Chapter 3
Robustness in Fingerprinting-Based Indoor Positioning Systems

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ABSTRACT

Indoor positioning systems have received increasing attention for supporting location-based services in indoor environments. Received signal strength (RSS), mostly utilized in Wi-Fi fingerprinting systems, is known to be unreliable due to two reasons: orientation mismatch and variations in hardware. This chapter introduces an approach based on histogram equalization to compensate for orientation mismatch in robust Wi-Fi localization. The proposed method involves converting the temporal-spatial radio signal strength into a reference function (i.e., equalizing the histogram). This chapter also introduces an enhanced positioning feature, which is called delta-fused principal strength, to enhance the robustness of Wi-Fi localization against the problem of heterogeneous hardware. This algorithm computes the pairwise delta RSS and then integrates with RSS using principal component analysis. The proposed methods effectively and efficiently improve the robustness of location estimation in the presence of mismatch orientation and hardware variations, respectively.

INTRODUCTION

Location awareness has become a crucial concern for various mobile applications (Gu, Lo & Niemegeers, 2009; Perez-Ramirez, Borah & Voelz, 2013; Sun, Zhu, Zhang & Fang, 2011). Recently, numerous studies have addressed location estimation by using existing Wi-Fi infrastructure to compensate for the weakness of the Global Positioning System (GPS) in urban areas and indoor environments (Bahl & Padmanabhan, 2000; Youssef & Agrawala, 2008; Fang, Wang, Huang, Yang & Chen, 2012). Because of the frequent deployment of access points (APs), Wi-Fi-based localization has gained considerable attention over the last several years, and the received signal strength (RSS) is commonly adopted as a positioning characteristic (Bshara, Orguner, Gustafsson & Van Biesen, 2010; Figuera, *et al.* 2011; Liao,

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et al. 2011). Among the various Wi-Fi positioning systems, the fingerprinting-based approach, is one of the most feasible solutions (Youssef, Agrawala & Udaya Shankar, 2003; Tsui, Lin, Chen, Huang & Chu, 2010; Fang & Wang, 2011). This chapter focues on the location fingerprinting systems, which is based on a RSS-mapping approach. Based on the pre-recorded RSS from different reference locations, denoted as fingerprints or radio map, the user's location is estimated by mapping the currently measurement with the pre-stored fingerprints. Because this approach provides a high positioning accuracy in a GPS-less environment, researchers have recently proposed various fingerprinting-based localization algorithms (Kuo & Tseng, 2008; Shin, Chon & Cha, 2012). Although Wi-Fi-based localization shows great promise, a key challenge in real-time location estimation is managing the robustness issues (Bernardos, Casar & Tarrio, 2010; Mazuelas, *et al.* 2009). This chapter will discuss two robustness issues of the fingerprinting localization systems, including the orientation mismatch and heterogeneous hardware.

The first robustness issue discussed in this chapter is the orientation mismatch. The performance of fingerprinting based localization systems degrades severely when radio environments between training and testing RSSs differ from each other (Fang, Wang, Chiou & Lin, 2012). In fact, radio irregularity is a common occurrence in wireless environments (Gezici, 2008; Liu, Darabi, Banerjee & Liu, 2007; Roberts & Pahlavan, 2009). One type of radio mismatch is caused by the different user orientations, referred to as "orientation mismatch". The human body consists of more than 50% water and, hence, might block the transmission of 2.4-GHz Wi-Fi radios (Ladd, *et al*. 2002). In a fingerprinting-based system, the mismatch between training and locating orientations makes it difficult to accurately determine the location based on RSS patterns. Researchers have performed experiments regarding the impact of user/device orientation on RSS. Previous studies have acknowledged this orientation problem and have indicated that RSS varies substantially depending on the user's orientation, even at a fixed location (Liu, *et al.* 2012; Kaemarungsi & Krishnamurthy, 2004).

To overcome this problem, (Papapostolou & Chaouchi, 2009) proposed a compass-assisted approach, in which the testing RSS is matched according to the orientation-matched radio map only, rather than the entire database. A similar approach was presented in (Sanchez, Quinteiro, Hernandez-Morera & Martel-Jordan, 2012; Papapostolou & Chaouchi, 2009), in which fingerprinting is extended with orientation information. These approaches effectively reduce the orientation mismatch effect; however, they require prior orientation data to enrich the radio map and real-time feedback from a digital compass. Although current high-level smartphones can be equipped with compass sensing functions that provide real-time user orientation, reconstructing a radio map for every possible orientation is extremely time-consuming and infeasible.

The second robustness issue discussed in this chapter is the heterogeneous hardware. Many studies have indicated that RSS variation between diverse Wi-Fi devices may exceed 25 dBm, even in the same location (Kaemarungsi & Krishnamurthy, 2004; Kaemarungsi, 2006). Possible reasons include a lack of consistency in the various industry standards and the use of different chipsets and antenna. Based on IEEE 802.11 standard (IEEE standard for information technology, 2007), RSS is not restrictively defined, and it is left as implementer's choice, but must indicate energy in the channel. Variation in RSS resulting from heterogeneous devices causes large bias error in localization systems (Figuera, *et al.* 2011; Fang, Wang, Chiou & Lin, 2012). Such variation in hardware is inevitable in the real world due to the tremendous growth in recent years of new Wi-Fi devices, such as iPhones, iPads, and Android devices, which is expected to continue.

To overcome this difficulty, researchers have devoted considerable effort to designing robust localization systems that provide valid location information despite the use of heterogeneous devices. Common

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