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Global Navigation Satellite Systems as Signals of Opportunity for Environmental Applications

Reflectometry and Scintillation

By

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Global Navigation Satellite Systems as Signals of Opportunity for Environmental Applications

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The proposals on opportunistically utilizing Global Navigation Satellite Systems' (GNSS) signals for environmental monitoring came to light hand in hand with proposing the GNSS systems themselves. GNSS satellites broadcast signals that can be exploited for positioning, navigation and timing anywhere and at any time on Earth. The high temporal and geographic availability of the GNSS satellites, together with particular properties of the GNSS signals, made them an ideal remote sensing tool. Here, the satellites are considered as radio signals sources to be utilized by passive remote sensing sensors. Many applications have been successfully deployed based on this concept including GNSS-Reflectometry (GNSS-R), and GNSS scintillation.

Today, less than 50 years after the first GNSS satellite was launched and less than 30 years after the first GNSS system was declared fully operational, GNSS systems contribution to environmental monitoring is evident in our daily life. Opportunistic use of GNSS signals as remote sensing data sources is already contributing to weather forecast and environmental hazards monitoring, including hurricanes and floods. Moreover, the upper atmosphere environment, that is affected by both space and Earth environmental conditions, is monitored using GNSS signals. Monitoring the ionospheric conditions is important because it affects directly and indirectly many of the critical infrastructures on Earth. Scintillation, which is rapid random fluctuations in the amplitude and phase of radio waves resulting from the signal passing through plasma density irregularities in the ionosphere, is the most important source of ionospheric errors that affect GNSS systems in particular.

In this thesis, detecting floods using special GNSS receivers and a technique known as GNSS–R is discussed. Also, detecting ionospheric perturbed conditions leading to ionospheric scintillations using another type of special GNSS receivers, known as Ionospheric Scintillation Monitoring (ISM) receivers, is discussed.

For floods detection, the feasibility of using data from GNSS–R receivers mounted onboard small Unmanned Aerial Vehicles (UAVs) are investigated. Tak-

ing into account the constraints imposed on/by such platforms, a signal processing methodology that respects such constraints when processing the signals reflected by the potential floods is implemented. The method roughly estimates the reflected signal strength with respect to the noise floor, and it is demonstrated that such rough estimation is capable of accomplishing the water detection task with high accuracy. Also, the importance of UAV-based multi-constellation GNSS–R receivers for accurate estimation of water extents is investigated. Moreover, the importance of the UAV-based GNSS–R sensor calibration is discussed. It is demonstrated that, for floods detection, the calibration is not strictly necessary. However, for estimating the amount of reflected power and the height of the water surface (i.e extracting more parameters of the water/floods), calibrating the sensor is necessary.

For scintillation detection, the utilization of Machine Learning (ML) algorithms for detecting scintillation in GNSS data to overcome the known limitations of the scintillation detection metrics is discussed. ML techniques has demonstrated success in many scientific fields including GNSS signal processing and scintillation modelling. It is demonstrated that ML models are able to perform better than the scintillation metrics thresholds in scintillation detection. It is also demonstrated that ML models can detect scintillation in environments where interference, multipath in particular, exists. In this regard, 98% detection accuracy, 2% scintillation miss-detection and 2% scintillation false alarm is demonstrated for a model developed for equatorial scintillation, while 95% accuracy, 5% scintillation miss detection and 5% scintillation false alarm are demonstrated for high latitude phase scintillation detection. The abilities of various ML algorithms, with different hyper-parameters, in carrying out the detection task is also investigated. It is found that bagged decision trees give superior performance. Finally, various measurements available in ionospheric scintillation monitoring records as well as in high rate post-correlation data are investigated. For low latitude scintillation, the signal intensity measurements at high rate (50 Hz) are essential and sufficient. On the other hand, it is found that 3-minutes Total Electron Content (TEC) data are able to surpass the scintillation metrics in detecting polar scintillations. This could open the door for unprecedented expansion in global scintillation monitoring by utilizing a wide range of professional GNSS receivers, other than the ISM receivers, that are already providing TEC measurements.