Effects of Ionospheric Scintillation on GNSS Positioning Error

When analyzing GNSS random positioning errors, it is often assumed that the pseudorange error of each satellite has an uncorrelated normal distribution with zero-mean and common variance. However, in practical applications, the pseudorange error may differ in variance if one or more satellite ranging signals are deteriorated by ionospheric scintillation or multipath effects.

We study the characteristics of the random GNSS positioning errors when the pseudorange errors differ for each satellite. An analytical formula is derived for the covariance of the positioning error by using singular value decomposition (SVD). The SVD is applied to decompose the geometry matrix and explore the relationship between the positioning error, the pseudorange errors, and the geometric distribution of satellites. In the formula, the covariance of the positioning error is composed of a uniform error covariance together with additional contributions from those satellites with larger pseudorange errors. The eigenvectors and eigenvalues of the positioning error covariance can be calculated by SVD method. The eigenvectors of the uniform error covariance define the principal directions of the 4-dimensional error ellipsoid, and the eigenvalues are the squares of the semi-axes. The additional part from individual satellites has only one eigenvector and one eigenvalue. This makes the positioning error ellipsoid enlarge mainly along a direction related to both the overall satellite geometry and the position of the specific satellites as a result of a rank-1 modification of the pseudorange error variance matrix each time.

We validate the theory by simulating the GPS constellation and pseudorange measurements. The positioning error is examined as any one, two or four pseudorange errors are increased. The resulting positioning error is a composite of error from the uniform pseudorange error and those from satellites with the larger pseudorange errors. The simulation results confirm the expected characteristics of the covariance and positioning error theory. The horizontal positioning error distributions are presented to demonstrate the variations of the orientation and size of the error ellipses with the pseudorange error of specific satellites.

We also validate the theory by the GNSS observation data from south area of China where the ionospheric scintillation occur frequently. When one pseudorange error are enlarged by ionospheric scintillation, the positioning error ellipsoid enlarge along a direction related to both the overall satellite geometry and the position of the specific satellites distribution according to the theory.