Application of Street Tracking Algorithm in a feedback configuration for an integrated INS/GPS navigation system

Nguyen Van Thang[a], Chu Duc Trinh[b], Tran Duc Tan[b]

[a] Broadcasting College 1, Ha Nam, Viet Nam, [b] VNU University of Engineering and Technology, Hanoi, Vietnam. E-Mail: nguyenbathangvov@gmail.com

Abstract

When satellite's signal outage occurs, a single GPS receiver will be unable to provide a reliable solution, and an INS/GPS system would continue to use the raw IMU data to compute a solution. Several complementary methods have been proposed to provide a system with highly accurate position, velocity, and attitude in challenging GPS environments. In our previous study [1], we have proposed new algorithm called Street Tracking Algorithm (STA) to enhance the correctness of the integrated system. However, this algorithm can only improve the accuracy of the position of the vehicle due to its feed-forward configuration. This paper is an extended work of [1] when we proposed a feedback scheme that combines STA with the conventional INS/GPS system. In this novel configuration, both velocity and position parameters are enhanced. The experimental result has showed that when GPS signal is lost, we can control the position error is around 2.5 m, and the velocity error is around 3.2 m/s.

Keywords: Inertial Navigation System (INS), Global Positioning System (GPS), Inertial Measurement Unit (IMU), Street Tracking Algorithm (STA), Kalman.

1. Introduction

Recently, INS/GPS integrated systems have been popularly used in navigation and guidance field. However, selecting low-cost or high-cost INS/GPS integrated systems depends on each specific application. We combine INS with GPS to make use of advantages and limit disadvantages of them. It means that when GPS signal is available, information determined by INS is always combined with one determined by GPS to find out the most precise parameters such as attitude, velocity, position of moving object [2], [3]. In case of unreliable GPS signal or GPS outage, INS will directly provide those parameters. From advantages and disadvantages of INS and GPS lead to novel methods to minimize limitations of each system or integrated system. We can consider some approaches:

The system improves accuracy by implementing a technique known as "Zero Velocity Update" (ZUPT). The ZUPT technique combine with related signal processing algorithms, typical errors of proposed system are around 2% of distance traveled for short walks. When walking continuously for a few minutes, the error increases gradually beyond 2%. So, the system can utilize in military, security personnel as well as emergency responders [4].

Another method can help a quad-rotor helicopter flying autonomously during GPS outage is to use a motion planning algorithm [5]. This novel algorithm permits the vehicle to have ability to localize itself varies across the environment, different features of environment provide different degrees of position. Consequently, an extended study that combined this algorithm with the Unscented Kalman Filter (UKF), and described a sampling algorithm that minimizes the number of samples required to choose the best path for flying [6].

In order to performance improve of a low-cost INS/GPS, Ruijie et. al. proposed Adaptive Kalman filtering techniques use the residual sequences to adapt the stochastic properties of the filter on line to correspond to the temporal dependence of the errors involved [7]. That proposal uses three adaptive filtering techniques that are artificially scaling the predicted Kalman filter covariance, the Adaptive Kalman Filter and Multiple Model Adaptive Estimation.

In this paper, we proposed an integrated system that utilized an algorithm named Street Tracking Algorithm that improves both position and velocity information of the land vehicle during GPS outage. The paper is organized as following: Section 2 presents the working principles of GPS, INS and INS/GPS integrated system. Section 3 presents the proposed configuration scheme and its operating principle. Results and discussions are mentioned in Sect. 4 and conclusion is given in Sect. 5.

2. Working principles

2.1 Global position system (GPS)

Principle of determining the coordinates of the GPS receiver (R) bases on the formula distance = velocity × time. Satellites (Sats) emit signals including their location, and the signal emitting time. The GPS receiver calculates the distance from the satellites to its position. The GPS receiver location is the point of intersection of spheres with center is satellites, and the radius is the signal broadcasting time from the satellite to the GPS receiver multiple velocity of electromagnetic wave rate. However, in order to find out longitude, latitude, and height the receiver needs to see at least four satellites (see Fig. 1).

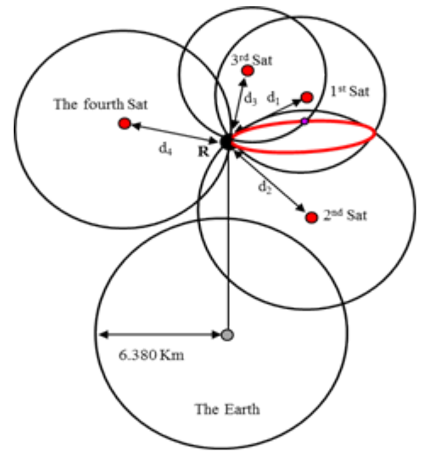


Fig. 1. Determination of the GPS receiver's position.

2.2 Inertial navigation system (INS)

An inertial navigation system normally consists of three parts such as an inertial measurement unit (IMU), support electronic elements, and a navigation computer. The IMU utilizes gyroscopes and accelerometers to maintain an estimate of the position, velocity, and attitude of the moving object equipped itself. This object could be aircraft, spacecraft, surface ship, a land vehicle etc. Fundamental principle of INS can be explained as follows: Before working, INS is set up standard information about position (latitude, longitude and height), and attitude. When INS starts working, gyroscopes and accelerometers in an IMU provide velocity and angular (pitch, roll and yaw) increments to navigation computer. Computer bases on these increments and the above standard information to determine information about position, velocity and attitude at the present time (t_1). Familiar to this determining, the position information at the next time (t_2) will be found out via the position information at the latest time (t_1) and increment or decline of parameters of velocity, acceleration, and angle during the period from t_1 to t_2.

2.3 INS/GPS integrated system

With a view to integrate INS and GPS, it can use one in three basic integration methods such as loosely-coupled, tightly-coupled, and deeply-coupled. However, this study utilizes the loosely-coupled integration method (see Fig. 2) [8].

In this scheme, after receiving and processing information come from satellites, the processed information is put into the navigation processor inside the GPS receiver to calculate position (P_{GPS}) and velocity (V_{GPS}) of moving object when GPS signal is available. P_{GPS} and V_{GPS} continue to be processed one time again in external navigation processor before outputting the most precise navigation parameters about position P and velocity V. In case of GPS outage, accelerometers and gyroscopes in IMU will provide angular increment, velocity increment respectively to navigation processor so as to calculate three parameters such as velocity, attitude, and position. After that these are output directly without combining with information provided by GPS.

An external navigation filter computes position (P_{INS}), velocity (V_{INS}) and attitude (A_{INS}) from the raw inertial sensor measurements and uses the GPS position and velocity to correct INS errors. An advantage of a loosely coupled system is that the GPS receiver can be treated as a black box. The blended navigation filter will be simpler if using GPS pre-processed position and velocity measurements. However, if there is a GPS outage, the GPS stops providing processed measurements and the inertial sensor calibration from the INS/GPS filter stops as well.

In an INS/GPS integrated system, when working in common mode INS is always supported by GPS. It means that the GPS position and velocity are used to correct INS errors. But in case of GPS outage, INS will computer, output parameters without supporting of GPS [2]. The reason why the use of kind of this combination is INS having high-speed update, self-contained navigation ability while GPS has low-speed update and depends on the weather condition, environment condition, seeing how many satellites etc. It is clear that this integrated system could bring into play advantages and limit disadvantages of each system.

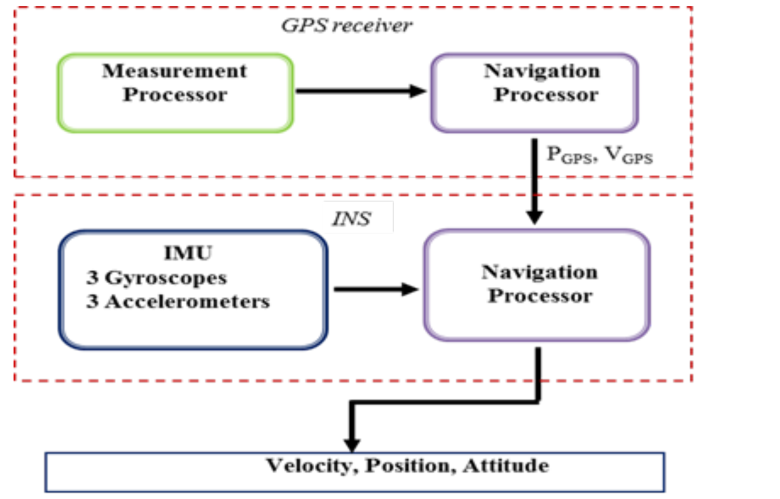


Fig. 2. The INS/GPS system using loosely-coupled integration method.

3. Proposed configuration scheme

The proposed INS/GPS/feedback P_{STA} system is shown in Fig. 3. It should be presented here for complete understanding:

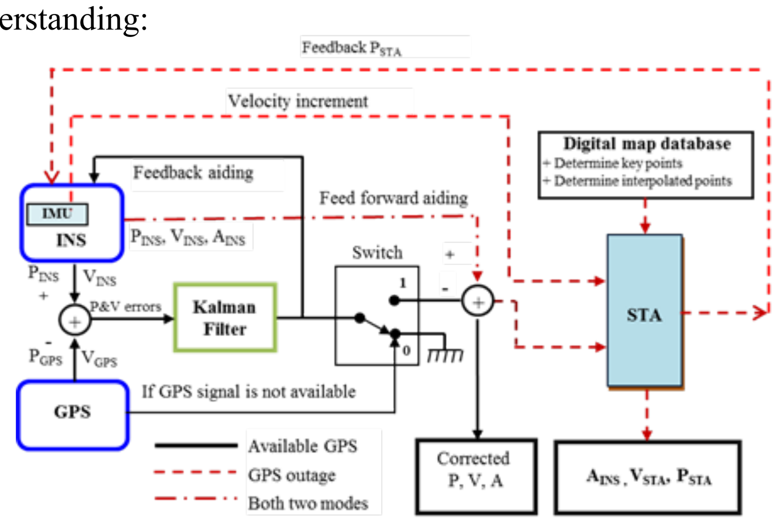


Fig. 3. The proposed INS/GPS/feedback P_{STA} system

When GPS signal is available, the state of the switch is "1" and the system would run in the solid lines and dotted line. It means that the system can work well without STA and digital map. However, if GPS signal is lost, the state of the switch is "0" and the system would run in the dotted line and dashed lines. In this scenario, the Kalman filter will work in prediction mode, and the Street Tracking Algorithm would enable to assist position information based on digital map.

In the computer, we have to store the information of the trajectory of the vehicle. The data is prepared in two steps. The first step is determination of key points based on digital map. The second step is determination of interpolated points based on above key points. The aim of the second step is to increase the reference points (key points or interpolated points). It supposed that d_{ref} is reference distance; this means that d_{ref} is distance from starting position of the vehicle to any reference point. The distance of d_{ref} is the sum of the line segments between two consecutive reference points since starting point.

Before GPS outage, the STA block stores the last reliable location of the vehicle at the time of t_s having distance of d_s (distance from starting position of the vehicle to the last reliable location) (see Fig. 4). The distance of vehicle ran to the time of t_k is calculated by:

$$d = d_s + d(t_k) \qquad (1)$$

where $d(t_k)$ is the distance of the vehicle from the moment the GPS signal is lost to the epoch t_k. Note that this distance is computed by integrating the velocity provided directly by the IMU:

$$d(t_k) = \int_{t_s}^{t_k} v(t)\,dt \qquad (2)$$

It is easy to see that $d(t_k)$ is only the distance from t_s to t_k. It cannot provide the information of longitude or latitude. The STA will determine its longitude and latitude by comparison of d with the reference distances d_{ref}. It will search which value of d_{ref} would have nearest distance to d (to ensure that ε is smallest):

$$\left|d - d_{ref}\right| < \varepsilon \qquad (3)$$

After that, we will obtain the corrected position of the vehicle as the longitude and latitude of reference point having distance of found d_{ref}. It means that the vehicle will be pulled to the fixed location determined in the database.

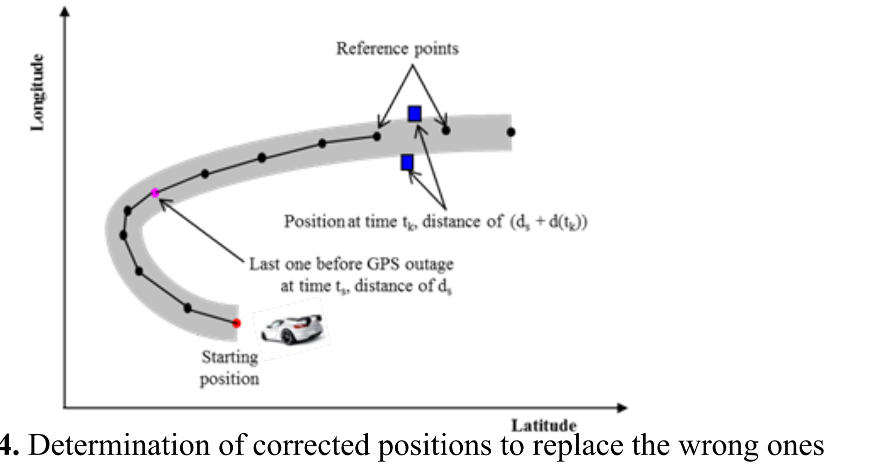


Fig. 4. Determination of corrected positions to replace the wrong ones

It is clear that when amount of the reference points increased the performance would be improved. However, it also needs to have a balance between the performance and the complexity. The limitation of integrated system without feedback P_{STA} is that it could not improve information of velocity. Thus an integration scheme using feedback P_{STA} is proposed as shown in Fig. 3. After obtaining corrected position P_{STA} from output of STA block, this information is feedback to INS to continue to correct parameter of velocity. The different between two continuous P_{STA} divide the updated period T_S would provide the velocities V_N and V_E:

$$V_N(t_k) = \frac{P_{STA}^N(t_k) - P_{STA}^N(t_{k-1})}{T_S} \qquad (4) \qquad\qquad V_E(t_k) = \frac{P_{STA}^E(t_k) - P_{STA}^E(t_{k-1})}{T_S} \qquad (5)$$

Note that we should not use the position information as the longitude and latitude because the change of the position in degree is very small. In (4) and (5), the positions are measured by the distance in the North and the East.

4. Results and Discussions

Hardware configuration used in this study includes a computer, a GPS receiver, an IMU named MICRO-ISU BP3010 consisting of three ADXRS300 gyros and three ADXL210E accelerometers. The calibration process for this IMU is presented in [9, 10]. From the digital map, we determined 92 key points and 410 interpolated points for STA block. Trajectory of line segments is formed via those reference points. The moving trajectory of the vehicle; trajectory of line segments, and trajectory drawn by GPS in open-sky condition are shown in the Fig. 5. In this scenario, GPS signal was assumed to be lost within 200 seconds from the 900^{th} to 1100^{th} second. The output parameters of the system in this scenario will be compared with the actual GPS's output. We can observe the velocities in the North and the East (V_N and V_E) in Fig. 6. It is easy to see that the system could not adapt with the real moving. The velocities are nearly unchanged until the GPS signal is available again. Even if we use STA with feed forward configuration, we could not obtain the information of the velocity. It means that the velocity of the INS/GPS system with STA in feed forward mode is the same Fig. 6. Using STA with feedback configuration, the velocities have been estimated as shown in Fig. 7. Obviously, the velocities can adapt with real moving.

The result would be better if we increase the number of the key points and interpolated points. The positions of the vehicle before using STA are shown in Fig. 8.a. When GPS signal is available, the integrated system offers positions matched with reference curve. However, when GPS signal is lost, the integrated system (the dotted curve) is bias from the reference trajectory (the solid curve). The maximum position error caused by INS is over 1000 meters in the North and about 50 meters in the East during the period of 200 seconds and this error is unacceptable. However, this is improved a lot after using feedback P_{STA} (see Fig. 8.b). .

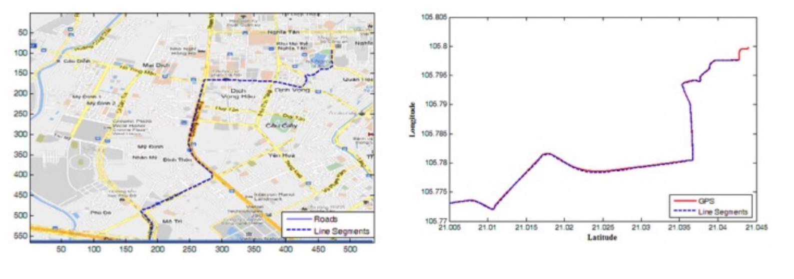
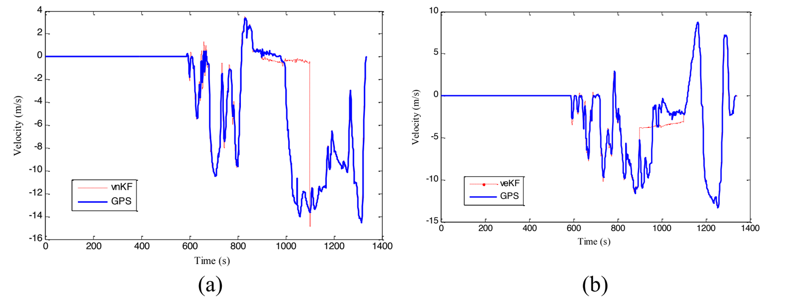


Fig. 5. The trajectories of roads and line segments (left) and the trajectories of GPS and line segments (right)



(a) (b)

Fig. 6. The velocity in the North (a) and the East (b) without feedback P_{STA}

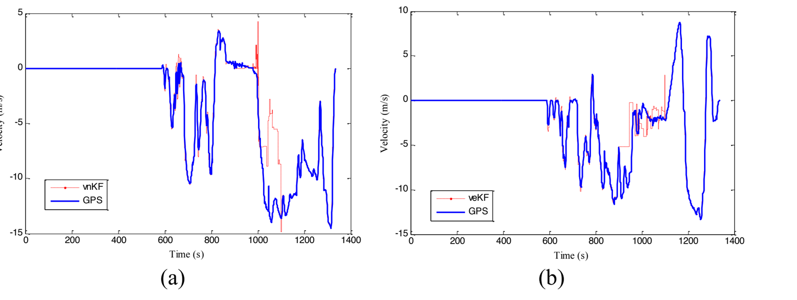
In order to quantify the performance of this system, we calculated the error as

$$e = \frac{1}{N}\sum_{i=1}^{N}\left|\hat{P}_i - P_i^{ref}\right| \qquad (6)$$

where and are estimated and reference values, and N is total number of samples. Consequently, we can calculate the position and velocity errors based on the data as shown in Fig. 7 and Fig. 8. The position error is 2.5 meters and the velocity error is 3.2 m/s. These errors are entirely acceptable.

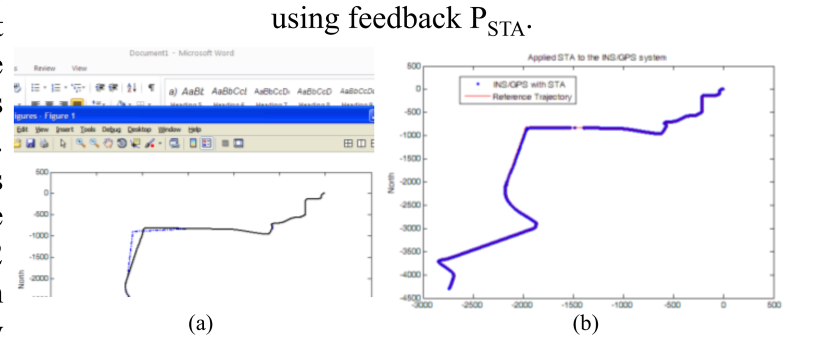
5. Conclusion

In this paper, we have proposed a Street Tracking Algorithm in a feedback configuration in order to accurately improve the both position and velocity of the land vehicle when the GPS signal is lost. This algorithm works based on INS position output, velocity increment from the IMU and a digital map. The performance of the proposed system has been verified with experimental data. The position error of the system is controlled around 2.5 meters and the velocity error is controlled around 3.2 m/s. This system can be applied in vehicle navigation, railway transportation navigation, etc.



(a) (b)

Fig. 7. The velocity in the North (a) and the East (b) using feedback P_{STA}.



(a) (b)

Fig. 8. The trajectory of the INS/GPS system before (a) and after (b) using STA.

References

[1]. Nguyen Van Thang, Chu Duc Trinh, Tran Duc Tan, *Application of Street Tracking Algorithm to Improve Performance of a Low-cost INS/GPS System*, Journal of Automation and Control Engineering, Vol.1, No. 3, pp. 1-5, May 2013.

[2]. T. D. Tan, L. M. Ha, N. T. Long, H. H. Tue, N. P. Thuy, *Feedforward Structure Of Kalman Filters For Low Cost Navigation*, International Symposium on Electrical-Electronics Engineering (ISEE2007), Ho Chi Minh City, Viet Nam, pp 1-6, 2007.

[3]. T. D. Tan, L. M. Ha, N. T. Long, N. D. Duc, N. P. Thuy, *Integration of Inertial Navigation System and Global Positioning System: Performance analysis and measurements*, International Conference on Intelligence and Advance Systems, Malaysia, 2007, pp.1047-1050.

[4]. Lauro Ojeda. and Johann Borenstein, *Personal Dead-reckoning System for GPS-denied Environments*, IEEE International Workshop on Safety, Security, and Rescue Robotics (SSRR2007) Rome, Italy, September 27-29, 2007.

[5]. S. Prentice and N. Roy, The belief roadmap: Efficient planning in linear POMDPs by factoring the covariance, in Proc. ISRR, 2007.

[6]. Ruijie He, Sam Prentice and Nicholas Roy, *Planning in Information space for a Quad rotor Helicopter in a GPS-denied Environment*, the IEEE International Conference on Robotics and Automation (ICRA 2008).

[7]. Christopher Hide, Terry Moore and Martin Smith, *Adaptive Kalman Filtering for Low-cost INS/GPS*, the Journal of Navigation (2003), 56, 143–152.

[8]. Sung W., H. Dong-H wan, K. Tae and J. Sang, *Design and Implementation of an Efficient Loosely-Coupled INS/GPS Integration Scheme*, Chungnam National University, Korea, 2002.

[9]. L. M. Ha, T. D. Tan, N. T. Long, N. D. Duc, N. P. Thuy, *Errors Determination Of The MEMS IMU*, Journal of Science VNUH, July, 2007, pp. 6-12.

[10]. Tran Duc Tan, Huynh Huu Tue, Nguyen Thang Long, Nguyen Phu Thuy, Nguyen Van Chuc, *Designing Kalman Filters for Integration of Inertial Navigation System and Global Positioning System*, in The 10th biennial Vietnam Conference on Radio & Electronics, REV-2006. Hanoi, November 6-7, 2006, pp. 266-230.