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ORIGINAL ARTICLE

Using Allan variance to analyze the error characteristics of GNSS positioning

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Abstract Currently, we evaluate the positioning accuracy of GNSS mainly by providing statistical values that can represent the overall error level, such as CEP, RMS, 2DRMS, and maximum error. These are solid indicators of the general performance of the GNSS positioning. But some applications like GNSS/INS integrated system require a detailed analysis of the error characteristics and knowledge of the precise error model. This requirement necessitates the modeling of the error components of the GNSS positioning solutions. In our research, the Allan variance method is proposed to analyze the GNSS positioning errors, describe the error characteristics, and build the corresponding error models. Based on our research, four dominant noise terms are identified in the GNSS positioning solutions, that is, 1st order Gauss-Markov process, Gaussian white noise, random walk noise, and flicker noise, which indicates that white noise is not always enough and appropriate to model GNSS positioning errors for some applications. The results show that the Allan variance is a feasible and effective way to analyze the error characteristics of the GNSS positioning solutions.

Keywords GNSS positioning · Allan variance · Error analysis · Error modeling · Time series

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Introduction

Global Navigation Satellite System (GNSS) has been applied in almost every field, where position information is needed, such as GNSS-aided INS (inertial navigation system). For GNSS/INS loosely coupled integrated system, the GPS position is used to estimate the errors in the INS state and calibrate the inertial sensor. The GNSS/INS integration algorithm normally uses Kalman filter to fuse data. The standard Kalman filter requires the measurement noise to be white noise. Most of the algorithm designs regard GNSS error as white noise to make it simple to handle (Shin 2001; Groves 2008). However, treating all of them as white noise will cause the Kalman filter output variance/covariance matrix, that is, P matrix, to be smaller than the realistic estimation error level, that is, too optimistic. Therefore, some researchers suggest enlarging the parameter of the GNSS white noise in the Kalman filter, that is, the measurement error variance matrix of Kalman filter, that is, R matrix, to somehow compensate the inconsistency issue (Groves 2008). But this method is just a compromise. Actually, almost all of the GNSS-related error sources are time or space correlated, such as ephemeris errors, ionospheric and tropospheric delay, and satellite geometry (Tralli and Lichten 1990; Rankin 1994; Bierman 1995; Ge and Liu 1996). We speculate white noise is not always optimal for modeling the GNSS positioning error in some applications.

A number of pioneering studies investigated the error characteristics related to GNSS position solutions, which can be classified into two categories roughly. Some focused on investigating and modeling the GNSS error sources, such as troposphere delay (Rankin 1994; Bierman 1995; Ge and Liu 1996) and receiver clock error. Others focused on the coordinate instability of the monitoring station derived

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