A Multifrequency Multistage Fingerprinting-based Radiolocation System Based

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Abstract*—This paper presents a multifrequency and multistage indoor robot localization system based on fingerprinting. The proposed system relies on a 900 MHz Long Range Radio (LoRa) along with 2.4 GHz Wireless Fidelity (WiFi) and Bluetooth (BT) networks. By exploiting different propagation characteristics of different Radio Frequency (RF) signal wave within a Gated Recurrent Unit (GRU) framework, Received Signal Strength (RSS) measurements are used for indoor localization purposes. Similar to conventional fingerprinting systems, the system is consisted of two phases: data acquisition and learning (offline), and localization (online). In offline phase, the signal maps for various AP's are constructed via RSS information and path loss exponent is learned by a network consisted of GRU, whereas the online phase contains an information fusion based localization method. *Add some result once get it

I. Introduction

Inverse pyramid:

- P1: Background
  1) Inverse pyramid
  2) Last sentence: introduce the area of the title of your paper as a significant topic
  3) 5 refs (books, review papers, journals, no conf)
- P2-3: Background
  1) Original classification: Support the objectives with each sentence
  2) Appreciate their work, their focus however different
  3) no technical words
  4) 10 refs (journal, conference papers)
- P4: Objectives
  1) 1-3 objectives
  2) the first sentence: this paper presents

The organization of the paper as follows. Section II lays out the fundamentals of the radio wave propagation, while Section III covers the details of the proposed system. Section IV demonstrates the validity of the proposed system in different environments. In Section V, the experimentation results will be concluded and future work will be addressed.

II. Fundamentals of Radio Wave Propagation in Radiolocationing

This section will cover the fundamentals of radio wave propagation in regards to Fingerprinting-based Indoor Radiolocationing Systems (FIRL). FIRLs are consisted of two main phases. The first phase, i.e. offline phase, involves with collecting some form of measurements about the anchor nodes placed in the environment, with corresponding positions. Let m_j^i and d_j^i to be the measurement obtained from anchor node i at a location j, and the radial distance of between location j and the anchor node i, respectively. The measurement space $\boldsymbol{m}^i = \{m_j^i | i = 1 \dots n_{node}, j = 1 \dots n_{loc}\}$ are often constructed in either frequency domain [refer CSI], or time domain. The measurements are then used to approximate the propagation function f_d^i of each anchor node.

$$f_d^i : \boldsymbol{m}^i \mapsto \boldsymbol{d}^i \tag{1}$$

One of the most popular fingerprint is Received Signal Strength (RSS) in FIRLs due to its simplicity in acquiring the fingerprints. The fundamental relationship between transmitted and received signal strengths P_t and $P_r(d)$ occurred between ideal antennas in an empty space with a distance d separation is characterized by Friis' Free Space Equation (FFSE) given below [1].

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi d)^2} \tag{2}$$

In Equation (2), G_t, and G_r denote unitless gains of transmitter and receiver antennas, respectively, whereas λ is the wavelength of the radio wave. However well-known, FFSE is not able to model propagation mechanisms, i.e. reflection, diffraction or scattering occurring along the the propagation path, due to the fact that it can only model Line-of-sight (LOS) propagation. Thus, it is often impractical to utilize it in indoor localization problems where reflection and diffraction occurs along the propagation path. Moreover, since the received signal strength is often minuscule level, FFSE is denoted in decibel scale relative to a milliwatt.

$$\begin{aligned}\widetilde{P}_r(d) = \widetilde{P}_t + 10\log G_t + 10\log G_r + \\ 20\log\lambda - 20\log d - 20\log 4\pi\end{aligned} \tag{3}$$

$\widetilde{P}_r(d)$ and $\widetilde{P}_t$ represent received and transmitted signal strengths decibel scale. However, neither Equation (2), nor Equation (3) holds true for the distance $0 < d < \lambda$. Thus, received signal strength generally is denoted relative to a reference point d_0 with a prior corresponding received signal strength.

$$\widetilde{P}_r(d) = \widetilde{P}_r(d_0) + 20 \log \frac{d_0}{d} \tag{4}$$

Based on FFSE, path loss occurring along the propagation path can be derived as the difference between transmitted and received signal strength. Equation (5) represents a special Path Loss (PL) model, i.e. Log-distance Path Loss (LDPL) which describes the attenuation relative to a reference point. One of the major advantages of LDPL model over FFSE is that LDPL model can account for obstructions and corresponding wave propagation in the space with varying values of PL exponent n.

$$\overline{PL}(d) = \overline{PL}(d_0) + 10n \log \frac{d}{d_0} \tag{5}$$

$$n = \begin{cases} < 2, & \text{if the space structure guides the radio waves} \\ & \text{along the propagation path} \\ = 2, & \text{if the space is empty,} \\ > 2, & \text{if there are obstructions along the propagation} \\ & \text{path} \end{cases} \tag{6}$$

One of the most visited solution in FIRLs is to estimate n by fitting a curve to collected fingerprints. Given a mean PL at an unknown location $\overline{PL(d)}$, PL exponent n and a mean PL at the reference point d_0 $\overline{PL}(d_0)$, the propagation function of anchor node i f_d^i can be obtained by solving LDPL for the radial distance d^i.

$$f_d^i = d_0 10^{\left(\dfrac{\overline{PL}(d) - \overline{PL}(d_0)}{10n}\right)} = d^i \tag{7}$$

However, in order to obtain radial distance from anchor node i d^i, PL exponent n should be estimated from the data collected during the offline phase. Let $\boldsymbol{m}^i = \{\widetilde{P}_r^{i,j}(d) | j = 1 \ldots n_{loc}\}$ and $\boldsymbol{d}^i = \{d_j^i | j = 1 \ldots n_{loc}\}$ be the RSS fingerprints acquired from anchor node i during surveying and corresponding distances from anchor node i, respectively. The estimated radial distance from anchor node i $\hat{d}^i$ can be obtained with the approximated propagation function $\hat{f}_d^i(m_j^i, n_i^*)$.

$$\hat{f}_d^i(m_j^i, n_i^*) = d_0^i 10^{\left(\dfrac{\widetilde{P}_t - \widetilde{P}_r^{i,j}(d) - \overline{PL}(d_0)}{10n_i^*}\right)} = \hat{d}_j^i \tag{8}$$

where n^* is the overall PL exponent which minimizes the absolute localization error $|d_j^i - \hat{f}_d^i(m_j^i, n^*)|$ where $j = 1 \ldots n_{loc}$.

$$n^* = \arg\min_n \boldsymbol{e}^i = \arg\min_n \{d_j^i - \hat{f}_d^i(m_i, n)\} \tag{9}$$

After obtaining the approximated propagation function, the measurements acquired from the anchor nodes are mapped to relative radial distances in order to distinguish the absolute position of the agent in the environment, which forms the offline phase of the FIRLs.

III. Multifrequency Multistage Radiolocation System

This section will explain Multifrequency Multistage Radiolocation System (MFMS) in greater detail. Akin to other fingerprinting-based radiolocation systems, MFMS consists of two main phases. During the offline phase, RSS information from anchor nodes are collected at many locations in the environment and used to approximate the radio wave propagation function. The online phase, on the other hand, makes use of the approximated propagation function obtained in the former phase. However, one major difference between MFMS and conventional approaches is that MFMS employs three types of radio setups to infer the location of the agent. The main motivation behind employing multisource information is to exploit the diversity of the propagation characteristics of the different frequencies.

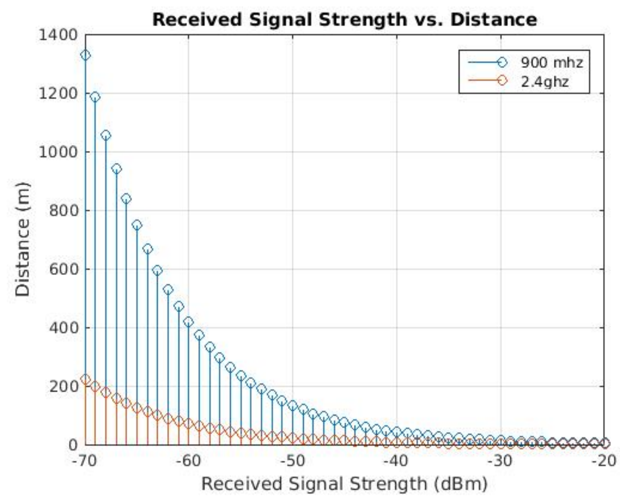

Fig. 1: RSSI readings of NLoS and LoS APs acquired with a stationary agent

A. Temporally- and Spatially-coherent Path Loss Exponent Estimation

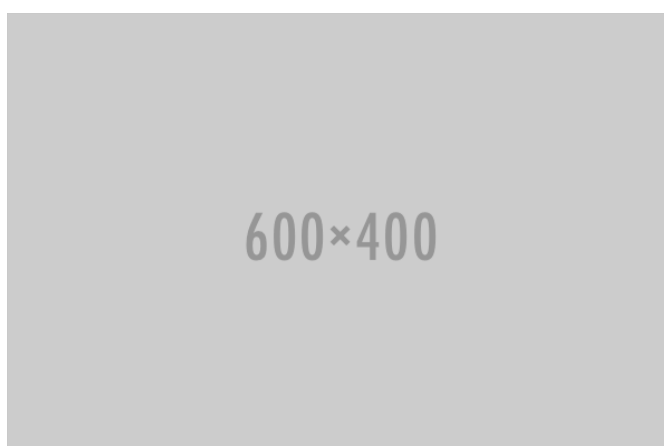

Fig. 2: GRU

B. System

As it can be seen in the Equation (5) and Figure 1, the received power and separation distance has a log-linear relationship. This figure implies two fundamental problems in radiolocationing systems: The first problem is that as the carrier frequency increases path loss increases significantly, which limits the radio covarage and localization ability of the system in large environments. On the other hand, as the carrier frequency increases, the separation between two antennas, i.e. the anchor node and the target to be localized, can be identified with finer spatial resolution. Therefore, the trade-off between radio coverage and spatial localization resolution can be resolved by employing different frequencies in indoor localization systems by fusing the information acquired from the anchor nodes using different carrier frequency.

Figure 3 shows the outline of the MFMS in the hardware scope. In order to achieve wider spatial coverage, MFMS employs XBees working at 900 MHz. On the other hand, finer spatial resolution accomplishment is achieved by ESP32 modules which runs at 2.4 GHz WiFi and Bluetooth. In other words, each anchor node contains an XBee working at 900 MHz and an ESP32 module working at 2.4 GHz WiFi and Bluetooth.

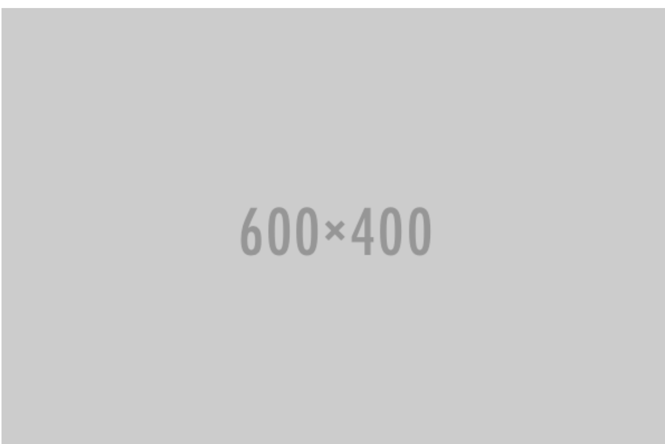

Fig. 3: MFMS Anchor Nodes

IV. Experimentation

A. Experimental Setup

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B. Results

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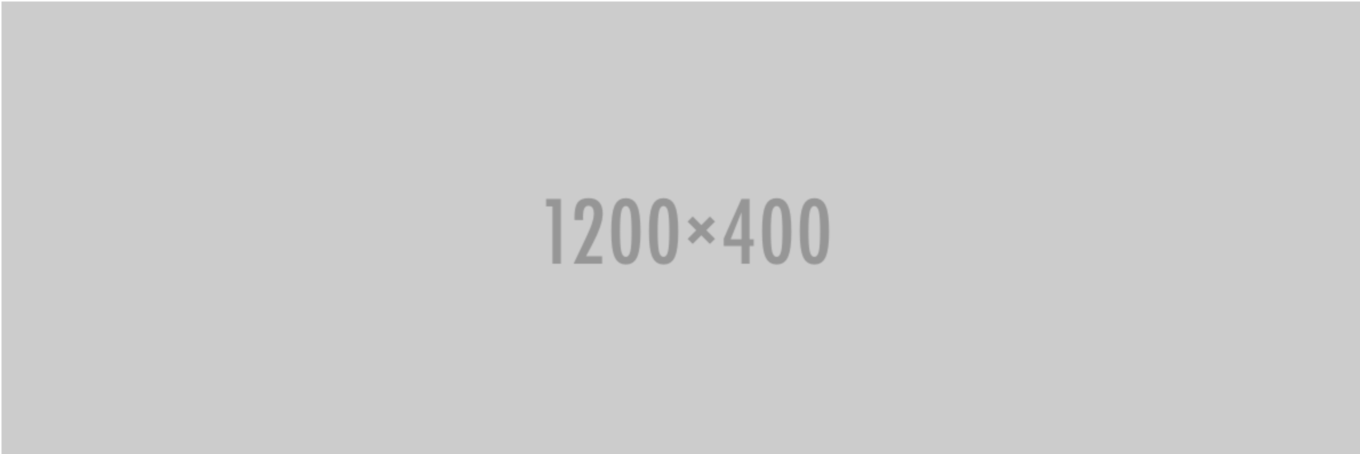

Fig. 4: MFMS Model

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V. Conclusions and Future Work

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Acknowledgments

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