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FM radio for indoor localization with spontaneous recalibration

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ABSTRACT

The position of mobile users has become highly important information in pervasive computing environments. Indoor localization systems based on Wi–Fi signal strength fingerprinting techniques are widely used in office buildings with an existing Wi–Fi infrastructure. Our previous work has proposed a solution based on exploitation of a FM signal to deal with environments not covered with Wi–Fi signal or environments with only a single Wi–Fi access point. However, a general problem of indoor wireless positioning systems pertains to signal degradation due to the environmental factors affecting signal propagation. Therefore, in order to maintain a desirable level of localization accuracy, it becomes necessary to perform periodic calibrations of the system, which is either time consuming or requires dedicated equipment and expert knowledge. In this paper, we present a comparison of FM versus Wi–Fi positioning systems and a combination of both systems, exploiting their strengths for indoors positioning. We also address the problem of recalibration by introducing a novel concept of spontaneous recalibration and demonstrate it using the FM localization system. Finally, the results related to device orientation and localization accuracy are discussed.

1. Introduction

The myriad positioning techniques in existence today have enabled a number of interesting applications that require appropriate levels of precision. For a number of applications (e.g. outdoor navigation), GPS leads the way, while the picture is not as clear-cut when it comes to indoor positioning. A number of technologies for indoor positioning exists, varying in characteristics, methods used, precision and cost. Technology with the highest precision and lowest cost is the ultimate aim, however in practice typically there is a trade-off between the performance and the associated costs, such that a positioning technology becomes cost effective. Over the past number of years, a significant amount of work has been invested in the use of IEEE 802.11 (Wi–Fi) networks for the purpose of localization [1–7]. The cost-effectiveness lies in the fact that Wi–Fi networks are increasingly present in everyday life and a variety of mobile devices supports them.

The localization approach that these systems take is based on the fact that each point in the space has a unique fingerprint of signal parameters. In this approach, the location of a mobile unit is found by comparing the signal parameters observed from nearby access points (the *location fingerprint*) to the database which matches fingerprints with real coordinates. The acquisition of such a database (*calibration*) is a laborious and time-consuming process, since achieving a satisfactory localization performance requires the measurement of a large number of location fingerprints. Another drawback of the localization systems based on IEEE 802.11 wireless networks is that the electromagnetic field is prone to fluctuations due to various factors which can cause the degradation of the positioning accuracy [8]. Due to these fluctuations, the calibration process must be repeated periodically (*recalibration*) in response to performance degradation, which makes these

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systems inconvenient for practical use. A number of projects have addressed this problem using specific hardware capable of refreshing training set with updated measurements [8,5]. This approach is often costly due to additional hardware and increases the complexity and maintenance overhead of the system.

Moreover, while Wi–Fi coverage in large areas such as airports, enterprises and shopping malls is realized using multiple access points (APs) where localization might work well, in case of smaller areas such as private houses, these localization systems do not work, since a single access point (such as a Wi–Fi router for example) is not sufficient to localize a mobile device. In addition, use of Wi–Fi is prohibited in interference-prone environments, while FM signals are allowed. In these environments, the localization system cannot be built on the top of the pre-existing infrastructure; rather, such a localization system would require the acquisition of additional equipment.

Considering the above shortcomings, we have devised a FM-based localization system that has the ability to spontaneously recalibrate in response to signal degradation and in turn address the issues faced by other localization systems. The contribution of this paper is threefold: (i) further improvement of the FM positioning system we proposed in [9], (ii) a synergetic approach based on the combined advantages of FM and Wi–Fi positioning systems and (iii) the introduction and the proof of the concept of spontaneous recalibration for FM positioning.

The paper is organized as follows. The section that follows provides a critical review of the ongoing research work. Our methods and description of the experiments are provided in Section 3. In Section 4 we discuss the accuracy of FM and how it can be improved. Then, in Section 5, we compare performance of Wi–Fi versus FM positioning. In Section 6 we demonstrate the benefits of a combined, hybrid Wi–Fi + FM positioning system. In Section 7 we describe spontaneous recalibration and analyze obtained results. The impact of the user's orientation on the localization accuracy and estimation of user's orientation is examined in Section 8. Finally, we provide a discussion and summary in Section 9 and X respectively.

2. Related work

2.1. Localization

There is a spectrum of approaches to indoor localization that rely on different types of sensors and on different types of modeling the information obtained from an environment. The majority of indoor positioning systems are based on Wi–Fi [1,10,11], GSM [12], Bluetooth [13], RFID [14], ultrasound [15,16] and infrared [16,17]. To acquire user's location, such systems analyze the proximity of a mobile unit to a certain sensor, time of signal propagation or received signal strength, or both. Dedicated localization systems can provide high accuracy however they require expensive, specialized hardware, especially for large-scale deployments (e.g. [18]).

There are two general approaches to wireless localization: signal propagation modeling and signal fingerprinting. Propagation modeling techniques rely on the received signal strength indication (RSSI), the angle of arrival (AOA) or the time of arrival (TOA) measurements. Then, mathematical models are applied on these parameters to determine the location of the user [6]. Since all the characteristics of signal propagation are difficult to be considered within the same model, the propagation models usually have limited accuracy [2]. This is one of the main reasons why the research work has been more focused on fingerprinting techniques (e.g. [1,10,19]) or the combination of the two [4]. The fingerprinting approach is based on comparing the observed measurements at the unknown location with all known measurements, where the best match is returned as the estimated location.

The use of the IEEE 802.11 wireless infrastructure for localization has garnered significant interest over the past decade, due to the wide deployment and good coverage in urban areas. One of the first projects that employed the RSSI fingerprint technique was RADAR [6]. Both, propagation modeling and fingerprinting have been used and the authors reported 25th and 50th percentile errors of 1.92 m and 2.94 m respectively. In order to determine the mobile user's location, the k-nearest neighbors (kNN) algorithm was applied. Wassi et al. [2] studied the multilayer perceptron, generalized radial neural network and kNN algorithms applied to the signal strengths measurements recorded from three IEEE 802.11b access points in an indoor space. The experiments have been performed in the 75 m long corridor with a width of about 2.5 to 4.5 m; they reported a 2.4 m median error and demonstrated the kNN algorithm to slightly outperform the neural networks. Ferris et al. [1] designed Wi–Fi localization system using Gaussian processes in conjunction with graph-based tracking. They modeled users moving through the rooms on the same floor as well as more complicated patterns of moving such as going up and down stairs. When tested over the 3 km data in the three floor building with 54 rooms the average error was 2.12 m.

In our previous work [9] we presented preliminary results of FM positioning for indoor environments. In this paper we improve positioning results by considering different experimental setups and additional signal processing methods (described in the sections that follow). There are few other works dedicated to FM positioning. The first positioning system based on FM radio was presented by Krumm et al. [20]. It was an outdoors-only positioning system that employed a prototype wristwatch device featuring an FM receiver, to distinguish six districts of Seattle using the signals broadcast from public FM stations. They recognized the correct district in about 80% of cases. More advanced algorithms enabled the system to locate the user with 8 km median accuracy [21]. Recently, Fang et al. [22] presented a comparison of FM and GSM outdoor localization within 20 reference points on an area of about 1 km^2. With 6-channel fingerprints, GSM accuracy was better than that of FM. However, by employing more FM channels they were able to improve FM performance significantly. It can be seen, that the previous works focus on outdoor localization using broadcast FM signals and special