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Device-Free Localization and Human Mapping for Ambient Assisted Living: Radio Map Approach

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***Abstract*— A radio frequency (RF) based device-free indoor localization (DFL) has attracted a lot of research effort due to its simplicity, less costly and compatibility with the existing hardware equipped with RF interface compared to the existing positioning system. An advanced monitoring system, known as Ambient Assisted Living (AAL) has been developed using DFL and Internet of Things (IoT) technologies. In this paper, we present a probabilistic DFL system using passive radio map method based on a non-parametric histogram-based approach to locate and map the passive target position in an indoor area. The proposed technique is based on a radio map concept in locating human position using received signal strength indicator (RSSI). The Bayesian inversion was introduced in the proposed approach for estimating the density function and the Probability of Error metric (PoE) was used to evaluate the tracking accuracy of the system. We firstly performed system analysis on the deterministic approach for comparison with the proposed probability approach. The results show that the probabilistic approach can accurately locate a passive target with an error probability of 0.0782 compared to the deterministic approach that gives high PoE of 0.2463.**

Keywords—Device-free Localization, deterministic localization, probabilistic localization, passive radio map, Ambient Assisted Living, Internet of Things

I. Introduction

Ageing people are increasing proportion of the world's population. Nevertheless, in modern society, the conventional ways of taking care of elders in the family are no longer effective. The advancement of IoT technology allows assisted healthcare to be monitored remotely, unattended and provides early warning system. This paper demonstrates Radio Map method to localize and map human position without wearing any devices for assisted healthcare application.

The existing human positioning technology requires additional sensor such as Global Positioning System (GPS), Passive Infrared (PIR) sensors, video camera, etc. which incur cost and have several drawbacks. With the marvellous advancement in communication network and ubiquitous deployment of wireless indoor system, the location-based services (LBSs) have become increasingly important in people daily life. Extensive research effort has been done on the human localization with the integration of different device-based technologies, including, GPS, ultra-wideband (UWB), infrared, Radio-Frequency Identification (RFID), and Zigbee, resulted in the development of several location determination systems where special device or hardware is required in all these systems [1,2].

While research on device-based localization techniques has made tremendous progress in improving the localization performance, there has been a tremendous growth in the DFL techniques caused by several important applications such as intrusion detection and tracking, sensor-less sensing, low-cost security and surveillance, as well as home automation. Compared to the device-based techniques, localization and activity awareness using DFL does not involve any device attached, or neither requires the target to actively participate in the localization process. Therefore, we refer to this target as a passive target.

The data collected at monitoring point is based on the signal level or RSSI. It works based on the radio irregularity phenomenon, which often considered as a drawback in wireless. In DFL system, the radio irregularity has been seen as a benefit in which can be utilized to locate changes in the indoor environment. However, due to the complex multipath propagation behaviour as well as shadowing effects created by the presence of obstacles in wireless indoor environment, most of the Wireless Local Area Network (WLAN) based localization system implemented the radio map approach to capture the relation between RSSI and user's location [2]. Xu et al. [3] adopted a cell-based radio map approach based on RSSI extracted from wireless sensors to count and locate multiple passive targets in indoor environments. By using WiFi technology, Seifeldin et al. [4] employed a zone-based radio map approach into the DFL system for large-scale typical office environments to estimate the number of passive targets and locate their position into zones.

In works [5, 6], the authors used deterministic algorithm in detecting human presence in indoor environment, where the RSSI was represented by scalar values, which are mean and variance. In this paper, we propose and analyse the performance of probabilistic DFL system in an indoor environment which consists of two phases: offline training and online localizing phases. Our algorithm is based on probabilistic passive radio map, which implements the non-parametric histogram-based approach into the training dataset for RSSI distribution estimation at each location during offline phase, and uses Bayesian inversion method to perform matching operation during the online phase. We firstly analysed the performance of the system using similar deterministic approach presented in [6] and compared with the proposed probabilistic histogram-based approach.

II. The Device Free Localization and Human Mapping Algorithms

A. Deterministic DFL Approach

In the deterministic approach, we proposed an algorithm based on RSSI attenuation for our DFL system as shows in Fig. 1, which consists of initialization, detection and

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localization phases. In this experiment, the DFL system was deployed using XM2110 IRIS nodes as signal transmitters, Xsniffer node as a signal receiver, and an application server (AS) which collects and processes RSSI information from the Xsniffer node. During the initialization phase, the receiver sends the RSSI data received from each node to a desktop for data processing and analysis. The system then computed the baseline reading and set the attenuation threshold. The baseline of each radio links when the monitoring area is empty are collected and used as indicators to estimate the signal attenuation when person entered the monitored area. The attenuation, denoted as α is defined as the difference between RSSI measured at time t, $r_i(t)$ and the baseline measurement, $\hat{r}$:

$$\alpha = r_i(t) - \hat{r} \tag{1}$$

where $\hat{r}$ was computed by taking the average measurement of the RSSI sample of each links during the empty room scenario:

$$\hat{r} = Average\{r_i\} \tag{2}$$

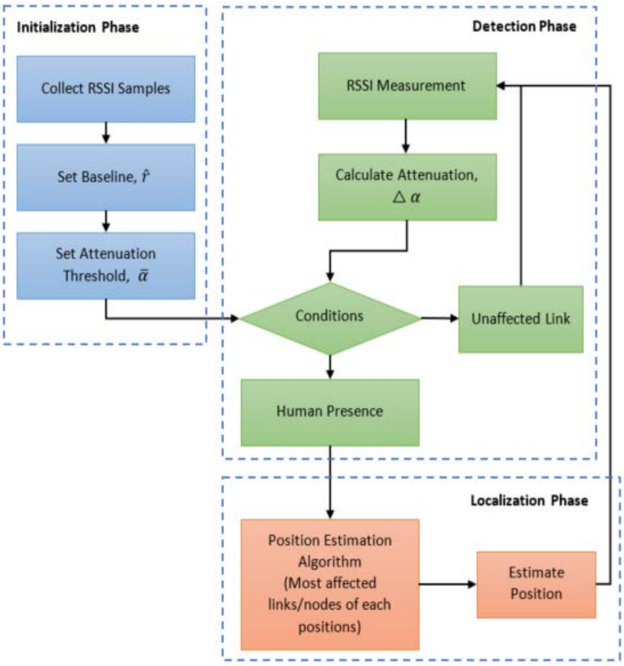

Fig. 1. The deterministic algorithm of a DFL system.

Signal attenuation is one of the valuable parameters for human or object detection in wireless sensor network. The attenuation is able to indicate the changes in the signal behaviour when the radio links of the network were obstructed or blocked by object or human. The average attenuation when people presence in the network links was set as the threshold value of the detection system and denoted as $\bar{\alpha}$. In this experiment, the threshold $\bar{\alpha}$ was set to be 3.00 dB based on the minimum attenuation value measured when human presence in the networked area, during the initialization phase.

During the detection phase, the receiver collects and updates the RSSI measurement of each nodes for every consecutive window. The attenuation of each link is evaluated using below conditions:

$$Condition,\ c = \begin{cases} \Delta\alpha > \bar{\alpha}, \text{ unaffected links} \\ \Delta\alpha \leq \bar{\alpha}, \text{ human presence} \end{cases} \tag{3}$$

The algorithm in the detection phase is based on work presented in [6]. In this work, we improved the deterministic algorithm by adding the position estimation algorithm, which determine the target position based on the three most affected links or nodes.

B. Probabilistic DFL Approach

The algorithm for the probabilistic approach is shown in Fig. 2. We described the proposed algorithm based on the offline training phase and online localizing phase as:

1) Offline training phase: Passive Radio Map Construction: The testbed area consists of N static transmitter nodes, M static receiver nodes, the total number of $N \times M$ radio links, and P calibration locations. A passive target stands at each of P locations for a period of time and RSSI measurements from each radio link are collected, processed and stored in a radio map. We use a non-parametric histogram-based approach to construct the radio map where the histogram of RSSI distributions of each radio link at each location is stored in the radio map.

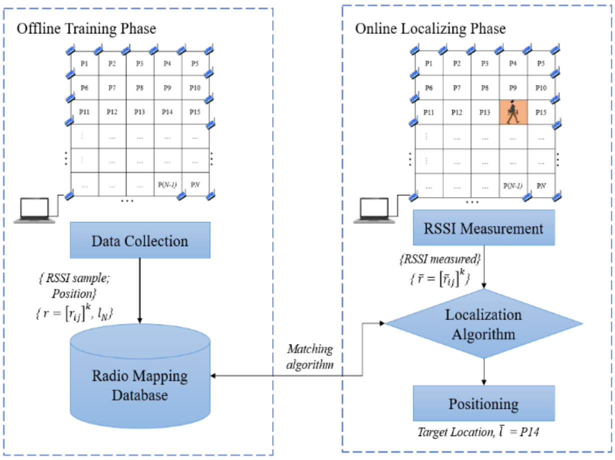

Fig. 2. The proposed probabilistic algorithm for the DFL system.

2) Online localizing phase: Tracking Algorithm: During the online tracking phase, the proposed system is required to determine the location of the passive target. Let k represent the number of radio links, which is equal to $N \times M$. The AS periodically receives a k-dimensional vector of RSSI measurement of each radio link, $\hat{r} = [\hat{r}_{ij}]^k$, where $\hat{r}_{ij}$ denotes the RSSI of receiver i from transmitter j. Bayesian inversion probabilistic based on maximum likelihood method is used which select the radio map location l that maximizes the probability $P(l|\hat{r})$ as described in Equation 4:

$$arg\ max_l\ P(l|\hat{r}) = arg\ max_l\ P(\hat{r}|l) \cdot P(l) / P(\hat{r}) \tag{4}$$

Since $P(\hat{r})$ does not depend on any l location, it can be factored out:

$$arg\ max_l\ P(l|\hat{r}) = arg\ max_l\ P(\hat{r}|l) \cdot P(l) \tag{5}$$

Equation 5 can be reduced by an assumption that all location are equal-probable:

$$arg\ max_l\ P(l|\hat{r}) = arg\ max_l\ P(\hat{r}|l)$$

$$= arg\ max\ \Pi^{M}_{i=1}\ \Pi^{N}_{j=1}\ P(\hat{r}_{ij}|l) \qquad (6)$$

Using this method, the density function $P(\hat{r}_{ij}|l)$ is estimated using histogram-based approached.

III. Results and Discussions

This section describes the environmental setup for the experiment, and introduces the evaluation metric to analyse the localization performance, and presents the analysis of experimental results of both approaches

A. Experimental test-bed

The experiment was conducted in a home environment located in a suburban with no wireless access point present in the environment. The wireless radio network was constructed using eight IRIS nodes which used IEEE 802.15.4 (Zigbee) transmission protocol as shown in Fig. 3. Seven of the nodes were configured as the transmitters (N1-N7) with a transmission rate of 300 ms, while another one was configured as a receiver running Xsniffer firmware to sniff and collect the RSSI from the transmitting nodes. The receiver was mounted on a MIB520 interface board and connected to a laptop via USB port. The experiment considered a living room covered with typical furniture. Only half of the living room was considered since we decided to have a small-scale experiment. The selected area was discretized into four locations (Position A, B, C and D) spaced one meter apart, which represent the radio map locations. As per presented in Section II, the deterministic approach selects the most three affected nodes to estimate the target locations.

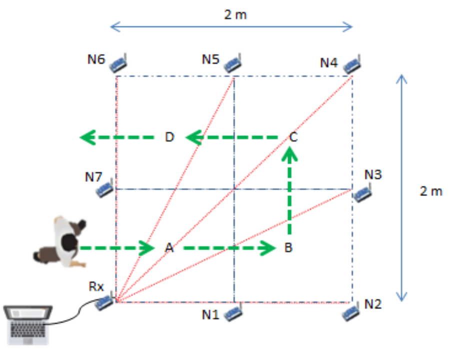

Fig. 3. Layout of experiment.

Table I shows the result of the affected nodes (Y) and unaffected nodes (N) when target stands at each position. Based on Fig. 3 and Table I, the three most affected links that will be used to estimate the position of target in the deterministic algorithm are N3, N4 and N5, which are the Line of Sight (LoS) links. To construct the radio map in the probabilistic approach, a person was instructed to stand at each location and the receiver recorded 200 samples from each transmitter at each location.

B. Evaluation Metric

We used Probability of Error (PoE) metric to evaluate the tracking accuracy and the performance of both approaches. The PoE is defined as the probability that the location estimated by the proposed system does not match with the true location, which is associated with the total number of times the system correctly identified the target location.

TABLE I. Affected (Y) and unaffected (N) links when target stands at the predefined positions.

Position	N1	N2	N3	N4	N5	N6	N7
A	N	N	Y	Y	Y	N	N
B	N	N	Y	N	N	N	N
C	N	N	N	Y	N	N	N
D	N	N	N	N	Y	N	N

C. Performance Evaluation

To evaluate the localization performance, we have considered two different cases: ideal environment and temporal variation environment. In the idea environment case, the cross-validation technique has been used to evaluate the system performance. In the temporal variation environment, the independent test set technique has been selected to evaluate the accuracy of the system.

1) Ideal Environment: In the ideal environment case, the experiment was continuously repeated 6 times in the same day using same walking and standing trajectories so that we will have 6 set of data (Set 1, 2, .., 6). Each individual set is then used as the testing data while the other five datasets are used for training the system. The results from all dataset are averaged to find the average system performance. Fig. 4 shows the RSSI data of Set 1 measured from each node during the experiment when a person stands at the predefined position in the monitored area. Fig. 5 shows the absolute attenuation measured from data set A when a person stands at each position, used in the deterministic approach.

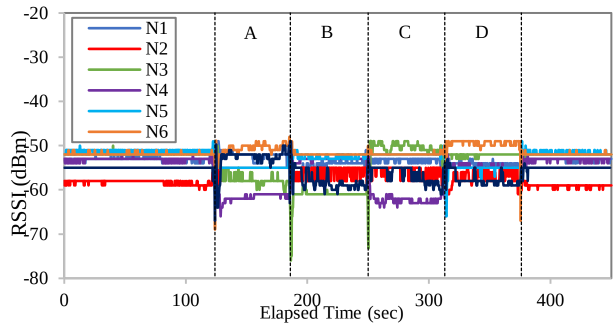

Fig. 4. RSSI reading of Set 1 when a person stands at different position in the network area.

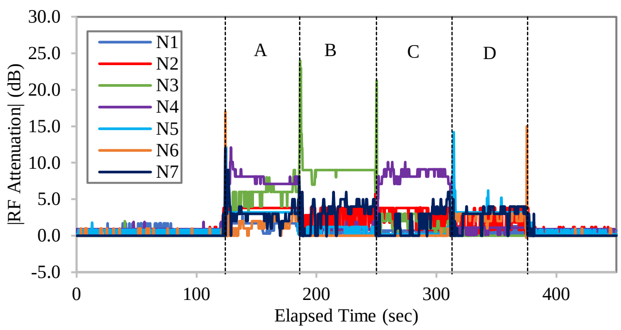

Fig. 5. Attenuation reading of Set 1 when a person stands at different position in the network area.

The examples of RSSI distribution histograms of node N1 of each location used in the probabilistic approach are shown in Fig.6. Table II summarized the results of our experiment in the ideal environment case using cross-validation technique for both deterministic and probabilistic approaches. Using the probabilistic approach, the DFL system is able to accurately locate the position of human in ideal environment with error probability of 0.0782 compared to the deterministic approach, which gives higher probability of error, 0.2463.

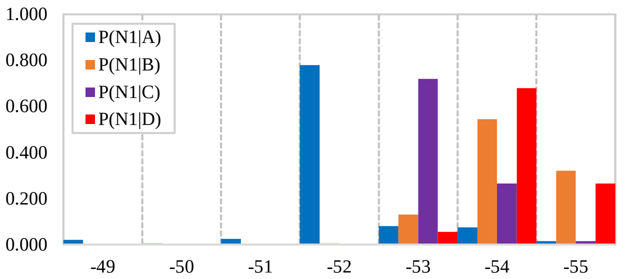

Fig. 6. RSSI distribution histogram of Set 1 for node N1 at each location.

TABLE II. RESULTS OF DETERMINISTIC AND PROBABILITY APPROACHES UNDER CROSS-VALIDATION TECHNIQUE FOR IDEAL ENVIRONMENT.

Training set	**Probability of Error (PoE)**	
	Deterministic	***Probabilistic***
Set 1	0.216	0.089
Set 2	0.213	0.074
Set 3	0.422	0.095
Set 4	0.215	0.066
Set 5	0.189	0.067
Set 6	0.223	0.078
Average	**0.2463**	**0.0782**

TABLE III. RESULTS OF PROBABILITY APPROACH UNDER INDEPENDENT TEST SETS TECHNIQUE FOR TEMPORAL VARIATION ENVIRONMENT.

Test set	**Time**	**PoE**
Cross-Validation	Same day	0.0782
Set A	1 day after	0.2350
Set B	2 days after	0.2980

2) Temporal Variation Environment: In temporal environment case, the effect of time change was used to evaluate the accuracy of the proposed system. The aim of this second experiment is to identify the factors that affect the system accuracy. It is expected that changes in time will significantly reduce the accuracy of the system. The same experiment was repeated after one and two days in the same room so that we will have two independent test sets (Set A and B). Similar to previous experiment, 200 samples per location was recorded for each independent test sets. Table III shows the performance comparison between independent test set technique and the cross-validation result presented in the ideal case, using proposed probability approach. As per expected, the system performance is degraded when there are changes in time since the environment may have changed significantly. In addition, the difference between the test sets results might be due to the measurement uncertainty of the hardware or position uncertainty of the person.

IV. CONCLUSIONS

The passive radio map method was implemented in a device-free human localization and mapping system using probabilistic Histogram-based approach. The performance of the proposed probabilistic approach was evaluated in the ideal and temporal changes environments, and compared with the deterministic approach, which exploits the RF signal attenuation of the three most affected nodes. Using the cross-validation technique for the ideal environment, the probabilistic approach is able to accurately locate the passive target with an average error probability of 0.0782, compared to the deterministic approach with higher PoE of 0.2463. The effect of temporal variation was analysed using independent test set technique and the result proved that changes in time reduced the system accuracy. However, although the localization accuracy reduced, the probabilistic approach still outperform the deterministic approach. Due to the small-scale experiment, the above study was evaluated without any optimization. Up-scaling system for large-scale implementation may require additional features to suit the real scenarios. These up-scaling and system optimization will be considered in the future work.

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