A New Approach for Indoor Navigation Using Semantic Webtechnologies and Augmented Reality

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Abstract. Indoor navigation is an important research topic nowadays. The complexity of larger buildings, supermarkets, museums, etc. makes it necessary to use applications which can facilitate the orientation. While for outdoor navigation already exist tried and tested solutions, but few reliable ones are available for indoor navigation. In this paper we investigate the possible technologies for indoor navigation. Then, we present a general, cost effective system as a solution. This system uses the advantages of semantic web to store data and to compute the possible paths as well. Furthermore it uses Augmented Reality techniques and map view to provide interaction with the users. We made a prototype based on client-server architecture. The server runs in a cloud and provides the appropriate data to the client, which can be a smartphone or a tablet with Android operation system.

Keywords: Indoor Navigation, Augmented Reality, Semantic Web, Ontology, Mobile Application.

1 Introduction

Indoor navigation is one of the actively researched areas of nowadays. Good examples are the large buildings, complex supermarkets, warehouses, university campuses, museums, etc. where it takes a longer time to find a given destination. The importance of the research topic is illustrated by the increasing industrial interest. For example in the autumn of 2012 some large companies collaborated and set the aim to make a standard indoor navigation system.[1] For outdoor navigation there are tried and tested solutions but these methods cannot be applied for the indoor case. These systems are usually based on Global Positioning System (GPS) that requires permanent radio wave communication with satellites around the Earth. These radio wave signals cannot be provided within the buildings therefore this method is not working at indoor navigation. The following case illustrates well the complexity of the problem: the Ericsson had an indoor navigation research project but it was terminated in August 2012, thence the home page of the research is unavailable.[2]

[1] http://www.computerworld.com/s/article/9230537/Nokia_Samsung_Sony_join_forces_to_improve_indoor_navigation
[2] https://labs.ericsson.com/apis/indoor-maps-and-positioning/

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Several attempts have been made to make accurate the indoor navigation. Existing methods use infrared signals [1], ultrasound [2], signal strength of various wireless connections such as GSM (Global System for Mobile Communications), Bluetooth, and Wi-Fi [3,4,5,6], inertial sensors to track user movements [7] as well as various digital image processing algorithms [8,9] to the positioning.

One of our objectives was to review the possibilities which are necessary for indoor navigation. The implemented system based on our research uses built-in sensors of mobile phone and Augmented Reality to provide the navigation. Both opportunities are based on the interaction of users. The system uses the advantages of semantic web to store the data and to compute the possible paths. The Semantic Web [10] aims at creating the "web of data": a large distributed knowledge base, which contains the information of the World Wide Web in a format which is directly interpretable by computers. The goal of this web of linked data is to allow better, more sensible methods for information search, and knowledge inference. To achieve this, the Semantic Web provides a data model and its query language. The data model – called the Resource Description Framework (RDF) [11] – uses a simple conceptual description of the information: we represent our knowledge as statements in the form of subject-predicate-object (or entity-attribute-value). This way our data can be seen as a directed graph, where a statement is an edge labeled with the predicate, pointing from the subject's node to the object's node. The query language – called SPARQL [12] – formulates the queries as graph patterns, thus the query results can be calculated by matching the pattern against the data graph. The implemented prototype was tested in one of the campus of Eötvös Loránd University with the help of different types of users (students, teachers).

The structure of the paper is as follows. After the introductory Section 1 we present the related work in Section 2. Then, in Section 3, we give the details of the design of the implemented system. Then, we give two examples in Section 4 to demonstrate the usability of our application. Afterwards we describe our future plans in Section 5. Finally, we summarize our experiences in Section 6.

2 Related Work

There is a good summary of indoor navigation solutions in [13]. In this section we present some already existing indoor navigation methods. All methods have a common property that their main objective is similar to our goal: to develop an efficient indoor navigation system running on mobile phones (or on handheld PC).

Baus, Krüger and Wahlster present a hybrid navigation system in [14] that uses different technologies to determine the position of the user. They implemented a component to provide the indoor navigation. When the paper was written there were not available mobile phones with enough capacity, therefore authors used handheld PC-s.

According to Schmalstieg and Reitmayr [15] the data model has to be independent from any specific application and their implicit assumptions. The Semantic Web provides such a data model. In their paper they investigate how this model fits the requirements of Augmented Reality applications and how such a system can be developed. The difference between our and their system is that they did not store maps and did not use map view for visualization.

Mulloni et al. [16] implemented a real time marker-recognizer tool on mobile phones. They compare solutions with the navigation method based on maps and with the navigation method based on GPS. Based on their tool they developed an application for indoor navigation. This was used in poster presentation of a conference. Similarly to our system they use the appropriate map and assign the markers to show the new location. The advantage of our system compared with Mulloni's system is that in our case the necessary information can be downloaded dynamically with a QR code and we do not need new installation while in their case it is required to download the new release of the software and to install it onto the mobile phone.

Mulloni, Seichter and Schmalstieg describe an Augmented Reality interface to support indoor navigation in [17]. They combine activity-based instructions with information points for the localization. We also used this technique. In addition the authors made comparative case studies to evaluate of their system.

3 Architecture of Our Prototype

In this section we describe the main functions of the system. First, we review the investigated techniques, then present the architecture of our prototype and give the details of the functions.

3.1 Investigated Techniques

We studied several available navigation solutions. The first solution is a navigation based on WiFi signals that have been analyzed in a lot of papers [4,5,6]. In previous works the accuracy of positioning was increased by installing new devices (e.g. router). These devices are used as fingerprints. Our goal was to avoid the deployment of further WiFi devices, instead we wanted to use the already existing ones to guide the user to its destination.

First we wanted to identify the exact position. The positioning was not correct, because of the measurement errors. Therefore we focused on defining large areas, so we split the map to cells. The signals were often unstable, therefore we often got wrong results. To solve this problem we created a solution to accept a cell only if it was adjacent to the previously correctly determined. Unfortunately, the tests showed that this still made a lot of mistakes. Later we added direction information to our measurement to correct the accuracy of the measurement [5], but it was not still enough to be able to determine the accurate position based on WiFi signals. Because of these unsuccessful attempts we discarded the WiFi navigation.

The next investigated solution was the pedometer that used the accelerometer and the compass of the mobile device [18]. We successfully apply this technique, the details are given in Section 3.3.

3.2 Server Components

The system has client-server architecture where the server is rarely used. The server is a cloud application using the CloudFoundry Micro system that provides a private cloud server for development. The application we made in CloudFoundry can be easily deployed to another cloud provider system.

The map necessary to the navigation was made by the OpenStreetMap map editor [19], which provides latitude and longitude coordinates to the corresponding points. The map stores POIs (Point of Interest), which are required for the final destination or the route calculation. This editor saves the data in XML format. We could transform this file automatically by means of the server to semantically interpreted content. We implemented the transformation with XSLT. The objects of the map are transformed to N3 format.

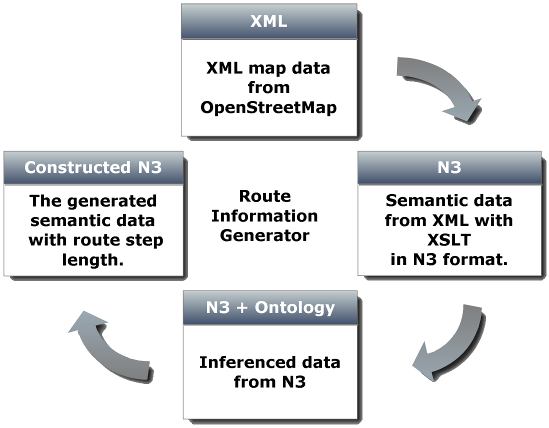

Fig. 1. The process of generating semantically annotated route data

The semantic layer contains well-annotated data which are extracted from the map and represent the environment. The correspondence between the map data and the semantic content was made with the INO ontology [20] that is extended by us. This extension contains the required concepts about navigation routes (e.g. POI, Passage, Corridor, Exit, etc.). In order to determine what points can be reached from a certain point, we needed the `hasAvailable` property that tells which points can be reached directly.

The map contained only those pieces of information that were necessary for drawing. We extracted the possible relation between two adjacent points from these pieces of information. Afterwards we ran an inference, which used the symmetric property to determine the possible steps. On the resulting routes a CONSTRUCT query provided by SPARQL was executed, which calculated the distance between two points based on the coordinates. The CONSTRUCT query makes a new RDF dataset from an existing RDF graph. This is the final dataset that is used by the client on the client side. This eliminates the need for storing all of the existing route information. Thanks to the `hasAvailable` property we can inference the possible routes from the points and their direct connections. This saves significant space for us.

3.3 Client Functionality

The client side is a device running Android operation system, which has built-in accelerometer, compass and camera. The first two are required to use the map function and the last is required to use navigation based on Augmented Reality. The system uses only those resources that are essential to the navigation, therefore it increases the energy efficiency.

First, we read the QR codes which store the current coordinates of the locations and the identifier of map located on highlighted places. The server sends all map data when starting the application so we do not need permanent internet connection to the navigation, therefore our solution is cost effective. After that the user chooses a destination and selects one from the possible visualization and starts the navigation.

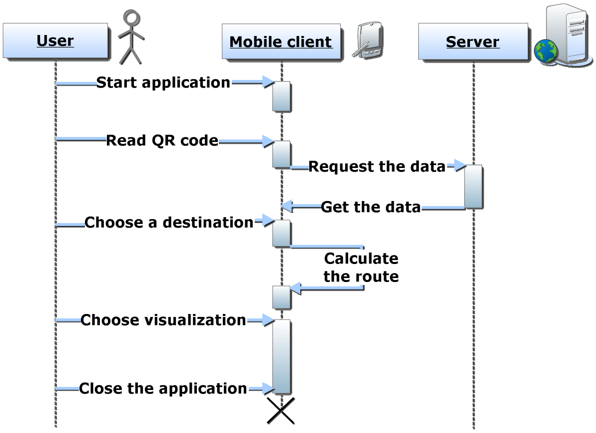

Fig. 2. The workflow of our system

One function of our system is the previously mentioned map mode with pedometer. It is based on the built-in accelerometer and compass. With the user interaction we can follow the motion of the phone. The phone displays the way that leads to the destination and the travelled distance on a map view. The pedometer has a calibration screen, where we can set our height. From the height the phone can calculate the length of the steps with mathematical methods. Since the step sizes may be different, it can cause small errors in positioning. A lot of small deviations lead to inaccuracies in the long term. In our case, the navigation is limited to a small area, so the error is less noticeable. On the basis of our experience, the pedometer method is able to determine our position with an accuracy of 50 cm. Our position can be updated with reading QR codes placed in the building.

Another feature of our navigation system is that we used Augmented Reality for the visualization [21]. Augmented Reality (AR) is a wide spread technology, by means of which the real physical environment can be extended by computer generated virtual elements. The system created this way is located between the real and the virtual world. We used the marker-based version of Augmented Reality, which uses markers for registration in 3D. This technique uses the markers for reference points, where it displays the augmented content. We also investigated the natural feature tracking (NFT) option, but for two reasons we have decided not to use it. The first and most important point was that the application should also run on simple devices with small capacity. The cheaper types of Android phones do not have suitable hardware for NFT resource intensive operations. Another aspect was that the sign, which is used for navigation stands out from its environment. This aspect is better suited for traditional approach that uses markers.

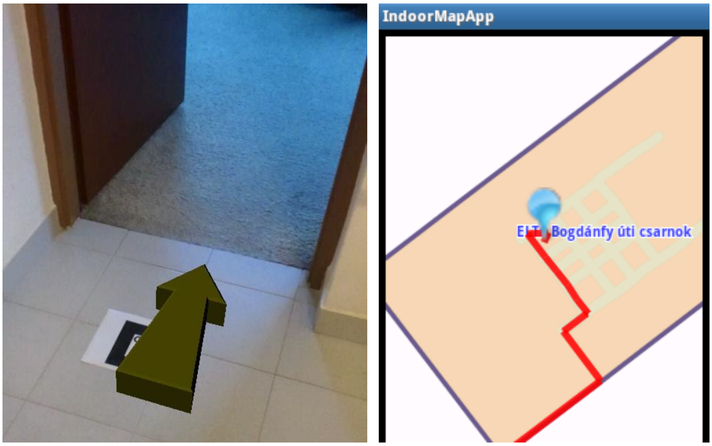

Fig. 3. Visualization with AR and with pedometer on the map

Our idea was the following: we can use the crosses of map for navigation points and assign markers to them. A directed 3D arrow was defined to the marker. This arrow always points to the nearest point, which is in the route towards our final destination. Since the 3D models can be of large size, we used a model that produces the right direction with linear transformation. The detection of markers requires quadratic time. This depends on the number of the markers, because the system compares each marker to all others. In our case for the efficiency we can use only one marker for all. Because the markers are located also in POIs functioning as possible destinations thus the Augmented Reality based navigation provides accurate positioning.

4 Use Cases

The need is increasing for using indoor navigation in public places, office buildings, universities, hospitals, etc. In this section we present the functions of our application by using two scenarios namely an implemented and a fictional one. The first scenario is about the building of our research center and the second one is about a shopping center where the application can help the navigation.

Since the prototype is made for general purposes, of course, it is not limited to these two tasks, but with these two different use cases we want to demonstrate the flexibility of our application.

4.1 Research Building

In the first scenario we tried the system in our research building. We made a prototype application for this. The building has many rooms and a large lecture hall. Our aim was to help the navigation between important points (e.g. rooms, doors, tables) of the building. We mapped the building and each important point was saved to a map. On Fig. 3 one can see the map view and the shortest path from the current position to the exit on it. The application was tested on a device that has weak hardware (Samsung Galaxy Mini with 600 MHz processor) and running Android 2.2 operation system.

4.2 Shopping Center

The next example illustrates another possible case when our system could be used. Because the shopping centers usually have large area it is difficult and time-consuming task to find a given store inside them. The information boards are placed only in certain specific places, so the information is not available from anywhere inside the store. A lot of time can be saved by using a mobile device, which clearly shows the shortest path to our destination. For this purpose our application provides a cost effective solution that needs only cheap paper and plastic markers. These markers can be placed easily to the walls or the floor with stickers, so it is a really cheap way to help peoples to navigate. We can also use the map view based on the pedometer.

5 Future Work

Several further developments are planned. One of the goals is to improve the pedometer method. The QR code can provide a solution for this problem. When the client recognizes the QR code then he gets the accurate position, so he can be compare it with the position on the map view. This way it is possible to correct the position of pedometer.

A possible improvement of Augmented Reality view is to develop various navigation commands in addition to the arrows showing the right direction. With help of textual instructions we can learn how far away the destination is. As another opportunity the system does not only display an arrow but also shows the whole road section in front of the camera.

Currently to find the shortest path between two points a traditional graph search algorithm was used. We are planning to determine this path based on pure semantic web technology, namely we would obtain the shortest path with SPARQL queries. This method provides benefits at the personalization (when we would like to forbid the usage of certain path elements, e.g. staircase, elevator). Because of the inference ability of Semantic Web, the personalization can be done by using only one SPARQL query. For performance purposes the results of comparing of the two methods are also interesting for us.

6 Conclusion

Indoor navigation is one of the actively researched areas of nowadays. We achieved the following results. Firstly, we reviewed the state of the art of indoor navigation and investigated the technologies required to indoor navigation. A general, efficient system was designed based on the obtained results. Then we implemented a client running on Android operation system. With our system a user can navigate through an environment which has a map and contains arbitrary markers and QR codes. The application provides two different types of visualization for the navigation. Both are based on the interactions of users. The first is the pedometer method using the built in accelerometer and compass of the device. It also displays the way that leads to the destination and the travelled distance on a map view. The second visualization tool uses Augmented Reality, which extends the image of the camera with computer generated virtual objects. The system uses the advantages of Semantic Web to store the data and to compute the possible paths. Therefore our system combines two current technologies, Augmented Reality and Semantic Web to implement efficient and accurate indoor navigation. Our prototype was tested in one of the campuses of Eötvös Loránd University which was mapped and provided with markers.

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