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A data driven partial ambiguity resolution: Two step success rate criterion, and its simulation demonstration

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Abstract

Ambiguity Resolution (AR) is a key technique in GNSS precise positioning. In case of weak models (i.e., low precision of data), however, the success rate of AR may be low, which may consequently introduce large errors to the baseline solution in cases of wrong fixing. Partial Ambiguity Resolution (PAR) is therefore proposed such that the baseline precision can be improved by fixing only a subset of ambiguities with high success rate.

This contribution proposes a new PAR strategy, allowing to select the subset such that the expected precision gain is maximized among a set of pre-selected subsets, while at the same time the failure rate is controlled. These pre-selected subsets are supposed to obtain the highest success rate among those with the same subset size. The strategy is called Two-step Success Rate Criterion (TSRC) as it will first try to fix a relatively large subset with the fixed failure rate ratio test (FFRT) to decide on acceptance or rejection. In case of rejection, a smaller subset will be fixed and validated by the ratio test so as to fulfill the overall failure rate criterion. It is shown how the method can be practically used, without introducing a large additional computation effort. And more importantly, how it can improve (or at least not deteriorate) the availability in terms of baseline precision comparing to classical Success Rate Criterion (SRC) PAR strategy, based on a simulation validation. In the simulation validation, significant improvements are obtained for single-GNSS on short baselines with dual-frequency observations. For dual-constellation GNSS, the improvement for single-frequency observations on short baselines is very significant, on average 68%. For the medium- to long baselines, with dual-constellation GNSS the average improvement is around 20–30%.

Keywords: Multi-GNSS; GPS; Partial ambiguity resolution; Success rate; Availability

1. Introduction

Ambiguity Resolution (AR) plays an important role in GNSS precise positioning. Correctly fixing the ambiguities significantly enhances the baseline precision. When the precision of the float ambiguity solution is poor, however, the success rate of fixing the full set of ambiguities will be low. Consequently the fixed ambiguities might be incorrect, which usually brings large errors to the fixed baseline solution.

Facing this challenge, we consider to resolve a subset of the ambiguities with high success rate, in order to still contribute to the baseline precision. Suppose there are n ambiguities in total, theoretically there will be 2^n possible subsets, including the full set and null set, as each ambiguity can be included or excluded from the subset.

How to choose a proper subset is the main concern in PAR. Several PAR strategies have been proposed in the

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literature, with different criteria applied. In this study we aim at maximizing the expected precision gain of the baseline solution, which will translate in a higher probability that the baseline errors are smaller. In other words, the availability will be increased, where availability is defined as the probability that the positioning accuracy can meet a given requirement. Assuming that the performance requirement is set by a maximum allowable positioning error ϵ, this can be expressed as:

$$Avail_{\epsilon} = P(||\mathbf{b}_e - \mathbf{b}|| < \epsilon) \tag{1}$$

with $\mathbf{b}_e$ and $\mathbf{b}$ the estimated and true baseline vector, and $||\mathbf{b}_e - \mathbf{b}|| = \sqrt{(\mathbf{b}_e - \mathbf{b})^T(\mathbf{b}_e - \mathbf{b})}$.

Teunissen et al. (1999) proposed a strategy that selects the subsets fulfilling a Success Rate Criterion (SRC), which will be called SRC in this study. SRC first decorrelates the float ambiguities to the largest extent with integer matrix Z, then it extends the subset from the most precise float ambiguity to include the largest number of decorrelated ambiguities such that the success rate threshold is still exceeded. Through setting the threshold of the success rate, the failure rate can be controlled at a low user-defined level. However, it may often select a small subset, and fixing this subset eventually contributes marginally to the baseline precision.

Li et al. (2010), Feng and Li (2008), Feng (2008), Dai et al. (2007, 2011), Li et al. (2015) and many other researchers proposed Wide-Lane/Narrow-Lane (WL/NL) cascading strategies. A WL/NL strategy first forms WL combinations and resolves them by Integer Rounding (IR), and then updates the NL float ambiguities and resolves them. In the PAR strategies, only a subset of the WL and if possible NL ambiguities is fixed. These strategies reduce the computing time when there are too many ambiguities.

Li et al. (2013) proposed to combine WL/NL and SRC, which first resolves the WL ambiguities, updates the L1 ambiguities, and then resolves a subset of L1 ambiguities selected by SRC. This strategy shortens the computing time and controls the failure rate at a low level.

Mowlam (2004), Takasu and Yasuda (2010) proposed a strategy that selects a subset based on satellite elevation angles. This strategy either raises up the cutoff angle or excludes the lowest satellites one by one, until the success rate is above a threshold. For the same reason as with SRC, this strategy may also select only small subsets. Moreover, applying elevation-dependent weighting can already account for the lower precision of the float ambiguities from low-elevation satellites.

Brack and Günther (2014), Brack (2015) proposed a strategy called General Integer Aperture (GIA) estimation, which provides an alternative way to control the failure rate. GIA first resolves the full set, and then validates the integer ambiguities, and excludes those ambiguities rejected by the validation. It focuses on providing a reliable subset of integer ambiguities.

Model Driven PAR strategies such as SRC, elevation ordering, and WL/NL employ only the a priori model to choose the subset. Even though the fix rate will be high and the failure rate will be low, the subset size is often small, and contributes not much to the baseline precision.

In this study, we propose a Data Driven strategy that tries to fix larger subsets with a low failure rate. Instead of selecting a small subset with a high success rate by SRC, we try to fix a larger subset, and validate the solution with the Fixed Failure-rate Ratio Test (FFRT). FFRT provides the critical value of the ratio test and guarantees a controlled failure rate. If the larger subset can be fixed, this will result in better baseline precision.

As we will see, for weaker models, there is a trade-off between the subset size and the fix rate with controlled failure rate: if larger subsets are extended from smaller subsets, the larger the subset, the smaller the fix rate and vice versa. In order to achieve a high availability of a precise baseline solution, we need to find an optimal balance between the fix rate and the subset size. Therefore, the aim is to find a relatively large subset, which maximizes the precision gain expectation driven by the fix rate and subset size. After the relatively large subset being fixed, we apply FFRT with a sufficiently low failure rate. If this subset is not accepted by FFRT, we choose to fix the subset given by SRC and validate it by the ratio test. If a subset is fixed in this two-step strategy, called Two-step SRC (TSRC), it should be larger or at least equal to the subset given by SRC, and therefore achieve higher availability than SRC.

The remaining of this document is structured as follows. Section 2 reviews integer ambiguity resolution. Section 3 describes the SRC algorithm. Section 4 introduces the TSRC algorithm with a demonstration example and implementation of the algorithm. Section 5 shows and compares performance of the new strategy with full AR and SRC under short, medium and long baseline scenarios. Section 6 discusses several interesting topics. Section 7 summarizes the main contributions of this study.

2. Integer ambiguity resolution and validation

A GNSS observation model can be cast in the following linearized equation

$$\mathbf{y} = A\mathbf{a} + B\mathbf{b} + \mathbf{e}, \tag{2}$$

where $\mathbf{y} \in \mathbb{R}^m$ is the vector of code and carrier observations; $\mathbf{a} \in \mathbb{Z}^n$ is the vector of unknown ambiguities; $\mathbf{b} \in \mathbb{R}^p$ is the vector of baseline components, and may possibly contain residual atmospheric delays as well; $\mathbf{e} \in \mathbb{R}^m$ is the vector of measurement noise, which is assumed to have a zero-mean Gaussian normal distribution; A and B are the design matrices for the ambiguities and baseline components respectively.

Here we clarify that throughout this paper, the bold letters represent vectors and the normal letters represent scalars.

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