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Integer phase ambiguity resolution method for absolute GLONASS observations

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Abstract. With the help of modern navigation satellite systems it is possible to determine the coordinates of points with millimeter accuracy due to the precision measurement of the carrier phase of the navigation radio signal. However, in the course of achieving this accuracy, a nontrivial problem of resolving the integer phase ambiguity arises. The most difficult part is to determine the integer number of wavelengths between the phase centers of the transmitting antenna of the navigation satellite and the receiving antenna. An exact solution to this problem using the integer least squares method, although it exists in theory, is not applicable in practice due to the prohibitively high computational complexity. In this regard, a number of authors have developed various suboptimal methods for resolving integer phase ambiguity, which allow solving a problem with varying degrees of uncertainty. In this case, the problem can be considered satisfactorily solved for relative coordinate determinations from GPS (global positioning system) and GLONASS (global navigation satellite system) observations, as well as for absolute coordinate determinations from GPS. As for the absolute determinations of coordinates from GLONASS observations, the situation is complicated by the fact that GLONASS, unlike GPS, uses frequency-division multiple access. In other words, if all GPS navigation spacecraft broadcast navigation radio signals on a single frequency, then GLONASS satellites broadcast on different frequencies. This paper generalizes one of the modern and effective methods for resolving integer ambiguity for GPS observations, MLAMBDA, to the GLONASS system. The ultimate goal of the work is an independent algorithm for absolute determination of coordinates with millimeter accuracy using the GLONASS system. In the course of the work, the MLAMBDA formalism was generalized to navigation systems with frequency division of access, and the first results of independent coordinate determinations from GLONASS observations in absolute mode were obtained.

Keywords: GNSS, GLONASS, phase ambiguity, PPP, MLAMBDA

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1 Introduction

An absolute method for precise processing of GNSS measurements was proposed in Zumberge et al. (1997) and was called Precise Point Positioning (PPP). Initially, this method did not take into account integer phase ambiguity. In the original PPP, integer phase ambiguity was considered as part of the overall, unmodeled pseudorange error (Teunissen P.J.G. 1995). Later, new versions of PPP began to appear that attempted to isolate the integer phase ambiguity error from the overall error budget. Currently, there are two main approaches to estimating integer phase ambiguity. Firstly, FCB (fractional cycle base) methods (Chang et al. 2005), where hardware signal delays are calibrated and subtracted from the total pseudo-range error, and the remaining part is considered as a phase error. Secondly, IRC (integer recovery clock) methods (Chang et al. 2005), which are based on correction of the on-board clock of a navigation spacecraft. It was shown in Chang et al. (2005) that both methods are equivalent in principle.

2 MLAMBDA-method

This work is devoted to the development and implementation of the MLAMBDA method. This method has shown a fairly high efficiency in determining integer ambiguity. The implementation of the MLAMBDA algorithm for the GNSS absolute positioning method is considered, and it is also shown that this method is not directly applicable to the GLONASS system. The work formulates an extension of the method that allows it to be applied not only to GPS, but also to GLONASS measurements. The GLONASS and GPS systems are very close to each other, but fundamentally differ in the principle of separating signals from different satellites. The GPS system uses code division of satellite signals, so that each GPS satellite uses a unique modulation code on a common carrier frequency, while the GLONASS system implements frequency division, so that each GLONASS satellite in view uses a single modulation code on a frequency unique to each satellite. Each of the access division principles has its advantages and disadvantages, but in the case of frequency division of signals, integer phase ambiguity resolution is complicated by the presence of several carrier signals of different frequencies instead of one in the case of GPS. The authors of the article modify the MLAMBDA method so that it can also be applied to GLONASS measurements. The MLAMBDA method is a development of the LAMBDA (Least-squares AMBiguity Decorrelation Adjustment) method proposed in Teunissen P.J.G. (1995). According to Zumberge et al. (1997), the GNSS observation model can be written as

$$E(x) = Aa + Bb, D(x) = Qx, \tag{1}$$

where x is a vector of GNSS data of order m, a and b are vectors of parameters of order n and p, respectively, A and B are matrices of the observation model that relate the data vector to the model parameters. The known covariance matrix of x is Qx. The vector x is assumed to represent the differences between observations and simulated values. These may be observations with double phase differences or codes, or both. A solution is sought in such a way as to minimize the sum of squared differences between the simulated and observed data. The basic idea is to first apply an orthogonal triangular decomposition to equation (1). The first part consists of full floating-point parameters, the second part - of difference floating-point parameters and, finally, the third part - of integer parameters, that is, of phase ambiguities. The solution is then carried out in three steps. First, a floating-point solution to problem (1) is sought, assuming that all integer parameters are equal to zero. Second, the problem is solved for integer parameters using the floating point solution as an approximation to the final one. Third, the calculated parameters, both floating point and integer, are substituted into (1), and how close the quadratic norm of the solution is to the minimum is estimated through a search process.

3 Implementation of the algorithm

The LAMBDA method solves the problem using integer least squares (ILS) to obtain estimates of integer double-difference ambiguities. The LAMBDA method consists of two stages – decorrelation with reduction and search. First stage is meant to prepare problem for solving it. On the second stage, the task is to find the optimal estimate or several optimal estimates of the parameter vector in the hyperellipsoidal domain. For real-time kinematic GNSS and other high-dimensional applications, computational speed is critical. In this paper, we are working with modified LAMBDA method (MLAMBDA), which can significantly reduce the computational complexity of the LAMBDA method for high-dimensional ILS problems. Numerical results show that MLAMBDA reductions are also more computationally efficient than traditional ones. For verification purposes, in addition to the optimal estimate, a second optimal estimate, which produces the second smallest value of the objective function, is often also required. As part of this work, two stages of the LAMBDA method were implemented: reduction and search. At the current time, the authors have managed to achieve the functionality of the method for combined GPS+GLONASS measurements using third-party data on inter-frequency phase shifts. The results of the algorithm are shown below in Fig. 1. As a continuation of the work, it is planned to adapt the algorithm to the “GLONASS only” mode, as well as to estimate inter-frequency phase shifts directly from measurements.

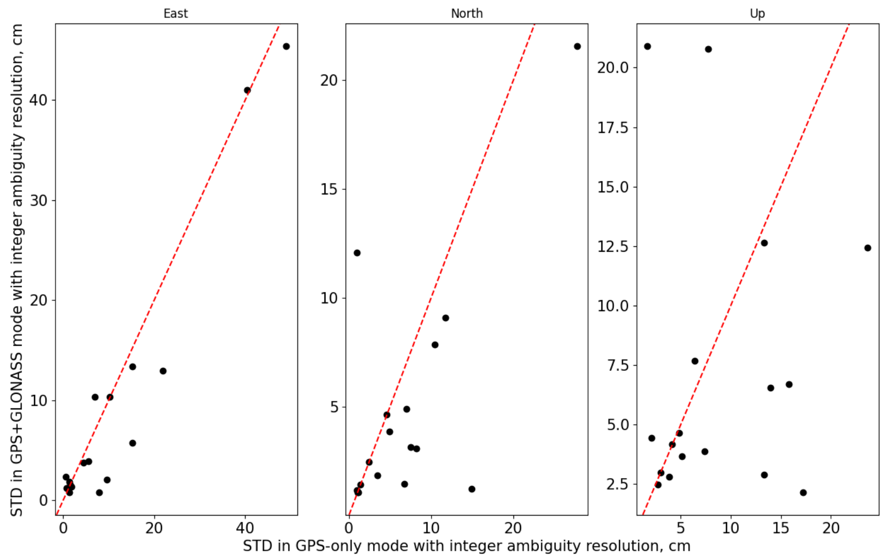

Fig. 1. Figures demonstrate RMS of 17 navigational solutions of day observations in two different modes: GPS-only and GPS+GLONASS.

4 Summary

Based on MLAMBDA, an algorithm for estimating integer phase ambiguity, applicable to satellite navigation systems with frequency division of signals, in particular to the GLONASS system, is obtained. Currently, the performance of the method has been tested in GPS+GLONASS mode, as well as using third-party data on inter-frequency phase delays. Satisfactory results of the algorithm's operation in this mode were obtained. The algorithm correctly estimates integer phase shifts both in the case of GPS and in the case of GLONASS. As a development of this work, it is planned to develop the functionality of the algorithm in the “GLONASS only” mode, and also to implement the assessment of inter-frequency phase shifts directly from observations, without resorting to third-party data sources.

References

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