Poster Abstract: A Case for Magneto-Inductive Indoor Localization

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***Abstract*—In this work, we show that the magneto-inductive (MI) indoor localization using tri-axial coils possesses unique advantages over the RF-based techniques. The spatial distribution of a generated magnetic field strength can be easily predicted using simple linear models. In addition, the field strength is very stable over time, even in the presence of moving people, which makes MI localization a promising indoor positioning technology.**

I. Introduction

In the past years, there has been a growing interest in localization systems using magnetic fields [1]–[7]. This is partly because cheap magnetic sensors are nowadays available in almost every hand-held smart device. In addition, these systems usually operate at extremely low frequencies, in the near field region. Consequently, the corresponding signals are non-propagating, and they do not experience multipath and shadow fading, such as the high frequency radio waves. Unlike microwaves, the magnetic fields experience no absorption by water (e.g. by the human body), which makes them very attractive for localization inside highly populated buildings, where people are continuously moving [8]. Moreover, they do not usually require line-of-sight between devices, as they have the ability to penetrate through soil, concrete and rock with negligible attenuation [2]. Existing magnetic localization approaches use either indigenous magnetic fields, such as the Earth's magnetic field and/or the magnetic fields generated by home electronics [5]–[7], or low-frequency magnetic fields generated locally, in purpose for localization [1]–[4]. The major challenge in indoors is accounting for the distortions in the magnetic field, in the vicinity of massive metallic objects such as building structures, elevators, etc. In spite of that, we provide few results showing that the magnetic field strength is much more predictable than the strength of the radio waves.

II. System Description

Our measurement system consists of one magnetic transmitter (TX) and one magnetic receiver (RX) that operate at a carrier frequency is 2.5KHz, and at symbol rate of 32 symbols/s. The Received Signal Strength Indicator (RSSI) is estimated by measuring the energy at the receiver, corresponding to a known preamble of 120 symbols. One particularity of our system is that both TX and RX are equipped with tri-axial coils, which makes the RSSI invariant to the relative rotations of TX and RX [1], [4]. RX is connected to a computer via the USB port, where the data is stored and processed offline.

III. Experimental Results

We performed a fingerprinting experiment in a large lecture room. Fig. 1 (left column) shows the measurement scenario, with TX at the origin (black square marker) and RX moving on the horizontal X-Y grid (black dot markers), whose step is 1 meter in each dimension. Three different heights were considered: $Z \in \{0,\, 0.75,\, 1.5\}$ meters, respectively. The three plots in the left column of Fig. 1 show the RSSI magnetic map for each horizontal "slice". We may notice that the constant RSSI curves are approximately circular (with small variations at the floor level). The signal strength is easily predictable, unlike for example the WiFi signals that are subject to severe fading. Therefore, the range estimation can be done using simple models. In Fig. 2, we show how the overall RSSI decreases with distance. The red dots represent the measured RSSI values at all points of the rectangular lattice used in the fingerprinting experiment. Few extra-measurements (indicated by black "×" marker) were taken at larger distances in order to show the RSSI trend. The model is estimated from the measurements using linear Least-Squares (LS), and is shown in Fig. 2 by the continuous thick gray line. We may notice

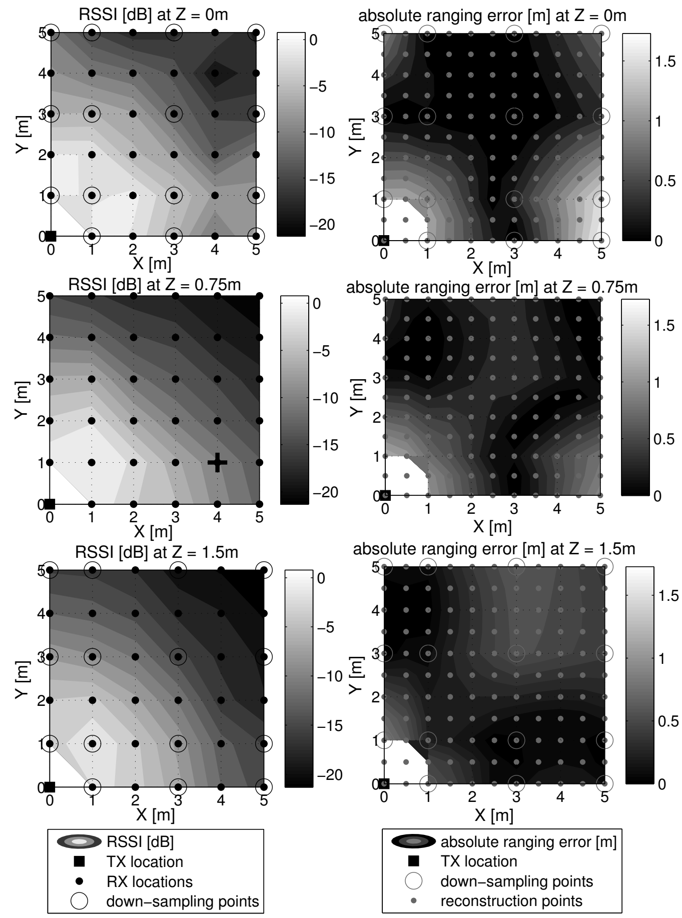

Fig. 1. Sparse magnetic fingerprinting (RSSI – left column) and ranging using the reconstructed RSSI (error in the range estimate $\hat{r}$ – right column).

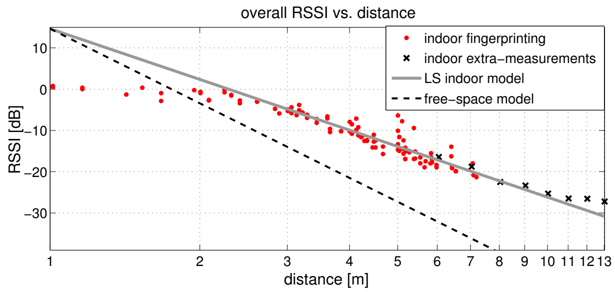

Fig. 2. The decay of RSSI with distance r. Measurements vs. models.

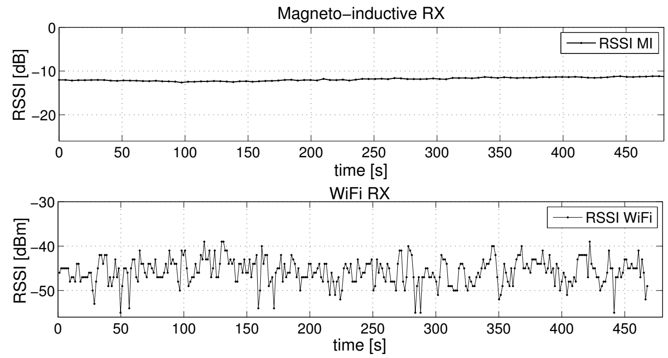

Fig. 3. The RSSI stability over time. Magnetic link vs. WiFi link.

that the slope corresponding to the derived indoor model is about 40dB/decade, compared to the free-space model whose slope is 60dB/decade [2], shown in Fig. 2 by the black dashed line. Therefore, the magnetic field strength decays slower in indoors. This phenomenon might be caused by the fact that the surrounding ferrous materials act as passive re-radiators [1].

In order to prove the spatial predictability of the RSSI, we down-sampled the 3 slices approximately by a factor of 2 along X and Y axes. In the vertical dimension, the middle horizontal slice was eliminated completely. The down-sampling points are marked in Fig. 1 with black/gray circles. We reconstructed the missing data using simple 3D linear interpolation of the down-sampled data with a resolution of 0.5 m in all three dimensions. The reconstruction points and the corresponding ranging errors are shown in the right column of Fig. 1 (only 3 out of 7 interpolated horizontal slices are shown). Despite the sparse down-sampling, the signal is predicted with an accuracy of few dB. Slightly larger ranging errors occur at the floor level, but overall, the signal is much easier to predict than, for example, WiFi. The overall ranging bias using the interpolated RSSIs and our LS model is $b_r = \mathrm{E}\{\hat{r} - r\} = 0.09$ meters, whereas the standard deviation of the ranging errors is $\sigma_r = [\mathrm{E}\{(\hat{r} - b_r)^2\}]^{1/2} = 0.45\text{m}$. The maximum ranging error is $e_{\max} = 1.73\text{m}$ at $Z = 0$, and only 0.88m at $Z = 1.5\text{m}$. This shows that ranging models for magnetic localization are very reliable and that compared to the radio maps, the magnetic maps are much easier to reconstruct from spatially sparse samples. Similar results were obtained when the range was estimated using the LS model in Fig. 2 only (no fingerprinting) and the RSSIs: $b_r = 0.14\text{m}$, $\sigma_r = 0.53\text{m}$, and $e_{\max} = 1.73\text{m}$. The slightly larger variance might be caused by the fact that the range estimation was done in a per-measurement basis, the spatial correlation being neglected. The RSSI is easily predictable, and this is particularly important when fingerprinting-based localization is used. Much of the tedious map construction work can be avoided by using sparse sampling.

Another important advantage of MI localization is that the generated magnetic field strength is very stable over a long period of time, unlike RF-based techniques. In Fig. 3, we show the variation of the RSSI of the magnetic link versus the RSSI corresponding to a WiFi link. RX and TX were stationary, placed at the same location in both cases, about 4 meters apart, with TX at the origin. The location of RX from which the RSSI time variation was analyzed is marked by a black cross in middle subplot of the first column in Fig. 1 (corresponding to $Z = 0.75$ meters). The RSSI was recorded for a period of approximately 8 minutes for each of the transceivers, while two persons were walking between TX and RX, crossing the link, and approaching TX and RX. We may notice that the RSSI corresponding to the magnetic transceiver has negligible variation compared to the RSSI of the WiFi. A similar analysis is given in [8], but for the Earth's field.

IV. Conclusion

In this paper, we show that when tri-axial coils are used both at TX and RX, the indoor magnetic RSSI is very easy to predict both in space and time, unlike the RF RSSI used in most of the wireless standards. The fast decay of the magnetic field is undesirable from the point of view of the transmission range, but it allows to distinguish between very closely-spaced distances. This has been shown in [2] for underground animal tracking. Our future work will focus on RSSI fingerprinting independently in each axis. We aim to achieve full 3D location and orientation estimation using a single transmitter.

V. Acknowledgements

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