UWB Localization with 2-D Interpolation and K-Nearest Neighbor Based on Measurement Data

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Abstract

The indoor localization has several techniques that are used to estimate a location such as the received signal strength (RSS), the time of arrival (TOA), the time difference of arrival (TDOA) and the angle of arrival (AOA). Nevertheless, all above techniques are considered only signal from direct path. Therefore, they cause more error in dense multipath fading channels such as indoor environments. Now, UWB fingerprinting localization has been developed for this purpose. In this paper we evaluate the performance comparison of indoor localization based on UWB-fingerprinting using 2-D interpolation and K-Nearest Neighbor for building fingerprint patterns based on measurement data. Using vector network analyzer (VNA) to measure the channel frequency transfer functions S_{21} at frequencies ranging from 3 GHz to 11 GHz. Biconical antennas were used as both transmitter (Tx) and receiver (Rx) antennas with vertical polarization. The accuracy of estimated distances is studied and shown in the terms of cumulative distribution function (CDF). From the results, we found out that 2-D interpolation gets the best performance with high accuracy and precision, which the distance error is very low with the average value is 0.40 m, while the maximum of distance error is 2.00 m.

1. Introduction

In recent years, The UWB localization system can be used logistic in healthcare tracking industrial and military service [1]. There are several traditional techniques that are used to estimate a location such as the received signal strength (RSS), the time of arrival (TOA), the time difference of arrival (TDOA) and the angle of arrival (AOA). These techniques are used to estimate the location by considering from power loss, delay time or angle of received signal [2], [3]. Nevertheless, all above techniques are considered only signal from direct path.

Now, the fingerprinting localization is popularly used to estimate the location. The benefit of this technique provided highly accurate location estimation [4]. Usually, there are several algorithms are used to estimate a location using fingerprint concept and UWB signal sush as K-Nearest Neighbor (K-NN) [5],[6]. However, K-NN algorithm is to give the distance value in database only. We try to find the algorithm which can be determined the distance out of the database. Then, we can see that 2-D Interpolation which can be used to solve the problem. It is a method of constructing new data points within the range of a discrete set of known data points.

In this paper, we discuss about the performance comparison between 2-D Interpolation algorithm and K-NN algorithm for UWB indoor localization with fingerprinting concept. The VNA is used to measure the UWB channel measurement in the frequency response mode at the frequencies ranging from 3 GHz to 11 GHz. All of the measurements are used the biconical antennas as both transmitter (Tx) and receiver (Rx) antennas with vertical polarization. The path loss and delay time of first three-path were investigated to perform the fingerprints and signatures. Then, the positions were estimated by using 2-D Interpolation algorithm and K-NN algorithm. The accuracy of estimated distances is shown in terms of cumulative distribution function (CDF)

2. **UWB –Fingerprinting localization**

2.1 Signal model

For UWB signal, the rectangular passband waveform is considered as the UWB transmitted waveform. This rectangular passband waveform in time domain $v_{\mathrm{t}}(t)$ and its spectral density function $V_{\mathrm{t}}(f)$ are represented by:

$$v_{\mathrm{t}}(t)=\frac{A}{f_{\mathrm{b}}}\left[f_{\mathrm{H}}\mathrm{sinc}(2f_{\mathrm{H}}t)-f_{\mathrm{L}}\mathrm{sinc}(2f_{\mathrm{L}}t)\right], \tag{1}$$

$$V_{\mathrm{t}}(f)=\begin{cases}\frac{A}{2f_{\mathrm{b}}} & \left||f|-f_{\mathrm{c}}\right|\le\frac{f_{\mathrm{b}}}{2}\\ 0 & \left||f|-f_{\mathrm{c}}\right|>\frac{f_{\mathrm{b}}}{2}\end{cases}, \tag{2}$$

where A is the maximum amplitude, f_{b} is the bandwidth, f_{c} is the center frequency, $f_{\mathrm{L}}$and f_{H} are the minimum and maximum frequencies, respectively. Consequently, the spectral density of received signal $V_{\mathrm{r}}(f)$ can be calculated by using

$$V_{\mathrm{r}}(f)=V_{\mathrm{t}}(f)\cdot H_{\mathrm{c}}(f), \tag{3}$$

where $H_{\mathrm{c}}(f)$ is the frequency transfer function of channel obtained by using measurement scheme described in section 3.

Then, the received signal in time domain $v_{\mathrm{r}}(t)$ is evaluated by using inverse Fourier transform:

$$v_{\mathrm{r}}(t)=\int_{-\infty}^{\infty}V_{\mathrm{r}}(f)\,e^{\mathrm{j}2\pi\mathrm{ft}}df. \tag{4}$$

2.2 Algorithms

A. 2-D Interpolation using spline method

The interpolation is a method of constructing new data points within the range of a discrete set of known data points. It is the approximation of a complicated function by a simple function. Suppose we know the function but it is too complex to evaluate efficiently. Then we could pick a few known data points from the complicated function, creating a lookup table, and try to interpolate those data points to construct a simpler function. The data with 1 m space are interpolated to be 0.01 m space using 2-dimensional spline method [7]

B. K-Nearest Neighbor Algorithm (K-NN Algorithm)

The K-NN is an algorithm for classifying objects based on closest training examples in the feature space. It is amongst the simplest of all machine learning algorithms: an object is classified by a majority vote of its neighbors, with the object being assigned to the class most common amongst its *k* nearest neighbors (*k* is a positive integer, typically small).

2.3 Analysis

The estimated position is considered from the position that has minimum difference between its signature and fingerprint. The fingerprint error at (x,y) position $e_{\mathrm{f}}(x,y)$, which represents the difference between its signature and fingerprint, is defined as

$$e_{\mathrm{f}}(x,y)=\sqrt{\sum_{i=1}^{3}\left\{\frac{[PL_{\mathrm{i}}(x,y)-PL_{\mathrm{ti}}]^2}{\sigma_{\mathrm{PL_i}}^2}+\frac{[t_{\mathrm{i}}(x,y)-t_{\mathrm{ti}}]^2}{\sigma_{\mathrm{t_i}}^2}\right\}}, \tag{5}$$

where $PL_{\text{fi}}(x, y)$ and $t_{\text{fi}}(x, y)$ are the path loss and delay time of fingerprint at (x, y) position of path i^{th}, PL_{si} and t_{si} are the path loss and delay time of signature of path i^{th}, $\sigma_{\text{PL}_{\text{fi}}}$ and $\sigma_{\text{t}_{\text{fi}}}$ are the standard deviation of path loss and delay time of fingerprint of path i^{th}.

After that, the estimated position $(x_{\text{e}}, y_{\text{e}})$ is considered as the position with minimum estimated error and can be written as

$$(x_{\text{e}}, y_{\text{e}}) = \arg\min e_{\text{f}}(x, y), \quad (6)$$

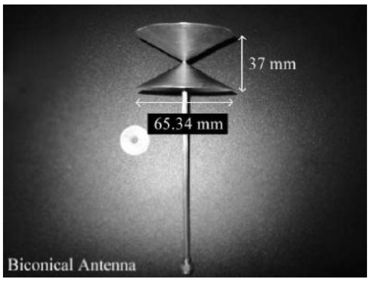
The accuracy of UWB fingerprinting is considered in the term of distance error. The distance error e_{d} can be defined as

$$e_{\text{d}} = \sqrt{(x_{\text{c}} - x_{\text{e}})^2 + (y_{\text{c}} - y_{\text{e}})^2}, \quad (7)$$

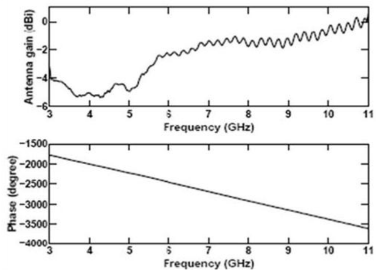
where $(x_{\text{c}}, y_{\text{c}})$ is the correct position.

3. Measurement Description

The measurements were done at the corridor of 12$^{\text{th}}$ floor, E-Building, Faculty of Engineering, King Monkut's Institute of Technology Ladkrabang. The VNA is used to measure the UWB channel measurement at the frequencies ranging from 3 GHz to 11 GHz. The biconical antennas are used with vertical polarization as both Tx and Rx antennas. The structure and dimension of biconical antenna and biconical antenna transfer function magnitude and phase shown in Fig. 1



(a)



(b)

Fig. 1 The structure and antenna transfer function (a) Dimension of biconical antenna. (b) Magnitude and phase of biconical antenna.

First, the measurements were done to collect the data to build the fingerprints. A total of 15 positions with 1 m space are measured. After that, the measurements were done to collect the data to build the signatures. A total of 45 positions with 0.5 m space in the same area are measured. The Experimental setup and measurement model are shown in Fig. 2.

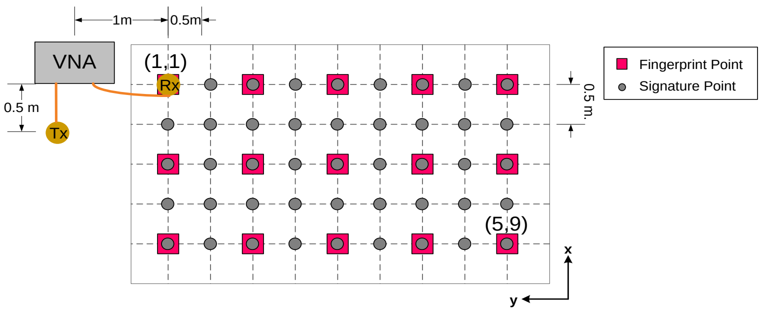


Fig. 2 Experimental setup and measurement model

4. Experimental Results and Discussion

For 2-D Interpolation, The average of distance error is 0.40 m. The maximum of distance error is 2.00 m. For K-NN Algorithm (K=1), the average of distance error is 1.67 m. The maximum of distance error is 3.35 m. For K-NN Algorithm (K=2), the average of distance error is 1.51 m. The maximum of distance error is 2.55 m. For K-NN Algorithm (K=3), the average of distance error is 1.48 m. The maximum of distance error is 2.36 m.

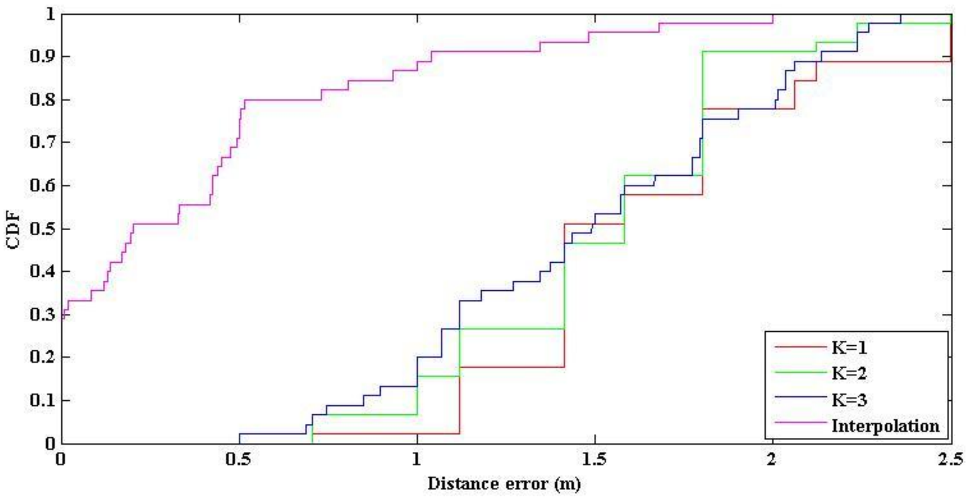


Fig. 3 CDF for distance error.

5. Conclusions

In this paper, we discuss about UWB-fingerprinting localization with 2-D Interpolation and K-Nearest Neighbor based on measurement data. From the results, we found out that 2-D interpolation's average distance error is 0.4 m. For the K-Nearest Neighbor, the average distance error for every case is at least 1.48 m. We can conclusion that 2-D Interpolation has the better accurate than K-Nearest Neighbor.

In the future work, we will consider the performance comparison between 2-D interpolation with other algorithms such as neural networks, probabilistic method and find more other algorithms for the accuracy improvement.

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