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ORIGINAL ARTICLE

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Marked-up maps: combining paper maps and electronic information resources

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Abstract Mobile devices have been used as tools for navigation and geographic information retrieval with some success. However, screen size, glare, and the cognitive demands of the interface are often cited as weaknesses when compared with traditional tools such as paper maps and guidebooks. In this paper, a simple mixed media approach is presented which tries to address some of these concerns by combining paper maps with electronic guide resources. Information about a landmark or region is accessed by waving a handheld computer equipped with an radio frequency identification (RFID) reader above the region of interest on a paper map. We discuss our prototyping efforts, including lessons learned about using RFID for mixed media interfaces. We then present and discuss evaluations conducted in the field and in a comparative, exploratory study. Results indicate that the method is promising for tourism and other activities requiring mobile, geographically-related information access.

Keywords Mixed-media interfaces · Geographic maps · Mobile interaction devices

Abbrevations RFID: Radio frequency identification · GIS: Geographic information system

1 Introduction

Paper maps have been used for centuries. They are relatively unconstrained by size or weight, inexpensive to produce, and easy to manipulate, fold, and store. Maps are a communicative medium, combining in their design knowledge of human cognition, formal models of sign communication (semiotics), and an understanding of how maps are interpreted 'lexically' by individuals [1]. However, maps on small mobile devices, in part due to size limitations, typically employ a very sparse visual representation, present small portions of a larger map, and are encumbered by implementations of navigation techniques (such as zoom and pan) that were originally designed for desktop computers. While recent efforts to improve the map viewing experience on small screens are promising [2, 3] it seems unlikely that paper maps could be surpassed in terms of *static* context and visual presentation. In this paper, the use of paper maps as artifacts for mobile information retrieval is discussed, and our related research is presented.

Paper maps are interesting real world artifacts to augment in part because they are themselves an information resource. Like books [4, 5], we can use the information presented on a map as a launching point for queries by connecting the paper map to digital information. People already know how to use paper maps for navigation, planning and discovery. Additionally, and unlike many books, paper maps are readily used when mobile. The fact that paper maps present static views is often advantageous, by allowing an individual to become familiar with a particular representation of a city or region, which he/she can then refer to with confidence. However, paper maps, as static views, are limited in the scope of information presented, the level of detail available, and the manner in which information is presented. They can also rely heavily on spatial search, which brings with it innate limitations in the perception and management of visual complexity [1] Fig. 1.

We present a technique for relating paper maps and electronic information resources using radio frequency identification (RFID) technology, called Marked-up maps. After discussing related work and motivating the research, our current prototype is discussed in detail. Two evaluations, one conducted in a mobile setting and

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Fig. 1 A Marked-up map of the Montreal subway, providing access to tourist information

the other a comparative scenario-based user study are then presented, and results discussed. Finally, we raise several issues that motivate future work.

2 Motivation

2.1 Background

There exists a significant body of work concerning the integration of paper and digital information. Some potential benefits of this are discussed by Johnson et al. in [6]. *Paper user interfaces* provide a link with digital resources, normally through pen-based interaction such as form completion. Marked-up maps are a type of paper user interface, in that information is retrieved using a paper map, however this occurs through a handheld computer.

Tangible user interfaces integrate digital systems into the real world by capturing input and providing output through physical artifacts. In [7], Ullmer and Ishii provide a framework for situating tangible computing technologies. Marked-up maps shares some attributes of *spatial* tangible systems, in that relative spatial position directs interaction, and *relational* tangible systems, as symbols on the tangible resource (map) are linked to digital material. The MetaDESK [8] is a tangible user interface which provided tangible interaction for digital maps. In Marked-up maps, the map itself is the tangible artifact, providing a 2D representation of physical space, and the handheld computer is used both as an interaction device and to present digital information. As such, Marked-up maps are an example of a mixed-media interface, in which relations are expressed and manipulated by direct interactions between physical and digital media, in a manner similar to that presented by Grønbæk et al. in [9].

Augmented reality projects digital information onto the real world, usually visually or aurally. Augmentation of books, either by projecting on a nearby surface [4], or directly on the pages of the book itself [5], explore augmented reality as a way to combine physical and digital information resources. Looser et al. [5] discuss the use of magic lenses, as described in [10], as an effective interaction technique for augmented reality. We are interested in using a handheld computer as a lens to provide a floating, interactive overlay for paper maps, much as described by Fitzmaurice in [11].

In [12], Bryce Allan provides an evaluation of spatial organizations of textual data. His findings indicate that a spatially-organized representation of textual data can assist some users in navigation and recall of information structure. Geographic information system (GIS) systems employ the geospatial as a primary organizing principle for information. In the case of a simple hypertext resource linked to a paper map, spatial organization is used to indicate geographical relationships, but may additionally promote recall and access of related information resources.

Screen size is an important factor to consider when dealing with electronic maps. Alternative map viewing techniques in the literature include focus plus context, and detail in context, both of which try to address screen real estate issues by providing some indication of surroundings while focusing on or providing greater detail for a particular region. Baudisch et al. [13] evaluated a technique called focus plus context, in which a high-resolution (focused) region is provided inside a larger, lower-resolution display. They found the technique advantageous for route finding on maps, which was attributed to increased context around the focused region, and the ability to use a single map view. This approach requires the use of a large, stationary display, as does other research considering the use of maps for information retrieval in public spaces involving mounted, digital map displays [8, 14, 15].

A paper map does not have the same size constraints as most electronic devices, and is very portable. If paper maps could be combined with electronic resources in an unambiguous way, they would provide useful context for geospatially-oriented information retrieval.

2.2 Paper versus electronic maps

To help motivate the integration of paper maps with digital information, we considered common attitudes toward electronic and paper maps. We surveyed 111 individuals, asking simply whether they preferred paper or electronic maps, and to give reasons for their preference. Respondents were predominantly Computer Science students, and so might be expected to exhibit a higher than average preference for electronic maps. 65 of these respondents were given the option of indicating that they “liked both equally”. Of these, 17 stated a preference for paper maps, 22 for electronic maps, and the remaining 26 said they had no clear preference. An additional 46 respondents had to choose between paper or electronic maps. Of these, 24 stated a preference for paper maps, and 22 for electronic maps.

Reasons given in support for paper maps were varied. The most often cited reason was portability. While maps on a handheld or laptop are portable in some sense, they lack the ready availability of a paper map folded up and stuck between seats in an automobile, for example. Paper maps were also seen by some as providing a clearer, more accessible view that displays a wider region and is easier to study and manipulate (by rotating, folding). Others liked being able to write on paper maps, and several respondents cited the tangible nature of paper as a benefit.

A variety of reasons were also given by those who said they preferred electronic maps. Most prevalent were that electronic maps can provide greater coverage and control over level of detail (via overlays, zoom and pan), and provide the ability to search for locations by name or another textual or descriptive feature.

When respondents indicated that they had no clear preference for paper or electronic maps, they overwhelmingly indicated that paper maps were more useful when traveling, and electronic maps before or after.

2.3 Maps and electronic guides

Maps are not used in all location-based information systems. Location-awareness is often used to provide directional guidance and to frame information retrieval, sometimes in place of a map. For example, Cheverst et al. mention that they introduced maps into the electronic Lancaster GUIDE system only after requests from several users [16]. Other projects which included maps during later phases of design include Sotto Voce [17], and the Costa Aquarium guide [18].

Much electronic tour guide research [including 16–18] has grappled with the tension between context-driven information ‘push’ and user-driven information ‘pull’. Integrating an electronic resource like a guide with a paper map provides a clear way to achieve information pull, recognizing that information needs while touring or way-finding are not always dictated by current location.

We have developed a mixed media prototype that recognizes the advantages of paper maps for way-finding en route, but augments the maps with location-specific information accessible (i.e. ‘pulled’) via a handheld computer.

3 Marked-up maps

In this section, our prototype implementation is described, and several technical issues are discussed.

3.1 Use scenarios

3.1.1 Public information kiosk

A group of tourists are enjoying a walk along a city waterfront. They encounter an information kiosk on the boardwalk, showing a schematic map of the waterfront area. The map identifies points of interest, but does not provide much detail.

By waving a handheld computer (or ‘smartphone’) over particular landmarks, the group retrieves detailed information on the handheld. The interaction does not require the group to take sole control over the kiosk, and the retrieved information can be taken with them as they continue their walk.

3.1.2 Personal map

A motorist is reviewing the route to her destination, marked on a paper road map. She wonders if her bank has a branch on the way.

By first placing a handheld device over the legend icon for bank on the map, and then along the length of the route, the motorist expresses a query for banks in the region specified. She finds a listing for the bank, marks its location on the paper map, puts the handheld device away and continues her journey.

3.2 Technical implementation

In our prototype, map locations are identified using small, flat RFID tags or labels affixed to the back of the map. Labels can be arranged in a regular grid (Fig. 1, 2), or used to mark specific locations of interest (Fig. 3). An RFID reader is attached to the back of a handheld

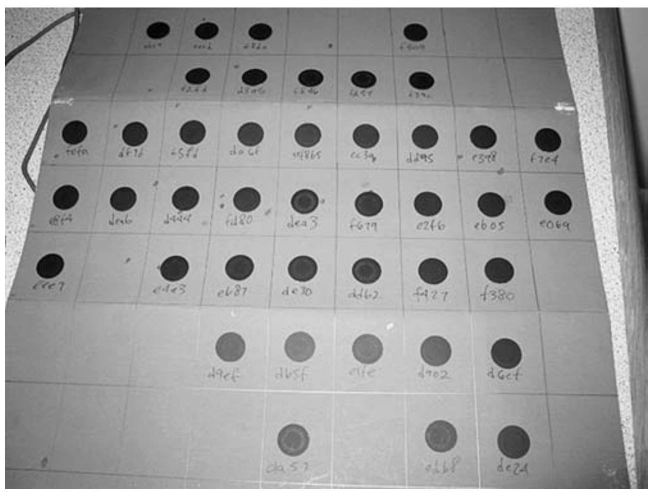

Fig. 2 Radio frequency identification tags placed in a regular grid, to be set below a paper map. In this way a grid can serve as the basis for more than one marked-up map

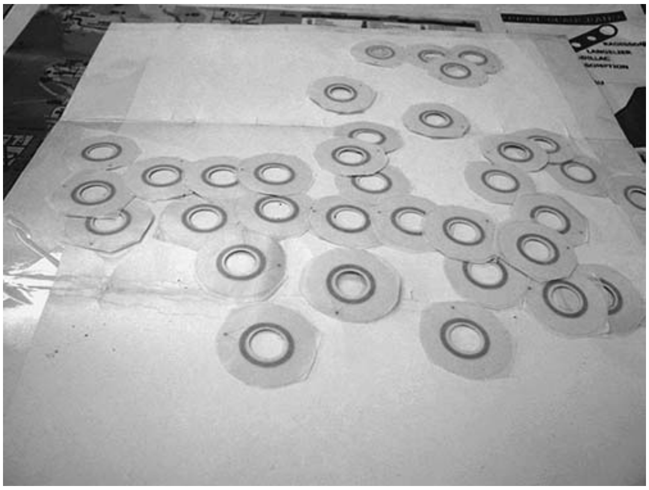

Fig. 3 Radio frequency identification tags placed beneath items of interest on a specific paper map

computer, such that locations are queried by holding the handheld display-side up in front of a map region (Fig. 4). Details about the selected region appear on the handheld screen when the user presses a physical button on the device. For our current prototype, we decided against automatically updating the information presented on each RFID read, as spurious reads can occur when tags are placed close together.

IPAQ h5550 handhelds were used, which provide a colour 360″×480″ pixel screen, and wireless network connectivity. A Phidgets RFID reader was attached to the back of the handheld; it is slim enough that participants were able to hold the handheld/reader comfortably in one hand (Fig. 4).

A simple client-server implementation was developed for the study presented in this paper. RFID reads are continuously sent to the server, which keeps track only of the most recent tag ID. The handheld user interface was accomplished using a standard web browser. Pressing a physical button on the handheld computer (mapped to a request for the server's base URL) causes the server to retrieve html-formatted information mapped to the most recently read tag ID, which is then displayed on the handheld computer screen. As such, the implementation permits point-and-click interaction with individual locations on a paper map. The resulting page can then be used to navigate to additional related information.

Fig. 4 Radio frequency identification reader attached to back of IPAQ handheld computer

Two styles of RFID tags have been used in our prototyping. Both are read-only, and of the EM4102 standard. The first is a thin, 20 mm diameter epoxy-coated stiff tag. These tags have a short read range (a few cm). Our reader found it difficult to read tag ids when these tags were placed within 1 cm of each other. The tags were used to create a generic, regularly spaced RFID grid (Fig. 2). The second style used is a pliable, adhesive RFID label. The labels are 50 mm in diameter, but can be overlapped up to the active center region (20 mm in diameter) without causing difficulty for our reader. The range of the labels is also greater by a few centimeters, allowing consistent interaction within 10 cm of the tag when the reader is held parallel to and above the tag. The labels were used to "mark up" specific landmarks on several styles of map (Fig. 3). The resolution provided by the tags has been sufficient for all demos created so far, but a finer granularity may be desirable in other cases. An overlay on the handheld computer providing a clickable version of the underlying region could counteract any limits in tag resolution.

In both cases (in regular grid, or by landmark) we have been able to read tag ids when a map is folded onto itself without difficulty. However, issues of variable range occur when tags are placed per landmark (see Fig. 3). That is, a tag placed beneath a landmark that sits in relative isolation compared to other tagged landmarks will have a greater read range than landmarks that are more closely spaced.

We considered placing "buffer tags" to balance out these differences, but to this point have not encountered a pronounced occurrence sufficient to cause confusion. Because our implementation reads tags by hovering the RFID reader *above and parallel to* the landmark, we only detect a difference in range in terms of the vertical distance from the tag. This has no effect when the handheld computer is held sufficiently close (within 10 cm) to the map for all interaction. An implementation utilizing pointer-based interaction will also require proximity of the pointer to the map to avoid spurious reads.

4 Field observations

Prior to evaluating our prototype in a user study, we wanted to evaluate it ourselves 'in the wild', to gain a better sense of how it might be used in a mobile context.

In this section, a field trial is described and reflections on the experience are presented.

4.1 Setup

The prototype underwent an evaluative field trial while attending a recent conference. A tourist map of Nottingham was "marked up" with information relevant to ourselves as sightseers, which was then used while touring downtown Nottingham (see Fig. 5). Tourist information was obtained from various websites about Nottingham and its attractions. Use of the prototype was intermittent over the course of one day of sightseeing.

By evaluating the prototype in context, we gained some understanding of the nature of queries that sightseers would like to perform using a typical paper map, the impact of occluding the paper map with the handheld, and patterns of use when mobile.

4.2 Observations

Overall we felt the marked-up map was an effective way to reference information. in the city. When touring Nottingham, the map itself provided hints about places of interest. By first situating ourselves on the map, we could then explore nearby places in more detail using the markup technique. The direct combination of spatial information with detailed information was illuminating at times, and the separation of the two types of information into map and handheld felt natural.

Using both a handheld computer and a paper map made *mobile* access cumbersome, however, especially for one person. Instead, the handheld computer was used to access information using the map when sitting down. This was acceptable as the information was used to plan itinerary and explore options. While seated, clicking on landmarks seemed natural and straightforward. Additional feedback (auditory, visual) that a read had occurred would have been welcome in the mobile context as well (prior to use outdoors we had relied on an audio cue from the server to indicate a read).

We also wondered when the handheld computer was being used, whether the handheld computer itself could display a map that was as useful as the paper map. However the survey knowledge that the paper map gave for planning and navigation was superior to the visual presentation provided by the electronic maps that we had available for use. After some time we wanted to ask specific questions, to frame our queries according to themes (admissions and hours of operation, bus schedules). The interface was good to browse with, since the landmarks on the paper map were large and constrained to tourist attractions and other details of interest to tourists. Unfortunately, having built the guide there was no real opportunity for 'surfing' the map resources; links to a greater number of resources would have been welcome in our case. Finally, we envisioned using the handheld computer as a secondary tool for retrieving details only, while annotating directly on the paper map, tracing routes and jotting notes.

Fig. 5 Using a marked-up tourist map in Nottingham's Broadmarsh bus station

5 Exploratory study

We conducted an exploratory user study to evaluate the technique in use with several different kinds of maps and guide resources. We also took the opportunity to observe general use of the markup technique by novice users, as we had become comfortable using it and were only rarely experiencing interference from nearby tags when selecting information.

The use of paper maps with electronic information resources may be a reasonable way to navigate and build survey knowledge, by giving geographic context to information. However, providing a direct link between the two resources is perhaps not necessary or even desirable. Another objective of the study was to explore this question further: is marking up maps really necessary or would accessing an online map supplement with your handheld computer be as beneficial? To allow comparison, we developed guide resources with electronic versions of the maps and hypertext indexes.

5.1 Design

The study employed a within-subjects design, counterbalanced on both order of interface and map scenario. Twelve participants (Ten male, Two female) were recruited from the Computer Science department at Dalhousie University. Participants took part individually in a single 1-h session during which they completed two separate trials. The experiment was conducted indoors, in a semi-public lab space.

Each trial involved a single map/guide combination (Montreal, Vancouver, or Nottingham). Five tasks were performed using one of the interfaces, and then five different tasks were performed using the other interface. Tasks were grouped so that tasks similar in nature and difficulty were encountered in each condition. Each task set consisted of four tasks involving information retrieval based on a single location, followed by a task requiring the use of spatial knowledge and access of information from more than one location. The order of task sets was held constant so that each set was attempted an equal number of times per condition. Details about specific tasks are provided below.

Prior to each trial, participants were given an introduction to the map and electronic resource they would be using. During the demonstrations the participants were made aware of salient features of the maps, including legend, orientation, and landmarks, and of how to navigate the guide resource. Prior to the marked-up map condition, participants were also given an opportunity to familiarize themselves with the RFID reading mechanism.

5.1.1 Measurement

A facilitator and observer were present throughout the experiment. The facilitator performed some observation during the tasks as well, and interactions were also captured on video. In addition to observational notes, the following aspects were measured:

- Time to complete task (or time taken until left incomplete)
- Whether task was completed correctly
- Number of switches between the paper map and the handheld computer
- Amount of time spent using the paper map

Each participant's stated preferences were captured in a post-trial evaluation, covering:

- Enjoyment
- Overall effectiveness
- Effectiveness in locating items of interest
- Effectiveness in relating the map with guide resources

At the end of the session, participants completed a brief evaluative questionnaire. An informal post-session interview provided an opportunity for discussion of the techniques, their experiences and suggestions.

5.2 Scenarios

Three different scenarios were devised, each using different types of maps, different kinds of electronic information, and different kinds of tasks. Each is described below.

5.2.1 Montreal subway

This scenario represented the use of markup with a vertical, mounted public map. The map chosen for this scenario was the schematic Montreal Metro (subway) map used regularly by Montreal's commuters. On this map subway stations, lines, and connecting commuter trains are presented in a spatially simplified manner over a representation of the island of Montreal. We mounted a 26″×26″ version of the map on a wall in the lab for the experiment (Fig. 6).

The digital information resource associated with the map was a handheld-friendly version of the interactive Montreal subway map developed by the Montreal transit commission, available online [19]. Each subway station was linked to a page listing nearby points of interest, the origin of the station's name, and providing access to a street-level map, and "Google Local"[20] links to nearby bars, restaurants and hotels. The information structure and level of detail provided in the guide was consistent across subway stations.

Tasks were modeled to represent the needs of a commuter. The first four tasks given to participants in each condition involved retrieving information associated with a single subway station, such as nearby parks and restaurants. The final task involved relating information across several adjacent subway stations, requiring knowledge of relative position.

5.2.2 Nottingham

The Nottingham scenario reflected use of a map by a tourist in the city. A large (18″×22″) tourist map was used, presenting downtown streets and large, iconic representations of city landmarks and tourist destinations (Fig. 7).

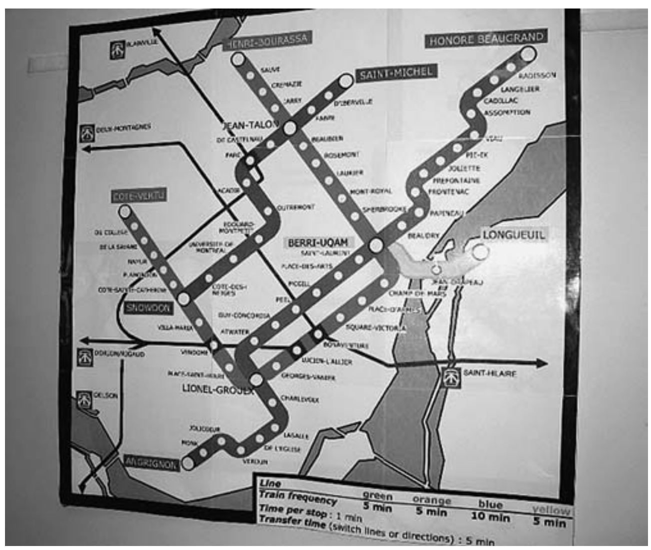

Fig. 6 Wall-mounted Montreal subway map

Each image is linked to a page of detailed information on the handheld computer. The nature of the information presented varied according to the landmark represented, but in general was current information, of use to a tourist in the city. For example, shopping centres linked to store directories, theatres to current and upcoming shows, and historical sights to longer descriptions and hours of operation. The linked information was shallow, that is, there were no hyperlinks to further resources provided on the pages.

As with the Montreal scenario, the first four tasks in each condition involved finding out information about a single attraction, such as local folklore, costs and hours of operation. The final task involved searching several related resources (shopping centres, or theatres). In each case the common map symbol (shopping bag, tragedy/comedy mask) operated as a visual cue for accessing similar resources.

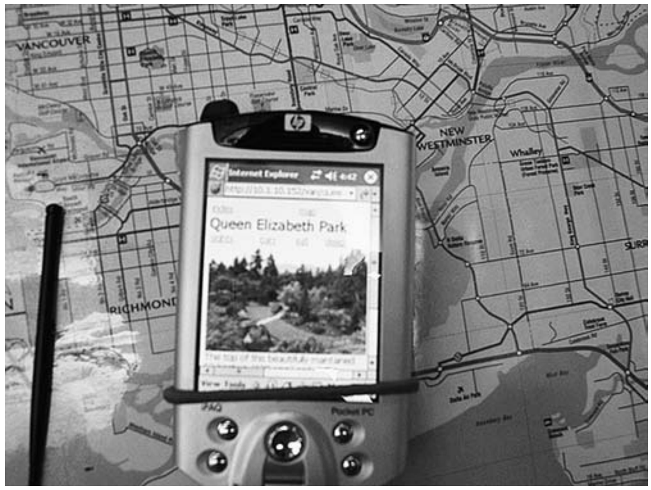

Fig. 8 Paper map of greater Vancouver and detail on handheld computer

5.2.3 Greater Vancouver

In the Vancouver scenario, a wide range of landmarks were linked to grid squares on a road map of the greater Vancouver region. The road map was a useful resource for navigation by itself, providing spatially accurate transit, district, and landmark data in a 16″×16″ format (Fig. 8). Tasks included under this scenario modeled route planning and orientation activities.

An index of points of interest was provided for each grid square. Selecting an item retrieved a page providing descriptive information about the item, plus "Google Local" links to nearby bars, restaurants, and hotels. In contrast with Nottingham, item descriptions were general and brief Table 1.

Under this scenario, the first three tasks in each condition involved simple information retrieval related to a single point of interest. For each task the relevant map grid square (informally termed 'quadrant' in the study) was given. The fourth task required comparison of two similar locations (markets, ferry terminals) in different regions of the map. Completing the task was facilitated by relating each resource back to the paper map. The final task required that information retrieved on the device be combined with information provided on the paper map (trail routes, beach locations).

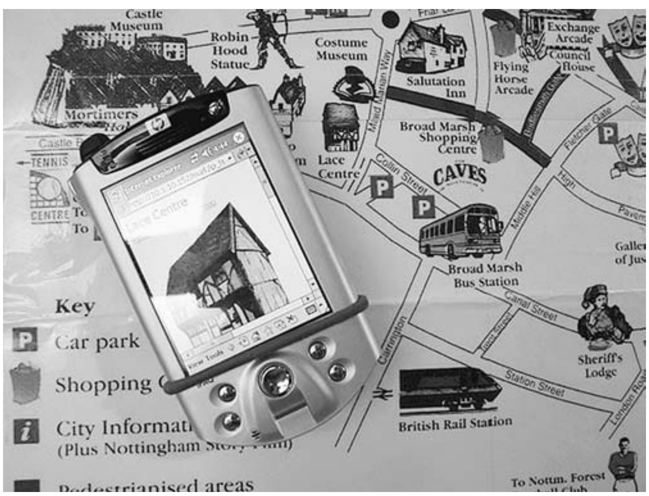

Fig. 7 Nottingham paper map and attraction detail on handheld computer

5.2.4 Electronic map and index

In the non-markup condition, participants were given an electronic version of each map and a textual index, which they could use along with the paper map to locate information. The electronic map is an exact copy of the paper map, designed to be viewed on a handheld computer screen (see Fig. 9, 10). Only a portion of the map was viewable at one time, and participants could view other regions of the map by scrolling in two dimensions (up/down and left/right), or dragging the map with the handheld computer stylus. No indication of the current visible portion of the map was provided other than the position of the scroll bars, and zoom was not available. Participants could compare the visible portion of the map on the handheld computer with the paper map. The maps are clickable and linked to resources in the same way as the paper maps in the markup condition.

In addition to the electronic maps, alphabetic indexes of the linked resources were provided (points of interest for Nottingham and Vancouver, subway stations for Montreal). Textual search was not provided.

Text search of the current page was not demonstrated to participants. One participant used the feature to locate items in the index because he was previously familiar with it.

Table 1 Summary of differences between scenarios

	Nottingham	Montreal	Vancouver
Scenario inspiration	Tourist in city	Subway commuter	Route planning, orientation
Map description	Illustrative map with large iconic landmarks and major routes. 18″×22″, used while seated	Schematic subway map, wall-mounted,26″×26″. Map features are consistent and large (subway stops and lines)	Accurate and detailed regional/road map with grid, 16″×16″. Small map symbols identify points of interest
Guide description	Information linked to each landmark. Format and information provided varies	Information linked to each subway stop, in consistent format	List of resource hyperlinks linked to each map grid square. Linked data is in consistent format
Task examples	The Flying Horse Arcade occupies a building that used to be what? You want to purchase stained glass and get a bite to eat. Plan a route from the bus station	Find the address of Bar Lingdon (near Université de Montréal station). Find the downtown YMCA on the green line	Where does the Dyke Walk begin at its north end? Which of the beaches near UBC have fire pits?

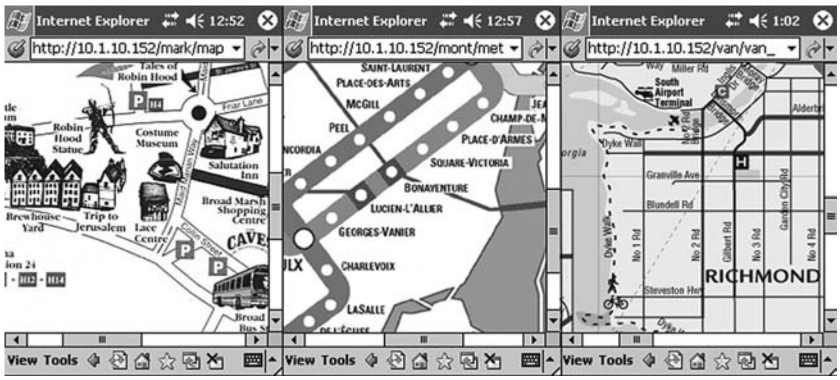

Fig. 9 Handheld computer versions of Nottingham, Montreal and Vancouver paper maps, respectively

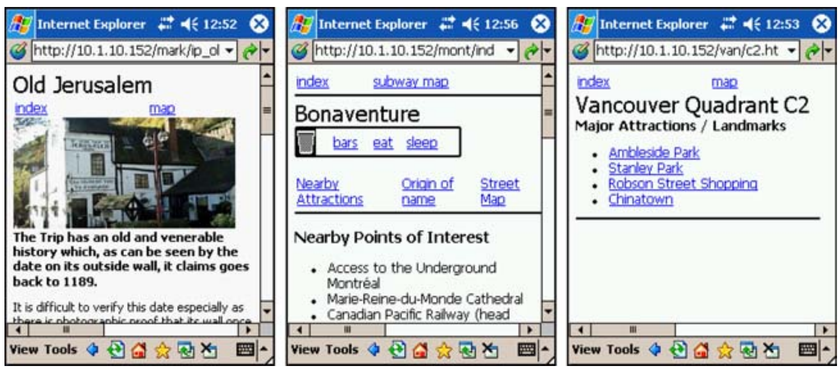

Fig. 10 Information linked to Nottingham, Montreal and Vancouver maps, respectively. In the markup conditions, these were linked to the paper maps. The non-markup conditions provided an electronic map and index which did the same

6 Results and Discussion

6.1 Quantitative Measures

In analyzing the results, we combined tasks according to the characterizations previously discussed. In the Montreal and Nottingham scenarios, four of five task results were combined under each condition to represent questions involving one location. three of five per condition in the Vancouver scenario were combined in the same way. The remaining 1 (for Montreal, Nottingham) or 2 (Vancouver) tasks in each condition involved more than one location and some interaction with the map itself, and so were considered separately. In this exploratory study, only 8 of 12 participants experienced a given scenario. As such, statistical significance on most measures was not expected, although some measures might be suggestive enough for further inquiry (see Table 2).

Table 2 Summary of quantitative results

	Nottingham		Montreal		Vancouver	
	Markup	No Markup	Markup	No Markup	Markup	No Markup
T (s)	565	612	338	372	460	552
P (%)	30	14	27	10	21	18
S	27	21	18	7	20	16

All values are average totals for all tasks in a given condition and scenario. *T* is the mean time taken to complete all tasks, in seconds. *P* provides the mean proportion of time spent using the paper map. *S* gives the mean number of switches between the handheld computer and the paper map

Overall there was no significant difference between conditions (markup, no markup) in time taken to complete tasks in any of the scenarios (although on average, participants were faster using the marked-up map condition). This contrasts with the impression of several participants who felt that they were faster in the no-markup condition. There was also no difference in the number of incorrect responses given.

Participants used the paper map significantly more often in the markup condition for Montreal scenario ($t(8) = 7.81$, $p < 0.001$). A similar significant difference in amount of paper map usage existed in the Nottingham scenario as well ($t(8) = 6.51$, $p < 0.001$). This suggests that, for these maps, some additional use of the map can be achieved using markup without adversely impacting time taken to retrieve information. This may in turn promote the development of spatial knowledge relevant to the resource(s) being sought out. However, when completing information-gathering tasks without a real geospatial aspect, participants tended to rely on the textual index in the no-markup condition. Our results do not indicate that people would prefer marked-up maps over a textual index for such tasks (see Table 3).

Participants used the paper map in the Vancouver scenario about as much in either condition. This may be because the map was more detailed, requiring more study when answering questions. In addition, under each condition participants taking part in the Vancouver scenario encountered two tasks with a strong geospatial component, versus one in the Montreal and Nottingham scenarios.

6.2 Qualitative Measures and Observations

Participant evaluations of the markup technique in comparison with the electronic map and index were mixed. Except for relating map and guide in the Nottingham scenario, no clear preference emerged between markup or electronic map and index for either the Montreal or Nottingham scenarios. Reasons provided for preferring markup include "natural", "so easy", "faster", "vivid", "you know where you are". Reasons for preferring no markup include "faster", "use the index", "less annoying", "avoid visual search".

Table 3 The number of participants preferring marked-up maps out of the eight total who encountered a given map scenario, by enjoyment and three measures of effectiveness

	Nottingham	Montreal	Vancouver
Enjoyable to use	4	5	6
Effective overall	5	5	6
Finding information	5	3	5
Relating info to map	**7**	4	6

Six of the eight participants experiencing the Vancouver scenario felt that the markup technique was more enjoyable to use, more effective overall, and more effective at relating the map to the information on the handheld computer. This may be due in part to deficiencies in the electronic-only guide for Vancouver (see Fig. 11), wherein it was only possible to get to the indexes for individual map grid squares via the electronic map, which most participants found too large and difficult to navigate. The general index provided the same links along with map square identifiers, but took longer to search through. In addition, several participants expressed that it was easy to use markup to access map square indexes when the required map square was known ("just point and go").

Seven of eight participants who experienced the Nottingham scenario felt that markup did a better job of relating the map to the information resource, which seems to correspond with the amount of time spent using the paper map in the marked-up condition. In the Montreal map scenario however, only three of eight participants felt the marked-up condition was most effective for finding information, and four of eight found it most effective for relating information to the map. It is possible that a sparse schematic map showing only subway stations was harder to relate to information than a map providing more direct relationship to the retrieved data (such as the iconic Nottingham map, which linked to pages with full colour images of the landmark selected).

As mentioned, most participants used the *electronic* maps very little or not at all in the non-markup condition. Several participants felt the screen was too small for the map. Others suggested that zoom or some other indication of relative position be provided. Most participants relied on the alphabetical index to complete tasks in the non-markup condition, turning to the paper map when they needed geospatial information.

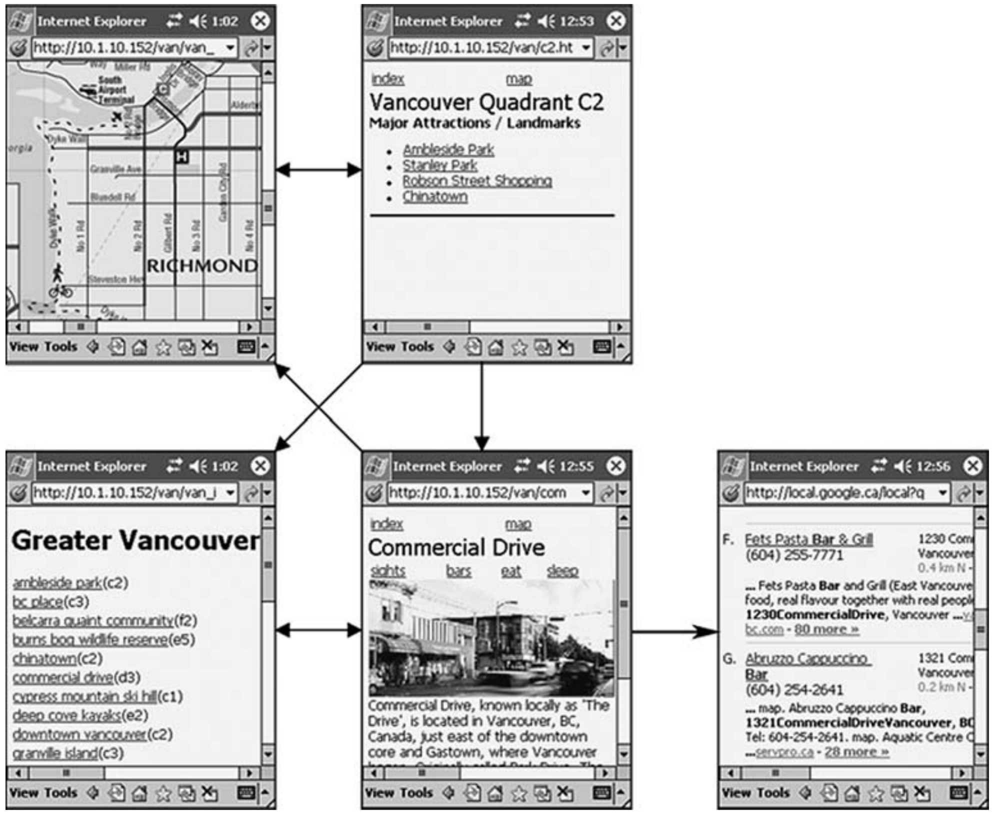

Fig. 11 Structure of Vancouver online resource. In the non-markup condition, several participants complained that there was no direct link from the general index or detail pages to the grid square index (informally termed 'quadrant' in the guide)

6.3 Interaction by novice users

The training given to participants in the study was brief, and we observed a range of comfort levels and levels of accuracy when using the RFID reader. It is interesting that several participants expected to be able to point at an item with their handheld computer before being shown how to use the reader. Once shown how to use it, most participants seemed comfortable with the technique, although a few expressed some frustration. Accuracy varied, but those who got misreads just tried to read the region again. When asked to provide suggestions for improvement of the interface, two participants wanted a "better pointer" or "narrower" scanner. Another suggested that further indication of "where they were scanning" be provided. Two participants found the interface "cumbersome", at least some of the time. These comments and observations suggest that pointing may be a more comfortable modality for many people.

In general, participants experiencing difficulty at the beginning improved over the course of the experiment, however one individual was tentative when using the reader throughout the experiment, not knowing exactly when/how the read would occur.

7 Summary

The experiences gained through our prototyping and evaluation activities have provided rich ground for further exploration of Marked-up maps. Differences in results across scenarios in the comparative study suggest that the effectiveness of the technique is dependent on the map, the information tied to it, and the needs of the user. There is also some indication that the map can be used for information retrieval without an obvious time penalty, at least for tasks of the sort explored in the study. This has the added benefit of indicating spatial relationships. Observation of novice users, participant comments and our own experiences suggest that the technique as implemented can be improved, but that the general principle has potential.

It is important to note that in the comparative study, most tasks participants performed were information gathering tasks, requiring little or no spatial knowledge. We expect the markup technique to show promise when there is some need to relate the information retrieved with spatial (route, landmark, and/or survey) knowledge.

8 Future work

We are still beginning to understand the benefits and drawbacks of RFID as a technology for interacting with paper information resources such as maps. The technology makes no explicit demands on the visual aspects of the information resource itself, which is clearly beneficial for map design, however the limited resolution of RFID is a challenge. In this section we discuss directions for future work, in light of the technique's strengths and weaknesses.

8.1 Occluding the paper map

Our prototype retrieves information as the handheld is positioned over the relevant map position. This is a straightforward interaction, and is less cumbersome than an untethered pointer-style RFID reader and handheld combination when used in a mobile context. However, a disadvantage of this approach is that it hides the portion of the map the user is enquiring about. A lens view mirroring the paper map below might address this issue, and allow for more precise geographic queries by tapping or outlining smaller regions on the handheld screen. Another option is to use a pointer-style reader or one that attaches to the top of the handheld computer. In these cases, more of the map area surrounding the reader would be visible. Interaction with such devices more closely resembles pointing as well, which may be a more comfortable mode of interaction for many users. One advantage of our prototype over this style of interaction is the potential for overlay lenses, discussed next.

8.2 Overlay lenses

By identifying location only, we can augment the map in many ways, as with electronic maps. Our current implementation provides a simple mapping between each RFID tag and an information resource. It is straightforward, however, to permit different categories of information to be linked to the same location, and be accessed on user request. Virtual overlays could be generated in a continuous, lens-like fashion on a handheld computer screen. This is challenging since RFID reads provide no direct indication of angle or rotation. We have developed a first prototype which displays the underlying map region as the reader traverses a paper map, but the display is not rotation-sensitive, and jumps from region to region. Some seamlessness might be achieved by analyzing RFID read sequences, and/or by combining RFID with computer vision techniques. When a reader reads an adjacent tag, the overlay image can be gradually shifted to the new location, and the rate increased if another tag is read during this time. Image recognition may be more feasible for large maps when constrained to a known region (as indicated by the RFID read).

8.3 Relating details back to the paper map

There are times when the information presented on the handheld display becomes disassociated in the user's mind from the map. Additionally, keyword search on the handheld retrieves information that may then need to be related to the map. Because a paper map is used, it is challenging to relate back to it. This might be facilitated by requiring all retrieved information to refer back to map grid squares on the paper map. It is also possible to provide a map view of the relevant location on the handheld. It is less clear how useful this approach would be: in our experience (using both electronic and paper maps during a city scavenger hunt), it is difficult to relate a handheld map view and a larger paper map view. This may be addressed by displaying the relevant region in the same way and at the same scale as the paper map. Providing these cues in combination may allow the user to readily locate positions on the paper map.

Alternately, because RFID tags are mapped to map positions, a directional indicator could be provided on the screen when the RFID reader reads an id other than the one associated with the information currently being displayed. This may usefully answer the question "where am I on my map?" for users with GPS or other positioning data.

8.4 More complex interaction

We are currently exploring a wider range of interaction techniques to query the space represented by the map. Many of the techniques carry over from electronic map interfaces, however, each may benefit from the use of a large, tangible paper map. We are particularly interested in whether a technique is appropriate for shared and/or personal use in a mobile context. For example, swiping the length of a street could mean a request for a directory of that street. Circling a broad region could indicate a desire for an overview of that region. A route request could be made by clicking a starting point and dragging to the desired destination.

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