Indoor Localization, Tracking and Fall Detection for Assistive Healthcare Based on Spatial Sparsity and Wireless Sensor Network

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ABSTRACT

Indoor localization and fall detection are two of the most paramount topics in assistive healthcare, where tracking the positions and actions of the patient or elderly is required for medical observation or accident prevention. Most of existing indoor localization methods are based on estimating one or more location-dependent signal parameters. However, some challenges caused by the complex scenarios within a closed space significantly limit the applicability of those existing approaches in an indoor environment, such as the severe multipath effect. In this paper, the authors propose a new one-stage, three-dimensional localization method based on the spatial sparsity in the x-y-z space. The proposed method is not only able to estimate and track the accurate positions of the patient, but also capable to detect the falls of the patient. In this method, the authors directly estimate the location of the emitter without going through the intermediate stage of TOA or signal strength estimation. The authors evaluate the performance of the proposed method using various Monte Carlo simulation settings. The results show that the proposed method is (i) very accurate even with a small number of sensors and (ii) very effective in addressing the multi-path issues.

Keywords: Compressive Sensing (CS), Fall Detection, Indoor Localization, Received Signal Strength (RSS), Sparsity, Time of Arrival (TOA)

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1. INTRODUCTION AND BACKGROUND

Indoor localization has been a long-standing and important issue in the areas of signal processing and sensor networks that has raised increasing attention recently (Pahlavan, Krishnamurthy, & Beneat, 1998; Pahlavan, Li, & Makela, 2002; Humphrey & Hedley, 2008; Li & Pahlavan, 2004: Becker et al., 2008; Chen & Kobayashi, 2002; Záruba, 2007; Shinno et al., 2008; Cheng et al., 2011; Hatami, Pahlavan, Heidari, & Akgul, 2006). As the number of elderly people grows rather quickly over the past few decades and continues to do so (He, Sengupta, Velkoff & DeBarros, 2005), it is imperative to seek alternative and innovative ways to provide affordable health care to the aging population (United Nations, 2009). A compelling solution is to enable pervasive healthcare for the elderly and people with disabilities at their own homes, while reducing the use and dependency of healthcare facilities. To this aim new technology and infrastructure must be developed for an in-home assistive living environment. One of the key demands in such an assistive environment is to promptly and accurately determine the state and activities of an inhabitant subject. The three-dimensional indoor localization provides an effective means in tracking the positions, motions, and reactions and detecting the falls of a patient, the elderly or any person with special needs for medical observation or accident prevention.

In assistive healthcare applications, the individual may wear a small device that could emit a radio frequency (RF) signal for localization. This emitter(s) propagates a signal that could be received and captured by several pre-mounted wireless sensors located in known positions. The sensors can estimate the location of the emitter after sharing some data and performing some processing.

The classic approach for localization is to first estimate one or more location-dependent signal parameters, such as time-of-arrival (TOA), angle-of-arrival (AOA) or received-signal-strength (RSS). Then in a second step, the collection of estimated parameters is used to determine an estimate of the emitter’s location. However, the AOA-based systems need multiple antennas or a scannable antenna that is usually very expensive (Humphrey & Hedley, 2008). The RSS-based methods require a costly training procedure and complex matching algorithms, while the positioning accuracy of these methods is largely limited by the large variance in indoor environments (Li & Pahlavan, 2004; Hatami, Pahlavan, Heidari, & Akgul, 2006). The TOA-based methods are usually very accurate. However, the accuracy of the classic TOA based methods often suffer from massive multipath conditions for indoor localization, which is caused by the reflection and diffraction of the RF signals from objects (e.g., interior walls, doors or furniture) in the environment (Pahlavan, Krishnamurthy, & Beneat, 1998).

In Comsa et al. (2011), the authors suggested a two-stage source localization method based on time-difference-of-arrival (TDOA) in a multipath channel exploiting the sparsity of the multipath channel for estimation of the line-of-sight component. In this method, the sensors don’t need to know the information on the specific transmitted symbols but, they require knowledge of the pulse shape of the transmitted signal. In Cevher et al. (2008), the authors presented a compressive sensing based distributed target localization. In this method, each sensor approximates the transmitted signal through its own received signal mapped to each one of the grid points. This idea helps to reduce the amount of data transmission in the sense of distributed localization but it lowers the quality of the estimation since each sensor estimates the transmitted signal just using its own received signal. Also, each sensor computes its own estimation of the emitter location that is not necessarily consistent with other sensors’ estimations.

In Pourhomayoun, Jin, and Fowler (2012), we proposed a 2-dimensional positioning approach based on the spatial sparsity and reported preliminary results for a stationary human target. However, that preliminary study came...
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