Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 54(12) (2023) 551-554
DOI: 10.22060/mej.2023.21380.7441

A New Direct Filtering Approach based on the Interactive Multiple Model Method in the Global Positioning System/Inertial Navigation System Integration

H. H. Sadrabady, E. Sadat Abdolkarimi, M. R. Mosavi*

Department of Electrical Engineering, Iran University of Science and Technology, Tehran, Iran

ABSTRACT: In this paper, to increase the navigation accuracy in the integrated Global Positioning System and Inertial Navigation System, a new direct filtering approach called Interacting Multiple Model-Refined Strong Tracking Extended Kalman Filter has been developed. In the proposed method, while using inertial navigation equations and tracking equations in order to improve the accuracy of position and velocity, to increase the accuracy of orientation, attitude estimation methods based on the gyroscope, accelerometer, and global positioning system have been used. In addition, in order to enhance the Extended Kalman Filter robustness against modeling error, the Refined Strong Tracking method has been used. The aircraft then verified the proposed method using data collected in a real field experiment. The results of the proposed method were compared with the results of the conventional indirect filtering method Kalman Filter, direct filtering Unscented Kalman Filter, and Interacting Multiple Model - Extended Kalman Filter. The results show the more accurate performance of the proposed method compared to the previous three methods in the Global Positioning System and Inertial Navigation System integration.

Review History:

Received: May, 08, 2022
Revised: Nov. 27, 2022
Accepted: Jan. 30, 2023
Available Online: Feb. 25, 2023

Keywords:

Global positioning system
Inertial navigation system
Direct filtering
Multiple model estimate
Interactive multiple model

1- Introduction

Today, in order to improve the accuracy in estimating the position and velocity, the integration of an Inertial Navigation System (INS) and Global Positioning System (GPS) using Kalman Filter (KF) methods is used. When Kalman filtering is used in GPS/INS integration, it is often classified as direct filtering or indirect filtering. The direct filtering method has less computational burden than the indirect filtering method. However, when using the direct method for integrated GPS/INS navigation, the system model has uncertainties such as mismatch of model components, random error of system noise, and random drifts, which lead to the deterioration or even divergence of the filter solution. These errors are named modeling errors and adaptive Kalman filter algorithms are considered to solve this problem [1].

One of the common adaptive methods is multiple model estimation, which is a structural adaptive method. This method provides more reliable estimates by using more than one filter with different models and in parallel [2]. Another adaptive method is the adaptive fading memory filter approach, which is a type of covariance scale method. The strong tracking Kalman filter is one of the adaptive fading memory filters in which the strong tracking algorithm includes a Suboptimal Fading Factor (SFF) [1]. In this paper, a new direct filtering method based on Interacting Multiple Model (IMM) estimations is developed. In the structure of the models, tracking models and mechanization equations are used to model the movement behavior of the flight vehicle. In the structure of the models, the Extended Kalman Filter (EKF) is responsible for estimating the values. The EKF has less computational burden than other non-linear filter methods. However, it suffers from the first-order linearization errors of the nonlinear system. To make the EKF robust against modeling errors, a Refined Strong Tracking (RST) method is employed.

2- Methodology

In order to develop the proposed method, modeling for the movement behavior of the vehicle is introduced. For modeling, common tracking models [3] along with inertial mechanization equations have been used. The Extended model includes three movement models as follows:

• The first model: It is intended for straight movement at a constant speed.

• The second model: This model is intended for turning movement at a constant height. In this model, the common velocity and position tracking equations for rotational movement at constant height are adapted to be used in North-East-Down (NED) coordinates.

• The third model: The third model is intended for

*Corresponding author’s email: m_mosavi@iust.ac.ir

Table 1. Comparison between computational load values and RMSEs of position and velocity between conventional KF, UKF, IMM-EKF, and the proposed IMM-RSTEKF methods.

Parameter	Conventional KF	UKF	IIM_EKF	IMM-RSTEKF
φ(m)	1.67	1.993	2.203	1.401
λ(m)	2.192	2.369	2.510	1.450
V_N(m/s)	0.0709	0.0547	0.0420	0.0422
V_E(m/s)	0.0792	0.0872	0.0485	0.0485
V_D(m/s)	0.0546	0.0464	0.0429	0.0429
Computational load (s)	5.283	22.227	10.404	11.517

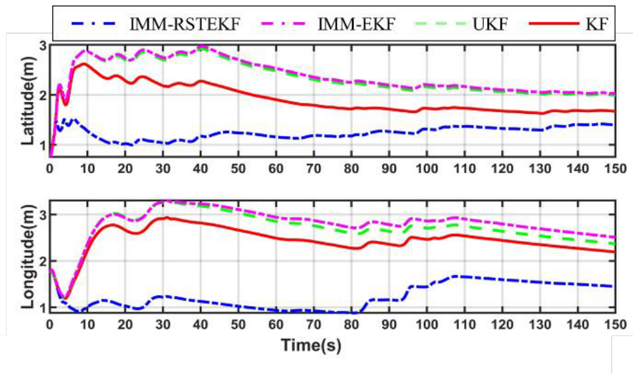

Fig. 1. Comparison of the RMSE values of position in longitude and latitude between conventional KF, UKF, IMM-EKF, and the proposed IMM-RSTEKF method.

accelerated movement. In this model, the mechanization equations of the common INS are used for the velocity and position equations.

In addition, in the structure of models, to increase the observability of attitudes, attitude estimation methods based on accelerometer, gyroscope, and GPS have been used [4]. Then, in the structure of the models, the EKF was used to estimate the values. The EKF has less computational burden than other non-linear filter methods. However, it suffers from the first-order linearization errors of the nonlinear system. To make the EKF robust against modeling errors, the RST method is employed [1]. The advantage of this method compared to other methods is the use of the SFF in the predicted covariance matrix to reduce the impact of modeling errors.

However, using this coefficient in time intervals where there is no kinematic model error will reduce the accuracy of the filter. One of the advantages of the RST method is to use the SFF only in the time intervals when the kinematic model error exists. For this purpose, it uses the assumption test method to identify the time intervals when the kinematic model error occurs. Finally, the proposed method is developed with the help of integrating the models introduced by the IMM algorithm and is named the Interacting Multiple Model-Refined Strong Tracking Extended Kalman Filter (IMM-RSTEKF).

3- Results and Discussion

In order to evaluate the proposed method, the data collected in a real field test by Meraj Airlines flight has been used. In this test, the intended air vehicle performed various maneuvers during a 150-second time period. In this simulation, the proposed method is evaluated along with the indirect filtering methods of conventional KF, direct Unscented Kalman Filter (UKF), and IMM-EKF filtering. To compare the output results of the filters, the Root Mean Square Error (RMSE) component has been used. The RMSE is defined as Eq. (1):

$$RMSE = \sqrt{\frac{1}{n}\sum_{k=1}^{n}\left(Y_{ok}-Y_{pk}\right)^{2}} \quad (1)$$

where n is the number of samples, Y_{ok} is the optimal response, and Y_{pk} is the estimated response. The results of the RMSEs of position and velocity of the methods are given in Table 1. According to the results reported in Table 1, the proposed method has been able to reduce the position and velocity error by more than 12% and 34%, respectively, compared to the conventional Kalman filter. Also, compared to UKF, it can reduce the position and velocity error by more than 12% and 29%, respectively. In addition, in terms of speed, it has the same results as the IMM-EKF method, but in terms of position, it has been able to reduce the position error by 14%. This improvement is due to the use of the RST method in the structure of the proposed method.

Figs. 1 and 2 show the RMSE values of position and velocity for all four conventional KF filter methods, UKF, IMM-EKF, and the proposed IMM-RSTEKF method.

4- Conclusions

In this paper, a new direct filtering approach in GPS/INS integration is introduced. In the proposed method, the tracking models and mechanization equations of the INS were used in order to improve the accuracy of position and velocity. Attitude estimation based on the gyroscope, accelerometer, and GPS were used. Also, in order to prevent the increase of the gyroscope drift error, the closed loop method was used in the structure of the models. In the structure of the models, the EKF is responsible for estimating the values. The EKF has less computational burden than other non-linear filter methods. However, it suffers from the first-order linearization errors of the nonlinear system. To make the EKF robust against modeling errors, an RST method was used. In the following, the Extended models were integrated with each other using the IMM method. The IMM-RSTEKF calculates the success probability of each model at each filter

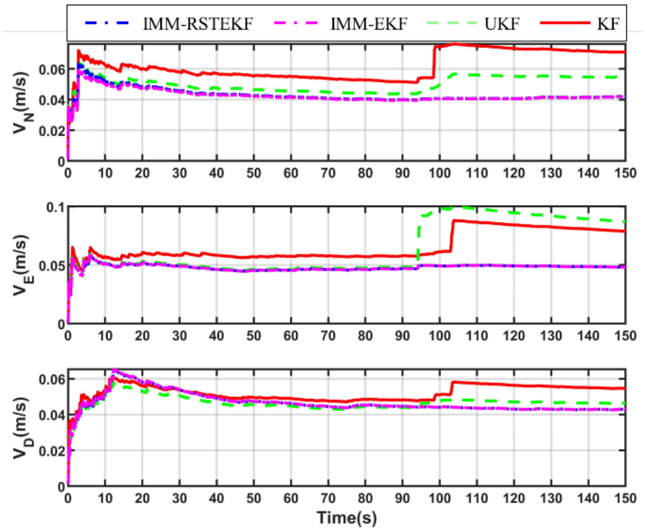

Fig. 2. Comparison of velocity RMSE values in the north, east, and down directions between conventional KF, UKF, IMM-EKF, and the proposed IMM-RSTEKF method.

run and provides a realistic hybrid solution for the vehicle's motion behavior. Simulation results with real field test data verified 12% and 34% improvement in position and velocity, respectively, compared to the conventional KF indirect filtering method. Also, they reported an improvement of 12% and 29% in position and velocity, respectively, compared to the direct filtering method of conventional KF. In addition, the use of the RST method resulted in a 14% improvement in position compared to IMM-EKF.

References

[1] G. Hu, W. Wang, Y. Zhong, B. Gao, C. Gu, A new direct filtering approach to INS/GNSS integration, Aerospace Science and Technology, 77 (2018) 755-764.

[2] A. Akca, M.Ö. Efe, Multiple model Kalman and Particle filters and applications: A survey, IFAC-PapersOnLine, 52(3) (2019) 73-78.

[3] X.R. Li, V.P. Jilkov, Survey of maneuvering target tracking: dynamic models, in: Signal and Data Processing of Small Targets 2000, SPIE, 2000, pp. 212-235.

[4] Z. Wu, M. Yao, H. Ma, W. Jia, Improving accuracy of the vehicle attitude estimation for low-cost INS/GPS integration aided by the GPS-measured course angle, IEEE Transactions on Intelligent Transportation Systems, 14(2) (2012) 553-564.

HOW TO CITE THIS ARTICLE
H. H. Sadrabady, E. Sadat Abdolkarimi, M. R. Mosavi, A New Direct Filtering Approach based on the Interactive Multiple Model Method in the Global Positioning System/Inertial Navigation System Integration, Amirkabir J. Mech Eng., 54(12) (2023) 551-554.

DOI: 10.22060/mej.2023.21380.7441