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 and Function Approximation Methods

The first part of this section will first cover the fundamentals of radio wave propagation in regards to radiolocationing systems based on fingerprinting while the second part will present a brief description of function approximation methods with a emphasis on a stochastic function approximation method, i.e. Gated Recurrent Unit (GRU).

A. Radio Wave Propagation In Radiolocationing Systems

The fundamental relationship between transmitted power P_t and the received power P_r occurred between ideal antennas in an empty space with a distance d separation is characterized by Friis' Free Space Equation given below [1].

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi d)^2} \tag{1}$$

In Equation (1), $P_r(d)$ and P_t denote received, and transmitted power with d meters separation between two antennas in Watts, respectively. G_t, G_r, and λ represent unitless gains of transmitter and receiver antennas, and the wavelength of the radio wave, respectively. Since the received power is minuscule level, Equation (2) represents Friis' equation in dBm.

$$\begin{aligned} P_r^+(d) = P_t^+ + 10\log G_t + 10\log G_r + \\ 20\log\lambda - 20\log d - 20\log 4\pi \end{aligned} \tag{2}$$

$P_r^+(d)$ and P_t^+ represent received and transmitted powers decibel scale. However, neither Equation (1), nor Equation (2) holds true for the distance $d = 0$ and $d < \lambda$. Thus, received power generally is denoted relative to a reference point d_0 with a prior corresponding received power.

$$P_r^+(d) = P_r^+(d_0) + 20\log\frac{d_0}{d} \tag{3}$$

Along with representing the received power with a reference point, path loss is another common terminology used in field. The path loss $PL(d)$ represents the attenuation occuring between receiver and transmitter antennas in decibel scale. Equation (4) represents a special path loss model, i.e. Log-distance Path Loss (LDPL). LDPL describes the attenuation relative to a reference point. One of the major advantages of LDPL model over Friis' free space model is that log-distance path loss model can account for different spaces by varying values of n.

$$\overline{PL}(d) = \overline{PL}(d_0) + 10n\log\frac{d}{d_0} \tag{4}$$

where n is the path loss exponent and varies depending on the environment. Please note $n = 2$ for empty spaces where there is no reflectors, diffractors or scatterers available in the propagation path. While the most visited solution in fingerprinting-based indoor radiolocationing system is to estimate n by fitting a curve to collected fingerprints.

Given the mean path loss $\overline{PL}(d)$ at a location, the path loss exponent n and the mean measurement $\overline{PL}(d_0)$ at the reference point d_0, the propagation function of anchor node i f_d^i which maps measurements to radial distance d can be written as below.

$$f_d^i = d_0 10^{\left(\dfrac{\overline{PL}(d) - \overline{PL}(d_0)}{10n}\right)} = d^i \tag{5}$$

B. Function Approximation Methods

However, in order to obtain radial distance from anchor node i d^i, the path loss exponent n should be estimated from the collected data. Let $\mathbf{m}^i = \{m_j^i | j = 1 \dots n_{loc}\}$ and $\mathbf{d}^i = \{d_j^i | j = 1 \dots n_{loc}\}$ be the 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 $\hat{f}_d^i(m_j^i, n_i^*)$.

$$\hat{f}_d^i(m_j^i, n_i^*) = d_0^i 10^{\left(\dfrac{P_t^+ - m_j^i - \overline{PL}(d_0)}{10n_i^*}\right)} = \hat{d}_j^i \tag{6}$$

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

$$n^* = \arg\min_n \mathbf{e}^i = \arg\min_n \{d_j^i - \hat{f}_d^i(m_i, n)\} \tag{7}$$

Least square estimation, linear regresion, SVM, Neural Nets, genetic algorithm and bla bla bla.

III. Multifrequency Multistage Radiolocation System (MFMS)

This section will explain MFMS in greater detail. Akin to other fingerprinting-based radiolocation systems, MFMS consists of two main phases. During the offline phase, Received Signal Strength (RSS) information from anchor nodes is collected at many locations in the environment and used to approximate the radio wave propagation function. The online phase, on the otherhand, 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 different sources of information 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.

As it can be seen in the Equation (4) 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.

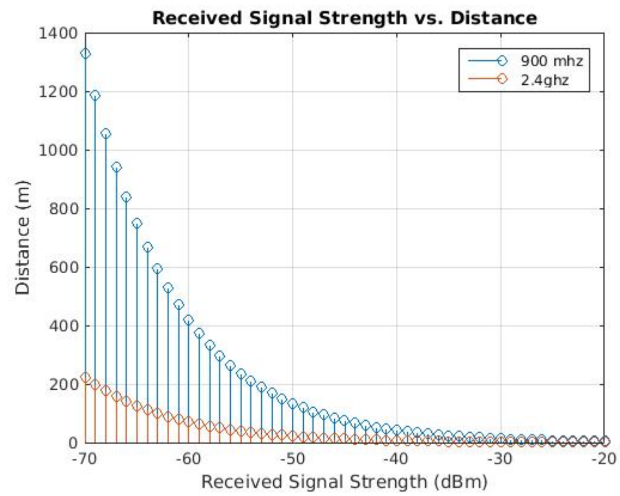

Fig. 1: RSSI readings of NLoS and LoS APs acquired with a stationary agent

Figure 2 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.

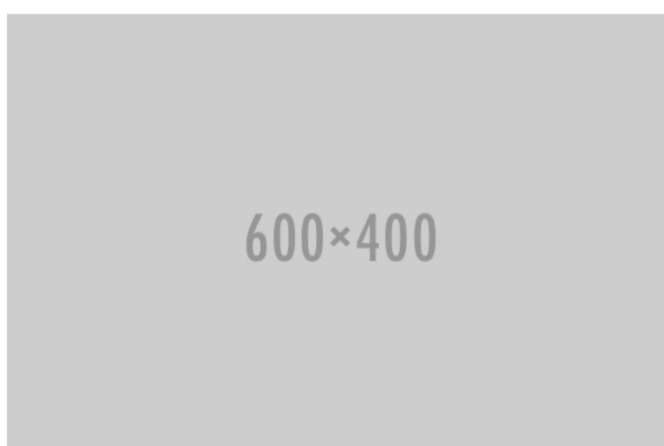

Fig. 2: MFMS Anchor Nodes

A. Offline Phase

1) Data Acquisition:

2) Training:

B. Online Phase

1) Inference:

2) Information Fusion:

IV. Experimentation

A. Experimental Setup

1) Hardware:

2) Software:

B. Results

V. Conclusions and Future Work

VI. Acknowledgments

References

[1] H. T. Friis, "A note on a simple transmission formula," *Proceedings of the IRE*, vol. 34, no. 5, pp. 254–256, 1946.