Title:
Analysis of high-frequency GNSS time series by Machine Learning techniques for real-time monitoring of volcanic and seismic active areas

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Research program

Monitoring ground deformations with systems capable of providing accurate and real-time high-frequency data represents a scientific and technological challenge that, thanks to the use of different types of instruments, is leading to a new and more careful implementation of the early warning systems available in the Control Rooms of the major volcanological and seismological observatories around the world. In particular, INGV, at its Naples and Grottaminarda Sections, has recently implemented real-time ground deformation monitoring systems using high-frequency (1 Hz) GNSS data for the monitoring of Neapolitan volcanic area (Campi Flegrei, Vesuvius and Ischia) and the seismogenic areas of the southern Apennines. These systems are aimed at identifying sources of surface deformation associated with significant variations in the state of volcanoes and seismogenic structures.
The availability of this huge amount of data requires GNSS time series analysis tools that enable the monitoring system to timely and reliably recognize precursor signals of magmatic/seismic processes, such as variations in deformation trends, as well as the estimation of the seismic source parameters. High-frequency time series are classically characterized by background noise of significant amplitude. Therefore, the main problem to be addressed in the analysis of high-frequency GNSS signals is the improvement of the signal-to-noise ratio.

The aim of this project is to evaluate the effectiveness of denoising techniques based on classical frequency domain filtering methods (Fourier analysis) and signal decomposition methods based on Discrete Wavelet Transform (DWT), Empirical Mode Decomposition (EMD) and Principal Component Analysis (PCA). These techniques are routinely very 'onerous' in terms of computing resources and, therefore, unsuitable for implementation in 'real time' systems. We aim to develop a proxy that has the same effectiveness as the well-known filtering techniques, but a low computational cost, such that it can be used for real time applications. This objective can be achieved through the use of the state-of-the-art Machine and Deep Learning techniques, which, by virtue of their flexibility and complexity, are able to theoretically reproduce any non-linear function. In the present project, the large

availability of high-frequency data will make it possible to suitably train an algorithm to emulate GNSS time series analysis systems, thereby increasing the potential for detecting transient signals in ground deformations.

Proposal for a PhD position

The project will be developed jointly with two INGV Sections (Naples Section, "Osservatorio Vesuviano" and Irpinia Section, Grottaminarda), and will take advantage of the availability of historical GNSS time series acquired on the NeVoCGPS and RING networks, as part of the INGV's volcanological and seismic surveillance activities, as well as analog simulators designed *ad hoc* for the production of synthetic deformation signals.

The research will be developed, over the three-years of the PhD program, as follows:

1st Year: Literature research and study of the theoretical foundations of signal analysis. Use of GNSS data processing software.

2nd Year: Data analysis; 6-month internship abroad at the University of Beira Interior (Portugal), for the study of advanced GNSS data denoising techniques, and the Hebrew University of Jerusalem (Israel), for the study of Machine Learning techniques. Presentation of research results at international conferences and in peer-reviewed articles.

3rd Year: Development of real time algorithms for the recognition of transients in ground deformation signals to be implemented in monitoring systems of the investigated areas. Presentation of results at international conferences and in peer-reviewed articles. Writing of PhD thesis.

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