

Strategy of Reliable Ambiguity Resolution for Static and Kinematic Applications

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BIOGRAPHY

Holger Kotthoff graduated in geodesy at the Technical University of Bonn, Germany, in 1998. He worked with Dr. James Campbell at the Geodetic Institute of the University of Bonn from 1998 to 2000 on determination of site motions by GPS in the lower rhenish embayment and in the context of Indian tectonic plate kinematics. In July of 2000, he joined Leica Geosystems in Switzerland as part of the data processing group, further developing the real-time and post-processing kernel used in various products.

Christian Hilker completed his studies of Surveying at the University of Applied Sciences in Bochum, Germany, in 1999. Following that he continued working on a concept to optimize GPS session planning using digital image processing on pictures picked up by a 180° fisheye lens. Since May 2000 he has worked for Leica Geosystems as a software engineer in the data processing group also working on real-time and post-processing algorithms.

Christian Ziegler studied Surveying at the Technical University in Karlsruhe, Germany, and graduated in 1990. Following this, he joined the Institute of Geodesy at the Technical University of Darmstadt as a research assistant where he finished his doctorate concerning the development and verification of a local positioning system in 1995. Since then he has been a member of the GPS data processing group within Leica and co-developed the real-time processing kernel of Leica's System 500 sensors.

ABSTRACT

Nowadays the quality of a GPS processing software goes hand-in-hand with reliable ambiguity resolution. By their nature, the processing strategies to fulfill these requirements differ between RTK and post-processing: Whereas real-time applications aim for a fast solution using a limited range of data epochs, post-processing strategies can make use of the whole data period observed.

Euler et al. [1] described the strategy of a repeated search process, increasing the reliability of position results based on fixed integer ambiguities in real-time systems. By carrying out interval-wise ambiguity searches in the background, the integer ambiguity set currently used can be reliably confirmed meaning that discrepancies, which can lead to an alarm state, can be detected. This ensures high reliability especially under difficult environmental conditions, and in addition, also reduces the time for the initialization process compared to single search algorithms.

Meanwhile post-processing software benefits from the fact that the more data epochs used in the search process, the more reliable the ambiguity resolution that can be achieved. As a type of extended single search algorithm, this will normally lead to a high rate of fixed ambiguities as verified by special testing criteria (e.g. ratio test) - however there is no true indicator for how reliable the results really are.

This paper describes how the advantages of a repeated search process can be utilized in post-processing to obtain more reliable position solutions based on fixed integer ambiguities. It also introduces a new processing scheme, enabling fixed solutions on increased baseline lengths without losing the factor of ambiguity resolution reliability, and discusses the problems encountered during testing. Implemented in the new software package SKI-Pro V3.0 the results under different environmental conditions are finally compared to those yielded by a conventional post-processing kernel. These tests demonstrate that the new strategy increases the number of total fixed solutions whilst significantly decreasing the number of wrong fixes.

INTRODUCTION

GPS post-processing softwares today claim to produce very accurate results, high reliability ambiguity

resolutions and be for everyone simple to use, especially for inexperienced people.

Over the last few years, the average observation period for a static occupation has decreased from several hours to the order of minutes, whereas at the same time the typical baseline length has increased. Of course the user demands have remained the same.

The most effective and economic way of surveying can be achieved using real-time systems. After an ambiguity initialization, the surveyor is able to position with high accuracy until the ambiguity solution is lost and he has to re-initialize again.

The statement above shows that it is very important to have a reliable ambiguity solution as a basis for accurate positioning results.

To fulfill these needs, the real-time processing kernel of Leica's System 500 makes extensive use of repeated search processing [1]. Up to now, the post-processing and real-time kernels within Leica surveying products have been different. Now, with the recent release of SKI-Pro V3.0, the power of the real-time kernel is combined with the advantages of the post-processing environment, showing increased performance on all different baseline types and lengths.

REPEATED SEARCH PROCESSING

Whereas long initialization times for fixing ambiguities in real-time systems are considered as unproductive, solutions fixed prematurely often run the risk of dealing with the wrong ambiguity set. The decision regarding the optimal time to fix the integer ambiguities is always a trade-off between speed, performance and reliability of the whole system.

In Leica's real-time System 500, the integer ambiguities are continuously recomputed at certain intervals as part of a background process. So long as the solutions are identical, the system outputs its coordinates with highest precision. The presence of different integer ambiguity results will lead to an alarm state and, once the previous solution has been proven as incorrect - the system will continue with the newly found ambiguity set as will monitoring courtesy of the background repeated search process.

In post-processing one can as well make use of the repeated search process and - because there is no need of calculating positions and ambiguities in parallel - the ambiguity estimation can be done in a pre-run, keeping the search results for every satellite (figure 1).

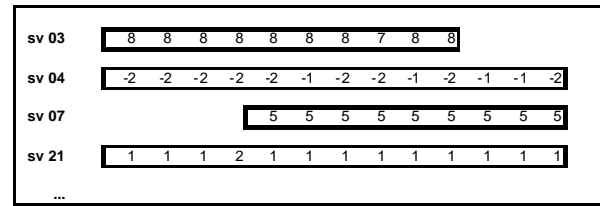


Figure 1: Ambiguity values for a set of satellites

To verify the integer ambiguity values, one can introduce a limiting percentage above which an ambiguity will be not accepted. In figure 2 we see the situation after the validation process for all satellites, using a criteria of 80% repeating values.

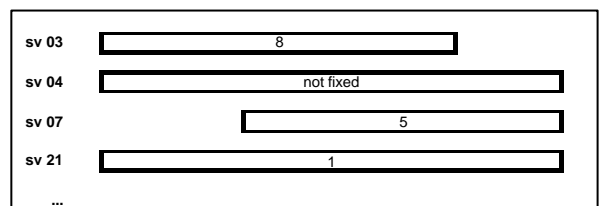


Figure 2: ambiguity values after validation process with 80% criteria

As a result, satellite 4 is excluded from the position calculation (using fixed ambiguities) which follows the ambiguity search process, and that subsequently reduces the risk of introducing a wrong ambiguity integer.

Figure 3 shows the whole processing implemented in the new kernel.

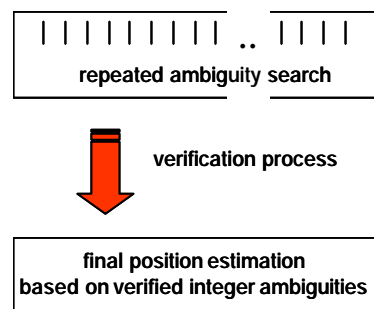


Figure 3: Repeated search processing flow for kinematic and short-period static data

In addition to the validation process of each satellite ambiguity, the repeated search principle provides the possibility to count the number of independent fixes, which is increased whenever the ambiguity sets of two consecutive searches are identical. This information together with the time period used for the position calculation based on fixed ambiguities, as done in SKI-

Pro V3.0, can help the user to judge the quality of the solution.

Because the processing kernel was optimized for real-time applications, the benefits of the repeated search processing are mainly experienced on short and medium static and kinematic baseline lengths. For longer static baselines, the performance improvement is less noticeable due to the fact that observation period is too short and with it the number of observations used for one search.

‘INIT ON FLOAT MARKER’

To extend the baseline length and reduce the number of possible ambiguity sets, a simple strategy can be applied.

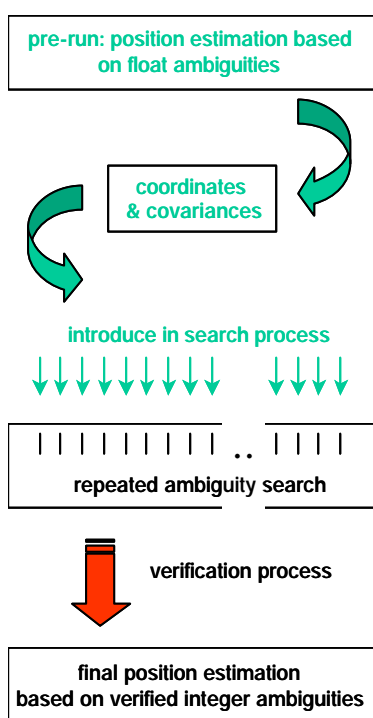


Figure 4: Init on float marker process on static baselines as implemented in SKI-Pro V3.0

Therefore we make use of the advantage of init on known marker strategies where when initializing one usually knows the site coordinates to an uncertainty of less than a few centimeters. The processing algorithms now introduce the coordinates as additional pseudo-observations possessing a high weight that will in turn lead to a significant decrease of possible ambiguity sets in the ambiguity search space, allowing fast and reliable solutions.

Because in most cases we don't have apriori coordinates with such accuracy, we first estimate coordinates using a

phase float, introducing nearly all observations from the whole period, and then apply them as reference coordinates for an initialization on known marker solution.

This can lead to a few problems which one has to overcome them: the observation period for calculating a float solution, which is accurate enough for an initialization process, needs to be longer than a few minutes.

When we use too many observation epochs the variances of the estimated coordinates are too optimistic and the correct ambiguity set might lie outside of the search space. If only a part of the observation period is used, we lose the advantage of the geometrical change of the satellite constellation as well as minimizing the influence of multipath effects and the coordinates might not be good enough. Also we have to treat single and dual frequency data in a different manner.

The solution of the above problems is a trade-off between sampling rate, observation period and a more realistic estimation of the variances, which can be found by experience.

Every time a new search process is started, a so-called 'initialization on float marker' is carried out, introducing the estimated coordinates and variances of the pre-run. The results of the ambiguity resolutions are also monitored and handled in the same manner as when not using this initialization mode. Figure 4 gives a good overview on the sequence of the different calculation steps.

In the next section, some test results will be shown to illustrate the new kernel's increased performance under different environmental conditions.

TEST RESULTS

Test field Germany, Sachsen-Anhalt

To show the advantages of the repeated search processing, we consider a rover within a network of four reference stations. Baseline lengths of 3, 22, 38 and 50 kilometers were observed over 10 hours under medium ionospheric conditions in October 1996. The rover observation period was split into five-minute pieces affording a total of 480 baselines.

Figures 5a and 5b show the horizontal positioning results of fixed solutions as a difference to the mean plan position. Note that the scaling for the two graphs is different to better identify the single positioning results.

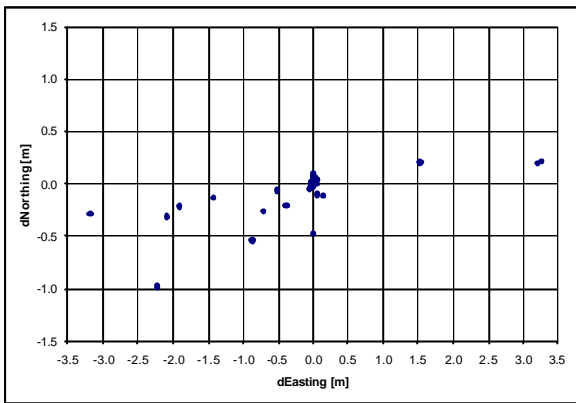


Figure 5a: Positioning pattern of a conventional post-processing kernel

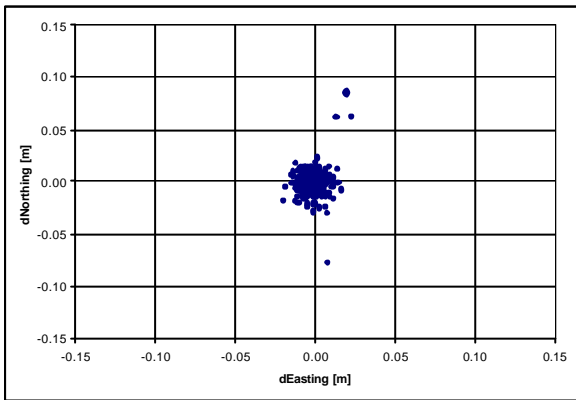


Figure 5b: Positioning pattern using repeated search processing with new kernel in SKI-Pro V3.0

For a more meaningful interpretation of the results, we have to distinguish between the different baseline lengths. Table 1 lists the number of solutions per baseline together with the number of correct and wrong fixes. A limit of 7.5 cm in horizontal as well as in vertical component was applied as averaging criteria.

Table 1: Summary of fixes for different baseline lengths using different processing kernels

Baseline length[km]	conventional		SKI-Pro V3.0	
	#wrong	#ok	#wrong	#ok
3	0	120	0	118
22	1	118	0	120
38	5	112	2	111
50	16	100	3	105
S	22	450	5	454

While the conventional kernel yields a comparable amount of correctly solved solutions, the number of wrong fixes is significantly reduced with the introduction

of the repeated search processing strategy implemented in the recently released SKI-Pro V3.0.

As one can see from the two graphs above, the new kernel eliminates all gross wrong fixes and provides much more reliable results. The benefits of the repeated search algorithms are especially obvious on medium length baselines where the old kernel delivered more weak solutions.

Test field Germany, SAPOS reference station network

As an example for the behavior on long baselines we compare the position results in a reference station network including baseline lengths between 48 and 147 kilometers, measured in March 2000 under quite high ionospheric conditions. All stations delivered 24 hours of data. We split the rover observation period in 23 1-hour pieces, which leads us to a total of 207 baselines.

The effect of introducing the new init on float marker strategy in combination with the repeated search process can be step-wise reconstructed.

Fig. 6a – 6c show the horizontal positioning results of an ionospheric free fixed solution as a difference to the average position. All three diagrams have identical scaling.

To figure out wrong fixes we used an averaging limit of 9 centimeters for each horizontal and vertical offset.

The post-processing kernel using the conventional search strategy fixes 182 baselines, 53 of them are fixed wrong. Using the new kernel without the init on float marker strategy leads us to 138 fixed baselines and also to 53 wrong solutions. In difference to the conventional kernel we now have the possibility to identify a possible wrong fix with the help of the ambiguity statistics. This is even more important when you don't have the possibility of averaging independent sessions. In table 2 we see a sample of key numbers for a correct and a weak fix related to the results shown in figure 6b.

Table 2: Key numbers of ambiguity statistics

	Correct	Wrong
# independent fixes	118	1
Duration fixed position	59'45	17'45
Duration not fixed position	0'00	42'00

Whereas the wrong solution is based on a single independent fix during one hour, the correct solution is verified by 118 independent fixes. In addition to this value the duration for the fixed position solution becomes more important the longer the baselines are. Whereas

during ambiguity search L1&L2 single difference equations are used and ionospheric influences cannot be fully eliminated by applying models, the position computation is based on the ionosphere free linear combination and therefore might reject different observations in the filter process.

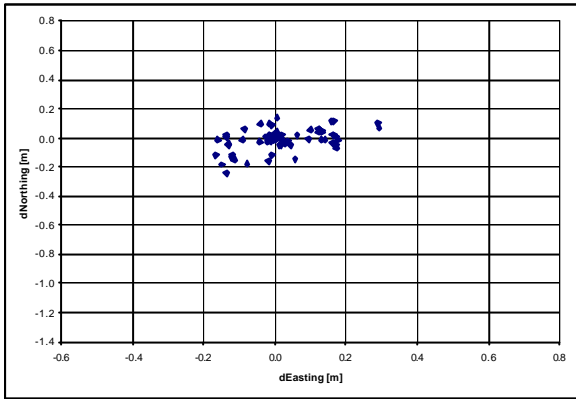


Figure 6a: Positioning pattern of conventional post-processing kernel

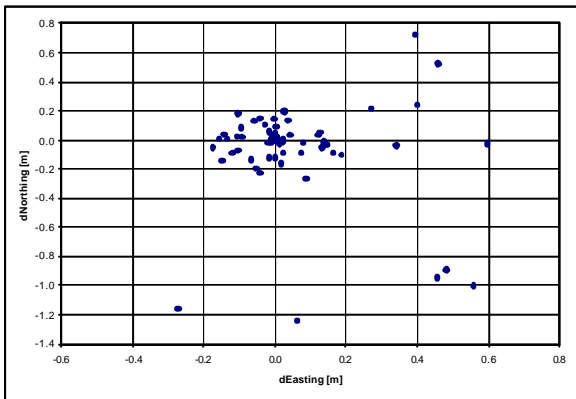


Figure 6b: Positioning pattern of new kernel without t init on float marker strategy

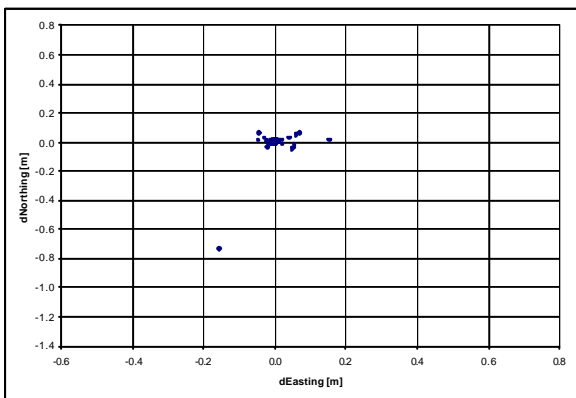


Figure 6c: Positioning pattern of new kernel using init on float marker strategy

Including the new init on float marker strategy we see a significant performance boost (cf. figure 6c): 197 of the 207 baselines have been fixed, only 9 of them are wrong fixes.

The high quality of the solutions is due to the accurate float coordinates of the pre-run. The benefits of an ionospheric free linear combination for this observation duration and baseline length, being already very closed to the fixed solution, show up in stabilizing the ambiguity initialization process. This is also represented by the fact that between init on float marker and conventional repeated search the average amount of independent fixes increased by a factor of three and the middling duration for a fixed solution enlarged by nearly ten percent.

Test field Germany, Niedersachsen

As a further example for the improvements that go hand-in-hand with the combination of repeated search and init on float marker strategy, two very long baseline length of 177 and 190 km had to be solved, which were observed under good environmental conditions in December 2002 in Niedersachsen, Germany, using different non-Leica antenna / receiver type combinations. One has to mention here that fixing ambiguities on baseline length of this size has never been the goal of previous developments so far; nevertheless it shows the big potential of the new strategies.

After splitting the rover observation period in seven two-hour pieces, we had a total of 14 baselines as base for comparisons.

Figures 7a – 7c illustrate what one could already see before: the new processing strategy not only prevents from gross wrong fixes, it also increases the number of total fixed positioning results.

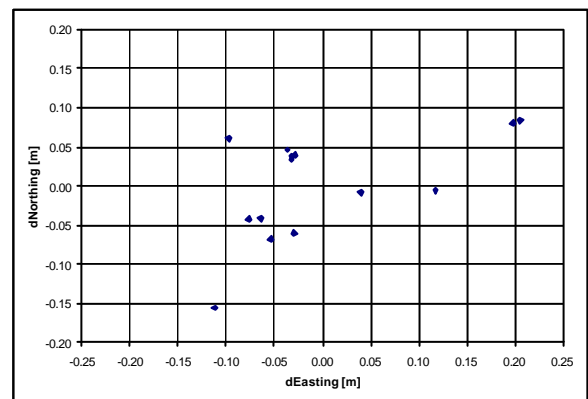


Figure 7a: Positioning pattern of conventional post-processing kernel

The main gain is introduced with the init on float marker concept, leading to 14 correct fixed positioning solutions. Without it the number of correct solved solutions decreases rapidly.

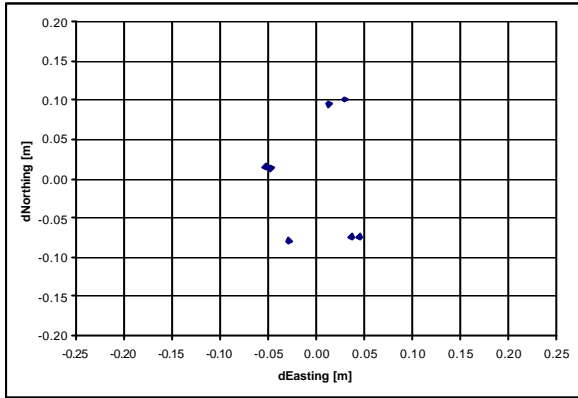


Figure 7b: Positioning pattern of SKI-Pro V3.0 without using init on float marker strategy

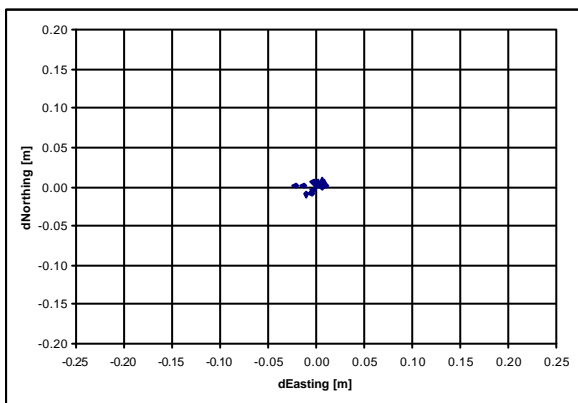


Figure 7c: Positioning pattern of SKI-Pro V3.0 using init on float marker strategy

different test results, all leading to the same conclusion: while significantly decreasing the number of wrong fixes the total number of correct fixes is increased.

The recently released post-processing software SKI-Pro V3.0 makes use of the new strategies. With it the baseline length for fixed positioning results can be extended to 150 km and beyond without losing the aspects of reliability.

REFERENCES

- [1] H.-J. Euler, C. Ziegler. „Advances in Ambiguity Resolution for Surveying Type Applications“ in proceedings of ION GPS 2000, Salt Lake City, Utah, September 19-22, 2000

CONCLUSION

The principles of the repeated search processing and the adaptation to the post-processing environment have been discussed. The test results on short and medium length baselines show an increase in the number of correct fixed positioning results. Especially on medium baseline length the number of wrong fixes decreases in comparison to a kernel using a conventional search process. Additionally ambiguity statistics can help to distinguish between right and wrong ambiguity solutions if needed.

A new strategy named ‘init on float marker’ was outlined in its simplicity. The advantages on static baselines of more than 50 km have been shown with the aid of