Indoor Localization of the Points of Interest using RO-SLAM

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Abstract: This paper describes an indoor localization system based on RO-SLAM technique, which has been led to experimentation. The proposed system has been considered to have low power consumption. The nodes of the network are based on the well-known architecture TelosB. A distance estimation study has been developed in order to determine the relationship between radio power signal strength in a radio link and distance between nodes. This relationship has a high variability and given its importance for successful tracking, much of this work has been devoted to its study. This system could be applied as a usefull solution for localization in a warehouse, where GPS-based system does not work. Based on the results obtained, this system is deemed as feasible because the motes have been localized with an acceptable error (1.2 m) under real conditions.

1 INTRODUCTION

This work, on the one hand, evaluates experimentally the accuracy of a particular estimation of the distance from the power level of received signals using a sensor network deployed with TelosB motes (J. Polastre, 2005), and on the other hand, it uses such estimations as input to an implementation of the RO-SLAM algorithm (*Range-Only Simultaneous Localization and Mapping*) (F.R. Fabresse, 2013) to find the coordinates x and y for each device.

The organization of this paper is described as follows. First, the objectives of this work are described. Second a panoramic of the distance estimation methods based on RSSI is addressed. From this study a method of estimation, which will be led to experimentation, will be selected. The whole description of the system used is given in section named *System Study*. Then, the evaluation of the estimated distance calculation and the mote position estimations are explained in section *Experimental Results*. Finally, the paper includes a section of conclusions and certain approaches for future work.

2 OBJECTIVES

The main objective of this work is the localization of multiple fixed targets or markers, distributed in a completely unknown environment using a mobile system or robot which do not know its position.

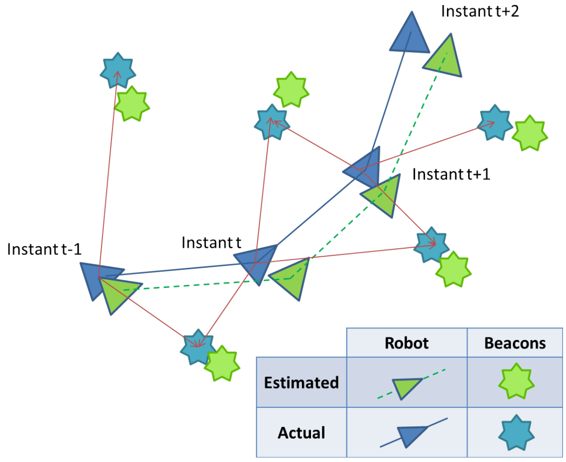


Figure 1: SLAM problem diagram.

An application of this approach could be the location of goods (beacons) on a large warehouse (unknown environment) taking advantage of a common mobile system, such a truck cleaning, a crane, a trolley, etc. In other words, the problem is to solve the case in which a mobile system is in an unknown map and an unknown position. When the system moves, the system builds incrementally a map and determines its position in this map.

This problem, as shown in Figure 1, can be solved using different approaches. A booming technique in recent years, with interest to research is to employ the

RO-SLAM method. An interesting article about RO-SLAM is described in (J.L. Blanco, 2008).

The beacons or landmarks, which are shown in Figure 1, are the characteristics of the map that provide a quantifiable measure of what has been the movement of the system. For this purpose, it is possible to use a wide variety of sensors: lasers, cameras, sonar, wireless sensor networks, etc.

The difference between SLAM and RO-SLAM is based on the fact that, RO-SLAM solves this problem considering that the information received by the system is only the distance to the beacons. That is, the system knows that it has a beacon at a distance fixed but the direction is unknown. SLAM also knows the direction in which the beacon is located. The RO-SLAM scenario allows the use of simplified sensors: less sophisticated and therefore less expensive sensors.

A frequent and cheap way to implement a distance sensor is based in the use of wireless communications. There are many manufacturers that provide this kind of sensors. Therefore, to make a localization based on the power level of the RF signals (*Received Signal Strength Intensity*, RSSI), the first step is to have a quantitative correlation between distance and power level of a radio link. This essential first step has required a big percentage of the time spent on the development of the work described in this paper. The success of the localization technique designed is based on the accuracy of this step.

3 PANORAMIC OF RSSI VS DISTANCE MODELS

This section collects a summary of the most important models presented in the literature that relates the strength of the radio signal received in a wireless device and emitted by a transmitter and the distance between them.

Currently, the RSSI propagation models in wireless sensor networks (WSN) include the model of free space, the bidirectional ground reflectance model and the log-normal shadow model or log distance path loss model (J. Xu, 2010).

The free space loss (*FSL*) measures the spread of the power in free space without obstacles. If the distance (d) is measured in meters and the frequency (f) is measured in hertz, the formula of the FSL could be:

$$FSL(dB) = 20log_{10}d + 20log_{10}f - 187.5 \quad (1)$$

In practice, the relationship between distance and received signal power is more complex than the above expression. Actually, the received power will be the sum of a series of signals coming from different directions, due to reflections objects and obstacles that partially block the signal. Thus, the received power resulting may be higher or lower than the output when space free.

The ground bidirectional reflectance model is very accurate when used in urban environment (J. Xu, 2010) but can not be applied to the context of this work due to the heights of the antennas (below 50 meters).

Furthermore, the log-normal shadow model is a more general propagation. It is suitable for both indoor and outdoor communications. The model provides a number of parameters that can be configured according to different environments (J. Xu, 2010). The model is usually expressed as the following equation:

$$L(dB) = P_o + 10nlog_{10}(\frac{d}{d_o}) + X_\sigma \quad (2)$$

Where L is the loss of power on the path, n is the path loss exponent, d is the distance between transmitter and receiver, X_σ is a Gaussian random variable with standard deviation σ and P_o is the received power referenced in the distance d_o.

Over the years there have been a large number of models to predict the path loss in typical wireless environments as large urban cells, small urban cells, and more recently in buildings. These models are mainly based on empirical measurements at different distances for a given range of frequencies and in a particular geographical area or building. Examples of these models are the model Okumura, Hata model or model of COST 231 (H. Rábanos, 2006). All these models are complex for their application in the present work, therefore the simplified model of the log-normal shadow model is chosen for the experimentation.

This simplification is specified by Chipcon in (A. Faheem, 2010). Chipcon is a transceivers manufacturer of the TelosB motes. The RSSI is given by the following expression:

$$RSSI(dBm) = -10nlog_{10}d + A \quad (3)$$

Where n is the propagation exponent, d is the distance from the transmitter measured in meters and A is the strength of the received signal at a distance of one meter. In this approach to the problem, *RSSI* and A parameters are known. In this way, n (4) can be cleared and estimated as an average with each pair of (RSSI, distance) collected in the experiment to find a plausible parameter value. Then, the distance (5) can be cleared in order to calculate its estimated value according every RSSI value. Finally, it is interesting to

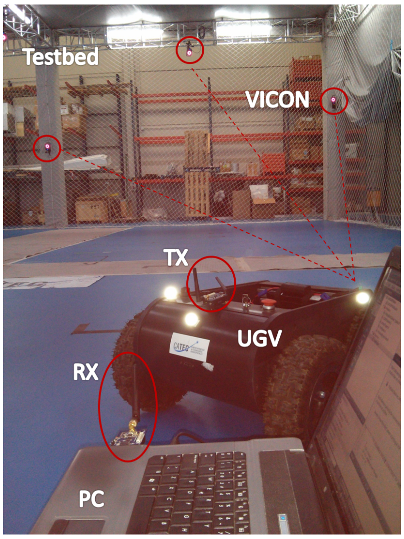


Figure 2: System with UGV (Unmanned Ground Vehicle).

quantify the error with that approximation.

$$n = -\frac{RSSI - A}{10nlog_{10}d} \quad (4)$$

$$d = 10^{-\frac{RSSI-A}{10n}} \quad (5)$$

This approach presents a problem of validation. Experimentally it is proven to be valid only beyond one meter distance between transmitter and receiver.

4 SYSTEM STUDY

During the workflow, the system used for the study has evolved. The systems used in chronological order have been:

- Simulation system based on ROS (Robot Operating System) (ROS, 2015) and MRPT (Mobile Robot Programming Toolkit) (MRPT, 2015), which estimates the positions of beacons using RO-SLAM algorithms. Using this simulator, the accuracy of estimated positions was tested versus:
  - Number of beacons.
  - Concentration of beacons.
  - Error distance.
  - Error odometry.
  - Robot route.
- Actual system (Figure 2) formed by:
  - an UGV (Unmanned Ground Vehicle),
  - two TelosB motes with external antennas, MTM-CM3000 MSP Rev 01 model (TelosB, 2015) and

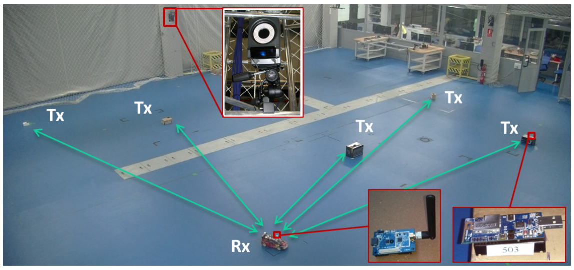


Figure 3: System for RO-SLAM.

  - the infrared positioning system, VICON (VICON, 2006) as ground-truth[1].

  This system has been used to evaluate the estimated RSSI/distance relationship.
- Actual system formed by:
  - an autonomous car in scale,
  - six TelosB motes with intern microstrip antennas and other one with external antenna for the reception.
  - The VICON system as ground-truth.

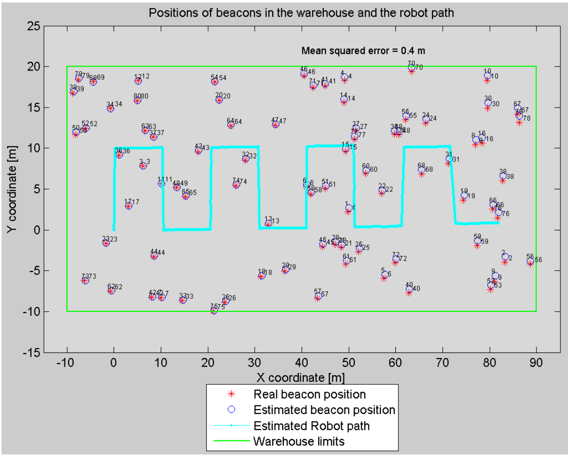
  This system has been used to evaluate the estimated localization of the motes using the RO-SLAM technique.

Thanks to the simulation system, three major conclusions are obtained:

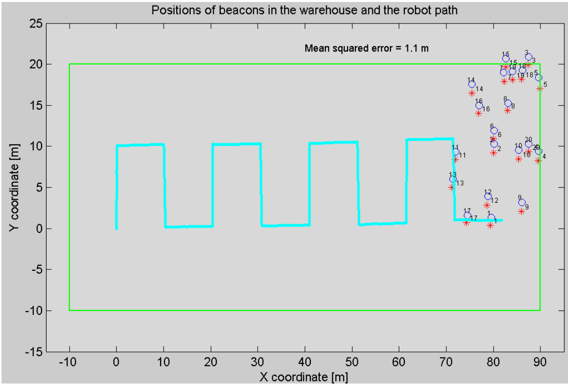
- Odometry information is necessary in a RO-SLAM system if you want an acceptable RMS in position (e.g less than 5 meters).
- The concentration of beacons and path robot are decisive. The best situation is a rich homogeneous concentration characteristics (shown in Figure 4(a)).

  If at the beginning of RO-SLAM algorithm no input data are obtained (as shown in Figure **??**), it will accumulate biggest error in the above situation. Similarly, the error decreases (uncertainty of the beacon positions is reduced) more rapidly as soon as the robot turn. Therefore, if the robot does not rotate at the start of its travel, the obtained location is worst (as can be seen in Figure 4(c)).

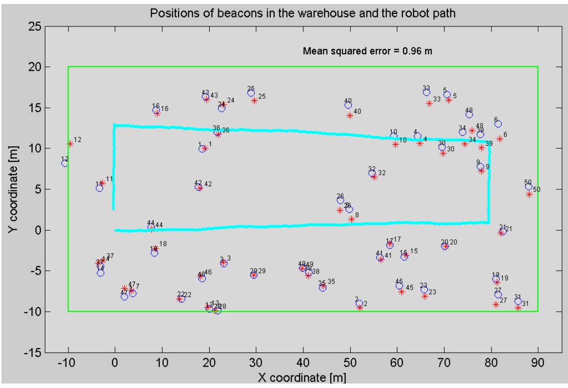
[1]The VICON system is the most advanced optical motion capture system available. Determines the position of the moving objects in the volume which controls with a millimeter accuracy and very low latency (2.5 ms). Reflective marks will be placed on those objects that we want to capture their movement. As shown in Figure 2, these marks are added to UGV. In this manner, its position is known at any instant and the distances to TelosB motes (whose positions have also learned using VICON) can be calculated.



(a) Analysis of the number of beacons.



(b) Analysis of the arrangement of beacons.



(c) Robot path analysis.

Figure 4: Simulation results.

- Distance errors are obtained as far away surroundings $[0.6, 1.2]$ m under favorable conditions.

Based on these results, the actual experiments focus on a homogeneous deployment of beacons. This way since $t = 0$, the robot receives signal transmitting motes considering a reliable odometry.

All the software used in this study was designed and implemented in C/C++ language. Including communications systems, logging, configuration and control. The control part refers to the drivers of mobile platforms implemented in Matlab/Simulink©. Also, the scaled RC car has been modified to have an autonomous position control by adding a new design hardware based on the board Raspberry Pi (Raspbery Pi, 2015).

The software embedded on the motes manages the communications between motes. This software is based on the tutorial *Demo RSSI* (RSSI Demo, 2015). The communication is configured to send data every 100 ms and the transmission power is not restricted so that there is constant communication throughout the testbed. The communication channel used in the CC2420 transceiver is channel 26 (TinyOS toolchain, 2014) corresponding with the center frequency 2480 MHz. In this way, there are no problems of interference between wireless communication (IEEE 802.11g) as shown in Figure 5 because the channel 13 is not used in the work environment.

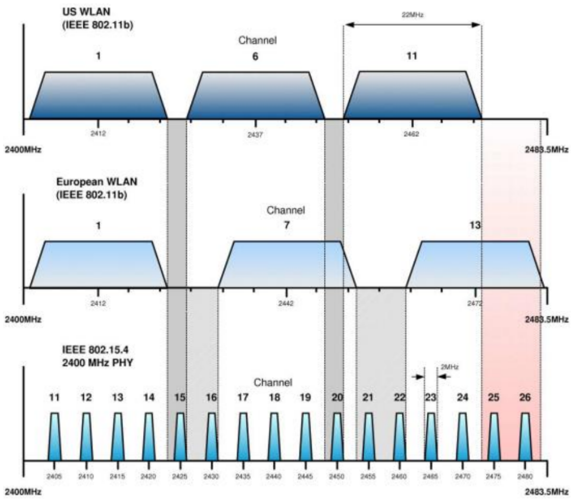


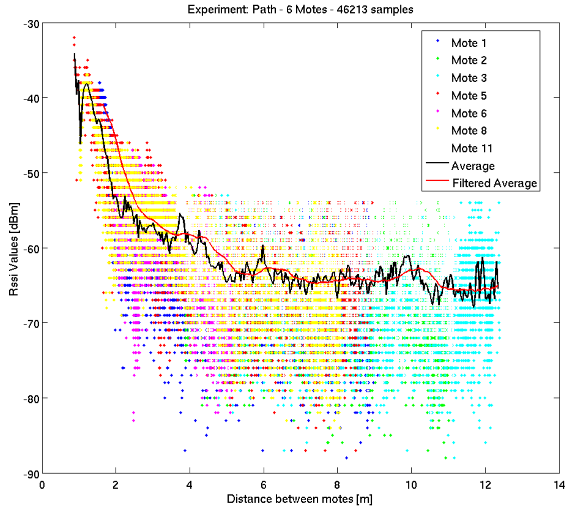
Figure 5: No channel overlapping between WLAN and LR-WPAN[2].

5 EXPERIMENTAL RESULTS

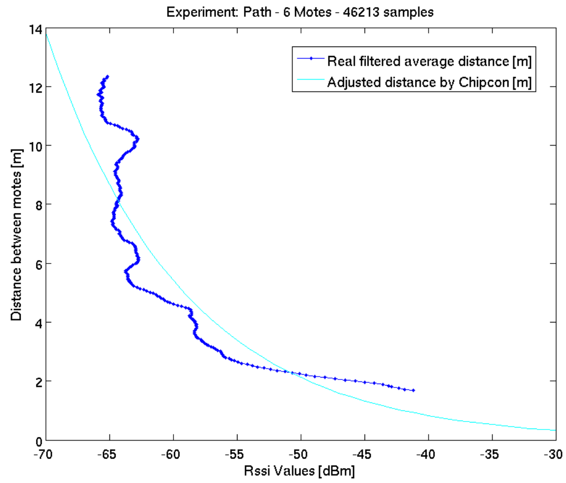
In this section all results and analysis of the files stored during the experiments are included. The processing of these data was performed using the Matlab tool.

It is needed to know that the CC2420 transceiver of TelosB devices calculates the RSSI of 8 symbol periods and stores the result in the record

[2]Keep in mind that the division of channels in 802.11b is the same as in 802.11g.

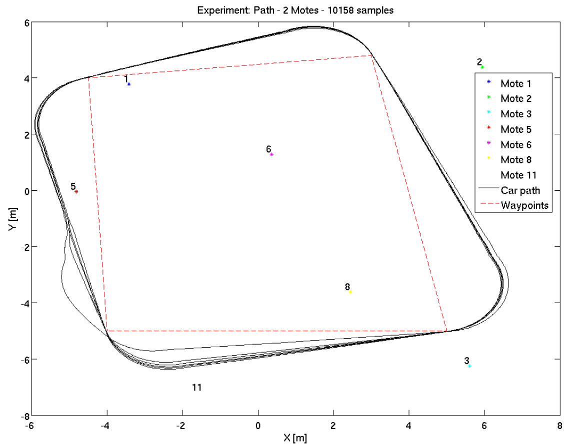


(a) RSSI measurements versus radio link distance.

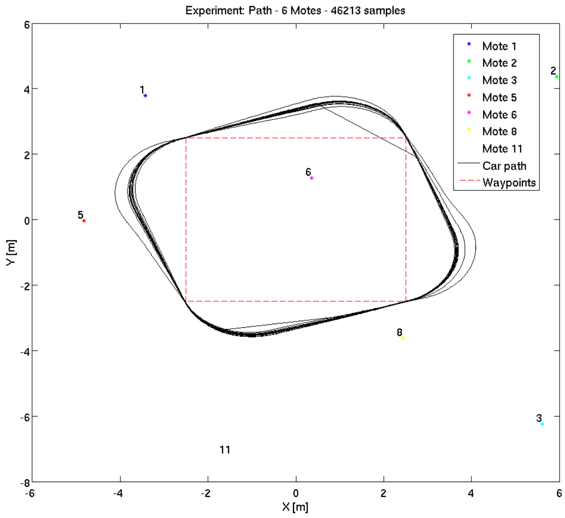


(b) Chipcon model adjusted to the samples.

Figure 6: Received Signal Strength Intensity (RSSI) samples and generated model.



(a) Ground-truth 1.



(b) Ground-truth 2.

Figure 7: Robot paths and mote locations.

RSSI.RSSI_VAL. Texas Instruments specifies the formula 6 to calculate the received signal power (P) in dBm.

$$P = RSSI\_VAL + RSSI\_OFF\_SET \qquad (6)$$

The $RSSI\_OFFSET$ of CC2420 is empirically found during development of the system. It is approximately $-45dBm$ (CC2420 Datasheet, 2007). The graphics contained in the present document have that offset added to the captured data during the experiments.

5.1 Results of the Distance Estimation

In Figure 6(a), it is possible to appreciate the great variability of RSSI data and data discretization ($1dBm$). This is the discretization of the sensor hardware.

Given the variability of RSSI data for a same distance, a previous treatment is applied in order to minimize the data variability. The procedure to minimize it is based on the calculus of the average of the data. This is an approach used in various studies such as (J. Xu, 2010). Furthermore, a 20th order data filtered has been made, as shown in Figure 6(a) to calculate the unknowns Chipcon model.

The model obtained against the actual distance based on the RSSI values is shown in Figure 6(b) where the root-mean-square error (RMSE) is 0.9 m in the distance range [1, 10] m. This is the validity range of the approach. All these measures were collected during the execution of the experiments shown in Figure 7 at slow velocity (0.01 m/s).

Samples collected at high speeds (1 m/s) have

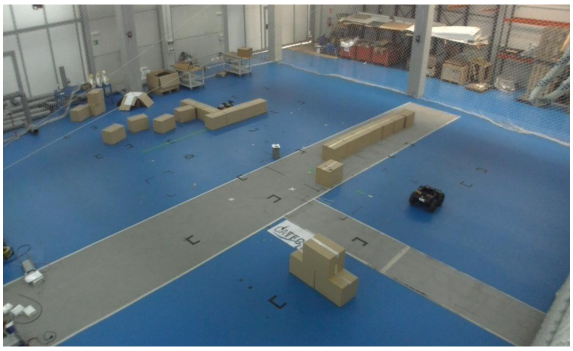


Figure 8: Experiment with constant obstacle in the radio link.

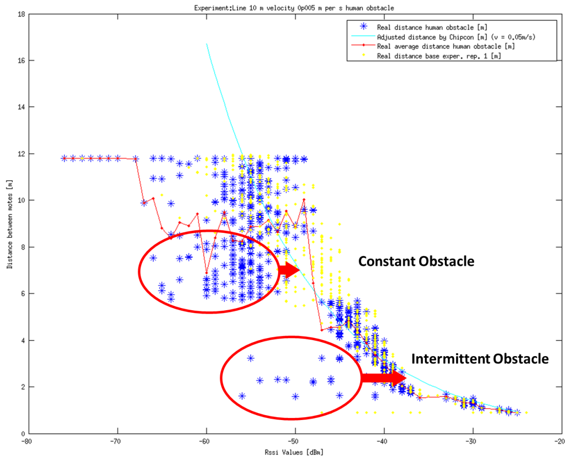


Figure 9: Relationship RSSI/distance with intermittent obstacle in LOS.

been also analyzed, and except for the logical reduction of the samples, no significant change in the previous ratio RSSI/distance is appreciated.

Furthermore, experiments have been conducted to evaluate the effect of obstacles. First, by the transit of a person in the LOS[3] and second, using a permanent carton wall placed in the LOS of the communication, as shown the Figure 8.

In the case of the person transit, given the multipath communication of the scenario and the obstacle used in the experiment which does not obstruct the entire Fresnel zone, the communication between motes is not interrupted. But it is causing a decreased level of received signal and therefore, the estimated RSSI/distance using the relationship of the basic experiment (same conditions but without obstacle) has major errors.

When there is decrease in the received signal strength, the estimation indicates a farther distance between the motes when in fact they are closer. This situation is caused by the fact that the communication between nodes is occluded. This is shown in Figure 9, where a set of samples have been shifted to lower RSSI values having the same distance from the basic experiment.

In the case of carton box, the obstacle has no impact on the Fresnel zone due to the absorption of the radio signal by this material is insignificant. Therefore, the collected samples during the experiment does not reflect the existence of an obstacle in the LOS.

Finally, experiments have been performed using the technology 802.11g, where it has been evidenced that the estimated model fits the data worse (the RMS error of the approximation increases) when the hardware is changed.

[3] *Line Of Sight*

5.2 Results of the Localization Estimation using RO-SLAM

In this section the estimation of the positions of the motes for three conditions are evaluated:

- No odometry error (Figures 10(a) and 11(a)).
- Low odometry error, 0.001 m and analyzing only the measures included in the validity range of the estimated model (Figures 10(b) and 11(b)).
- Odometry error 0.01 m (Figures 10(c) and 11(c)).

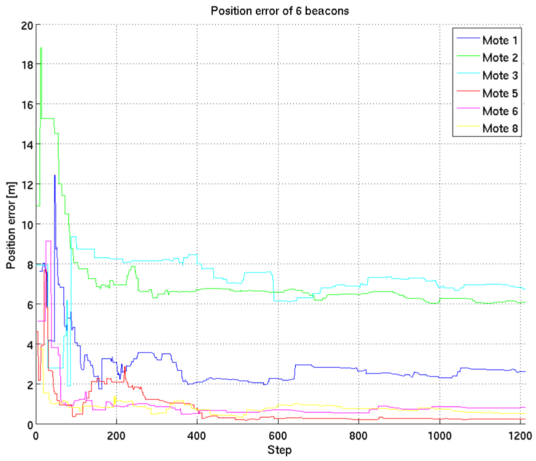
In the most favorable situation (without odometry error), three motes are perfectly located (RMS less than a meter). If the mote disposition is observed, these three motes coincide with the motes that are within the route and therefore, available RSSI measures are over 360 degrees. The worst located motes are far away from the robot path.

If the odometry error is increased to 0.001 m (by adding a normally distributed variable error to the actual displacement), the location of the central motes (5, 6 and 8) is worse but using the validity range of the Chipcon model, distances between 1 and 9 meters, the location of far motes is improved by a meter.

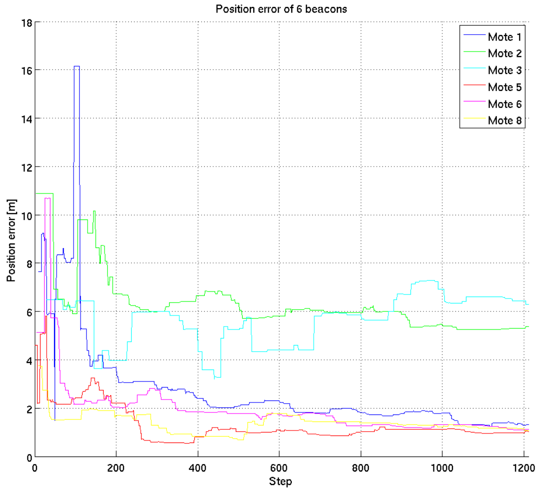
Finally, the rise of odometry error to 0.01 m causes a significant increase in RMS (several meters), except in the mote 8 in which it remains close to one meter.

Based on these results, it can be concluded that the validity range of the model should be applied. It could be even limited to the best modeled area $[2.5, 7]m$. Furthermore, a mote is better localized if the mobile robot includes measures in all directions around it.

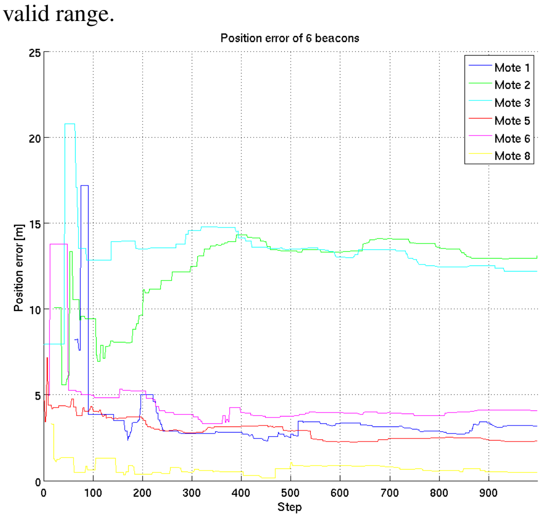
In the first instance, this system is valued due to the fact that the motes can be located with an acceptable error (1-2 meters) under real conditions. An error



(a) Case: No odometry error.

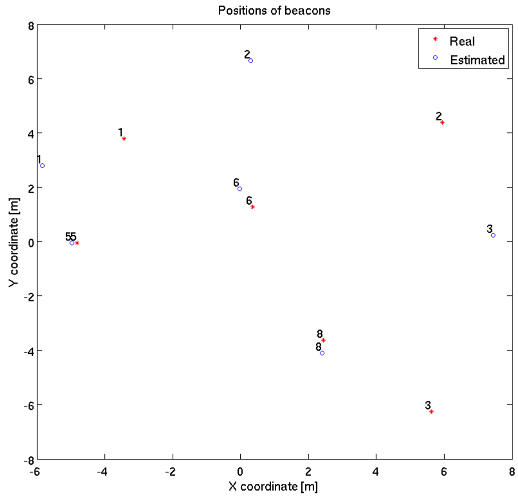


(b) Case: Odometry error 0.001 m and measurements into valid range.

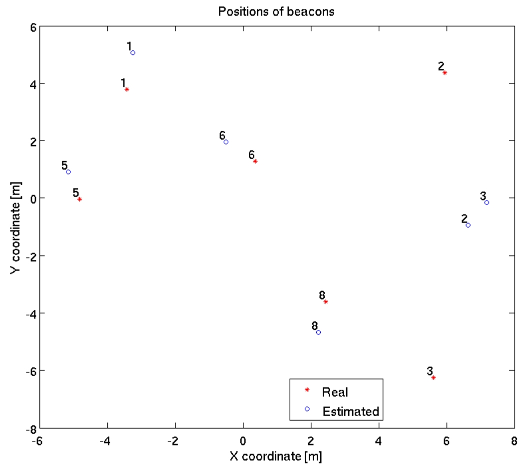


(c) Case: Odometry error 0.01 m.

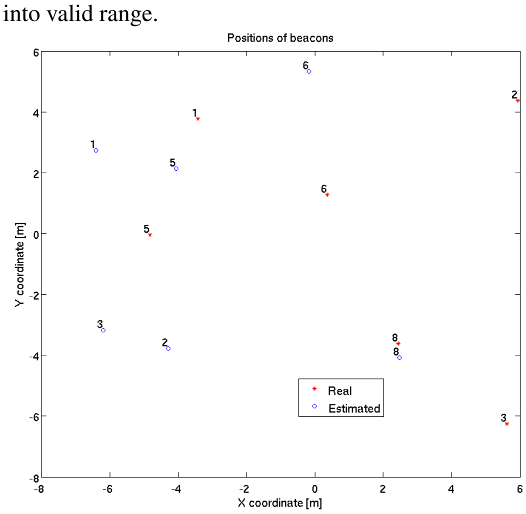
Figure 10: Error evolution during the mote location estimation.



(a) Case: No odometry error.



(b) Case: Odometry error 0.001 m and measurements into valid range.



(c) Case: Odometry error 0.01 m.

Figure 11: Actual mote locations and its estimation.

odometry 0.01 m can be assumed by sensors on the market today. However, the system must be brought into a more extensive testing campaign covering topics such as obstacles.

6 CONCLUSIONS

Thanks to this work certain limitations and aspects of the RSSI/distance relationship that have been applied in the development of an indoor positioning system based on RSSI measurements are known.

Talking about the distance estimation and the estimation of the mote positions, the results are promising. More data collection, refinement parameters and the application of techniques more advanced could reduce the obtained errors and make the system robust to adverse conditions. The indoor localization for most applications, such as navigational assistance or finding property (about one or two cubic meters) in a warehouse (100 or 200 m), an error of 1 or 2 meters is acceptable.

7 FUTURE WORK

The central problem of this work is very wide and can be extended along different paths and objectives. Some of them are:

- Repeating the experiments in other different environments: free space, rich in metal scenarios, communication between rooms, floors, etc.
- Study of the filtering techniques and data fusion as the radio link quality, LQI, for best results as (S.J. Halder, 2012).
- Comparison with other wireless devices with different hardware and features.
- Greater experimentation with RO-SLAM, even approaching it to a 3D location.
- Investigation of the obstacles effect and interference on RSSI-distance relationship. Keeping this relationship updated in an adaptive system using, for example, known reference nodes (A. Awad, 2007).
- Research about the localization systems based on the relationship studied, methodologies, techniques, precision applications.

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