A Billion Signposts: Repurposing Barcodes for Indoor Navigation

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ABSTRACT
Barcodes are all around us—on books, groceries and other products—but these everyday markers are typically used for a single focused purpose. In this paper we explore the concept of "piggybacking" on ubiquitous markers to facilitate indoor navigation. Our initial probe—BookMark—allows library visitors to scan any nearby book to provide a custom map to the location of a desired item. In contrast to previous indoor navigation systems, our approach repurposes existing markers on physical items that are already in the navigation space, meaning that no additional infrastructure is required. We evaluated the BookMark probe in a large university library, showing its potential with real library users. In addition, we illustrate how the general technique shows further potential in other similar barcode-rich environments.

Author Keywords
Indoor navigation; reuse; barcodes; piggybacking; libraries.

ACM Classification Keywords
H.5.2 User Interfaces: Interaction styles, Prototyping

INTRODUCTION

Barcodes are used in abundance in many everyday situations – their tried and tested robustness has made them ubiquitous for speeding up routine data entry. Current uses are rather unimaginative, however, and there are very few situations when these markers are used for anything other than their intended purpose. Researchers in the CHI community have previously tried to address this by making digital markers more appealing (e.g., [3]), using attractiveness to hide mundanity. In our view, though, the beauty of barcodes is not in their aesthetics, but in what their visibility and ubiquity affords.

Here we look at everyday barcodes from a new angle, taking advantage of the fact that they are easily recognisable, and usually placed on items stored in specific locations. Our approach is a re-seeing of barcodes not just as tags, but as huge numbers of tiny signposts to other barcoded items. Knowing a user is near a particular item can both locate them in the physical space, and help guide them to other items. We consider this as a way of piggybacking on infrastructure that is already available: attaching to an *existing* framework without altering the underlying items or the navigable space itself.

Figure 1. Barcode piggybacking granularity: (a) shelves in libraries; (b) product zones in supermarkets; (c) departments in department stores.

While automated navigation has largely been solved for outdoor spaces, indoor navigation is still a difficult and often complex proposition. Many prototypes have shown potential solutions, but these usually require complex new infrastructures, or serious effort labelling and precisely measuring existing environments (e.g., [4]). Our insight is simple but effective, allowing us to quickly, cheaply and reliably establish a new method for scalable indoor navigation.

There are several different levels of precision possible when using barcodes for this purpose (see Fig. 1). High granularity can be achieved in places such as libraries, where thousands of items are stored in an ordered manner in known locations within a relatively compact space. In places such as supermarkets, without extensive mapping effort (which our design aims to avoid), a coarser level of granularity is possible – we may know only that a bottle is within the soda section, for example. Finally, in department stores, scanning an item might give only a broad area, such as, say, the perfume department. In many ways this changing level of accuracy is analogous with how existing outdoor navigation systems work, and how giving even an approximate positional indication can still be useful.

The probe we discuss tests the concept in a library, which offers the highest level of location precision. Libraries have long been important not just as archives but as physical spaces – even in today's digital world, new libraries are being built, and they remain a popular and valuable asset to academics, archivists and bibliophiles alike. In our initial discussions with librarians, it was clear that library users often get lost, and a significant proportion of librarians' time is spent helping people find items. Our prototype is capable of (1) determining the location of a user via a simple scan of *any* book; then, (2) directing them to any other book based on this knowledge. The probe was evaluated with library users, and its success shows potential for such navigation schemes in similar environments.

BACKGROUND

Previous indoor navigation designs can be broadly grouped into three categories: dead-reckoning, beacon-based and sensor-based. Each has its own tradeoffs, as summarised by Fallah et al. [2]. Most notably, dead-reckoning techniques degrade in accuracy over time as errors accumulate; beacon-based versions often involve large-scale augmentation of the physical environment; and, sensor-based approaches require considerable computational power and custom hardware. One type of beacon-based approach—WLAN triangulation [1]—piggybacks on WiFi signals to estimate location – as we piggyback on a much lower-level technology, barcodes. However, such schemes depend on dense and universal coverage, and highly-accurate maps. In practice, location accuracy with real systems in this sort of context (e.g., libraries or supermarkets) is likely to be around only 10–20m.[1]

Previous research has looked at barcodes, QR codes and other scannable markers for navigation support. Mulloni et al. [4], for example, describe an indoor navigation system using custom scannable codes. Other schemes have been proposed to combine both QR codes to locate a starting point and a dead-reckoning approach for location tracking (e.g., [6]). However, designs such as these require a precisely-registered network of *additional* codes that must be added to objects and walls around the building, or suffer from existing problems such as dead-reckoning error accumulation. More similar to our approach is that of Nicholson et al. [5], who used shelf-edge barcode labels in a small supermarket to help blind users navigate to product areas via verbal directions and waypoints. Their approach was to precisely map individual items to positions; here we take advantage of the sorting and grouping of existing collections to minimise this effort.

Library navigation

We demonstrate the use of barcodes for navigation via a library-based probe. Previous library systems have typically used WiFi appropriation or beacon-based designs. Walsh [7] reviews these and other common location technologies that have been used to support library navigation, such as adding additional QR codes around the building and on individual items, or adding tags or other markers to shelves. Because of the ordered way in which books are stored, libraries know where books are, right down to where they should be located on a shelf. Libraries also have maps that let people use a call number to find items. In some cases these maps are very detailed, illustrating exactly where a book is located (Fig. 1 (a)); in others it may give only a broader area (Fig. 1 (b) or (c)). Depending on map granularity, then, our piggybacking approach can offer macro, micro and also larger-scale navigation.

BOOKMARK: PIGGYBACKING ON BARCODES

To test the potential for indoor navigation via barcode piggy-backing, we created *BookMark* to help users locate books within a university library. Figure 2 illustrates its usage in a typical book finding scenario. As this figure shows, the purpose is to enable the library visitor to accurately locate themselves

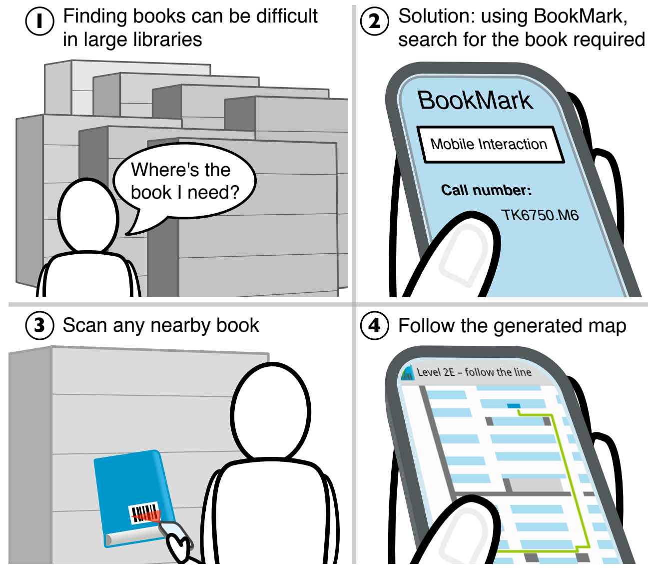

Figure 2. A book's online record is easy to find, but discovering its physical location can be difficult. Hundreds of bookcases are stored in each area, and book search engines often give only a call number, and possibly the floor that the item is on. With BookMark, scanning *any* nearby item at any point generates a customised map to the desired book.

relative to any books that they are looking for. The application is freely available to download from the Google Play store.[2]

Implementation

Our main goal was to demonstrate how existing barcoded items can be appropriated within ordered collections, such as libraries, without the need to make changes to the items or the space containing them. BookMark works by using the standard ISBN barcodes printed on the back of published books (rather than library-specific tags) to identify their physical location within the library. Knowing that user is next to a particular book precisely locates them within the building. Using this information, we are able to facilitate navigation within this space without the need for, say, WiFi-triangulation or dead reckoning. Key to our technique is the fact that there are many codes on many items, and also that items are organised in a structured and catalogued manner. This meticulous organisation is essential for workers in these environments (such as librarians or supermarket shelf-stackers) to be able to locate and restock or replace items. We piggyback on this ordering to support accurate indoor navigation.

Everyday usage

BookMark is an Android application that can be used to find any item in the library collection. When a user scans an item, the application first uses the ISBN encoded within the barcode to retrieve the book's call number from the library database. The application's shelf map is then queried using this call number to determine which shelf the user is standing closest to, based on the known ranges of books on each shelf. Once the user's location has been found, the system can then draw a map to any other book (located on its shelf via the same procedure). If a book is on a different floor or wing to the user's current location, the system directs them to the nearest door or staircase and displays an instruction to confirm when

[1] See, e.g.: http://skyhookwireless.com/ estimated accuracy.

[2] See: http://goo.gl/LUOh0m.

arriving at the required area. When the user confirms arrival, a new map is drawn of the destination area, indicating where to go next. If the user gets lost or sidetracked, they can simply scan any other book to update the map.

One of the major benefits of the piggybacking approach is its scalability – navigation can be implemented with very little time and effort on behalf of the host organisation. To set up in a different library, for example, librarians need only to link their call number database to floor plans of the building. No additional signage or equipment is required in the library itself.

EVALUATION

We tested BookMark within a busy and well-used university library. Sixteen participants (9M, 7F; aged 18–55) took part in individual 30 min trials, and were given a gift voucher as an incentive. Our goal in this trial was to test the approach with real library users in order to gain subjective ratings and comments on its functionality and usability. It was also an opportunity to "stress test" the piggybacking technique, as we did not control which items participants chose to scan to locate themselves. A prerequisite for participants was that they had searched for and found at least one book in this library in the past, in order to allow us to compare experiences.

The library

The library in which the prototype was tested spans two wings over four floors, with many different stairwells, corridors and elevators connecting areas. The collection is organised into categories using the Library of Congress system, and each item is labelled with a call number. An online book search engine can be accessed by library users to help look up call numbers. Once a call number is found, library users typically use the signposts and maps located around the building to locate the general area in which a book is located (e.g., by wing and floor only). As with many such large sorted collections, finding individual items can be difficult due to both the sheer number of items and their arrangement within the building. We tested the BookMark system over two floors in one wing of the library, containing approximately 120,000 items in total.

Procedure

Each participant was met in the library for a study briefing and to obtain informed consent. Following this, participants answered questions regarding their current use of the library, including a Likert-like rating from 1 to 7 (7 high) of the ease of finding books. They were then given a demonstration of the system in the area of the library where the study was conducted. The main part of the study was a set of book finding tasks, in which participants were asked to locate 10 books from a selection of 20 over two levels of the library (10 on each level). Books were displayed in the application as a list, randomised between participants, and giving no indication of the location of the book other than the title and author. Each task involved selecting a book to search for, then scanning any other book to retrieve a custom map. At any point participants could choose to scan further books to update the map. Once a book had been found, participants selected the option to begin finding a new book, which checked the just-found item off the list. This process was repeated until 10 separate books had been found. A member of our research team accompanied the participant at all times to ensure their safety and to observe behaviour. No assistance was given to participants during the study tasks, nor were they prompted as to which books to scan to find their location – participants were free to scan any item. After the tasks were completed, we conducted a semi-structured interview, which involved Likert-like ratings of the ease and speed of finding books using the BookMark system, and general comments on its usability and overall features.

Results

All participants completed all tasks (i.e., successfully found 10 books using BookMark). Turning first to participants' previous library experiences, all participants said that they visited the library at least once a year, with nine visiting at least once a month, one visiting at least once a week and two visiting once or more per day. The average time taken to find an item in the library prior to the study was reported to be approximately 10 min per book on average, with an average of three books found per visit (s.d. 2.5). While this is clearly only an estimate on participants' behalf, more importantly, 13 participants (81 %) said that they had been in a situation where they were unable to find a book they were looking for. Three of these participants said that the time taken to find books had deterred them from visiting the library again at a later date.

Participants rated the ease of finding books during normal library use as 4.0 out of 7 (s.d. 1.2), compared to 5.9 out of 7 (s.d. 0.6) using BookMark. A Wilcoxon signed-rank test shows a significant difference between these scores ($p < 0.005$, $W+ = 7$, $W- = 129$), indicating that BookMark makes locating books easier than users' previous experiences in the library. Qualitative comments made by participants both during the study and in the post-study interviews strengthened these findings: *"it would save a lot of time," "it's like a sat nav for the library!"* and *"if it was available I'd use it every time."*

Observations during the book finding tasks supported ratings for the system's effectiveness and speed, but also illustrated methods of recovering from potential errors. Of the 160 books found during the trial, there were 15 cases (2.5 % of the time) where participants became "lost" – that is, they misread the map and needed to regain their bearings mid-search. Nine of these cases (six participants) resulted in scanning another book to generate a new map. One participant even commented when rescanning a book: *"right – I am lost; but it's OK because I can help myself."* In the remaining six occasions (three people), participants got back on track by using other methods, such as counting physical shelves, searching for landmarks (such as doors, pillars or stairways), or matching the call number of the desired book to physical signage. In the vast majority of the 160 tasks, participants moved, uninterrupted, directly from their position to the location of their desired book.

Control study

While this paper is not about optimising book finding per se, to validate our results we performed a between-groups control study using the same method as when using BookMark. The system was replaced by an existing, library-produced paper map of the two floors in the wing used in our study. This map shows the layout of shelves on a floor, and broad call-number ranges. Such maps are available at the library's help-desks.

We recruited 16 new participants with the same demographic profile as the previous set. Each of these participants was allocated a unique list of 10 books to find. Each list was the exact set of books—and the order in which they were found—as chosen by each one of our previous participants. The participants began the sequence of book searches at the same point in the library as participants in the previous study. The time they took to complete each book finding task was then measured from the moment they were given a book's details (title, author and call number) to the moment they found the book on the shelf. After finding a book, they then moved to the next book in the task set until all 10 were found.

The study confirmed that BookMark was faster to find books. The mean time to find a book in the control study was 117 s (s.d. 81.1) compared with 73 s (s.d. 40.4) using BookMark. A Welch's t-test shows this result to be highly significant: $p < 0.0001$ ($t = 6.07$, $df = 233$). While 2 min is markedly faster than the 10 min estimated by participants, note that this time does not include finding the correct wing or floor from the library entrance. BookMark provides library users with a map directly to the required book from anywhere in the library.

DISCUSSION AND CONCLUSIONS

In this paper we have demonstrated how the ubiquitous but mundane barcode can be adopted to provide additional functionality. Rather than modifying or creating an entirely new infrastructure, we have shown how piggybacking off such a widely implemented framework can provide a fast, low-cost, scalable method of indoor navigation. In contrast to previous research approaches, our technique requires no additional hardware or additional external power. We have demonstrated the approach via a sample application and trials with library users, and shown how it is perceived as easier and faster than traditional methods of library navigation.

Limitations

The use of existing frameworks in this type of application is clearly not without its limitations. For libraries in particular there are two main potential factors. Firstly, some older books may not have a printed ISBN, meaning that they cannot be scanned to discover the current location of a user (although they can still be found using the application). In these cases, users simply need to ensure they select a book that has barcode on the back. Books that have been replaced in an incorrect location are another potential issue. If an item that is on the wrong shelf is scanned, then the map given will inevitably be incorrect. If this situation occurs, users will need to scan another book. This did not happen during any of our user trials.

Implications for future ubiquitous tagging

While barcodes have been largely overlooked in HCI until now, many researchers have been considering the utility and design of future tags and object identifiers as part of a wider Internet of Things agenda. For example, presently there is much interest in the use of embedded wireless chip identifiers (the most common commercial implementation being NFC).

We have been able to piggyback on barcodes for two reasons. Firstly, barcodes are visible and highly recognisable. The first machine-scannable barcode design used ultraviolet ink, invisible to the user so as not to detract from product packaging. This approach failed, partly due to the code being hidden from the person scanning. The type of information piggybacking we have demonstrated would not have been possible if it were not for the visual properties of the barcodes themselves.

The second repurposable aspect is that barcodes are based on an open specification. In contrast, RFID and NFC tags, and their ilk, are generally hidden from view, which greatly reduces their appropriability. Furthermore, such tags can be encrypted or use proprietary formats – rightfully so in some security-critical cases, but in others this can seriously restrict the ways in which they can be reused for other purposes.

We have demonstrated how it is possible to piggyback on existing ubiquitous infrastructure without any additional alterations. The question we would like to pose to the community is: how can we make future marker designs appropriable enough for others do to the same? We postulate that developers and designers of future schemes should consider how to make their designs both visible and open to other uses. We therefore suggest that designers ensure that any new digital markers offer visual, haptic or other affordances, and openness wherever possible, to encourage piggybacking as a method of creating new and exciting uses for these infrastructures.

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REFERENCES

1. Bahl, P. and Padmanabhan, V. RADAR: an in-building RF-based user location and tracking system. In *Proc. INFOCOM '00*, 2000, 775–784.
2. Fallah, N., Apostolopoulos, I., Bekris, K. and Folmer, E. The user as a sensor: navigating users with visual impairments in indoor spaces using tactile landmarks. In *Proc. CHI '12*, ACM (2012), 425–432.
3. Meese, R., Ali, S., Thorne, E., Benford, S., Quinn, A., Mortier, R., Koleva, B., Pridmore, T. and Baurley, S. From codes to patterns: designing interactive decoration for tableware. In *Proc. CHI '13*, ACM (2013), 931–940.
4. Mulloni, A., Wagner, D., Barakonyi, I. and Schmalstieg, D. Indoor positioning and navigation with camera phones. *Pervasive Computing* 8.2 (2009), 22–31.
5. Nicholson, J., Kulyukin, V. and Coster, D. ShopTalk: independent blind shopping through verbal route directions and barcode scans. *The Open Rehabilitation Journal* 2 (2009), 11–23.
6. Serra, A., Carboni, D. and Marotto, V. Indoor pedestrian navigation system using a modern smartphone. In *Proc. MobileHCI '10*, ACM (2010), 397–398.
7. Walsh, A. Blurring the boundaries between our physical and electronic libraries: location-aware technologies, QR codes and RFID tags. *The Electronic Library* 29.4 (2011), 429–437.