

3D Indoor Location and Navigation System Based on Bluetooth

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Abstract

Over last years, Indoor Positioning and Navigation Systems (IPNS) has been subject of intense study and research ought to it has become a blind spot with regard to Positioning and Navigation Software. None of proposed indoor solutions has been as successful as outdoor systems like Global Position System (GPS). Our proposal presents the design and implementation on mobile device(the most common), of a 3D positioning and navigation system for indoor based on the use of Bluetooth (BT) radio technology and implemented using Java and J2ME, this implementation is adaptable to whatever indoor environment (commercial centers, offices, museums, etc.) previously modeled and loaded. This 3D model can be build using the most common 3D design tools with M3G formats support. Location is implemented on BT with distributed estimation (the mobile device performs it).

Keywords: Indoor Environments, Radio Navigation, BT, Mobile Devices, 3D Models.

1. Introduction

Many applications require Knowledge about the environment to locate and identify the position of an entity (user, device, and so on), some areas where these needs can be found from industry [1], e-marketing [2], health and emergency services [3][4] to automatic activation services [6][7][8][9][10].

An important part of these environments is the use of location systems, identification and navigation targeted to mobile devices with wireless capability, which enable to use applications automatically based on an authorization given by the user previously located in a certain position within the system coverage area.

To estimate the location we decided to use BT technology because it is widespread in typical mobile devices and has as main hardware features: low power consumption, low cost and low interference with devices that work on the same frequency range. About software features, BT is widespread supported, documented and

used on Java and J2ME due to its high degree of standardization, platform independence and development under the GNU GPL license.

The remainder of the paper is organized as follows: in section two we present some important works and concepts related to 3D IPNS. In section three, we present the methodology and argue the selection of the location method used, modeling techniques and radio frequency technology. In section four we describe some test executed. Finally we report our conclusion.

2. Related work

IPNS in the last years have become an important subject in several areas, like:

Industry: enterprises seek to increase the value of their products or services, through competitive advantages such as improving the safety of employees, reducing delivery errors, streamlining of the production and supervision, among other aspects. This is made by using GPS and tracing through Radio Frequency Identification systems (RFIDs) to locate, identify and navigate to monitor employees and company's products [1].

E-marketing: Companies use systems to locate and identify users who offer products or services based on their position inside (or near) the store or previous customer's preferences. The system detects the closest way to arrive to certain position for example a box to make a payment, among others [2].

Health and emergency services: a common task for this systems is get the location and send information concerning to patients, health personnel, medical equipment, emergency routes, among others [3][4].

Automatic activation services: In words of Mark Wieser, father of ubiquitous computing: "Ubiquitous computing has as its goal the nonintrusive availability of computers throughout the physical environment, virtually, if no effectively, invisible to the user" [8]. Mobile devices work on intelligent environments (domotics) that interact with the user according to his needs to improve the quality of life itself (including those with special needs), this way allowing the accessibility of them to anyone. There are several kind of interfaces for these systems such as sound, graphical 2D/3D [6][7][8][9][10].

Over last years, main series of location systems have been developed, some of the main features are [11] [12]: Physical location and symbolic location, Absolute versus relative, Localized location computation, Accuracy and precision, Scale, Recognition, Cost and Limitations

A. Classification and limits of location systems

Location systems can be classified by the type of working environment: outdoor and indoor systems. This classification is due to the lack of functionality in internal environments of the external methods (since these were the first to emerge) like GPS [13].

B. Location systems and methods for outdoor environments

GPS: It is a global navigation satellite-based GPS receivers process the signal to determine the 3D position (latitude, longitude and altitude) [14][15].

Cell Identification (Cell-ID): This method takes into account the fact that mobile networks can provide an approximate position of a mobile device based on information about the nearest cell (it's necessary a cell network connection)[16][17].

Angle of Arrival (AOA): This technique uses an array of addressable antennas (at least two), the objective of them is to calculate the AOA of the signal. This technique commonly is used in conjunction with others to obtain a better approximation of the location [18][19].

Time of Arrival (TOA): This technique is based on the fact that electromagnetic waves travel at a constant speed in space. Therefore the distance between two points can be calculated using the time delay between the transmitted waves. There is a linear relationship between arriving time and distance. In a similar way, TOA technique is used in conjunction with other techniques [20].

C. Location systems and methods for indoor environments

Infrared-based systems: These systems use the proximity among electronic devices using infrared technology [21].

Ultrasound-based systems: These systems are based on tags for the items to be controlled, using the ultrasonic signals that they emit and receive. The simplest method to calculate the orientation, is based on the calculation of the relative orientation [22]

Electromagnetic-based systems: These systems generate electromagnetic pulses in a transmitter antenna. The system estimates the position and orientation of the receiving antennas; this is done by measuring the response in three orthogonal axes (x, y, z) of the transmitted pulse [23].

Vision-based systems: Computer vision technology is used to detect the location of an object/person. Recently, these systems are directed towards the use of augmented reality techniques and tracking markers [24][25].

Physical contact-based systems: These systems are based on physical contact between a person/object and the system (pressure sensors). The function of these sensors is to detect the presence of a specific kind of pressure on them to be used later in the tracking [26][27].

Radio frequency-based systems: These systems use receptor-emitter devices that read and send RF signals. These signals can be fixed or mobile at 2.4 GHz or 5.8GHz (depending on the technology: Wi-Fi, BT, GSM, RFID and others). These systems rely on different location techniques that don't require a special physical infrastructure. The use of these technologies has increased in recent years [28][29].

D. Most common location techniques in indoor RF-based systems

Geometric: this technique uses geometric properties to tract a location problem [30][31]. Main geometric techniques are:

Trilateration: the position of a mobile receiver-transmitter can be calculated based on the distance among this one and other receiver-transmitters placed in fixed positions.

Triangulation: This technique uses triangles trigonometry to determine the location of objects. Triangulation can be divided into subcategories: Lateralation and Angle.

Application examples' of these techniques can be found in [32][33].

Pattern Recognition (PR) or fingerprinting: these techniques attempt to engage a received power levels vector (RSS, Received Signal Strength) obtained from multiple access points with a defined calibration test, once a time without the need for geometric algorithms [34][35][36]. Specific techniques that use PR are:

K-Nearest Neighbors (KNN) methods: This method is based on the idea that while the RSS was received at the mobile transmitter-receiver, it doesn't depend linearly on the distance to the fixed receiver-transmitter, but some relation exists; can be ensured that if the receiver-transmitter is very close to fixed-mobile emitter receiver, the received power is high, and vice versa. Exploiting this idea, a database of locations or radio map (a set of test vectors) can be created, it contains the position of each location (coordinate of reference) and the RSS of the access points. To locate a mobile transmitter-receiver, a vector of powers and coordinates is read, and then compared with the database of locations. The next step is to search the closest test vector to the received one. After this, a vote can identify what is the most likely location. Finally, the euclidean distance can be used to estimate the distance between the received vector and the closest test vector (other measures of distance also can be used).

Bayesian methods: A Bayesian network containing the points of interest is built in the training phase. The next step is to train the system a certain time on each of the points of interest, collecting RSS samples periodically. During the training phase a priori probability is to establish a location $p(L)$; after this, conditioned posteriori probabilities are defined in function to receive a RSS feed from an access point $p(E|L)$. These methods model also impossible transitions from one location to another, through a similar Hidden Markov Model (HMM).

Support Vector Machines (SVM): This method is a paradigm of Neural Networks, in which measure/observation vectors are processed. Processing is done by using a hypothesis space of linear functions over a space with a greater dimension (space of high-dimensional features) where the dimension of observations is induced by a kernel function with the objective to obtain a hyperplane to separate linearly the observations and let to locate points in the most reliable as possible way. This is done by using hyperplanes to separate the set of training points into two subsets, each one contain a different label. From all possible planes there only one optimal separating hyperplane (OSH) which is calculated by maximizing the distance between the optimal separation hyperplane and the closest training pattern, in other words the maximum margin (especially inductive bias of the SVM).

Neural Networks Methods: this method uses a Neural Network (NN) to estimate the location through processing distinct RSS emitted from fixed receptor-emitters. The NN is implemented by a multilayer perceptron in which the inputs entries may be the RSS of each fixed receptor-emitters and the output is likely to be in each of the locations. Implementation using these techniques can be found in: [37][38].

E. 3D modeling: basic concepts

In order to perform 3D modeling of objects is necessary to have some basic knowledge of concepts such as [39]: Three Dimensional spaces (3D): A virtual mathematical space which is represented into a program, it is defined by a Cartesian system of three axes (X, Y, Z), where the crossroad of these is called the origin whose coordinates are (0, 0, 0). Modeling: It consists on creating a scene from the mainstream of individual objects to which have certain properties. To do it, it's common to draw on modeling techniques such as:

NURBS (Non Uniform Rational B-Splines): a complex mesh is created using splines to represent an object with a more curved or organic appearance.

Predefined Structures Modeling: predefined structures given by the software are used to create other complex objects or scenes starting from them.

Extrude Modeling: replicas of points, lines or planes that form a mesh are expanded or contracted in one of the

Cartesian coordinates (X, Y, Z) obtaining a complex mesh.

Modeling with Boolean Operations: a boolean operation (subtraction, intersection or union) is applied between two meshes, a new and different mesh is obtained from this operation.

Polygon mesh modeling: meshes are designed to satisfy with the rule that each line is shared at most by two planes.

Boundary Representation Modeling (B-Rep): an object is represented by the boundary of it. In other words this object is described in terms of the elements that are part of its surface (points, lines and planes).

Textured Modeling: consist in using the alpha channel and images as textures, rather than the application of materials (colors) on the meshes to obtain a simple object, this object simulates a more complex structure than what it seems.

Rendering: this process is carried out by a computer that performs complex calculations to obtain a 2D image that corresponds to a 3D model, previously designed.

3. Methodology

After analyzing the related work to location of IPNS, we chose to design our system using radio frequency technology. Analyzing costs (energy and economic), technology diffusion, signal range, the use in tracking systems, programming complexity, interference among other devices that work with the same type of signals (see Table 1) that produces packet loss, among other aspects, the option we have selected as best is BT [40][41].

Table 1. BT vs Wi-Fi, comparative of packet loss

Traffic BT	Traffic Wi-Fi	BT Loss	Wi-Fi Loss
30%	30%	0.007	0.574
30%	60%	0.006	0.580
60%	30%	0.007	0.576
60%	60%	0.006	0.580

KNN method was determined as the most appropriate method to calculate locations, ought to the system is running on mobile devices and this method requires few computational resources and provide a good estimate of the location and approach [42]. Other feature required is portability, that's why several languages and development tools were analyzed (C, C++, C, J2ME and Android) and their support to BT and 3D Modeling.

BT support:

- C/C++: BT Engine API, Microsoft BT y BT Library (BtLib).
- C: 32feet.Net, desarrolloMobile.NET, BTAccess, BTW-CE SDK for Windows Mobile Development Platform y BlueTools.

- J2ME: JSR-82.
 - Android: Android BT API
- 3D modeling support:
- C/C++: OpenGL-ES y Managed Direct3D Mobile (MD3DM).
 - C: OpenGL-ES y Managed Direct3D Mobile (MD3DM).
 - J2ME: Java building for OpenGL-ES (JSR-239) y Mobile 3D Graphics (M3G o JSR-184).
 - Android: OpenGL-ES.

Even though some of the tools and languages provide a wide variety and range of features and components inside their API's, as mentioned before the desired feature is the support of the largest possible variety of devices, so we decided to use J2ME [43][44][45]. Selecting the API, the list of 3D modeling support is reduced to JSR-239 and JSR-184, so the features of each one were analyzed:

Development as soon and realistic as possible [46][47] was our criteria our choice to JSR-184 (it uses 3D design tools to generate models) sacrificing in return greater memory space required and the use of more processing resources during rendering, but these requirements can be covered with current capabilities of mobile devices.

We analyzed different 3D modeling tools that support generation of JSR-184 compatible models: Autodesk 3D Max, Autodesk Maya and Blender. We decided to use Blender although the user interface is less friendly and there are few clear references about the generation of models compatible with the JSR-184, however it's free, robust, multi-platform, widely used and whose export plugin M3G model is more complete than the other two tools.

We tested our system using a model from the Instituto de Computación (IC, Computing Institute), of the Universidad Tecnológica de la Mixteca. The model of the corridors and contours of the building was done by using a Total Station, a GPS and a prism with the objective to obtain as precise measurements as possible. The dimensions of the offices were made manually using a metric tape.

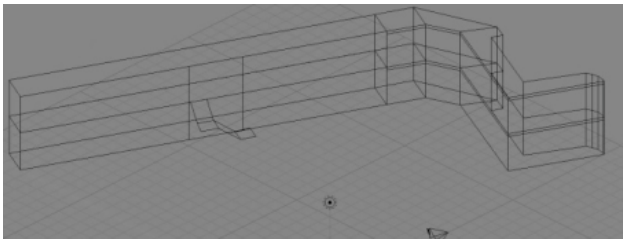


Figure 1. Wired 3D Blender Model of IC.

The IC 3D model was made using techniques for polygon meshes, B-Rep, boolean operations (Figure 2a), textures and extrudes (Figure 2b).

After applying the last mentioned techniques we got the model in Figure 3.

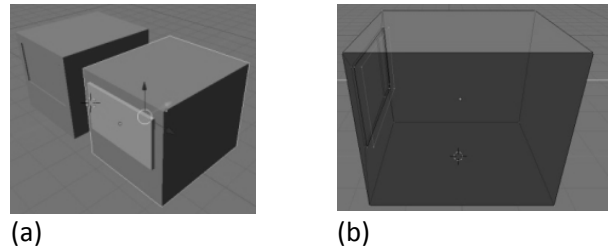


Figure 2. Boolean operations and the use of extrudes to build our model .

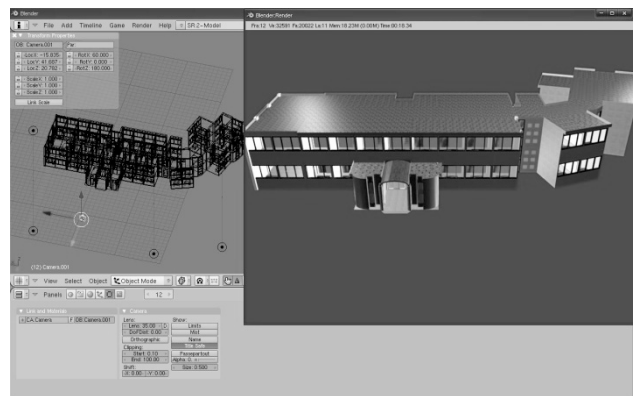


Figure 3. 3D Blender Model using textures and lights.

Along our tests about J2ME BT API, we observed that access to RSSI of mobile devices was not possible. In order to maintain the original project we designed a server application to get the RSSI, and send it to the client application running on the mobile devices. To support it we made a survey of implementations for J2SE JSR-82 and we got that there is a division in two groups: API's that fully implement the BT stack (Blip-Net, Harald, aveLink, Whiteboard SDK and JavaBT) and external Stack BT implementations (AvetanaBT, BlueCove, ElectricBlue, JBlueZ y Impronto SDK). We decided to use the second option, ought to even though they are Operating System dependent they don't block the hardware access for other applications, so we choose AvetanaBT by its cross-platform feature (versions for MAC OS and Windows have a cost) added to the support for obtaining the RSSI parameter [48]. The client application runs on Linux, it was necessary to compile AvetanaBT API (the code was modified to support up to 3 computer-enabled device Bluetooth). In order to retain the portability, a Linux Live-CD was generated using the 8.14 Xubuntu distribution installed on a laptop through the program Remastersys Backup (see Figure 4).

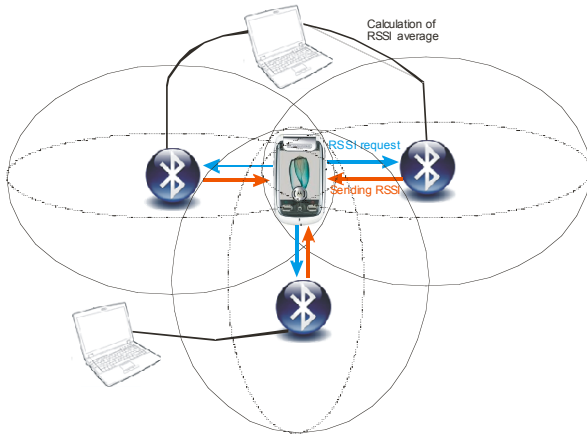


Figure 4. 3D-IPNS Architecture

The KNN method running on the client has the task to create the radio map pattern, to do it we draw on a DataBase (DB), so we made a survey of available DB supporter by J2ME. We detected PerstLite [49][50] as the most complete and suitable to our application. A second server application was designed for sample collection, this application runs on the mobile devices and get the RSSI from the original server, in a similar way, once the samples were collected another server application was implemented to establish a connection with the sample collector to generate a flat file which serves as radio map for the first original client during the location process.

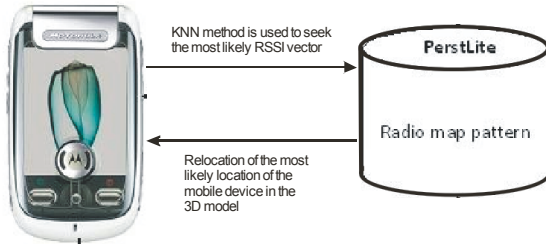


Figure 5. Database Architecture

4. Tests

Our 3D IPNS was executed on 2 laptops working as servers (see Figure 4); the tests were performed with 3 BT USB with a coverage range of 10m (all class 2). The range within the offices was about 6m (due to signal attenuation produced by the walls). Taking into account that there is an ability to receive the signal in the second floor from the same BT devices, we observed a range decrement of 2m inside the offices and the corridors.

The BT USB were fixed in the ceiling of the 1st floor in order to obtain the largest possible coverage, the first device was placed 6m from the wall at one extreme of the building and the next two devices at a distance of 12m in a straight line giving an area coverage of 36m long for the

first floor, while for the 2nd floor a 32m long area was obtained (due to signal attenuation suffered when passing through the ceiling of the first floor).

The client application ran in a Motorola A1200 cell phone with a J2ME virtual machine compatible with JSR-184. Inside the server, the RSSI number is customizable. At the end of captures, an average is calculated and sent to the client application to obtain the location. We made tests to measure the response time (Table 2).

Table 2. Times to collect RSSI

Number of collected samples	Total time
300	2000 ms
200	1300 ms
100	700 ms
50	200 ms
20	180 ms
10	110 ms

Based on the times obtained during the tests and changing the number of samples, we detected that the best value for this parameter with an acceptable response time is 100. Using this benchmark, the time needed to calculate the location and display it in the 3D model in the client application was between 22,000ms and 57,000ms with an average time at most of the cases of 30,000ms. These results obey to the BT limitations in hardware and software, common in actual mobile devices, ought to in these systems it's not possible to establish parallel connections, so serial connections and disconnections are necessary in the devices controlled by the server application. Once that enough data are obtained by the client, it's possible to compute the location and display it inside the 3D model. In Table 3 we compare results of our system and other documented ones.

Table 3. Comparison of our system and other IPNS

System	Reading time (samples/sec)	Response time (sec)	Location & Navigation
Cricket [22]	3	1	2D
LEASE [51]	2	1	2D
IPNS based in Fingerprinting [35]	30	1	2D
LANDMARC [52]	67	1	2D
Locadio [28]	3	1	2D
IPNS in Camera Phones [24]	1	10	2D/3D
Our proposal	15	1	2D/3D

Locations not considered inside the radio map pattern, but close to them have 50% accuracy by providing an estimate of the location. In the 1st floor can be seen an overall precision of 2m with an accuracy of 90% when the

client application device remains static (for an extended period). If the device is in constant displacement, the accuracy decreases to about 60% to 80%. With respect to the 2nd floor we detected a precision of 3m with an accuracy of 80% when static, in constant displacement the accuracy is of about 60% to 70%.

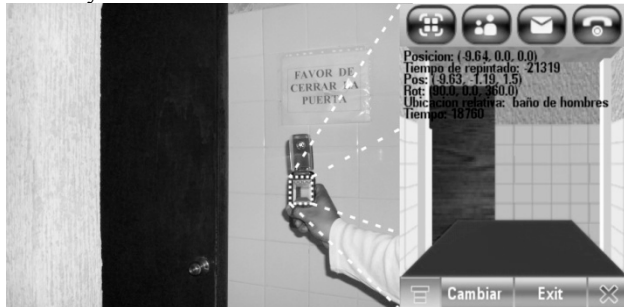


Figure 6. System running on a Motorola A1200.

4. Conclusion

Based on our test and results we can conclude, that working parameter for system are acceptable (indoor locations), by using few computational resources and a location calculation acceptable considering that our application is focused on mobile devices. It's possible to improve the calculation times for location if mobile devices manufacturers would change the BT implementation in hardware/software by implementing multiple connections in parallel.

Another aspect to be fulfilled is the rapid development and adaptability to any indoor environment. It's not necessary an expensive or specialized infrastructure, as well as the system calculates the 3D location in contrast to other systems that have only implemented 2D location. As an additional feature, the user can navigate and display the 3D model at any time.

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