Three Step Bluetooth Positioning

Alessandro Genco

University of Palermo, Department of Computer Engineering,
Viale delle Scienze, edificio 6, 90128 Palermo, Italy
genco@unipa.it

Abstract. This paper discusses a three step procedure to perform high definition positioning by the use of low cost Bluetooth devices. The three steps are: Sampling, Deployment, and Real Time Positioning. A genetic algorithm is discussed for deployment optimization and a neural network for real time positioning. A case study, along with experiments and results, are finally discussed dealing with a castle in Sicily where many trials were carried out to the end of arranging a positioning system for context aware service provision to visitors.

1 Introduction

Many pervasive computing applications rely on real time location to start and manage interaction with people in a detected area. Time and space information are therefore basic elements in arranging mobile context aware services which take into account context factors such as who, why, where, when. Dealing with wide areas, multiple interaction devices, such as remote multi-displays, could be available in one service hall. In such cases a pervasive system can start interaction with who explicitly addresses a selected device by means of some manual action on a touch screen or a mouse, or by means of some voice sound. Nevertheless, there are some kinds of application, as for instance advertising messages, which require interaction to start autonomously. People who are around should be attracted by some customized message exactly arranged on his personal profile and current position in a display neighborhood.

We may feel some worry in looking at a pervasive system as a big brother; however there is some convenience for us in customized services and furthermore, such an interaction modality could be the one preferred by people, because it does not require any manual action to be performed. Once preserved the not invasive requirement of pervasive applications, it is undoubted that system proactive behavior could be a general suitable approach to mobile human computer interaction.

Besides the problem of selecting the nearest interaction device, position aware services may need to rely on position data which must be more accurate than simple location. There are several pervasive applications indeed, which require a maximum error in position coordinates to be kept very low, less than one meter for instance. This is the case of a security system, which is arranged to protect an area around a

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precious artifact. There are also some cases which require additional position data, like the human body compass angle. People who are looking at an object, as for instance visitors who are looking at an artifact, or factory operators who are checking some manufacturing process could be provided with context aware information which take into account who is looking at what.

The above two basic positioning elements are to be used in conjunction with a higher level point of view to allow a system to arrange those services someone may expect in a given reality [1], [2], [3].

2 Why Bluetooth

We used Bluetooth (IEEE802.15.1) in our positioning experiments because of two main reasons. One is that Bluetooth technology is widely implemented in cellular/smart phones, thus being something quite chip and wearable, and therefore very easy to own. The other reason is that the Bluetooth (BT) technology embedded in cellular phones, allows distances to be estimated by link quality values within a BT covered area which we can suppose to be a 30~40 m. circle approximately. We have also to mention some problems encountered in using cellular embedded Bluetooth devices which mostly deal with BT service implementation by different brand factories. In many cases we had to deal with compatibility problems or service restrictions.

However, given the Bluetooth amazing commercial success, we can hope in near future to deal with standardized Bluetooth services.

Actually, WiFi (IEEE802.11x) can also be used for positioning, as well as any other RF communication technology which provides link quality values. Nevertheless, most of positioning problems which come from link quality measure unreliability, can be discussed with similar considerations for a class of technologies. Therefore, apart some different featuring specifications, discussions on Bluetooth can be considered as representative of a group of communication technologies which are capable of providing positioning information.

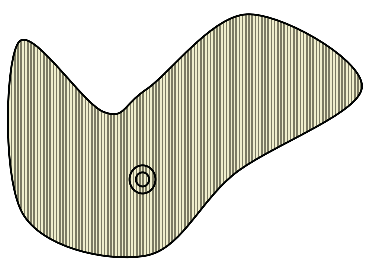

Fig. 1. *An Iso-LQ curve*

An actual problem of positioning by RF communication technologies comes from estimating distances on link quality measurements, which are affected by a high degree of uncertainty. Measured RF link quality equal values actually draw a region which is very unlikely to be a circle because of obstacles and noises. Therefore, position estimation by triangulation, even performed on more than three reference nodes, cannot be accurate. An irregular-shaped region around a RF terminal (Fig. 1) is a more realistic case to be tackled by means of methods which are capable of dealing with uncertainty and site depending solutions.

Distance estimation between a mobile device and a number of reference devices whose location is known is a research topic of several approaches [4]. Some contributions can be found in literature with the end of arranging solutions to be free from site noises.

Among these, ActiveBats [5] and Cricket [6] are based on ultrasound *time-of-flight* lateration, with an accuracy of few cm or less. The *time-of-flight* method estimates distance between a moving object and a fixed point by measuring the time a signal takes to travel from the object and the fixed point at a known speed. This method could be a good one because time of flight and distance have a reliable relationship. The actual problem is in clock accuracy requirement. A 1 μs error in timing leads to a 300 m error in distance estimation.

The Ascension Technology MotionStar system [7] is based on magnetic sensors moving in a magnetic field around their source. This system provides a very high accuracy but needs very expensive hardware.

RX power level positioning method is quite similar to TOA positioning. Both methods locate mobile devices on the intersection of three (or more) circles. The circles radius is evaluated on the measured strength of received signals, thus assuming a direct relationship between signal strength and distance which unfortunately, as said above, can be affected by obstacles and noises.

The Angle Of Arrival (AOA) method processes the direction of a received signal. Position is estimated by triangulation when two reference devices at least measure the signal angle of arrival from a mobile device [8]. This method obviously requires some expensive hardware to evaluate angles of arrival.

The Cell Identity (CI) method looks at the network as divided into cells, each cell being the radio coverage area of a single reference device. A mobile device connected to a given reference device is assumed to be inside its cell. Cells overlapping and connectivity-induced geometric constraints can improve accuracy [8]. One more time, as mentioned above, radio coverage cannot be assumed to be a circle and therefore accuracy cannot be high.

3 Bluetooth Positioning

Hallberg et al. [9] developed two different methods based on BT Received Signal Strength Indicator (RSSI) values: the direct method, which requires a BT device to be programmed, and the indirect method, without any programming being needed. The first one gives a good accuracy by programmable hardware. The second one is cheaper, but its accuracy is very poor, with a worst-case error of 10 meters.

SpotOn [10] and MSR RADAR [11] are based on RF signal power level measurement. They process the RSSI (Received Signal Strength Information) value to give an accuracy of 3-4 meters or more.

The BT Local Positioning Application (BLPA) [12] uses RSSI values to feed an extended Kalman filter for distance estimation. A good accuracy is achieved only by theoretical RSSI values, while unreliability of actual values gives unreliable distance estimation. The BT Indoor Positioning System (BIPS) [13] is designed for tracking mobile devices in motion inside a building. The BIPS main task is real-time tracking of visitors in a building. This led researchers to deal mainly with timing and device discovering, thus achieving an accuracy of 10 meters.

Finally, Michael Spratt [14] proposed the Positioning by Diffusion method based on information transferred across short-range wireless links. Distance estimation is achieved by geometric or numeric calculations.

4 Three Step BT Positioning

BT devices measure RX power level by using both RSSI and *Link Quality* (LQ) parameters. These are implemented in the BT module and can be read through HCI (*Host Controller Interface*) commands [15]. LQ is a quite reliable parameter for distance estimation, differently RSSI only allows to know whether a device is in a given base station power range or not [16]. The use of LQ is recommended by the BT standard specifications, so it is available on most commercial devices. LQ represents the quality of a link in a range from 0 to 255, and a correlation can be assumed between distances and LQ values. We know LQ values are not reliable in measuring distances. Therefore, we need to avoid geometrical concerns and let a BT positioning system to take advantage from LQ values to be processed according to their site depending specificity. Here we discuss a three step procedure which turned out to be capable of providing high definition positioning by the use of low cost BT devices. The three steps are: site LQ sampling, BT base station deployment, and finally, real time positioning.

4.1 Positioning Step 1: Site Sampling

The end of this step is to collected a first sample of LQ measures to allow us to attach a set of LQ ranges to each cell. A range is a set of three values: the lowest, the highest and the mean value of all LQ values measured in a cell from a given BT base station in one point.

The site we investigated is the Manfredi's Castle in Mussomeli - Italy (Fig. 2a), whose map is sketched in Fig. 2b. We split the tourist area in a number of cells, which are rooms, roads, and areas around artifacts. There are two cell types: cells that represent rooms, parts of large rooms, or parts of roads; and cells which represent sub-areas around columns, portals, or other artifacts. We assumed an irregular

Fig. 2a. *Manfredi's Castle in Mussomeli (Italy)*

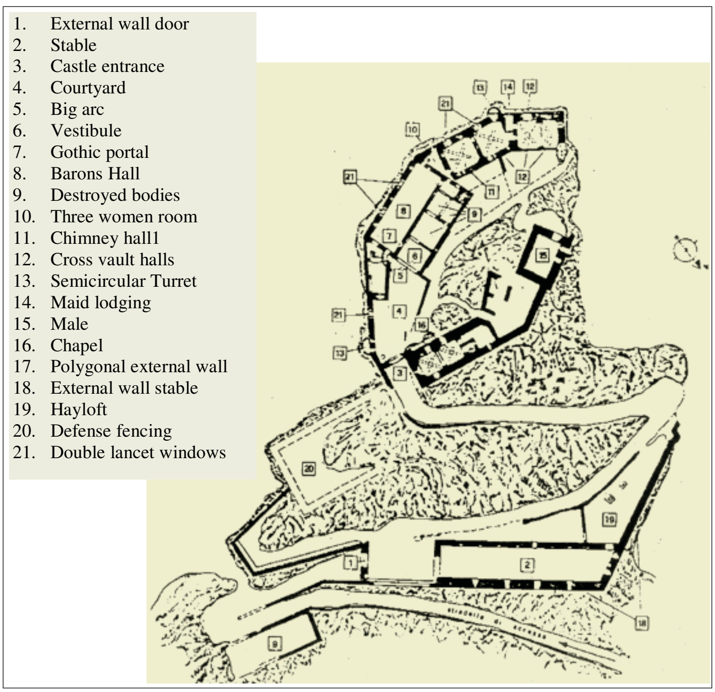

Fig. 2b. *Castle map*

Fig. 3. *Cells layout*

quadrilateral shape for the first kind of cell, a width (typically a diagonal), and a maximum error of 1 meter. Differently, we assumed a circular shape for the second type, a diameter of 2 meters, and a maximum error of 0.5 meters.

Fig. 3 sketches the cells layout. Blue points are centers of circular cells; red points are places where Bluetooth base stations (BT-BS) are allowed to be put.

The analysis of this first set of measures suggested us some considerations. One is that is very hard to find any correlation between obstacles and link quality. Some walls turned out to stop BT coverage; other walls seemed to be glass or air. Only very deep walls or floors turned out to completely stop BT coverage. For instance, BT-BS's which were placed in lower floor areas, did not read any LQ value from mobile terminals (BT-MT) moving on higher floor areas, and vice-versa.

Mainly due to the end of dealing with indoor and outdoor areas separately, we decided to split the site area in two sub-areas (green dotted line in Fig. 3). The results of these measurements are in a matrix whose generic (i,j) element contains a LQ values range measured from the BT-BS at the i^{th} position to the BT-MT moving within the j^{th} cell. A range can also be read as an estimation of the maximum theoretical accuracy in a cell (8 LQ units in a 2 m. cell cannot give an accuracy greater than 2/8 m.). A generic (i,j) range set to [0,0] tells us that the BT-BS placed at the i^{th} position cannot detect any BT-MT in the j^{th} cell. Table 1 shows part of the output file, where rows are for N_S possible stations, and columns are for N_A areas.

Table 1. LQ Ranges

	1	2	...	N_A-1	N_A
1	0,0	160,165	...	161,185	163,175
2	0,0	180,188	...	195,230	201,255
:	...	...	...	...	...
N_S-1	210,212	190,205	...	0,0	145,156
N_S	240,250	181,185	...	0,0	0,0

4.2 Positioning Step 2: BT Base Station Deployment

Several BT positioning experiments were carried out according to different positioning methods, namely triangulation [16], fuzzy logic [17] and neural network. A common result of these experiments is that positioning accuracy can be heavily affected by erroneous arrangements of the available base stations. Actually, we are unlikely to be allowed to put a base station in the middle of a room, for instance, and further constraints may come when dealing with a heritage site; base stations should be invisible and only selected places are available. Therefore, a relevant step in arranging a BT positioning system should be to optimize BT-BS deployment in a subset of places which are the only ones permitted by site specific constraints. The problem can be enounced in the following terms: given the total number of places where a base station can be put, select a minimal subset which allows the system to evaluate the position of a BT mobile terminal in any part of the site, with the highest accuracy degree.

Many optimization methods can be used to this end; we used a genetic algorithm because of its easy scalability. Each possible deployment is represented by an individual chromosome of a population. A chromosome has as many genes as places where BT-BS can be put. Each gene represents a possible BT-BS position, which can be set either to *true* if a BT-BS is placed in that position, or to *false*.

f	t	f	f	f	t	t	f	t	-	-	-	-	t	f	f	t	t	f	t	f

Fig. 4. *Deployment Chromosome*

An acceptable solution has to return a deployment layout whose coverage is unique for all areas, also achieving a required accuracy.

An optimal solution maximizes coverage quality, and minimizes the number of BT-BS required. The quality index of each station-area couple (*s,a*) is defined by the ratio (1) with n_a being the number of sub-areas to be singled out by positioning.

$$q_{s,a} = \frac{[LQ_{\sup} - LQ_{\inf}]_{s,a} + 1}{n_a} \quad (1)$$

Each deployment chromosome includes a number of BT-BS, along with their $q_{s,a}$ value. The chromosome quality takes into account all $q_{s,a}$ values, which represent the contribution of each BT-BS s to the whole chromosome quality.

4.2.1 Some Genetic Algorithm Details

We start generating a population of 50 chromosomes and assigning each gene a probability p to be included in a chromosome. Each chromosome is checked for acceptability and fitness value.

Once the initial population is generated, evolution starts. A maximum of 10 chromosomes are killed each step (20% of population) depending on age. Each chromosome has a percentage probability to die which is equal to its age. So, if a chromosome is 20, it has a 20% probability to die. A constant number of surviving chromosomes are then coupled to generate new chromosomes thus replacing the killed ones. Coupling is performed according to a one-point-crossover and alternating gene exchange (one time the initial part and one time the final part). The evolution steps are repeated 1000 times.

A best solution is detected at each evolution step, and eventually it replaces the previous one if better. At the end of the process an absolute best solution is singled out.

4.2.2 Experiment Results

Here we discuss the experiments carried out in the upper area of the Mussomeli's castle. We split the area in 16 quadrilateral cells and 6 circular cells (Fig. 5). Results

Fig. 5. *Castle's upper area layout and coverage. Areas in different levels are sketched side by side*

Table 2. Upper Area BT-BS Deployment Selection

Initial probability (%)	Maximum allowed error Quadrilateral areas	Circular areas	Fitness	BT-BS
10	1	0,5	0,14	10
	0,75	0,375	------	------
	0,5	0,25	------	------
	0,25	0,125	------	------
15	1	0,5	0,13	12
	0,75	0,375	------	------
	0,5	0,25	------	------
	0,25	0,125	------	------
20	1	0,5	0,17	10
	0,75	0,375	0,16	11
	0,5	0,25	------	------
	0,25	0,125	------	------
25	1	0,5	0,12	12
	0,75	0,375	0,11	15
	0,5	0,25	------	------
	0,25	0,125	------	------
30	1	0,5	0,11	14
	0,75	0,375	0,11	16
	0,5	0,25	------	------
	0,25	0,125	------	------

are shown in Table 2. First column lists the probability for a gene in a chromosome to be "t"; second column lists the maximum allowed error (in meters) for each cell type, third column lists fitness values, and fourth column lists the number of BT-BS's deployed by a solution.

Table 2 tells us that a minimal number of ten BT base stations could be effective for the investigated area, thus achieving an accuracy of 1 m. for rooms and 0.5 m. for cells around artifacts. Some better accuracy can be achieved at the cost of deploying a greater number of base stations.

4.3 Positioning Step 3: Real Time Positioning by Neural Network

The high degree of uncertainty entailed by LQ values leads to the high complexity of their relationships with mobile device position. As previously remarked, positioning needs most to relay on site dependent solutions and not to deal with geometric laws. Each site has its own obstacles and environment noises which affect LQ measures; therefore, we need to assume each LQ value as specific for a given place. A positioning system need to learn LQ values as they are, without any concern with distances between BT-MT and BT-BS.

A Neural network is a solution in such a direction. A neural network can learn the LQ distribution, tune its weights, and then, be ready to provide real time position fast estimates. We also carried out some experiments by means of fuzzy logic which gave good results in terms of accuracy. Unfortunately, fuzzy algorithm computational complexity turned out to be high for real time positioning. Differently the neural network turned out to be very fast.

Experiments were carried out on a single-layer neural network with n inputs, one output, a linear activation function and no hidden layer. This simple network gives its output as (2) , where x_j are inputs and w_j are weights. Input is a m-dimensional array of LQ raw values, and no preliminary processing is required. We started our experiments with 10 base stations which we placed within the castle upper area according to a deployment given by the genetic algorithm.

$$y = \sum_j w_j x_j + \theta \tag{2}$$

The training set is given by the LQ values read by mobile devices placed in 5 known positions. Once trained, the network gives a good accuracy with a maximum relative error of 3% of the theoretical accuracy produced by the deployment optimization step.

5 Conclusions

This paper demonstrates the relevance of arranging a Bluetooth positioning system according to a three step procedure: sampling, deployment optimization, and neural network real time positioning. The first step suggested us to avoid geometrical strategies because of the unpredictability of how obstacles and noises can affect link quality. The second step demonstrates that a theoretical accuracy can be set according to an optimal base station deployment. The third step proved the effectiveness of a neural network especially as far as real time positioning is concerned.

Our best result, in a case study on positioning in a castle, was 10 base stations and accuracy better than 0.5 meters. Even better accuracy can be achieved according to different problem setup, for instance, by increasing the number of base stations to be deployed. The used approach gave solutions which were specific for the castle problem; nevertheless, the same approach can be used for detecting optimal arrangements of Bluetooth base stations for positioning in any area, as well as for using any other RF communication technology which is capable of providing link quality values.

Layout optimization should be considered an unavoidable step for positioning. Once base station deployment has been optimized, various methods can be adopted for actual positioning.

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