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Design and Implementation a Constrained Adaptive Estimation Algorithm for Low-cost Integrated Navigation System in Urban Area

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ABSTRACT: Due to stochastic noises, modeling uncertainties and nonlinearities in low-cost inertial measurement units, the positioning error of strap-down inertial navigation systems are increased exponentially. So, the inertial navigation system is integrated with aiding navigation systems like a global navigation satellite system by using an estimation algorithm to obtain an acceptable positioning accuracy. In the urban area, the global navigation satellite system signal may be obstructed because of tall trees and buildings. Therefore, in the present paper, a novel constrained adaptive integration algorithm is developed for integration of the strap-down inertial navigation system and global navigation satellite system. In this algorithm, the velocities constraints in body frame in addition to altitude constraints based on a barometer data are firstly developed, and then a constrained estimation algorithm is designed based on the proposed constraints. In addition, a type-2 fuzzy algorithm is used to calculate the estimator parameters based on vehicle maneuvers. The real vehicular tests are used for implantation and validation of the proposed algorithm. The experimental results indicate that the proposed adaptive constrained estimation algorithm enhanced the estimation accuracy of the strap-down inertial navigation system steady states.

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1. INTRODUCTION

The purpose of the Strap-Down Inertial Navigation System (SINS) is to calculate the position, velocity, and orientation of the vehicle by integration respect to time of inertial sensors outputs. This method can be easily employed using low-cost micro-electro mechanical system grade Inertial Measurement Unit (IMU). The main limitation of low-cost IMU is due to the stochastic noises, modeling uncertainties and nonlinearities in low-cost IMU [1]. In order to compensate this scarcity, the SINS should be integrated with an aiding navigation system such as a Global Navigation Satellite System (GNSS). The GNSS is employed to broaden the effectiveness of SINS in different situations. In this respect, position and velocity components of GNSS are used to compensate for the stand-alone SINS navigation errors. However, the signal of GNSS may be blocked because of tall trees and buildings in urban areas. The GNSS signal blockage causes some side effects such as instability in the vertical channel of SINS parameters [2].

One of the efficient approaches to integrate the SINS/GNSS is Kalman Filtering (KF). Nourmohammadi and Keighobadi [3] present a cubature kalman filter for SINS/GNSS integration system. In another work, a fuzzy adaptive KF is presented to enhance the long-term performance of conventional SINS/GNSS navigation systems [4]. As a centralized and decentralized point of view to kalman filtering approach, Nourmohammadi and Keighobadi [5], with some assumption in vehicle velocity components, predicted the vehicle future states and used it in the integration algorithm during GNSS outage. Godha and Cannon [6] proposed an Extended Kalman Filter (EKF) with altitude and velocity constraints for SINS/GNSS integrated system. With an intelligent approach to SINS/GNSS integration system, Musavi and Keighobadi [7] illustrate a fuzzy neural network approach for approximation of IMU uncertainties. Rafatnia et al. [2] present a recurrent wavelet network for SINS/GNSS data fusion algorithm.

In this study, with using constrained fuzzy EKF, the SINS/GNSS navigation system is integrated to improve the accuracy and reliability of the integrated navigation system. In this respect, the velocity and altitude constraints are developed for the SINS/GNSS system, and then a constrained fuzzy EKF is used as data fusion algorithm for this system. Finally, some real vehicular tests are conducted to verify the performance of the proposed information fusion algorithm for integrated SINS/GNSS system. The results indicate that the proposed algorithm reduced mean value and standard deviation of estimation error and increased the reliability of the system during GNSS-outage.

2. METHODOLOGY

The overall structure of the proposed data fusion algorithm is shown in Fig. 1. An IMU system includes 3-axis accelerometers, 3-axis gyroscopes and barometer, and thermometer with 100Hz updating rate is used. The GNSS

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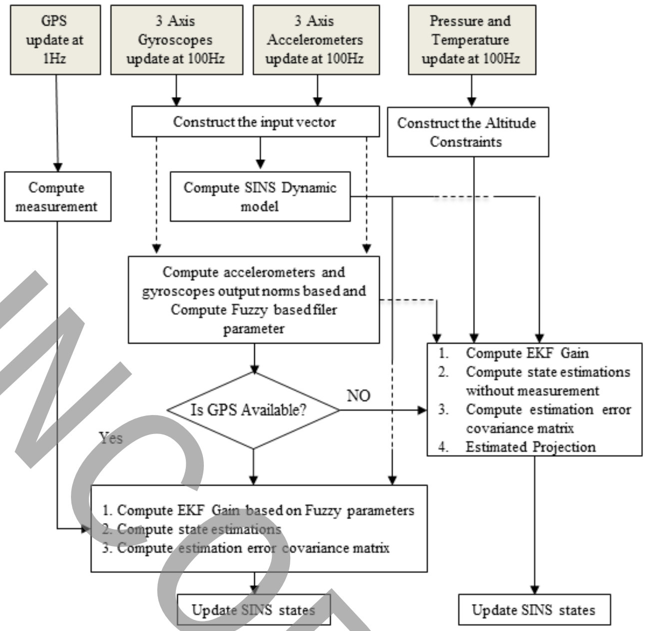

Fig. 1. The overall structure of the integration algorithm

receiver with 1 Hz updating rate is used to obtained reference position and velocity components of the vehicle. According to Fig. 1, the norm of IMU data is used to compute fuzzy based EKF parameters. In addition, air data sensors data are used to construct the altitude constraints.

3. DISCUSSION AND RESULTS

In order to implementation of the proposed data fusion algorithm for SINS/GNSS navigation system, some vehicular real test performed in Azarshar, Iran. The vehicle trajectory during the test is shown in Fig. 2. According to Fig. 2, the test is conducted in an urban area with different dynamically maneuvering. In addition, because of tall trees and building different GNSS-outage are experienced during the test. The altitude of the vehicle is shown in Fig. 3. According to Fig. 3, the vehicular test has been applied approximately for 400 seconds and the altitude of the vehicle is changed more than 20 meters.

The estimation result of the latitude-longitude trajectory of the vehicle for both constrained adaptive EKF and unconstrained EKF based integrated navigation algorithms

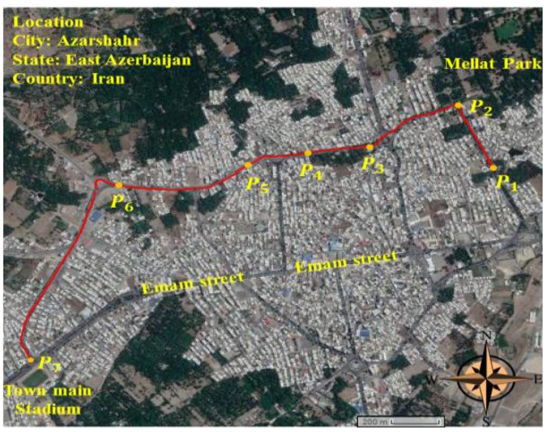

Fig. 2. Vehicular trajectory

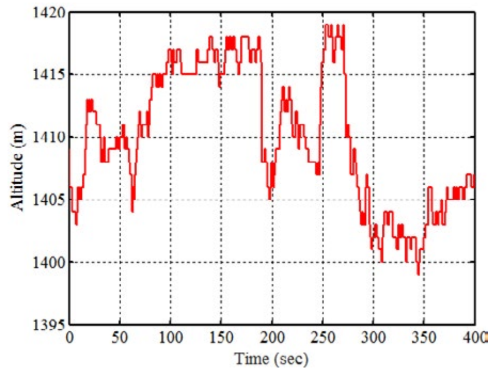

Fig. 3. Vehicular altitude

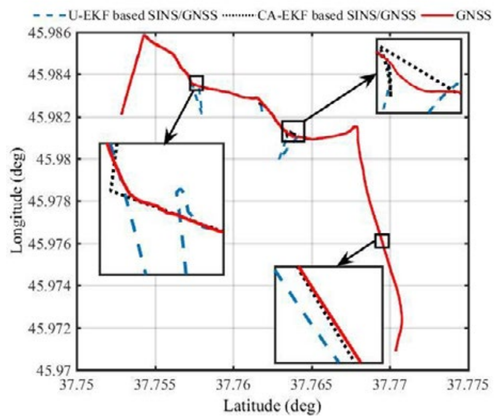

Fig. 4. Estimated vehicular trajectory

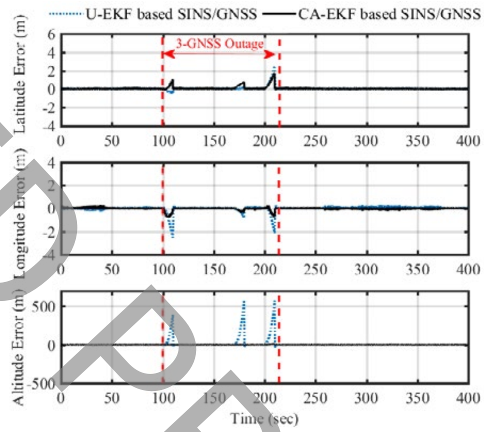

Fig. 5. Estimation error of vehicular positions

is presented in Fig. 4. Accordingly, the estimation error of position and velocity components of the vehicle with respect to the reference GNSS data are shown in Figs. 5 and 6, respectively. According to these results, the proposed algorithm improved the accuracy and reliability of the SINS/GNSS navigation system.

4. CONCLUSION

For enhancement navigation reliability and accuracy of integrating SINS/GNSS during GNSS-outage; an adaptive constrained integration algorithm has been designed in this paper. Fuzzy logics are defined to determine automatically

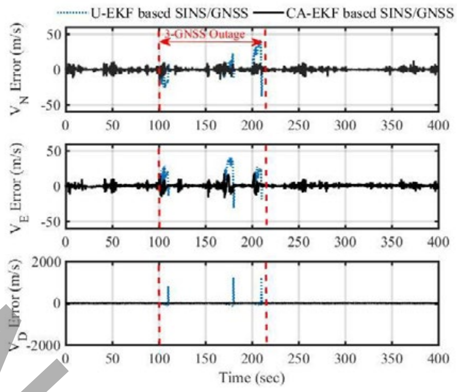

Fig. 6. Estimation error of vehicular velocity

the covariance matrix of system noise in fuzzy EKF algorithm. The proposed information fusion scheme for the SINS/GNSS is employed in various vehicular tests. The results indicate that the proposed adaptive constrained integrated algorithm improved reliability and accuracy of the integrated navigation system.

REFERENCES

[1] S. Sukkarieh, E. Nebot, H. Durrant-Whyte, Achieving integrity in an INS/GPS navigation loop for autonomous land vehicle applications, in: Robotics and Automation, 1998. Proceedings. 1998 IEEE International Conference, *IEEE*, Leuven, Belgium, 1998, pp. 3437-3442.

[2] S. Rafatnia, H. Nourmohammadi, J. Keighobadi, M. Badamchizadeh, In-move aligned SINS/GNSS system using recurrent wavelet neural network (RWNN)-based integration scheme, *Mechatronics*, 54 (2018) 155-165.

[3] H. Nourmohammadi, J. Keighobadi, Decentralized INS/GNSS system with MEMS-grade inertial sensors using QR-factorized CKF, *IEEE Sensors Journal*, 17(11) (2017) 3278-3287.

[4] H. Nourmohammadi, J. Keighobadi, Fuzzy adaptive integration scheme for low-cost SINS/GPS navigation system, *Mechanical Systems and Signal Processing*, 99(2018) (2018) 434-449.

[5] H. Nourmohammadi, J. Keighobadi, Design and experimental evaluation of indirect centralized and direct decentralized integration scheme for low-cost INS/GNSS system, *GPS Solutions*, 22 (2018) 1-18.

[6] S. Godha, M. Cannon, GPS/MEMS INS integrated system for navigation in urban areas, *GPS Solutions*, 11(3) (2007) 193-203.

[7] N. Musavi, J. Keighobadi, Adaptive fuzzy neuro-observer applied to low cost INS/GPS, *Applied Soft Computing*, 29 (2015) 82-94.