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Wearable indoor pedestrian dead reckoning system

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ABSTRACT

We introduce a wearable pedestrian indoor localization system with dynamic position correction. The system uniquely combines dead reckoning and fiducial marker-based localization schemes, exclusively using widely available, low end and low power consumer hardware components.

The proposed system was tested with various walking patterns inside a building, achieving an indoor positioning accuracy of 3.38% of the total distance walked. This accuracy is comparable to those obtained with solutions deploying specialized high cost hardware components. The low cost wearable system proposed herein could serve as the foundation for a pervasive solution for indoor way finding and patient tracking.

1. Introduction

The estimation of indoor user position is a key challenge in the development of ubiquitous computing environments because location is a fundamental aspect of a user's context [1]. A system must be location-aware in order to seamlessly deliver context-relevant information to the user [2]. Therefore, to realize a truly pervasive system, an accurate indoor positioning system is necessary.

In recent years, localization systems based on pedestrian dead reckoning (PDR) have gained interest among the scientific community. In PDR systems, position estimation is achieved by double integration of accelerometer measurements, while the orientation is estimated by integrating the angular velocity obtained from gyroscopes [3] or by obtaining the direction of the geographical north pole using magnetometers. The latter are oftentimes combined with gyroscopes, as they are prone to errors due to metallic structures and electrical appliances in the vicinity [4]. Inertial sensors (accelerometers and gyroscopes) are prone to drift errors. To mitigate such drift errors during pedestrian tracking, the properties of human gait can be exploited, resetting the velocity and acceleration values when the accelerometers are known to be static. This technique is called "zero-velocity updates" or ZUPT [4].

As mentioned in [4], most of the experiments in the previous literature regarding PDR do not consider varied and realistic walking patterns. Recent research has presented PDRs capable of tracking the movements of a pedestrian without imposing restrictions on how and where a person walks. For example, Sagawa et al. [5] propose a method to measure the distance traversed without imposing constraints on speed, or stride length. This system used a combination of 3 accelerometers, a gyroscope and an atmospheric pressure sensor. The system was only tested during straight-path walking and stair climbing tasks, achieving a horizontal distance estimation error of less than 5.3% of the total distanced traveled. A PDR system capable of tracking unrestricted pedestrian movements that achieves an indoor positioning accuracy within 0.3%

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of the distance traveled is presented in [4]. This solution uses a hardware device named InertiaCube3, which is composed of 3 accelerometers, 3 gyroscopes and 3 magnetometers. Localization is achieved by combining the location information provided by the sensors using Kalman filters.

Other authors have considered combining PDR systems with localization systems based on external location references to recalibrate or enhance the accuracy of the dead reckoning navigation system. Recent research proposes the recalibration of inertial navigation systems for vehicles using image processing [6–8]. Of particular interest for this work are indoor pedestrian tracking solutions which combine inertial sensors and image processing. In [9] a camera was used to recalibrate an indoor localization system designed for pedestrians, using pattern classification to determine the movement performed by the user, and Kalman filtering to combine the location data provided by the sensors. The inertial tracking system was custom made, and the hardware setup was not fully described in the article. In [10] a camera was mounted on the head, pointing in the superior direction with respect to the user. Several markers were positioned on the ceiling and walls, arranged in a high density pattern of about 1.7 markers per square metres. InertiaCube2 was used as the inertial measurement device, which contains a sensor array similar to InertiaCube3, described above. The localization accuracy achieved by this system was not reported.

1.1. Motivation

Although indoor pedestrian navigation systems have been previously investigated, prior solutions require custom made hardware [9] or specialized commercial components which are expensive and not readily available to the general public. For instance, the InertiaCube family of devices have been used in [4,10], producing solutions in the thousands of dollars. Further, both studies only present data from a single indoor localization experiment.

Pedestrian localization applications in the fields of rehabilitation, patient monitoring or personnel tracking require solutions that are economically attractive and readily available on the market. These requirements are particularly relevant for technological solutions in developing countries, where specialized hardware is difficult to acquire or prohibitive in terms of cost [11,12]. In light of these observations and the review above, it is clear that further research is needed to develop cost effective localization systems that allow indoor pedestrian tracking for unrestricted navigation in real-time. We hypothesized that an indoor pedestrian navigation system can be built using mainstream hardware components, while achieving position errors comparable to previously published solutions.

The specific objective of this work was to investigate an indoor pedestrian navigation system that:

- Can be easily built and deployed by using mainstream hardware components,
- Does not require major infrastructure alterations, such as the installation of wireless network equipment,
- Requires less than 1 fiducial marker per 10 square metres, and
- Yields real-time location estimates with an accuracy comparable to that of solutions found in recent literature.

The reason for limiting the amount of fiducial markers in the environment is to minimize the size of the database associated with the fiducial markers and the visual clutter, which would be unacceptable in health care facilities and public buildings. In this paper, we introduce novel features to the PDR field by proposing the usage of mainstream, low-cost hardware components in the creation of an indoor PDR system with image processing-based recalibration.

2. System design

2.1. Hardware set-up

Our PDR system is composed of a unique combination of sensors, namely:

- A Nintendo Wii remote control to obtain tri-axial accelerometry data,
- A Gyrosense Gyropoint air mouse to obtain angular velocity from its dual-axis gyroscope,
- A Logitech QuickCam Pro 4000 webcam to detect visual markers fixed in the environment, and
- A small form factor computer with a bluetooth interface and USB ports.

To record the data acquired by the sensors, the small form factor computer was mounted on an Ergotron mobile workstand cart. A bluetooth dongle and the Gyrosense wireless receiver were connected to the computer. The laptop was pushed along by an experimenter while the subject walked on the predefined circuit.

The Wii remote control was mounted on the lateral side of the right ankle. The gyromouse was mounted anterior to the abdomen, with one sensitive axis in the superior–inferior direction and the other in the mediolateral direction. The camera was mounted on the left shoulder of the participant. Although the camera location differed from the foot location, they were spatially correlated. The data processing stage (Section 5) specifically compensated for this location difference. The hardware arrangement is presented in Fig. 1.

Thirty distinct visual markers were positioned at the corners of a predefined polygonal indoor circuit. We created a database containing the positions of each marker within the building. These marker positions were obtained with a laser distance measurement tool. The distances were measured twice and then averaged to correct for measurement deviations. A marker consisted of a letter-sized sheet of paper with a unique 17×17 cm^2 symbolic image. The visual markers and the image processing algorithms used for image localization are described in detail in [13].