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Enhancing base station connectivity with directional information of movement☆

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Abstract

High-performance smartphones with various sensor capabilities, including the inertial measurement unit, allow us to have higher freedom to localize our movements and utilize them for other applications. In this paper, we present a simple method to estimate the heading of a user using only a digital compass, accelerometer, and gyroscope. Several experiments were conducted using an Apple iPhone. In addition, we also present an algorithm to reduce the number of handover attempts in a dense base station environment. A series of simulations were conducted on OPNET in various emulated environments to present the effectiveness of the proposed method. The simulation results show that our proposed algorithm effectively reduces the ping-pong effect in a dense base station environment.

Keywords: Navigation; Handover; WLAN; Smartphone

1. Introduction

Mobile devices have advanced rapidly from heavy voice-only phones to light and intelligent smartphones capable of providing various services and applications for everyday lives. When the mobile devices are not equipped with sensors, researchers suffer to use the sensors within the devices. One of the research topics is estimating the current position of the user by utilizing the previously determined position and estimated direction, which is calculated by using measurements from the accelerometer and gyroscopes [1–4]. However, the low accuracy and high bias of inertial measurement units (IMUs) in smart devices make dead-reckoning based navigation difficult for everyday usage. Along with these sensors, other works utilize a cellular network or the GPS to localize the current position [5–7].

One of the algorithms presented in this paper measures the *heading* of the user by using an IMU instead of the power-consuming GPS because of the difficulties in dead reckoning. The results from the sensors are combined with the reference frame to determine the initial heading. After finding the heading, the Connectivity Enhancement (`CE`) algorithm presented in this paper filters an optimal base station (BS) along the direction of movement instead of the opposite direction to decrease the number of handover attempts. Although the connectivity algorithm described in this paper is based on the Long Term Evolution (LTE) protocol, any mobile wireless network in need of a handover can utilize this algorithm. The performance of the Estimation of Heading (`EH`) algorithm is evaluated to show that the `EH` algorithm provides accurate measurement and its results can be achieved by using only IMU with a simple and low computation algorithm. In addition, a series of simulations are performed to validate the `CE` algorithm based on the IEEE 802.11 protocol.

2. A proposed handover algorithms

The proposed handover scheme is composed of two separate algorithms: the `EH` and `CE` algorithms. Although the algorithms are completely separate methods, the `EH` is used to assist `CE`.

2.1. Estimating the heading of user

The heading of the user can be determined by combining the sensors within the mobile device to measure the following

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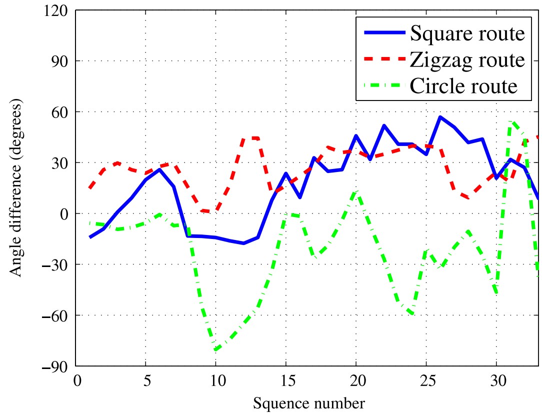

Fig. 1. Angle difference between result of EH and actual angle.

Table 1
Average and standard deviation of error.

Routes	Average error (degrees)	Standard deviation (degrees)
Square	11.26	24.79
Zigzag	26.80	12.47
Circle	−20.82	30.18

seven parameters: the accelerations and orientations along the x-, y-, and z-axes and along the direction of magnetic north. The rotational information is used to transform the device-centric acceleration measurement into user-centric acceleration using the reference frame [8]. The concept of the reference frame involves converting some measurements in one orientation to another. In this paper, the acceleration is measured with respect to the mobile device and then converted with respect to the surface of the Earth. The flow of estimating the heading of the user, or the EH algorithm, is as follows: The device's acceleration, A_{Phone}, and orientation are constantly measured using the angle of difference on the Cartesian 3-axes system. A 3×3 axis transformation matrix can be formed with the orientation measurements and is denoted as R^{Earth}_{Phone}. The measured value of A_{Phone} is transformed to the acceleration with respect to the surface of the Earth after determining the axis transformation matrix, A_{Earth}, as in Eq. (1), to view the acceleration of the user instead of the device. Note that both A_{Earth} and A_{Phone} are according to the Cartesian x-, y-, and z-axes.

$$A_{Earth} = R^{Earth}_{Phone} * A_{Phone}. \quad (1)$$

After successfully converting the acceleration measurements in respect from the mobile device to the surface of the Earth, the estimation of initial direction of movement is triggered when the through determining whether the magnitude of acceleration exceeds the gravity of the Earth, 9.81 m/s^2. Thereafter, the user's heading can be determined by Eq. (2):

$$\theta_{User} = \arctan \frac{Accel_{Earth,x}}{Accel_{Earth,y}}. \quad (2)$$

The measured acceleration along the z-axis may be discarded after conversion. Therefore, the measurements along the x- and y-axes are used to determine the heading. The resulting heading of the user, denoted by θ_{User}, is combined with the data from the digital compass to relate it with the magnetic north. The constantly measured orientation and magnetic north will enable the tracking of the user as long as the acceleration along the x- and y-axes is theoretically zero. The experiment was conducted using an application that utilizes the sensors included in the Apple iPhone 4 to gather information about the acceleration, orientation, and magnetic north. The optimal threshold magnitude of acceleration along the x- and y-axes is set to 2 m/s^2 for effective tracking after the initial heading is estimated. The goal of this experiment was to measure the initial heading, then track the user. The iPhone was held in a normal grip while the user walked in various paths: square, zigzag, and circular. Then, the collected data were processed in MATLAB to transform the coordinates using the reference frame.

The results from this experiment are shown in Figs. 1 and 2 and in Table 1. Fig. 1 shows the difference between the angle obtained as the result of the EH and the actual angle of movement, and Table 1 shows the average and standard deviation of the difference. The results show that the EH algorithm shows less than 30° error on an average. In addition, the standard deviation of the error is not very large considering the offset.

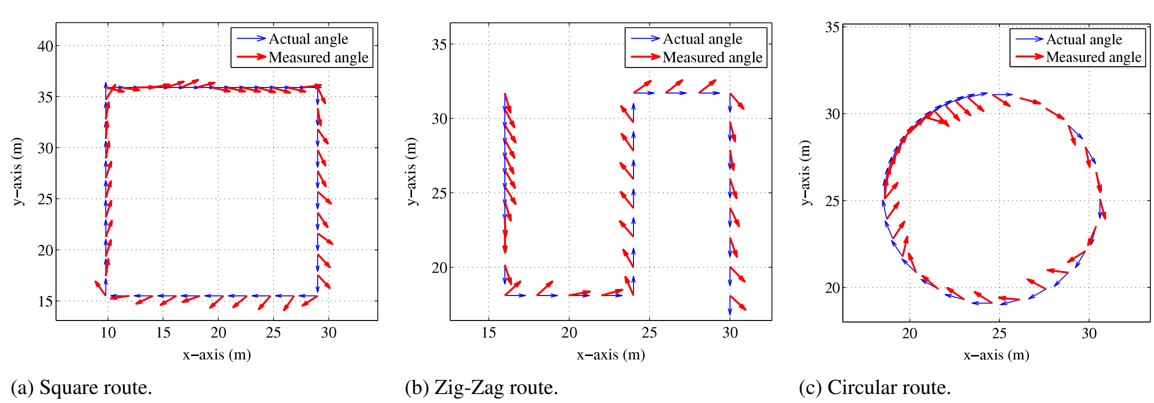

Fig. 2. Measured angle and actual angle of movement for experimented routes. Measured angles are shown as red arrows, and actual angles are shown as blue arrows. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)