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RSS-based indoor localization with PDR location tracking for wireless sensor networks

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ABSTRACT

Traditional indoor localization techniques typically rely on a single communication source such as RF signals, ultrasound, inertial sensors, and geomagnetic fields. In wireless sensor network (WSN), received signal strength (RSS) based approach is one of the most commonly used localization techniques. It is simple to implement and costly efficient, but the estimation accuracy is significantly reduced in non-line-of-sight (NLOS) conditions. pedestrian dead reckoning (PDR) uses inertial measurement unit (IMU) for location tracking. Its tracking accuracy is not affected by the interference in NLOS conditions, but the location error is accumulated in long distance tracking. We propose the RSS-based indoor localization algorithm combined with PDR location tracking for wireless sensor networks. The objective is to compensate the NLOS localization error by using PDR, while mitigating the accumulated error of PDR by using RSS-based localization method in LOS conditions. Lab scale experiment and large scale simulation results show that the proposed algorithm significantly reduce the location estimation errors in wireless sensor networks.

1. Introduction

The interest on the indoor localization techniques has been grown rapidly as it has many practical applications in our daily life. Various information sources such as RF signals, ultrasound, inertial sensors, and geomagnetic fields have been used for indoor localization.

In wireless networks, the signal's numerical data such as received signal strength (RSS), time of arrival (TOA), time difference of arrival (TDOA), and angle of arrival (AOA) [1–3] are used for indoor localization. Among these, the RSS-based approach is one of the most commonly used localization techniques because of its simplicity for implementation in RF based networks. In the RSS-based localization techniques, the RSS values from nearby reference nodes are collected to estimate the target node location. The RSS-based localization shows fairly good estimation accuracy in line-of-sight (LOS) conditions but it has problems with estimating the location in NLOS conditions [4,5].

Pedestrian dead reckoning (PDR) is one of the inertial measurement unit (IMU) based location tracking techniques [6,7]. Gyroscope and magnetometer are used for obtaining the heading direction of the target node, and accelerometer is used in step detection and step length estimation. The location is updated by adding the step displacement to the location of prior step. PDR approach does not use wireless signals and its localization accuracy is not affected by the interference in NLOS conditions. Instead, the running duration of PDR is related to the location tracking accuracy.

To compensate the NLOS error of RSS-based localization methods and the errors of IMU-based localization techniques in long distance tracking, various hybridization techniques have been proposed recently. In [8,9], the authors combine IMU-based localization method with Wi-Fi fingerprinting method using Kalman Filter. IMUs are used for predicting the target location and Wi-Fi fingerprinting is used to compensate the predicted location. In [10], the author uses the user movement data, RSS measurements, and historical information of locations in the hidden Markov model. In [11], the authors propose a wireless assisted PDR system which involves a DR module, ad-hoc WSN, and an information center with map database. PDR is combined with wireless telemetry and map matching algorithm.

In this paper, we propose the RSS-based indoor localization algorithm combined with PDR location tracking in wireless sensor networks. In LOS condition, RSS-based geometrical least square (RSS-LS) is used for location estimation. Since the starting PDR location is resetted by RSS-LS in LOS condition, the tracking error of PDR can be reduced. The target node's location is estimated by using PDR in NLOS condition, and it compensates the NLOS estimation error of RSS-LS. This algorithm does not require the radio map

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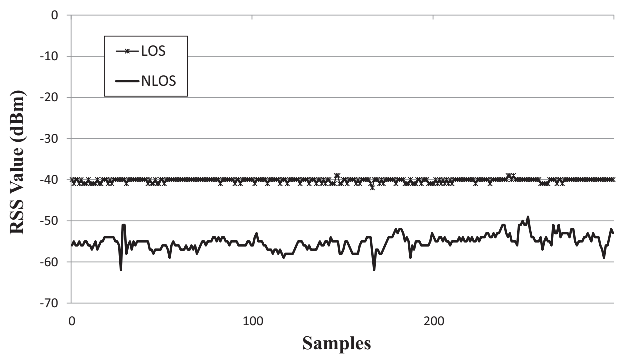

Fig. 1. RSS measurements in LOS and NLOS conditions.

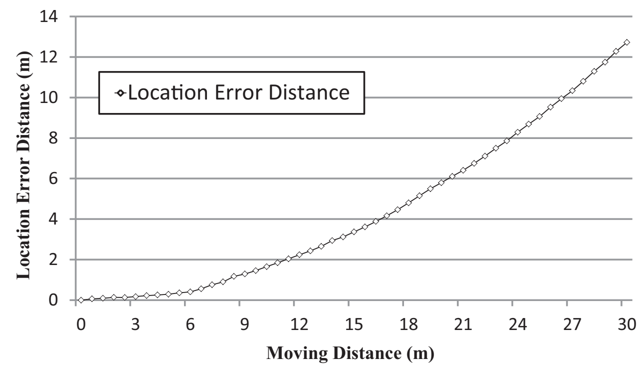

Fig. 2. PDR location error distance vs. moving distance.

collecting processes and provides the simplicity of implementation in wireless sensor networks.

The remainder of this paper is organized as follows. We begin with Section 2 by stating the characteristics and problems of RSS-LS and PDR methods. The proposed algorithm is explained in Section 3, and the experimental results and performance evaluations are presented in Section 4. We conclude the paper in Section 5.

2. Problem statement

RSS-based localization techniques can be categorized into two types. In Bayesian approach, RSS values are considered as random variables and the location of the target is estimated using the probability functions of the collected RSS vectors. Maximum likelihood (ML) method is one of the Bayesian localization approaches.

In geometric approach, which is being used throughout the paper, we deal with the geometrical relationship of the nodes. The distance d between the target and a reference node is computed from the measured RSS values and the path loss model [12].

$$P = P_0 - 10\mu \log_{10}\left(\frac{d}{d_0}\right) \quad (1)$$

where P denotes the measured RSS, μ is the path loss constant, d_0 is the reference distance which is typically 1 m, and P_o is the RSS measurement at $d = d_0$.

The location of the target is estimated from the calculated distance. In the geometrical LS approach, the coordinates of the target, $(\hat{x_0}, \hat{y_0})$, is obtained as follows:

$$(\hat{x_0}, \hat{y_0}) = \underset{(x_0, y_0)}{argmin}\left\{\sum_{i=1}^{N} |d_i - \sqrt{(x_i - x_0)^2 + (y_i - y_0)^2}|\right\} \quad (2)$$

where N is the number of the reference nodes, d_i denotes the computed distance to the ith reference node, and (x_i, y_i) is the coordinates of ith reference node.

Interference is the biggest challenge of RSS-based indoor localization methods. Fig. 1 shows the RSS measurement results over time. Two MTM-CM3000 wireless modules [13] are placed at 1 m above the floor and 3 m apart to each other. When a person is standing between two wireless modules, RSS measurements show NLOS attenuation. The NLOS attenuation level is around 15 dBm and its standard deviation is 1.79. Geometrical LS method provides inaccurate estimation result because the RSS measurements in NLOS condition distort the distance information.

Pedestrian dead reckoning (PDR) is one of the IMU-based location tracking methods. The target node estimates its heading direction, detects each step, and estimate corresponding step length using magnetometer, gyroscope, and accelerometer. The target's current location is being updated by adding the computed displacement of each step to the estimated location of prior step [6,7].

The localization accuracy of PDR is not affected by interference because it does not depend on the wireless signals. However, the location error of each step is being accumulated as PDR is continuously being used. Angle measurement errors and poorly estimated step lengths both cause the PDR estimation error. The angle measurements from magnetometer and gyroscope are not perfect due to the limited sensing capabilities. Magnetometers are vulnerable to indoor magnetic interference and gyroscope suffers from the bias drift. The RMS noise of MPU3050 gyroscope is 0.0017 radian (0.1°) per sec and this causes bias drift error [14]. Bias drift can also be increased as the temperature of the sensor rises. Fig. 2 shows the location error of PDR along with the moving distance. A person whose step length is 0.6 m is walking straight while holding Galaxy Nexus smartphone. As shown in Fig. 2, the PDR location error keeps increasing while PDR is continuously being used.

3. Proposed algorithm

We propose a new indoor localization algorithm to improve the performance of RSS-based least square (RSS-LS) estimation method by combining with PDR location tracking. Two different estimation methods are used to complement each other. RSS-LS is mainly used for location estimation in LOS conditions, and PDR location tracking is used when the NLOS condition is detected. In this system, we consider a 2D coordinate system for simplicity.

3.1. Overview

The proposed algorithm is an iteration cycle of two phase routines: location estimation and location determination. In the location estimation phase, two methods are used independently to estimate the location of the target node. The target's trajectory is being tracked by PDR for a certain period of time, called PDR duration. The location at the end of PDR duration becomes the PDR location of the target node. Next, the target node selects four reference nodes with the highest RSS values in order and creates $\binom{4}{3}$ subsets by choosing three reference nodes at a time. Four LS results are obtained by performing RSS-LS on each subset and the center of them becomes the LS location of the target node. In the location determination phase, we check if the chosen 4 reference nodes are under the NLOS conditions and select better estimation result for target node's current location (Fig. 3).