DESIGNING AND PERFORMANCE EVALUATION FOR AN INDOOR LOCATION AND TRACKING SYSTEM

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***Abstract*—The goal of this paper is to present an improvement of our methods, published at Rev2004 Conference, for positioning and tracking objects (laptops, PDAs) inside an 802.11b WLAN. We have modified the wrapi.dll for a facile data acquisition in LabVIEW and have passed over the entire application to LabVIEW due to its easier way of programming, possibilities for signal processing and a more facile information presentation.**

The positioning system operates by recording and processing signal strength information at multiple base stations positioned to provide overlapping coverage in the area of interest. We have used the signal strengths received from the WLAN base stations to build a radio map for the layout of the floor and have stored it into a database.

The on-line phase the algorithm calculates the position of the mobile user, by comparing its actual unknown position (in the signal strength space) with all the reference point’s positions stored in the radio map, provides the best match and display the result on the laptop or PDA screen, in XY coordinates.

Furthermore, we have implemented in LabVIEW some methods to compensate the errors produced due to walls, furniture reflections and human body diffractions.

Also, experimental results and conclusions concerning the accuracy of a system for positioning and tracking objects (laptops) inside an 802.11b WLAN are presented.

***Index Terms*—indoor location, positioning error, radio map, signal strength.**

I. INTRODUCTION

Several approaches have been proposed for indoor location sensing; such as radio frequency [1] - [5], [8], [9], ultrasonic [6], [7], infrared sensing [10], and scene capture analysis. Position-based location systems track objects by reporting their coordinates in a frame of reference. The actual position measurements may be made in many ways. Object locations can be sensed directly, using measurements of fields generated or affected by them, or by contact methods. Also, locations can be deduced from measurements of other physical properties of the object.

In the REV2004 paper [12] we have described the positioning algorithm using the radio signal strengths average and weights, the signal spatial distribution obtained in the offline phase and the data acquisition system created in Visual C++.NET.

In this paper the improved positioning and tracking algorithm using the estimated locations history is presented and the entire application written only in LabVIEW 7.1.

II. THE LABVIEW APPLICATION DESCRIPTION

The testing environment is located on a hallway on the second floor, in a concrete building, with 20 cm thick walls and usual wood and glass doors and windows. The surface on which we have experimented has the following dimensions: 18m x 3m. The base stations (ASSUS, SMC AND IPC1) are placed as the Fig. 1 shows. For collecting data from the 42 locations marked in the figure with green colour, we used a laptop with a PCMCIA Lucent Orinoco wireless card.

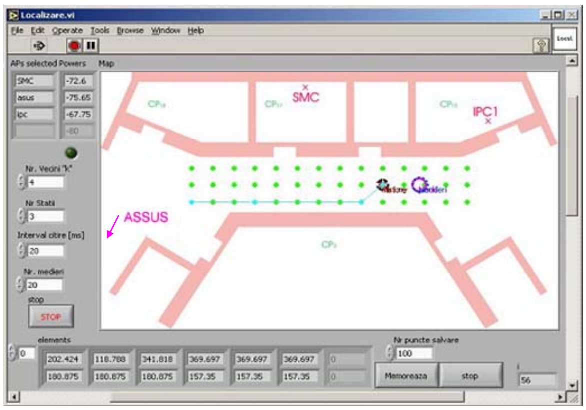

Fig. 1. The testing environment and the estimated positions of the mobile user using the average, weights and history of the last 5 positions

One important step of the research methodology represents data acquisition. The user can move through the rooms and on the hallways. Hence, the data collection points used offline were gathered from this area.

In this way, we can register information regarding the radio signal function of the user’s position. This information is used for building and validating signal propagation models, during the offline analysis and for real time assumptions on the user’s location.

The used driver extracts the information about SS (Signal Strength) and SNR (Signal to Noise Ratio) from the board each time a package is received. In the testing environment, the mobile station registers SS data and the access points (base stations) send packages (beacons) at regular intervals.

The file WRAPI.DLL represents a utilitarian function library, which acquires the information regarding the transmission and returns it in a form, which can be used by software. This library is free of charge and available at [12] address.

The library makes the connection between the network protocol NDIS (Network Device Interface Specification) included in Windows XP and the LabVIEW applications (LabVIEW Data Receiver, LabVIEW Tracker), providing them a collection of functions and data types. The LabVIEW applications LabVIEW Data Receiver and LabVIEW Tracker localize the user in a wireless network and check its movements by measuring the wireless card signal power, in the following manner:

- using the WRAPIOpenNdisDevice function, the NDIS protocol is initialised;
- the WRAPIEnumerateDevices function returns all network cards;
- the WRAPIGetAPList function specifies the radio access points (AP) the wireless network card can detect;
- the WRAPIGetAPPower returns the signal power detected by the wireless network card;

We had to expand the WRAPI library in order to offer clients the possibility of obtaining the power of the signal, but also the name of each virtual network. This was necessary, because working with virtual base stations (access points) in an ad hoc network, the mapping between information from the databases and from the base stations using MAC (Medium Access Control) network addresses was not possible. The problem arises from the fact that, on the computer where the base station is mounted, the virtual MAC changes almost randomly at each reboot. Moreover, the LabVIEW environment asks for input string variables.

A. *LabVIEW Data Receiver*

For the process of data acquisition in the offline phase, we created an application, which regularly (at the wish of the user) checks the wireless driver to determine the power of the signal received by the mobile station (on which the application runs) from the base stations. These powers will then be transmitted to the database.

The main window of the LabVIEW application Data Receiver.vi is shown in the Fig. 2.

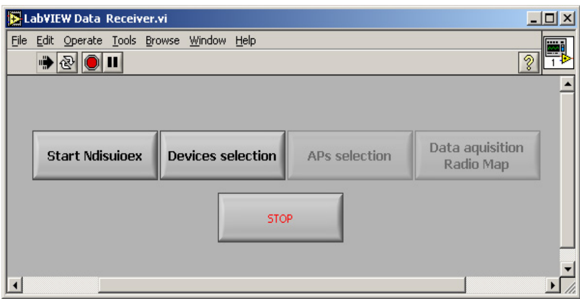

Fig. 2. The „LabVIEW Data Receiver" application panel

The NDIS protocol is initialised with the aid of the "Start Ndisuioex" command. Then we select the base stations (access points), which will be used by the positioning system. Even if in the building (neighbourhood) there are more radio access points, the radio map and the localization of the user will be done using only selected access points.

By activating the „Devices Selection" command, the panel from the Fig. 3. appears, whose diagram is shown in the following figure, Fig. 4.

Fig. 3. The selection of the system hardware devices having network functions

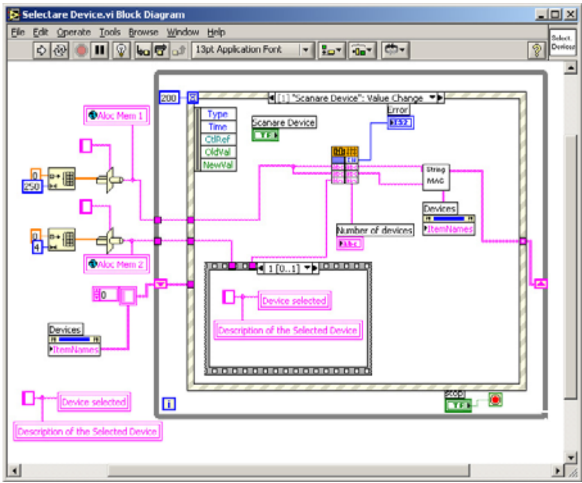

Fig. 4. The network devices selection diagram

Using a specific function of the driver (WRAPI EnumerateDevicesString2), we ask for a list with all hardware devices capable of network functions. The proper functionality of the application depends of the success of this function. If this fails, an error message appears. If the list has only one element, we make the assumption that this is in fact the wireless network card of the user. If we have more elements in the list, a dialog window appears, with all found devices and the user will select the network card to be utilized.

By using the WRAPI GetAPListString2 function, the selected access points are introduced in the „Base station 1, 2, 3" fields and a one-to-one mapping between real base stations and those from memory is done (Fig. 5.). These access points are the reference points for realizing the radio map. The selected device is then prepared for checking with the aid of the specific function called

WRAPIOpenNdisDevice. Once again the success of this function determines the subsequent functionality of the application.

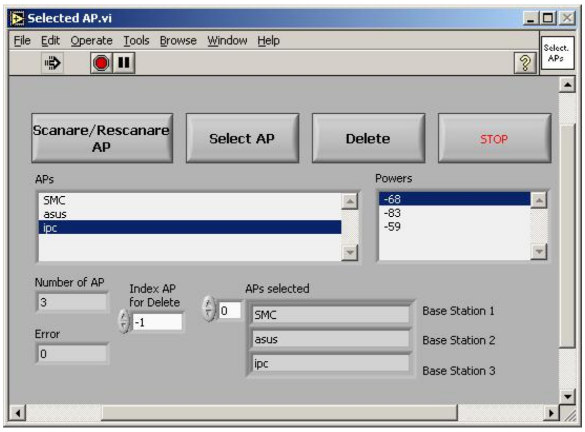

Fig. 5. The panel where are displayed all the access points scanned by the mobile user wireless card, and the received signals powers [dBm]

If during the signal mapping on the studied surface, some radio emission from other access points or wireless cards occurs, these are ignored, the measurement being done only using the user-selected points. The option of deleting selected base stations and the one of rescanning the radio environment are also implemented. We can select those access points, which give a better area coverage. This can be done because we can see the powers in the right side, as shown in the Fig. 5.

Then, from the main panel of the LabVIEWData Receiver, we select the command „Data Aquisition – Radio Map" (Fig. 2.) and the following window (Fig. 6.) opens:

The program can be used in two ways:

- manually: reading data is done by pushing "Start/Stop test" button; only one power reading is done and the result can either be displayed (if ListView is selected) or introduced in the database (if Database is selected). The signals are not processed. This mode is used for testing the values read by the application from the driver and it is useful when we want to diagnose the current situation and to check the visibility of all access points;
- automatically: the time between two readings is specified and optionally, the number of readings. If this number is specified, then at the end of the reading sequence, an average of the read values is computed. This average is then recorded in the database.

The user also controls the coordinates of the point for which the reading is done (using X and Y values) and its orientation (and of course, that of the station), by manual selection of the "Orientation" command (the options described are for the four cardinal points).

The application needs, for connecting to the database, the computer address where the database is stored, a username and a password. The application will not work if this data is not provided.

If the initialising step has completed, the program is ready to collect data from the driver and to transmit it to the database. For this purpose, we have to use the automatic mode and to specify the time (in milliseconds) between two consequent readings and the number of these readings.

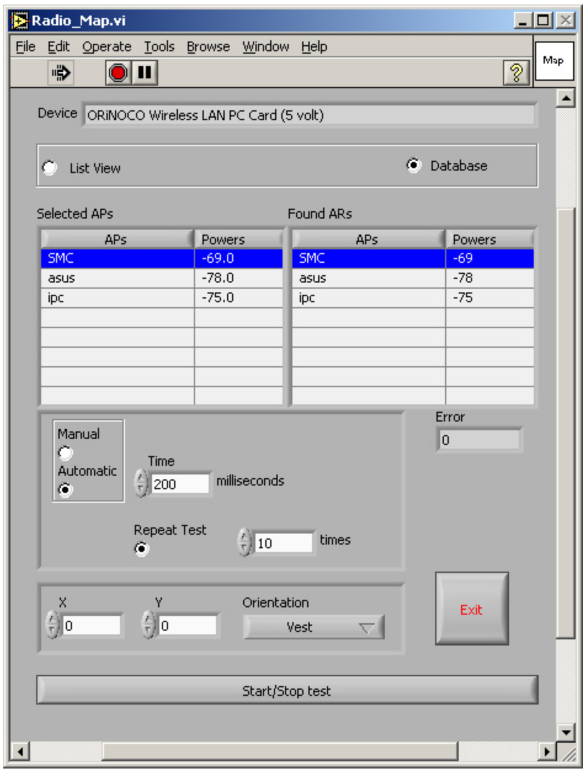

Fig. 6. Data acquisition and radio map building panel

We also have to select the radio button ("Database") corresponding to saving data into the database (the information is only displayed in the ListView field on the main window).

Because of the synchronization with the WRAPI driver and data consistency, the interval between two consequent readings cannot be smaller than 50 milliseconds.

The current values of the received signal power from the access points are read with the function WRAPIGetAPListString2, displayed in the ListView window and temporary saved for future processing. For each access point, the program memorizes a sum of read signal powers and their numbers. A very important fact must be mentioned: one reading of all signal powers of the visible access points, may return more values for the same point or even no value. For the latter case the implicitly set value is -100 dBm. For this reason, the assumption, that after six consequent readings the sum contains six real terms for each access point, is wrong.

The average function is called at the end of one data reading cycle. Its role is to compute for each access point, an average value of all read values and to save it into the database, taking into account the current accessed point, its coordinates (X and Y) and orientation chosen by the user at the beginning of the reading cycle.

If the combination <id, X, Y, Orientare> is already present in the database and we make another measurement for the same point, the new information overwrites the old one.

B. LabVIEW Tracker and the on-line phase

After the offline phase was completed, we started the first tests corresponding to the online phase. The online phase is done with the aid of another application called LabVIEW Tracker, which realizes the estimation of the user's position, by comparing the received signal powers, from the base stations, with the ones from the database. The offline set of values that resembles the most with the ones from the online phase is chosen as the current set. The physical point corresponding to this set of values represents, if we don't have other correction algorithms, the estimated user's position on the map. The application starts by selecting „Localisation – Tracking" command from the panel shown in the Fig. 7. This command determines the point where the user is located on the map and displays it into a graphical form.

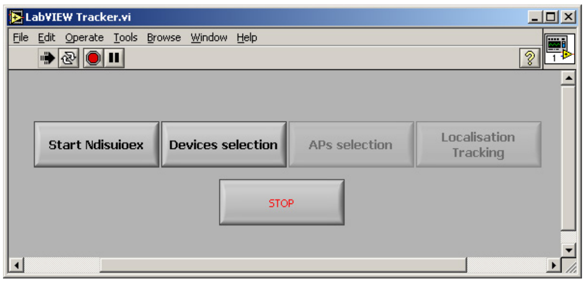

Fig. 7. The „LabVIEW Tracker" application panel. The application starts when the „Localisation – Tracking" command is selected

In the first phase, the radio map is initialised and the offline acquired and saved values of signal powers are read. The map is overlaid on the studied medium. Then, the received signal powers from different access points, in unknown locations where the user may be located, are read. This reading is done in a prior determined interval. The obtained information is compared to the one from the database and the estimated user's position is displayed within a circle (Fig. 1.). The user can stop or start the localization process and can also set the interval between two consequent readings.

The circle symbolized with a dotted black line, represents the user's location determined only with the minimum Euclidian distances. But this attempt to obtain an estimation of user's position is unsatisfying. The measured signals instability is given by a very high variation of the estimated position.

One way to solve this problem was to consider the previous value of the estimated point. The coordinates of the newly obtained point represented an average between the coordinates of the previous point and the ones of the point obtained from the estimation algorithm. Unfortunately, the estimation instability remained high, especially when the user stayed in a single place. In addition, a visible delay of the estimation appeared when the user moved fast.

The next algorithm improvement idea was based upon the fact, that the selection of the nearest neighbour with respect to the current point is not always justified. If the distances between the current point and two neighbours are almost equal, then the second neighbour can be a better approximation. Hence, instead of determining (in the signals space) the nearest point with respect to the current one, we search the four nearest points, for north, south, east and west orientations. From these four points is chosen the one physically nearest to the previous point. In this way, the minimum distance criterion from the powers point of view is also verified for the physical space.

Unlike the basic analysis, when the nearest neighbour point was considered, we consider now the first k neighbours, k having different values. The assumption is that often there are more neighbour points, which lie almost at the same distance (from the signals point of view) with respect to our point of interest. Taking into account the variation of signal power for a certain point during consequent measurements, we concluded, that there is no reason to choose only the nearest neighbour and to reject other neighbour points. The second reason for choosing more neighbour points is that the error vector (in the physical space) corresponding to each neighbour is differently oriented. By averaging the coordinates of the neighbour points, we will obtain estimation, which is very close to the real user's position.

The circle drawn with a continuous pink line resulted from the computation of the Cartesian coordinates averages for k neighbours. The number of neighbours can be set from the main window from the Fig. 1.

The only reason for which the advantages of the average computation are not significant is that k nearest neighbours from the signals space are not necessarily k distinct physical points. Many times, some neighbours from the signals space correspond to the same physical point. In this way, the average method does not significantly improve the position's estimation.

The dotted blue circle indicates the location, taking into account also the associated weights of the k neighbours.

In the Fig. 1. we observe that there is a difference between the position calculated with the aid of minimum Euclidian distances and the one obtained by averaging and weight, which indicate the correct user's location.

We used a history of the last 5 estimated points from the trajectory of the subject, in order to introduce some physical constraints (forced positioning error limitations due to aliasing phenomenon of the signal from the wireless channel). Once the shortest path is determined, we estimated that the actual user's position is the starting point of the probable trajectory (Fig. 1.). The program also displays the last 5 points on the trajectory.

The last program improvement consisted in adding a safety criterion: the physical distance between the previous point and the estimated point is computed. If this distance overrides a certain value, the new point is chosen on the direction given by the estimated point, but at a maximum distance given by the previous point. This safety method does not allow jumps of the estimated point, higher than the ones predicted (the diagonal between two nearby reference points on the radio map).

Because the information already in the database and obtained in the offline phase is time averaged, we can use the same idea: readings that are more consequent are averaged and then the value obtained is used for the localization algorithm. This means that the refresh of the user's position is done seldom, but in the same time we have a better precision in estimating the position of the user.

The coordinates given by the localization algorithm are then scaled, in such a manner, that they match the map of the considered area. These coordinates are transmitted to the graphical module, which does the graphical part, drawing the map and the point where the user is located.

III. PERFORMANCE EVALUATION AND ERROR ANALYSIS FOR THE INDOOR LOCATION AND TRACKING SYSTEM

To evaluate the system's performance, we have done some experiments; we've used two 802.11b APs and have measured the received signal power in 15 reference points. In addition, we have used the error in distance *e* to quantize how well the system works and to check the accuracy. We have defined the location estimation error, *e*, as the linear distance between the position (x,y) computed by the system and the real user coordinates, (x_0, y_0) given by the following formula:

$$e = \sqrt{(x - x_0)^2 + (y - y_0)^2}$$

We've made several measurement tests (60 for every reference point) and have modified some parameters, which can determine the location identification. These experiments were repeated many times to avoid statistic errors.

During the experimental tests, we have studied the effect of the chosen number of neighbours of the estimated point, the influence of the environment, the effect of the number of the APs selected to contribute at the location's determination and the effect of modifying the distance between reference points from the radio map.

To illustrate the influence of the above parameters we have used the cumulative distribution function (CDF) of the positioning error..

A. *The effect of the chosen number of neighbours*

One of the main conditions for a proper functioning of the algorithm is a good choice of the number k of reference neighbour points that have to participate at the coordinates averaging. We give values for k from 2 to 5, computing then the coordinates of the user. The obtained results are given in the Fig. 8.

As we can see, for k = 4 we obtain the best localization. Increasing this value to 5 does not give a better accuracy, but increases the time for computation and the complexity of the algorithm. For this reason, for the next experiments, we set the value of k to 4.

From a statistical point of view, we may say that in 50% of the cases the distance error is almost 1 meter and the maximum error is somewhere around 2 meters (for 100% of the studied cases).

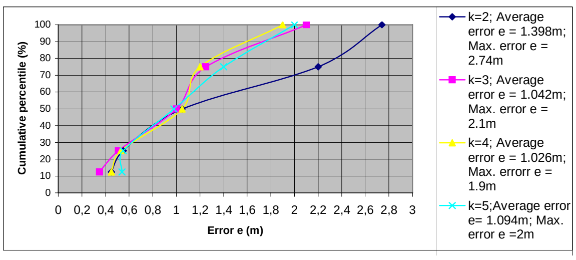

Fig. 8. CDF of the positioning error when the parameter k (the neighbors number of the first estimated reference point) is variable

B. *The influence of the environment*

To see the behaviour of the algorithm under different medium conditions, we took the measurements at different day moments: in the morning, when the people subject the environment to radio interferences from the area and in the evening, without people crossing the area. In the Fig. 9 we can observe the obtained errors after signal processing.

Analysing these results we concluded, that there is no substantial accuracy difference, between the measurements taken under these two environment conditions. This shows that the method of the radio reference points is a good choice for the identification of the position, because it overcomes almost all interferences.

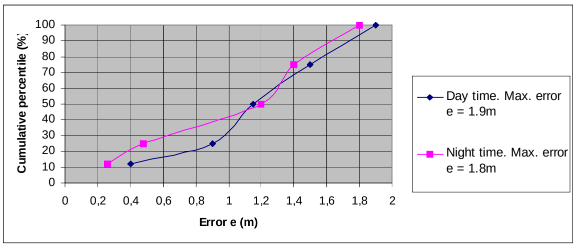

Fig. 9. CDF of the positioning error for environmental different conditions

C. *The effect of the number of radio access points selected for positioning*

One of the problems in using radio frequencies to localize objects is the inconsistency of the received signal power. This is due to the environment, but also to the devices. In most cases, the environment factors have the greatest impact on accuracy and on the maximum detection distance (furnishings and people movements also included). Another cause for the reduction of accuracy is receiving signals on different channels than the direct one, between emitter and receiver (NLOS – Non Line Of Sight). Even if NLOS does not block the transmission, like in the case of infrared radiation, this process creates the multi-path problem and interferences occur in the received signals.

To improve the precision we may increase the number of radio APs, hence increasing input data quantity. In this manner the positioning system may have better results. First we used two access points, and then we added another one. From the error point of view, we obtained a significant decrease (Fig. 10). Adding more radio access points also influences the data processing time. For this reason, we should make a compromise between precision and system-computing speed, especially when the user's tracking is done.

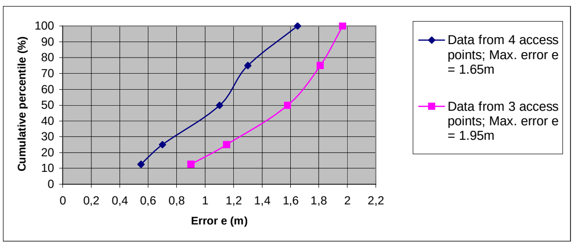

Fig. 10. CDF of the positioning error for a variable number of radio access points

D. The effect of the position of reference points on the radio map of the floor

Normally, the position of the radio reference points and their density should influence the precision. To verify this assumption, we placed the reference points on the radio map, from meter to meter. We repeated then the measurements from 2 to 2 meters and from 3 to 3 meters.

The error decreases indeed if the number of points grows, but this decrease is not spectacular, due to the inertia of the wireless network. At a certain distance from the access point, there is a fluctuation of 2-3% from signal power. The positioning algorithm can overcome this, but affecting the precision of the measured distance.

Increasing the number of reference points also increases the complexity and the time necessary for realizing the radio map.

We can make a compromise, by placing more points near areas where our interest is high and placing few points, in areas where we don't need a precise localization.

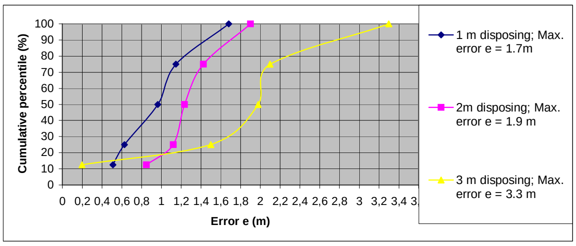

Fig. 11. CDF of the positioning error for a different disposing of the reference points from the radio map

IV. CONCLUSIONS

To implement the localization algorithm and to track mobile objects in a WLAN 802.11b network, we used more wireless cards or fixed access points with known coordinates.

One of the first problems was acquiring the signal powers, received from the base stations in each reference point from the environment and building the offline radio map.

Because the manufacturers of wireless devices did not make these devices to be used in localization applications, the only way to obtain the information about the signal power was to use a driver, which extracts it and makes it public, for a further usage.

Considering the propagation conditions, we placed reference points from 1.4 to 1.4 meters or even less and we did the measurements orientating the antenna towards the four cardinal points, and measuring for each point, with the purpose of diminishing the error given by the human body.

The manual data acquisition from access points implies a higher duration, during which the environment might change and might introduce human errors. Hence the radio map might not reflect the real situation of the tested medium. To resolve this problem we designed an efficient acquisition system (LabVIEW Data Receiver), which does the measurements and saves data in a very short time, for each reference point. In this way, the process of realizing detailed maps for big buildings is easy, being in the same time as accurate as the mathematical methods, based on signal propagation.

To view the user on the map and to track him when he moves, we designed the LabVIEW Tracker application, which characterizes the online phase of the algorithm. This phase computes in real time the user's coordinates and makes the necessary corrections to improve precision. The obtained positioning precision, for 50% of cases, was about 2.3 meters.

As we can see, the best localization is obtained when the neighbours of the first estimated reference point, that participate at the coordinates averaging, equals to four. Increasing this value does not give a better accuracy, but increases the time for computation and the complexity of the algorithm.

Analysing the results obtained when the environmental conditions are changing we can conclude that there is no substantial accuracy difference between the measurements taken under these two conditions (day time and night time).

The number of radio APs used for positioning is a very important parameter of the system, but adding more than four APs the data processing time increases and the estimated point remains "behind" the user when tracking. For this reason, we should make a compromise between precision and system computing speed.

The density of the reference points existing on the radio map of the layout of the floor should be big to have a better accuracy, but again we have to do a compromise between the positioning error and the complexity of the algorithm.

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