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Open-Source Indoor Navigation System Adapted to Users with Motor Disabilities

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Abstract

This paper describes the development of a mobile indoor navigation system, supported by a GIS and built using only open source tools. For the sake of simplicity a single building was chosen for the tests converting the floors to digital information from paper plans. The rooms geometry was saved on a proper database with all the adjacent information associated, which can in turn be provided to the clients application by APIs and Web Services. The system is able to calculate the most adequate path between any of the rooms taking into account the user profile which is defined by it's degree of mobility (eg. wheelchair). By reading a QR code placed in key places inside the building the user can obtain, on a mobile phone, his current position and receive orientations to any room that he might want to go. The directions hints are complemented with the presentation of real pictures associated to key locations in the path to validate that the correct path is taken by the user.

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Keywords: Indoor Navigation System, Open-Source Tools, QR Codes, Accessibility.

1. Introduction

Location awareness has always been a challenge for mankind. For outdoors and open spaces locations there are already various solutions available, and they are known to work in almost every corner of the world, but the same cannot be said about indoor environments. However, in recent years the interest in indoor location determination has grown with applications in fields like asset tracking, health care, location based services, logistics, shopping, security or tour guides [1][2]. When one thinks about people with some kind of mobility condition, indoor location

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awareness can be very important. They cannot follow paths that are not suited for their condition and sometimes finding an elevator or even a proper bathroom can be very difficult. While there are various systems to estimate a user's position inside a building, there is no standard for indoor localization [3][4]. Since it is application dependable, there is the need to select one that fits certain requirements better and develop the necessary components to achieve the best accuracy and precision possible [5].

The most common methods used in outdoor environments cannot be used within buildings because they use radio signals for the distance estimation which behave quite differently in indoor conditions. There is no line-of-sight between the sender and the receiver that makes the signal travel through reflections inside the building. Thus it is impossible to calculate the distance, and systems like the GPS will not work [6].

Indoor location and tracking systems can be devided in two groups: active and passive. The most common method in the first group is the Wi-Fi radio fingerprinting scheme [7] and systems that use the wireless local area network (WLAN) are the most common [5]. This kind of system requires the user to be in range of several Wi-Fi transmitters, which can be unavailable in some areas of a building and the signal can sometimes be blocked by elements of the infrastructure, like thick walls. It also requires a regular calibration, which can be time consuming and involves new measures when the physical conditions change or there are more people using the network [8]. The RFID technology is also suitable for dense environments but the building needs to have these tags at very frequent intervals, which interfere with the buildings architecture. There are other types of sensors, like Bluetooth, but they require a permanent electronic infrastructure and they are hard to deploy [9].

There are also passive methods, based on inertial sensors and dead reckoning. These methods consists on knowing a precise starting point, calculate travelled distance and measure the heading direction of the user. That can be used to estimate the approximated user position. They have the advantage of being independent from the infrastructure but they get more imprecise overtime [8]. Despite this imprecision there are some successful works that use the magnetometer and accelerometer [10], while others use the gyroscope and accelerometer [7] [11], in order to estimate and update the user position.

In order for the system to be capable of providing routing information a geographic information system (GIS) module is needed. It is a computer system designed to capture, manage, analyze, and display any type of geographically referenced information. This type of software has benefits to almost every kind of industry [12]. That information is derived from data such as floor plans properly organized according with the building infrastructure. These plans must contain data about its rooms, corridors, stairs and elevators, which are the elements used to obtain routing information.

In this paper it is proposed a method to build a mobile indoor navigation system. It was created using a dead reckoning approach that is supported by visual markers distributed along the building and a set of geo-referenced pictures representing key views located in the calculated path. The system is scalable and built using open-source software and can be implemented in any kind of building. A smartphone application to handle the navigation between the buildings rooms or specific point was developed.

The next section of the paper describes the proposed system which includes the indoor maps and paths creation, followed by the description of the Indoor GIS responsible for generating navigation routes. Then it will be described the purpose of the visual markers, the key views supporting the navigation and finally the capabilities of the client app. In the last section some considerations are made concerning the system's state of development and future work.

2. Proposed System

The system is divided in four main modules as the following diagram shows (Fig. 1). These modules will be described in detail next.

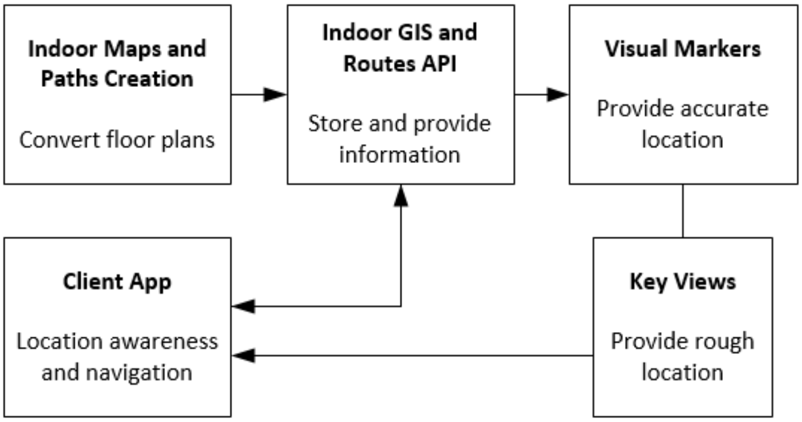

Fig. 1. System Overview

2.1. Indoor Maps and Paths Creation

The first step was to obtain the image file of the building floor plan used for testing. In this step there were some challenges due to the starting requirements:

- convert the image into a format that could be managed;
- find an open-source tool for indoor map creation;
- geo-reference the plant and make sure that the image reflects the real size and dimensions of the building.

The solution found was a tool called JOSM [13], which is the editor of the OpenStreetMap project, built in java and cross-platform. This project is a collaborative platform for geographic data. It is developed by a community of volunteer mappers who contribute and maintain updated data on roads and other elements around the world. OpenStreetMap is available in open data, under license Open Data Commons Open Database License (ODbL) [14].

The reasons behind this choice had to do with the abundant number of plugins available, the free tagging scheme that can be used while creating the maps and the structure of the file generated by this program, a XML document very easy to understand and to extract data for later use. On the downside, mapping tools in general are oriented to work with roads and other elements of the “outside world”, therefore there is no standard way to create an indoor map. For example, even if all the rooms of the floor are drawn on this software, when opening it on QGIS, a popular GIS software, it will be impossible to interpret the information as intended right out of the box. This happens because there is no standard tagging scheme for indoor maps.

There are some projects on the wiki of JOSM software dedicated to indoor mapping that can solve this issue [15]. None of them is final, and in anyway a must follow to create this kind of maps since they are only ideas and proposed tagging schemes for this purpose.

In this project the approach used to create indoor maps consisted on drawing the outline of the building from a satellite image of Bing Maps. Then, overlaying the image of the floor plan accordingly to that outline, it is drawn every room represented on the floor plan (Fig. 2).

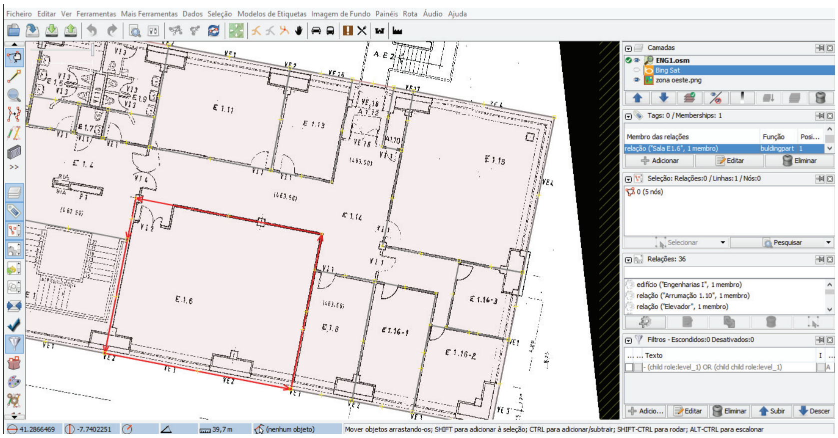

Fig. 2. Drawing of a Room

In order to represent the building infra-structure the rooms are organized accordingly to the building levels and are tagged as follow [16]:

- Name – name of the room;
- Level – floor level where is located;
- Ref – the internal reference (ex. F1.20);
- Bpart – describe the room accordingly to its type (room, office, wc, storage, vertical passage)
- Verp – if bpart is a vertical passage we must fill verp with (stairs or elevator).

The tags are used to identify all the rooms according to it's type and functionality. They also allow to make a distinction between stairs and elevators. It is also necessary to create a path, as a sequence of nodes, for each corridor in each floor. Comparing to the outside world, we can consider the rooms as buildings and the paths as roads. The path just needs to connect the rooms available and have a tag with the level that represents.

With this first step complete, the next step consists of implementing a way to manage this information properly, design the Indoor GIS and integrate the maps created with existent software and databases.

2.2. Indoor GIS

In order to have an indoor GIS that can be properly managed, a dedicated database is needed, and a server to provide data to the client application. To manage all the processes needed to store data in a database engine a module was developed (Back Office Tools in Fig. 3). This module is able to read the files created in the previous step, on JOSM, and make all the necessary arrangements enabling anyone to easily store the data.

For the database engine it was chosen the PostgreSQL with the PostGIS extension. To deliver the maps it was used a GeoServer instance and a simple REST API for the routes. The following diagram shows how the system is implemented:

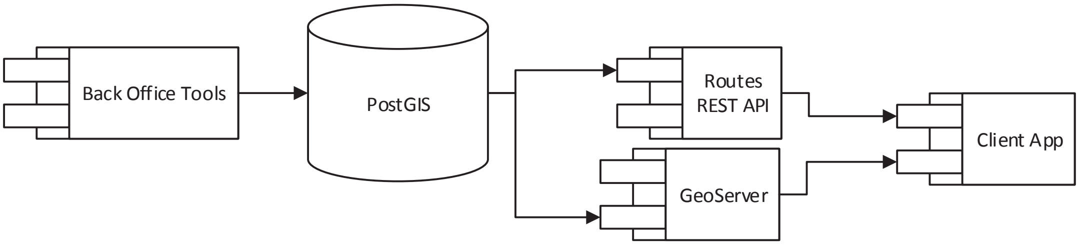

Fig. 3. Indoor GIS Overview

2.2.1. PostGIS

The PostgreSQL is an open source object-relational database system. It is a very powerful engine and can be easily integrated with applications developed in languages such as Python or C#. The PostGIS is a spatial database extender for PostgreSQL, allowing storage and query of information about location and mapping [17]. The PostGIS is the main reason for choosing this technology for storing because it has also a module named pgRouting, which provides geospatial routing functionality.

The next step is devoted to store the information contained on the XML generated by JOSM (OSM file) on the database. Following the approach suggested by [18] it was decided to create a tool in Python capable of reading the OSM file, creating polygons and lines for each room or path, and save them in a 2D GIS layer (shapefile).

The shapefile format is a popular geospatial vector data format for GIS in which the data is composed by points, lines and polygons that can be easily stored. This kind of format is composed by three mandatory files [19]:

- .shp -- Main file; a direct access, variable-record-length file in which each record describes a shape with a list of its vertices.
- .shx -- Index file. In the index file, each record contains the offset of the corresponding main file record from the beginning of the main file.
- .dbf -- dBASE table file; a constrained form of DBF that contains feature attributes with one record per feature. The one-to-one relationship between geometry and attributes is based on record number. Attribute records in the dBASE file must be in the same order as records in the main file.

This format allows the storage of the room's geometry and the tags associated earlier. In addition the database engine provides tools to import these files (Fig. 4).

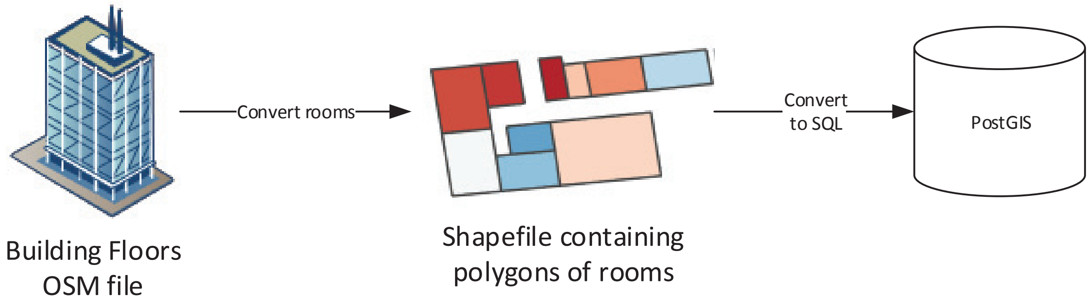

Fig. 4. Converting and adding rooms to PostGIS

After adding all the rooms and paths into the database it is necessary to create routes. For route calculation it is needed to build a topology with the paths data (nodes). The routes are generated with pgRouting which extends the

PostGIS/PostgreSQL geospatial database to provide geospatial routing and other network analysis functionality [20].

For any given edge in our path data the ends of it will be connected to a unique node and to other edges that are also connected to that same unique node, resulting in a graph that can be used for routing.

After running the SQL scripts needed for that task, the tables of the paths will have a topological information associated with them, and new tables with the vertices (unique nodes) are added to the database. Finally, in order to properly id the vertices the rooms containing any of those nodes can be calculated and with this, identify which nodes corresponde to a room in a path.

2.2.2. Geo Server

The GeoServer project is a full transactional Java (J2EE) implementation of the OpenGIS Consortium's Web Feature Server specification and Web Coverage Server specification, with an integrated Web Map Server [21]. This server can be connect to the PostGIS database and for that it is needed to publish the building table and the tables with the vertices.

The server outputs data in various formats, but the interest is in the GeoJSON format. This format is basically the geographical features of the objects along with their non-spatial attributes using the JSON notation. The output is a fairly light file and classes can be easily created to decode it on the client application.

2.2.3. Routes API

In this case it is used a simple API, created with Flask which is a micro framework for Python. In order for this API to return a route, it must receive a source and a target point. These points are ID's of vertices created earlier. The API runs a pgRouting function of the Dijkstra algorithm [22] on the database and returns a path of nodes with the shortest path. The data is also returned on the JSON format.

2.2.4. Visual Markers

As mentioned before the system uses visual markers to perform the correspondence between the building rooms and the client accurate position in the application since they are geo-referenced. These markers are QR codes, which were generated after the process of room identification was complete and are positioned at half height of each room door in order to be accessible by any user. The reading process of this kind of code is very fast and reliable. The code itself can contain a big quantity of data, which is ideal to store all the information that the client application needs to correctly identify the building and room in question. The use of this type of barcodes in orientation systems is not new and has been used in projects such as [23] [24].

2.2.5. Key Views

Since the visual markers can be far apart from each other, the application contains in a database, pictures of key views of the building that can provide a rough position between those markers. These pictures enable a visual validation of the path being followed.

There are a few considerations to take into account before making available any picture on the systems database: to prevent situations where the floors of a building look alike, it is important that the picture captures a distinctive element, this can be a unique sign, a placard or any other element that can be easily recognized. They also should have a correspondence with nodes on the paths, it is required that the picture is geo-referenced and associated with locations that will be present when a route is generated. Each of those points can contain various images, the purpose of that is to provide pictures taken in a node with at least two directions, for that an image needs a source and target point in order to give an orientation. This concept is better illustrated with the help of the Fig. 5.

Related work shows us that the use of images to navigate inside buildings is, in some cases, possible by taking a picture and comparing it with a database of images [25] or using those images as visual landmarks to localize and validate low vision user's path [26]. In that case the recognition is automatic and doesn't need the user confirmation.

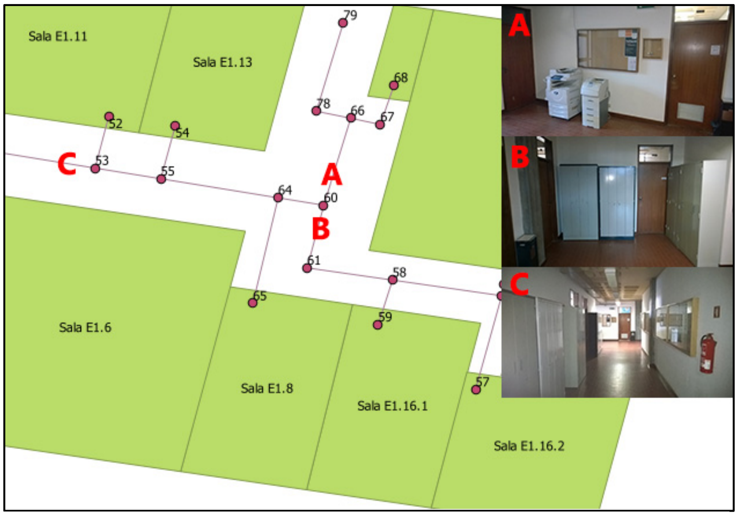

Fig. 5. Key Vivid Images for nodes 60 and 53

2.3. Client App

When the user reads a QR code placed on the building, the application retrieves the corresponding building from the GeoServer instance and draws it on a map control. It also gets all the nodes in order to provide the rooms list and locations. After that it marks on the map the current position of the user (blue circle on Fig. 6).

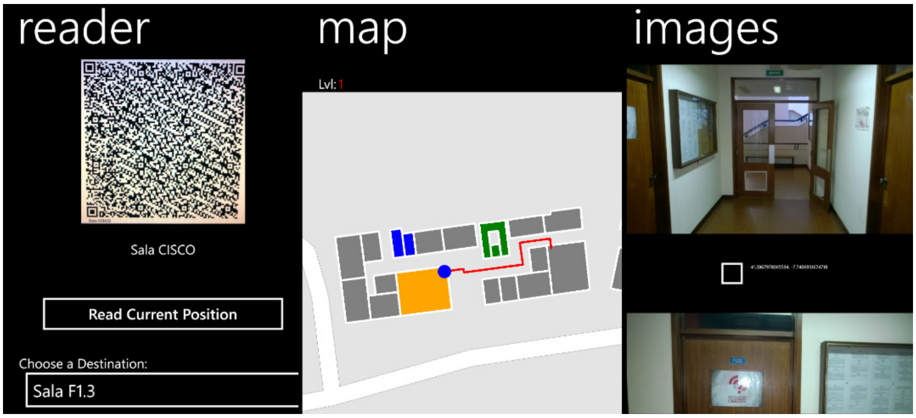

Fig. 6. Screenshots of the application

Next, the user can choose any of the rooms of the list and get the shortest route to that destination based on his profile (mobility conditions). This profile is important to adapt the generated routes to the user condition. When needed the application can choose elevators over stairs and adapted bathrooms over normal ones. This can be observed in the example of Fig. 7 where the current position (user position) and final destination are in different levels. After the user has chosen the room (final destination) the application guides him (real time position) along the path.

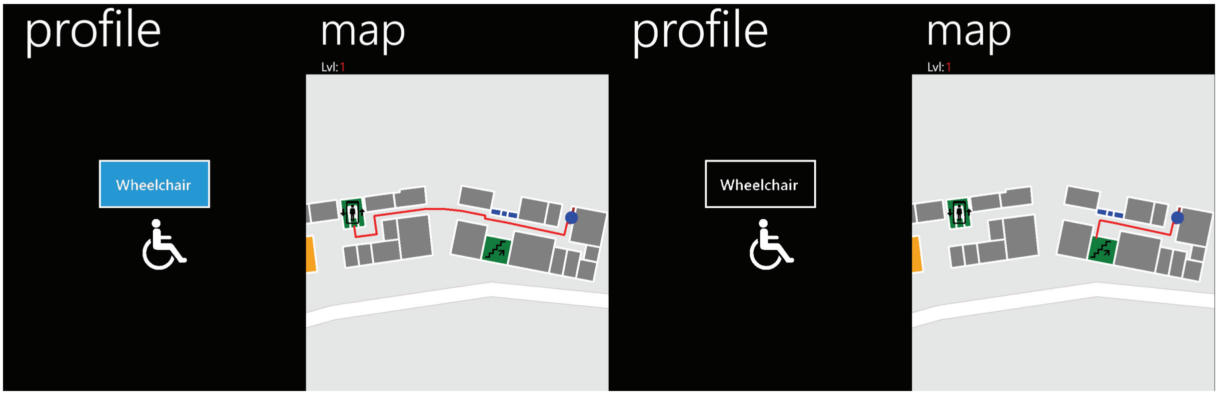

Fig. 7. Screenshot of profile choosing and routing differences when changing levels.

The implemented application takes advantage of the phones compass in order to orientate the map control in a very precise way. In this system, key views are displayed to provide a rough position of the user, since the use of a accelerometer to measure the travelled distance revealed itself to have a high value of errors, as mentioned before, and almost impossible for a person in a wheelchair to use. By making these images available it is expected to make the navigation process much more natural and easier. The user can know his relative position on the map and compare what can be seen on the surrounding environment with the associated key views for each route. On Fig. 8 it is presented an activity diagram that resumes the current state of the navigation process.

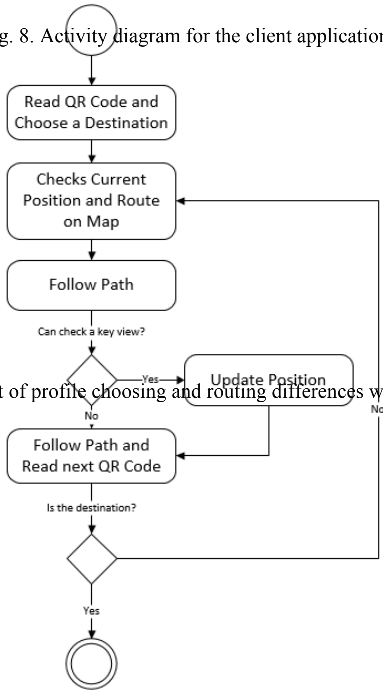

Fig. 8. Activity diagram for the client application

3. Conclusion

In this paper a method is presented to build an indoor navigation system adapted to users with motor disabilities, using only open source technologies. It was explained how to create the floor plans for the case study and shown that the same technique can be extended to any building.

Next, the plans are stored in a proper database with the relevant information to support the indoor navigation. This way, with the maps and routes servers, an Indoor GIS was created capable of providing data to the implemented application, and to any other capable of reading it and display it properly.

Despite the final system is still under development it can already show the indoor map on a smartphone and see the generated routes between rooms. At this stage of development the navigation module already includes support to the user positioning at each step of the path. This is accomplished showing to the user photos of key views associated with several nodes along the calculated route, so it can be visually confirmed that the correct path to the destination is being followed.

The user profile is also taken into consideration, for instance if a wheelchair is used to move, the generated routes are based not only in the distance between rooms but also possible inaccessible paths for the user like the existence of stairs. In this case de system will generate routes that contain elevators when moving between levels for example.

Future work includes the improvement of the navigation module. The purpose is to merge the key views and the routes in order to make it the more intuitive as possible, and even try to make the recognition of this key views automatic with the help of the phone's camera. The final version of the system will also allow to adapt the route showed accordingly to other mobility conditions of the users. More tests are also required to guarantee that the system is robust and accurate and improve the usability.

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