Amazon-on-Earth Library Navigator

Indoor Navigation Using Un-Augmented Mobile Phones

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***Abstract*— This paper describes the Amazon-on-Earth project that enables users to look for, navigate to and find objects of interest inside a physical space. We implemented a working prototype system in one of the libraries on our campus and ran a user study to see if there was any advantage to using the system relative to the existing library information services. Results show that subjects using our service were able to find information about a book 35% faster and were able to navigate to a book 52% faster. We also found that the control group made four times as many navigational errors and had to ask for help five times more than the experimental group. Measuring qualitative variables we found that subjects using our system rated the ease of finding the book in the library as easier than the control group and felt more positive towards the service. The results make it clear that the use of such a service can substantially help a user find an object inside a space in a faster, easier and more pleasant fashion. We end the paper by pointing out a number of shortcomings of the system and how they might be dealt with.**

Keywords- Indoor Navigation; Mobile Phone; QR Code

I. INTRODUCTION

For a number of years now, efforts have been made in research and product circles to enable digital information services within the context of real world scenarios. The growing sector of powerful Smartphones with their multiple embedded sensors and networking systems have made them a prime focus in consumer based location based services. These have spawned a number of commercial systems that can point out relevant physical services close to a person's current location [3, 6]. Such systems are mostly used while driving or walking near or within a shopping area. While our system uses location as an important dimension, we focus on using ***indoor*** navigation to enable users to find ***objects*** in the physical world and to interact with them. Thus, our "objects" do not transmit their existence to the world (there are simply too many of them to make this feasible)- but once a user using our navigation maps finds them, the system enables a number of relevant functions to be enacted in relation to the object.

This paper has the following structure: we start with a short section about previous related work. We then describe the system we have built and present the empirical study we have run to test its effectiveness. We then present the results of our study and end with a discussion of shortcomings and how the system can be improved.

II. RELATED WORK

1) Mobile Interaction with the Real World

Smith et al. [15] presented a prototype for mobile retail and product annotation services. Their system enabled the user to scan the object's barcode and receive relevant information about that object which was found on existing web services such as Amazon.com. Their system used a special purpose barcode scanner to decode the object's ID for further querying (since then, 1D and 2D visual tag decoding software have become available for most Smartphone systems). But their system did not help users find an object within a physical space, nor to conduct a transaction to buy the object if the user wished to. Many additional research projects have focused on this space in the last few years, i.e., [3][4][7][13].

Broll et al. [4] present models for tag – service interfacing. The physical tag (be it a visual barcode or a Near Field Communication (NFC) RFID tag) was used as shortcuts to online services. Henze et al. [7] go further by showing how the camera can be used not only to decode visual tags, but also as a tool to create visual (photo based) tags in the real world. Although interesting, these systems only focus on linking a physical device to online services without exploring navigation per se.

Figure 1: Visual Contextual Bookmarks [6].

Rukzio et al. [13] explored different tag based services but focused mostly on how tags can be used to enable phone-based discovery and access to online services. Using NFC tags embedded inside public posters, a user can walk up to a poster, visually identify the NFC enabled functions as landing spots on the poster and activate the services by touching their NFC enabled phone to the landing spots.

More relevant to our work, Serra, Caboni and Marotto [14] showed the use of 2d barcodes as part of an initial indoor navigation system, but they used barcodes only as URL addresses to download maps of an indoor space onto a mobile phone.

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2) *Indoor Navigation*

Nokia Research [9] ran a public trial of their Locate Sensor system in the Kamppi shopping center in Helsinki in 2009. The system enables mobiles phones to track and present the location of special tags on the phone's screen. In this case the use was mostly for advertising- enabling a person to look for a specific store in the shopping center and receive promotional coupons relevant to their location. But their system relied on the use of special purpose hardware.

Puikkonen et al. [12] tested a WIFI based indoor navigation system in the Kamppi Mall also. Their system showed the location of the user on the map, but at very low precision (resolution was about 50 meters- meaning that it could localize a person to the level of a section of the Mall and no more). Although such services show future promise, the low resolution exhibited makes them of limited use for most cases.

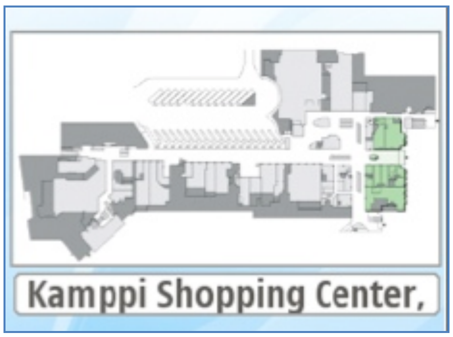

Figure 2: Kamppi Indoor Shopping Service [11].

Mulloni et. al. [8] developed and tested the Signpost indoor navigation system. After implementation they focused on studying end user's feedback about the ease and usefulness of the system. They compared the user ratings for a simple 2D map view with no location information in it, a more advanced model using discrete point localization (using 2D barcodes) that shows the location of the last seen marker and a third and most sophisticated model using a simulation of a real time indoor GPS (using a wizard of Oz approach where an operator would walk behind the subjects and update the location on the application). They found that discrete localization was seen as easier to use and more useful than the simple map approach, whereas the real time indoor GPS simulation was deemed most useful. Since it is not practical to have an operator walk behind every user, the most relevant result of their study in our opinion is that they show that indoor navigation using 2D barcodes is a realistic and useful approach.

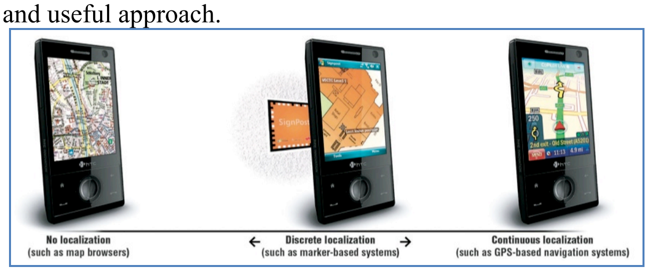

Figure 3: Signpost Indoor Navigation System [8].

Another point of interest in their system was that they kept the camera on at all times and had it continuously search for tags in the environment, automatically updating the location on the map when a marker was seen. Although this seems promising from a user interface point of view, they admit that such an approach was deemed impractical in their real world tests since it consumed too much power and depleted the battery too fast. Additionally, although their system could show the last seen marker location on the map, their system did not generate navigation paths to a target location for the user.

Nokia research recently [10] showed a prototype of their Indoor Navigator system using the Nokia High Accuracy Indoor Positioning system. In demos presented at the Nokia World Conference in 2010 they seem to show very high precision, but we have not seen any research presenting their capabilities systematically. Although simpler to install and maintain than previously mentioned high precision systems, it still needs the installation of special purpose positioning equipment.

III. AMAZON-ON_EARTH LIBRARY NAVIGATOR

Our Amazon on Earth Library Navigator project explores a method of enabling map-based navigation inside a physical space, but with the added value of being able to show the user their last known or current location as well as being able to generate a navigation path to a wanted target, *all without the need for any specialized or expensive localization hardware.* Our service also offers pre and post object finding services. This project is a continuation and improvement of our previous work [5].

A. *Description*

Our project focuses on enabling a person with the following main capabilities:

- Search for information about an object they are interested in
- Physically find that object in an indoor space via a navigation path drawn on a map
- Receive recommendations about relevant alternative objects
- Pick-up-n-Go: Pick the object up, purchase the object, and carry it out of a store.

1) *System Test Location*

We implemented the system in one of the libraries on our campus. The reason for this was proximity and ease of access, and should not be taken to mean that we are focusing only on libraries. The opposite is true - a library to us is a representation of a physical retail store. Such a store has stock (the books), a physical space to view the stock and handle it (the book cases and desks), and a checkout counter where people can buy (borrow) the books. To us, such a system is conceptually equivalent to retail stores, while allowing us to explore and test flows and methods without the obvious difficulties involved in using a real store location.

2) Scenarios

The AoE Library Navigator system enables our users to perform the following scenarios:

a) Finding Information about a book

Our user is looking for a specific book they need for their work. They go to our web site and run a search for the book (using key words, author names or ISBN number). They receive an information page about the book and can browse the information that has been gathered from the Google Books and Amazon web sites using their public application programming interfaces (API's). Information about a book can also be accessed by scanning the barcode on the book with our application. This process returns the ISBN number that is then fed into our web-based query system, returning the same information page.

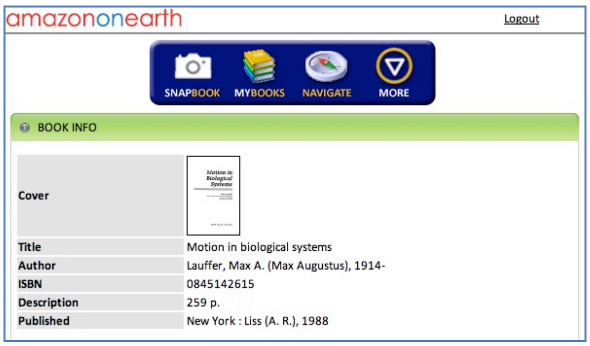

Figure 4: AoE Library Navigator Web Site Book Information Screen

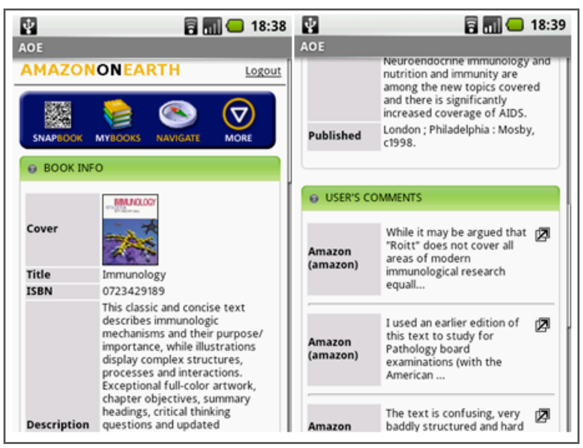

Figure 5: AoE Library Navigator Phone Book Information Screen

Figure 6: AoE Library Navigator: Tag Based Information Search: Scanning the book barcode initiates a web based search

b) Adding a book to their personal list

If they are interested in the book, they can enter it into their book list after signing in to the system. They can now go to the "store" to view the book, and check it out.

c) Navigating to the book in the library

Once they arrive at the library, they launch the AoE Library Navigator mobile application and select the book they are interested in. This brings up a navigation map that shows them the path they need to take in order to reach the book. If they navigate properly, they will reach the bookcase that holds the book they are looking for. If they get lost, they can walk to one of a number of public and centrally located navigation tags and scan them or alternatively, take any book from the shelves and scan its barcode. This will give them a new map with an updated path to reaching the bookcase.

Figure 7: AoE Library Navigator: Navigate Screens

If they find that the book is not there, they can get information about additional books that can be relevant for them. The other books can be scanned using their bar codes and available information can be viewed.

d) Taking the book with them

Lastly, if the user wants to take the book with them, they can select the Check Out option under the book screen and receive feedback that the book has been successfully checked out and that they can take it with them.

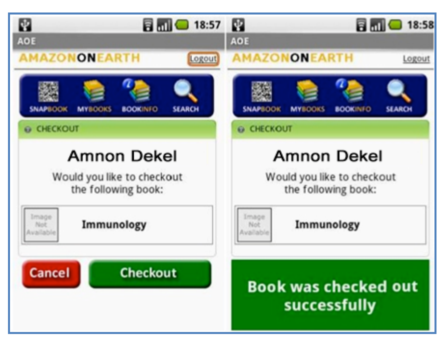

Figure 8: AoE Library Navigator: Check Out Screens

B. Technical Description

Figure 4-18 presents the main Amazon-on-Earth Library Navigator (AoE) system modules:

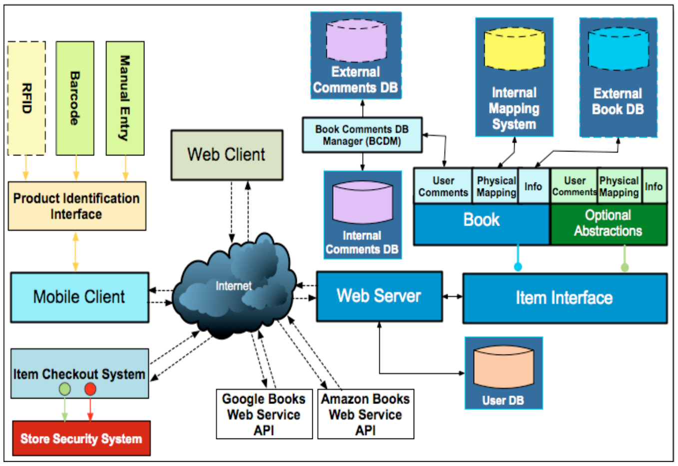

Figure 9: AoE library navigator architecture

1) External databases

- EXTERNAL COMMENTS DB: Uses Google Book information and Amazon's ratings and opinions. Enables us to shows this information for any book in the library.
- EXTERNAL BOOKS DB: Use the library's web site as the main search database. Since the library would not allow us to interface directly to their internal database, we access the book database by sending HTTP queries directly through their public web site.
- MAPPING SYSTEM: A mapping database that interfaces with our Map Middleware and returns results as text (may include links to maps stored on the web).

2) Book Comments Database Manager (BCDM)

An item may have several servers where users' comments are stored. The BCDM layer supplies a convenient abstraction for multiplexing comments from and to several DBs. This allows us to present a single interface where the user can see comments that were created internally by library visitors as well as externally via the Amazon and Google books APIs.

3) Internal comments DB

Since not all DBs are writeable, this DB is used to store local users' comments.

4) Users DB

Stores data regarding users who are eligible to access the system (i.e., User names, passwords, and custom data: "My Books", Preferences and user privileges).

5) Item interface

This is an interface for generalized access to information about an item. The information is separated into 3 sub-categories:

- INFO: General information for identifying and describing the specific item.
- POSITION: Positioning (global and/or local, absolute and relative to a given point)
- COMMENTS: Getting/adding comments capabilities (might use the BCDM interface if many sources for comments are available).

6) Mobile Client Application

The mobile part of the service is enabled via a native Android application. The application is responsible for:

- Preserving the internal state of the user's requests
- Initiating requests to the server(s) based upon requests.
- Parsing data returned from server(s) as response to requests.
- Displaying the incoming data.
- Interacting with Physical World Objects via the Physical World Connectivity Module

7) The Physical World Connectivity (PWC) Module

This module is responsible for acquiring and analyzing information from the world in the following methods:

- 1D/2D barcodes
- Keyboard input
- Optional: RFID and Voice Recognition

Output of this module is unified for all acquisition methods. At this point in time only 1D/2D barcodes and Keyboard input are supported. Adding RFID and Voice recognition is relatively simple. Voice input is already available via the Android input method, but the results will need to be parsed appropriately for our use. RFID input will soon be available via the NFC interfaces that are starting to be used in the newest Android phones (i.e., Nexus S in Dec 2010).

Figure 10: Navigation Tag and Resulting Map

8) Map Middleware System

The system includes a Library Map descriptor and Location Pattern Convertor (what we call the Map Engine). We use the Dijkstra algorithm for finding the shortest path in a directed graph between a start location and the target location. The system converts any possible location string that might be received from an external source (such as web-sites or similar) to one of the targets in the map. In other words, this function connects between any string (from decoded Tags) to the set of strings used as location names/aliases in the map.

We developed a Map Builder desktop application that makes it easy to insert new maps into the system and then connect between a textual target and their symbolic location on the map. The result is a database with relations between a symbolic code and their symbolic location on the represented maps.

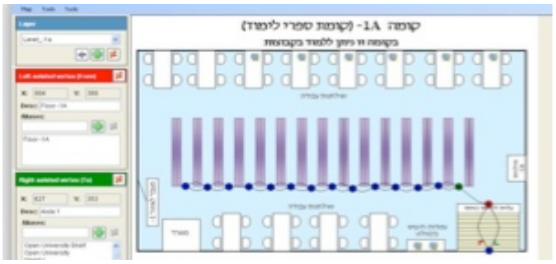

Figure 11: AoE Library map builder

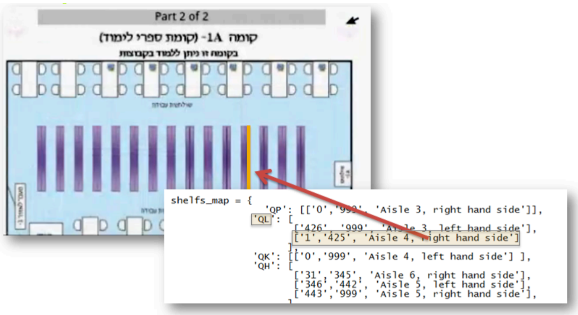

Figure 12: Relating symbolic location to visual map

The Output of the Map Engine is:

- A graphic representation of the Map. Draws a line on top of the map to mark the resulting path.
- An ordered list of Edges. Indicating the x,y coordinates of the starting and ending points relative to the graphics coordinates.
- An ordered list of Strings. These are the textual directions relevant to the layer being shown.

We have created some enhancements to the Dijkstra algorithm. First is **Angle Testing** with built in thresholds to determine if the instructions should be "Go straight", "Turn Right" or "Turn left". We then use **Edge Grouping** to enable us to present simpler instructions to the user: instead of [go straight to shelf 1→go straight to shelf 2 → go straight to shelf 3] we get [go straight to shelf 3].

We initially developed a Java prototype on a Sony Feature-phone but later changed to the Android platform.

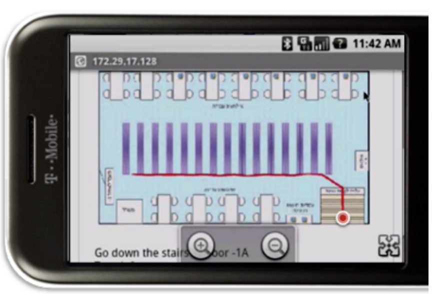

Figure 13: Android based Aoe library navigator

The navigation screen presents the navigation broken up into floor-sized sections. So if a path necessitates moving through more than one floor, the navigation on the first part will steer the user to the stairs and tell them to travel to the additional floor. The second part of the navigation will continue from there. This allows us to break the navigation into easier to understand paths for the user and also leaves more screen real estate free for showing the largest graphic possible.

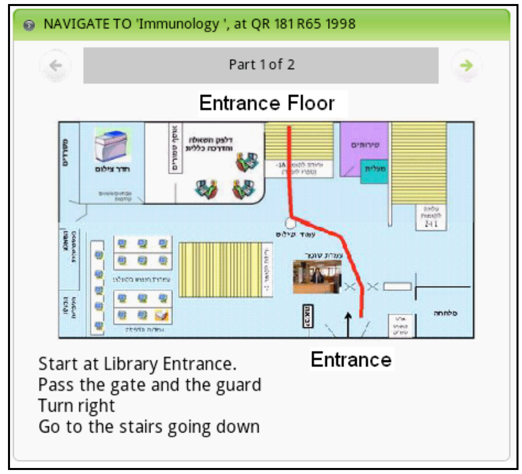

Figure 14: AoE library navigator: navigation map to the target book

C. *Implementation*

We implemented the system using a mixture of web based and native mobile technologies. The server modules were written in Python, and hosted within an Apache HTTP server. The mapping application was implemented in .NET and it created an XML map file for the library, above which the navigation path was drawn at run time with Python. The Databases were implemented in SQL Lite. The check out part of the scenario used HTTP POST to write to a Check out service on the HTTP server. The checkout station used a barcode scanner interfaced to a netbook computer that in turn was connected to an Arduino Microcontroller system for activating the demagnetizer. The check out system worked but because of time and financial constraints was not hooked up to a demagnetizing station- so although a book could be checked on the phone, and the barcode scanning system could check with the service that it was in fact checked out and could be taken out, the book had to be manually demagnetized.

IV. User Study

A. *Method*

We sent out a call for subjects and recruited students from departments at the University that are located on a separate campus at the other side of the city. This was to ensure that they were not acquainted with the physical premises of the library. Subjects were invited at 30-minute increments and were tested alone.

Subjects first read a general explanation about the test procedure in which it was made clear to them that there is no correct or incorrect performance. We asked them to act as naturally as possible and that in the performance of the tasks they were given they could ask for help from anyone in the building except for the tester.

1) *The Tasks*

We used a between-groups design. Both groups were asked to search for information about a specific book and then navigate to and find the physical book in the library.

CONTROL GROUP: This group used the existing IT infrastructure in the library (a number of computer stations using a well known library management and search system). The subjects walked over to a station and ran a search for the book. They then wrote down the library code for the book. This was the first variable we measured: *time to find information* about the book. We then asked them to find the physical book. They were told that they could ask for help from the librarians or other people in the library. This was the second variable we measured: *time to find the physical book* in the library. We also recorded how many navigation *errors* they made and how many times they asked for *assistance* in the process of finding the book. After they found the book we asked them a number of qualitative questions to gauge how they felt about the system and their experience of using it. We then explained the study to them. Ten subjects were in this group, 5 of them male and 5 female.

EXPERIMENTAL GROUP: This group was given the same tasks using our system. The initial information lookup about the book was done on a laptop using the web site we created for the system. After they found the information about the book they were asked to add it to their book list on the system (My Books). This was the parallel step of searching for and writing the book code information by the control group. They were then given a mobile phone (an HTC Nexus 1) with the AoE Library Navigator application running on it and were asked to open the book information in the application and tap the Navigate button. This brought up the Navigation map to the book. We explained to them how to use the application and then told them that they now needed to find the physical book in the library using the map. We explained that they could ask for help from anyone in the library (except for the tester) and also showed him or her how to use the built in feature to scan strategically placed tags or books in the library if they got lost. They then started the search for the book and we timed how long it took them to find it, how many navigation errors they made and how many times they asked for assistance. After they found the book we asked them a number of qualitative questions to gauge how they felt about the system and their experience of using it. We then explained the study to them. Ten subjects were in this group, 5 of them male and 5 female.

B. Results

Figure 15 shows the results of the test. As can be seen, the two main metrics (time to find information about the book and time to navigate to and find the physical book) show a clear advantage for the experimental group. The average time to find information about the book was 77 seconds for the control group but only 51 seconds for the experimental group (35% faster) (T=1.93, P<0.05). The control group then took an average of 287 seconds to find the physical book, while the experimental group took only 138 seconds on average (149 seconds faster- 52% faster) (T=5.29, P<0.01).

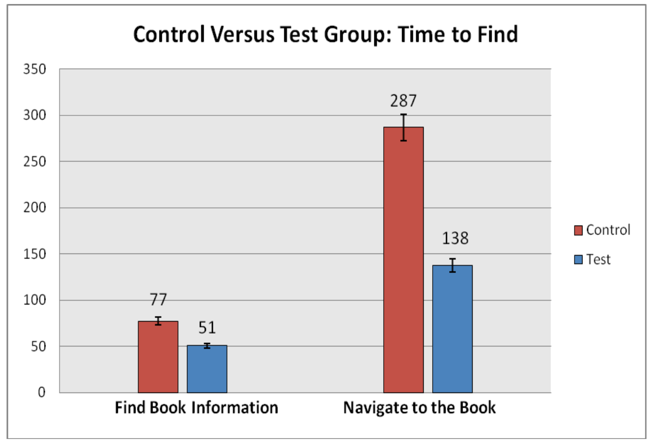

Figure 15: Results of Second Navigation Test (in seconds).

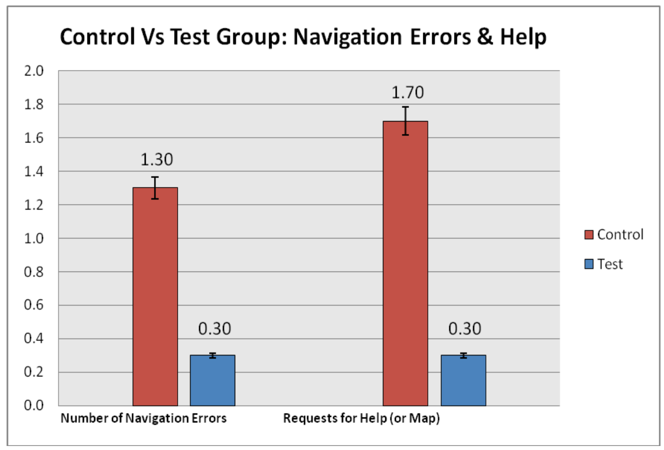

Figure 16: Navigation Errors and Requests for Help.

We also analyzed the amount of navigation errors that were made by the subjects and how many times they requested help in finding the book. We define a navigation error as a situation where instead of getting closer to the target the user's navigation at a certain point in time enlarges the distance from the book. By Assistance we mean asking for help from another person or the librarian or by scanning barcodes to request a new map. As can be seen in Figure 16, once again the experimental group showed an advantage. Whereas the experimental group showed an average of 0.30 navigational errors per task, the control group made an average of more than 4 times as many navigation errors (1.30) (T=3.87, P<0.01). The control group also needed much more assistance – they asked on average 1.70 times for assistance per task, while the experimental group asked for assistance only 0.30 times on average per task (more than 5 times as much). (T=6.33, P<0.01).

Figure 17 shows the qualitative questionnaire results.

Ease of searching for information about a book: Both groups rated the ease of searching for information about a book as "Easy" (Control = 4.6, Experimental group = 4.5).

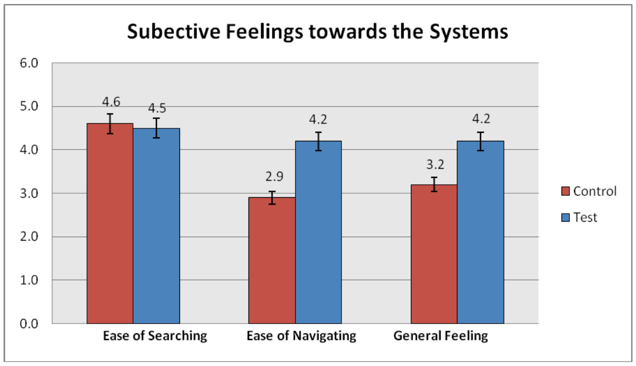

Figure 17: Subjective Feelings towards the systems.

Ease of finding the book in the library: Not surprisingly, the experimental group showed an advantage here- giving on average the rating of "Easy" (4.2) while the control group viewed this on average as neutral (2.9). ($T=4.99$, $P<0.01$).

Feelings towards the method: We found a difference in how positive or negative the subject's feelings were towards the methods - The experimental group showed positive feeling towards the system (average of 4.2) while the control subjects showed a neutral feeling towards the system (average of 3.2). ($T=2.23$, $P<0.05$).

V. General Discussion

The results show a very clear advantage for using the system. Not only is the time to find a book drastically lowered (by 52%), but also the time to find *information about* a book was lowered by 35%. Additionally, the amount of navigation errors made while looking for the books was lowered substantially, and probably because of that, the need to ask for assistance also dropped substantially. Only one of the experimental subjects made a real navigation error (they went down the wrong set of stairs and found themselves in a different part of the library). That subject then used the navigation barcodes on one of the walls to get a new map generated and was able to reorient themselves and continue the search for the book.

Interestingly, even though the empirical evidence shows that using the system for finding information about a book is faster with our service, on average, the subjects rated the regular library search system to be as easy to use as the experimental system. We think that this has to do more with familiarity than with usability. Most users know and have had experience using the in-library catalog search systems, while none of them have used our system before. This novelty might cause them to think that the existing system is easier to use even while the data shows that it might not be. It seems that a 35% reduction in time is not pronounced enough to be felt by the users as large enough to warrant them to feel that it is better than something they already know and feel comfortable with. For that to happen they must see a much more pronounce performance change.

That is precisely what we think has happened when subjects rated how easy it was to find the book. As shown in the results, the experimental group felt that it was easier to find the book using our system relative to the control group. So in this case, although they were used to searching for books using the standard catalog stations and then physically search using the book coding system, the performance enhancement offered by our system was pronounced enough to make that crossover- and even though it was not familiar to them, they rated it higher than the control group. This "added value" that they received from the new system seems to have caused them to show a general positive feeling towards it, while the control group showed a neutral feeling towards the system they know so well. We see this as meaning that if your system offers enough value to the end user, that added value can overcome their built in bias towards using something they are familiar with.

A. *Future Improvements*

While building this service and testing it we have found a number of things that need to be improved before such a service can be used in the real world.

1) *User Interface Design*

The interface design we have used can and should be improved.

1. We found that users found it initially difficult to understand the map and it was not clear to them where the path starts. This can easily be solved by adding a START HERE tag and placing it in the proper place on the map.
2. We found that users sometimes missed seeing the actual book library code on the map screen- this is important information since they need it in order to identify the actual book on the shelf. This information should be made more pronounced and visible on the screen.
3. The current architecture breaks up the multi- floor navigation into multiple screens. This means that when the user moves from one floor to the next, they need to request the next map from the server by tapping the next button. In hindsight we think it will be better to download all parts of the navigation into one screen and have the user scroll through the screen to reach the later parts of the navigation path. This also ensures that all the data has been downloaded and cached on the phone at the beginning of the navigation and potential WIFI or Cellular Data weak spots will not disrupt the navigation.

2) *Check Out System*

Because of time and financial constraints we did not finish the physical demagnetizer station. We built a physical and working proof of concept but did not add it to the final testing scenario. A system without this feature will still be useful, but allowing the full cycle from search, find, pickup and go will make this an even better system.

3) *Enhanced Social Input:*

Although the current system can access and show comments about a book from Amazon and Google books, its built in social features are limited to allowing a user to add their own comments about a book into the system. These comments stay in the system and are not published to the Amazon or Google books systems. We think that this service will be enhanced if its users can add and publish information about a book. Thus, users should be able to tweet or publish to their Facebook pages that they have checked a book out, what they think about a book, and also create socially based lists that can help others. This data can then be used as a crowd-sourced collaborative filtering service that can offer an alternative book to the one being searched.

VI. Summary and Conclusions

The Amazon on Earth Library Navigator is the first system we have built in our efforts to enhance indoor navigation. We have developed a system that includes a back end and middleware service to map an existing physical space and the locations of objects in it. Working at the Harman library, we were able to create a system that allows a user to search for information about a book, add that book to their book list, and then inside the library, use our service to receive a personal map showing a navigation map to the book. If the user gets disoriented during their walk to the book, they can scan preconfigured navigation tags, or alternatively, use the barcodes on the books themselves, to generate a new map. The new map will show them the path from the current location to the book they are looking for.

We ran a series of tests to explore the utility of the system, and after ironing out some initial problems, we show that the service in fact has promise: Using our service, subjects were able to find information about a book and then navigate to that book substantially faster and with less mistakes than using the existing method of doing this in the library. We found that while users did not feel that the service was easier to use for finding information about a book, they did feel that it made finding the physical book in the library an easier task.

All this makes us conclude that such a service does in fact offer real value for people in such situations. If the system makes it easier and faster to find a book, then the time saved can be used for other purposes- if to find additional books, or to have more time to think about what books are relevant to find. But we view this prototype as representing a more general model in which such services can help people find things within indoor spaces. These things can be books, but they can be merchandise in commercial settings (i.e., products in a store) or objects inside large warehouses. Additionally, such a service can also be used by people moving through unfamiliar surroundings: this can be a new worker in a large building- the Pentagon for example, or an emergency services worker needing to find someone quickly in an unknown building. Many additional use cases can be thought of where such a system can be useful

A. *Limitations*

Such a system has some very clear limitations. The first one is that the system can only work as long as the target objects being looked for have a known location and they do not move. If an object is moved and its location is not updated in the system, then the utility of the system breaks down, since the map generated will send a person to the last known location of the object. Another limitation is that the system does not provide the user with a real time signifier of his or her own location within the building. Being able to do so will help the end user orient themselves within the space, just as a car GPS system shows the location of the car relative to the path being taken. These issues are dealt with in another project.

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