

People Location System based on WiFi Signal Measure

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Abstract—This work presents a people location system based on WiFi(Wireless-Fidelity) signal measure. The current locations systems based on WiFi are mainly applied in the location of indoor robots using the measure of their communications interface and the measures of other additional sensors. The advantage of the system presented in this work is that it is not necessary to add additional hardware (HW) to the people whom is tried to locate, neither in the environment, because we use the WiFi communications infrastructure. A probabilistic method based on a Hidden Markov Model (HMM) is used to determine the location of the people in the environment. In addition, a study of the WiFi signal measure is made in indoors with the main objective to obtain the necessary conclusions for the design of the system. The proposed method has been tested in a real environment. The results and conclusions obtained in the work are presented.

I. INTRODUCTION

The boom of the radio networks during the past few years is causing the growth of numerous wireless tools, devices and emergent applications. These networks are becoming critical elements in the infrastructure of network available in most of the public buildings (universities, airports, stations of train, courts, hospitals, etc.), commercial buildings (coffees, restaurants, cinemas, commercial centers, etc.) and even in the particular houses. In addition in the homes, the use of these radio networks favours mobility to execute manifold tasks in which it is known like Intelligent Houses. Different developing WiFi projects exist in cities such as Paris, Barcelona, etc.

The recent interest in the applications of estimation of the position inside a wireless network and the increasing demand of this systems causes that the investigators apply it to one of the fundamental problems that appear in the field of robotics such as the localization. The determination of the pose (position and orientation) of a robot by means of a physical sensor is not a trivial problem and often its "the main problem to solve about robots with autonomous capacities" [1]. There are several localization systems that work in indoor, such as based on infrared [2], vision [3], ultrasound sensors [4], laser [5] and Radio-Frequency (RF) systems [6].

Many robotic platforms use wireless networks to communicate with resources of computation, human-machine interfaces and even with other robots. Due to the decrease of the costs of the networks that have been mentioned, many robots are equipped with WiFi interfaces 802.11b/g. In many applications of location sensors use laser of high cost opposite to the computational cost that involve the image processing of the vision sensor. In other cases, the WiFi sensor is used both

localization sensor and communication interface. Therefore it is not needed to modify the environment with additional marks.

The Wifi location systems use the network infrastructure 802.11b/g to determine the position of the devices without the requirement to use additional hardware. This characteristic turns them suitable systems to work in indoor environments where traditional techniques, like the System of Global Positioning GPS (Global Positioning System) [7], aren't useful. In order to estimate the position of the robot the level of signal is received in the WiFi interface from each one of the access points (APs) that form the structure of WLAN network. This measurement is function of the distance and the obstacles between the APs and the robot.

In [8] they calculate the distance to the all APs applying a propagation model and then they use these distances within a triangulation algorithm to obtain the estimated position. Unfortunately, in indoor environments, the wireless channel is very noisy and RF's signal is affected by the phenomenon of the reflection, refraction and diffraction, in what it is known as effect of the multiway, which does that the received level of signal was a complex function respect of the distance.

To solve this problem, they propose Wifi location systems based on radiological priori maps [6], which stores the levels of signal received of each of the APs in certain points of the interesting area. These systems work in two phases: training and estimation. During the first one, radio map is manually builded or using a robot in teleoperation mode. In the phase of estimation a vector is obtained by the levels of signal received from each of the APs and they are compared with the radio map to obtain the estimated position using a matching technique.

The localization techniques are divided in deterministic and probabilistic ones. In the first group, the environment is divided in cells and a pattern is learn in the training stage then in the estimation stage the position is obtained by comparing with this pattern [6] [9] [10]. In the other hand, the probabilistic techniques maintain a belief distribution over all positions. These techniques achieve higher precision but with a higher computational cost. In [11] the authors use a Bayesian Belief Network to obtain a belief distribution over the estimated position. In [12] they use a probabilistic technique, a recursive Bayesian filter, based on a Monte Carlo sequential sample system.

The Bayesian approximation is usually apply in cases where the environment is modeled as a grid. Another way is to

discretize the environment like a topologic map. In this case the location is based on the identification that the robot has reached a node of the map according to some geometric information of the environment.

The systems based on robotic platforms use the sensors of the robots to improve the location, whereas this work proposes to make the location of people who don't have any additional hardware. In order to obtain this objective the system has been divided in three stages: training, detection of people based on a Bayesian network and location based on a HMM. A previous stage of system training is used in the environment, which must be executed only one time for each environment and conditions of work. This work demonstrates that the detection and location is possible in real environments.

The rest of the work is organized of the following way: the point 2 describes the procedure of measurement of the WiFi signal, the point 3 shows the development of the location system on HMM, the point 4 provides a description of the test-bed, the implementation of the system and the results obtained in this work. Finally the point 5 shows the conclusions and the future work.

II. WiFi SIGNAL MEASURE

In this section an introduction to the WiFi signal measure is presented, which is interesting to understand the working of the location system that has been developed. It is necessary consider that for the networks 802.11b working to 2.4 GHz the wavelength it is 12.5 cm, and this is the resonance frequency of the water, that means that the presence of people in the environment affect the measurement of the WiFi signal.

In [13] three main causes of variation of the measurement of the level of signal in a WiFi interface are identified:

- 1) Temporary variations: when the measuring device of the WiFi signal remains in a fixed position, the level measurement of signal changes with the time.
- 2) Variations of small scale: the level of signal changes when the measuring device is moved in small distances, below the wavelength.
- 3) Variations of large scale: the level of signal changes with the distance due to the extenuation that suffers RF's signal with the distance.

Besides these variations, this work proposes the study of the following ones:

- 4) Variations of large orientation: they are produced due to a substantial modification in the orientation. It is tried to discriminate between the four basic orientations: North, South, East and West.
- 5) Variations of small direction: they are those that are observed when modifying the direction of the measurer in few degrees.

From the study of the Wifi signal variations we can conclude that one of the main causes of the variations are the presence of people in the measurement environment. Due to the people contain a high percentage of water, they represent a factor of considerable attenuation of the level of WiFi signal, mainly

when these are in the direct way between the access point and the measuring device. This effect is less appreciable in the cases in that the people are in a secondary way of the signal.

In addition to the people in the environment, this measurement can be affected by the interferences produced by devices that work in the same rank of frequencies, such as the Bluetooth devices, wireless keyboards, wireless mouses etc. Therefore, its necessary to make a previous study of the temporal variations to make the design of the location system.

The variations of large scale are due to the attenuation that suffers RF's signal with regard to the distance. These variations give an idea of the position that must occupy the measuring device inside the environment beside the restriction about the possible displacements of the measuring equipment inside it.

Like the variations of large scale, the variations of large orientation also provide an idea of the restrictions about the possible positions that the measuring equipment can adopt inside the environment. These variations are defined as those that suffer the measurement of the WiFi signal when the measuring equipment is located in each of four basic orientations (North, South, East and West).

The variations of small scale are the variations that the signal suffers when the measuring device is moved in small displacements and always below the wavelength, that is, below 12.5 cm. These variations together with those of small orientation introduce restrictions on the small displacements of the measuring device, so much linear as angular that can suffer the measuring equipment without the received signal suffers a variation.

In order to make the measures of the WiFi signal level, the interface has been equipped with *scanning* capacity. This capacity allows to take samples from all the access points or base stations that are in the range of the measurer. The highest frequency to which the acquisition can be made is to 4 Hz.

To make the study of each one of the enumerated variations in this section a serie of samples is taken in the environment to be analyzed. Once N_s samples have been acquired, the two main parameters that are studied are the average level of the samples taken (Equation 1) and the variance from the same ones (Equation 2).

$$\overline{RSL}_{APu} = \frac{1}{N_s} \sum_{N_s} RSL_{APu}, \forall u \in x \quad (1)$$

$$\sigma_{APu} = \sqrt{\frac{1}{N_s - 1} \cdot \sum_{N_s} (RSL_{APu} - \overline{RSL}_{APu})^2}, \forall u \in x \quad (2)$$

Where RSL_{APu} is the level of signal received ("Received Signal Level") in the WiFi interface for the access point APu of the whole set of x access points.

III. DESCRIPTION OF THE LOCATION SYSTEM

The design of the location system is divided in three different stages: training, localization of people and finally the tracking of them. The estimation stage is based on a

neuronal network whereas the localization stage is based on a HMM.

During the training stage, the system tries to adapt itself to the environments. The training of the neuronal network consists on applying a serie of cases in which it is known the exit of the system, this is, the presence or absence of people in the environment. The entry vector of the neuronal network is form by the average and variance of the level of WiFi signal obtained by the measuring equipment which is in a fixed position of the environment, whereas the exit vector will be introduced by a person who carries out the supervision of the system for each of two possible cases (presence/absence).

Once the neuronal network has been trained, its exit during the detection stage will indicate if there is people in the environment or no. In the case of obtaining an exit of absence of people in the environment it will not be necessary to execute the location algorithm.

For the design of the location and tracking systems a HMM is chosen. A Hidden Model of Markov is a stochastic process composed of some hidden states ($q = \{q_t\}_{t \in N}$) and some observations ($\{O = \{o_t\}_{t \in N}\}$) whose states are stochastically dependent on the hidden states, that is to say, it is a bivaried process (q, O). The HMMs can also be considered as stochastic generative systems, which are used in the model of temporal series.

In a stochastic Markov process the future state does not depend on the past, the future state only depends of the current state. This means that if a stochastic variable q_{T-1} denotes the state of the process at the time $t - 1$, then the probability of transition at the moment t is defined as in the equation 3.

$$p[q_t = \sigma_t | q_{t-1} = \sigma_{t-1}] \quad (3)$$

Formally, a chain of Markov is defined like (Q, A) , where $Q = \{1, 2, \dots, N\}$ are the possible states of the chain and $A = (a_{ij})_{n \times n}$ is a matrix of transition of states in the model. If $A(t) = a_{ij}(t)_{n \times n}$ is independent of the time, then the process is called homogenous and the probabilities of transition of states are obtained as shows the equation 4.

$$a_{ij}(t) = p[q_t = j | q_{t-1} = i] \quad (4)$$

In the transition matrix, in addition, the properties shown in the equation 5 are fulfilled.

$$\begin{aligned} 0 \leq a_{ij} \leq 1, \quad \forall 1 \leq i, j \leq N \\ \sum_{j=1}^N a_{ij} = 1, \quad \forall 1 \leq i \leq N \end{aligned} \quad (5)$$

A Hidden Model of Markov is a chain of q joined to a stochastic process that takes values in an S alphabet and it depends on q . These processes advance in the time in a random manner from one state to another and emitting a random symbol of the alphabet S at every moment. When it is in the state $q_{T-1} = i$, it has the probability a_{ij} of moving to the state $q_t = j$ at the following moment and the probability $b_j(k)$ of emitting the symbol $o_t = v_k$ at the time t . Only the symbols emitted by the process q are observable, but not the route or

sequence of states q , because of this fact the Model is called "hidden", since the process of Markov q is not observed.

In this work the Hidden Process of Markov q represents the different positions that can occupy the people in the environment, whereas the transition matrix A represents the probability of evolving between the different positions from it. In order to make the adjustment of the transition matrix, it is needed to establish the people movement model around the environment, and it can be made as in a manual form, introducing it by an expert user, or by means of an automatic training method. The problem to solve is to know the sequence of states or positions of the environment, by where the user has advanced (q_1, q_2, \dots, q_T), having as input the succession of observations (O_1, O_2, \dots, O_T) during a series of steps of execution T . For it the algorithm of Viterbi [14] is used which obtains the maximization in the probability of the way followed by the user to locate.

IV. IMPLEMENTATION AND RESULTS

This section describes the environment used for testing the location system presented in this work, the characteristics of the implemented system and the results of the proposed experiments to validate the people location system.

A. Test-Bed

The Test-Bed environment was established on the 3rd floor of the Polytechnic School building in the corridor number 4 of the Electronic Department at the University of Alcalá. The layout of this zone is shown in Figure 1. It has a surface of 60m x 60m, with about 50 different rooms, including offices, labs, bathrooms, storerooms and meeting rooms.

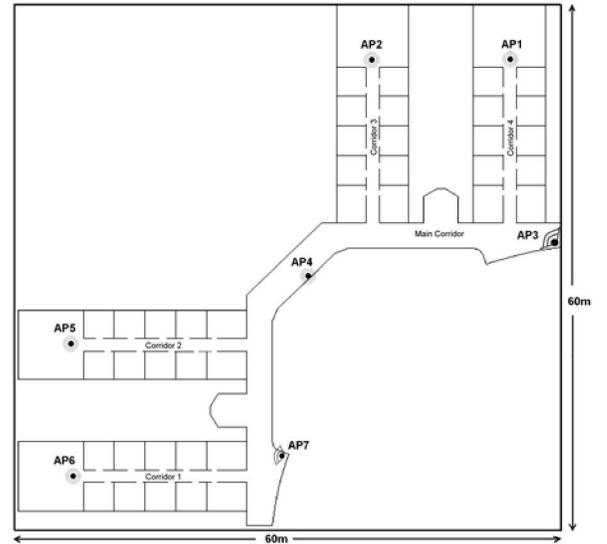


Fig. 1. Test-bed. Department of Electronics

Seven Buffalo Access Points (APs) (WBRE-54G) were installed at the all environment. Five APs were connected to omnidirectional antennas and two APs (AP3 and AP7) were connected to antennas of 120° of horizontal beam-width (AP3

y AP7). The APs act as wireless signal transmitters or base stations.

B. Implementation

With the objective to verify the correct operation of the localization system, in this work a laptop has been used like measuring equipment with the following configuration: operating system Linux Network Hat 9,0, wireless card Orinoco PCMCIA Gold, "wireless tools" developed by Jean Tourrilhes [15], orinoco driver with the patch of Moustafa Youssef [10] to obtain simultaneous measures of the WiFi signal respect to all the access points, which is known like *scanning*. This equipment is in a fixed position of the environment and it obeys the restrictions imposed by the variations studied in the section II.

Figure 2 is a simplified scheme of the implementation of the system. In this figure the access points and the laptop can be emphasized where the location system is implemented. In the APs, its two functionalities are emphasized:

- To establish the communications inside the wireless network.
- To represent a point of reference for the location system.

The laptop shows the different application layers that are used to obtain the proposed location system:

- In the first place is the layer of the HW interface that is used like communication interface and measurer of the level of received WiFi signal.
- After HW interface WiFi is the calculation layer, which is used to obtain the measures of the signal level, noise level and the values of the average and variance of the signal.
- The detection layer is useful to indicate to the main application when the presence of people in the environment has been detected.
- The location layer is useful to locate the different people who are in the environment and to make the people tracking in order to indicate it to the main application.
- The main application shows the results of the detection and location stages.

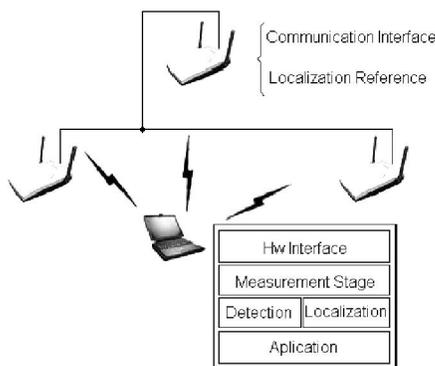


Fig. 2. System implementation

C. Results

To estimate the variation that can suffer the received signal depending on the time an experiment has been designed in which the measuring device has taken samples during a complete day, a sample per second. 60 samples have been taken from the level of signal received with the objective to filter the noise obtained in the WiFi interface. This test has been realized from 16:00 on Friday until 16:00 on Saturday, at the back of the Corridor 4 where its located AP1. The frequency of acquisition and representation is 1Hz. The Figure 3 shows the level of received signal in the access point AP2 for this bottom of corridor.

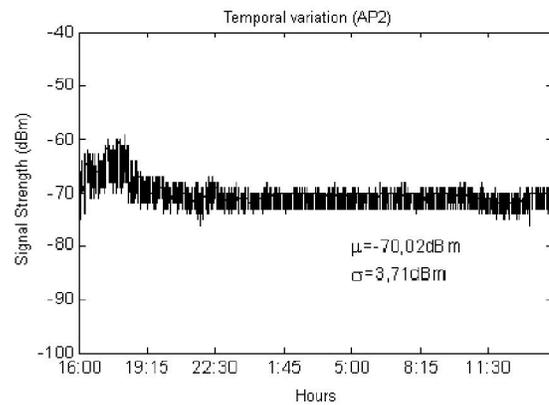


Fig. 3. Temporal variations (AP2)

In absence of people and wireless devices, such as Bluetooth devices, the measurements kept stable. This happens in the hours between 21:30 on Friday and 16:00 on Saturday. Besides, the variance during this time is smaller than during the hours in which persons exist in the environment. This demonstrates that it is possible to detect the presence/absence of people in the environment.

To verify the effect of the large scale an experiment has been made that consist in discretize the test-bed in 67 separated cells 80 cm. The measurer was located along different positions of the environment. The positioning was made of manual form to avoid direction mistakes or small scale. The measures were made in absence of people and radiological interferences to avoid contaminate with noise the measurement. 300 samples were taken in each position in order to construct its histogram and obtain the average value of these samples. The Figure 4 shows the results of this experiment.

It has been verified that a variation of the received signal level from each one of the access points based on the value of the distance to it, it was up to 20 dBm in 20 m of distance. The signal level is larger when the measurer is closer to an access point. About the analysis of the measures of large scale, the conclusion is that the level of measured WiFi signal based on the distance is not trivial in the case of propagation indoors and that the realization of a propagation model depends on the characteristics of the environment therefore it is not possible to obtain a general model that is independent of the environment.

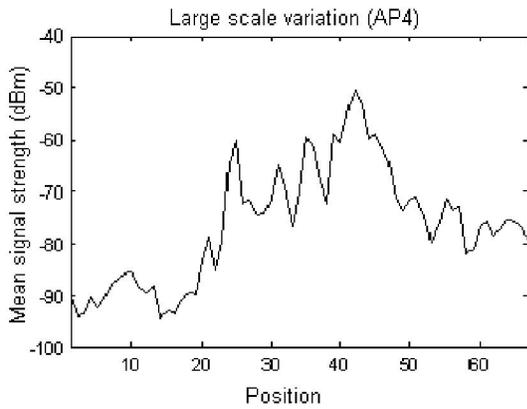


Fig. 4. Large scale effect (AP4)

In addition it is verified that the level of received signal in each one of the 67 positions is different and therefore it make necessary to select one of the positions to fix the location of the measurer during the tests.

To test the effect of the large orientation an experiment has been designed that consists of placing the measurer in different positions inside the 67 in which the environment have been discretized and to take 300 samples for each of the APs and each of four basic orientations, which have been named like: 0° , 90° , 180° and 270° . Once obtained the 300 samples the histograms for each one of the directions have been constructed, according to it appears in the Figure 5. This experiment has been made in different positions from the environment in order to extract a few general conclusions that can be applied in all the cases.

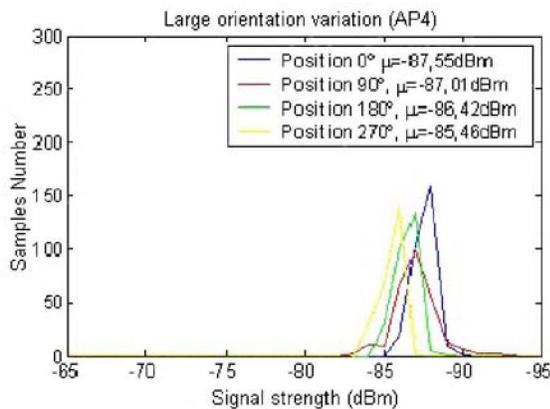


Fig. 5. Large orientation effect (AP4)

As can be observed in the Figure 5 the histograms obtained for each one of the four directions are different, getting to take place a maximum change of up to 5 dBm in the average values of each one of the histograms.

The variations of small scale have been studied making small displacements of the measuring equipment respect to a reference position. The displacements have been made in increases of $1/4\lambda$ with the objective to recognize the maxi-

imum displacement that can be made on the measurer of the WiFi signal without a modification of the signal. The largest variation usually is around $1/2\lambda$ and $3/4\lambda$ for the access points of largest influence, which are the APs that more close are of the device that makes the measurement, in which the histogram varies to 6 dBm. The variations in equal or inferior displacements to $1/2\lambda$ are around the 2 dBm for the corridors in which there is minor influence of a access point and up to 5 dBm for other displacements.

As with the variations of small scale, to study the effect of the small direction, small displacements of direction have been made with increases of 3° (from 0° to 9°) to determine the maximum direction that can be modified respect to a reference direction without the measurement of the WiFi signal is modified. The signal received in the access points of largest influence is affected until in 2 dBm for variations of 9° . Whereas inferior variations to 9° cause inferior variations of signal to 1 dBm. When the signal comes from a AP of smaller influence, the variations are not superior to 1dBm for any of the cases.

In order to make the training of the system, data that come from 100 different situations have been used. The results obtained in this stage have been of 90% of successes. Once trained the system, the operation of the people detection system in the environment has been verified, obtaining the 80% results of successes.

In order to verify the operation of the location and tracking systems 10 complete routes through 8 located states of the environment at bottom of Corridor 3 have been made. The matrix of transitions has been adjusted manually based on the study of the people movement by the test-bed. The observations have corresponded to the average value of 60 samples obtained in the WiFi interface. The Figure 6 shows 3 complete routes with the real value and the value considered according to the proposed algorithm. The percentage of successes during this stage was 50%.

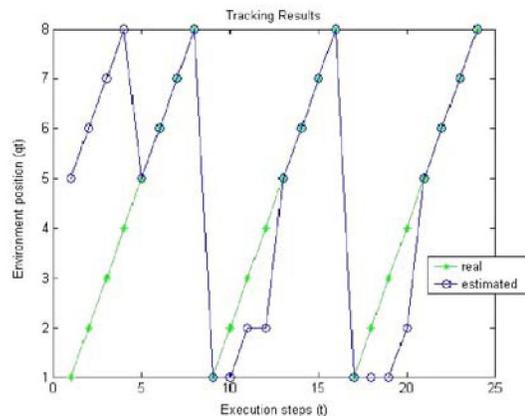


Fig. 6. Localization and tracking results

V. CONCLUSIONS AND FUTURE WORKS

In this work we presented a people detection and location system based on measurement of the WiFi signal. A study of the measurement of the WiFi signal has been made with the objective to extract the necessary conclusions to make the design of the location system.

The system does not need an additional hardware neither in the environment nor in the people to detect, which is one of the principal attractions of the system, besides to allow the adaptation from the system very easily to new environments. But in this case, the system requires a previous training that was only realized once by each environment and conditions of work.

The location and pursuit of the users in the environments has been made using a HMM and the algorithm of Viterbi, with a percentage of the 50% of success, observing that the system is very sensitive to the manual adjustment of the matrix of transitions. As future work that is proposed is the adjustment of the matrix of transitions and the observation using the algorithm EM to increase this percentage of success.

VI. ACKNOWLEDGMENT

This work has been funded by grant S-0505/DPI/000176 (Robocity2030 Project) from the Science Department of Community of Madrid, and TRA2005-08529-C02-01 (MOVICOM Project) from the Spanish Ministry of Science and Technology (MCyT).

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