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Review

A dual-rate hybrid filtering method to eliminate high-order position errors of GPS in POS

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ABSTRACT

The Position and Orientation System (POS) serves as a key component for the airborne remote sensing system, which integrates Strapdown Inertial Navigation System (SINS) and Global Position System (GPS) to provide the reliable and continuous motion compensation using Kalman Filter (KF). However, the high-order position errors resulting from C/A (Coarse/Acquisition) Code GPS cannot be effectively compensated or estimated by the traditional KF, which severely weakens the imaging quality. In this paper, we propose a Dual-rate Hybrid Filter (DHF) to deal with the high-order position errors based on Least Squares Support Vector Machine (LSSVM) and Kalman Filter. DHF builds a low update rate filter by integrating high-precision SINS and online LSSVM to isolate the high-order position errors. Meanwhile, the high update rate filter of DHF maintains the advantages of traditional SINS/GPS integrated navigation system to restrain the accumulation errors of system. The experimental results show that the proposed method significantly reduces the high-order position errors by 84.6% at each sampling period comparing with the conventional single KF based SINS/GPS integrated navigation system.

1. Introduction

Airborne remote sensing system is widely used in nature disasters rescue, hazard assessment, and battlefield reconnaissance because of its features like being rapid, flexible, and having high resolution. By carrying various remote sensing loads such as Synthesize Aperture Radar (SAR) and aerial digital camera, airborne remote sensing system can acquire a wide range, highly accurate and multi-layered space–time information of global surface and deep earth in real time. This is also theoretically based on uniform rectilinear motion. While the actual flight turns out to be complicated due to atmospheric conditions and aircraft maneuvers, which may cause imagery blur, and deformation, even can't form image [1]. In order to achieve high precision real-time imaging, the problem of consistency among the domains of space–time-spectral must be solved. As a result, Direct Georeferencing (DG) systems have been used to directly measure the position and orientation of the sensor for motion compensation that is used in airborne remote sensing system since 1994 [2]. POS is a product of the DG systems that provides location, speed, and attitude information in real time.

For high resolution SAR imaging loads, its working wavelength (λ) is 1 mm $\sim$ 1 m electromagnetic wave. Motion errors can cause loads imaging to decrease resolution, defocus, and even not imaging. SAR imaging generally requires low frequency motion errors is less than $\lambda/16$, high-frequency motion errors is generally less than 0.008λ [4]. Although the algorithm can effectively remove the stationary or linear motion errors in the process of image processing, it is especially sensitive to higher order motion errors [5]. Therefore, higher order motion errors are one of the main factors that affect the resolution of SAR imaging in the motion compensation of SAR products using POS products, while it still cannot be eliminated completely by traditional SINS/GPS integrated navigation algorithm. Hence, SAR requires both short-term high relative accuracy, and long-term absolute accuracy for real-time motion compensation from POS.

In order to retain the dynamic accuracy of SINS, yet keep the absolute accuracy of GPS, a Kalman Filter is used in POS [2]. Therefore, POS's architecture is similar to the GPS/INS integrated navigation system, which uses three orthogonal gyroscopes and three orthogonal accelerometers to measure the 6 dimensional parameters (x, y, z, pitch, roll, and heading) of the imaging load, and its algorithm also inherits part of the GPS/INS integrated navigation system. GPS/INS integrated navigation system, its precision is generally kept at meter level, and the precision can meet the demand. However, the position precision of POS product directly determines

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the resolution of remote sensing load imaging. Meter level accuracy cannot meet the needs of remote sensing load imaging.

Since POS usually choose high-precision inertial sensors, the SINS can provide high precision and high smooth position information in relatively short term [6]. In the SAR load image processing, the position and attitude data provided by SINS are used only during the synthetic aperture time. The aim is to avoid the effects of high order errors. However, the introduced high-order position errors mainly result from GPS data. The position information from GPS itself may contain severe high-order position errors due to dynamic variation of ionosphere and troposphere in the GPS signal path. In addition, the SINS data is interpolated to each GPS epoch, which also leads to the output data jump equivalent to the introduced high-order position errors [7].

In order to eliminate high-order position errors resulting from GPS, a common practice for POS is to improve the filtering algorithm and structure. A dual-strapdown navigation structure has been used in motion compensation during SAR image processing [8,9]. In every synthetic aperture time, the structure enables another independent set of strapdown algorithm to provide motion compensation parameters for SAR, so that the system can isolate GPS high-order position errors during these periods. While, in the cases of long synthetic aperture time, the inertial navigation's position error will increase rapidly. Moreover, a large amount of residual position errors among adjacent sections output by this method also cause a certain bad influence on imaging data processing and resolution [10].

With the above limitations of the existing methods, the high-resolution real-time imaging applications have strict motion compensation requirements on high-order position errors. Therefore, this paper proposes a DHF method to eliminate the high-order position errors resulting from GPS. The rest of this paper is organized as follows: Section 2 analyzes the high-order position errors in POS, where the features of those errors in POS and their effect on the imaging resolution are introduced in this part; Section 3 presents the DHF method and includes the design of its scheme, and the online LSSVM prediction algorithm; the experiment and results are analyzed and discussed in Section 4; and Section 5 concludes this paper.

2. Analysis on the high-order position errors resulting from GPS

2.1. Features of GPS high-order position errors in POS

High-order position errors of GPS data are manifested as acute jump. It mainly comes from the delay errors generated by the dynamic changes in the propagation path of the ionosphere and troposphere (see Fig. 1) [11–13]. In the real-time situation, the most widely used high-precision positioning technology is Real Time Kinematic (RTK). It removes most of the GPS rover station's observation data jump by means of finite difference [14].

In airborne remote sensing applications, the RTK technique needs to set up ground based station in the experimental area, and transmits its observations and coordinates information to the GPS rover station of aircraft by radio communication in real time. However, the effective range of RTK differential is limited, generally 20 ∼ 50 km [3] (see Fig. 2). Hence, when the distance between GPS ground based station and aircraft is below 20 km, the GPS positioning mode is almost carrier-phase differential (RTK-GPS). With the distance increasing, the mode turns to pseudo-range differential (PSRDIFF) in the RTK decay area. When the aircraft moving out of RTK is in a valid area, the GPS switches to single point mode (C/A GPS) [15]. Due to the factors of aircraft's route planning or surroundings of antennas, etc., GPS cannot guarantee the state of differential in the whole course.

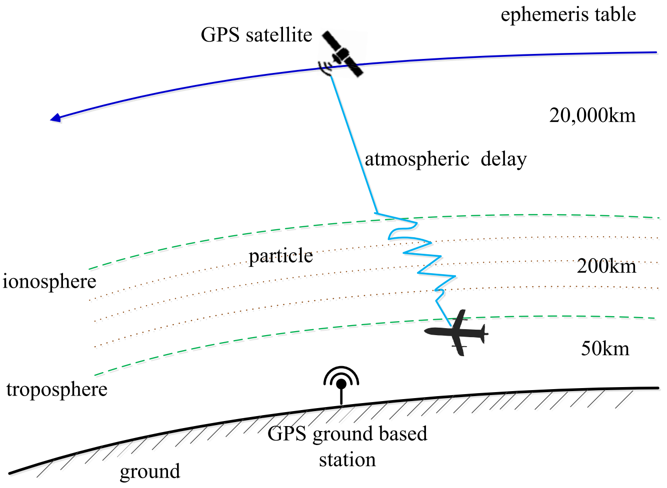

Fig. 1. Schematic diagram of GPS position error caused by ionosphere and troposphere delay.

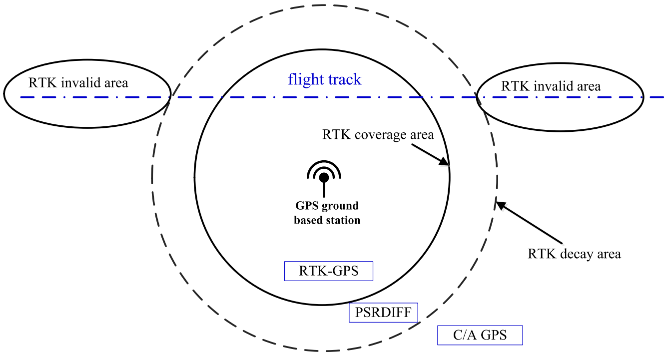

Fig. 2. Schematic diagram of GPS positioning mode change.

Fig. 3 shows the GPS position error curve. Through the analysis of the GPS data from flight tests, the GPS errors can be divided into GPS outliers (Panel B of Fig. 3) and GPS system errors. There are plenty of related references and processing methods about GPS outliers, and one simple way is to discard the abnormal point [16]. While the laws of the GPS system errors can hardly be described by a particular model (Panel A of Fig. 3), it will indirectly affect the accuracy of motion compensation.

As shown in Fig. 4, 100 s GPS system position error information is intercepted from the experimental data. As commonly described in the literature [17], a polynomial fitting is carried out on the GPS system error curve, and it can be decomposed into four forms: (a) constant error; (b) linear error; (c) quadratic error; and (d) the quadratic residual error. The quadratic term and its residual error are the high-order position errors in this paper.

Since the limitations of RTK technology, the GPS data in Fig. 3 contain both differential-GPS and C/AGPS. Two pieces of GPS data is extracted from Fig. 3 under the positioning mode of differential-GPS and C/AGPS respectively, and their high-order position errors are contrasted in Fig. 5. The high-order position errors in C/A GPS are greater than that of the differential-GPS in flight tests. The differential-GPS's high-order position errors range from $(-0.002, 0.003)$ m, while the C/A GPS range from $(-0.2, 0.2)$ m. Thus, this article is aimed at online removing high-order position errors resulting from C/A GPS.