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Approach to Sensor Node Calibration for Efficient Localisation in Wireless Sensor Networks in Realistic Scenarios

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Abstract

Localisation or position determination is one of the most important applications for the wireless sensor networks. Numerous current techniques for localisation of sensor nodes use the Received Signal Strength Indicator (RSSI) from sensor nodes because of its simplicity and cost. Non-linearities in RSSI circuits, the antenna radiation pattern and path loss model parameter estimation may result in accuracy of the localisation algorithm. Therefore, environmental characterisation of radio propagation basic mechanisms is a fundamental step toward the design of ranging and localisation algorithms able to work properly in realistic scenarios. Furthermore, positioning systems are migrating towards hybridisation where data coming from heterogeneous technologies are fused to improve localisation accuracy and coverage. This paper presents an improved mathematical model for ranging using RSSI in realistic practical scenarios as well as measurement methodologies to use during calibration experiments in order to quantify each parameter involved in a localisation algorithm using a sensor data fusion approach.

Keywords: Antenna Radiation Pattern; Node Localisation; Sensor Data Fusion; Gauss-Newton Optimisation.

1. Introduction

Received Signal Strength Indicator (RSSI) is basically a measurement of the power present in a received radio signal. This does not require additional bandwidth, energy or hardware. These features of RSS measurements make it relatively inexpensive, simple to implement and make this technique appealing. This ranging method is very popular in the localisation research community as can be found in [1,2,3,4].

The most common sources of ranging errors using RSSI include reflections on nearby objects, radio frequency noise, and variable characteristics of the communication channel. The biggest source for errors in distance estimation and hence localisation error for most localisation algorithms based on RSSI or Radio Frequency (RF) connectivity is the assumption that the antenna radiation pattern is perfectly circular or spherical in shape. It is therefore assumed

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that the formula for RSSI attenuation over distance, as described by the log shadow model, is directly applicable.

In the real world, however, the pattern of radio transmitted at the antenna is neither a circular nor a spherical shape, and the path loss model is not valid due to problems caused by the sensor mote and the environment of the sensor field.

The wide availability of radio signal strength attenuation information on wireless radios has received considerable attention as a convenient means of deriving positioning information. While much attention has been paid ton localisation accuracy and computational effort, the impact of irregular antenna radiation patterns have been often recognised with a number of empirical studies having been conducted[5],[6]. However, its inclusion in the localisation algorithms considered were generally dismissed for future study.

Positioning systems are migrating towards hybridisation where data coming from heterogeneous technologies are fused to improve localisation accuracy and coverage. With the advances in Microelectromechanical systems (MEMS) technology, sensors such accelerometers and gyroscopes are found in many devices and are easy and cheap to implement in new designs.

Data fusion is the process of dealing with the association, correlation, and combination of data and information from single and multiple sources. The goal is to refine position estimation more so than any single source could do. In the proposed algorithm, orientation data, accelerometer data as well as the RSS data, coupled with the antennae radiation patterns are used to provide an initial estimate from which the final position can be refined in few steps using an optimisation method such as the Gauss-Newton method.

This suggests that additionally to fact that the antenna effects need to be carefully considered in signal strength schemes, measuring techniques and calibration of all sensor involved in the localisation process need to be also analysed.

2. Related work

Lymberopoulos et al.[6] provided a detailed characterisation of signal strength properties and link asymmetries for the CC2420 radio using a monopole antenna. They showed that the antenna orientation effects are the dominant factor of the signal strength sensitivity in 3-dimensional network deployments. Srinivasan et al.[7] evaluated RSSI values provided by the CC2420 radio, and came to the conclusion that the problems older radios had with RSSI due to hardware miscalibration are no longer observable, and that RSSI is a promising indicator when its value is above a certain sensitivity threshold. The results also indicated that the RSSI value for a given link had very small variation over time.

Other authors have analysed the effect of the antenna polarisation on the accuracy of RSSI-based localisation[8]-[9] and other factors on RSSI[10]. The studies in[11,12] show that the performance of RF-based localisation degrades in the presence of an irregular radio range.

However, none of these works have included a developed mathematical model and algorithm to include the antenna radiation pattern and node orientation in localising the sensor nodes.

Attempt to model the radiation pattern described as Radio Irregularity Model (RIM) has been presented in[13] but no further research to include it in a localisation algorithm has been presented.

3. Improving The Accuracy of Distance Estimations

Accurate information on position of wireless users is crucial, not only for emerging location-based services and applications, but also for network optimisation. In order to develop an accurate positioning and tracking algorithm for realistic practical scenarios, propagation characteristics of the environment should be well understood , especially the sources of errors.

Major Sources of Error:

Zhou et al [13] categorised the causes of radio irregularity into two main factors:

- the heterogeneous properties of devices;
- the non-isotropic properties of propagation media.

Device properties include the antenna type (directional or omnidirectional), transmission power, antenna gains, receiver sensitivity, receiver threshold and the Signal-Noise Ratio (SNR). Media properties include the media type, background noise and various other environmental factors. Some attempts to mitigate these irregularities can be found in literature and can be summarised as follows:

3.1. Additive Noise

Even in the absence of multipath signals, the accuracy of the arrival time and RSS is affected by additive noise. Averaging a number of measurements should reduce this effect and ultimately the error induced by it.

$$RSSI = \frac{1}{N}\sum_{i=1}^{N} Measured\_RSSI_i \tag{1}$$

3.2. Multipath

Multiple signals with different amplitudes and phases arrive at the receiver and signals add constructively or destructively as a function of the frequency, causing frequency-selective fading. Averaging a number of measurements as shown in Equation (1) should also reduce this effect.

3.3. Asymmetric Links

An asymmetric link is defined as one in which the connectivity of node A to node B is significantly different from that of node B to node A on condition that the transmission power of node A and B is the same. The link asymmetry is caused by factors such as the presence of obstacles, the asymmetric multi-path effect and the antenna orientation. Since an obstacle-free environment is assumed in this study, focus is placed on the asymmetric link problem caused by antenna orientation.

The asymmetric link has been regarded as an inherent problem in WSNs. However, for accurate localisation in both range-free and range-based techniques, it is essential that this issue be resolved. Sungwon Yang and Hojung Cha in [12], show that the asymmetric link of the RSS problem can be eliminated by solving the antenna orientation problem. Consequently, the asymmetric link problem in WSNs is not an independent issue, but a problem that is dependent on the antenna orientation problem.

3.4. Antenna Radiation Pattern

In the real world, the pattern of radio transmitted at the antenna is neither a circular nor a spherical shape, and the path loss model is not valid due to problems caused by the sensor mote and the environment of the sensor field. The nodes used in literature such as the Micaz, the TelosB and the TMote sky, just to name a few, are all equipped with an inverted F antenna whose typical radiation pattern, as described in [14], is shown in Fig. 1.

Even in the hypothetical case where an ideal omnidirectional antenna is designed, due to the presence of the electronics on the electronics board or impact of the enclosure, the radiation pattern is distorted, meaning the transmitted and received power is not the same for all board orientations. For these reason, it becomes imperative to take the antenna radiation pattern of each node into consideration when designing an algorithm for accurate node localisation

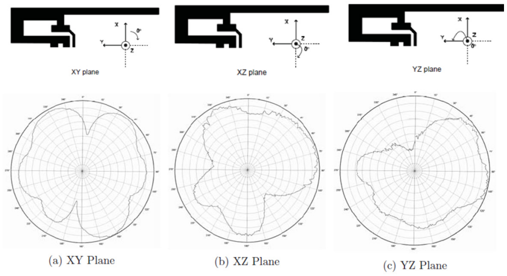

Fig. 1. Inverted F Antenna Radiation Patterns

system in WSN.

To ensure that the localisation algorithm takes the antenna radiation pattern into account, the orientations of the antennae of each sensor node must be known. An earth magnetic sensor is used for this effect. An integrated magnetic sensor and tri-axial accelerometer sensor that achieve this study's objective is the LSM303DLHS from ST Microelectronics.

3.5. Log shadow RSSI Ranging Model

The formula of the RSSI commonly used ranging method is the log shadow formula given in Equation (2).

$$RSSI_{ij} = P_{Tx}(j) - P_{L_{d0}}(j) - 10\eta \log\left(\frac{d_{ij}}{d_0}\right) + X(\sigma) \tag{2}$$

This model does not take into account the effects of the antenna radiation pattern and nodes' orientations.

3.6. Error Introduced By Radiation Pattern

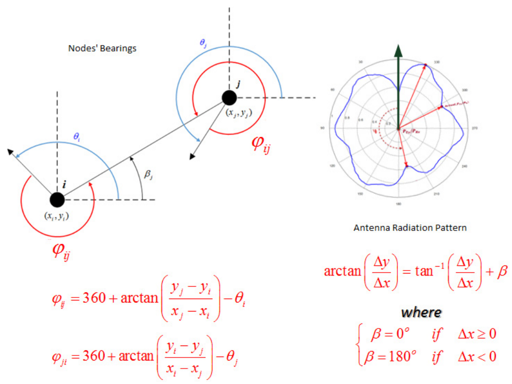

Fig. 2. Effect of Antenna Radiation Pattern

From Figure2, the error introduced by the Antennae radiation patterns can be expressed as in Equation (3).

$$Ant_{Err}(dB) = Patrn_i(\varphi_{ij})(dB) - Patrn_j(\varphi_{ji})(dB) \tag{3}$$

where $Patrn_i$ and $Patrn_j$ represent the antenna radiation pattern of nodes i and j respectively.

3.7. Improved RSSI Ranging Model

This study introduces these effect to obtain an improved RSSI model as shown in Equation (4).

$$RSSI_{ij} = P_{Tx}(j) - P_{L_{d0}}(j) - 10\eta \log\left(\frac{d_{ij}}{d_0}\right) + Ant_{Err} \tag{4}$$

Here, $X(\sigma)$ is assumed to be negligible in this study:

$$X(\sigma) \approx 0$$

It should be noted that the value of Ant_{Err} dependent on the coupling of antennae radiation patterns $Patrn_i$ and $Patrn_j$, φ_{ij} and φ_{ji}. φ_{ij} and φ_{ji} are directly linked to respective nodes orientations, θ_i and θ_j, as shown in Fig. 2.

3.8. Position Tracking

Dead reckoning is exploited to estimate the position of a mobile device by using the previous inertial values. The kinetic model uses inertial measurements originating from accelerometers for each of the three space axes. However, the accelerometer data used to compute a node position, are affected by noise from the sensor themselves as well as the measurement process. An additional error to the estimated positions is induced by numerical computation.

The outputs of these sensors are affected by ripples around the actual values, resulting in an growing error due to the double integration needed to transform accelerations into displacements.

Given an average noise N, the space estimation error e will rise over time t according to Equation (5):

$$e(t) = N.\frac{t^2}{2} \tag{5}$$

Hence, periodic recalibration of the position using GPS or similar technologies, in this case the RSS based localisation, is needed.

Therefore, the estimated position are only used as a staring point in the localisation algorithm and for an efficient, accurate and exhaustive localisation process, RSSI data, antennae radiation patterns data, nodes orientations data (from the magnetic sensor) and accelerometer data should be fused in a optimisation algorithm such as the Gauss-Newton optimisation method as proposed in this study.

4. Experimental Setup and Results

Fig. 3 depicts the experimental setup.

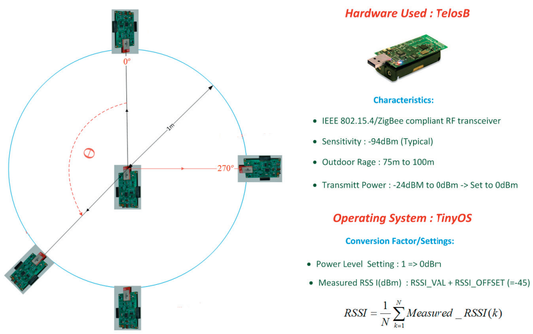

Fig. 3. Experiment setup

To empirically characterise the parameter in the improved RSSI ranging model, two sets of calibration experiments were conducted.

The first set of measurements collected aimed at characterising the antenna radiation pattern. Note that the radiation patterns can be found in the data sheet of the sensor node's radio module can be measured, using the setup depicted in Fig. 3. For this purpose, two TelosB sensors from Crosbow technology were used and the setup is shown in Fig. 3 were used. The RSSI values given by TinyOS are usually not in dBm units, and should be converted by the platform specific relation to get meaningful data out of it. The conversion can be found in the datasheet of the radio platform , in this case the TI CC2430.

Only 36 measurements were taken and considered in the determination of the radiation pattern. A coarse radiation pattern was obtained from the measurements. After interpolation, a more refined radiation pattern was obtained with a resolution of 1^o as depicted in Figure 4.

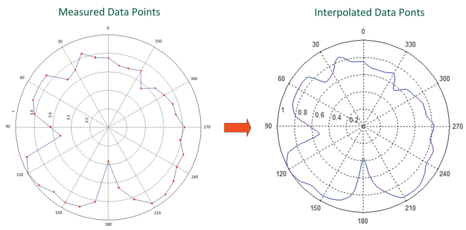

Fig. 4. Radiation Pattern from RSSI Measurements

The second set of measurements were conducted at different distances from the transmitting node and taking care that the relative bearing from each nodes remained constant for separate measurements at distances d1, d2, and dn respectively.

A curve fitting tool was used to plot the graph depicting the relationship between the measured RSSI and the log of the corresponding distances from which they were measured and approximate the relationship with a linear equation as shown in Fig. 5.

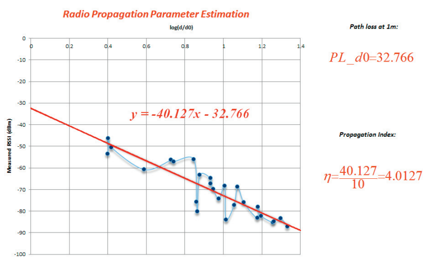

Fig. 5. Empirical characterisation of radio propagation parameters

The format as depicted in Equation (6).

$$y = -mx - b \tag{6}$$

comparing Equation (6) to Equation (4), we can deduce the propagation index and path loss at reference distance used in the ranging model as depicted in Equations (7) and (8).

$$\eta = \frac{m}{10} \tag{7}$$

$$PL_{d0}(dB) = -b \tag{8}$$

Figure 6 outlines the accuracy of the the simulation experiment using the developed algorithm by comparing its localisation errors to the approach that does not make use of the antenna radiation pattern, both using the Gauss Newton optimisation method.

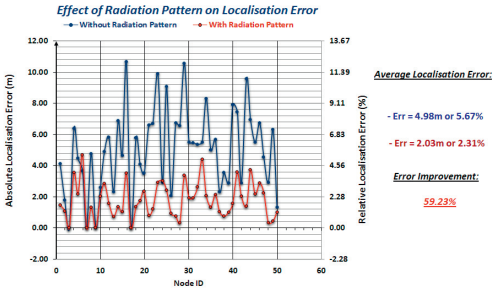

Fig. 6. Simulation Results of 50 Nodes with Antenna Radiation Pattern

Same localisation algorithm was used on real data obtained from Department of Information Engineering of the University of Padova [16] to highlight the effect of the nodes orientations coupled with the antennae radiation patterns. The data did not specify the information about nodes orientations, therefore an assumptions was made that all nodes were facing in the same direction. We proposed three experimental cases, where we assumed the directions of the nodes and calculated the localisation errors per node. The first case did not take the antenna radiation pattern and nodes orientation into account, the second one assumed the node facing in the direction of the x-axis an the last case assumed the nodes facing in the direction of the y-axis.

Figure 7 shows that the effect that the orientation of the nodes can have on the localisation accuracy

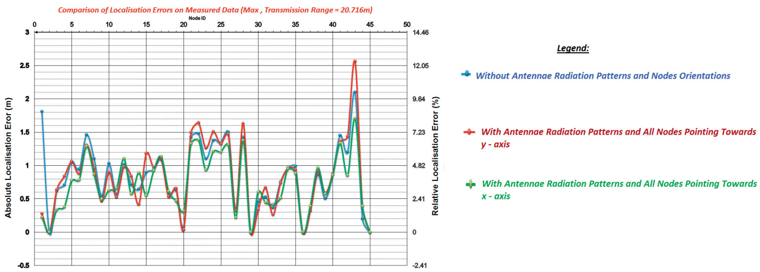

Fig. 7. Effect of Node Orientation of 50 Nodes with Antenna Radiation Pattern

The Gauss-Newton algorithm iteratively finds the minimum of the sum of squares. The update mechanism is described in the Equation (9).

$$X_{k+1} = X_k - \left(J_k^T J_k\right)^{-1} J_k^T \xi_k \tag{9}$$

where J_k is the Jacobian matrix(gradient) of the cost function estimated at $X - k$ and ξ_k is the residual error matrix form by the individual terms of the cost function computed as will be shown in Equation (10).

$$f = \sum_{k=1}^{M} \left\| d_{ij}(k) - \tilde{d}_{ij}(k) \right\| \tag{10}$$

where:

$$d_{ij}(k) = \sqrt{(x_{i(k)} - x_{j(k)})^2 + (y_{i(k)} - y_{j(k)})^2} \tag{11}$$

and

$$\tilde{d}_{ij}(k) = 10^{\left(\frac{P_{Tx}(k) - P_{L\_d0}(k) - RSSI_{ij}(k) + Ant_{Err}(k)}{10\eta}\right)} \tag{12}$$

5. Conclusion

In this paper we have presented a improved RSSI ranging model and have demonstrated that the relative antenna orientation between receiver-transmitter pairs is a major factor in signal strength variability, even in the absence of multipath effects. This suggests that many schemes using radio signal strength on similar radios should carefully consider these factors before going to actual deployments. In addition we have presented an exhaustive approach to sensor node calibration. This includes the empirical experiments to characterise the propagation index and path loss at reference distance used in the RSSI log shadow ranging model as well as the characterisation of the antenna radiation pattern of the sensor node' antennas. We have also shown the effect of the obtained radiation pattern on the overall localisation accuracy. We further explored the mitigation of measurement error of all other sensors data that could be involved in a sensor data fusion approach to node localisation. As future works, we plan to explore the dynamic calibration mechanism of the propagation parameter as the environment change.

References

1. Riccardo Masiero and Michele Rossi. "'RSSI Based Tracking Algorithms for Wireless Sensor Networks: Theoretical Aspects and Performance Evaluation"'.*Thesis, University of Padova*,2006.
2. Gauri A. Naik , Madhavi P. Khedekar et al. "'Comparison of RSSI techniques in Wireless Indoor Geolocation"'. *Computing and Communication Systems (NCCCS), 2012 National Conference*, 2012.
3. XuanLong Nguyen and Tye Rattentbury. "'Localization algorithms for sensor networks using RF signal strength"'. *CS 252 Class Project, Citeseer*, 2003.
4. Giovanni Zanca et al. "'Experimental comparison of RSSI-based localization algorithms for indoor wireless sensor networks"'.*Proceedings of the workshop on Real-world wireless sensor networks* , 2008.
5. Kamin Whitehouse , Chris Karlof, and David Culler. "A practical evaluation of radio signal strength for ranging-based localization". *ACM SIGMOBILE Mobile Computing and Communications Review 11, no. 1* , pp. 41-52, 2007.
6. Lymberopoulos, Dimitrios, Quentin Lindsey, and Andreas Savvides. "An empirical characterization of radio signal strength variability in 3-D IEEE 802.15. 4 networks using monopole antennas." *Wireless Sensor Networks. Springer Berlin Heidelberg*, pp. 326-341, 2006.
7. Kannan Srinivasan and Philip Levis,"'RSSI is Under Appreciated"' *Proceedings of the Third Workshop on Embedded Networked Sensors (EmNets 2006)*,2006.
8. Barralet, Mark, Xu Huang, and Dharmendra Sharma. "Effects of antenna polarization on RSSI based location identification.", *Advanced Communication Technology, 2009. ICACT 2009. 11th International Conference on*, Vol. 1. IEEE, 2009.
9. Huang, Xu, Mark Barralet, and Dharmendra Sharma. "Accuracy of location identification with antenna polarization on RSSI.", *Proceedings of the International MultiConference of Engineers and Computer Scientists*, Vol. 1, 2009.
10. Stoyanova, Tsenka, et al. "Evaluation of impact factors on RSS accuracy for localization and tracking applications.", *Proceedings of the 5th ACM international workshop on Mobility management and wireless access. ACM*, 2007.
11. Tian He et al. "'Range-free localization and its impact on large scale sensor networks"'.*ACM Transactions on Embedded Computing Systems (TECS)*, 2005.
12. Yang, Sungwon, and Hojung Cha. "An empirical study of antenna characteristics toward RF-based localization for IEEE 802.15. 4 sensor nodes." , *Wireless Sensor Networks. Springer Berlin Heidelberg*, pp. 309-324, 2007.
13. Zhou, Gang, et al. "Impact of radio irregularity on wireless sensor networks." *Proceedings of the 2nd international conference on Mobile systems, applications, and services. ACM*, 2004.
14. Texas Instruments, Application Notes DN0007 "'2.4GHz inverted F antenna"', pp 4-8.
15. Gary A. Glatzmaier and Paul H. Roberts, "Rotation and magnetism of Earth's inner core" , *American Association for the Advancement of Science, vol 274* , pp. 1887-1891, 2012.
16. Filippo Zanella, "Automatica Fixed Sensor Compagn.", *Department of Information Engineering, University of Padova*, url=https://github.com/r4m/rssi-data/blob/master/20101109/20101109_Automatica_Fixed_Sensor_Campaign_PUBLIC.zip, 2010.