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Developing location-aware navigation guides that use mobile Geographic Information Systems.

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Abstract

This research aims to design and implement a location-aware travel guide prototype for pedestrians, with the aid of mobile Geographical Information Systems (GIS). Unlike the traditional paper maps, the digital travel guide intends to offer a customized user interface and a location-specific travel service. Development was first done on a Desktop Computer with the essential files transferred to a Personal Digital Assistant (PDA) subsequently to carry out field trials. With the aid of Global Positioning Systems (GPS), the prototype has the ability to pinpoint the location of the current user accurate to a certain tolerance. This detection is performed at specific intervals and a list of landmarks is furnished to the user through a VB script-based interactive graphical user interface (GUI). The users are able to obtain comprehensive information on surrounding buildings or sights, both in textual and digital image form. A novel indexing method built upon road segmentation was implemented to increase the search efficiency. Experimental results show that this indexing method has significant response improvement over the exhaustive search method, thereby facilitating travelers to find their right way and enjoy the trip.

INTRODUCTION

In many countries today, mobile computing technology has become ubiquitous. Many people own Personal Digital Assistants (PDAs), mobile phones, tablet PCs and other forms of mobile devices. In fact, PDA ownership was projected to treble, based on a study by the IDC Western Smart Handheld Devices Review 1998-2003 *(1)*. With increased processor speeds and improved Operation Systems, a great variety of applications can be installed on PDAs to provide sophisticated services to users *(2, 3)*.

Traditionally, maps have been the primary tools employed for navigation. Whether in a foreign land or simply finding our way in unfamiliar territory, pedestrians and tourists alike refer to static paper maps for orientation and route finding. One disadvantage of maps is that the graphics are static and it is often difficult to pinpoint one's location.

The prototype developed in this research seeks to harness mobile technology to improve on the use of maps. It seeks to provide relevant location-based services to the pedestrian; textual information, pictures of landmarks can be readily available to the user through a friendly, point-and-click interface. In addition, to facilitate its use for the general public, a user-friendly, customized interface has been designed to enhance its convenience and practicality. Furthermore, this project employs Global Positioning Systems (GPS) to track the user so as to provide real-time relevant information. The majority of research work in Advanced Traveler Information System (ATIS) focuses on information systems in vehicles *(4)*. This has led us to concentrate on a design that emphasizes pedestrians. In our prototype development, the area of study and implementation chosen was the National University of Singapore (NUS) campus in Kent Ridge.

This navigation guide prototype offers substantial advantages for navigation information systems because the maps change from static raster graphics to interactive graphical representations allowing the presentation of the most extensive information possible thus satisfying the demands of the pedestrian users. The device functionalities can also be extrapolated to areas such as tourism, defense and transportation.

As a great diversity of applications could be involved, it was necessary to place emphasis on certain important elements such as Geographic Information Systems (GIS) application and Database Management System (DBMS). The areas of research were therefore narrowed and focused mainly on developing functionalities in the prototype user interface, as well as an efficient spatial access method in place of exhaustive search when dealing with spatial searching algorithm. With the aid of positioning technology, the user interface component was integrated with GPS and mobile devices to carry out field tests whenever assessment of system usability was required.

COMPONENTS AND DESIGN

User's Requirements Identification

To ensure the navigation guide prototype meets the end users' requirements, the emphasis of the design has to be placed on the accessibility of functionalities of the end product. Different criteria have been outlined to satisfy end users' requirements, i.e. the system has to be context-sensitive (location-aware in our case), flexible, informative, and user friendly. These criteria are used as the measures to assess the usability of the end product at the stage of system evaluation. These requirements are discussed in details below.

System Architecture

There are a series of hardware and software used in this research both at the stage of design and implementation. At the initial stage when the design and testing of the system took place, several GIS software was run on a Desktop Computer, providing the platform to accomplish user interface customization and searching algorithm development. The hardware served the purpose at the later stage when being brought to site during field tests. Two light-weight hardware devices were utilized, including the Pocket PC, Compaq iPAQ H3700 series, which functioned as the guide unit and Global Positioning System (GPS), Trimble GPS Pathfinder Pocket, providing positioning information.

The system architecture is illustrated in Figure 1 showing the data flow from Personal Computer (PC) to the mobile device at different phases. At design stage, we utilized a range of GIS software to perform data manipulation and user interface customization on PC. For implementation stage where the users carry the system on field, the necessary data was first transferred to Pocket PC through the wireless card. During the field trials, a GPS was attached to the Pocket PC to obtain positioning information.

The GIS software used in this project is ArcGIS, which comprises three integrated core applications: ArcMap, ArcCatalog, and ArcToolbox. However, only ArcCatalog and ArcMap were used for creating the NUS map in this research. The map data files contained four layers; three are in vector format (shapefiles) showing buildings, streets and pedestrian walkways, respectively, and one in raster format acting as a background image of NUS campus. ArcPad is a mapping tool for working with GIS data in the field. The map created in ArcMap has to be converted to format supported by ArcPad before being transferred to ArcPad for the use on site. Customization of ArcPad can be performed using the ArcPad Studio. All customization development was done within a Windows desktop environment. The customizations, in terms of applets, default configurations, and so on, were then deployed on a mobile device via a copy of ArcPad.

In order to perform customized tasks, scripts were required to call and run certain subroutines when the events associated with the objects were fired. Each process involved in the user interface is demonstrated in Figure 2.

A new VBScript source code file named **ArcPad.vbs** was created. The spatial and non-spatial data embedded in the map was accessed through personalized Controls such as buttons and drop down list on the custom forms that generated a range of events as they were operating, and subroutines created in a single VBScript source code file can be called when these events occurred. The script was associated with events allowing the form to perform custom actions such as the popping up of forms and display of building picture images.

GPS Correction

Inevitably, GPS itself has some sources of errors. The positional accuracy of the GPS used is 15 to 20m (uncorrected). In addition, the streets layer provided in the map symbolizes the center line of the road network in NUS. When the pedestrians carry the hand-held unit and travel around the campus, they will most probably walk on the pedestrian walkway instead of the middle of roads (Figure 3). It is therefore necessary to snap the GPS Tracklog to the nearest vertex of the line features stored in the walkway layer.

The action of snapping the point features in GPS Tracklog was automated by VBScript source code. Whenever a new GPS position is received by ArcPad and is being added into the map as a new feature, the fired *OnFeatureAdded* event of the Map will call and execute a subroutine that accomplishes the snapping of GPS Tracklog.

When the database is first established, exhaustive search is used to search for buildings within the search limit defined by the users. As commonly known, exhaustive search would definitely be the last resort to be adopted in order to attain an efficient search of the database. Therefore, an alternative was proposed to replace the exhaustive search by adopting the indexing method *(5, 6)*.

Indexing Method

The main feature of this prototype is its capability to display information of buildings in the vicinity of users depending on the search radius specified by users. The spatial searching algorithm was incorporated in the VBScript source code that automated the customized tasks. Bearing in mind that all buildings in NUS were stored as polygonal features, when searching for the buildings that fulfills the criteria, the system had to access to every item in layer “polygon.shp” from first record to the last record, subsequently every single coordinate of each vertex of polygon features in order to calculate distance between the buildings and user’s current location. For example, if there are n polygons, then the complexity of the exhaustive search is $O(n)$.

Therefore, such a time consuming algorithm should be replaced with a more efficient searching algorithm using, e.g. the indexing method.

The lack of spatial indexing in ArcPad leads us to develop our own indexing method called Route Segmentation B-Tree (Figure 4). The algorithm was implemented by first splitting the streets to a certain number of segments and subsequently assigning indices to each street segment. Whenever searching was initiated, the system would look for the nearest street segment from the user’s current location and search only for buildings features “belonged” to that particular record, instead of all buildings. Assuming all segments have the same number of buildings allocated to them, it can be approximated that, with the same total number of n polygons, the complexity of the indexing algorithm is $O(\log n)$.

Before the algorithm of indexing was developed, it was necessary and crucial to first build a data structure with proper size. The size refers to the appropriate number of road segment because it critically determines the relative reduction in order of growth by using indexing algorithm instead of exhaustive search. Due to time constraint, the selection of size was not studied in details. By intuition, the length of each segment varied from 5 to 6 times of the average length of the larger dimensions of all buildings that were within 100m from the all the segments. It resulted in having 36 route segments in the campus map.

There were a total of four layers in the NUS campus map but only streets layer and polygon layer were involved in the route indexing method. Within ArcCatalog and ArcMap application environment, a new field called “ID” was appended into the layer “polygon.shp” and “route.shp”. Each record in those layers was assigned a unique “ID”. In layer “route.shp”, additional field other than “ID” named “Bldgs_Id” was created to store “ID” values of buildings in polygon layer that are “belonged” to each record in streets layer. Each ID value was separated by space character. The buildings were considered belonging to the streets layer if any point in the polygon feature fell within 100m radius from any record in streets layer. As a result, some IDs of buildings appear more than once in the field “Bldgs_Id”. The allocation process started with creating a buffer zone of 100m around each record in street layer (Figure 4)

After the same procedures were performed to a total of 36 records in streets layer, a co-relation and spatial relationships between the streets and buildings in NUS were formed based on their proximity. When the implementation of the database was completed, we proceeded to writing the VBScript source code. The pseudcode of the indexing algorithm that based on the B-tree (Balance-tree) is given below:

Pseudocode of the Indexing Algorithm

Indexing Algorithm

```
Input:      pUser – point object representing user's current location
            S – search radius with pUser as centre of circle
Event:      OnPosition in GPS – new GPS position received
Output:     A series of building records in buildings layer found within S
Comment:    New GPS position returned in a pre-defined interval calls the subroutine
            embedded with indexing algorithm to search for buildings with certain distance
            away from user. Search results are displayed in user interface.

Sub_Indexing
    Set minimum distance, say d = Distance to first vertex in first part of first record in streets
                    layer
    Loop through streets layer to search for nearest vertex from pUser:
        If distance of record to pUser, say Curr_d < d then
            Update d
            Store the buildings IDs of this record to dynamic arrays, A
                If Curr_d = d then
                    Store the building IDs of this record to dynamic arrays, A'
                    If the attributes in A' = attributes in A then
                        Erase the attributes in A'
                    End If
                End If
        End If
     If arrays A and A' are empty then Exit
     Join the elements in A and A' to form a string, say str_All
     Search for space character in str_All to extract unique building IDs, say ID(i)
     n = number of unique IDs found in str_All
     If no buildings ID found then Exit
     For i = 1 to n do
         Go to record i in buildings layer
         Get the record attributes and store them in dynamic arrays
     Next
     Set all objects to be nothing
End Sub
```

Improvement of Efficiency in Performing Spatial Queries

The built-in function "Timer" in VBScript was utilized in the source code to retrieve the system time. A start time and an end time were inserted within lines of code to acquire the difference of both to give the process time of those two algorithms. For the exhaustive search, 30 points representing user's locations were picked arbitrarily on the map by mouse clicking, and the average computation time was 3.6s.

As for the indexing method, it was found that the maximum number of candidates in terms of buildings needed for distance checking was 34. As compared to exhaustive search which retrieves location coordinates from 134 buildings, indexing method only needs to access to about 10% of the candidates to perform the same spatial query.

Making use of the higher numerical precision available in Personal Computer (PC) system clock, the results acquired were scaled to reflect the process time on the mobile device, which has a lower Processor speed. The Pocket PC used in this project is iPAQ H3700 with 64MB as the main memory. By replacing exhaustive search with indexing method, the process time has been reduced by 2.4s or 67%, from 3.6s to 1.2s.

USER INTERFACE OF THE PROTOTYPE

One of the features of our navigation guide is the ability to capture real time location of the user using GPS and promptly provide access to the information of the nearby buildings or landmarks through interactive user interface.

Three custom forms and two custom tools were created in the user interface (Figure 5). The first custom form "Welcome Note" enabled users to select or enter a value in meter as the search radius. In the drop down list on the form, a choice of 50m or 100m was available. Users could also choose to enter a new value not greater than 100m. This search limit was used as the tolerance when the code searched for buildings that located within the search radius from users' current locations. Whenever the users want to change the value of search limit, they were free to click the custom tool button to open the second custom form "Change Search Limit" and input a new search limit.

Context-awareness of the system was featured in the third custom form "Building Information" (Figure 6(a, b)). As long as the function was activated by clicking on the corresponding custom tool available on the toolbar, the form providing information of buildings found within the search limit would automatically pop up. Within the form, there were three page tabs allowing users browse the general descriptions of selected buildings as well as their colored picture images (Figure 7(a, b)).

FIELD TEST

A field test was carried out after the completion of user interface customization in ArcPad Studio and transfer of data into the mobile device.

Before the system was distributed to the users for field trials, a walkthrough was carried out and several observations were made and noted:

- The times needed to receive the first signal from Global Positioning System (GPS) at different locations,
- Areas with more obstructions that blocked the signals from satellites,
- Stretches of roads where relatively longer time was taken to search for buildings,
- Personal experience from a point of view of end-user

It was found that problems that surfaced as a result of deployment of GPS could not be avoided. For instance, there are certain areas in the campus that could not detect sufficient number of satellites to capture the accurate positioning information of users.

Given a limited time span, 15 undergraduates without prior experience with ArcPad were randomly selected to experience the system. Before the actual field trials took place, the users were given demonstration on how to use the functions in the system and they were given 5 minutes to familiarize with the system. The walkthrough session was conducted in a very flexible way in the sense that the users were not forced to walk through all the roads in NUS. However, they had to at least use the system for 45 minutes.

Those users were interviewed so that they could feedback on the usability and user-friendliness of the system as third parties. A collection of recommendations and opinions was gathered and served as the reference to further refine the system efficacy for future research. There were three basic questions asked to obtain their general feedbacks on the system's user-friendliness, advantages over conventional maps and the users' potential usage in the future. They had to give their answers of “Yes” or “No” in the scale of 1 to 5. The results are shown in Figure 8. In general, the feedbacks were encouraging and positive, though some of the users did provide suggestions to improve the system.

Out of 25 randomly selected undergraduate students who were given the prototype user interface to perform field test, 60% of them commented that the navigation guide is a more useful tool than conventional maps to navigate the surroundings in NUS. Results relating to functional benefits derived from the system (Figure 8(a)) were very supportive as were results relating to the user friendliness (Figure 8(b)) and disposition of users to use such a system were it to be available (Figure 8(c)). Nevertheless, the tests by other age groups still need to be carried out.

All users also acknowledged that the colored picture images aided in recognizing the actual buildings. Some of them did point out that the screen is too small to provide the users a better view of the relative location with respect to the other buildings in the campus. Besides, buttons that opened a page without picture image should be disabled because this would result in disappointments with the system. In general, majority of the users preferred explanation and demonstration prior to their experiments with the interface.

CONCLUSION

This paper presents the design and development of a prototype navigation guide for pedestrians, which is context-sensitive, integrating the use of GPS, GIS and PDAs. The development effort has focused on the customization of GUI, the context-aware functionalities and an efficient indexing method to replace the slower exhaustive search method for spatial access.

The prototype possessed a friendly user interface that displayed a fully-colored NUS map. It allowed for various GIS operations including distance measurement and attributes identification. In addition, users get to browse photos of landmarks and buildings. In the course of testing the system, user feedback has been taken into account and the interface was updated accordingly.

Another important feature in this research was the implementation of a newly developed spatial searching algorithm. It made use of the basic model concept of B-tree algorithm and was fit into the data model in this research. Such an indexing method has not been explored before in the area of navigation. By replacing the exhaustive search that finds a solution by trying every possibility, nearly 70% of running time has been saved, as compared to running the system on with an exhaustive search algorithm.

Nevertheless, the prototype still needs some improvement. For example, the interface can be made friendlier. Also, more pertinent information may be provided to users in terms of the user interest or profile that can be input manually or downloaded through the wireless network at the beginning of the navigation.

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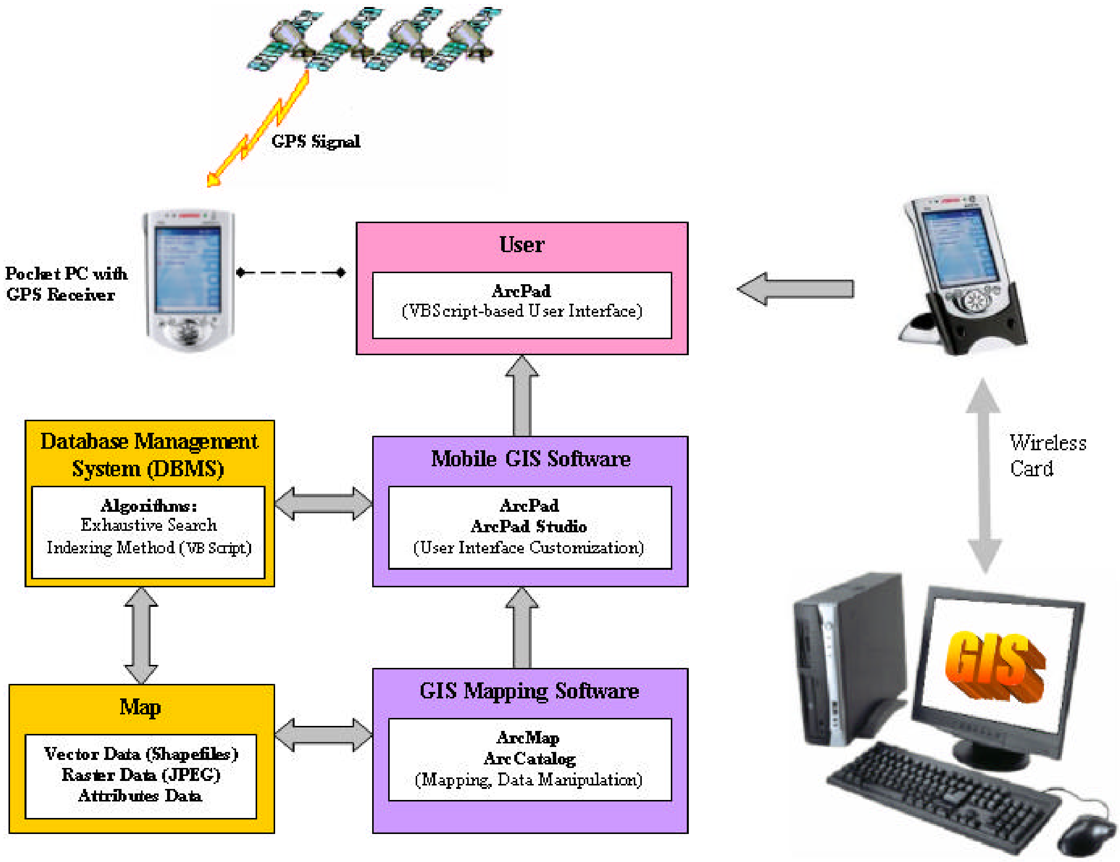

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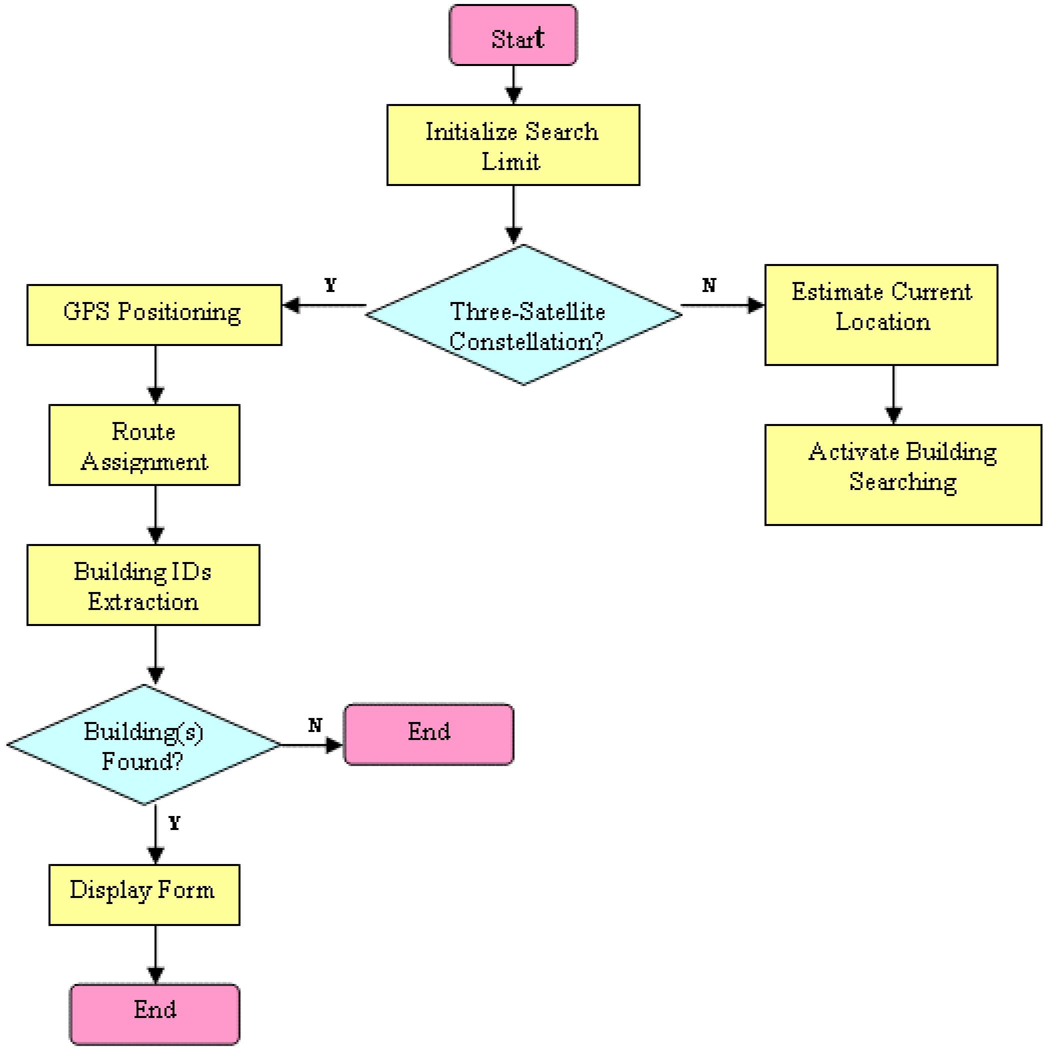

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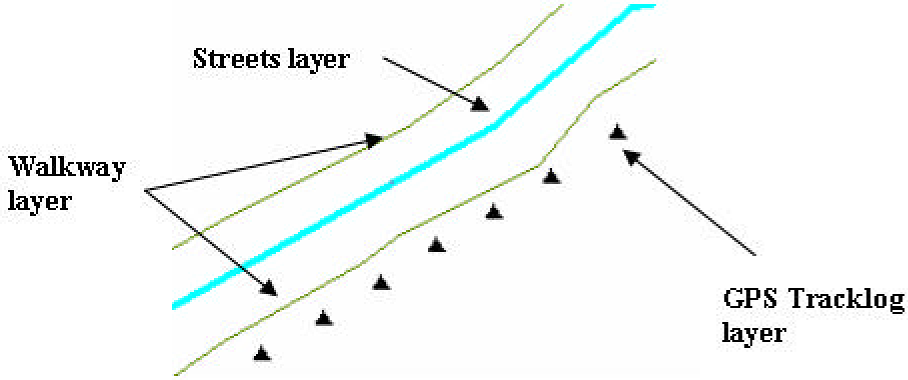

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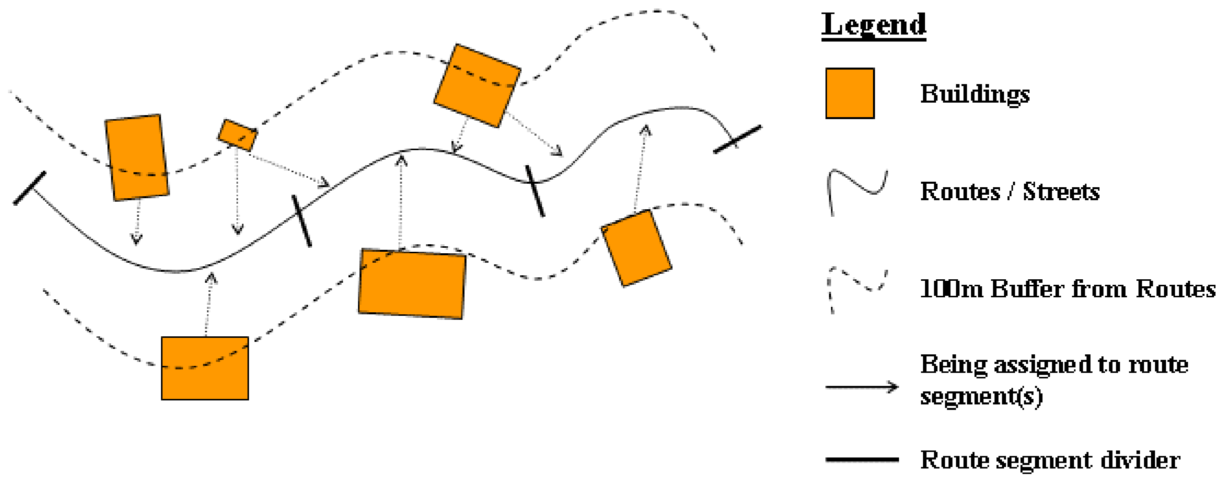

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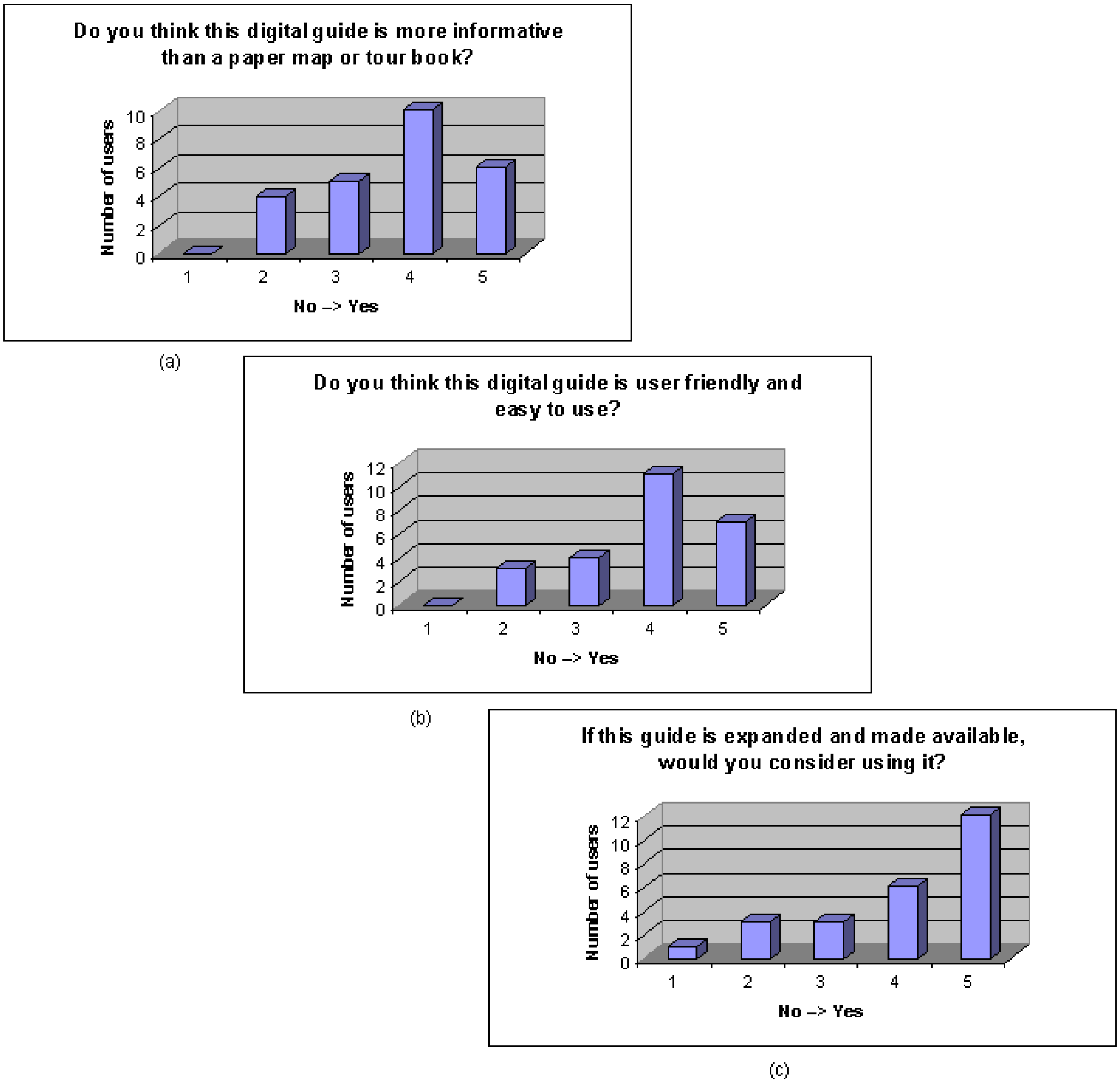

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