PS05-03

An Efficient Solution of Real-Time GNSS Data Processing and its application in satellite clock estimation

Shengfeng Gu[1], Xiaopeng Gong[1], Fu Zheng[1], Yidong Lou[1], Chuang Shi[1], Maorong Ge[2], Harald Schuh [2]

[1]GNSS Research Center of Wuhan University, China [2]Deutsches GeoForschungsZentrum, Germany

Abstract

The computational efficiency becomes a critical issue due to the increasing number of satellites and stations and it could hinder the further development of GNSS applications. In this contribution, we overcome this problem from the aspects of both dense linear algebra algorithms and GNSS data processing. First, in order to fully explore the power of modern microprocessors, the Square Root Information Filter (SRIF) solution based on the blocked QR factorization employing as many matrix-matrix operations as possible is introduced. In addition, by exploiting design matrix of pseudo-range, as well as performing the real-time ambiguity resolution, the algorithm complexity of GNSS data processing is further reduced. Then, the processing efficiency is validated in multi-GNSS (GPS / BDS / Galileo) satellite clock estimation with over 80 globally distributed stations. As for the unblocked method, it suggests that it will cost about 31.38 s per epoch. While, based on our new algorithm, it only takes 0.50 s and 0.31 s for multi-GNSS clock estimation per epoch for float and fixed clock solution, respectively, without any loss of accuracy.

Objectives

- Find an efficient GNSS LSQ solution for general-purpose applications with limited computing resources
- Analysis the performance of the new algorithm in Multi-GNSS real-time clock estimation

Basic Model

SRIF with QR factorization

LSQ problem can be solved by either Kalman filteTher or SRIF with identical result theoretically. However, the SRIF based on QR factorization is suggested in GNSS data processing as numerically more stable. The traditional unblocked algorithm is rich in vector-vector, matrix-vector multiplication. While, for effective use of the power of most modern computer, the granularity of these operations is too small compared with the blocked operations.

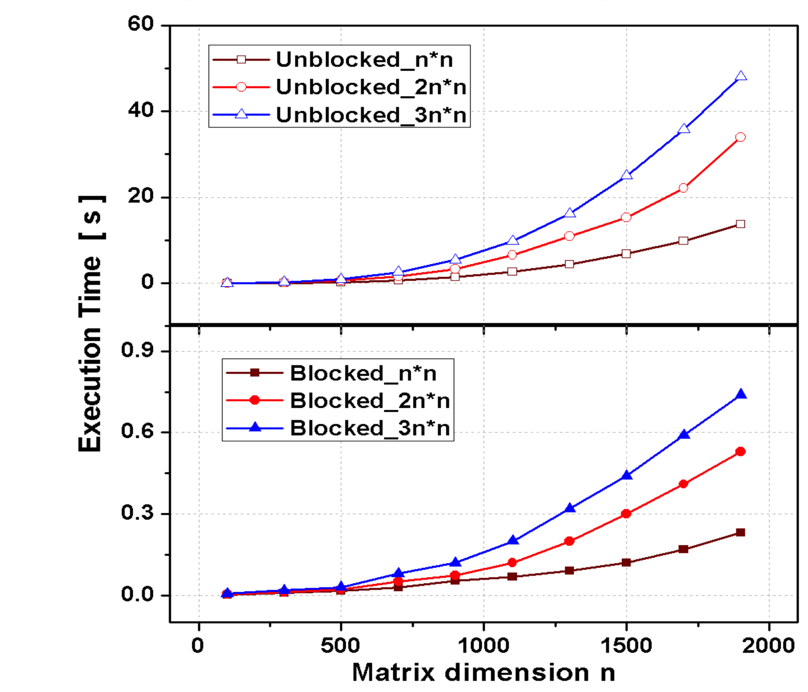

Fig. 1 Execution time for QR factorization with simulated matrices; upper panel is unblocked QR factorization and bottom panel is blocked one

Based on the simulated matrix with a dimension of $n*n$, $2n*n$ and $3n*n$, we give a comparison between unblocked and blocked QR factorization. Fig. 1 presents the time used for QR factorization of unblocked and blocked methods. It is clear that time consumed for QR factorization is almost in exponential growth with the increase of matrix dimension. Meanwhile, blocked QR factorization method can greatly improve the processing efficiency. For example, the QR factorization of a matrix with a dimension of 5700-by-1900 will cost about 50 s for the unblocked method while it only needs about 0.8 s for the blocked method.

Optimization for GNSS data processing

Optimization of QR factorization

With carrier-phase and pseudo-range as observations and ambiguity as parameters in GNSS data processing, the computation load can be reduced by centralizing the carrier-phase observations and ambiguity parameters. Presented in Fig. 2 and Fig. 3 are the procedures of filter and prediction of SRIF, respectively. As presented, 1) in the Blocked-front method, we put the ambiguity parameters (blocks in blue) in front of all parameters and list the carrier-phase observations (Aj1) before pseudo-range observations (Aj2); 2) in the Blocked-end method, the ambiguity parameters are listed at the end of the parameters. For the purposes of this example, we partition the matrix for factorization into two slabs, i.e., blocks of columns. And for each step in either filter or prediction, one slab as highlighted in red box is involved in the QR factorization: the slab is transferred to the registers and factored using the Householder reflection; upon completion, all the subdiagonal elements are annihilated and the upper triangular matrix is written back to the memory for the corresponding slab.

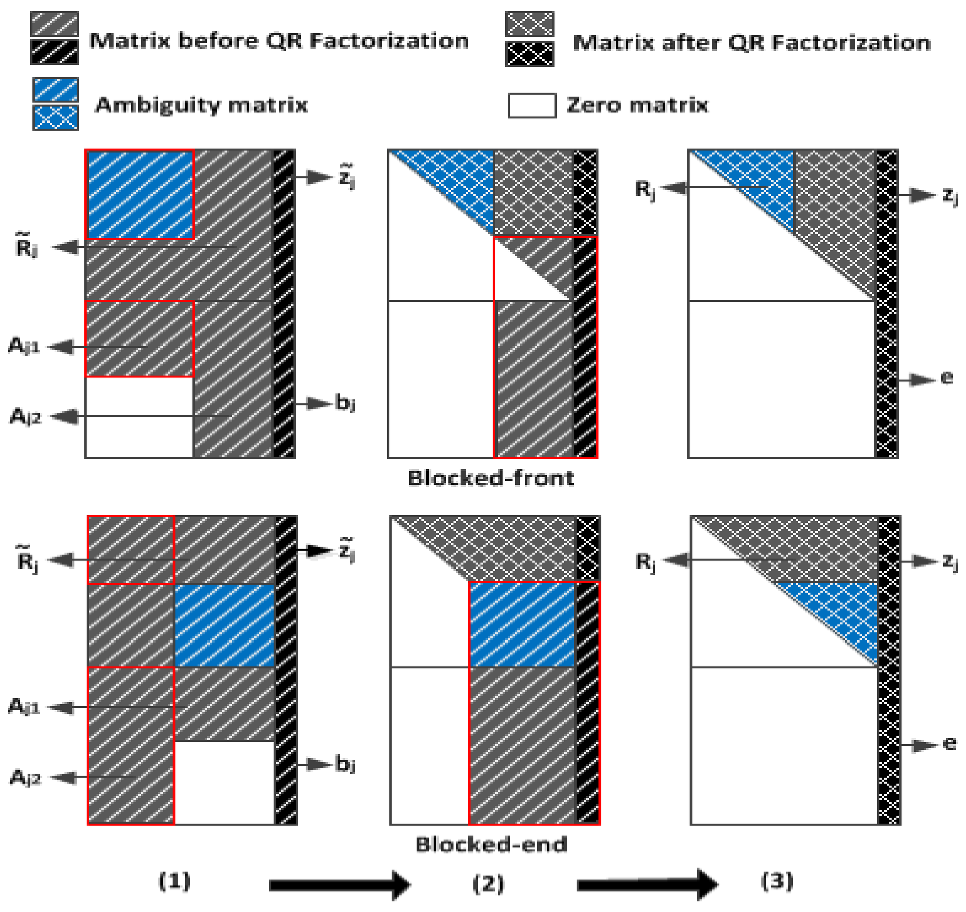

Fig. 2 Filter for the Blocked-front (upper) and Blocked-end (bottom) methods with different arrangement of ambiguity parameters. $\tilde{R}_j$ and $\tilde{z}_j$ are the prior information matrix before QR factorization; R_j and z_j are the information matrix after QR factorization; A_{j1} and A_{j2} are the design matrices of carrier-phase and pseudo-range observations, respectively; b_j is the prior residual vector, i.e., OMC; e is the posteriori residual vector.

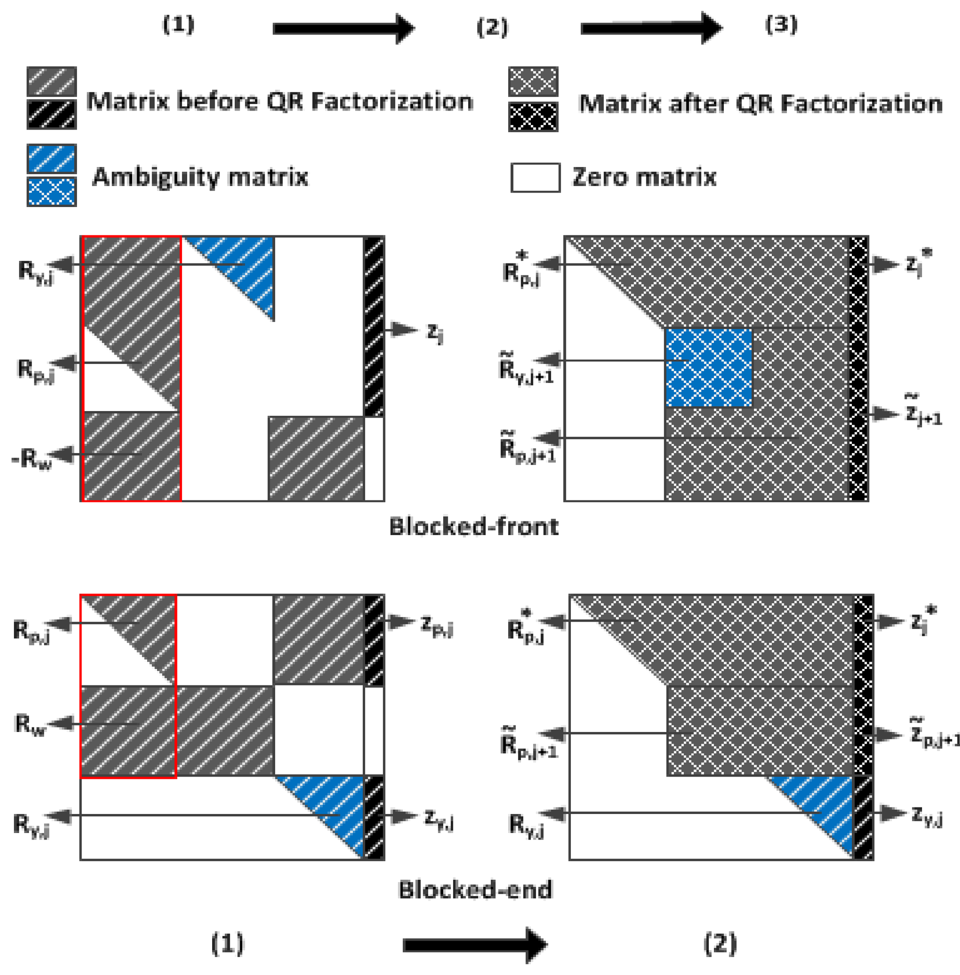

Fig. 3 Prediction for the Blocked-front (upper) and Blocked-end (bottom) methods with different arrangement of ambiguity parameters. R and Z are the prior information matrix before QR factorization; $\tilde{R}$, R^* and $\tilde{z}$, z^* are the information matrix after QR factorization; the subscripts p, y denote the random walk and constant parameters, respectively; j and $j+1$ denote the epoch subscripts; R_ω is derived from the dynamic noise.

By optimizing the arrangement of ambiguity and carrier-phase, the Blocked-front and Blocked-end methods are expected to benefit since the zero elements are centralized. Concerning the comparison between these two methods, the filter is more time-consuming with the Blocked-end method, while, the prediction is more time-consuming with the Blocked-front method. Actually, the decision whether the Blocked-front or the Blocked-end method should be applied depends on the ratio of the parameter number of ambiguities (n_y) and other unknowns (n_p), which is denoted as $r = n_y/n_p$ in this study.

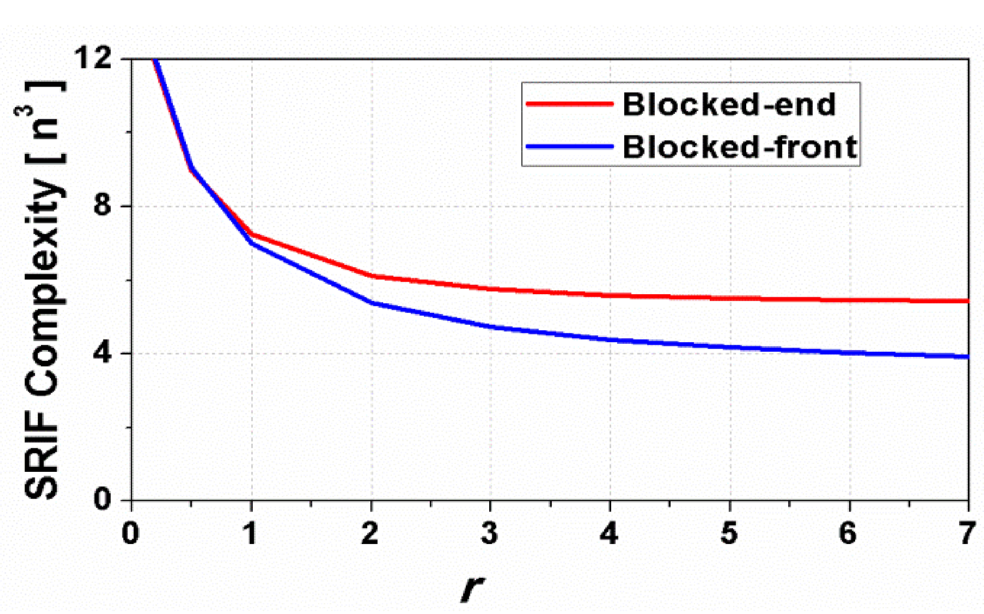

Fig. 4 Comparison of algorithm complexity of SRIF, which includes filter and prediction; r is defined as the rate of parameter number of ambiguities and other unknowns. Here we assume that m is equal to 3n.

As suggested in Fig. 4, the algorithm complexities are almost identical when r is less than 1 for the Blocked-front and Blocked-end methods. In summary, for an efficient GNSS data processing, the Blocked-front method with ambiguity parameters in front of all unknowns is suggested.

Experiments and results

Data collection and processing strategy

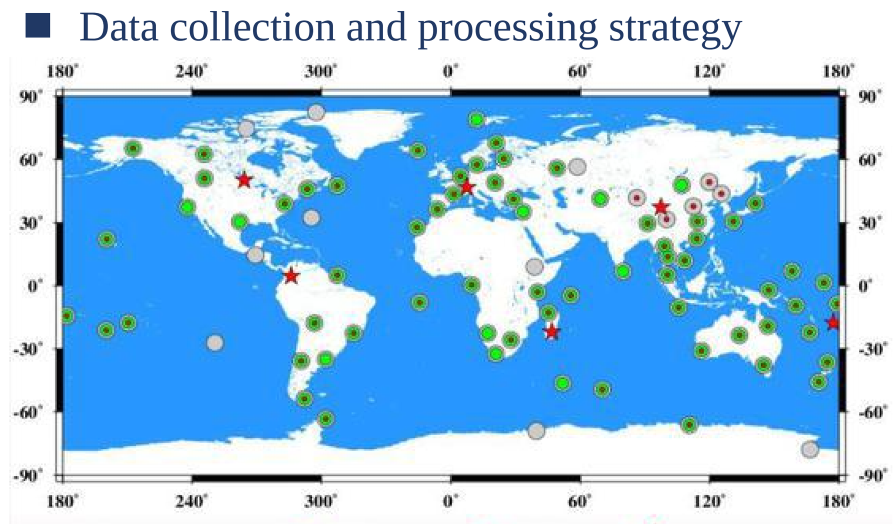

Fig. 5 Distribution of 88 GNSS stations; points in gray, green and red represent stations capable of tracking GPS, Galileo and BDS, respectively; red stars are stations used for PPP validation. The data is collected from days 183 to 189 of 2016 with 30 s intervals. All the data is processed in simulated real-time mode

Parameters	Processing strategy	Unknowns
Station coordinate	Fixed with static PPP solution averaged over one week using PANDA	0
Satellite orbit	Fixed with GFZ final multi-system orbit products	0
Receiver clocks / ISBs	One clock for each system as white noise parameter, and no ISBs are involved	~246
Satellite clocks	White noise and one clock for each satellite	~55
Troposphere	One zenith troposphere delay for each station as random walk	~82
Ionosphere	Eliminated with dual-frequency ionosphere-free combination	0
Ambiguity	Constant for each continues arc	~1230
Total		~1613

Un-differenced satellite clock solution

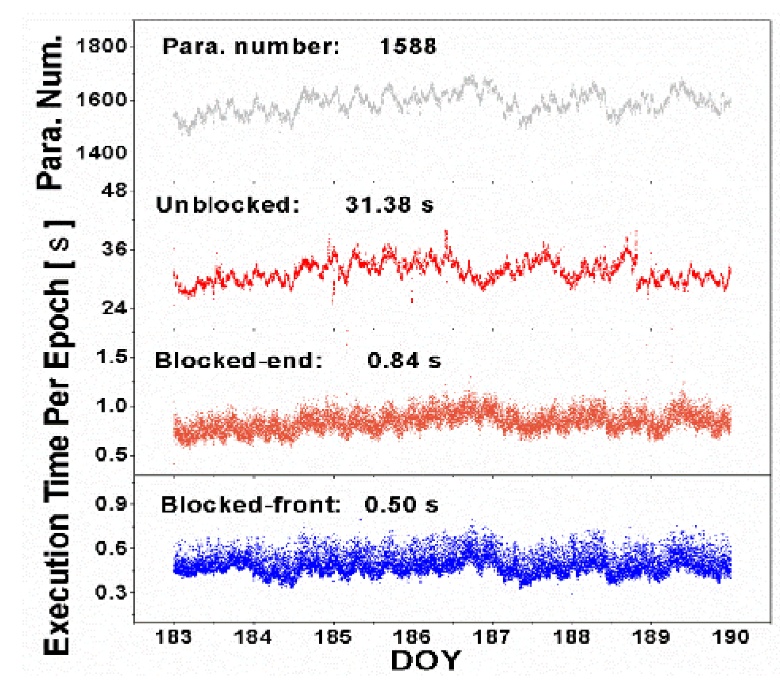

Fig. 6 Parameter number and the execution time per epoch; gray points are parameter number; red, orange and blue points are execution time per epoch for the Unblocked, Blocked-end and Blocked-front method

With about 1588 parameters for each epoch, it takes about 31.38 s for SRIF with unblocked method per epoch. While, the average time used for SRIF per epoch with the Blocked-end and Blocked-front method is 0.84 and 0.50 s, respectively, which implies a significant improvement for real-time data processing

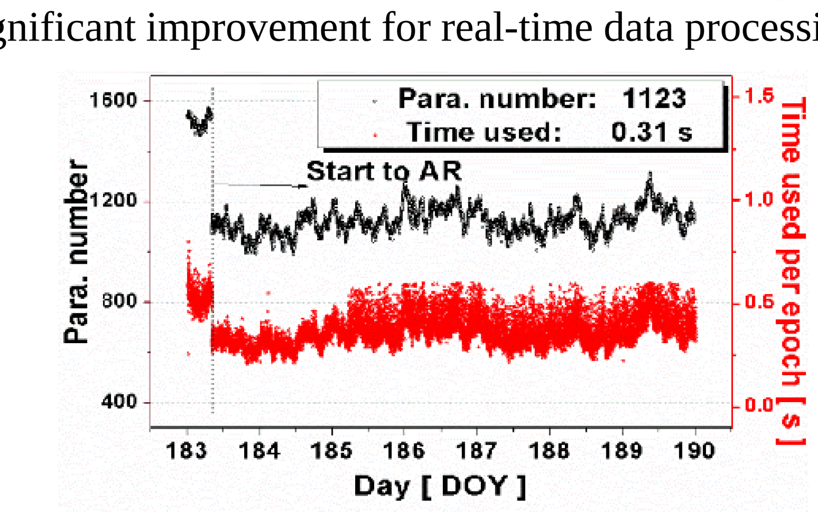

Fig. 7 Parameter number and the execution time per epoch with ambiguity fixed and eliminated

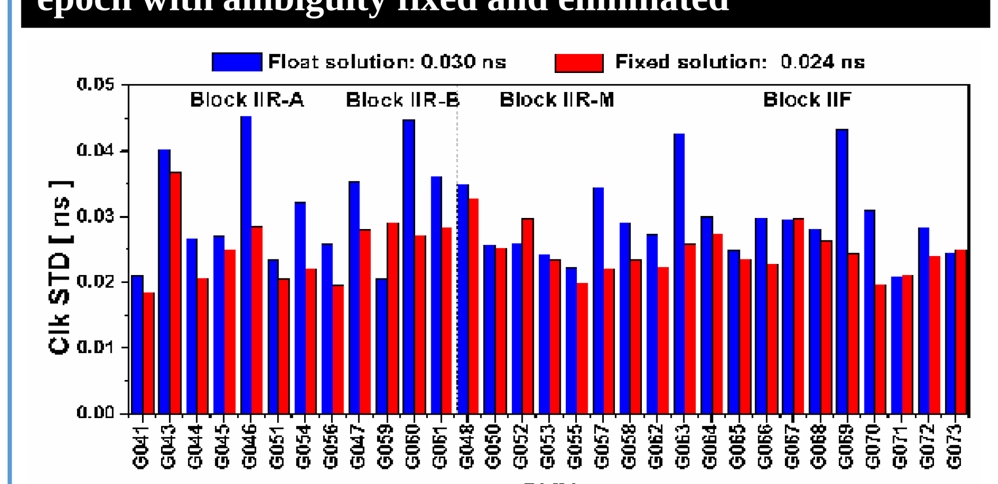

Fig. 8 Accuracy of clock estimates compared with GFZ product for GPS; blue and red bars are float and fixed solutions, respectively.

Station	PPP Float			PPP fixed		
	U	N	E	U	N	E
dlha	4.9	1.5	1.7	4.1	1.3	1.0
zim3	3.7	1.8	2.4	3.4	1.5	1.5
voim	3.8	1.5	1.8	3.9	1.5	1.4
laut	4.8	1.2	2.3	4.4	1.2	1.4
dubo	4.5	2.2	2.2	4.1	2.2	1.7
bogt	5.1	1.1	1.5	4.6	1.1	1.3

Clock products with ambiguity resolution are evaluated in terms of PPP. Compared to PPP float solution, the improvement in U, N and E are 8%, 5% and 29% on average

Conclusions

- Compared to unblocked method (31.4s/epoch), the average time used for SRIF per epoch is about 0.8s and 0.5s for the Blocked-end and Blocked-front method, respectively. When ambiguities are fixed, it only need 0.3 s/epoch.

Acknowledgements

We thank the IGS and China North Industries Group Corporation and China Earthquake Administration for providing the BDS/GNSS real-time streams

This work is funded State Key Research and Development Programmer (2016YFB0501802)

References

Puglisi C (1992) Modification of the Householder Method Based on the Compact WY Representation. Society for Industrial and Applied Mathematics. Siam J Sci Comput 13(3):723-726. doi:10.1137/0913042.

Demmel JW. (1997). Applied Numerical Linear Algebra. SIAM—Society for Industrial and Applied Mathematics

Montenbruck O, Steigenberger P, Prange L, Deng Z, Zhao Q, Perosanz F et al (2017) The Multi-GNSS Experiment (MGEX) of the International GNSS Service (IGS) – Achievements, prospects and challenges. Adv Space Res 59(7):1671-1697. doi:10.1016/j.asr.2017.01.011

Shengfeng Gu: gsf@whu.edu.cn / https://www.researchgate.net/profile/Gu_Shengfeng