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Indoors Localization Using Mobile Communications Radio Signal Strength

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1. Introduction

Radio frequency (RF) indoors localization is adopted by automated guided vehicles (AGVs) positioning due to availability of communications framework sub-system (*e.g.* ZigBee wireless network) in the entire working system. AGV (*i.e.* a type of wheeled mobile robot) communications sub-system can therefore support RF localization hardware without additional cost. Mobile communications for indoors environments have many applications and are generally implemented with a personal digital assistant (PDA) for people to exchange information efficiently. In this perspective, examples of applications of RF indoors localization are resources (*e.g.* products at an automatic warehouse) or people (*e.g.* doctors in a hospital). The main problem to overcome corresponds to radio signal strength which is difficult to relate to distance to transmitter in indoors environments due to obstacles and objects that cause multi-path, interferences, noise, etc. (Azenha *et al.*, 2010). As radio signal strength is measured with noise, this fact leads to fluctuations on its values which then require filtering (*e.g.* low-pass filtering, Kalman filtering).

At the present, research is being made in order to develop low-cost navigation hardware such as inertial navigation systems (INSs). INSs are composed of inertial sensors such as accelerometers and gyroscopes (Fu & Retscher, 2009). Namely, low-cost gyroscopes with a drift below 1 degree/hour have been described. Position is computed according to double time integration of acceleration and orientation is computed according to time integration of angle rate provided by a gyroscope. Therefore, in indoors environments, INS can become an aiding scheme to the dead-reckoning algorithm (Borenstein *et al.*, 1996; Azenha & Carvalho, 2008b) in the near future. Dead-reckoning is the most adopted scheme for indoors localization, because other systems such as global positioning system (GPS) do not work indoors. Dead-reckoning can use accelerometers and gyroscopes for INS navigation or rotary encoders and gyroscopes or magnetic compasses for wheeled AGVs indoors navigation. RF localization schemes are also being developed for indoors localization purposes, because they increase system efficiency in terms of its lower cost and they can have sufficient accuracy characteristics.

RF indoors localization methods are therefore means of attenuating AGV dead-reckoning navigation errors (Azenha & Carvalho, 2007b; Azenha & Carvalho, 2008a; Azenha *et al.*, 2008; Park *et al.*, 2009). Dead-reckoning (from sailing: deduced reckoning) navigation method makes use of odometry and heading measurement signals. Dead-reckoning is prone

to systematic, non-systematic and numerical drift errors which, in general, increase with traveled distance. Dead-reckoning algorithm performs well in indoors quasi-structured environments for a given period of time or for a given traveled distance, which one is more critical and that depends on current AGV trajectory. So, there is a need of attenuating dead-reckoning errors which, as a result, correspond to localization errors. AGV indoors localization can then resort to RF multilateration, trilateration, triangulation or fingerprinting techniques.

In this chapter, state-of-art of RF indoors trilateration technique for AGV indoors navigation is presented. It is described work-in-progress on AGV, or other objects or people, localization in indoors quasi-structured environments (Borenstein *et al.*, 1996; Azenha & Carvalho, 2006; Azenha & Carvalho, 2007a; Zhou & Roumeliotis, 2008; Azenha & Carvalho, 2008b; Roh *et al.*, 2008). In the work of Bekkali *et al.* (2007), an adaptive Kalman filter is adopted to work with Gaussian noise in location estimate for multilateration method with radio frequency identification (RFID) hardware. In this research direction, Fu & Retscher (2009) present a work about RF indoors localization with trilateration which shows some signal power propagation models which are developed to be applied in localization in indoors environments.

RF trilateration method is adopted in this chapter due to the promising characteristics of wireless communications networks, as written above. In this scheme, the distribution of fixed nodes is very important for the trilateration algorithm to be successful. Distribution of fixed nodes is dependent on the building lay-out (*e.g.* machines, buffers, people walking paths) and building dimensions. In this line of thought, the fixed nodes distribution has to be a compromise between number of nodes and localization of them. Using trilateration method, at least three fixed nodes should be in range of a mobile node for trilateration to be possible to be performed. This system is intended to be a modular system in terms of easy setup and of specific applications independence. Nevertheless, some limitations in these properties are addressed in sections three and four. In fact, node concentration properties are very important to be taken into account and they are dependent on other objects lay-out. Another consideration corresponds to system cost. In fact, the low system cost corresponds to the low-cost in devices and in their maintenance.

Results show that a localization accuracy of down to three meters is possible depending on the lay-out of environment (*i.e.* objects and persons moving or placed in the environment and building construction materials). This result shows that some applications of localization in indoors quasi-structured environments, such as automated warehouses, can benefit from this system because those applications may accept these accuracy limitations. This chapter is organized as follows. Next section presents the background of RF indoors localization methods. Following that section, RF indoors trilateration method state-of-art is shown. Next, application of this method is discussed and then the conclusions end this chapter.

2. Background

Four two dimensional (2D) localization methods are considered: multilateration, trilateration, triangulation and fingerprinting. GPS and other similar systems are not considered because they do not work and therefore they do not perform well in indoors environments (Ni *et al.* 2004; Sugano *et al.* 2006; Tadakamadla, 2006).

Multilateration method is based in TDOA (Time Difference of Arrival) (Patwari *et al.*, 2005). It needs at least three nodes to estimate an unknown position. With the measurement of the time difference between two nodes in a single communication, estimating the radius

distance between them is possible. The interception of the radius distance measurement gives the estimated position.

Trilateration method (Shareef *et al.*, 2008; Peneda *et al.*, 2009, Azenha *et al.*, 2010) requires at least three fixed nodes with omnidirectional antennas. Receiver Signal Strength Indication (RSSI) of the communications between the fixed node and the unknown node is used to compute the distance between them. As it does not know the direction, this distance is the radius of the circumference with the fixed node in the center. The interception of the circumferences gives the estimated position of the unknown location node. However, due to the presence of reflection, multi-path, etc. phenomena, trilateration method becomes a challenger task for engineers. In fact, these phenomena make RSSI, an indication of RF signal strength for trilateration method, to have a difficult behavior to adopt by localization systems. For example, a stronger RSSI may not be corresponding to a closer communication node.

Triangulation technique uses the geometry of triangles to compute object location (Hightower & Borriello, 2001). It requires at least two reference nodes and this technique uses the AOA (Angle of Arrival) to estimate the communication angle between the reference and the direction of unknown node. It uses the properties of directional antennas to find a maximum of RSSI signal in order to obtain the direction of object location.

Fingerprinting technique (Tadakamadla, 2006) requires measurement of RSSI at several locations to build a database of location fingerprints. In order to calculate a position, some measurements of RSSI of fixed nodes are obtained and then it is queried to the database and tried to find the same conditions. Fingerprinting method is not appropriated when the lay-out of environment changes very often, because all the calculations and RSSI measurements must be done again.

Multilateration method has the crucial problem that an accurate time synchronization of the received signals is needed. Triangulation method has the disadvantage of using directional antennas to compute a position. Fingerprinting technique requires large time consuming to perform an exhaustive data collection for a wide area network (Kaemarungsi, 2005).

The method that is discussed in this chapter is the trilateration one. This method is efficiently implemented in a wireless communication framework and it only requires that the hardware can measure RSSI with some accuracy. It is modular and, in general, it does not require too much processing to estimate a position. With its modularity properties, trilateration is superior to triangulation and fingerprinting because it is easier to build localization system into existing communications hardware. So, the communications sub-system can therefore support RF localization hardware without additional cost. Then, a low-cost solution can be obtained. Localization accuracy requirements are dependent on the application. In indoors industrial environments, some meters down to some centimeters is the accuracy range which can be found. For example, in an automatic warehouse, some products are required to be located with an accuracy of some meters or, on the other hand, in a control application, AGVs may require a localization accuracy of some centimeters.

3. Indoors localization using RF trilateration

In the following, RF trilateration localization algorithm is shown. Consider n fixed points or beacons with Cartesian coordinates (x_{1i}, x_{2i}) with $RSSI_i$ (dBm), $i = 1,…,n$. $RSSI_i$ (Alavi *et al.*, 2009) is measured for mobile node communication link i ($i = 1,…,n$). In Figure 1 trilateration approach is depicted for three beacons example. Each RF transceiver sends and receives its

signals through an omnidirectional antenna. So, signal propagation is independent from direction. Then, distance d_i between mobile node and fixed point i (beacon) can be calculated according to equations (1a-d). Equation (1a) stems from corresponding isotropic RF propagation signal attenuation due to its spatial power distribution (Goldsmith, 2005). This is a linear logarithm model of RSSI as function of distance d_i. It is an approximation of free space RSSI attenuation model which takes into consideration non-ideal medium characteristics by the introduction of n_{Ai} parameter. Equations (1c-d) are a rewrite of equation (1a). Equations (1e-g) show sensitivity of distances d_i to RF experimental parameters.

$$\text{RSSI}_i = A - 10 n_{Ai} \log_{10}(d_i), i = 1,...,n \tag{1a}$$

$$d_i = \sqrt{(x_1 - x_{1i})^2 + (x_2 - x_{2i})^2}, i = 1,...,n \tag{1b}$$

$$n_{Ai} = -\frac{\text{RSSI}_i - A}{10 \log_{10}(d_i)}, i = 1,...,n \tag{1c}$$

$$d_i = 10^{-\frac{\text{RSSI}_i - A}{10 n_{Ai}}}, i = 1,...,n \tag{1d}$$

$$\frac{\partial d_i}{\partial \text{RSSI}_i} = -d_i \frac{\log_e 10}{10 n_{Ai}}, i = 1,...,n \tag{1e}$$

$$\frac{\partial d_i}{\partial A} = -\frac{\partial d_i}{\partial \text{RSSI}_i}, i = 1,...,n \tag{1f}$$

$$\frac{\partial d_i}{\partial n_{Ai}} = \frac{\partial d_i}{\partial \text{RSSI}_i} \frac{A - \text{RSSI}_i}{n_{Ai}}, i = 1,...,n \tag{1g}$$

Parameters A (dBm) and n_{Ai} are obtained by experimentation and are variables depending on radio propagation environment properties. A (dBm) is RSSI measurement value at distance $d_i = 1$ m and n_{Ai} is attenuation constant which is dependent on medium propagation characteristics. In general, parameter n_{Ai} uncertainty has more influence on d_i calculation error than parameters RSSI_i and A uncertainty.

Knowledge of distances d_i ($i = 1,...,n$) makes possible the calculation of mobile node location (x_1, x_2) through intersection of the circumferences i with centre at point (x_{1i}, x_{2i}) and with radius d_i ($i = 1,...,n$) (Azenha & Carvalho, 2008a). For three beacons case study, if the Cartesian coordinate system is chosen with $x_{11} = 0$ m, $x_{12} = 0$ m, $x_{22} = 0$ m, then a simple closed-form system solution (x_1, x_2) can be obtained. On the other hand, as in practical studies beacons are chosen to be different for distinct location calculations and more than three beacons are usually present in the environment, some more general solution algorithms are adopted as for example numerical algorithms.

In indoors environments, due to some observed phenomena (*e.g.* interferences, changing objects, multi-path) in RF signals propagation, RSSI_i must be carefully acquired (Azenha *et al.*, 2008) to minimize error in distances d_i ($i = 1,...,n$) calculation. In the following sub-sections, RSSI measurement considerations and fixed node distribution are described.
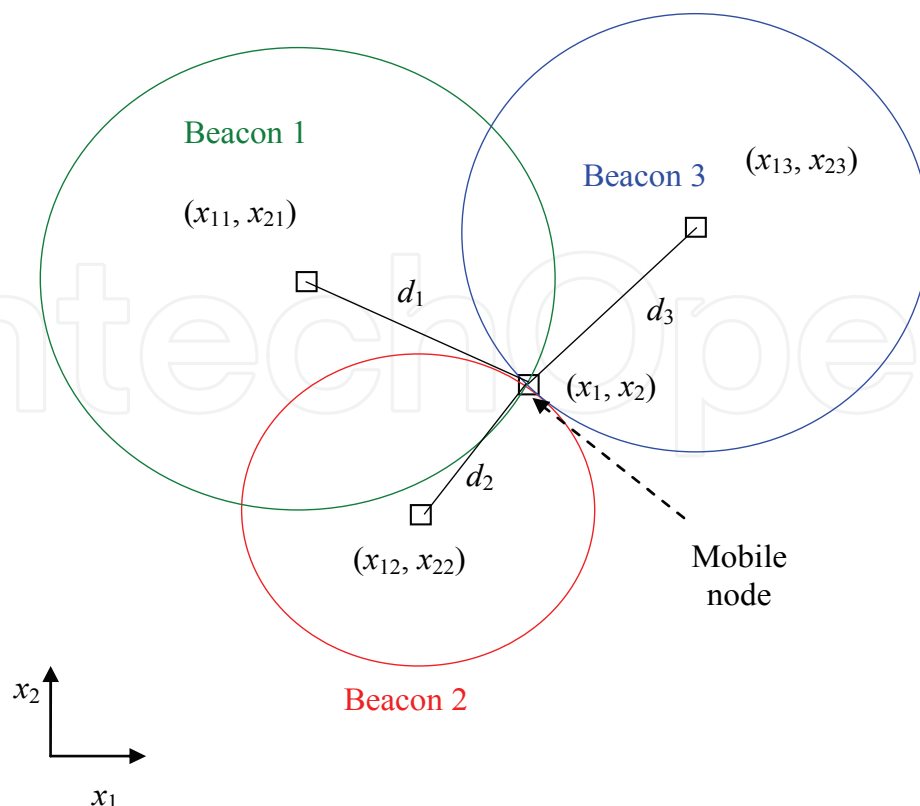
Fig. 1. Trilateration approach example for three beacons

3.1 Most frequent errors in indoors wireless communications
In what concerns RSSI measurement procedure, two types of errors are considered: systematic errors and random errors (Peneda *et al.*, 2009). For the first type the errors can be compensated or their effect minimized in acquisition process. The random errors are the ones that cannot be sufficiently modeled.

3.1.1 Systematic errors
Systematic errors are the ones that are possible to directly compensate (Peneda *et al.*, 2009). In trilateration method, the omnidirectional antennas properties are crucial. So any kind of errors that they introduce in the system make the results become worse. The omnidirectional antennas are not isotropic antennas, so for some directions the transmission power is different. One of these particular cases is when the transmission nodes have different heights. The power of transmission changes with the direction. In fixed nodes and target nodes, it is necessary to be careful with the position of each antenna because, the radiation pattern is not ideal.

So, to compensate these errors, ensuring that the nodes have the same height and the antennas position is the same is needed. With this configuration, some integrity in the results can be guaranteed. The solution could be achieved using antennas with a better radiation pattern, but this can make the localization system more expensive.

In this localization method, the distribution of fixed nodes is very important to the final result. As much more nodes localization system has the final result accuracy is better. Also, the distribution can not have an exceeding number of nodes, because this increases costs. Distribution has to take into consideration the metallic objects placed in industrial

environment (Tadakamadla, 2006). These objects induce a signal reflections problem and in a RSSI measurement this reflected signal can add to the received and measured signal without system knowledge.

If target node is in the middle of two metallic objects this could be a serious problem, because target node can communicate but signal reflections make target node estimate other position than the correct position. To improve a good distribution some distance from nodes to this metallic objects are sufficient to decrease the signal reflection errors.

The weather conditions, like temperature, relative humidity and pressure, in indoors environment, could influence the final result in the localization system. Equation (1a) shows that the RSSI measurement has a relationship with the RF propagation parameters A (dBm) and n_{Ai} ($i = 1,...,n$). These parameters change with these weather conditions and have different values as the signal attenuation in the atmosphere is not the same for all conditions. So, if RF propagation parameters are different, RSSI measurement changes for the same position. To prevent this error, target node has to know the accurate RF propagation parameters. The implemented framework, in this study, has a function that estimates the signal propagation parameters without the measurement of temperature, relative humidity and pressure. This function implements a mathematical process to estimate the RF propagation parameters but this process also depends on the RSSI measurements. So the measurement of temperature, relative humidity and pressure with this process could help to find better accurate RF propagation parameters. In addition, weather conditions also influence electronic components such as integrated circuits and batteries. Experimental results show, meanwhile, that if temperature and humidity do not change more than 10 % then RSSI measurements are not changed by these conditions. In fact, in indoors industrial environments, temperature and humidity usually do not change significantly in one day. This is confirmed by experimentation as humidity does not change in the same location and temperature also remains constant in one day in the same location. Because in indoors industrial environments, temperature and humidity are nearly constant in one day, RF propagation parameters A (dBm) and n_{Ai} ($i = 1,...,n$) need only to be adapted periodically (*i.e.* to perform system calibration). On the other hand, calibration can be made in an automatic way by the localization framework.

3.1.2 Random errors

Random errors are also possible to compensate, but a better result is not guaranteed (Peneda *et al.*, 2009). Signal reflection causes a random error because it is impossible to detect if a RF signal is reflected or not. Decreasing the signal reflection effect is possible as suggested previously. In addiction, signal diffraction and scattering are also found as random errors (Tadakamadla, 2006).

Transmission power and transmission frequency could induce some errors to the system. If power transmission is not controlled, all localization system fails because, to the same distance and the same RF propagation parameters, RSSI measurement becomes different. Also, due to electronics tolerance, some frequency deviations may appear which introduce errors.

RSSI measurement may not have enough resolution because it does not make a strong contribution to localization error. RSSI measurement of 1 dBm resolution is sufficient to not introduce conversion errors, because these errors do not have an influence to the localization accuracy. Other errors such as multi-path and interferences are the dominant contributions to localization errors.

3.2 Fixed nodes distribution

In this sub-section, fixed nodes distribution considerations are described, because this subject is very important to have good system performance. The distribution of fixed nodes is very important for the trilateration algorithm to be successful. Distribution of fixed nodes is dependent on the building lay-out (*e.g.* product buffers, machines, people walking paths) and building dimensions. In this line of thought, the fixed nodes distribution has to be a compromise between number of nodes and localization of them. Using trilateration method, at least three fixed nodes should be in range of a mobile node for trilateration to be possible to be performed. In practice, due to limitations in battery of fixes nodes or to obstacles in the middle of communicating nodes, at least four fixed nodes are adopted for this purpose. Four nodes at the worst case are adopted in order to face system difficulties such as node low battery voltage (*i.e.* needing to be replaced) or obstacles in range of the communication link which deteriorates RSSI measurement.

Also, at locations where product buffers are located, fixed node concentration is intended to be higher. Product buffers which have dimensions dependent on the requirements of storage space are also evaluated in terms of node concentration. Node distribution has to be rationalized in terms of cost with factors such as of battery replacement, software updates of reconfigurations, nodes replacement, etc. On the other hand, a zone that is better to make calibration of RF propagation parameters can be identified to be adopted by this system. There is a need of identifying several calibration zones and if a product buffer is very large then several calibration zones inside it can be chosen. Each calibration zone is chosen in order to identify typical RF propagation parameters A (dBm) and n_{Ai} ($i = 1,…,n$). This procedure is applied in warehouses where this system is deployed.

This system is intended to be a modular system in terms of easy setup and of specific applications independence. As much more nodes localization system has the final result accuracy is better. Also, distribution can not have an exceeding number of nodes, because this fact increases costs. Maintenance of system nodes also increases cost, so the higher the number of nodes the higher the system cost. Nodes distribution can be adapted to lay-out of environment in order to take advantage of more important zones where more mobile nodes are located (accuracy can be improved with more placed beacons). Distribution also has to take into consideration the metallic objects placed in industrial environment. Because of these limitations, the modularity of the systems becomes reduced and so these are some limitations of the localization system. As a communications framework can be adopted by this localization system, it may be necessary to add more fixed nodes to existing network in order to make possible locating mobile nodes. This is a constraint to the modular and low-cost localization system properties.

4. Error mitigation and experimental results

RSSI measurement accuracy is critical to get acknowledge on position in a localization system. A bad RSSI acquisition value makes localization system to have poor estimation. This makes the entire system to fail and there is no way to detect it. In order to improve localization system results, some compensation filters are applied in RSSI measurement process. Power consumption in ZigBee networks is low. Nevertheless, for reducing power consumption, the nodes should only communicate when necessary, transmitting power should be low but significant and therefore the system is able to perform well without the need of replacing batteries too many times.

This section presents some experimental results on RSSI measurements and on different height of beacons and of mobile node considerations which have to be taken into account.

4.1 Filters

Some measurement filters can be adopted to improve RSSI acquisition quality, namely that in equation (2) and others which save and compare past RSSI acquisitions and outputs most repeated RSSI value.

$$\text{RSSI}_i(k)_{acquired} = 0.75 \cdot \text{RSSI}_i(k)_{measured} + 0.25 \cdot \text{RSSI}_i(k-1)_{acquired} , i = 1,...,n \quad (2)$$

In equation (2), variable $\text{RSSI}_{acquired}$ is post-processed RSSI value and $\text{RSSI}_{measured}$ is RSSI value in raw input just after measurement. Parameter k is acquisition value order index.
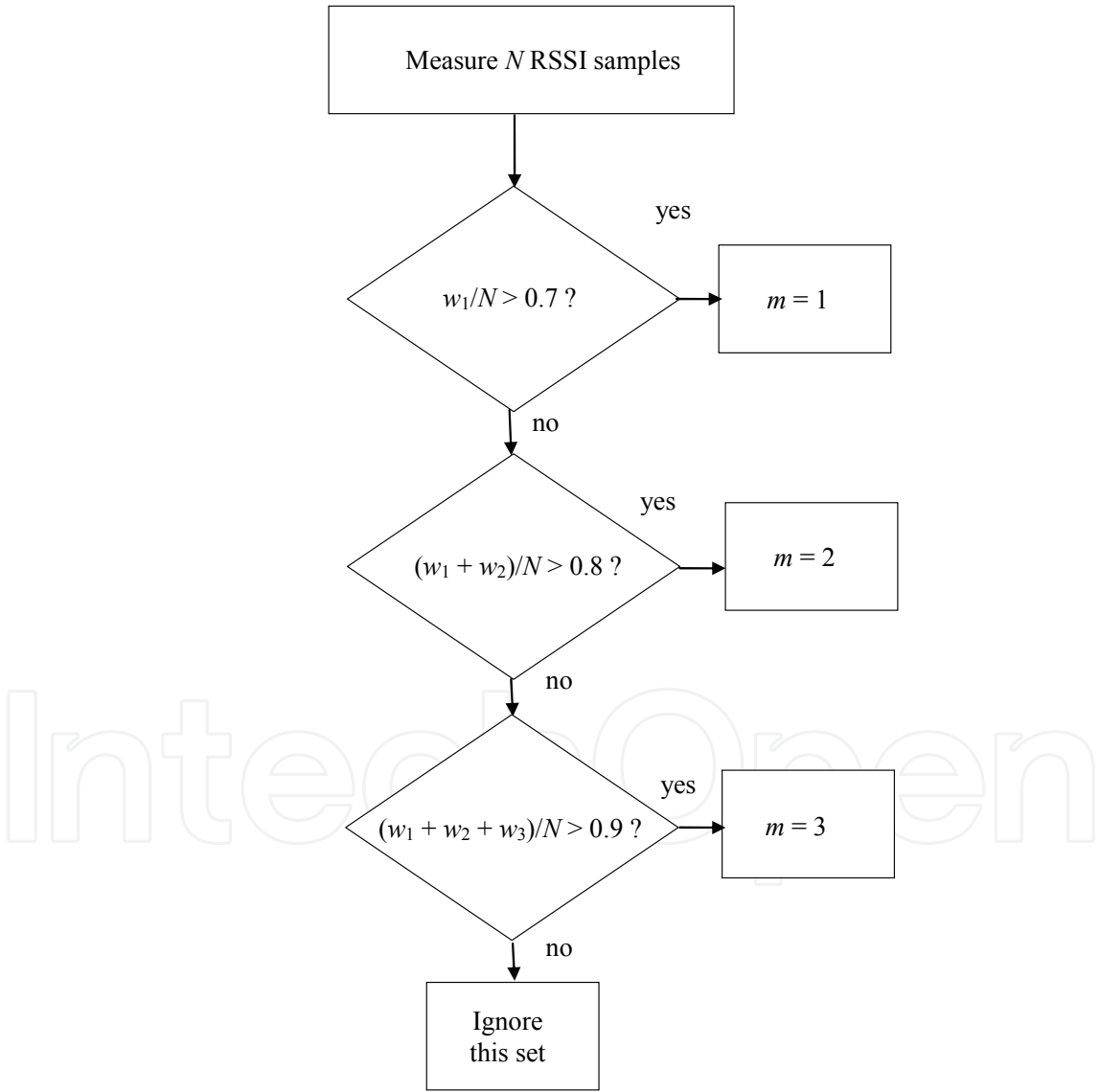
Fig. 2. Weighted-mean filter (3) algorithm

Weighted-mean filter (3) provides an average of the most repeated RSSI in set values. In set values there are some different RSSI values but only the most repeated values (one, two or

three different values) are considered. If there are more than three most repeated different values, the set values have too much variations and it is better not to work with this set.

$$\text{RSSI} = \frac{w_1 \text{RSSI}_{w1} + w_2 \text{RSSI}_{w2} + \dots + w_m \text{RSSI}_{wm}}{w_1 + w_2 + \dots + w_m} \quad m \leq 3 \qquad (3)$$

In equation (3) w_i ($i = 1, \dots, m$) is the number of repetitions of a RSSI value, and RSSI_{wi} ($i = 1, \dots, m$) is RSSI sample value repeated with number of repetitions w_i ($i = 1, \dots, m$). Figure 2 depicts filter (3) algorithm.

From knowledge of signal propagation conditions it is reasonable to estimate a signal level threshold which allows distinguishing 'good' measurements from 'bad' measurements. So, if w_1 is larger than 70 % of the measurements then RSSI = RSSI_{w1} is considered, else if $w_1 + w_2$ is larger than 80 % of them then $m = 2$ is considered.

These two types of filters have some differences between them. The first filter (2) is applied for every RSSI measurement in the sample. So it is difficult to get which RSSI measurement is good. The set of measurements in a sample, from which measurements are more constant, is considered as the good RSSI value. The second filter (3) is applied only after the sample set of RSSI measurements is completed and it ignores the measurements that have a low repeatability, which are considered as errors.

Filter (3) assumes that if w_1 is larger than 70 % of the measurements then RSSI = RSSI_{w1} is considered. RSSI is measured with a resolution of 1 dBm. So, for example, if w_1 is 70 % and w_2 is 30 %   and $\text{RSSI}_{w1} = -40$ dBm   and $\text{RSSI}_{w2} = -39$ dBm,   then filter (3) outputs RSSI = -40 dBm. This fact is supported by the reason that having another scheme of calculating RSSI with for example an arithmetic mean leads to an output that is not appropriate for dealing with practical RSSI measurement accuracy. With another example, if w_1 is 70 % and w_2 is 30 % and $\text{RSSI}_{w1} = -40$ dBm and $\text{RSSI}_{w2} = -35$ dBm, then filter (3) outputs RSSI = -40 dBm. This fact is supported by the reason that probably this result is the correct RSSI measurement. These assumptions are based on the fact that a resolution of 1 dBm is sufficient to be considered for the RSSI measurements. In fact, increasing this resolution does not increase system performance due to the noise added to those measurements and to the random errors. These errors are not possible to compensate in order to make worthwhile increasing resolution. Then, these errors, which are not possible to compensate, do not influence system accuracy, because a resolution of 1 dBm for RSSI measurement is sufficient.

Another task to be performed corresponds to RF output power. For example in ZigBee networks, the nodes should be requested to send a signal only when strictly necessary, being transmitting power low but strong enough to be effective. Using these recommendations, batteries can be used in an acceptable lifetime cycle for all communication nodes.

4.2 RSSI measurements

In Figure 3, working environment lay-out for experimental setup is depicted. There are four beacons (P2, P3, P4, P5) and a mobile node with unknown location. Lay-out corresponds to an indoors quasi-structured environment where temperature is about 23 °C and relative humidity is about 49 %. RSSI measurements for distinct time instants are shown in Figure 4 ($A = -41$ dBm). Each RSSI value is shown in Figure 4 after applying filter (3).

There are fluctuations in RSSI values during the time interval of measurements due to interferences in RF signal propagation. For the first two hours the fluctuations are larger and

then, due to the removal of a computer located near the mobile node, the interferences decreased. So, due to the presence of metallic objects near the nodes, some large RSSI measurement errors may arise. An active component, like a computer or industrial machines, has a contribution to RSSI fluctuations stronger than a passive metallic object. Having RSSI measurement errors, RF localization methods have then corresponding errors. This is the most important problem to handle in this type of localization method.
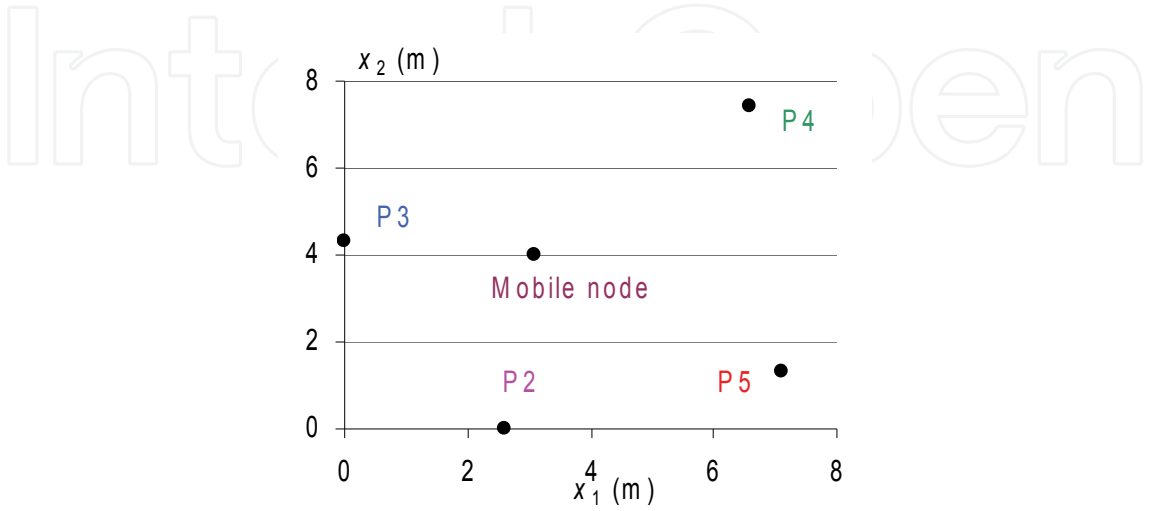
Fig. 3. Tested environment lay-out
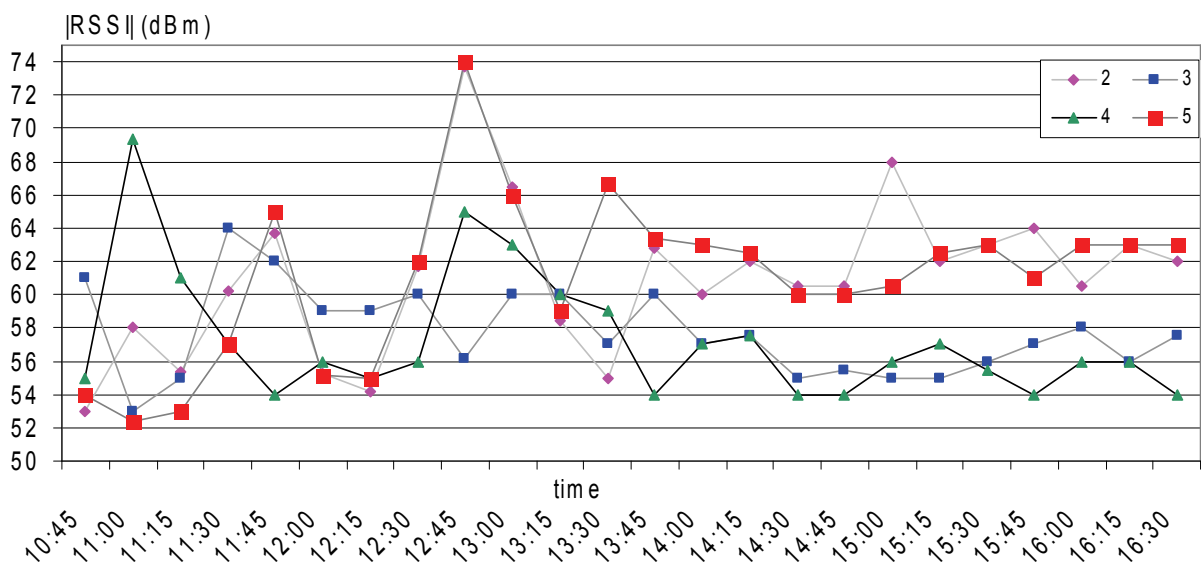
Fig. 4. RSSI measurements during nearly six hours with the same environment lay-out

Even in a good distribution for an industrial environment, some persons and objects could be moving (*e.g.* cars, automated guided vehicles, products) and this causes a poor acquisition. In fixed nodes distribution it is important that the localization system works well in these cases.

In this experiment four fixed nodes are used and the results corresponding to some of them are poor. In order to improve the final result, the network should provide all possible locations with more fixed nodes around them.

In the trilateration method, omnidirectional antennas properties are crucial. So any kind of errors that they introduce in the system make the results become worse. The radiation pattern is not completely a symmetrical one, so transmitted power is slightly different according to the transmitted direction. One of these particular cases is when the transmission nodes have different heights. The power of transmitted signals changes with the direction. In fixed nodes and target nodes, it is necessary to be careful with the position of each antenna because, as mentioned before, the radiation pattern is not ideal. So, indoors localization methods based on this approach requires calibration for different directions.

4.3 Different height of nodes

As written above and keeping the antennas orientation 'stable' in the time, trilateration algorithm is developed to apply to same height of both beacons and AGV. Otherwise, some corrections to RSSI values must be made to take advantage of trilateration algorithm. For example, consider Figure 5a where a beacon i is located at height h_i relatively to AGV. A special case occurs when h_i is smaller than 10 % of d_i. Then, this correction can be ignored because the approximation error is not significant (Figure 5b). In this case RSSI ≈ RSSI' can be assumed. This corresponds to the area between the line $h_i = 0.1\ d_i$ and $h_i = 0$ meters (grey area in Figure 5b). In these working points the correction can be ignored due to the small error of approximation.
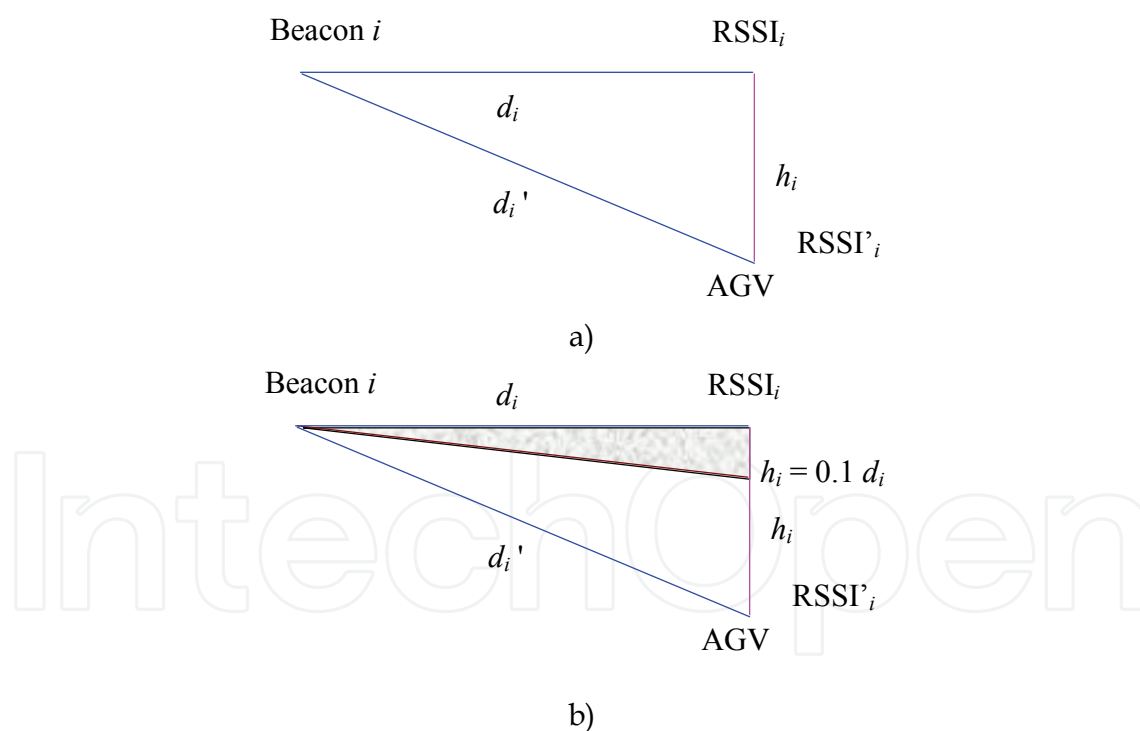

Fig. 5. Different height positions correction

Considering Figure 5a, the following equations (4a-e) are derived:

$$d_i = \sqrt{d_i'^2 - h_i^2} \tag{4a}$$

$$\text{RSSI}_i = A - 10\, n_{Ai} \log_{10}(d_i) \tag{4b}$$

$$\text{RSSI}'_i \approx A - 10n_{Ai}\log_{10}(d'_i) \qquad (4c)$$

$$\text{RSSI}_i - \text{RSSI}'_i \approx -10n_{Ai}\log_{10}(d_i) + 10n_{Ai}\log_{10}(d'_i) \qquad (4d)$$

$$\text{RSSI}_i \approx \text{RSSI}'_i - 10n_{Ai}\log_{10}\left(\frac{d_i}{d'_i}\right) \qquad (4e)$$

where equations (4a-e) are the corrections to apply to RSSI values in order to make possible the adoption of trilateration algorithm without modifications. Some issues are also raised now because distances from AGV to beacons are unknown. So, some type of distance estimation should be made or, by other means, a look-up table relating RSSI values can be made off-line. Using a look-up table eliminates the need of estimating distances but introduces interpolating errors which for high distances can become unpractical. In some cases, a look-up table can be used for correcting RSSI values obtained in range of obstacles with known location in order to overcome limitations of RSSI measurement in indoors quasi-structured environments.
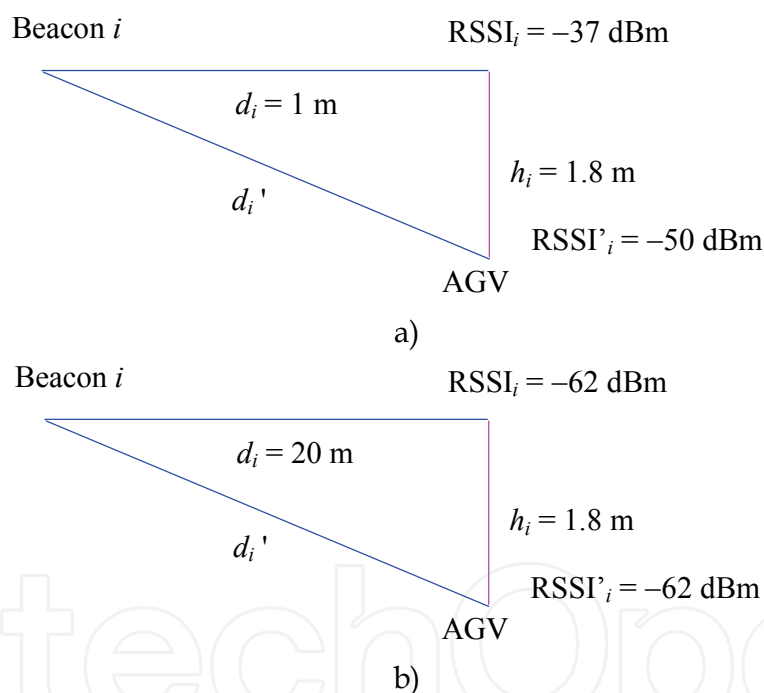

Fig. 6. Different height positions experimental results

Considering Figure 6, an example of RSSI measurements is shown. Figure 6a confirms the need of taking into account the different height for the beacon and for the mobile node antennas. So, this result confirms equation (4e) for $n_{Ai} = 3.25$. Figure 6b, on the other hand, confirms the negligible error occurred when the height difference of antennas can be neglected as h_i is smaller than 10 % of d_i.

So, to compensate these errors, ensuring that the nodes have the same height and the antennas position is the same is a good practice. With this configuration some integrity in the results can be guaranteed. The solution could be achieved using antennas with a better radiation pattern, but this can make the localization system more expensive. Nevertheless, some constraints on space limitations can lead to the different heights of nodes occurrence.

5. Trilateration experiments

Some localization results using commercial chip CC2431 from Chipcon (Texas Instruments) are shown in this section. This chip accepts location of fixed nodes and their corresponding $RSSI_i$ ($i = 1,…,n$) and it accepts a single RF propagation parameters set (*e.g.* $A = -40.0$ dBm, $n_{Ai} = 2.50$). Then, after computing mobile node location estimate, this output result can be analyzed in order to obtain the chip localization performance.

Locations of beacons and of mobile node are depicted in Figure 7. Beacon i is located at position P_i ($i = 1,…,4$). $RSSI_1 = -51$ dBm, $RSSI_2 = -52$ dBm, $RSSI_3 = -43$ dBm and $RSSI_4 = -60$ dBm are measured within communications sub-system. Filter (3) is applied in order to obtain these RSSI results. In this experiment, RSSI values after filtering are nearly constant in time, in contrast to that results encountered in Figure 4. This fact leads to a better performance of localization system.

Trilateration is made using localization engine of commercial ZigBee network chip CC2431 with several RF propagation parameters combinations: i) $A = -40.0$ dBm, $n_{Ai} = 2.50$; ii) $A = -36.5$ dBm, $n_{Ai} = 3.00$; iii) $A = -36.5$ dBm, $n_{Ai} = 2.75$; iv) $A = -37.5$ dBm, $n_{Ai} = 3.00$. This chip considers A and n_{Ai} communication link i parameters ($i = 1,…,n$) equal respectively to all links i. So, this is a constraint for this localization engine, because parameters A and n_{Ai} are the same for every link i ($i = 1,…,n$).

Nodes transmitting power is programmable within this ZigBee network and it must be set according to a compromise between battery lifetime and effective communications power for at least a twenty meters span workspace. In free space, ZigBee protocol can meet requirements of some 64 meters for workspace span.
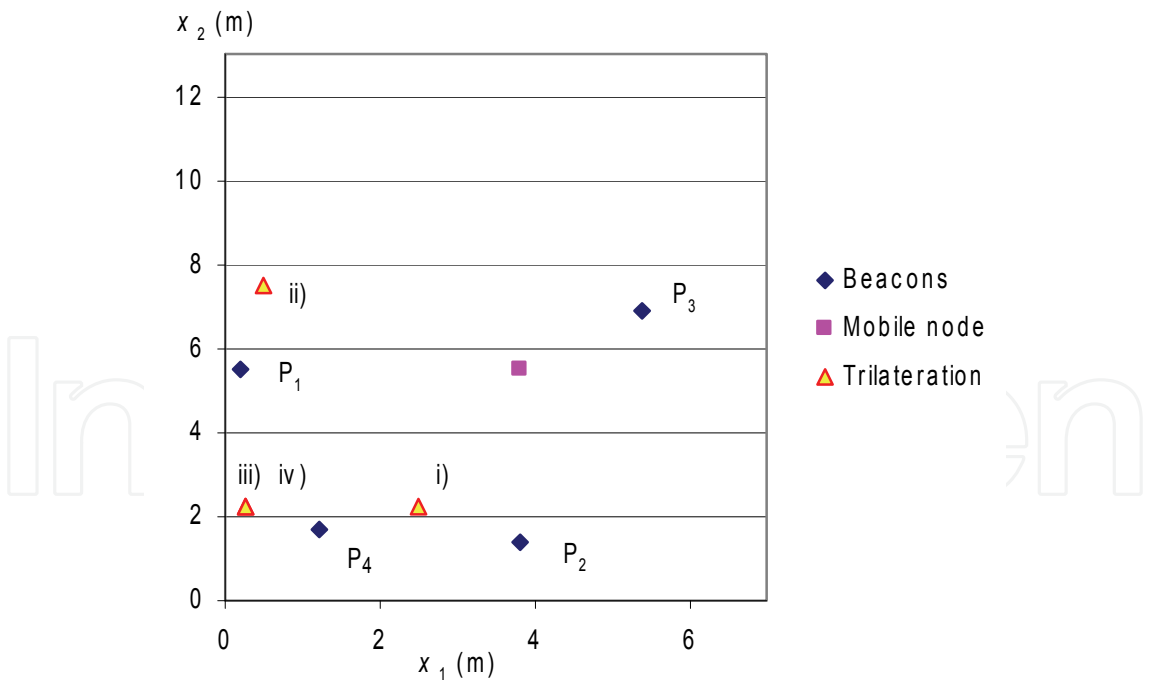

Fig. 7. Trilateration example using ZigBee commercial hardware

As it can be concluded by analyzing Figure 7, parameters A and n_{Ai} strongly influence trilateration localization error. So, in order to obtain better localization results, these parameters should be carefully estimated. Parameters A and n_{Ai} estimation is therefore a crucial factor in order to get a good localization performance using this commercial chip. In

this experiment, parameters A and n_{Ai} variations are small but, as it can be concluded, they influence greatly the localization accuracy. This workspace dimensions are reduced in terms of maximum workspace dimensions. In fact, workspace dimensions are only limited by the total number of network nodes accepted by the system specifications (which are related to maximum radiation allowed by ZigBee protocol and transmitting power). Therefore, maximum transmitting power is limited by ZigBee protocol and so, in this way, workspace dimensions are limited.

6. Future research directions

Future research work is planned to develop computation of distances from receiver to transmitter using RSSI for trilateration schemes and are intended to be compared in terms of interpolation algorithms. Filters that process RSSI raw measurements are a key research direction in order to improve distances evaluation. Using available commercial chips to carry out trilateration schemes using RSSI measurements is also a future research direction. New commercial chips are now a main experimental material under test. New chips may have more stable transmission power signals and better frequency stabilization. Studying and comparing AGV localization performance of triangulation and trilateration is also intended to be exploited. Experimental work with artificial neural networks for localization improvement is also in progress.

According to experimental results, systematic errors resulted from increasing received signal power when reflections happen. Then, it points out to optimize the physical configuration of the mobile network through elimination of reflection paths between the nodes. For instance, the current communicating node (*i.e.* current beacon to perform trilateration) must be installed closed to the ceiling of the space where the measurements are performed.

7. Conclusion

In this chapter, a trilateration scheme based on RSSI measurements for indoors localization in quasi-structured environments is presented. Procedure for trilateration has some characteristics which are summarized below:

- Localization error in general increases with increasing distance d_i ($i = 1,…,n$);
- $RSSI_i$ ($i = 1,…,n$) values need to be accurately acquired to minimize localization error.

In current chapter, research is done in an indoors quasi-structured environment. Results show that a localization accuracy of down to three meters is possible depending on the lay-out of environment (*i.e.* objects and persons moving or placed in the environment and building construction materials). If post-processing filters are developed then an increase of accuracy is expected to be obtained. The main radio propagation link i parameter with influence on the localization accuracy is n_{Ai} ($i = 1,…,n$). For long distances d_i ($i = 1,…,n$), corresponding RSSI is lower, so localization error increases accordingly. Errors affecting attenuation parameters evaluation correspond to localization errors and minimizing them is therefore a current research direction.

An experiment on RSSI measurement with application of filtering is shown to minimize interference effects. In this localization method, the distribution of fixed nodes is very important to the final result. As much more nodes localization system has the final result accuracy is better. Also, distribution can not have an exceeding number of nodes, because this fact increases costs. Nodes distribution can be adapted to lay-out of environment in

order to take advantage of more important zones where more mobile nodes are located (accuracy can be improved with more placed beacons). Distribution also has to take into consideration the metallic objects placed in industrial environment. Because of these limitations, the modularity of the systems becomes reduced and so these are some limitations of the localization system. These objects could induce a signal reflections problem and, in a RSSI measurement, this signal reflection effect changes the power of the received and measured signal being difficult to process it. Some issues on systematic and random errors found in this RF trilateration scheme are therefore presented such as antennas imperfections, different heights of fixed nodes antennas and mobile nodes antennas, interferences and other problems required to have their effects minimized.

This approach has properties which are dependent on the application of localization, because lay-out influences beacons distribution. Nevertheless, this system can be considered a modular system because, having taken some care in choosing distribution of nodes, this system is easy to setup and it can be deployed in a systematical way.

Weather conditions in indoors quasi-structured environments are not a question to be taken into consideration, because they do not change in a day according to experimental results. So, calibration (*i.e.* of RF propagation parameters) is made periodically in order to take weather changes into account. Also, automatic calibration (*e.g.* daily) can be programmed.

This chapter ends with a trilateration experiment (section five) using ZigBee commercial hardware and some insights on RF propagation parameters influence are presented. In fact, these parameters are very important to be estimated accurately in order to reduce localization error.

8. Acknowledgements

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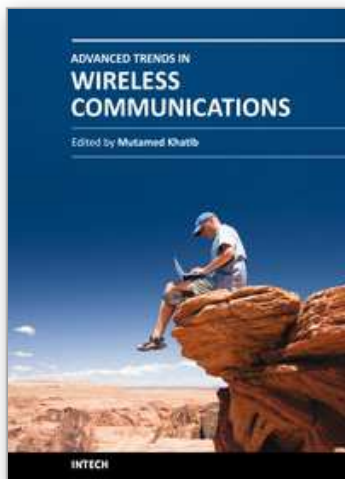
Advanced Trends in Wireless Communications

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Physical limitations on wireless communication channels impose huge challenges to reliable communication. Bandwidth limitations, propagation loss, noise and interference make the wireless channel a narrow pipe that does not readily accommodate rapid flow of data. Thus, researches aim to design systems that are suitable to operate in such channels, in order to have high performance quality of service. Also, the mobility of the communication systems requires further investigations to reduce the complexity and the power consumption of the receiver. This book aims to provide highlights of the current research in the field of wireless communications. The subjects discussed are very valuable to communication researchers rather than researchers in the wireless related areas. The book chapters cover a wide range of wireless communication topics.

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