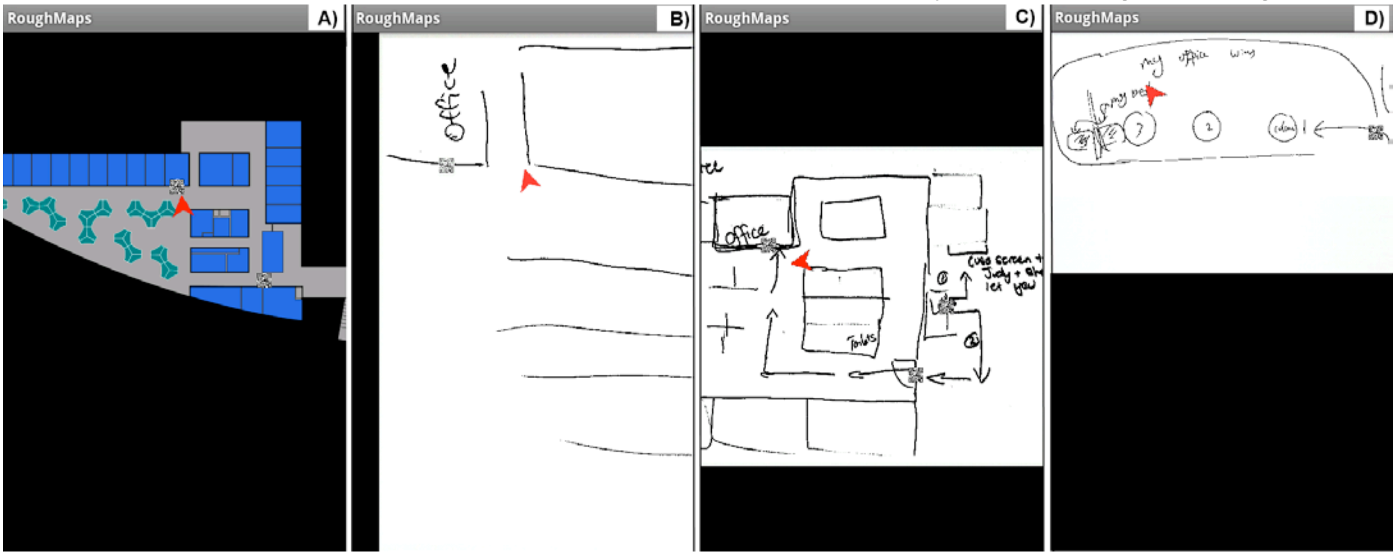

Figure 7. Symbolic maps used for route calculation during the positioning accuracy evaluation, showing a to-scale map (A), two hand-drawn maps (B, C), and a symbolic map based on a sequence of visual instructions (D).

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