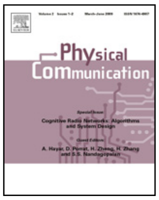
Physical Communication 13 (2014) 4–16

Contents lists available at ScienceDirect

Physical Communication

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



Full length article

Sensor-based dead-reckoning for indoor positioning

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ARTICLE INFO

Article history:
Received 10 July 2013
Received in revised form 15 November 2013
Accepted 18 November 2013
Available online 12 December 2013

Keywords:
Sensor positioning
Accelerometer
Gyroscope
Magnetometer
Stride length modeling
Stride length measurement
Experimental testing

ABSTRACT

This paper presents a method of indoor position determination using an accelerometer, compass and gyroscope which are typically available in devices such as smart phones. The method makes use of measurements from such a device worn on the body, such as attached to a belt. The accelerometer in the device estimates the stride length indirectly from the vertical acceleration associated with walking, while the compass and gyroscope measure the heading angle. The position of the subject is then determined by combining the stride length distance estimates and the heading information, but corrected periodically at known checkpoints within the building. The method was tested with a range of both males and females wearing the device, at different walking speeds and styles. The experimental results demonstrate that the stride length estimation can be accurate to about 7 percent. The measured data agree closely with a theoretical dynamical model of walking. The results also show that the position of the subject can be determined with an accuracy of 0.6 m when walking along an indoor path.

1. Introduction

This paper concerns the development of a personal locater for indoor tracking. The requirement to track people inside buildings has wide applications, including security, emergency services, and medical applications in hospitals and nursing homes. The types of technologies that can be applied for indoor positioning include radiolocation, ultrasonics, and various sensors including accelerometers, gyroscopes and magnetometers. In practice, no one technology has a clear dominance in all applications, so that a practical system may involve deploying a hybrid of two or more types of technology. In this paper the development of a sensor-based indoor position location system is described. However, the system operation requires some form of radio data communications, which could include the cellular phone network, wireless LANs (Wi-Fi), or wireless sensor networks. The particular experimentation described in this paper is based on an outdoor radiolocation system called Precision Location System (PLS) developed by CSIRO (see Fig. 1), which also incorporated appropriate sensors. However, the radiolocation function was not utilized, but the data transmission facility was used to communicate with base stations located within the test buildings.

For outdoor applications a GPS-based application is appropriate where the 10–20 m positional accuracy is adequate, but for indoor applications the accuracy required is typically of the order of 1 m. Further, GPS signal blockage into a building and the degrading of positional accuracy due to non-line-of-sight multipath propagation generally means that some other alternative methods of position determination are needed for indoor applications. One possibility due to its widespread adoption for data transmission is Wi-Fi positioning [1–4], but the accuracy of such systems is typically in the range of 3–5 m. For better accuracy other radiolocation methods such as ISM band systems [5–7] and ultra-wideband (UWB) [8–11] have been shown to have an accuracy of 0.2–0.5 m. However, such systems require special equipment not commercially available, and require base stations to be located throughout the coverage area. With the advent of "smart" phones/Tablets with

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http://dx.doi.org/10.1016/j.phycom.2013.11.013

Fig. 1. The mobile unit mounted on the hip as used for the position location experiments.

both sensors (accelerometers, gyroscopes, compass) and data communications as standard, an alternative approach is to use dead-reckoning techniques [12,13] for position determination. Dead-reckoning does not provide absolute position determination (as with the above-referenced methods), but rather provides positions relative to the starting point by integrating sensor data associated with both the heading angle and the displacement. Such methods will have errors that increase over time due to the integration of the sensor data, so that some periodic correction of the position data (using some other independent technique) is necessary. Thus while dead-reckoning methods have merit due to the availability of the necessary sensors in commonly used commercial devices, obtaining the desirable accuracy (say 1 m) requires careful attention to its implementation.

1.1. Overview of related work

There are a significant number of GPS-free walking/gait analysis systems and approaches reported in the literature especially for paraplegics or patients with some specific diseases such as Parkinson or Spastic Cerebral Palsy [14–16]. Stride/gait information is inferred from inertial measurement unit (IMU) sensors (accelerators, gyroscopes, or both) which are usually attached to the feet or shoes, thighs and legs, or waist [17–20]. To minimize system complexity a number of gait analysis systems only using gyroscope sensors were proposed in [21,22]. A single uni-axial gyroscope attached on each shank can be used to detect the time of gait events and a simplified biomechanical gait model can be employed to reduce the number of sensing units for gait analysis. It is possible to use a smaller number of sensing units on certain body segments to estimate movement of other segments.

In many cases IMU sensors are integrated with other types of sensors to perform a more complicated task or multiple tasks. The built-in sensors in a smart phone can be used to map the environment and monitor user activities. These embedded sensors may include the IMU sensor, light sensor, pressure sensor, thermometers, cameras, GPS receivers, and microphones. In [23] an IMU-based pedestrian trajectory system is proposed, which consists of a stepping aware module, stride length module and walking direction module. Energy consumption is an issue since the IMU sampling is relatively energy hungry. A prototype of dead-reckoning system is reported in [13] for indoor mapping, which consists of a stride length measurement unit (SiLMU), a fiber optic gyro, a compass, and a laser scanner. The SiLMU is an ultrasound-based device which measures the distances between the ankles based on time-of-flight. The ultrasonic transmitter is placed on a foot, while the receiver is placed on the other foot. The length measurement is performed continuously at a rate of 60 Hz. In [24] a step information monitoring and sensing (SIMS) system is reported for coaching support and biomechanics research in sprinting. The system consists of two subsystems: an on-body foot-pressure sensing system and a track-side video-sensing system. The data from the sensors in these two subsystems are fused to generate stride parameters of athletes.

A number of IMU-free sensor systems have been developed or proposed for stride/gait analysis. In [25] video data from two web-cameras and depth imagery from a single Microsoft Kinect were employed to measure stride-to-stride gait variability passively in a home setting. It was intended to assess the fall risk of elderly individuals so that measures can be taken to reduce the fall rate. In [26] a model-based approach is proposed for estimating position, gait and motion parameters. A hierarchical and structural model of the human body is used. Soft kinematic constraints are introduced to supplement the motion model limited by hard kinematic constraints. These constraints are in the form of stochastic distributions obtained from various body configurations during specific activities. In [27] an optical flow sensor attached to the leg of a pedestrian is used to generate optical flow data which are a projection of the velocity and angular velocity of the leg. A dynamic motion (walking) model, termed the spring loaded inverted pendulum model, is exploited to estimate leg states and infer stride length. In [28] textile sensors were fixed on pants and socks worn by healthy subjects. These sensor embedded pants and socks are as wearable and washable as ordinary ones. The data transmission is wireless. The digital signals from these sensors can be analyzed to estimate step length, cadence, walking speed, center of pressure and center of mass trajectory.

1.2. Overview of proposed method

Many of the methods reported in the literature are related in particular to stride length measurement and have particular application areas (such as biomedical research), and typically have sensor arrangements (such as on feet) which would be impractical for general use. Thus the basis of a sensor-based dead-reckoning location system described in this paper is as follows. The sensors are required to measure displacement distance from a starting point, as well as the heading angle of the track. An absolute heading