CORRECTION OF CYCLE SLIPS IN STAND-ALONE GPS RECEIVER DATA FOR PHASE SCINTILLATION INDEX EVALUATION

Patrick LASSUDRIE-DUCHESNE, Rolland FLEURY
LEST - ENST Bretagne, Technopôle Brest-Iroise, CS 83818, 29238 BREST, FRANCE, Email: Patrick.LassudrieDuchesne@enst-bretagne.fr

ABSTRACT

The present paper deals with the evaluation of phase scintillation indices (such as σ_ϕ) from GPS receiver data. More specifically, the problem of cycle slip correction is addressed. Cycle slips are encountered if, by accident, a signal loss of lock occurs. Then, the receiver integer phase counter is reinitialised which causes a jump in the accumulated phase measurements [1]. Cycle slips usually have a deleterious effect on scintillation index evaluation as depicted in **Fig. 1**. Although algorithms for cycle slip correction exist, most are applicable only to differential GPS data [2], [3], [4], [5]. The present paper deals with the problem of cycle slip correction for dual-frequency stand-alone receivers [6]. Such configurations are encountered in particular when GPS receivers are used to monitor ionospheric activity on a regional or global scale [7]. An algorithm is proposed that corrects for cycle slips as small as a few wavelengths in range.

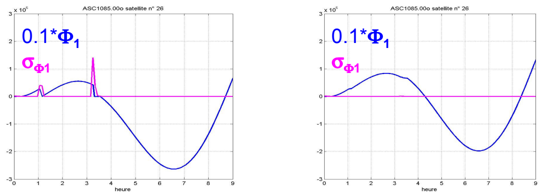

Fig. 1. Phase index evaluation with cycle slips due to receiver loss of lock (left, schematically) and after phase data correction (right)

PROBLEM DESCRIPTION

The problem of cycle slip detection can be approached in a simple way by visualizing the raw data measured by a GPS dual-frequency receiver. These are R_1 and R_2, the code pseudo-ranges measured at frequencies f_1 and f_2 and Φ_1 and Φ_2, the measured accumulated phases in range units (m) at f_1 and f_2.
Since these quantities present large variations during a satellite pass, their small-scale features can be best visualized using such combinations as: $dR = R_1 - R_2$ and $d\Phi = \Phi_1 - \Phi_2$.
An example of the dR and dΦ variations is shown in **Fig. 2**. Cycle slips are clearly visible on dΦ. On dR, however, it can be noticed that the background noise produces fluctuations as large as 1 m, a level far above the phase measurement noise. The reason for this is that the code measurement resolution is quite poorer than the phase measurement resolution, hence yielding a higher noise level in the code range data. The noise level is thus the main limitation to using dR and dΦ combinations.

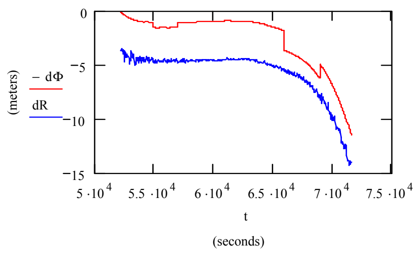

Fig. 2. Example of differential phase $d\Phi$ and code-range data dR showing cycle slips and measurement noise level

MATHEMATICAL MODEL

The fundamental equations for dual frequency GPS data are:

$$\Phi_1 = \rho - I + \lambda_1 N_{01} + \lambda_1 K_1$$
$$\Phi_2 = \rho - \alpha I + \lambda_2 N_{02} + \lambda_2 K_2$$
$$R_1 = \rho + I + m_1$$
$$R_2 = \rho + \alpha I + m_2$$

ρ = the satellite-receiver geometric distance; $\alpha = (f_1/f_2)^2 = (154/120)^2$
I = ionospheric group delay (in range units) at L1;
R_1 and R_2 = code pseudo-ranges at L1 and L2;
Φ_1 and Φ_2 = accumulated phases in range units (m);
m_1 and m_2 = pseudo-range residuals resulting from multipath, measurement noise and biases;
N_{01} and N_{02} = phase integer ambiguity constants;
K_1 and K_2 are step functions of time that take integer values to account for the cycle slips.

This equation can be written in matrix form:

$$\begin{bmatrix} \Phi_1 - \lambda_1 N_1 \\ \Phi_2 - \lambda_2 N_2 \\ R_1 \\ R_2 \end{bmatrix} = \begin{bmatrix} 1 & -1 & 0 & 0 \\ 1 & -\alpha & 0 & 0 \\ 1 & 1 & 1 & 0 \\ 1 & \alpha & 0 & 1 \end{bmatrix} \begin{bmatrix} \rho \\ I \\ m_1 \\ m_2 \end{bmatrix} = [A] \begin{bmatrix} \rho \\ I \\ m_1 \\ m_2 \end{bmatrix}$$

Which can be inverted to give (with the notation: $dX = X(t_n) - X(t_0)$ for all variables) :

$$\begin{bmatrix} \rho \\ I \\ m_1 \\ m_2 \end{bmatrix} = [A]^{-1} \begin{bmatrix} \Phi_1 - \lambda_1 N_1 \\ \Phi_2 - \lambda_2 N_2 \\ R_1 \\ R_2 \end{bmatrix}$$

hence:

$$\begin{bmatrix} d\rho \\ dI \\ dm_1 \\ dm_2 \end{bmatrix} = [A]^{-1} \begin{bmatrix} d\Phi_1 - \lambda_1 K_1 \\ d\Phi_2 - \lambda_2 K_2 \\ dR_1 \\ dR_2 \end{bmatrix}$$

RESULTS

The above mentioned cycle slips are easily detectable in the dm_1 and dm_2 solutions due to the low noise level (**Fig. 3**).

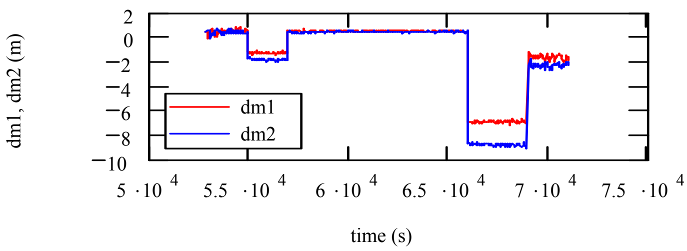

Fig. 3. Example of dm_1 and dm_2 combinations

The cycle slips contained in (dm_1, dm_2) are modelled by step functions of time that can be obtained by conventional median filtering techniques in order to smooth out the noise in the dm_1 and dm_2 combinations. **Fig. 4** shows the effect of cycle slip corrections.

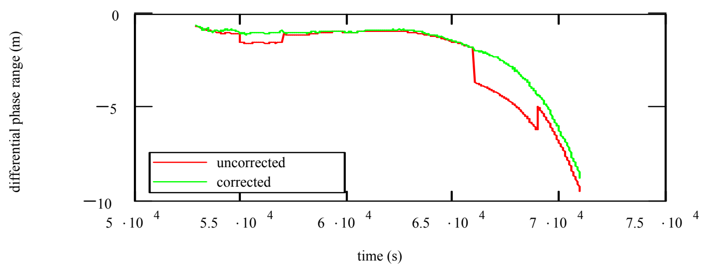

Fig. 4. Corrected and uncorrected differential phase ranges

CONCLUSION

An algorithm to correct phase GPS measurements for cycle slips has been described. The algorithm is suitable for the post-processing of data from dual-frequency stand-alone receivers. The preliminary results analysed in this paper show that the algorithm is efficient for the correction of cycle slips as small as a few cycles. This algorithm has proved useful in evaluating phase scintillation indices from GPS receivers on a global scale. However, statistical analyses remain to be performed to assess the robustness and reliability of the proposed algorithm for data from heterogeneous receivers located in an variety of geographical situations.

ENST Bretagne
LEST UMR CNRS 6165

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