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XXXVII Cycle

# Satellite Navigation Signal Exploitation for Atmospheric and Environmental Monitoring


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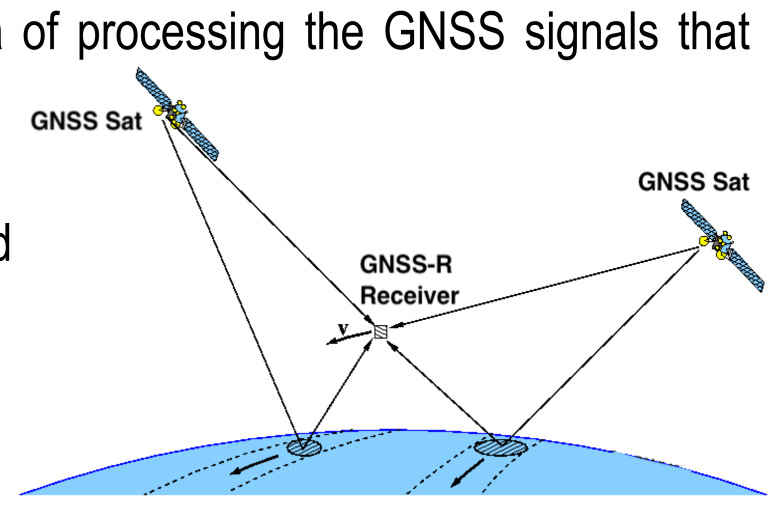
## Research context and motivation

- The Global Navigation Satellite Systems (GNSS) such as GPS, GLONASS, and Galileo have been established as one of the most critical infrastructures widely used for position estimation and navigation purposes. However, they are also fundamental tools for many scientific applications, including atmospheric monitoring and environmental remote sensing.
- A significant source of error in GNSS positioning is signal propagation through the atmosphere (ionosphere and troposphere layers). The free electron density in the ionosphere affects the speed of the transmitted signal and introduces propagation delay due to the interaction between charged particles and the electromagnetic wave of the signal. The troposphere is the humid part of the atmosphere, which causes attenuation power in a signal. If the effects of these layers are not modeled well enough, they can lead to material misstatement. By reversing the problem, if the GNSS receiver is static and its position is known with high accuracy, it is possible to process GNSS observables to characterize the effects along the signal propagation path, thus estimating the properties of the atmosphere, thanks to a large number of satellites and signals available today.
- Furthermore, the received signals at the antenna of the GNSS receivers could be reflected from another surface, known as Multi-path and is a major error source for GNSS receivers. In the past decades, the idea of processing the GNSS signals that have been reflected and diffused by the terrestrial surfaces has been introduced and is called "GNSS-reflectometry (GNSS-R)". This is achieved thanks to special receivers onboard satellites and/or drones and it enables environment characterization, known as remote sensing.




## Addressed research questions/problems

- To provide a model of the atmosphere in a specific area, the required system must include static receivers of which the position is known with high accuracy. Digital Signal Processing (DSP) techniques can be applied to extract the differences between the received signal at the antenna and the ideal received signal based on the known position. Along with classical methods that have been studied and proposed recently, Machine learning (ML) which is the consistent study of intelligent algorithms and systems can be a new tool in this process to assist in the characterization of the signal features in a statistical sense. ML focuses on applications that learn from experience to improve their decision-making process or predictive accuracy over time. ML algorithms can aid in providing a model of the atmosphere at the top of known points and also predicting the area where there is not enough information or received signal.
- In the GNSS band, radio frequency interferences (intentional or unintentional) are an important aspect since they are a threat to the use of GNSS signals for atmospheric monitoring, biasing the estimation of ionospheric parameters. Such spurious signals need to be identified and their type must be recognized to be able to mitigate them.
- The sudden and rapid fluctuations of phase and amplitude of the GNSS signals triggered by electron density irregularities are commonly referred to as ionospheric scintillations. GNSS signals experience deep signal fading and random phase fluctuations in the presence of scintillations and may cause an outage in the receiver. The GNSS signals can be exploited as signals of opportunity to monitor ionospheric irregularities by processing the GNSS signals through dedicated ground-based monitoring equipment. In this field, optimizing the GNSS monitoring station is an important aspect and more specifically, the reduction of its computational complexity and the increase of its efficiency.

## Novel contributions

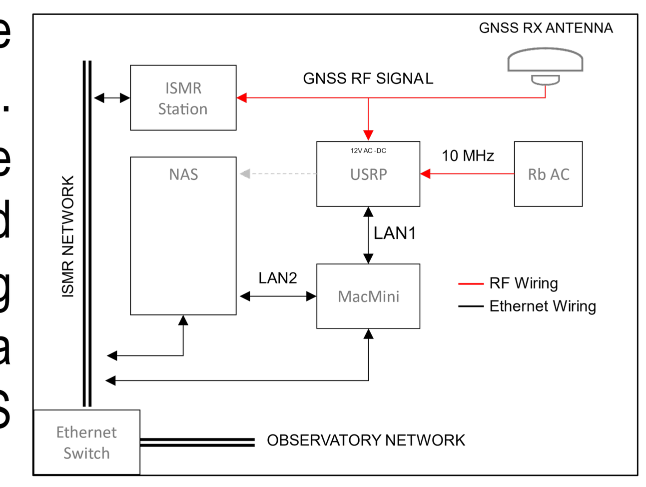
- The paper "Detection and Classification of GNSS Jammers Using Convolutional Neural Networks" proposes a method for automatic and accurate detection of chirp signals which are known as the most common type of disruptive or interfering signals. The classifier is a Convolutional Neural Network (CNN) based on multi-layer neural networks that operate on the representation of the signals in transformed domains.

## Submitted and published works


- I. Ebrahimi Mehr and F. Dovis, "Detection and Classification of GNSS Jammers Using Convolutional Neural Networks," International Conference on Localization and GNSS (ICL-GNSS), Tampere (Finland), 2022, pp. 01-06.

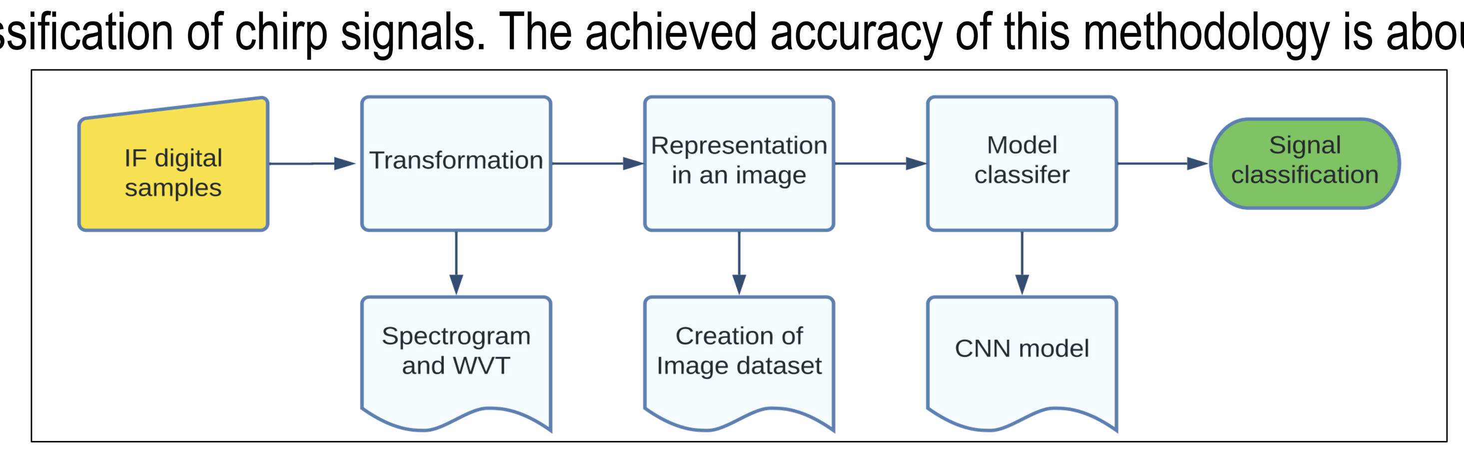

## Novel contributions

- This figure illustrates the high-level block scheme of the GNSS monitoring station that is installed in Lampedusa. In this architecture, Mac-mini is in charge of grabbing the GNSS signals and storing them in the Network-Attached Storage (NAS). Since NAS has a Linux-based operating system and the capability of running a container, the idea is to dockerize all the required applications for GNSS signal grabbing and run it in NAS directly.




## Adopted methodologies

- A general scheme of the adopted methodology for detection and classification of chirp signals is depicted in figure below, where the input is digitized GNSS signals in the presence or the absence of chirp signals. Since chirp signals behave differently in terms of time and frequency characteristics, Wigner-Ville and Short Time Fourier transforms are used. Then the representation of transformed signals is stored as an image in order to create image datasets. In the last step, a CNN classifier is implemented for the classification of chirp signals. The achieved accuracy of this methodology is about 95%.




- To optimize the architecture of the GNSS monitoring station, a Docker container with the Linux base operating system (Ubuntu) host all the required program for signal grabbing. Additionally, a user interface (flask python application) is developed to reconfigure all the parameters and to see the system's log. Some improvements of new architecture are :
  - Using two USRP simultaneously instead of one in the old architecture.
  - The sampling frequency is increased from 5 MHz to 10 MHz .
  - Each sample is stored in 32 bit instead of 16.
  - The Mac-mini is removed from the architecture (less cost and complexity).

## Future work

- Since the detection and classification of chirp signals in the GNSS band show high accuracy, the next step of this work is to design a model which is capable of identifying even more types of interference, either intentional or unintentional.
- The further step of the new GNSS monitoring station is to design a post-processing stage after grabbing the signal to identify the scintillation phenomena, which need to be installed in the same container.

## List of attended classes

- External - ESA-JRC international summer school on GNSS 2022 (22/07/2022, hours :50)
- 01UJBRV – Adversarial training of neural networks (06/06/2022, hours: 15 )
- 01TRARV – Big data processing and programming (01/03/2022, hours: 20 )
- 01UJZIU – Information visualization and visual analytics (30/06/2022, hours: 20 )
- 01RGBRV – Optimization methods for engineering problems (07/06/2022, hours: 30)
- 02SFURV – Advanced scientific programming in MATLAB (21/04/2022, hours: 30)
- 01QRPRV – Satellite Navigation signal exploitation for atmospheric and environmental monitoring (30/06/2022, hours: 15)
- 02LWHRV – Communication (5/8/2022, hours: 5)
- 01RRPRV – Lean start-up and business for innovation management (19/4/2022, hours:20)
- 08IXTRV – Project management (20/04/2022, hours: 5)
- 01RISRV – Public speaking (12/07/2022, hours: 5)
- 01SWPRV – Time management (11/04/2022, hours: 2)
- 01NDLRV – Lingua italiana II livello (17/02/2022)

## Award

- International Conference on Localization and GNSS – Best Paper Award
- ESA/JRC International Summerschool on GNSS 2022 - Project Competition - Rank No. 2

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