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Smartphone based intelligent indoor positioning using fuzzy logic

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HIGHLIGHTS

- An experimental investigation of indoor positioning algorithms.
- A fuzzy logic based scheme to select the best localization algorithm depending upon the size of the room, the number of beacons available and the strength of the RSSI signal.
- Evaluation of indoor positioning in real world conditions (office building).

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ABSTRACT

Smartphones are indispensable helpers of people in their daily routine, including functions that serve the disabled or aged people finding their outdoor location. This paper presents an experimental investigation of the indoor positioning algorithms based on the signal strength received from the Bluetooth Low Energy (BLE) beacons. We have implemented and compared several positioning algorithms (Proximity Localization, Centroid Localization, Weighted Centroid Localization, Weight-Compensated Weighted Centroid Localization Based on RSSI, Fingerprinting and Trilateration Localization). We also proposed and implemented a fuzzy logic based scheme to select the most fitting algorithm depending upon the size of the room, the number of beacons available and the strength of the signal. We have evaluated our scheme in real-world conditions (office building). The experimental results show that the algorithm of fingerprinting localization is the most suitable one. Finally, we propose a fuzzy logic system for the selection of an indoor localization algorithm based on the size of the room, the number of available beacons, and the strength of RSSI signal.

1. Introduction

Accurate positioning of people in public indoor environments using low cost solutions such as Wi-Fi and Bluetooth Low Energy (BLE) technologies or smartphone-based solutions is difficult due to surrounding conditions that affect the spreading of the signal making the determination of location prone to both noise and crowdedness of the environment. The problem is especially relevant to people with special needs such as aged, impaired or disabled, which may need special care and attention when moving around in large public buildings. United Nations reports that about 15% of the global population has some form of disability [1]. Therefore, the development of public use infrastructure and technologies that support accessibility, active and assisted living is important, especially in the context of developing Smart Cities [2]. Indoor Positioning Systems (IPS) have been previously applied in different environments such as transportation hubs [3], stores and supermarkets [4], libraries [5], museums [6], car parking lots [7], underground construction sites [8], and hospitals [9]. The business potential for such system is growing, and the predicted value of IPS services for 2020 is USD 10 billion [10], therefore, the research in the development of practical and affordable IPS systems is relevant, as has been emphasized by several recent reviews on the latest development in this domain [11,12].

Specifically designed traditional indoor location systems naturally allow achieving a high accuracy of localization, but also requiring a high cost of deployment [13]. The use of Wi-Fi technology for indoor positioning is challenging primarily due to removal or change of position of the access points (AP), other devices working in the same signal band, variations in internet traffic, signal availability and propagation effects, variability and noise of received strength signal (RSS) [14].

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Solutions involving the use of RGB-D sensors from the Kinect platform, in combination with WiFi-based positioning systems (WPSs) allow tracking people in indoor environments, but require a large number of devices to avoid occlusions [15]. Other solutions such as based on ultrasound sensors [16] have low precision due to noise interference. Smartphones with an addition of internal and external sensors, so called Beacons, often running on low powered Bluetooth protocol [17], or even over WiFi [18], allow doing this affordably and with an acceptable error rates. BLE technology [19] has emerged as one of leading choices in the field, as it ensures fine positioning. This technology is supported by contemporary mobile devices such as smartphones and tablets [20], and allows for providing additional services [21], ensures low power consumption [22], and the costs are reasonable.

The utilization of phone internal sensors, which is shown in [23], allows to achieve and effective indoor localization [24], moderating the drift in data estimations with a particle filter [25], in addition to Kalman filter [26], extended Kalman filter [27] and Least Square-Support Vector Machines (LS-SVM) for detecting indoor movement states [28]. Fusion of smartphone sensor measurement with those of wireless signals can provide reliability and robustness for different positioning scenarios [29,30]. Ma et al. [31] uses an improved Euclidean distance and joint probability to calculate intermediate results from several fingerprints, and then weighted fusion is applied to calculate the final value by weighting the Euclidean distances by their variances. Chen et al. [32] proposes a smartphone based localization method based on sensor fusion problem, but uses a Kalman filter instead of a particle filter. Liu [33] offers a similar method based on fine graining of features. Practical implementation usually suffers from inherent localization errors introduced by low-cost sensors and the complexity of human movements in real-world scenarios [34]. However, by using a location estimation model, an error can be reduced to around 2 m [35]. Camera and image processing can be utilized as well by the combination of an image recognition system with a distance estimation algorithm [36]. Lin et al. [37] use the proximity localization beforehand dividing the room into areas. The proposed method uses time-based Received Signal Strength Indication (RSSI) filtering to find the nearest beacon. Er Rida et al. [38] used the trilateration localization to determine the location. They suggest to install beacons on the ceiling as a grid. Zhu et al. [39] used the fusion method of trilateration and centroid. They suggested to establish the Beacons as an equilateral triangle. Bai et al. [40] used the fingerprint localization to determine the indoor location, suggesting to use with RSSI data from Wi-Fi and Bluetooth. Ma et al. [41] offered the RSSI ranking based fingerprinting method that uses Kendall Tau Correlation Coefficient (KTCC) to correlate a new signal position with the signal strength ranking of multiple iBeacon devices. Zou et al. [42] proposed the iBeacon technology based BlueDetect scheme for indoor–outdoor location detection and provision of seamless location based services (LBS) running on Android mobile devices. The scheme is supported by Wi-Fi and Global Positioning System (GPS) technologies in semi-indoor environments. Alshami et al. [43] proposed WLAN fingerprinting enhanced with RSS certainty, and used K-Nearest Neighbor (KNN) and Artificial Neural Network (ANN) classification for dynamic and multi-floor environments that account for people presence. Pei et al. [44] proposed training the fingerprint database for mobile indoor localization via crowd sensing. Xu et al. [45] proposed the Bayesian inference based KNN (BKNN) algorithm for improved localization robust to signal multipath propagation and environmental interference.

As indoor localization has to deal with noisy and uncertain Wi-Fi or Bluetooth signals, the fuzzy logic based approaches are often employed to address the uncertainty of the position measurements. Specifically, known methods such as formal concept analysis [46], symbolic signatures [47], vector quantization [48], or c-means clustering [49] can be fuzzified to address uncertainty, imprecise data or incomplete information.

The aim of this paper is to investigate the indoor positioning algorithms using BLE beacons. The objectives of the research are the following:

1. Investigate the broadcasting range of BLE beacon in a real world environment. What is the effect of the distance between the mobile device and the beacon on the signal strength? How does the orientation of mobile devices affect the signal strength?
2. Investigate, which indoor positioning algorithms using Bluetooth Smart Beacons show the highest accuracy.
3. Propose the fuzzy logic based scheme for the selection of most suitable indoor positioning algorithms based on room size, beacon number and signal strength factors.

The proposed approach is motivated by the ambiguity and uncertainety of the conditions in which BLE beacons are used, which provides a reason for the introduction and use of the fuzzy logic system.

2. Methods and algorithms

This section describes the model of the environment in which the indoor positioning algorithms are used. A positioned facility that receives the BLE signals is called agent. In this case, the "agent" means a smartphone. The model of environment includes several beacons and an agent. Without loss of generality, the space is regarded as a flat environment in which there may be interferences from walls — floors, diverse signals, etc. Fig. 1 illustrates an example of arrangement of the agent and the beacons in the plane, where B_i is ith beacon, (X_i, Y_i) is the Cartesian coordinates of ith beacon, P_i is the RSS from the ith beacon, A is the agent, (X_A, Y_A) is the Cartesian coordinates of the agent, and N is the number of beacons.

We describe the algorithms used to detect location of an agent using the power signals emitted by a few beacons in the room below.

The proximity algorithm [50] assigns to the agent the coordinates of the beacon, which emits the signal with greatest power. The algorithm is the simplest from a computational point of view. For instance, if four beacons are located in the room and the highest power signal $P1$ has been received from $B1$, then the agent is assigned the coordinates of $B1$ beacon. The advantages of this algorithm include the ease of implementation due to the low computational complexity and the necessity to know only the location of the beacons. The obvious disadvantage is very low accuracy. This algorithm is useful as an initial approximation, the result of which can be used for a different algorithm.

The Centroid algorithm [51] calculates the geometric center of the plane figure formed by multiple beacons. In this case, the coordinates of the agent are calculated as a linear combination of the coordinates of the beacons. Location of the agent is determined by the following formulas:

$$\begin{cases} X_A = \dfrac{1}{N}\displaystyle\sum_{i=1}^{N} X_i \\ Y_A = \dfrac{1}{N}\displaystyle\sum_{i=1}^{N} Y_i \end{cases} \quad (1)$$

here X_A, Y_A are Cartesian coordinates of agent; X_i, Y_i are the Cartesian coordinates of ith beacon; and N is the number of beacons.

The advantages of this algorithm include the ease of implementation, the complexity of computing is low and one needs to know