Ionospheric delay prediction and code-carrier divergence testing for GBAS using neural network and GPS L1

Irfan Sayim a, Haoxiang Lang a, Dan Zhang b
a University of Ontario Institute of Technology, Department of Mechanical Engineering, L1H 7K4, Oshawa, ON, Canada
b York University, Department of Mechanical Engineering, M3J 1P3, North York, ON, Canada

ARTICLE INFO

Article history:
Received 12 October 2016
Accepted 28 July 2017
Available online xxx

Keywords:
GBAS
GPS
Ionosphere
Total electron content
Neural network model
Navigation integrity

ABSTRACT

This paper presents a Neural Network (NN) model for predicting Ionospheric Delay (ID) which is used particularly in the Ground Based Augmentation System (GBAS) as a new and alternative approach. It is vital to have positioning solutions exhibiting high levels of performance in terms of navigation for aircraft to counter systematic errors in broadcast correction ranging measurements associated with GBAS, such as ID when using a Global Positioning System (GPS) L1 frequency receiver. In principle, ID can be simply estimated with the aid of dual frequency receivers (GPS L1 and L2) or a new GPS signal (L5). However, the GBAS relies only on the L1 frequency as the L2 frequency is not protected by Aeronautical Radio Navigation Service (ARNS) and L5 is not fully functional. In this context, the NN model is proposed to predict the ID from only GPS L1 pseudorange measurements. Benchmarking performed between prediction and conventional dual frequencies (GPS L1 and L2) illustrates the validity of the proposed method. In addition, divergence tests are performed to assess the effectiveness of predicted ID on the code-carrier. The possibility that ID type systematic and temporal errors in GBAS ranging measurements can be predicted accurately with only GPS L1 measurements is investigated. NN can also be used in the GBAS to reduce the code-carrier divergence effects between ground and airborne users.

© 2017 Elsevier Masson SAS. All rights reserved.

1. Introduction

The GBAS provides advanced navigation services for civil aircraft users during precision approaches and landing. In the development of GBAS, a key technical issue which has been a central focus of research for many years, is to provide adequate broadcast correction parameters (PR, B-value, df_r, etc.) to aircraft to ensure positioning solutions with the required high navigation performance solutions such as integrity, continuity, availability, and accuracy [1]. For instance, the navigation integrity risk is quantified and managed at the aircraft via the computation of the Vertical and Lateral Protection Level (VPL/LPL) with a maximum permissible integrity risk in the order of 10^-8 with respect to a Vertical Alert Limit (VAL) of 10 m for Category I aircraft approaches and landing [1]. These Protection Levels (PLs) are position error bounds with guaranteed navigation integrity [2,3]. Algorithms for the computation of PLs are built on the assumption of a zero-mean, normally distributed ranging error for aircraft, as well as for ground broadcast corrections [4]. Therefore, the GBAS Ground Facility (GGF) is responsible for providing normally distributed broadcast correction parameters to aircraft. Thus, aircraft compute the navigation risk through PLs with an indicated navigation integrity, and then use them for the initiation of a precision approach and landing. In reality, at the GGF, the PLs error model might be consistent with the effects of certain types of error sources such as the thermal noise of reference receivers and diffuse multipath; however, researchers agree that significant remaining errors, such as ground reflection multipath or other systematic errors, cannot be directly modeled by zero-mean normal distributions [5–7]. In fact, the GGF must generate a broadcasting sigma of normal distribution for the ranging errors of each satellite by taking into account all types of true (unknown) error sources. The ID is one of the existing systematic error sources that can be observed in ranging measurements [8–10]. In principle, ID can be easily estimated with the use of dual frequency receivers (GPS L1 and L2). However, the GBAS relies only on the L1 frequency as the L2 frequency is not protected by ARNS [20]. Moreover, in GBAS, the code-carrier divergence due to the ID in the Hatch Filter has to be monitored due to concerns about the consistency possibilities of receivers from different suppliers to GBAS ground stations and in aircraft [20,21,26]. The receivers used in terms of GBAS ground stations and aircraft are expected to be standardized.
However, the possibility of differences rationalizes the need for Code-Carrier divergence monitoring due to ID [8,9]. Therefore, the NN model-application has been designed to predict the ID from satellite pseudoranges by using only GPS L1 frequency measurements. In the literature, previously proposed NN-based ionospheric TEC (Total Electron Content) prediction analyses have been carried out in a wide area context by Sur and Paul [29] and Sur et al. [30], considering TEC estimation around the northern crest during low and moderate solar activity of the 24th solar cycle. The findings of these papers, however, are suitable for application to the wide area augmentations of GPS such as the SBAS (Space Based Augmentation System) in which the satellite-broadcast messages are formed using GPS L1 and L2. In GBAS, in contrast, the ground generated broadcast messages from the L1 code measurements are used in positioning solutions and navigation integrity quantification. Furthermore, in this work, the NN model has been selected for ID prediction because of its superior advantages in terms of establishing the complex nonlinear empirical solutions in different engineering applications in the past few years [12–18,24]. For example, the NN models:

1- use data to learn and to produce meaningful solutions to situations in which the data is incomplete or incorrect,
2- can adapt solutions over time and compensate for changes in circumstances,
3- estimate reliable past experience based theoretical, experimental, or empirical data results or a combination of these.

In this work, a multilayer feedforward NN is trained using a backpropagation algorithm; four combinations of inputs channels are selected as NN inputs. From a GGF site, the true satellite pseudorange measurements were recorded for two long-pass satellites (Pseudo Random Noise#: PRN#10 and PRN#27) for eight days. Then, the CMC (Code-Minus-Carrier) process was applied to obtain the raw measurements for generating the input parameters of NN. In the proposed NN model, satellite azimuth and elevation knowledge were used, along with CMC data for training, testing, and validating purposes. From an established NN model application, highly accurate ID prediction results were obtained for both satellite passes. The level of relative error between conventional dual frequency and NN models is within a few centimeters of standard deviation. Sensitivity analysis was also performed to identify the impact of each input channel on the output. It is also noted that the NN model does not require GPS L2 measurements, and only relies on L1 which makes the proposed NN model consistent with, and a unique solution to, GBAS architecture. These outcomes are also potentially valuable for forming broadcast sigma overbound and real-time ID code-carrier divergence monitoring, as outlined in the divergence tests.

2. Impact of TEC on GBAS integrity

In GBAS, a set of high quality GPS reference receivers and antennas are placed at precisely surveyed locations on the airport property (Fig. 1G). The ranging measurements (GPS SIS – GPS Signal in Space) from all satellites (Fig. 1S) in view are collected by the reference receivers and passed to a processing unit which smooths the measurements using Hatch Filter, and generates differential corrections for each satellite [1–3]. The corrections from all the reference receivers are averaged to form a composite ranging correction (one for each satellite) that is then uplinked to the aircraft receiver (Fig. 1A). The aircraft receiver applies the corrections to its own satellite ranging measurements for a highly accurate code-based differential GPS (DGPS) technique with high navigation performances [5].

The navigation performances are quantified within aircraft based on the broadcast parameters from the GGF. Therefore, the navigation performance can be meaningfully used by aircraft if the broadcast parameters are consistent with the true measurement data of the GGF [7]. Moreover, the GGF is responsible for providing the aircraft with the well-established broadcast parameters of the ground station’s measurements. For example, in the analysis of PLS, it is assumed that ranging errors were zero-mean normally distributed fault-free error models for the broadcast pseudorange corrections of GGF reference receivers. However, it is observed that significant uncertainty in terms of ID (Fig. 2) exists in ranging due to use of only L1 frequency at GGF. This effect also can vary due to solar activities, the time of day, the location of the user, and the season of the year. Moreover, L1 ranging measurements (CMC) can produce ID plus mainly site-related uncorrelated multipath ranging errors [11,12]. ID is computed by (5) and plotted as in Fig. 2. Such a distribution model of ID type actual error may not be consistent with the assumed theoretical Gaussian distribution of reference receiver ranging errors. Therefore, GGF must account for all types of
دریافت فوری
متن کامل مقاله

امکان دانلود نسخه تمام متن مقالات انگلیسی
امکان دانلود نسخه ترجمه شده مقالات
پذیرش سفارش ترجمه تخصصی
امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
امکان دانلود رایگان ۲ صفحه اول هر مقاله
امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
دانلود فوری مقاله پس از پرداخت آنلاین
پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات