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Kalman-filter-based integer ambiguity resolution strategy for long-baseline RTK with ionosphere and troposphere estimation

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Long-baseline RTK (real-time kinematic) over hundreds km has many difficulties compared to conventional short-baseline RTK. In the case of the short-baseline RTK, the errors of satellite ephemerides, the effects of ionosphere and troposphere are almost eliminated by forming DD (double-difference) measurement equations. For the long-baseline RTK, however, these errors and effects remain in the DD equations and degrade the RTK performance. It is also hard to resolve integer ambiguities into proper values reliably due to these errors and effects. In order to cancel the ionospheric effects, ionosphere-free LC (linear combination) of dual-frequency observables can be used. However, such simple LC does not maintain integer nature of the ambiguities. So a complicated multi-step procedure to resolve integer ambiguities by generating wide-lane and narrow-lane LC is often employed for long-range carrier-based positioning. It usually works well for static positioning in post-processing mode but would not provide sufficient performance for RTK in terms of reliability and convergence time. For the long-baseline RTK, the authors have been developing a Kalman-filter-based strategy to resolve integer ambiguities with estimation of ionosphere and troposphere parameters. In the strategy, the estimated states by the filter include kinematic rover positions, vertical ionospheric delay for each visible satellite, tropospheric ZTD (zenith total delay) at the rover and base-station sites and float ambiguities for dual-frequency carrier-phases. It intends to utilize real-time precise GPS satellite orbit provided IGS for over a hundred km baseline. It also uses Single-layer MF (mapping function) for ionosphere and NMF for troposphere. The temporal variations of the ionosphere and troposphere parameters are simply modeled as random-walk. The estimated float ambiguities by the filter are resolved as an ILS (integer least square) problem. We employs a well-known efficient method of LAMBDA to search the optimal integer vector. We implemented this strategy and test it with real data. At first, however, we did not obtain adequate performance for both initialization time and fixing ratio of solutions. So we added two improvements to the original simple strategy. One is "partial fixing" for integer ambiguities. The ILS-based ambiguity resolution usually fixes all of the ambiguities at the same time. If some estimated float ambiguities have large residuals, the result by ILS becomes unreliable and the validation process rejects the fixed solution. For the long-baseline RTK, additional estimation of atmosphere parameters causes long convergence time for the float ambiguities. Especially the rising satellites from the horizon sometimes raises the convergence problem. So we introduced "partial fixing" to our strategy. We separates the ill-conditioned ambiguities and hold them as float values. We only resolve the remains to integer values. To select the satellites with ill-condition, we use just satellite elevation angles. The ambiguities of satellites under the

predefined elevation mask angle are excluded from the vector to be fixed. The partial fixing improve the availability of (partially-) fixed solutions in exchange for a little degradation of positioning accuracy. Another improvement is "fix and hold" mode for integer ambiguity resolution. That means tight constraint to fixed ambiguities. At first, estimated float ambiguities are resolved by the usual way but once the integer solutions are verified by the validation process, the tight constraint to the integer solutions is introduced into the next update of the filter. An fixed ambiguity is held to an integer value until a cycle-slip occurs or the filter has large residuals. We call this behavior "fix and hold" mode. We expected these features much improve the initialization time and the fixing ratio for long-baseline RTK. According to the strategy described above, we implemented the algorithm and conducted some tests to evaluate the performance of long-baseline RTK. We already have an open source RTK software package RTKLIB developed by the authors. We implemented some additional functions in RTKLIB for long-baseline RTK including the support for IGS real-time precise orbit and the strategy for integer ambiguity resolution. At first, to demonstrate the "partial fix" and "fix and hold" for integer ambiguity resolution, we made a long-baseline RTK test by using the post-processing mode with the same condition of RTK. With the baseline length of 100 km, 24 hours data are processed by RTKPOST, which is an post-processing AP (application program) in RTKLIB. The fixing ratio of solutions was only 43.1% without "partial fix" and "fix and hold" modes after the validation by the simple ratio-test with the threshold of 3. The fixing ratio was improved to be 86.2% with "partial fix" and 96.8% with both of "partial fix" and "fix and hold". The RMS errors of the fixed rover position for the last case were 0.9 cm, 1.3 cm and 4.0 cm for the east, north and up component, respectively. Next, we used one week GPS observation data of Japanese continuous operating station network GEONET. We selected the rovers and the base-stations with from 50 km to 500 km baseline for the test. According to the test result, we obtained the fixing ratio of 99.8%, 96.8% and 98.7% for the 50 km, 250 km and 500 km baseline, respectively. The RMS errors of solutions were east 2.4 cm, north 1.8 cm and up 6.0 cm in the case of 500 km baseline. In the test for the data in summer time, however, we encountered a problem. The fixing ratio sometimes dropped to about 60%. It is considered that the performance degradation is due to large water vapor content variation in atmosphere. The strategy has an issue for troposphere estimation and needs some improvements in the future study.