Doctoral Dissertation
Doctoral Program in in Electrical, Electronics and Communication Engineering
(33.rd cycle)

Title : Analysis and Detection of Outliers in GNSS Measurements by Means of Machine Learning Algorithms

Author : Caner Savas
Supervisor : Prof. Fabio Dovis

Summary

Global Navigation Satellite Systems (GNSS) have a central role in many applications that require high accuracy and precision such as in air/marine transport, robotics, military operations, and precision agriculture applications. However, GNSS signals suffer from many error sources, such as interference/jamming, ionospheric/atmospheric anomalies, and multipath that affect the quality of the estimated position. To reach a high level of accuracy in the navigation, the GNSS errors must be corrected. GNSS modernization with the availability of multi-frequency signals and multi-constellations has been providing an improvement against the degradation effects of many error sources, leaving the scintillation effect that has a quasi-random nature and the multipath as the most significant and dominant error contributions in positioning. In parallel, the advancement of the technology for processors is boosting the fully software implementations of GNSS receivers running on a General-Purpose Processor (GPP), also for multi-band and multi-constellation architectures. Among the well-known advantages of such flexible implementations, the software approach opens the door to new paradigms for the implementation of the receiver functions needed for signal processing and position estimation, and receiver implementations have been constantly evolving to alleviate the performance degradation effects of error sources such as scintillation and multipath.

In this context, this thesis aims at analyzing the effects of scintillation and multipath through GNSS observables and measurements utilizing the implemented post-processing GNSS receiver and investigating and designing the scintillation and multipath detection methods based on Artificial Intelligence (AI) solutions. Assessing the performance analysis of GNSS receiver acquisition and tracking stages allows to choose the best setting of the acquisition and tracking parameters to provide the receiver operation at a comparable performance level by testing the robustness of the implemented algorithms under harsh amplitude and phase scintillation conditions. Detecting and monitoring the scintillation effects to estimate the ionospheric scintillation in its early stages and measure the scintillation parameters are important as well. With the evolving AI world, Machine Learning (ML) algorithms have gained importance to be applied for the detection of similarities and outliers among the observables and measurements. In this thesis, one of the proposed methods based on supervised machine learning algorithms, namely, Support Vector Machines (SVM) is implemented and analyzed through

different kernel functions such as linear, Gaussian Radial Basis Function (RBF), and polynomial for scintillation detection. The work addressed the investigation of an optimal kernel function and parameter settings for this specific task, trading-off performance, space and time complexity of the method. It is also known that the presence of multipath errors falsely inflates the measurements of the ionospheric scintillation activity. It is then of paramount importance to detect the satellite signals that suffer from the multipath effect to reach an acceptable positioning accuracy and to increase the scintillation detection performance. The developed and implemented multipath detection algorithms work at the measurement level and are based on unsupervised ML algorithms, namely, K-means and Self-Organizing Map (SOM). It is demonstrated in the thesis that this ML approach overcomes the limitation of the availability of training data sets a-priori obtained as representative of multipath and no-multipath conditions. The measurement sets computed for each tracked satellite signal, namely, carrier phase, pseudorange, and carrier-to-noise ratio are in fact used to create clusters of consistent measurements. The performance of the detection algorithms is assessed under different conditions with collected different datasets.

To sum up, within the framework of this thesis study, starting from the design and implementation of multi-frequency multi-constellation software GNSS receiver, a detailed analysis of different signal acquisition and tracking methods in order to test their robustness to the presence of scintillation and to select optimal setting parameters has been realized. Having analyzed the effects of multipath and scintillation on the receiver observables and measurements, investigation and use of AI solutions through different ML algorithms to develop new countermeasures have been studied.