Journal of Global Positioning Systems (2005)
Vol. 4, No. 1-2: 201-206

Journal of Global Positioning Systems
2005
© CPGPS

Performance Analysis of GPS Integer Ambiguity Resolution Using External Aiding Information

Sebum Chun, Chulbum Kwon, Eunsung Lee, Young Jae Lee, Teasam Kang

Department of Aerospace Engineering, Konkuk University, Seoul, Korea
e-mail: koreagnss@koreagnss.com Tel: +82-2-458-0164 Fax: +82-2-444-6670

Gyu-In Jee

Department of Electronics Engineering, Konkuk University, Seoul, Korea
e-mail: gijee@konkuk.ac.kr Tel: +82-2-450-3070 Fax: +82-2-3437-5235

Received: 27 November 2004 / Accepted: 26 October 2005

Abstract. The integer ambiguity should be resolved at the beginning stage of GPS carrier phase positioning. In this procedure, some additional information can be used to improve the ambiguity resolution performance, for example, the positioning information of INS/GPS integrated system and baseline constraint of two adjacent antennas. This improvement is well known by experiment or simulation. But the quantitative characteristic of the improvement is not known yet. In this paper, we analyse this improvement quantitatively using the success rate.

Key words: GPS, RTK, Success rate, Baseline Constraint, INS/GPS

1 Introduction

GPS carrier phase is applicable for real time navigation, attitude determination and geodetic surveys which require sub-centimeter positioning accuracy. But it needs to resolve GPS carrier phase integer ambiguities. The most popular way to determine integer ambiguities is a searching method. Many searching type algorithms to resolve the integer ambiguities have been proposed. But, the way to estimate the initial real ambiguities is mainly based on GPS C/A code information. Therefore the reliability is very low because GPS code information has a positioning error of 10~15m.

Bad precision of initial position increases the calculation time because it enlarges the searching space and memory usage. The size of searching space is eight times larger when the variance of initial position is doubled (Hofmann-Wellenhof et al., 1997).

To overcome this problem, many external aiding methods to improve initial position precision have been proposed. Aiding information gives more precise position. So the method which uses external aiding has better performance in resolving GPS carrier phase integer ambiguities. But previous researches show the performance experimentally, not quantitatively.

In this paper, we analyse the performance improvement of integer ambiguity resolution with external aiding using the success-rate. This result can be used in the design stage of integrated systems as the basic information for reliability analysis.

2 Resolution of integer ambiguities with external aiding

We can classify the externally aided methods to resolve integer ambiguity into three groups (Lu, 1994).

2.1 Searching space fixing

It is impossible to resolve integer ambiguities using the general analytic methods. Therefore we need to use a searching method. In the searching sequence, the first step is to fix searching space. The size of the searching space depends on the confidence interval of float ambiguities. So the searching space can be reduced by some external aiding information that makes the confidence interval of float ambiguities small.

Computation time and memory consumption can also be reduced by a smaller searching space size.

2.2 Object function

External aiding information can be used in the object function. It has the same effect as increasing satellite visibility. Furthermore, it has better quality than original GPS measurements in some conditions. So we can get more advantages than the increasing satellite visibility.

2.3 Validation

As mentioned above, the external aiding information has better quality, so it can be used as a standard to confirm if the resolved integer ambiguity is true or not.

In this paper, we concentrate on the use of baseline constraint between adjacent antennas and positioning information of INS/GPS integrated system as external aiding information. And we analyze the changes of the success rate with these aiding information.

3 Success rate

The integer ambiguity of GPS carrier phase can be resolved in the discrete integer domain. Its distribution has a shape of probability mass function (p.m.f) and the p.m.f. of integer ambiguity can be described with equation (1).

$$P(\breve{a} = z),\ \mathrm{z} \in \mathrm{Z}^n \tag{1}$$

'a' is the true integer ambiguity vector. Equation (2) is the probability distribution of float ambiguity.

$$p_{\hat{a}}(x) = (2\pi)^{-\frac{n}{2}} \sqrt{\left|Q_{\hat{a}}^{-1}\right|} \exp\left(-\frac{1}{2}\|x-a\|_{Q_{\hat{a}}}^{2}\right) \tag{2}$$

'$Q_{\hat{a}}$' is covariance matrix of float ambiguity. Therefore equation (3) is the probability to fix true integer ambiguity and it is defined as the integer ambiguity success rate (Teunissen, 1998a)

$$P(\breve{a} = z) = \int_{s_z} p_{\hat{a}}(x)dx,\ \forall_z \in Z^n \tag{3}$$

Success rate can be defined by the probability that the float ambiguity vector is in the pull-in region. Pull-in region is the region which makes the float ambiguity which is inside it true integer ambiguity. Figure 1 shows the distribution of float ambiguity and figure 2 is the pull-in region.

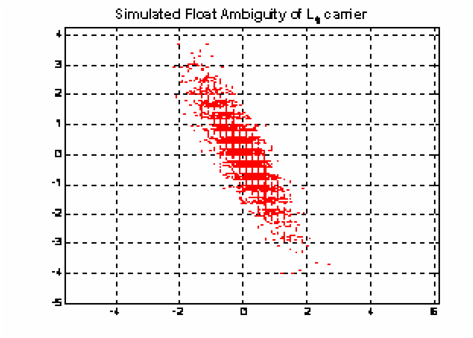


Fig. 1 Distribution of float ambiguity

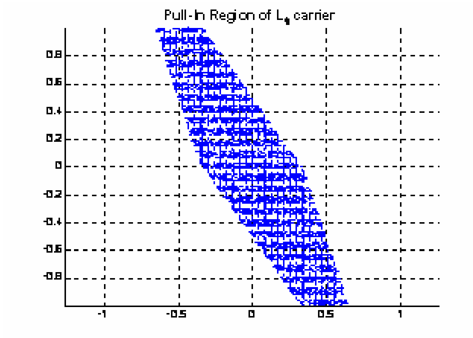


Fig. 2 Pull-in region

Success rate is the probability to fix the true integer ambiguity with a given float ambiguity. Estimation of the success rate doesn't need any real measurement, so it can be utilized as a designing tool for navigation system in the early stage of development procedure.

4 External aiding information

Improved navigation information can be provided by integrated navigation system which uses each sensor optimally. Followings are the method using baseline information and INS/GPS integrated system information. Each system has similarities that they decrease the variance of float ambiguity.

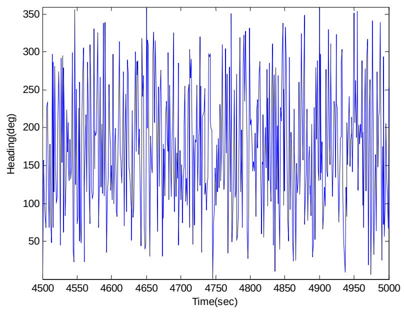
4.1 Baseline information between antennas

It is possible to measure the baseline length between two antennas in most cases to determine the attitude of a body. We apply baseline length constraints to improve initial position precision and it makes float ambiguity more precise

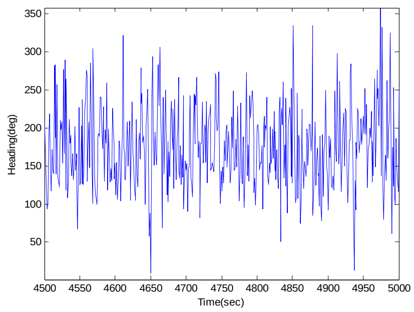
But the baseline observation model is nonlinear and the nonlinearity makes the final estimation results worse when general estimation methods, such as the least squares method or extended Kalman filter are applied. Particularly, it is remarkable when the baseline length is very short and the precision of initial position is poor. Equation (4) is nonlinear baseline observation model.

$$l = \sqrt{(x_A - x_B)^2 + (y_A - y_B)^2 + (z_A - z_B)^2} \quad (4)$$

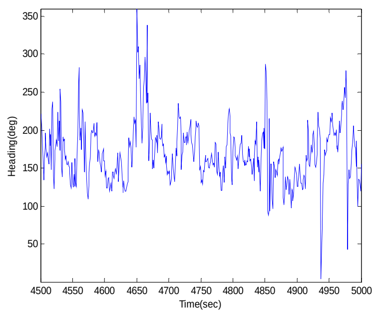
The unscented Kalman filter is proposed to reduce this linearization error. It utilizes unscented transform which is adapted for nonlinear transformation. The unscented transform uses several sigma points. Sigma points are generated from original state vector and its covariance matrix (Julier, 2004).



(a)



(b)



(c)

Fig. 3 Attitude determination result using C/A code and baseline constraint

(a:C/A code only, b:extended Kalman filter, c:unscented Kalman filter)

Figure 3 is the estimation result of initial attitude. Figure 3-(a) is the result of C/A code only, (b) is the result of the extended Kalman filter, which uses the linearized baseline observation model and (c) is the result of the unscented Kalman filter which uses a nonlinear model. We can find that the extended Kalman filter has a larger error than the unscented Kalman filter. Table 1 is the comparison of the estimation result with various estimation methods. The least squares case which uses the baseline constraint has the worse result than the C/A code only case (without the baseline constraint). It is the linearization error that makes the least squares method have larger errors when the baseline constraint is applied.

Tab. 1 Comparison of estimation result (unit: degree)

Least squares method (without BL)	Least squares method (with BL)	EKF (with BL)	UKF (with BL)
85.6758	91.1626	51.3863	41.5691

Figure 4 is the case that the initial position has a large error. This result shows that the extended Kalman filter has larger initial position sensitivity than the unscented Kalman filter. Therefore the extended Kalman filter takes a long time to converge. It looks like that the unscented Kalman filter is immune to the initial position error.

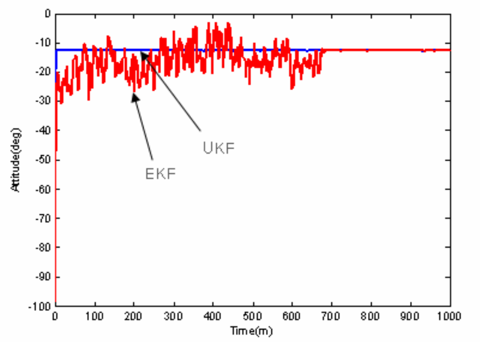


Fig. 4 Large initial position error

4.2 Positioning information of integrated INS/GPS system

An integrated INS/GPS system has higher availability than GPS carrier positioning information because we can assume that the navigation information of INS is given before GPS carrier phase information is given and we can utilize it in the estimation of float ambiguity. Figure 5 shows the trajectory of a vehicle and its variance of positioning result.

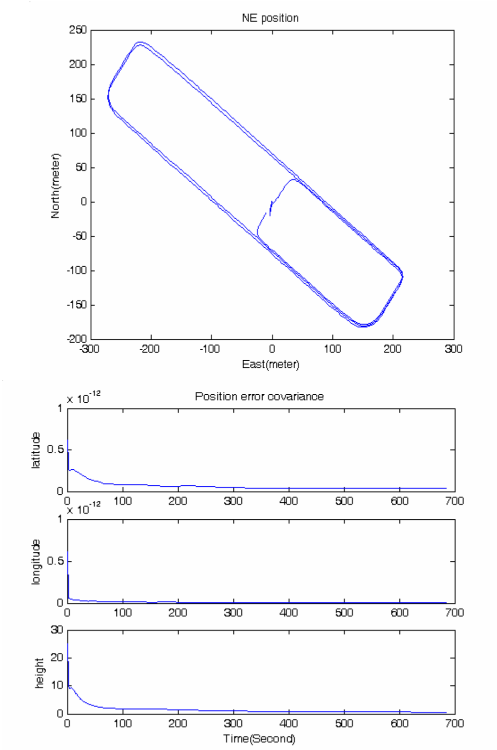


Fig. 5 Vehicle trajectory and the covariance of positioning result

5 Estimation of success rate

As mentioned above, the success rate cannot be estimated by analytic methods. Therefore we applied the Monte Carlo simulation method to estimate it (Teunissen, 1998b).

5.1 Success rate simulation

The covariance of float ambiguity must be estimated to analyse the success rate when the external aiding information is applied. The covariance of float ambiguity is determined by the covariance of initial position and carrier phase measurements. Equation (6) shows the relationship between the variance of float ambiguity and others.

$$Q_{\hat{a}} = Q_{\Phi} + \frac{1}{\lambda^2} H Q_{dx} H^T \tag{6}$$

Q_{Φ} is the covariance of carrier phase measurements and Q_{dx} is the covariance of initial position.

We can generate the adequate number of float ambiguity vector whose variance is derived by equation (6). And the success rate estimation can be performed by the Monte Carlo simulation with the generated float ambiguity vectors.

5.2 LAMBDA

We can estimate the success rate using the generated float ambiguity and Monte Carlo simulation. But large dimension of float ambiguity vector makes it impossible because of its huge computation time and memory consumption. LAMBDA (Least squares AMBiguity Decorrelation Algorithm) is the answer of this problem. LAMBDA uses decorrelation and sequential bootstrapping methods. These methods are effective in reduction of the computation time. Figure 6 depicts a full procedure of success rate estimation (Jong de P. J., 1996)

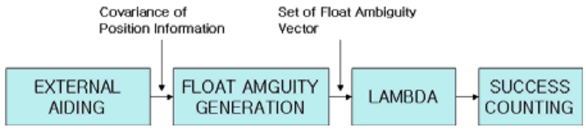


Fig. 6 The full procedure of success rate simulation

6 Result of success rate analysis

We applied Monte Carlo simulation method to estimate the success rate for the ambiguity resolution methods aided by the baseline constraint and INS/GPS integrated navigation system.

6.1 Baseline length constraint applied

The initial position information which is aided by the baseline constraint between adjacent antennas has smaller variance than the GPS C/A code only case. This information can make the precision of float ambiguity better. Figure 7 shows the change of observable satellites.

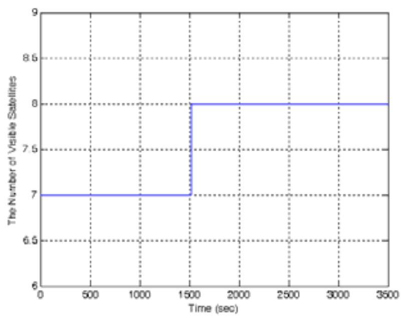
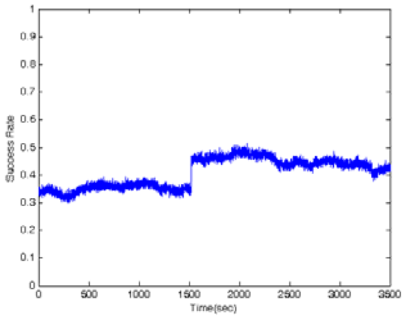
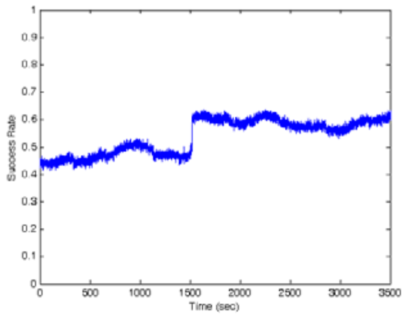


Fig. 7 Change of Observable Satellites

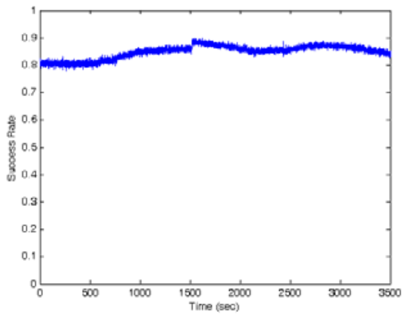
3500 float ambiguity vectors were generated and the success rate was estimated epoch by epoch. Figure 8-(a) is the estimation results of the success rate which uses C/A code information only. (b) is the result of the extended Kalman filter and (c) is the result of the unscented Kalman filter. From the figures, we can find the difference between these cases.



(a)



(b)



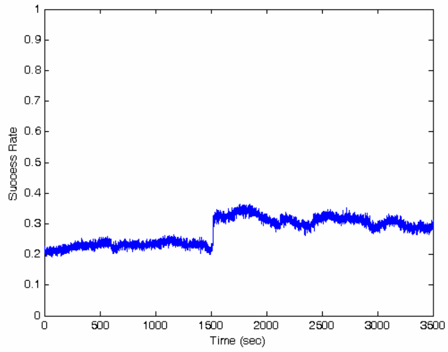
(c)

Fig. 8 Comparison of the Estimated Success Rates

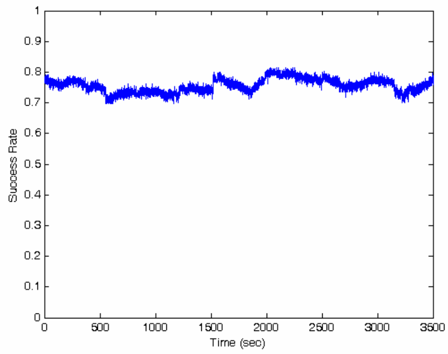
(a:C/A Code Only, b:EKF + Baseline Constraint, c:UKF+Baseline Constraint)

6.2 Positioning information of GPS/INS integrated system applied

It is possible to provide better positioning information when the INS/GPS integrated system gives the aiding information. Like a baseline constraint case, the INS/GPS integrated system can also increase the integer ambiguity success rate. To confirm it, the same simulation was repeated for the INS/GPS aided case.



(a)



(b)

Fig 9 Comparison of the Estimated Success Rates

(a:C/A Code Only, b:UKF+INS/GPS)

Figure 9-(a) is the result for the C/A code information only case, and (b) the result of INS/GPS integrated system. We can see that the success rate was significantly improved when we used INS/GPS position information.

7 Conclusion

The improvement of the success rate with the external aiding information has been analysed in this paper. We concentrate on the use of baseline constraint and positioning information of INS/GPS integrated navigation system as the aiding information.

We can see the improvement of success rate in both cases. Especially, an unscented Kalman filter has a higher ambiguity resolution success rate because the baseline observation model has large nonlinearities. It makes large error when we use a linearized model like an extended Kalman filter. INS/GPS aided case has a similar tendency with the baseline constraint case, but it is barely influenced by the change of observable satellites.

This result can be used as basic information for designing of integrated systems with various navigation sensors, because it does not need any real measurements, and only needs simulated measurements.

Acknowledgements

This paper was performed for the Aerospace Technology Research and Development Program funded by the Ministry of Commerce, Industry and Energy of Korea.

References

Hofmann-Wellenhof B.; Lichtenegger H.; Collins J. (1997): ***GPS Theory and Practice (4th Ed.).*** Springer, Wien New York.

Lu G. (1994): ***Development of a GPS Multi-Antenna System for Attitude Determination***, Dissertation, December 1994, Calgary, Alberta.

Teunissen P. J. G.; Kleusberg A. (1998a): ***GPS for Geodesy (2nd Ed.)***. Springer, Berlin Heidelberg.

Julier S. J. (2004): ***Unscented filtering and nonlinear estimation***, Proceeding of IEEE, Vol. 92, Issue 3, 401-422.

Teunissen P. J. G. (1998b): ***Success probability of integer GPS ambiguity rounding and bootstrapping***, Journal of Geodesy, Vol 72, 606-612.

Jong de P.J., C.C.J.M. Tiberius (1996): ***The LAMBDA method for integer ambiguity estimation: implementation aspects***, Delft Geodetic Computing Centre LGR Series No. 12.