Simulation Modelling Practice and Theory 65 (2016) 45–56

Contents lists available at ScienceDirect

Simulation Modelling Practice and Theory

journal homepage: www.elsevier.com/locate/simpat

A 3D indoor positioning system based on low-cost MEMS sensors

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ARTICLE INFO

Article history:
Available online 19 February 2016

Keywords:
Indoor positioning
ZUPT
Kalman filter
MEMS

ABSTRACT

A positioning system in the absence of GPS is important in establishing indoor directional guidance and localization. Inertial Measuring Units (IMUs) can be used to detect the movement of a pedestrian. In this paper, we present a three-dimensional (3D) indoor positioning system using foot mounted low cost Micro-Electro-Mechanical System (MEMS) sensors to locate the position and attitude of a person in 3D view, and to plot the path travelled by the person. The sensors include accelerometers, gyroscopes, and a barometer. The pedestrians motion information is collected by accelerometers and gyroscopes to achieve Pedestrian Dead-Reckoning (PDR) which is used to estimate the pedestrian's rough position. A zero velocity update (ZUPT) algorithm is developed to detect the standing still moment. A Kalman filter is combined with the ZUPT to eliminate non-linear errors in order to obtain accurate positioning information of a pedestrian. The information collected by the barometer is integrated with the accelerometer data to detect the altitude changes and to obtain accurate height information. The main contribution of this research is that the approach proposed fuses barometer and accelerometer in Kalman filter to obtain accurate height information, which has improved the accuracy at x axis and y axis. The proposed system has been tested in several simulated scenarios and real environments. The distance errors are around 1%, and the positioning errors are less than 1% of the total travelled distance. Results indicate that the proposed system performs better than other similar systems using the same low-cost IMUs.

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1. Introduction

The Global Positioning System is widely used in tracking locations at outdoors. However, it cannot be used in indoor environments because of its experience of sever signal attenuation. On the other hand, there are huge demands for high precision indoor positioning systems. Examples of the applications include tracking children's locations in shopping malls or large supermarkets, locating people with elderly dementia in providing support, and finding a car in a big parking garage.

Current indoor positioning technologies can be divided into two types: (1) infrastructure-based approaches and (2) infrastructure-free approaches.

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http://dx.doi.org/10.1016/j.simpat.2016.01.003
S1569-190X(16)00004-6/© 2016 Elsevier B.V. All rights reserved.

Infrastructure-based approaches obtain the indoor positioning based on the information collected from external infrastructure or external equipment, such as network nodes, WiFi signals, Bluetooth signals, radio frequency (RF) signals, magnetic signals and video signals.

Infrastructure-free approaches eliminate the need for external signals. Most of these approaches are based on inertial sensors, *i.e*., accelerometers and gyroscopes. These sensors can accurately collect data in a harsh environment. However, the drift and bias errors of these sensors cause serious problems. Recently, the zero velocity update (ZUPT) algorithm [1] was proposed to overcome the sensors' errors and improve their accuracy significantly.

Infrastructure-based solutions require the installation of infrastructure and tends to be more expensive [2], by contrast, infrastructure-free solutions are more flexible and low cost [3]. Recent years have seen the trend of moving toward to infrastructure-free solutions, however, the accuracy is too low to be used in real world applications [4]. To address this challenge, this paper proposes an infrastructure-free approach to achieve high precision 3D indoor positioning using a low cost sensor. Pedestrian dead-reckoning (PDR) is used in this paper to sequentially estimate the pedestrian's position. PDR consists of the double integration of current inertial sensor readings. When using PDR to calculate the position and velocity, the system will eventually be led to divergent because of the sensor error [5]. To solve this issue, we use Kalman filter model as basis model. It consists a prediction process and an update process. When there is an appropriate observation, Kalman filter can compensate the error by the update equation to keep the system relatively stable. ZUPT can very accurately detect the time when a pedestrian is standing still, *i.e*. the velocity of the pedestrian is zero. We use this information as the observation in Kalman filter, so it can eliminate system errors greatly. Comparing to the existing solutions, we use the barometer fused with accelerometer to obtain z-axis information by combine integrating ZUPT with Kalman filter. The existing solutions for height information achievement include the fusion of barometer and accelerometer, but as far as we know, none of them added ZUPT in the model. Because our system is foot-mounted, so ZUPT is available and we use it as our observation to eliminate error to get more accurate results. And the accurate height information will improve the results at x-axis and y-axis in Kalman filter, which will outperform than some other existing solutions.

The rest of this paper is organized as follows: Section 2 describes the related work. Section 3 presents the proposed mathematical model of the system, with the details of the design, framework and the processing methods. The simulation experiments to test the model and the results are detailed in Section 4. The paper is concluded in Section 5 with a discussion of limitations and future work.

2. Related work

There is a large amount of work in the area of indoor positioning with infrastructure-based approaches. A typical infrastructure-based approach is described in [6,7], which located a pedestrian using WiFi signal strength measurements. Bacak and Celebi [2] proposed an indoor positioning system based on the RF signal fingerprinting method. Aversa [8] used the heterogeneous wireless networks in localization. The IndoorAtlas and the DLR proposed indoor positioning solutions based on magnetic field information [9,10]. The advancement of Internet of Things presents another opportunity for different kinds of sensors and devices to obtain a variety of services to help them in positioning and in other functionalities [11,12]. The infrastructure-based system suffers from the signal interference and the installation and maintenance of a full set of signal transmitting and receiving devices can increase the system cost. It limits their usability, especially when there are no external sources of signal or when these signals are difficult to setup.

There are also a number of authors proposed kinds of infrastructure-free approaches to achieve indoor positioning. Krach [13], detected the state of motion of the pedestrian by measuring acceleration and angular velocity collected by an accelerometer and a gyroscope. In [14], authors estimated the velocity, position and attitude information of the pedestrian to create a pedestrian movement model by inertial calculation. In [15], the author achieved positioning by utilizing multiple cameras. There are other publications that combined the position information calculated by inertial sensors with other information sources, such as WiFi [16], magnetic field [17], and indoor plan [18,19], to obtain a higher accuracy. The infrastructure-free approaches remove the dependence from the signal source and reduce their maintenance cost significantly. Nevertheless, these methods still use expensive sensors to obtain high precision achievements and the majority are based on the two-dimensional plane [20–22].

In our previous work, Zheng et al. [23] developed a 3D indoor positioning system based on the Kalman filter model using low cost Micro-Electro-Mechanical System(MEMS) sensors. MEMS is the technology of very small devices, and merges at the nano-scale into nanoelectromechanical systems (NEMS) and nanotechnology [24]. The inertial sensors computed the position using the Pedestrian Dead-Reckoning (PDR) algorithm. The position, velocity, and altitude information of the pedestrian was then calculated. The acceleration and angular velocity were used to detect the time when the pedestrian was in contact with the ground while walking through the zero velocity update (ZUPT) algorithm. The velocity equals zero at the time when the ZUPT is satisfied. This was input into a Kalman filter as an observation value to eliminate systematic errors. A barometer was introduced to obtain height information to improve 3D indoor positioning system.

In this paper, we further improve the precise of the work. The barometer is integrated with the accelerometer and input to the Kalman filter for height information. We also use the height information calculated to distinguish whether the pedestrian is walking on flat ground, climbing stairs or taking an elevator. The Kalman filter is extended to 15-dimensions, and the acceleration deviation and gyroscope bias is added in the state vector. Combining these methods are beneficial for

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