A new method of hybrid indoor localization with inertial sensor

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Abstract. Indoor Localization has been an interesting and significant area of research in the recent days because of its diverse applications. However, current indoor localization method has some drawback in accuracy and it needs to be improved urgently. In this paper, we proposed a hybrid localization algorithm which combines the received signal strength indication with inertial sensors. The corresponding flow chart was also provided. Simulation results show that the proposed algorithm has made a great improvement in localization accuracy.

1. Introduction

There have recently been many studies on localization because location information is important for providing valuable applications. It is critical to several new services such as ubiquitous network systems \[1, 2\]. Localization techniques can be classified into several categories, such as using received signal strength (RSS), time of arrival (TOA), time difference of arrival (TDOA), angle of arrival (AOA), location fingerprint, and combinations thereof \[3\].

The traditional localization techniques of AOA, TDOA, and AOA was used in outdoor because of complex radio wave propagation \[4\]. Therefore, the location fingerprint technique, which generally uses RSSI, is attractive for indoor localization \[5, 6\]. The basic idea of the fingerprint approach is one kind of matching patterns based on localization technique. A multipath delay profile can also be used to locate a mobile terminal with pattern matching.

The main advantage of the fingerprinting technique is that it can provide a low-cost and high-accuracy localization solution by utilizing in-building Wi-Fi infrastructures. However, fingerprinting localization algorithm in the literature, such as the traditional $K$ nearest neighbor (KNN) algorithm, may bring large error when calculating location. The most important reason for the error is that these algorithms may select the wrong reference point for localization. In order to reduce the localization error in the fingerprinting estimation due to dynamic environment, there is also some paper use the Wi-Fi tag to resolve above problems \[7\].

Received signal strength indication (RSSI) is very convenient to obtain in the smart phone. Since the received signal contains noise and is also infrastructure dependent \[8\], a hybrid system of combing RSSI fingerprint with inertial sensor is worthy of study. Hence we make use of inertial sensors embedded on smart phone such as accelerometers and magnetic compass, to detect any motion and heading direction to reduce the error compare to traditional RSSI approach.
2. Localization based on RSSI fingerprint
The fingerprint technique was introduced in [9] as an effective approach for indoor localization. It utilized the received signal strength (RSS) in Wi-Fi circumstance. The detail procedure of RSSI localization is as follows.

Suppose an indoor localization system consisting of \( n \) access points and \( m \) reference points. In offline phase, the RSSI \( \{ R_i(x_i,y_j) | i = 1, \ldots, m, j = 1, \ldots, n, k = 1, \ldots, L \} \) is measured and recorded to the fingerprint with coordinate \( \{(x_i, y_j) | i = 1, \ldots, m, j = 1, \ldots, n\} \).

In this model, Euclidean distance of RSSI is used to evaluate the geographical relation between offline RSSI fingerprint and on-line RSSI. Euclidean distance \( D \) can be represented as
\[
D(x_i, y_j) = \| R - R(x_i, y_j) \|_2,
\]
(1)
Where \( R' \) denotes the on-line RSSI value. According to the KNN algorithm and the minimum Euclidean distance theory, the first \( K \) coordinates of \( N \) were selected. Then, by matching the minimum difference to off-line database, the optimal location of smart phone can be determined.

3. Hybrid localization system

3.1 Inertial Sensor System
When pedestrian moving with a smart phone in hand, outputs of the accelerometer in smart phone usually presents obvious periodic waveform. However, the uncertain pose of the smart phone will make it difficult to determine the orientation of the accelerometer’s with three axes in the navigation coordinate. As a result, the total magnitude of the three-axis acceleration is usually used as a pose-invariant signal feature. The magnitude \( a_m \) can be expressed as
\[
a_m = \sqrt{a_x^2 + a_y^2 + a_z^2},
\]
(2)
Where \( a_x, a_y \) and \( a_z \) are the measurements from the three-axis accelerometer. The axes of sensor readings are based on the smart phone.

![Figure 1. Velocity-Time Curve](image_url)

The horizontal axes and vertical axes represent time and velocity individually in Figure 1. The \( a(t) \) represents the changing acceleration values with time increase. The acceleration at any given \( t \) moment is the slope of the corresponding point on the curve. The displacement \( s(t) \) and velocity \( v(t) \) of an object can be obtained according to the integral principle in the continuous time from \( t_0 \) to \( t \).

Since the output value of the accelerometer is discrete, the velocity-time curve is discretized and the graph can be decomposed into many small right angle trapeziums. There is \( s(t_0) = 0, t_1 - t_0 = t_2 - t_1 = \ldots = t_n - t_{n-1} = \Delta t \). Where \( \Delta t \) is the time interval of acceleration sensor sampling. Thus the moving distance of the target object at the \( n \) moment can be represented as
\[
s_n = v_0 \cdot n \cdot \Delta t + [(n - 1) \cdot a_1 + (n - 2) \cdot a_2 + \ldots + a_{n-1}] \cdot \Delta t^2 + \frac{1}{4} (a_0 + a_n) \cdot \Delta t^2
\]
(3)
According to the equation (3), the displacement of the target can be obtained by the initial velocity \( v_0 \) and the acceleration of the accelerometer. However, when the \( n \) value is large enough, lots of mathematical operations are needed and the system memory consume too much. Therefore, iterative
method is adopted to simplify the calculation process. The equation of velocity and displacement can be written as

\[ v_n = v_{n-1} + \frac{a_n + a_{n-1}}{2} \cdot \Delta t, \]

\[ s_n = s_{n-1} + \frac{v_n + v_{n-1}}{2} \cdot \Delta t = s_{n-1} + v_{n-1} \cdot \Delta t + \frac{1}{4} \left( a_n + a_{n-1} \right) \cdot \Delta t^2. \]  

By equation (4) and (5), the current velocity \( v_n \) and displacement \( s_n \) can be obtained by calculating \( v_{n-1}, s_{n-1} \) and \( a_{n-1}, a_n \) obtained on the previous time.

### 3.2 Hybrid Localization Approach

The classical RSSI fingerprint localization method has disadvantage in accuracy. In inertial localization, there is also the problem of error accumulation. Although, the inertial sensor has a few drawbacks, it can estimate new location accurately if the last estimated location is offered. We turn to study on hybrid approach of localization. When RSSI fingerprint and inertial sensor are combined, they overcome each other drawbacks.

The hybrid localization approach uses the on-line RSSI value and acceleration value to determine the new location based on its previous location. If the RSSI value is accepted, the KNN algorithm can be used. Hence, the RSSI approach is reliable in the vicinity of access point. When the mobile terminal is not in the vicinity of any of access points, the inertial integral localization is used for localization. Accumulated error in inertial integral localization is reduced by re-initializing when the mobile terminal is in the vicinity of an access point again. The hybrid localization method flow chart is given as following.

If the location is determined by RSSI fingerprint only, error would increase distinctly when the RSSI value is low. If the inertial integral localization is used only, the error would increase as time goes on. Therefore, we use RSSI fingerprint and inertial sensors for hybrid localization which named inertial k-nearest neighbor (IKNN) algorithm. In our algorithm, only the difference of location by RSSI and inertial is less than 3 meters in same direction, the result is accepted.

Figure 2. Hybrid localization method flow chart

### 4. Numerical simulation

Simulations were conducted in a zone of size \( 6 \times 10 \times 3 \)m in 3D coordinate. The indexes of reference locations are shown in Figure 3. Adjacent receiver points are set in 1 m apart away.
In our experiment, the receiver point location is indicated by “RP” in Figure 3. The access points (APs) are set in 2-m tall. Monte Carlo simulations are performed to compare the performance of NN, KNN, IKNN and FKNN algorithm.

In Figure 4(a), we did the first simulation experiment which RSSI and inertial individually. When the difference between these two results is less than 3 meters in same direction, the result is accepted otherwise it should be measured again.

In Figure 4(b), the second experiment result is shown. Firstly, the discrete location points were obtained by inertial integral localization and then fitting curve was made by polynomial fitting. Secondly, the RSSI fingerprint was used to locate the target named fitting KNN (FKNN) algorithm. If the location coordinates deviated from the fitting curve more than 3 meters, the RSSI was measured again.

From the Figure 4, the cumulative distribution function raise when the error distance increase. We can see that the performance of the FKNN and IKNN algorithm are better than NN and KNN. The IKNN gets the best performance among of them.

Next, we did the third experiment to verify its cumulative effect of error between the inertial integral localization and hybrid localization.
5. Conclusion
In this paper, aiming to the low accuracy of indoor localization, we proposed a hybrid indoor localization method based on RSSI fingerprint database and inertial sensor. Our method can decrease the location error and adjust adaptively by referring the data from other single traditional method. The simulation results show the effectiveness of our IKNN algorithm.

Acknowledgments
The project is supported in part by the foundation of NanJing University of Posts and Telecommunications No. NY215164 and by A Project Funded by the Priority Academic Program Development of Jiangsu Higher Education Institutions and by the Key University Science Research Project of Jiangsu Province under Grant No. 14KJA510003. It also supported by the National Natural Science Foundation under grant No. 61271335 and No.61571233.

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