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Wavelet Neural Network employment for continuous GNSS orbit function construction: Application for the Assisted-GNSS principle

P. Pavlovčič Prešeren*, B. Stopar[1]

University of Ljubljana, Jamova 2, 1000 Ljubljana, Slovenia

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ABSTRACT

This paper presents a Wavelet Neural Network (WNN) employment for discrete precise ephemerides tabular data of Global Navigation Satellite System (GNSS) orbit approximation to obtain continuous orbit function. Orbit function is essential in positioning and navigation tasks, the advantage of continuity, however, is that it can also be used during GNSS signal interruptions. The essence of WNN continuous orbit construction is single function determination for the entire interval, while the interpolation methods follow several discrete function establishment. Specifically, we investigate the performance of the WNN continuous orbit approximation by comparison with well known polynomial and trigonometric interpolations. The experimental results show that our proposed method is superior to the traditional methods especially near the end of intervals, because they are not subject to large scale function oscillations as in the case of polynomials constructions. We propose a WNN construction using different mother functions of the WNN namely Mexican hat, Morlet function, Gaussian and Daubechies (D4) wavelet. Furthermore best algorithm for regression estimation is described; selection of neurons in the hidden layer of WNN is based on orthogonal least squares algorithm. The main objective of this article is to show that the presented method of orbit function construction could be used for GNSS ephemerides distribution and short-time prediction in the Assisted GNSS-networks.

1. Introduction

Global Navigation Satellite Systems (GNSS) are based on two fundamental principles: the well specified time, realized by onboard atomic clocks and in the ground based receivers, and the knowledge of satellite positions at any time. Any errors in time or in satellite positions directly affect the pseudorange accuracy which further impacts the GNSS positioning accuracy. Satellite clock and orbit errors have great influence over the accuracy of GNSS real-time solutions, especially on real-time precise point positioning (PPP), developed by Zumberge et al. [1]. Since PPP issues from absolute GNSS positioning, no effects could be eliminated forming differences (one, double or triple) as in traditional double differencing. Consequently PPP technique is more dependent on high quality predicted ionosphere, GNSS satellite coordinates and partly also on predicted state of satellites' clocks. Dousa explained in [2], that the latter could be estimated also in real-time, if high quality predicted GNSS satellite coordinates are available, but for such case continuous predicted GNSS orbit should be for disposal.

For simple navigation tasks real-time satellite positions and clocks are derived from broadcast ephemerides that are generated by the Control Segment (CS) of the specific technology, i.e. GPS (Global Positioning System) or GLONASS (rus. Globalnaja Navigacionnaja Sputnikovaja Sistema), uploaded into satellite's memory and further transmitted by the satellites to the user. Ephemeris data combine orbital and clock corrections, which GNSS receiver has to download from the satellites. Each satellite broadcasts only its own ephemerides data. In case of GPS technology satellites broadcast ephemeris data for 30 s and then re-transmit the data in case that GPS-receiver loses track of the data. GPS ephemerides are updated every 2 h, but remain valid for 4 h (−2 h to +2 h with respect to the time of ephemeris (TOE)). Hofmann-Wellenhof et al. [3], Rothacher [4] and Langley et al. [5] showed, that satellite position (from broadcast ephemerides) error grows in time and it is believed to be from 3 to 20 m level. GLONASS ephemerides are updated half-hourly and remain valid as long as the force model is valid, i.e. 15 min backward and forward with respect to the current state vector. As pointed out by Stewart and Tsakiri [6], GLONASS broadcast orbit inherent error is 20 m along track, 10 m cross track and 5 m in radial component. Extrapolation of any (GPS or GLONASS) broadcast ephemerides beyond the time of validation is not appropriate, since errors grow rapidly. Although GNSS broadcast ephemerides tie computationally to continuous functions, however, because of problematic accuracy, can not be

* Corresponding author. Tel.: +386 1 4768 631.
E-mail addresses: polona.pavlovcic@fgg.uni-lj.si (P.P. Prešeren), bojan.stopar@fgg.uni-lj.si (B. Stopar).
[1] Tel.: +386 1 4768 638.

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used beyond the interval of validation. In case of PPP technique they are not useful even during the time od validation.

In case that GNSS receiver has access to the WAAS (Wide Area Augmentation System), position determination can be improved according to the fact, that in WAAS GPS satellites' positions are updated in 15-min interval and broadcasted to the user every 2 min. Unfortunately, not all of GNSS receivers have access to the WAAS. Furthermore, for precise point positioning with desired accuracy of a few cm (like PPP), even improved broadcast ephemerides solution from WAAS is not good enough.

Since the accuracy of broadcast ephemerides diminishes in time, can reach several meters and is not appropriate for extrapolation, it is better to use predicted GNSS ephemerides, provided by GNSS services (for example IGS (International GNSS Service) or IGLOS (International GLONASS Service)) over the web. Precise GNSS ephemerides are packaged as daily SP3 orbit files at 15-min interval. They contain coordinates (x, y, z) and satellite clock correction values and their standard deviations. Because in the SP3 files positions and clock rates for all available GNSS (GPS or GLONASS) satellites are listed at 15-min intervals, precise ephemerides are often termed tabular. The accuracy of precise GNSS ephemerides depends on the ephemeris type (ultra-rapid (predicted half), ultra-rapid (observed half), rapid and final). Basically the accuracy is on the order of a few centimeters and remains the same for the interval (subinterval in case of ultra-rapid files) where data were generated from actual GNSS observations. The IGS near-real time ephemerides, i.e. ultra-rapid ephemerides, are produced every 6 h, but in some IGS processing centers predicted ephemerides are updated hourly [7]. Precise ephemeris accuracy and more reliable access od the data over internet outweights the weakness of precise orbit data form, usually containing only the position information. The precise ephemeris data disadvantage stems from the fact, that based on only the positional information orbit function re-construction can not be carried out using numerical integration process.

Recently Assisted-GNSS (A-GNSS) (Fig. 1) and Self-Assisted-GNSS (SA-GNSS) principles were introduced for more reliable positioning during reception gaps, see [8]. A-GNSS is based on the Assisted GNSS server, that downloads broadcast ephemerides and passes on to the user by more reliable external facilities and communication links (internet, DMB and so on). The primary benefits of A-GNSS to the user are in better acquisition sensitivity, also possible indoor acquisition and reduction of the time-to-first-fix (TTFF). Optimization of TTFF enables so called "warm" start of the receiver, which allows much faster navigation application (less than a minute) comparing to "cold" start, in which the GNSS receiver has to acquire all the data from the satellites (satellite signal, broadcast ephemerides, almanac) in order to start navigation and can take 12 or more minutes. Even the "warm" start rapids the beginning of navigation, the broadcast ephemeris accuracy problem in point positioning application remains. SA-GNSS on the other hand estimates the current satellite position based only on previous information (position and velocity of a GNSS satellite) and is not dependent on the network assistance. Several authors, such as Garrison and Eichel [9], Iubatti et al. [10] as well as Jongsun et al. [13], have studied alternative formulation of GNSS ephemeris data, that could be transmitted via A-GNSS communication link or could be used in SA-GNSS principle. That involves also data format optimization for better near-real time positioning applications.

In this paper we address the above-described problems with the broadcast and precise ephemeris data and propose an approach of precise continuous GNSS orbit construction using wavelet basis function networks. This approach is considered more efficient than the conventional approximation methods appeared in GNSS orbit construction. Further we show our previous research improvement, which was based on radial basis function network (RBFN) utilization [11]. Although RBFN approximation was proven to be well-functioning, GNSS orbit function presentation was not unique and because of that not most efficient. This is actually a known RBFN fact, presented already by Zhang et al. [12], and results from radial basis functions that are generally not orthogonal and are redundant. In case of WNN radial basis are replaced by orthonormal scaling functions, allowing unique and optimal orbit function construction. We show that WNN usage optimizes the operation of A-GNSS in terms of reducing amount of data to be transferred. Further we investigate, whether GNSS orbit function, derived from WNNs, could be used also for short time prediction, in case of loosing satellite track.

The rest of the paper is organized as follows: In Section 2 traditional methods of GNSS continuous orbit construction from tabular precise ephemeris data are discussed. In Sections 3 and 4 wavelet transform and Wavelet Neural Networks are introduced, and in Section 5 WNN regression estimation is discussed in order to find optimal wavelet network configuration. In Section 6 experiments and results are discussed which are followed by discussion in Section 7.

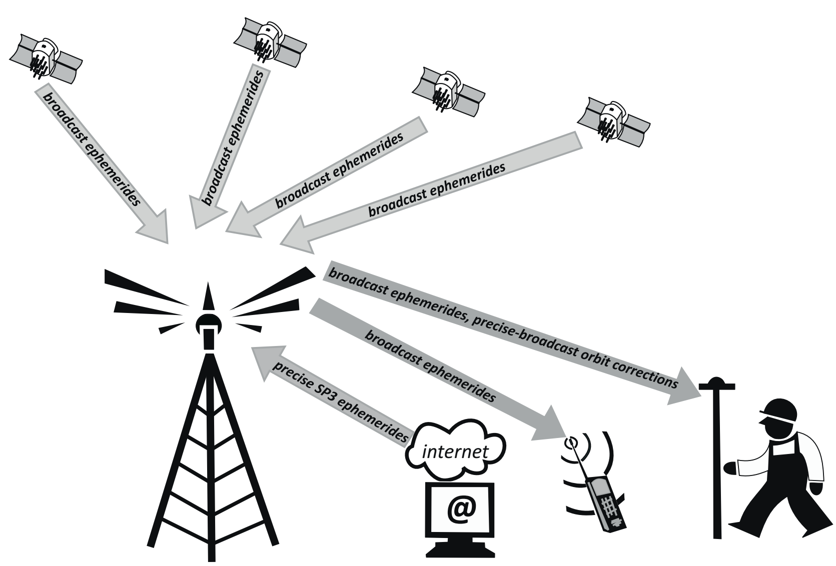

Fig. 1. Assisted-GNSS principle.