# Implementation of Real-Time Pedestrian Navigation System using Foot-mounted IMU

Liqiang Zhang, Yu Liu
School of Microelectronics, Tianjin University, Tianjin, P. R. China
zhangliqiang@tju.edu.cn, liuyu@tju.edu.cn

## Abstract

Pedestrian navigation technologies are widely used in the situations such as security, emergency, navigation and health care, etc. In order to achieve reliable positioning results, pedestrian navigation system (PNS) is being implemented by using numerous methods, such as Inertial Measurement Units (IMUs) based [1], wireless-based [2] and vision-based [3] technologies, etc. Among these technologies, IMUs-based methods are mainly based on pedestrian dead reckoning (PDR) theory using commercial foot-mounted IMU. Besides, this method is superior to the others due to its low cost, high reliability, anti-interference, especially no external infrastructure needed.

The PDR system can be divided into two categories [4] i.e. inertial navigation system (INS) and step-and-heading system (SHS). An INS is a system that tracks position by estimating the full 3D trajectory of the sensor at any given moment. An SHS is specific to pedestrians, estimating position by accruing {step-length, heading} vectors representing either steps or strides. However, the errors of the INS-based PDR system accumulate over time due to the nature of INS. Hence it is difficult for INS-based PDR system to achieve long-time localization. To solve this problem, Foxlin [5] has proposed the classical Kalman-based PDR framework named IEZ. Its key technology named zero velocity updating (ZUPT) is valid to minimize the velocity errors of the PDR system. Besides, Ilyas et.al [6] have proved that ZUPT can also minimize the roll and pitch errors simultaneously. But the heading error and sensors biases are the only key errors which are unobservable for IEZ. Hence the heading drift of the whole system is easy to happen over time.

For centuries, mechanical compass has been successfully used for navigation. Thus, the electronic compass (EC) algorithm [7] is an effective way to bound the heading error. But magnetic disturbances including soft and hard disturbance [8, 9] are stochastic and changing indoors. Hence, the disturbances are difficult to be predicted. Meanwhile, they are harmful to the magnetic heading [10-12]. As a consequence, some researchers do not suggest using EC algorithm indoors. One of these researchers is Borenstein who has proposed heuristic drift reduction (HDR) algorithm [13] and its improved algorithm named heuristic drift elimination (HDE) [14]. These two algorithms only rely on the data from gyroscope and do not require the magnetometer. But compared with straight-line motion, the HDR algorithm degrades its performance while turning and curving. Meanwhile, the HDE algorithm only performs well when moving along the dominant direction of a building. These drawbacks limit their application.

In SHS, pedestrian motion is divided into continuous one-step motion. The position can be calculated by accruing the vector {step-length, heading} of one-step one by one. Since the interval of one-step is short, its accumulated errors is smaller than those of INS-based PDR system. In our work, we implement the SHS-based PDR system using commercial off-the-shelf foot-mounted IMU. Our proposed stance phase detection method named dual ZUPT (D-ZUPT) [15] is utilized to detect the stance phase in order to separate each one-step from continuous walk motion. Since the pedestrian tends to walk straight to save his or her energy and many corridors are straight, HDR algorithm is utilized to correct the heading error during the straight-line motion. Meanwhile, we construct the indirect extended Kalman filter (EKF) to minimize the systematic errors using the error state vector {velocity, position, and attitude}. The scheme of our system is shown in Fig.1. Experiments including indoor normal walking as shown in Fig.2 have shown the total travelled distance (TTD) error is 7 ‰ (i.e. 1000 m travelled distance with 7 m positioning error).

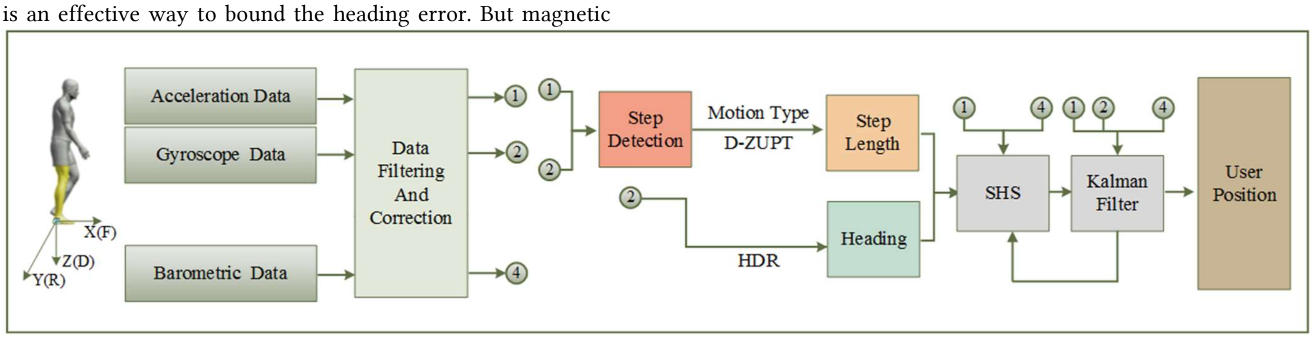


**Fig.1 The scheme of our PDR system**

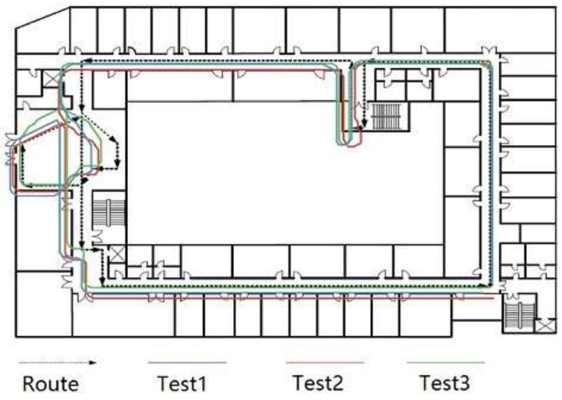


**Fig.2 We utilize the IMU named MTW from Xsens Company to achieve the walk experiment. The TTD error of positioning is 7 ‰.**

## References

[1] Bebek, Özkan, et al. "Personal navigation via high-resolution gait-corrected inertial measurement units." *IEEE Transactions on Instrumentation and Measurement* 59.11 (2010): 3018-3027.
[2] Dwiyasa, Felis, and Meng-Hiot Lim. "A survey of problems and approaches in wireless-based indoor positioning." *Indoor Positioning and Indoor Navigation (IPIN)*, 2016 International Conference on. IEEE, 2016.
[3] Mautz, Rainer, and Sebastian Tilch. "Survey of optical indoor positioning systems." *Indoor Positioning and Indoor Navigation (IPIN)*, 2011 International Conference on. IEEE, 2011.
[4] Harle, Robert. "A survey of indoor inertial positioning systems for pedestrians." *IEEE Communications Surveys and Tutorials* 15.3 (2013): 1281-1293.
[5] Foxlin, Eric. "Pedestrian tracking with shoe-mounted inertial sensors." *IEEE Computer graphics and applications* 25.6 (2005): 38-46.
[6] Ilyas, Muhammad, et al. "Drift reduction in pedestrian navigation system by exploiting motion constraints and magnetic field." *Sensors* 16.9 (2016): 1455.
[7] Jiménez, Antonio Ramón, et al. "Indoor pedestrian navigation using an INS/EKF framework for yaw drift reduction and a foot-mounted IMU." *Positioning Navigation and Communication (WPNC)*, 2010 7th Workshop on. IEEE, 2010.
[8] Angermann, Michael, et al. "Characterization of the indoor magnetic field for applications in localization and mapping." *Indoor Positioning and Indoor Navigation (IPIN)*, 2012 International Conference on. IEEE, 2012.
[9] Ladetto, Quentin, and Bertrand Merminod. "Digital magnetic compass and gyroscope integration for pedestrian navigation." *9th international conference on integrated navigation systems*, St-Petersburg. 2002.
[10] De Vries, W. H. K., et al. "Magnetic distortion in motion labs, implications for validating inertial magnetic sensors." *Gait & posture* 29.4 (2009): 535-541.
[11] Chung, Jaewoo, et al. "Indoor location sensing using geo-magnetism." *Proceedings of the 9th international conference on Mobile systems, applications, and services*. ACM, 2011.
[12] Afzal, Muhammad Haris, Valérie Renaudin, and Gérard Lachapelle. "Use of earth's magnetic field for mitigating gyroscope errors regardless of magnetic perturbation." *Sensors* 11.12 (2011): 11390-11414.
[13] Borenstein, Johann, Lauro Ojeda, and Surat Kwanmuang. "Heuristic reduction of gyro drift in IMU-based personnel tracking systems." *Optics and Photonics in Global Homeland Security V and Biometric Technology for Human Identification VI*. Vol. 7306. International Society for Optics and Photonics, 2009.
[14] Borenstein, Johann, and Lauro Ojeda. "Heuristic drift elimination for personnel tracking systems." *The Journal of Navigation* 63.4 (2010): 591-606.
[15] Liu, Yu, et al. "Step length estimation based on D-ZUPT for pedestrian dead-reckoning system." *Electronics Letters* 52.11 (2016): 923-924.