Real-time cycle slip detection and repair in multi-GNSS, multi-frequency data processing: Part 2
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Introduction
Cycle slip detection and repair are essential quality control steps in recovering the integer ambiguities when loss of tracking signals in GNSS precise positioning occurs. In this contribution, we present an improvement to the previous algorithm [1] for reliable real-time cycle slip detection and repair of the Australian Analysis Centre Software (ACS) Pre-processing and Data Editing (PDE) function. First, the traditionally used algorithm based on the quality control theory is used to detect and repair the cycle slips. Then if the cycle slips are detected but not reliably repaired, the information of subsequent epochs are used together to strengthen the model and achieve a higher cycle slip repair success-rate. With such an enhancement, the model becomes more robust to accommodate the measurement noise and the ionosphere disturbance.

Methodology
The original mathematical models for cycle slip detection and repair are [1]:
\[
E(\Delta p_0(t)) = \Delta p_0 + u_0 dI \\
E(\Delta p_1(t)) = \Delta p_1 - \mu_1 dI + \lambda_1 \Delta z_I \\
E(\Delta d(t)) = \Delta d(t - 1) - \Delta d(t - 1) \\
\]
where \( p \) and \( \varphi \) denote the un-differenced code and phase measurements, with noise of \( \sigma_p \) and \( \sigma_\varphi \) respectively, \( \Delta \) being the time-differenced (TD) operator between epoch \( i \) and \( i - 1 \), \( p \) contains all geometric terms together with zenith tropospheric delays, \( dI \) is the TD ionosphere residual, with the noise of \( \sigma_d \), \( \lambda_1 \) is the ionosphere coefficient, \( \lambda_2 \) and \( \Delta z_I \) are the wavelength and TD integer cycle slips on the \( f \) frequency. To detect the cycle slip, the quality control theory can be used with the null and alternative hypothesis as:
\[
E(\Delta p_0(t)) = 4x \\
E(\Delta p_1(t)) = 4x + Bb \\
\]
with \( x = [\Delta p_0(t), \Delta p_1(t)]^T \). Vector \( x \) consists of TD geometric distance and TD ionosphere residual. \( B \) is the wavelength coefficients for the cycle slip vector \( b \). The quadratic form of the least-squares residuals of the null hypothesis is:
\[
T = \theta^T \Theta \\
\]
Equation (6) follows chi-square distribution and it is compared with a critical value (e.g. alpha=0.001) to check if cycle slips occur.

Once cycle slips are detected, the alternative hypothesis (5), together with the PS-LAMBDA method [2], can be used to estimate and repair (resolve) the cycle slips to integers.

The performance of the cycle slip repair step is subjected to the model strength. In case of weak model strength (such as low elevation and high ionospheric disturbance), the success-rate of repair becomes very low. To increase the model strength, the improved algorithm consists from the following steps:
1. If cycle slips are detected from epoch \( i \) to \( i + 1 \) but not repaired,
2. Then in the \( i + 1 \) epoch, if no cycle slip occurs from epoch \( i \) to \( i + 1 \), a TD between epochs \( i + 1 \) and \( i \) can be formed and used together with the TD information from epochs \( i \) to \( i + 1 \) to perform cycle slip detection and repair.

The more epochs used, the stronger the model will become.

Results
Previously in [1] the performance of the CS detection and repair algorithms was evaluated with 1Hz data collected from 9 MGEX stations and 1 Australian CORS station. The real-data success-rates form [1] against the elevation are plotted on Figure 1.

The proposed algorithm for cycle slip detection and repair has been verified theoretically and numerically. The results indicate the effectiveness of the algorithm. Using the improved method increases the model’s strength even for cases with high ionospheric disturbances. The improvement is larger on the dual-frequency cases with high ionospheric disturbances. The improvement is larger on the dual-frequency cases with high ionospheric disturbances. The improvement is larger on the dual-frequency cases with high ionospheric disturbances.

Conclusions
The proposed algorithm for cycle slip detection and repair has been verified theoretically and numerically. The results indicate the effectiveness of the algorithm. Using the improved method increases the model’s strength even for cases with high ionospheric disturbances. The improvement is larger on the dual-frequency cases, even at low elevations, as expected, than for the triple-frequency cases, where the model is strong already.

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References