A Proposal for Design and Implementation of an Hybrid Navigation System Based on Open Data, Augmented Reality and Big Data
Applications for the Smart Cities

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Abstract: Indoor positioning and navigation systems have attributes which make their use inadvisable in certain applications. Our main purpose is to investigate these issues in order to improve accessibility in Smart Cities. In the last decade, there are increasing efforts to develop a sustainable and precise indoor navigation system to be used in any situation. There are interesting proposals but they suffer from various constraints (accuracy, cost, complexity, etc), so the use of hybrid and targeted solutions is mandatory. In an effort to address these problems, in this study we will develop an affordable and accurate indoor location system. Firstly, we will use geodata from the the Open Data initiative of the Spanish Conference of University Rectors. After studying its data model, we will create new methods to automatically derive new geometric layers, useful for accessibility studies. Then, all relevant information will be published via standard protocols and web services. In the second phase of this project, we will design an indoor positioning network (Bluetooth, WiFi, etc) based on indoor mapping. Finally, this positioning and navigation system will be used for performing different mobility experiments from the Smart Cities perspective.

1 MOBILITY IN THE "SMART CITIES"

Studying how cities grow and are managed is fundamental for achieving a sustainable development (Egger, 2006). In this context, Information and Communication Technologies (ICT) are useful for optimizing the management of certain consumer goods, reduce effects of pollution and improve energy savings at the same time. When speaking of ICT solutions for cities, the concept of "smart city" is often used to highlight the importance and potential of ICT to develop a competitive advantage and improve the quality of life. A Smart City applies adjustments, thanks to the knowledge acquired using sensors, wireless technologies and Big Data processes (McAfee and Brynjolfsson, 2012). Despite the widespread use of this concept, cities often have different needs because of their unique challenges. Therefore, the definitions may vary and issues related to sustainability will require a multitude of different solutions. This gives rise to some terms associated with Smart City such as smart transportation, smart environment, smart healthcare, smart energy, smart education, smart safety, among others (Nam and Pardo, 2011). In all these cases, one of the key challenges is to accurately locate people and objects in their dynamic behaviour. Access to this information and its use in a Big Data process may lead to better accessibility, energy saving, efficient resource management, assistance in emergencies or the inclusion of disabled people, among other topics. Consequently, the use of these data in urban analysis has become a trend in various scientific fields, including Geography (Kramers et al., 2014). Smart Cities services require a greater access to positioning and navigation data, both in outdoor and indoor spaces. While outdoor data could be easily collected with the current Geographical Information Technologies (GIT), data for interior spaces are more complicated to obtain. Certain political decisions, along with cheaper GPS chips have greatly facilitated many location based applications, available for smartphones and other mobile devices. Assistance in terrestrial, air or sea navigation, remembering where we parked our car, locating either a lost pet or quickly find the near-

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est hospital, are a few applications that are based on the GPS. Consequently, these widespread outdoor applications have increased the demand for indoor navigation applications.

1.1 Outdoor and Indoor Positioning

The GPS signal only works well under certain conditions, so its use inside buildings is often unfeasible (Kolodziej and Hjelm, 2006). Typically, the GPS is combined with INS (inertial navigation) to offer acceptable solutions in both environments, indoors and outdoors. However, the accuracy of INS, alone, is rapidly degraded with an increasing time of use, while the GPS signals are vulnerable to interference or may even be completely blocked in urban areas or inside buildings. Therefore, GPS can not always be used as reference for correctly applying INS indoors. This is why it is necessary to find a reliable indoor positioning technique, easily adaptable with existing GPS/INS systems. In recent years, there have been considerable technological proposals, including the use of Infrared, Bluetooth, Radio Frequency Identification (RFID) (Pirzada et al., 2013), Ultra-Wide Band (UWB) (Figueiras and Frattasi, 2010) or Wireless Local Area Network (WLAN) (Liu et al., 2007). Nowadays, the most commonly used indoor positioning systems are WiFi based (802.11 WLAN) and can be found in areas such as airports, office buildings, hospitals, among others. This system is the most popular and easy to implement, based on the fact that most widely used devices (e.g. mobile phones and computers) have WiFi receivers and many facilities have available WiFi networks to provide Internet access.

WiFi positioning systems has been tested applying various techniques based on the signal's time of arrival (Curran et al., 2011). However, there are still some major problems in terms of large latencies and lack of scalability (Yu et al., 2009). It is also important to know in advance the precise position of each WiFi antenna. Moreover, studies in which higher accuracies ($<$0.5m) were reached (Deak et al., 2012) used specific non-commercial hardware to build a positioning network. Above all these problems, existing WLAN networks are not designed nor implemented for positioning, and positions (distances) are difficult to measure accurately from commercial and/or cheap WiFi equipment. This way, several methodologies have been proposed based on WiFi location using the received signal strength (RSSI). Trilateration is used to approximate a model of signal propagation by converting the received signal strength on a measurement of distance from the antennas to the user's device. If three or more distance measurements are obtained from different access points, the user's position can be determined in a manner similar to GPS. Unfortunately, signals are easily blocked by all kinds of obstacles (people, walls, furniture etc), resulting in a significant decrease in accuracy. One of the most used methods to increase the accuracy requires setting up of a RSSI database for indoor environments. The latest experiments show that WiFi networks still lack the stability and reliability requirements needed, so its combination with INS still faces some problems (Cheng et al., 2014).

Recently, an interesting comparative analysis between different positioning systems, showed that the most viable alternatives would use Bluetooth beacons, followed by various WiFi based solutions (Deak et al., 2012). This study used a list of criteria of great importance from the perspective of sustainability, such as accuracy/precision, complexity, scalability and price. However, it is clear that the use of hybrid systems would be more appropriate in spaces with a previous infrastructure (e.g. Bluetooth + WiFi at an institution that already has a WiFi network).

1.2 Indoor Mapping

Locating a person or a device inside a building is only a half of the problem. If we want that position to be meaningful, we will need accurate indoor maps. There is already a new industry dedicated to the creation of such data. In 2013, Micello Inc had over 50,000 mapped buildings. Google and Nokia are also collecting indoor data. However, these are static and heterogeneous maps generated by different users. Lamentably, these sources are difficult to update and not standardized. For example, corridors in building plans may be encoded differently, so it will be very difficult to automatically derive topological networks, doors, among other interesting features. Access to outdoors geographic information can be more easily achieved through several Open Data initiatives, a remarkable example is OpenStreetMap (OSM). However, indoor geographical information is still scarce in Open Data initiatives. At the moment, there are only few open projects available, although it is expected that in the coming years, Open Data initiatives will follow the major companies (Micello, Google, etc). For example, OpenStreetMap already has a wiki about indoor maps (http://wiki.openstreetmap.org/wiki/Indoor_Mapping), while the i-locate project (http://www.i-locate.eu/), funded by the European Union, aims to create a public geoportal for sharing indoor mapping.

Another problem is that, in most cases, the information obtained from the Smart City will not follow any particular standard, using formats which are difficult to handle. To work with such information it is necessary to identify the city's objects, functions and relations, and store them using open standards provided by the Open Geospatial Consortium (OGC). Since 2012, the OGC promotes an established standard for the specification and representation of 3D urban models (CityGML). However, it was not until April 2014 that the OGC proposed a new standard for implementing indoor solutions (IndoorGML).

2 CONTEXT AND OBJECTIVES

Commercial solutions such as Micello, IndoorAtlas, Indoo.rs, Wifarer, Mazemap or Meridian offer multiple indoor positioning and navigation services, sometimes including interesting geospatial analytics. However, these are closed alternatives and their data are stored in their own cloud services, so there is no freedom to perform Smart Cities studies without special agreements.

In this position paper, we want to describe the key points of a three year project that will start in 2015. The main objective of this study will be to propose a hybrid (indoor/outdoor), sustainable, accurate and suitable navigation system to support various types of applications, from the most common, to improve accessibility, to the more complex, such as emergency management. This system will be based on detailed Open Data maps, coupled with a topological network (automatically recalculated) and an indoor positioning network. The proposed development will build upon free software and open data, and will allow researchers to start new studies about integrated mobility. This platform will be useful for calculating optimal routes for the disabled, planning and emergency management, mobility studies, among other applications. Additionally, this system will make the most of the newest Augmented Reality (AR) techniques for mobile platforms, which are specially useful in low visibility situations or when users experience difficulties when interpreting maps (visually impaired, complicated mapping variables, among other issues). The AR interface will be very minimalistic, showing basic navigation references (e.g. room codes as graduated circles and target path as a centered arrow). Finally, we will perform a series of experiments where different user profiles will generate a rich set of geographic data (paths and breakpoints) which will be analysed to obtain spatial mobility patterns. Unlike other projects mentioned above, this proposal is not closed and it does not focus on an individual aspect of these problems (positioning, mapping, navigation, etc). Our aim is to provide some necessary tools to complete a genuine mobility analysis using Big Data (see "Big Processing of Geospatial Data" by George Percival; http://www.opengeospatial.org/blog/1866). This project will achieve these specific objectives:

1. To study the SIGUA data model (Geographic Information System of the University of Alicante) for its compatibility with CityGML 2.0, IndoorGML and other open standards.
2. Develop new methods written in procedural languages (pl/pgSQL and pl/R) to automatically build a topological network from SIGUA's Open Data. Also, we will derive other useful features for accessibility studies (capacities, "bottlenecks", etc). As for example, these geometrical features could be extracted from Voronoi diagrams (Ramón et al., 2013).
3. Implement web services and a GIS platform to enable 2D queries.
4. Design an algorithm to calculate the most suitable distribution for a beacons network (e.g. Bluetooth, WiFi, RFID, etc.), according to their physical characteristics and economic budget.
5. Build a mobile application for 2D hybrid navigation and Augmented Reality.
6. Analyse these mobility data generated in a Big Data process with emphasis on path analysis and user's decisions.

3 INFRASTRUCTURE AND AVAILABLE DATA

The University of Alicante has ideal conditions for developing this project. The university has one main campus, a Science Park and 14 different locations, with 69 different buildings built in different dates, from the sixteenth century to the present. A total of 3,800 employees, 29,000 students and 4,000 rooms with very different characteristics (classrooms, offices, laboratories, among others). In charge of these facilities management, there is an office for Campus and Sustainability which promotes the development of a GIS at the University of Alicante (SIGUA).

The Geographic Information System of the University of Alicante (SIGUA) was born in 1997 with the aim of providing a series of personalized services related to spaces management. Since its inception, SIGUA has grown from a single spatial database built with commercial tools, to become a powerful information system, developed using FOSS, and backed by a PostgreSQL/PostGIS database.

The SIGUA's work experience aroused the interest of several companies and universities in Spain and Latin America, sooner this led to publish the generated knowledge as a FOSS and Open Data project, namely SIGUA.NET. This project is not an identical copy of all SIGUA services, or databases, as these have been developed specifically for the University of Alicante. Thus, SIGUA.NET is exportable to other universities and organizations. SIGUA.NET is available on the GitHub platform (https://github.com/labgeo). Source code is available to browse, extend its functionality, download a test geodatabase or "fork" and develop a different version. Obviously, as the project and its users community grow, SIGUA.NET will change in structure and name.

In addition, necessary data have been included in the new Open Data platform of the University of Alicante, called OpenData4U. This initiative joins to others described in a paper published by the Technical Committee on Information Technologies and Communications of the Spanish Conference of University Rectors (CRUE-TIC), which aims to promote and assist the Spanish universities to start their own Open Data initiatives.

4 METHODOLOGY

The first stage of this project is to implement a sustainable WebGIS, enabling multi-modal route calculations using different algorithms. This WebGIS will use data from the OpenStreetMap (OSM) and OpenData4U initiatives. These data sources can not be used to directly generate maps for navigation applications, so appropriate tools and methods are needed. OpenStreetMap is well documented and its processing is rather straightforward because the data stored in OSM are mainly street edges. In contrast, OpenData4U stores rooms as polygons with an assigned code activity. Converting OpenData4U into a navigation network could be done manually, but it would be unsustainable in the medium term. Therefore, in this phase we will generate automatic methods, based on computational geometry (e.g. Voronoi diagrams), for deriving the necessary information (Ramón et al., 2013). For example, if a new door is opened or a wall between two offices is removed, indoor maps should change, so it would be necessary to manually modify the topological network and its elements. This will be solved by using PostgreSQL/PostGIS techniques to automatically update the necessary data (interior and exterior doors, intersections, stairs and elevators, etc). However, to make these developments exportable to other projects (functions, triggers, methods, views, etc), we need to study the SIGUA.NET and OpenData4U data models and fit them into the open standards proposed by the OGC (CityGML and IndoorGML). Thus, these developments will be exportable to virtually any OGC standard implementation. Results from this first phase will be similar to other routing applications which are integrated into the most popular maps services (Google Maps, Bing Maps, etc), but in this case enabling the calculation of hybrid routes with transitions between indoor and outdoors spaces.

In the second stage of this project, we will design an accurate and cheap positioning network. As mentioned above, WiFi networks are widely used in combination with INS to provide position measurements at a moderate cost. Currently, the best choice to complete this network is the use of commercial Bluetooth beacons or creating a RSSI database. The low energy Bluetooth or Bluetooth LE (BLE) protocol has become a widely used technology in health, sports, security services and other new applications. The BLE is intended to operate under a reduced energy consumption at an affordable price while maintaining a range similar to the classic Bluetooth signal. In fact, most mobile operating systems including iOS, Android, Windows Phone and BlackBerry, and OS X, Linux, and Windows 8, support this protocol. In table 1 you can compare prices for some of the most distributed BLE beacons.

Any of these beacons would be appropriate to implement a positioning network, but we will test several models to assess the three key aspects: price, durability and accuracy. Nevertheless, accuracy will be improved by using indoor maps as context. The most reasonable prices range from 8 to 20€, but may decrease about 5-10 % depending on the order. For our study area (see section 3), we have made an initial estimate using at least 2 beacons per corridor, concluding that about 800 beacons would be needed to complete our network. Now, we can remove 300 beacons assigned to buildings without public indoor areas (e.g. All rooms have a door to the outside), as in those areas GPS and INS may suffice. Thus, considering 500 beacons, 8€ per beacon and a 10% discount, we could complete our network at a cost of about 3,600 € for the whole university's main campus. This estimate will not be manually completed in this project. For this purpose we will develop an algorithm for automatic definition of indoor navigation networks. We will create a function in the spatial database to accept the parameters as mentioned above (budget, activities,

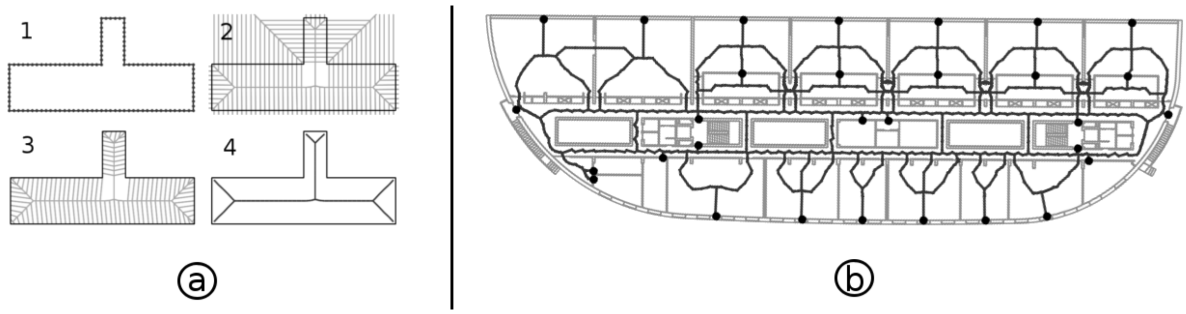

Figure 1: Automatic extraction of a navigation network from SIGUA cartography (Ramón et al., 2013).

required accuracy, WiFi previous infrastructure, etc) and other physical conditions (range, signal strength, overlaps, etc). This function will give suboptimal solutions for setting up any indoor positioning network.

Finally, based on the WebGIS and the proposed positioning network, a navigation system for Android devices will allow recording the most interesting navigation data in a remote database, following some OGC standards (OGC's Sensor Web Enablement):

- User identification data (e.g. an UID obtained by the Google API or provided by the Virtual Campus of the University of Alicante). Only with user's consent and compliance with national privacy laws.
- Theoretical routes requested by users, including query's time and location, origin, destination and break points (doors, intersections, etc)
- "Real routes" walked by users, including A-GPS tracks generated outdoors and indoor positioning provided by the beacons network

In the third stage of this project, we will start new research from the perspective of the Smart Cities. The project will be presented to different university groups of people to increase the number of users, queries and routes. We will make contacts with various departments, student associations, external service providers (mailing, Bicicampus, vending machines, etc), and other groups with special needs. Data collection will last for one year and may continue indefinitely once the project is completed. Simultaneously, after the first two months, a Big Data process will begin. The objective of this phase is to check (with real data) how can we identify useful mobility patterns (behavior). Although it is difficult to predict which issues will arise, we can mention the following:

- Favourite doors regardless of proximity criteria.
- Frequent trips that could be optimized (e.g. using multimodal transport links, time planning, etc).
- Routes discarded by excessive distance.
- Groups with special needs (e.g. to detect bad signalling, reserve parking areas, etc.)
- Changes in mobility patterns due to adverse weather conditions (e.g. during storms certain users vary their routes to walk across certain buildings).
- Need for improved emergency and evacuation plans (e.g. detect differences between the most used routes and those recommended by evacuation plans).

5 EXPECTED IMPACT OF RESULTS

As mentioned above, this project will generate software and data of a practical value. An open geodatabase for researching mobility patterns, an algorithm for designing a sustainable indoor navigation network and several tools for automatic extraction of mobility features based on OGC standards. However, this is a multidisciplinary research which combines concepts and terms of scientific, economic and social significance. Potential impacts of this project are not only of a technological nature and they will include:

1. Technology will contribute to an ecological design of the navigation system and efficient routes. Energy efficiency will be taken into account by choosing beacons with low power consumption. Also, this project will consider the affect of electromagnetic fields on human health, as an issue which makes more desirable the use of inertial navigation and identification of RSSI against the implementation of dense BLE or WiFi networks.
2. Open Geodata initiatives will be strengthened. In addition, the openness of technologies and data used makes the project of interest to developers and "infomediaries" interested in undertaking business models for indoor/outdoor integrated mobility. The open character of this project has

Table 1: Comparison of some BLE beacons (2014).

Product	Price	Web Page
Kontakt.io Smart Beacons	81$ (x3 beacons)	Kontakt.io
Estimote	99$ (x3 beacons)	Estimote.com
Gimbal Proximity Beacon - Series 20	20$ (x1 beacon)	Gimbal.com
Roximity iBeacon	120$ (x3 beacons)	Buyibeacons.com
RedBear Beacon B1	35$ (x1 beacon)	RedBearLab.com
KSTechnologies	60$ (x1 beacon)	KDTechnologies.com
Coin BLE Arduino Dev Board	40$ (x1 beacon)	OnlyCoin.com
tod	115.99$ (x3 beacons),	todhq.com
Onyx Beacon	59$ (x3 beacons)	onixbeacon.com

a positive impact on regional cohesion policies and open government, ensuring that the results of this project will be useful to many institutions involved in e-government.

3. Scientific and technical developments will boost technology transfer to different business models, creation of SMEs and innovative start ups for accessibility services.

4. The results will be released under open licenses, Open Database License (ODbL) for the collected dataset and General Public License (GPL, LGPL) for the software developed. Then, results will be disseminated in social media, specialized forums and the project web page. In addition, we will attend national and international conferences such as the Smart City Expo World Congress in Barcelona, the WIT Urban Transport, FOSS4G, the Iberoamerican Conference on Electronics Engineering and Computer Science or the next GISTAM conference. Finally, there are some international journals where the main results could be published (e.g. Technological Forecasting and Social Change, European Transport Research Review, Cities, Physical Communication, Computers or Environment and Urban Systems, among other possibilities).

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