Estimate of the electronic content of the ionosphere by needlets

Ph-D Thesis Committee - 2014

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Description :

The EGNOS system broadcasts to mono-frequency users corrections linked to the propagation of the GPS signal through the ionosphere. The quality of these corrections is the main contributor in the performance of availability of EGNOS signal . The ionosphere is a physical complex system the dynamics of which is mainly concentrated in geomagnetic Equator, the regions of average latitudes are less perturbed.

The combination " Geometry-free " of dual-frequency measurements of navigation signals allows to evaluate the ionosphéric delay of the pseudo-distance on the sight axis . This combination is affected by instrumental biases, that is the delays affecting the signal in the receiver and transmitter equipments.

To identify in the combination what is related to the bias in equipments and the effects of the ionosphérique dynamics it is necessary to model the ionosphérique delay. The ionosphere can be modelled either by a thin layer containing the whole of electronic density, either by a multilayer. Recent methods propose a decomposition of ionosphérique delay in Fourier series on the sphere (spherical harmonics) for every layer of the model (mono or multi-layers). It is a frequency decomposition which allows to extend the Fourier transform for a signal defined on a sphere rather than on an interval.

Unfortunately this modelling in spherical harmonics is not adapted to the analysis of signals whose frequency properties can vary locally on the sphere. In particular, this modelling is not satisfactory for the ionosphere in case of high space and/or temporal gradients. This errors of modelling implies a bad adjustment of the instrumental biases impacting directly the performance of the EGNOS system .

The objective of this thesis is to set up another modelling of a signal defined on the sphere. For that purpose, we suggest using decompositions in wavelets on the sphere (needlets), then to prototype this method to assess the performance with regard to reference data. The principle of a decomposition in wavelets is to be able to analyze locally the frequency properties of a signal and thus to obtain a better modelling than with an analysis in Fourier series. The objective is to decrease significantly the modelling errors , especially in equatorial region where the ionosphérique activity is high.

State of the art - Innovation :

The higher layers of the atmosphere, the ionosphere, affect the distribution the GNSS signals and degrade the precision of the measure of distance. Moreover the ionosphere the propagation of GNSS signal: the carrier and its modulation by the code travel propagate at different speeds. The speed of propagation of the code slows down and becomes slightly lower than the speed of light, which induces a delai in the measure of distance.
This ionosphérique delay depends mainly of the frequency of the signal and on the density of free electrons in the ionosphere. In compensation, the EGNOS system broadcasts parameters of ionosphérique correction to the users to compute their position.
Dual-frequency measurements are used to calculate this ionosphérique delay. However these measurements also contains the instrumental biases at transmit and receive level. Filtering methods allow to separate the constant part (equivalent to instrumental biases) and the dynamic part which contains the ionosphérique contribution. However the current models applied to the ionosphere are based on decompositions by means of spherical harmonics. Therefore, they do not take in consideration the geographical localization of the observations of EGNOS.
To by-pass this difficulty, it is necessary to use a base of functions linked to the localization on the sphere, whose dynamics model the local high frequency variations of the ionosphere.
Recently, it was built new bases of analysis wtih functions defined on the sphere which have much better local properties of approximation than the spherical harmonics [3]. In particular the needlets constitute an extension of the classic analysis by wavelets of a function defined on an interval. It allows the construction of bases which take into account space and frequency distribution on the sphere. Needlets were successfully used in the field of the astrophysics for the analysis of the cosmic microwave background (CMB) which is a problem of statistical analysis of data distributed on the sphere [1,2]. It is a tool of harmonic analysis which is at the state of the art of research in applied mathematics and signal processing, and potential applications are numerous in scientific domains (geophysics, meteorology, geostatistics, medical imaging).
Needlets thus appears as a promising tool for the analysis of the local properties of ionospheres. However, one of the difficulties is the use of the decomposition in needlets for the statistical analysis of measurements on the sphere with irregular sampling. In this context, thresholds must be defined to consider only the significant coefficients of the decomposition in needlets of the ionosphere for its reconstruction from incomplete irregularly distributed data. Then will be studied the possibility of improving the current algorithms of filtering based on the decomposition of the ionosphere in spherical harmonics.

[1] In full house sky, low foreground, high resolution CMB map from WMAP. Delabrouille, Cardoso, The Young person, Betoule, Fa ÿ, Guilloux, Astronomy and Astrophysics (2009)
[2] CMB power spectrum estimate using wavelets. Fa ÿ, Guilloux, Betoule, Cardoso, Delabrouille, The Young person, Physical Review (2008)
[3] Practical wavelet design one the sphere. Guilloux, Fa ÿ, Cardoso, Applied and Computational Harmonic Analysis (2009)

Laboratory:	Experience:
TBD	Research on statistics for image and signal processing applied to the analysis of large data . Applications in signal processing in the field of the navigation and in astronomical imaging. Partnerships with the Aerospace industry in Toulouse for research projects in statistics.

Candidate:

TBD

Financial partner (Co-Funding) **Any Comment** (1st contact , 2nd partner ? …)

TBD

Ph-D Thesis: Activities, steps

Preliminary analyses (Year 1):

Detailed study of the algorithms used by the system EGNOS for broadcasting of ionosphérique parameters correction.
State of the art of the methods of interpolation / smoothing on the sphere from incomplete data and irregularly spaced out,
Literature survey on needlets and use for problems of interpolation on the sphere,
Study of the possible extension of the use of needlets for the analysis of data in a model of ionosphere mono and/or multilayer.

Detailed analysis of the performances of the selected solutions (Year 2):

· proposal of new methods to estimate ionosphérique delai from decomposition in needlets, evaluation of performances from simulated signals.
· comparison with the current methods based on decompositions in spherical harmonics.

Characterization of the performances in real conditions (Year 3):

· coding of the algorithm for use in a processing chain with real data,
· definition of a strategy of experiments, and acquisition of database of measurements,
· processing (batch mode) of acquired data and analysis of the performances of the new method compared to classical ones.