

A Novel Study of the Pedestrian Integrated Navigation Monitoring System

^{1,2} Zhengqun HU, ¹ Lirong ZHANG, ¹ Junxia CUI, ¹ Chang LV

¹ National Astronomical Observatories, Chinese Academy of Sciences,
20A Datun Road, Chaoyang District, 100012, Beijing, China

² Graduate University of Chinese Academy of Sciences,
80 Zhongguancun East Road, Haidian District, 100086, Beijing, China
Tel.: +8610-64807612
E-mail: huzq@nao.cas.cn

Received: 18 September 2013 / Accepted: 25 October 2013 / Published: 30 December 2013

Abstract: An integrated system with multi-sensor is designed for pedestrian navigation. Magneto-resistive sensor is used to measure the heading angle for determining the track. Acceleration sensor is used to calculate walking distance by double integral via a threshold step detection algorithm. The new coordinate can be obtained by integrating the heading angle and the walking distance. Federal Kalman algorithm is used in the processing of solving location and orientation, which can combine with GPS to complete the design of pedestrian navigation monitoring system. Generalized extended approximation (GEA) is put forward to use in the processing of multi-sensor integration, which can reduce error brought by the sample data at different time between magneto-resistive sensor and acceleration sensor. The track of pedestrian integrated navigation monitoring system will be clearly determined with stability and reliability. *Copyright © 2013 IFSA.*

Keywords: Leave Integrated navigation, Sensor, Federated Kalman filter, Generalized extended approximation.

1. Introduction

The integrated navigation system of GPS and multi-sensor can compensate for each other's shortcoming [1]. In the integrated navigation system, the number and type is increasing, all sensors have different measurements and noise characteristics [2], which need to be comprehensively processing. An integrated system of multi-sensor is not only hardware combination, but also more innovation of combination method.

Sensor is sensing the measured information and can detect the information which is converted into electrical signal or other forms of information to be output according to certain rule. Different sensor is with different sensing function.

In pedestrian integrated navigation monitoring system, Dead-Reckoning (DR) is an important performance indicator. It includes heading angle and walking distance. Magneto-resistive sensor is used to measure heading angle [3-6], however how to combine with accelerometer in algorithm for reducing system error is not described clearly.

For pedestrians, its movement feature is complicated [7-8]. In most cases, pedestrians are all walking on the sidewalk or boulevard [9-10]. In addition, its motion path of different people is with unpredictability. Therefore improving positioning accuracy and determining the systematic movement track is very important for improving performance in pedestrian integrated navigation monitoring system.

In order to reduce systematic error in combination of heading angle and walking distance in the pedestrian integrated navigation monitoring system. We describe data fusion of multi-sensor from the perspective of method, analyze the performance impact on the combined system from the sensitivity of sensor, use magneto-resistive sensor to measure heading angle and use acceleration sensor combined with a threshold step detection algorithm to determine the walking distance.

Because the sampling points (includes heading angle and walking distance) at different time, which may result in systematic error. So Generalized Extended Approximation (GEA) [11] is proposed to be used in the integrated algorithm between heading angle and walking distance. The integrated model can combine the advantage of fitting and interpolation and lock the latest data [12], which is easy to be implementation in project. Experimental results show that GEA has great referenced value for improving positioning accuracy and tracking in pedestrian integrated navigation monitoring system.

2. The Integrated System

A pedestrian navigation monitoring system is designed by integration of GPS / magneto-resistive sensor / accelerometer sensor, etc. The hardware structure of this system is shown in Fig. 1.

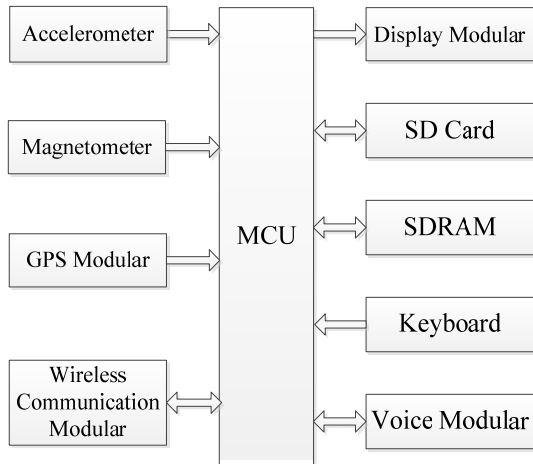


Fig. 1. Hardware structure of pedestrian navigation monitoring system.

The voice module and wireless transmission module are used to complete the function of monitoring in the combined system, Keyboard and display module complete the function of information input / output, SD card and SDAM play the role of data storage.

2.1. Data Fusion

We use magneto-resistive sensor and acceleration sensor to solve for the routes heading angle and

displacement distance of carrier, predict the two-dimensional coordinate through triangular conversion, each sub-module has a separate smoothing algorithm for filtering. We use GPS system as a reference to constantly revise the measurement parameter and then obtain accurate output system using the Federated Kalman Filter. The system data fusion processing is shown in Fig. 2.

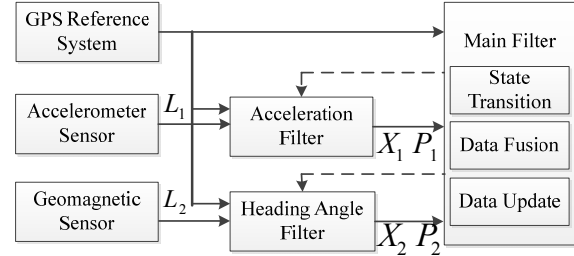


Fig. 2. Data fusion processing of the integrated system.

Each parameter filter independently update in time and update in measurement [1], when GPS completes to update in measurement each time, once the main system make an information fusion, and then according to the allocation factor for each subsystem to reset correction, the Federated Kalman Filter algorithm is shown [2].

$$\hat{X}_k = P_k^{-1} \left(P_{\hat{X}_{1k}} \hat{X}_{1k} + P_{\hat{X}_{2k}} \hat{X}_{2k} \right) \quad (1)$$

$$\hat{X}_{ik} = \bar{X}_k + K_{ik} (L_{ik} - A_{ik} \bar{X}_k) \quad (2)$$

The correction distribution factor of subsystem (the No. i) is α_i , then the correction distribution factor of the noise variance (δ) in this motion system is the same as α_i , namely

$$\begin{cases} P_i(k/k) = \alpha_i P(k/k) \\ \delta_i = \alpha_i \delta \end{cases} \quad (3)$$

2.2. Sensitivity of Sensor

Generally, sensitivity is an important physical quantity of the measuring instruments, improving the sensitivity can achieve higher measurement accuracy. However the higher of the sensitivity, the measuring range is often narrowed, the stability is often worse. Therefore, the sensitivity of design range is also an important technical indicator.

Resistance silicon strain sensitive factor is of 50~100 times higher than the metal strain gauge, the sensitivity of this type sensor is very high, which

generally has an output full-scale about 100 mV. For silicon piezoresistive sensor when the piezoresistive change, the output voltage signal change as follows

$$\Delta V_{\text{out}} = \frac{\Delta R}{R} V_{\text{in}} = \frac{V_{\text{in}} \pi_{44}}{2} (\delta_1 - \delta_t), \quad (4)$$

where $(\delta_1 - \delta_t)$ denotes the difference of orthogonal stress, π_{44} is the constant. Therefore, enhance the difference between orthogonal stress can increase the sensitivity of such sensors and then improve the measurement accuracy.

Under normal circumstances, we always hope that the sensitivity is a constant, which is conducive to the corresponding relationship between the input value and the output quantity, for easy reading, however in fact the sensitivity mostly only maintains a constant in a measurement range. So we must determine the linear range before we use it. Therefore, in the application of the magneto-resistive sensor and accelerometer, the sensor must be located as far as possible to meet the linear range for working.

2.3. The Heading Angle

Magneto-resistive sensor is with typical frequency bandwidth of 5MHz, the reaction effect in Magneto Resistance (MR) is very fast, which is not limited by coil and oscillation frequency and compatible to other equipment.

Magneto-resistive sensor has some advantages such as high sensitivity, solid state, no moving parts, high reliability and so on [3]. It can be used as the current production of integrated circuits, which is easy to install on the circuit board and the cost is very low. Magneto-resistive sensor is used to measure the direction of heading angle, which can provide critical navigation parameters in navigation system. The appearance of the Earth is surrounded by a strong magnetic field [4], the strength of which is about 0.3-0.6 Gauss, the horizontal component of the Earth's surface always points to the magnetic north pole.

The geomagnetic field is filled with the whole space of the earth [5]. Its distribution is on the surface of the earth which is shown in Fig. 3.

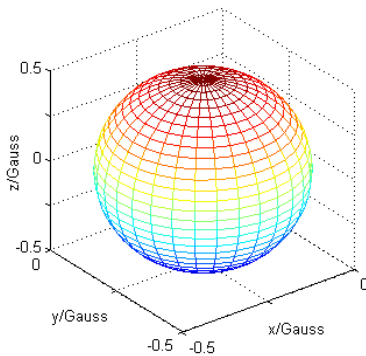


Fig. 3. The ideal geomagnetic field model.

According to the International Geomagnetic Reference Field model (IGRF), the geomagnetic field vector can be expressed as a negative gradient function of the potential function of the magnetic field. We can list systematically the tri-axial geomagnetic field components as [6]

$$\begin{cases} H_x = -\sum_{n=1}^{\infty} \sum_{m=1}^n \left(\frac{R_e}{r} \right)^{n+2} (g_m^n \sin m\lambda - h_m^n \cos m\lambda) \frac{m}{\sin \varphi'} P_m^n(\cos \varphi') \\ H_y = \sum_{n=1}^{\infty} \sum_{m=1}^n \left(\frac{R_e}{r} \right)^{n+2} (g_m^n \cos m\lambda + h_m^n \sin m\lambda) \frac{\partial P_m^n(\cos \varphi')}{\partial \varphi'} \\ H_z = \sum_{n=1}^{\infty} \sum_{m=1}^n \left(\frac{R_e}{r} \right)^{n+2} (n+1) (g_m^n \cos m\lambda + h_m^n \sin m\lambda) P_m^n(\cos \varphi') \end{cases} \quad (5)$$

where $P_m^n(\cos \varphi')$ denotes the Schmidt quasi-normalized Associated Legendre function with n orders and m times; g_m^n, h_m^n denote the Gaussian coefficients; the highest order of $n = 13$; R_e denotes the reference equatorial radius of the earth ($R_e = 6378.2 \text{ km}$); r denotes the geocentric distance; λ denotes the geomagnetic longitude; φ denotes the geomagnetic latitude; φ' denotes the geomagnetic cclati-tude ($\varphi' = 90 - \varphi$).

Assume that the angle α is between the direction of magneto-resistive sensor and the direction of magnetic north, and then

$$\alpha = \arctan(H'_x / H'_y) \quad (6)$$

Geomagnetic field is a function with spatial position and time, as the crust and the disturbance magnetic field and other factors, there are some measurement errors. In order to improve measurement accuracy, we use the acceleration sensor to measure the elevation angle φ_1 and roll angle θ_1 as the compensation in angle errors.

$$H'_x = H'_x \cos \theta_1 + H'_y \sin \varphi_1 \sin \theta_1 - H'_z \cos \varphi_1 \sin \theta_1 \quad (7)$$

$$H'_y = H'_y \cos \varphi_1 + H'_z \sin \varphi_1 \quad (8)$$

The HMC1022 magnetic sensor has the high sensitivity ($< 0.1^\circ$), bandwidth of 5 MHz, the magnetic field resolution 8.5nT, fast response time ($< 1 \mu\text{s}$) and high frequency output (1 kHz), etc. We can use the microprocessor and magneto-resistive sensor to design a measuring instrument of magnetic heading angle, which has certain advantages. This measuring instrument output the geomagnetic intensity with the differential voltage form which has a higher robustness performance.

The largest measured geomagnetic value on any electrical sensor bridge approximately is 0.625 Gauss, assume that HMC1022 sensitivity is

1.0 mV/V/Gauss, the maximum possible swing value of Electromagnetic Field (MF) on any one electric field bridge is

$$V_{MF} = 5.0 \times (\pm 1.0) \times 0.625 = \pm 3.125mV \quad (9)$$

The output voltage of HMC1022 usually in the level of mV, in order to ensure the precision of AD sampling, we need to amplify the output voltage in the level of 0~3 V, we use a differential amplifier AD620 as a master chip and use second-order analog low-pass filter circuit to reduce the high frequency components of geomagnetic signal.

A SET-RESET pulse is used to resolve the problem of the SNR reducing due to the use of the magneto-resistive sensor HMC1022 in long time and the impact by external magnetic interference in high strength, which can ensure measurement accuracy in a larger limit. Program control flow in reading count is shown in Fig. 4. Fig. 5 shows a pair of SET-RESET signal waveform.

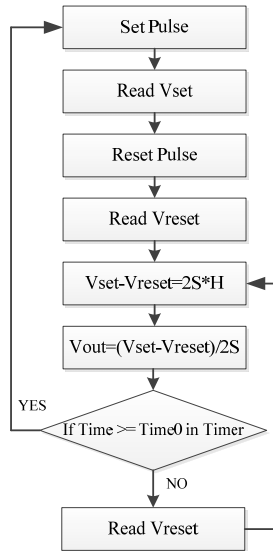


Fig. 4. Program control flow in reading count.

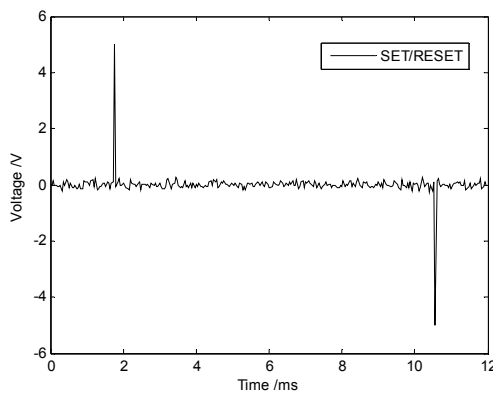


Fig. 5. A pair of SET-RESET signal waveform.

The magneto-resistive sensor module is placed on the position of 1 m from the origin to the coordinate origin which is used as the center. It uniformly rotated in counterclockwise direction with 90°, 180°, 270°, 360°, the sampling rate of data is 20 Hz, the heading angle measurement curve is shown in Fig. 6.

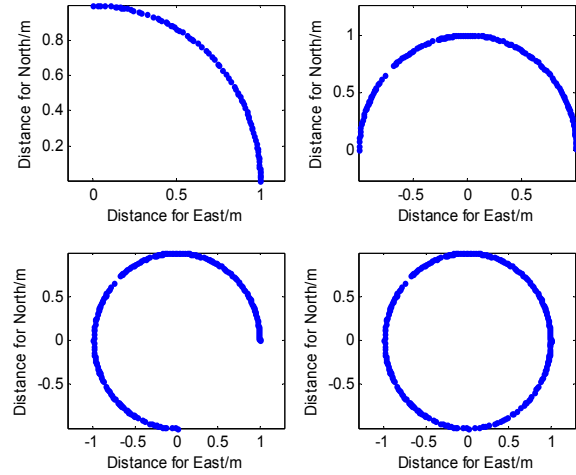


Fig. 6. Measurement curve of heading angle.

As can be seen from Fig. 6, the heading angle of this system can well distinguish the running track direction of the system, the interference is relatively small and the measurement data can be very stable.

2.4. The Displacement Distance

Dead-Reckoning is the most important component in pedestrian integrated navigation monitoring system, the accuracy of which determines the systematic performance [7].

Dead-Reckoning includes not only the measurement of heading angle, but also the measurement of walking distance in pedestrian integrated navigation monitoring system. They are both the important physical parameters in the location information of user. Since GPS has itself error, in order to obtain the accurate Dead-Reckoning information, we need auxiliary method.

When an accelerometer is used to measure walking distance, the phase state of sensor needs to be divided firstly [8]. It includes static state and movement state. In this paper, a threshold step detection algorithm is used to determine state of the sensor. The threshold includes average value (Threshold_AVE) and mean-square deviation (Threshold_MSD) of vector sum in a time interval T .

Provided that threshold Threshold_AVE is T_1 , Threshold_MSD is T_2 , when AVE is less than T_1

and MSD is less than T_2 , the acceleration sensor can be considered as a static state. Fig. 7 shows phase detection in terms of vector sum.

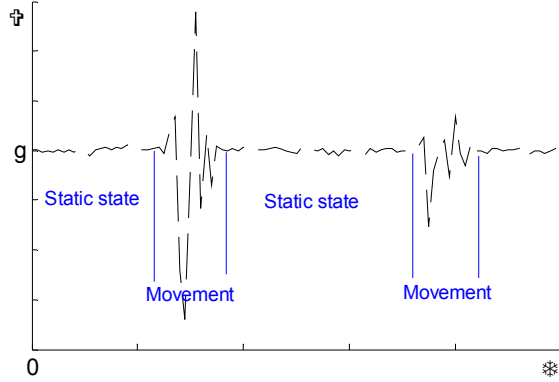


Fig. 7. Phase detection in terms of vector sum.

In the movement state, schematic obtained Dead-Reckoning is shown in Fig. 8. The heading angle θ_i is obtained via the magneto-resistive sensor. The walking distance d_i can be obtained by acceleration sensor.

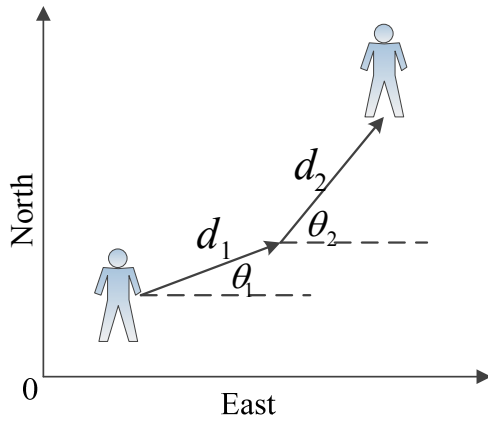


Fig. 8. Schematic of Dead-Reckoning in pedestrian navigation monitoring system.

According to Newton's second law, based on acceleration measurement, speed $v_i(t)$ and distance $d_i(t)$ can be obtained.

$$\begin{cases} v_i(t) = v_i(0) + \int_0^t a_i(\tau) d\tau \\ d_i(t) = d_i(0) + \int_0^t v_i(\tau) d\tau \end{cases} \quad (10)$$

In a movement state, the walking distance is obtained by double integral of acceleration [9].

Because the system is severely affected by noise, speed $v_i(t)$ may become negative by integral accumulation. In order to reduce the displacement measurement error, a cyclically measured acceleration value minus the average acceleration with zero boundary conditions, the speed will be obtained by integral with the revised acceleration. The obtained speed minus the average speed with zero boundary conditions, relative displacement with less error will be obtained by integral with the revised speed.

The direction angle θ_i measured by the magneto-resistive sensor, the eastward displacement of pedestrian is $x_i = d_i \cos \theta_i$, the north displacement is $y_i = d_i \sin \theta_i$, assuming the initial position of the pedestrian is (x_0, y_0) , after the elapsed time Δt , the new coordinates of the location is [10]

$$\begin{cases} x_n = x_0 + \sum_{i=1}^n d_i \cos \theta_i \\ y_n = y_0 + \sum_{i=1}^n d_i \sin \theta_i \end{cases} \quad (11)$$

The data fusion processing of the combined navigation system is shown in Fig. 9.

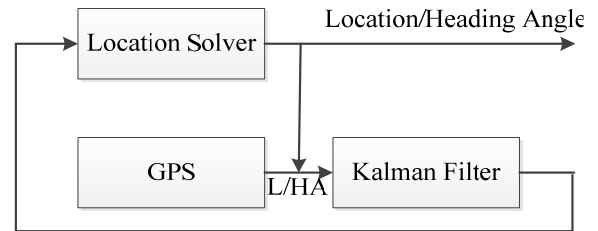


Fig. 9. Data fusion processing of the integrated navigation system.

The parameters of heading angle and displacement distance are obtained via magnetic resistance sensor and acceleration sensor. Firstly, it is with its measurement error, secondly is the sampling rate between them may be different, so the heading angle θ_i and the displacement distance d_i may be measured at two time or different time interval. If we want to induce the error an interpolation method will be used. The red dots (t_n, F_H) and (t_{n+1}, F_{D+1}) in Fig. 10 are interpolation dots, which can ensure that the heading angle θ_i and the displacement distance d_i participated in calculating are measured values at the same time.

General interpolation has some shortcomings such as low accuracy and information loss. In order

to overcome the shortcomings, generalized extended approximation is introduced in this paper.

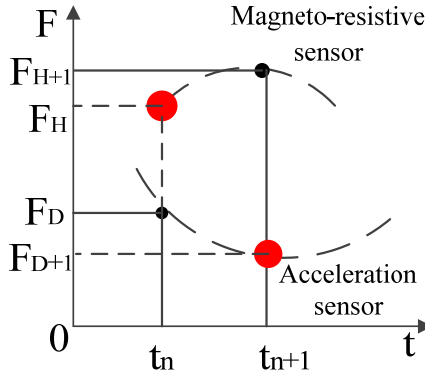


Fig. 10. Relationship between measurement and interpolation value.

3. Generalized Extended Approximation

Generalized extended approximation can make each unit nested in extended approximation unit domain. It uses the node information in extended approximation unit domain to improve approximation precision in approximating function and coordinate the approximation function between unit field and adjacent field. This method is without increasing degrees of freedom and scale. It only uses the original nodes and the degrees of freedom to improve the approximation accuracy with simple format specifications.

3.1. The Interpolation Model

Assume that in Δe interval generalized interpolating function is provided with $U_e(x)$ [11]

$$U_e(x) = a_1 + a_2x + a_3x^2, x \in [x_1, x_2], \quad (12)$$

where a_1 , a_2 , a_3 & a_4 are the undetermined coefficients, which can be determined by the following model [11]:

$$\begin{cases} \min I(a_1, a_2, a_3) = \sum_{i=0}^3 [a_1 + a_2x_i + a_3x_i^2 - U_i]^2 \\ \text{s.t.} \quad \begin{cases} a_1 + a_2x_1 + a_3x_1^2 = U_1 \\ a_1 + a_2x_2 + a_3x_2^2 = U_2 \end{cases} \end{cases} \quad (13)$$

Piecewise boundary point of this model meets interpolation condition, which ensures that the changes between each section have a better

coherence. In addition, nodes around the piecewise interpolation region (including points) information are used to achieve the best fitting between external and internal area, which adequately combines the advantages in interpolation and fitting-method.

3.2. The Extrapolation Model

Extrapolation equation after x_n is provided with [12]

$$F_e(x) = b_1 + b_2x + b_3x^2, x = x_{n+1}, x_{n+2}, \dots \quad (14)$$

Where b_1, b_2 & b_3 denote undetermined coefficients, which can be determined by the following model [12]

$$\begin{cases} \min I(b_1, b_2, b_3) = \sum_{i=0}^n [b_1 + b_2x_i + b_3x_i^2 - F_i]^2 \\ \text{s.t.} \quad b_1 + b_2x_n + b_3x_n^2 = F_n \end{cases} \quad (15)$$

For the extrapolation model, this model will fully utilize more prior data and play good role of the latest data point.

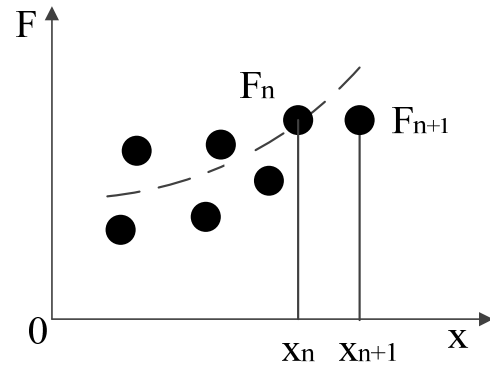


Fig. 11. Sketch of data extrapolation.

Generalized extended approximation integrates interpolation with extrapolation models. It not only can take advantage of more prior data, but also can lock the latest data point, which gives full play to the role of updating in real-time of the latest data points. Namely the latest data can be used for interpolation constraint processing. During the data fitting processing of using priori data, fitting points can be caught weight value. It can be determined by the update rate of data. Namely the data is newer, the weight is larger. Therefore, generalized extended approximation has a good performance in real-time.

Accelerometer and magnetometer are configured to send data respectively at 50 Hz and 20 Hz. The measured error is 3 mGs (1 δ) in magnetometer. The positioning precision is evaluated by ERROR

between the real coordinates and the simulation results. ERROR can be written as

$$ERROR = \left[(x - x_n)^2 + (y - y_n)^2 \right]^{\frac{1}{2}} \quad (16)$$

Where (x_n, y_n) denotes the user coordinate, (x, y) denotes the simulation result.

We mainly focus on Dead-Reckoning and positioning precision in the pedestrian integrated navigation monitoring system, so elevation may not be considered in this paper. Fig. 12 shows the positioning results of original method and Generalized Extended Approximation (GEA).

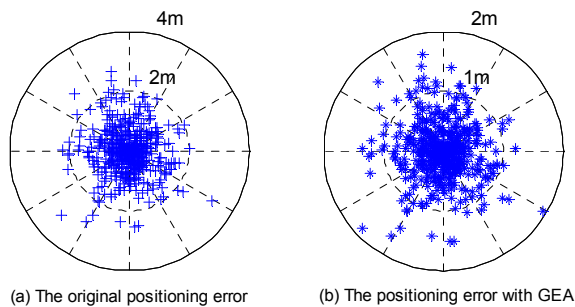


Fig. 12. Positioning results of original method and GEA.

As shown in Fig. 12 we can know that positioning error has been reduced and Dead-Reckoning is more clearly.

6. Conclusions

Efficient sensor technology is used to assist positioning system to complete combination navigation, and then precise location information can be obtained. This method in today's growing demand for location information services will have a good prospect for development. An integrated pedestrian navigation monitoring system based on MEMS has been proposed in this paper, which can realize the continuous positioning function indoor and outdoor.

- a) The acceleration sensor is used to assist correction the measured magnetic field from the magneto-resistive sensor which is calculated the heading angle with stability and reliability.
- b) A threshold step detection algorithm is used to calculate the walking distance based on single accelerometer, which can clearly detect phase state including movement and static state. The threshold value also can be self-adaptive for more movement models.
- c) Generalized extended approximation has been put forward to use in the processing of multi-sensor integration, which can reduce error brought by the sample data at different time

between magneto-resistive sensor and acceleration sensor.

The design of pedestrian integrated navigation monitoring system will have a certain value of in the relevant navigation field.

Acknowledgments

The work was supported by the National Natural Science Foundation of China(61001109); the National High Technology Research and Development Program of China (863 Program) (2012AA120800); the Pilot Program for the New and Interdisciplinary Subjects of Chinese Academy of Sciences (KJCX2-EW-J01) and the Knowledge Innovation Program of Chinese Academy of Sciences (KGCX2-EW-4071).

References

- [1]. Xiaoyue Zhang, Gongliu Yang, Chunxi Zhang, Integrated navigation method for SINS and odometer, *Journal of Beijing University of Aeronautics and Astronautics*, Vol. 39, No. 7, 2013, pp. 922-926.
- [2]. Hong Zhu, Guixia Guan, Yong Guan, Vehicle GPS/DR information fusion based on Federal Kalman filter, *Computer Engineering and Design*, Vol. 29, Issue. 20, 2008, pp. 5357-5359.
- [3]. Jianjun Wu, Weizhong Feng, Wei Yu, Study on electronic compass based on MEMS 3D magnetoresistive sensor, *Transducer and Microsystems Technologies*, Vol. 30, No. 8, 2011, pp. 83-88.
- [4]. Qianhao Lin, Zhenghong Qian, Tianping Gong, et al., Three-axis electronic compass based on GMR sensor, *Journal of Mechanical & Electrical Engineering*, Vol. 31, No. 1, 2013, pp. 55-59.
- [5]. Jing Zhao, Shan Gao, Vehicle positioning method of multi-sensor information fusion, *Digital Communication*, Vol. 40, No. 4, 2013, pp. 14-17.
- [6]. Yuntao Yang, Zhiyong Shi, Zhenzhen Guan, et al., Application of geomagnetic field in navigation and localization system, *Journal of Chinese Inertia Technology*, Vol. 15, No. 6, 2007, pp. 686-691.
- [7]. Jingsong Dai, Jing Li, Zongke Gu, et al., A research on utility of pedometer to measure walking, *Journal of Beijing University of Physical Education*, Vol. 32, No. 2, 2013, pp. 219-222.
- [8]. Sengyun Cho, Changook Park, MEMS based pedestrian navigation system, *Journal of Navigation*, Vol. 59, No. 1, 2006, pp. 135-153.
- [9]. Zengshan Tian, Lei Chao, Peiji Xing, et al., Research on a method for dead reckoning parameter estimation in pedestrian navigation system, *Application of Electronic Technique*, Vol. 36, Issue. 12, 2009, pp. 84-87.
- [10]. Yinghui Cui, Lin Zhan, Fall detection system based on three-axis acceleration sensor for the elderly, *Modern Electronics Technique*, Vol. 36, No. 3, 2013, pp. 130-132.
- [11]. Chunlin Ning, Huli Shi, Shengming Li, et al., A New Method of Constructing Weighted Matrix of WDOP,

- Journal of Astronautics*, Vol. 30, No. 2, 2009, pp. 526-531.
- [12]. Cheng Liu, Huli Shi, Zhaorui Wang, et al., An Enhanced Satellite Positioning Algorithm Based on Generalized Interpolation Method of Receiver Clock Error. *Journal of Astronautics*, Vol. 34, Issue. 2, 2013, pp. 186-192.

2013 Copyright ©, International Frequency Sensor Association (IFSA). All rights reserved.
(<http://www.sensorsportal.com>)