Pedestrian Dead Reckoning System Considering Actual Condition of the Foot-mounted IMU

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ABSTRACT

In this paper, we propose a pedestrian dead reckoning (PDR) system considering actual condition of the foot-mounted inertial sensors. The ZUPT-aided inertial navigation system (INS) combined with extended Kalman filter can reduce bias and white noise in gyro and accelerometer signals, but estimation error becomes large under various walking conditions. Therefore, the velocity during contact phase is estimated in order to improve the robustness and performance of the ZUPT-aided INS.

KEYWORDS

pedestrian dead reckoning, zero velocity update, inertial navigation system, extended Kalman filter

1 INTRODUCTION

Pedestrian dead reckoning (PDR) is one of the pedestrian navigation systems (PNS) based on inertial sensors and generally uses the assumption that the position is changed by each step without the help of any infrastructures. The PDR system for indoor navigation can be categorized according to the sensor placement such as shoe and handheld smartphone [1-8]. In case of foot-mounted inertial measurement unit (IMU), extended Kalman filter (EKF)-based inertial navigation system (INS) estimates the errors using zero velocity measurements during the stance phase [3-6]. In general, zero velocity update (ZUPT) uses walking characteristics of a pedestrian under the assumption that the velocity of foot becomes zero while it contacts with the grounds. ZUPT-aided INS can reduce the influence of the bias and white noises in the gyroscope and accelerometer signals but has serious limitations that cannot reflect the actual walking conditions under irregular walks. These limitations are occurred by wrong observation model in ZUPT-based INS. To be specific, the conventional algorithms using ZUPT assumptions consider sensor biases and white noise as major error factors of the estimated position. However, insufficient bandwidth of the foot-mounted IMU, nonzero velocity during stance phase, and undetected stance phase also affect the filter estimates, and these factors are mainly determined by sensor placement on shoe, material of shoes sole and the pedestrian's motion. In this paper, in order to overcome the mentioned limitations of the conventional PDR system, we consider actual conditions using the proposed approaches.

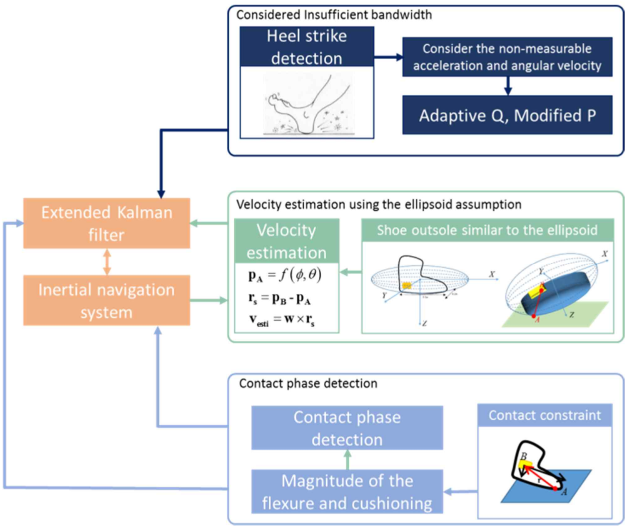

Figure 1: PDR system considering actual conditions.

The paper is structured as follows. Section 2 and 3 describe the concept of the algorithm and system requirements, respectively. The conclusion of the new approach is presented in section 4.

2 APPROACH MITIGATING LIMITATION OF ZUPT

In the following subsections, we point out how can overcome the limitations of the conventional PDR system with the new approach, and Fig. 1 shows the overall concept of the proposed algorithm considering actual walking conditions of a pedestrian. The advantages of the approach are as follows. Firstly, the system does not require any infrastructure thus works both outdoor and indoor and is easy to implement in any system. In addition, floor can be determined as far as a pedestrian is changing floor by stairs. Moreover, the algorithm works in real-time regardless of surrounding magnetic disturbances, different motions such as crawling and squat walking.

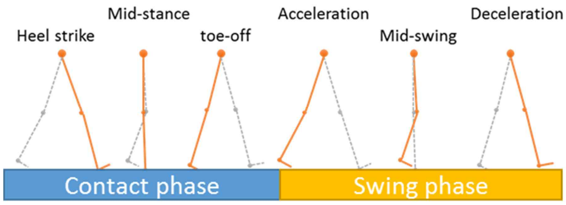

Figure 2: Step phase classification [7]

2.1 Consideration of the insufficient bandwidth

When the heel hits the ground prior to the stance phase, the foot-mounted IMU undergoes extreme dynamics [6]. The bandwidth of most foot-mounted IMUs ranges from 30 to 40Hz, but it is not sufficient to measure actual movement of the sensors during heel-strike. Consequently, non-measureable acceleration and angular velocity are occurred, and the integrated velocities from acceleration are not reliable because of inaccurate measures in heel-strike phase.

Therefore, the proposed adaptive EKF takes into consideration the non-measureable acceleration and angular velocity by heel strike impact. When the shoe hits the ground, the process noise Q, determined by sensor performance is changed to very large value so that the impact of the heel-strike is to be alleviated.

2.2 Velocity estimation using the ellipsoid assumption

The ZUPT in conventional PDR system assumes that the foot has no move on the ground during the stance phase. However, movement occurs in the actual situation especially when a pedestrian walks irregularly such as running, walking up and down the stairs, and squat walking. The majority of the nonzero velocity is caused by a rotation of the foot, so ZUPT assumption makes cumulative errors depending on the size of the actual velocity.

In order to overcome the ignored velocities during stance phase, the shape of shoes outsole is considered as ellipsoid for the contact phase from heel-strike to toe-off states in Fig. 2. If the outsole is similar to ellipsoid, the position of the contact point between ground and shoe can be calculated by using roll and pitch angle, and the velocity and position during the contact phase is accurately estimated regardless of walking types.

2.3 Contact phase detection

Detecting a stance phase for normal walks is relatively easy with the conventional algorithm, but the accuracy is severely degraded under unusual walks. It is because variance and norm of either the gyroscope or accelerometer signals are decision elements and are set only for the normal walks.

Using the estimated velocity in subsection B, the contact phase can be detected with the contact constraint between the surface and the foot. The acceleration can be calculated by using the dynamics during the contact phase. By comparing calculated acceleration and measured acceleration, it is possible to detect contact phase regardless of user motions.

3 SYSTEM REQUIREMENTS

The proposed algorithm is able to be performed using two foot-mounted IMUs, the commercial off-the-shelf (COTS) product manufactured by Xsens, with free of infrastructure. At the beginning of the operation, it is only required for gyros to be completely motionless for 5 seconds in order to measure static gyro bias, and a test subject is instructed to walk toward the way of the direction for the initial heading angle set-up.

4 CONCLUSIONS

In this paper, the new approach considering insufficient bandwidth and velocity during contact phase is proposed to improve PDR system performance. EKF with Q adaptation during heel-strike phase and velocity during contact phase efficiently improve the position estimates under various walking motions.

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REFERENCES

[1] Kappi, J., Syrjarinne, J., and Saarinen, J. (2001, January). MEMS-IMU based pedestrian navigator for handheld devices. *In Proceedings of the 14th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GPS 2001)* (pp. 1369-1373).

[2] Gusenbauer, D., Isert, C., and Krösche, J. (2010, September). Self-contained indoor positioning on off-the-shelf mobile devices. *In Indoor positioning and indoor navigation (IPIN), 2010 international conference on IEEE* (pp. 1-9).

[3] Foxlin, E. (2005). Pedestrian tracking with shoe-mounted inertial sensors. *IEEE Computer graphics and applications*, Vol. 25, No. 6, (pp. 38-46).

[4] Jimenez, A. R., Seco, F., Prieto, C., and Guevara, J. (2009, August). A comparison of pedetrian dead-reckoning algorithms using a low-cost MEMS IMU. *In intelligent signal processing (WISP), 2009. IEEE International Symposium on IEEE* (pp. 37-42).

[5] Feliz Alonso, R., Zalama Casanova, E., and Gómez García-Bermejo, J. (2009). Pedestrian tracking using inertial sensors, *Journal of physical agents*, Vol. 3, No. 1, (pp. 35-43)

[6] Nilsson, J. O., Skog, I., and Händel, P. (2012, November). A note on the limitations of ZUPTs and the implications on sensor error modeling. *In 2012 International Conference on Indoor Positioning and Indoor Navigation (IPIN)*

[7] Ju, H., Lee, M. S., Park, S. Y., Song, J. W., and Park, C. G. (2015). A pedestrian dead-reckoning system that considers the heel-strike and toe-off phases when using a foot-mounted IMU. *Measurement Science and Technology*, Vol. 27, No. 1

[8] Ju, H., Park, S. Y., and Park, C. G. (2016, October). Foot Mounted Inertial Navigation System using Estimated Velocity During the Contact Phase. *2016 International Conference on Indoor Positioning and Indoor Navigation (IPIN)*