Indoor Navigation Based on a Gait Recognition and Counting Scheme

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Abstract. GPS satellite positioning is currently a system used by people for navigation. As urban buildings become larger and their internal usages more diverse, the internal structure of the buildings turns into complex. Indoor positioning with GPS is often blocked by buildings, so that GPS is unable to accurately locate a user's position inside buildings. Currently, dead reckoning techniques can improve this issue in indoor positioning. However, the techniques need the deployment of many sensing devices in indoor environment, and the estimated distance would still result in serious errors. In this situation, it leads to the high cost of labor, materials, and equipment. In this study, we develop a gait recognition and counting scheme based on a self-made sensor to collect spatial data and user walks. The scheme can accurately calculate the number of walking steps, and then calculate the distance by effectively reducing the distance error.

Keywords: Indoors navigation · Gait · Accelerometer

1 Introduction

With the evolution of positioning technology, the quality of positioning and navigation systems are greatly improved. In outdoor positioning, GPS and Wi-Fi are mainly used. The system accuracy can be less than 10 m. As users are in tourism or search for landmark locations, it's a great application in a wide range of services. However, this accuracy is not enough to satisfy the needs of indoor positioning applications. For example, the positioning error by GPS in indoor spaces is often quite large, and it is also difficult to correctly locate a user's position. Therefore, the accuracy of indoor navigation and positioning is particularly concerned. In early days, Wi-Fi has always been considered as the most suitable technology for indoor positioning, but the shortcomings are also obvious. For instance, the accuracy is not good, the installation is not easy, and the power consumption is too high.

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In recent years, various schemes have been proposed. In a factory, infrared rays and lasers are used as positioning guides for equipment automation. Since the protocols for communication of various devices are all in diverse wireless communications, the positioning data cannot be exchanged, so that it cannot be widely used. In this study, a self-made sensor and gait recognition model are proposed to accurately compute the number of user's walking steps, which in turn assists in the positioning function of the sensor device.

Indoor positioning technology and gait analysis become more interesting in recent years. Traditional schemes for indoor positioning have various types of infrastructure, including infrared, narrow-band radio, ultrasound, ultra-wideband (UWB), wireless information (Wi-Fi) signal strength, radio frequency identification (RFID), inertial measurement unit (IMU), vision, etc. [1–3]. Due to the high cost of equipment, the deployment of positioning service cannot be popular. Recently, the progression of microelectronics causes the integration of many sensors, including accelerometers, magnetometers, and gyroscopes, more possible. These schemes not only have lower prices, but also are easy to carry. In recent years, extensive research on pedestrian dead reckoning (PDR) and navigational calculations is done, and there are also many PDR systems that use pedometers or accelerometers to detect gait [4–7]. Since there is no complete gait analytical model for counting steps in user's walking, the error rate of distance estimation is rather high indoors [8–10]. In this paper, a specific gait recognition and counting scheme is proposed to improve this issue.

This paper is organized as follows. Section 2 describes the research materials in the study. The method of indoor navigation proposed in this study is sketched in Sect. 3. The experimental results are discussed in Sect. 4. Finally, a conclusion is given in Sect. 5.

2 Materials

2.1 Experimental Instruments

In this study, a sensor module has an accelerometer, a gyroscope, and a magnetometer. For the accelerometer, it calculates the degree of displacement in the 3-dimensional directions through piezoelectric effects and has three dimension coordinates (X, Y, Z) to determine the acceleration values of external motions. The X, Y, and Z acceleration values related to human walking are generated by the accelerometer as the user walks. They can be calculated and drawn a sinusoidal wave similar to a sine wave. When a sensor device driver receives a waveform generated by the vibrations of the X, Y, and Z acceleration values, it will determine whether it is a step through the acceleration values.

For the gyroscope, it is not used in this research work since the magnetometer provides the orientation information. To accurately determine the azimuth of a user's walking direction, the magnetometer can determine the magnetic field strength by measuring the change of the resistance from the user's movement. In this application, the main purpose of using the magnetometer is to be as a compass for helping the establishment of a 2 dimensional coordinate system, which can provide users with a reference orientation when navigating indoors.

2.2 Gait Description

A complete gait is mainly divided into a standing phase (stance) and a swinging phase (swing) as shown in Fig. 1. The stance phase accounts for about 60% of the entire gait cycle time, and the swing phase 40% of the cycle time. In Fig. 1, there are seven gait events, i.e., toe off, feet adjacent, tibia vertical, initial contact, opposite toe off, heel rise, and opposite initial contact. The events subdivide the two phases into seven gait stages. For the stance phase, it includes the stages of loading response, mid-stance, and terminal stance; for the swing phase, it includes the stages of pre-swing, initial swing, mid-swing, and terminal swing [11, 12].

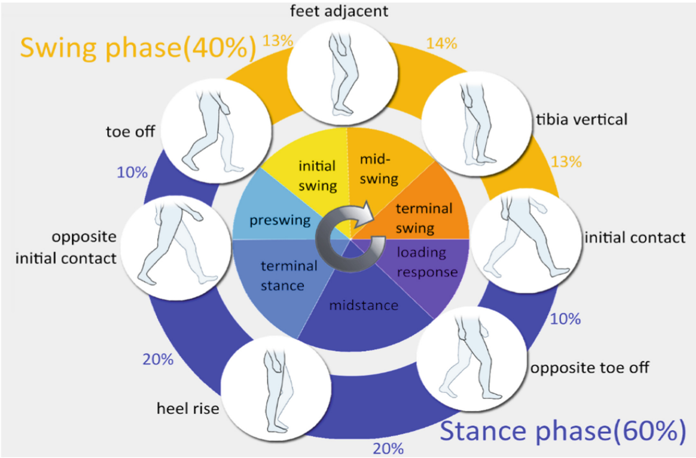


Fig. 1. A gait cycle with two phases, seven events, and seven stages

In Fig. 2, a signal waveform based on the root values of the sum of squares from every (X, Y, Z) acceleration of gait movements is presented. In the figure, each acquired gait data in 3-dimensional acceleration values is synthesized as a root value of the sum of squares from every (X, Y, Z) acceleration. In this way, the wearing directional deviation of a sensor module can be suppressed.

Since the collected physiological signals from the sensor modules are generated from electronic components and instruments, many noises such as electrical, swaying, muscle tail, and other noises are mixed together. To remove these noises, a signal spectrum analysis must be done before the followed signal processing. To discover the major spectrum of gait signals, fast Fourier transform is applied to analyze the frequency spectrum distribution of the acquired gait signals such as shown in Fig. 2. The spectrum analyzed results of the gait signals can be found in Fig. 3. It is obvious that all the major signals can be detected below 15 Hz.

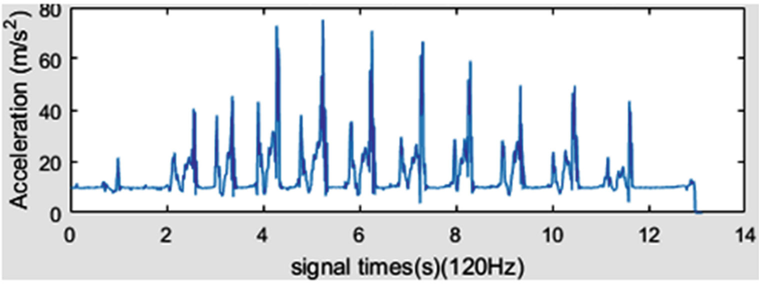


Fig. 2. The signal waveform with the root values of the sum of squares from every (X, Y, Z) acceleration of gait movements

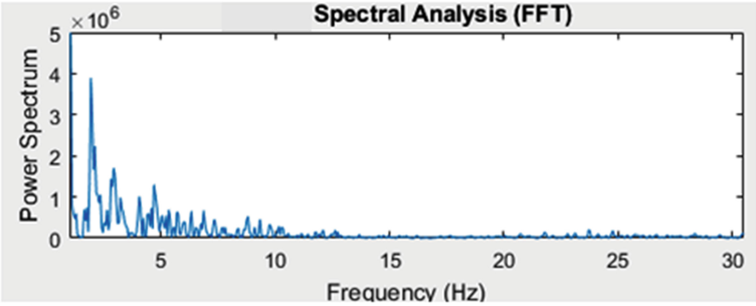


Fig. 3. The frequency spectrum distribution of acquired gait signals after fast Fourier transform

3 Methods

3.1 Gait Description

In order to collect the gait signals, a gait signal recording system is developed as shown in Fig. 4. In the figure, self-made sensor modules are installed inside of the insoles of a pair of shoes, and then the gait signals are acquired and communicated to a mobile phone APP for the initial signal processing of gait information.

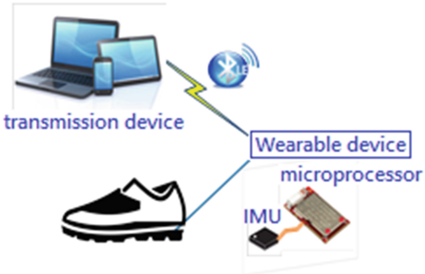
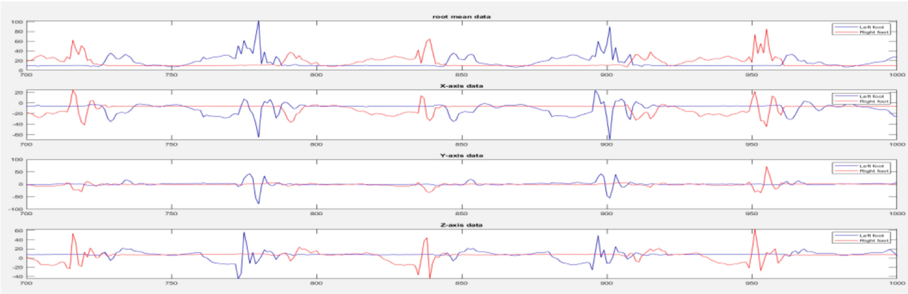
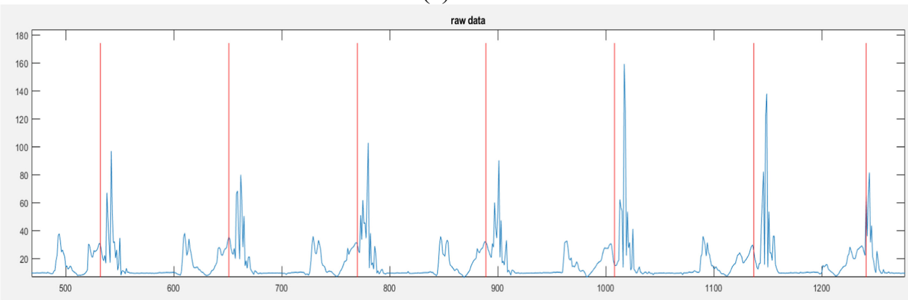


Fig. 4. A gait signal recording system

As shown in Fig. 4(a), the gait signals are acquired by the acceleration sensor modules, which are placed in the insoles of shoes. The signals have multiple peaks and troughs with different magnitudes, all of which are involved in the walking process. The resulting gait characteristics, including the step frequency, the number of steps, etc., can be determined as shown in Fig. 4(b). From the periodicity of each step, the above gait characteristics can be applied to the segmentation of gait cycles to get step counts for the calculation of moving distance in the indoor navigation (see Fig. 4(b)), (Fig. 5).



(a)



(b)

Fig. 5. (a) The gait acceleration signals acquired by the sensors; (b) The signals in the form of the root of sum of the square after the signal's segmentation

3.2 Indoor Positioning Computation

Step Length Estimation

Roughly speaking, the average human step length is about height (h) minus 100 cm. However, if a user's gait is arbitrary and irregular, then the average step length should be estimated a little greater than the above estimated value. Therefore, we adopt the following formula (1) to estimate the average step length (d) in the specific azimuth of one user's walking direction:

$$d = h * 0.5 \tag{1}$$

Dimension Coordinate Conversion
Suppose that one specific entrance of a big building is designated to be as the original point for the indoor navigation service of that building. Then, based on the first movement from the original point, any temporary stop can be marked with a location record by applying a mutual conversion scheme between a 2-dimension coordinate system and a polar coordinate system. That is, convert a detected polar coordinate into a 2-dimension X and Y coordinate, where the polar coordinate distance is equal to a step number timed by step length and again timed by the trigonometric value of an azimuth, after a directional movement by walking. The following formula (2), (3) is the X, Y conversion coordinate formula, where n stands for the number of steps, d the average step length, and θ the specific azimuth of one user's walking direction.

$$X = n * d * cos\theta \tag{2}$$

$$Y = n * d * sin\theta \tag{3}$$

The number of walking steps and the walking direction of a user are obtained through sensing one specific walking behavior, and the obtained data are used to compute the coordinate values of the X and Y axes in a pseudo 2-dimension plane.

In addition, we developed a pseudo map creation subsystem, which is automatically activated on every second to synthesize the proper spatial map corresponding to the indoor walking environment. Accordingly, a user needs only to press the button in the indoor navigation APP program executing on the touch panel of a smart phone for adding a new coordinate, and then a new locational coordinate for the current position or a special location mark (such as exit, stairs, classroom, etc.) will be inserted into the map database for later usage.

Dimension Coordinate Conversion
Before the action of indoor navigation, the interface of the indoor navigation will first post a message to request a calibration action to the magnetometer of the smart phone to reduce orientation errors. At the same time, the user's information is recorded, including the user's step length and initial position XY coordinates. The next step is to ask the user to choose to arrive at the destination. Then the coordinates of the destination and the coordinates of the initial position are transformed by two-dimensional coordinate transformation. After calculating the average steps and the estimated

distance of the user's walking, the magnetometer is activated to relocate the walking direction, and then an optimal walking path algorithm is devised to plan the forward path and navigate the user to his/her destination.

4 Experimental Results

In this study, the smart phone used is ASUS Zenfone 3 (Z012DA) with Andoird 8.0 operating system, and its processor is Qualcomm Snapdragon 625, eight cores, 2 GHz. To test the performance of the indoor navigation APP, two sets of testing scenarios were proposed and set up, namely "straight-line walking and then L-shaped cornering" and "S-curved continuous cornering".

In the test of the straight-line walking and then L-shaped cornering test, we found that the APP can effectively distinguish between cornering and straight-line walking. In

Table 1. Experimental results of the "straight-line walking and then L-shaped cornering" test.

Number	Test data	Result	Accuracy
1	50	49	98%
2	50	50	100%
3	50	50	100%
4	50	49	100%
5	50	50	98%
6	50	50	100%
7	50	50	100%
8	50	50	100%
9	50	50	100%
10	50	49	98%

Table 1, it can be found that nearly 100% accuracy can be obtained after a field trial testing. In this test, only a slight error had occurred to cause the miscounting of walking steps in the gait signal analysis due to the acquired gait signal's defects. Evidently, the experimental results shown in Table 1 support the effectiveness of the distance estimation in the indoor navigation.

In Table 2, the experimental results of the S-curved continuous cornering test are dropped, and it can be found the miscounting error does not exceed 2 steps. Actually, it does not affect the distance estimation used in the indoor navigation. One possible reason for miscounting the walking steps is probably due to the measurement of the specific azimuth of one user's walking direction. Although this test reveals a slight high error rate in estimating distance during S-curved continuous cornering, the navigation results are still acceptable.

Table 2. Experimental results of the "S-curved continuous cornering" test

Number	Test data	Result	Accuracy
1	50	49	98%
2	50	48	96%
3	50	48	96%
4	50	50	100%
5	50	49	98%
6	50	48	96%
7	50	49	98%
8	50	50	100%
9	50	50	100%
10	50	49	98%

5 Conclusion

In this study, a gait-based indoor navigation scheme for walking inside modern huge and complex buildings was proposed. This scheme integrates the techniques of gait signal analysis and 2-dimension spatial coordinate conversion to position users' locations for navigation. To test the performance of this system, two testing scenarios were devised, and from the analyzed gait signals for the distance estimation in navigation, our scheme can provide accurate results for indoor navigation. In comparison with previous works, our method has the benefits of low cost for installation and easy for deployment.

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