MaSAG23 Summer School and Conference
15-20 May 2023, Rome, Italy

SUMMER SCHOOL PROGRAM

Course 1: Mathematical Methods for Super-resolution Point-mass Recovery and Composite Signal Decomposition

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Abstract

Two intimately related problem areas in time series and composite signal processing will be discussed in this Workshop. The first is on the super-resolution inverse problem, with focus the following topics:

1. Introduction of "super-resolution wavelets (SRW)" and "continuous SRW transform" for resolving the super-resolution inverse problem, by isolation of the point-masses and amplification of the coefficients;
2. Explicit formulas for implementation of the continuous SRW transform and the corresponding search function;
3. Applications to microscopy for bio-medical research;
4. Introducing a Statistical tool for mixed probability function separation and recovery; and
5. Applications to healthcare in monitoring endocrine gland hormone secretion.

The second problem area is on "Empirical Mode Decomposition (EMD)" on the following topics:

1. Introduction of a modified sifting process for EMD on finite time-domains to avoid boundary artifacts;
2. Linear spline EMD for fast computation and real-time Hilbert transform implementation;
3. Construction of quasi-interpolation by cubic splines with local supports;
4. Enhanced cubic spline quasi-interpolation for direct computation of mean envelopes;
5. Local cubic spline interpolation for direct computation of mean envelopes;
6. Modified global cubic spline interpolation to minimize boundary artifacts;
7. Sifting process for computing IMF without computation of stopping criteria;
8. Hilbert transform on bounded intervals without boundary singularities as a result of the modified sifting process;
9. Pre-processing options for de-noising and for singularity removal of the first IMF; and
10. Implementation details of cubic spline EMD on bounded time-domain.

Course 2: Signal structures: Representations, Localization, Transformation, Interpretation

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Abstract
In this course, I will give an introduction to the mathematical tools involved in representing signals advantageously for certain applications. In order to so, inherent signal structures must be taken into account. We will first generally discuss the notion of structured signals and will then move on to mathematical basics of standard signal representations such as Fourier, Gabor and wavelet transforms. Then, adaptivity will be discussed: what is the potential, what are the pitfalls?
We will then move on to more specific and new results on sparse representations and representations used in convolutional neural networks. We will also touch on new results on analysis tools for data operators, which benefit from information about entire data sets instead of isolated data points. Finally, we will always give easily accessible examples from audio processing as application.

Course 3: Inverse problem theory and parameter fitting

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Abstract
Inverse problems are a relatively common occurrence in science, that appear when we need to find parameters that best fit experimental data. In these lessons, I will mostly describe the Bayesian approach to their solution, that provides a coherent and comprehensive framework where we find, as special cases, the common methods that provide convenient (and long-time popular) solutions. At the same time, I will also present very general solutions that — sometimes at a larger computational cost — may legitimately approach complex problems. I will pinpoint some common preconceptions and errors, that can easily be overcome, and that — although my examples will mostly be inspired by seismic tomography — can affect a wide variety of parameter fitting problems.

CONFERENCE PROGRAM

Time series analysis based on information-theoretic approaches for the study of the near-Earth electromagnetic environment

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Abstract

Learning from successful applications of time series analysis methods originating in complex systems science and information theory in one scientific field (e.g., atmospheric physics or climatology) can provide important insights or conceptual ideas for other areas (e.g., space sciences) or even stimulate new research questions and approaches. For instance, quantification and attribution of dynamical complexity in output time series of nonlinear dynamical systems is a key challenge across scientific disciplines. Especially in the field of space physics, an early and accurate detection of characteristic dissimilarity between normal and abnormal states (e.g., pre-storm activity vs. magnetic storms) has the potential to vastly improve space weather diagnosis and, consequently, the mitigation of space weather hazards. This review illustrates how complementary modern complex systems approaches have recently shaped our understanding of the coupled solar wind – magnetosphere – ionosphere system. The rising number of corresponding studies demonstrates that time series analysis based on information theory offers great potentials for uncovering relevant yet complex processes interlinking different geospace subsystems, variables and spatiotemporal scales.

On the time-frequency representation of nonstationary signals: old problems and new opportunities

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Abstract
In many applied fields of research, like Geophysics, Medicine, Engineering, Economy, and Finance, to name a few, classical problems are the extraction of hidden information and features, like quasi-periodicities and frequency patterns, as well as the separation of different components contained in a given signal, like, for instance, its trend.

Standard methods based on classical Fourier and Wavelet Transform, historically used in Signal Processing, proved to be limited when nonlinear and non-stationary phenomena are present. For this reason, in the last two decades, several new nonlinear methods have been developed by many research groups around the world, and they have been used extensively in many applied fields of research.

In this talk, we will review the Iterative Filtering technique [1] and its generalizations to handle multidimensional [2], multivariate [3], or highly non-stationary signals [4], as well as the newly developed time-frequency representation called IMFogram [5]. We will discuss the theoretical and numerical properties of this method and show its applications to real-life data.
We will conclude the talk by reviewing the main problems which are still open in this research field.

[1] A. Cicone, H. Zhou. Numerical Analysis for Iterative Filtering with New Efficient Implementations Based on FFT. Numerische Mathematik, 147 (1), pages 1-28, 2021
[2] A. Cicone, H. Zhou. Multidimensional Iterative Filtering method for the decomposition of high-dimensional non-stationary signals. Cambridge Core in Numerical Mathematics: Theory, Methods and Applications, Volume 10, Issue 2, Pages 278-298, 2017
[3] A. Cicone and E. Pellegrino. Multivariate Fast Iterative Filtering for the decomposition of non-stationary signals. IEEE Transactions on Signal Processing, Volume 70, pages 1521-1531, 2022
[4] G. Barbarino and A. Cicone. Stabilization and Variations to the Adaptive Local Iterative Filtering Algorithm: the Fast Resampled Iterative Filtering Method. Submitted
[5] P. Barbe, A. Cicone, W. S. Li, H. Zhou. Time-frequency representation of nonstationary signals: the IMFogram. Pure and Applied Functional Analysis, Volume 7, Number 1, 27-39, 2022

Time-Frequency analysis for ionospheric studies

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Abstract
The ionosphere is the upper part of the Earth's atmosphere where the presence of free-electrons and ions can impact the propagation of radio waves. The variability of the ionospheric morphology depends on regular phenomena (daily variation of sunlight, seasons, solar cycles) but also on quite unpredictable phenomena like Solar storms, geomagnetic storms and lithospheric events (earthquakes, volcanic eruptions, tsunami etc.).
The capability to monitor and study the ionosphere rely on ground based and space born instruments that measure remotely or *in situ* the characteristic of the ionized medium. One of the widely used ground-based instruments is the Global Navigation Satellite Systems (GNSS) receiver that, acquiring signals from satellites orbiting at about 22000 km, is capable of determine the number of free electrons in the ionosphere but also the presence of small scale (a few hundreds of meters) irregularities in the electron density distribution. To quantify such characteristics of the ionosphere, the so-called Total Electron Content (TEC) and Amplitude scintillation index (S4) are used, respectively. The former is the total number of free electrons in a cylinder of 1 square meter base and extended from the satellite in orbit down to the receiver at ground, the latter is an index representing the standard deviation of the amplitude of the signal received at ground normalized to its mean over a given time (usually 1 minute).
This talk will describe how the techniques for decomposition and analysis of non-stationary and non-linear signals, like Empirical Mode Decomposition and Fast Iterative Filter, can help in understanding the relationship between the time-frequency content of the above-mentioned ionospheric quantities and the source of their variability. After a brief introduction on ionospheric monitoring fundamentals, the talk will introduce some recent results achieved by the international scientific community thanks to the use of such advanced techniques.
Both studies on Space weather effects on the ionosphere and on Lithosphere-Atmosphere-Ionosphere coupling will be illustrated and discussed from data analysis and scientific point of view.

Signal decomposition, segmentation and denoising with time-varying wave-shape functions

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Abstract

Modern time series are usually composed of multiple oscillatory components, with time-varying frequency and amplitude contaminated by noise. The signal processing mission is further challenged if each component has an oscillatory pattern, or the wave-shape function, far from a sinusoidal function, and the oscillatory pattern is even changing from time to time. In practice, if multiple components exist, it is desirable to robustly decompose the signal into each component for various purposes, and extract desired dynamics information. Such challenges have raised a significant amount of interest in the past decade, but a satisfactory solution is still lacking. We will present a novel nonlinear regression scheme to robustly decompose a signal into its constituting multiple oscillatory components with time-varying frequency, amplitude and wave-shape function. We coined the algorithm shape-adaptive mode decomposition (SAMD). Then, we will introduce an algorithm to estimate multiple wave-shape functions (WSF) from a nonstationary oscillatory signal with time-varying amplitude and frequency. Suppose there are finite different periodic functions, as WSFs that model different oscillatory patterns in an oscillatory signal, where the WSF might jump from one to another suddenly. The proposed algorithm detects change points and estimates from the signal by a novel iterative warping and clustering algorithm, which is a combination of time-frequency analysis, singular value decomposition entropy and vector spectral clustering.

Radar signal processing for ionospheric research

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Abstract

Ionospheric research is pursued using a wide variety of radar systems with different sizes and capabilities, and the range of methods applied to this research is equally wide. Many of the methods are exemplified by coherent scatter applications which are used to study backscatter from field-aligned plasma density irregularities in the ionosphere. In this talk, radar imaging methods for coherent scatter radars will be discussed in detail. Aperture-synthesis images of ionospheric irregularities in the equatorial electrojet are computed using multiple-input multiple-output (MIMO) radar methods at the Jicamarca Radio Observatory outside Lima, Peru. MIMO increases the number of distinct interferometry baselines available for imaging along with the overall size of the synthetic aperture. The particular method investigated here involves time-division multiplexing or time diversity to distinguish pulses transmitted from different parts of the Jicamarca array. The method comes at the cost of a large increase in computation time and complexity and a reduced signal-to-noise ratio. The optimization tradespace of MIMO methods will be discussed.

Breaking the Limitations of Conventional Sea Wave Monitoring: A Micro-Seismic-Based Machine Learning Solution

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Abstract
This presentation showcases a novel approach to sea wave monitoring using machine learning algorithms for processing micro-seismic data. The conventional in situ solution using moored buoys is unreliable and often results in incomplete datasets. To address this, we propose a system that includes a micro-seismic measuring station and a machine learning algorithm to reconstruct missing buoy data accurately. By measuring micro-seismic signals generated by the sea waves, the algorithm is trained to provide missing buoy data. As the micro-seismic station can be installed indoors, this solution ensures high reliability. Our case study, using data from the Northern Tyrrhenian Sea, demonstrates that this approach can accurately reconstruct both significant wave height and wave period data. The experimental results show that our system overcomes reliability issues while maintaining accuracy.

Reference
Iafolla L., Fiorenza E., Chiappini M., Carmisciano C. and Iafolla V.A. (2022) Sea Wave Data Reconstruction Using Micro-Seismic Measurements and Machine Learning Methods. Front. Mar. Sci. 9:798167. doi: 10.3389/fmars.2022.798167.

Variational Signal Decomposition Into Jump, Oscillation and Trend

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Abstract

We propose a two phases signal decomposition method which efficiently separates a given signal into Jump, Oscillation and Trend. Both traditional Time-Frequency analysis methods, like Short Time Fourier Transform, wavelet, and advanced ones, like Synchrosqueezing wavelet, Hilbert Huang Transform or IMFogram, can fail when abrupt changes and jump discontinuities appear in the signal. We present a variational framework separating piece-wise constant jump features as well as smooth trends and oscillating features of a given signal. The proposed model is independent from the choice of basis functions, and doesn't have different level of decompositions which can be affected by large discontinuities. The optimization problem is efficiently solved by an alternating minimization strategy.

[1] A. Cicone, M. Huska, S. -H. Kang and S. Morigi, "JOT: A Variational Signal Decomposition Into Jump, Oscillation and Trend," in *IEEE Transactions on Signal Processing*, vol. 70, pp. 772-784, 2022, doi: 10.1109/TSP.2022.3145665.

Central and Non-central Limit Theorems Arising from Time-Scale Representations of Random Processes

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(2) National Yang Ming Chiao Tung University, Hsinchu, Taiwan
(3) Duke University, Durham, North Carolina, USA

Abstract
In this talk, we will consider a sequence of non-Gaussian processes arising from a stationary Gaussian process iteratively convolved with different scale wavelets and transformed by nonlinear functions. We will show that the limit of the distribution of the transformed process when the scale parameters of wavelets tend to infinity depends on the behavior of the Fourier transform of wavelets near the origin and the Hermit rank of nonlinear functions. For some cases, we further identify the speed of convergence by using the Malliavin calculus and Stein's method. The content of this talk is based on my recent work [1-2] with Yuan-Chung Sheu and Hau-Tieng Wu.

[1] Gi-Ren Liu, Yuan-Chung Sheu and Hau-Tieng Wu. (2022). Central and non-central limit theorems arising from the scattering transform and its neural activation generalization. *SIAM Journal on Mathematical Analysis* (in press, 45 pages; early version, 53 pages, arXiv:2011.10801).
[2] Gi-Ren Liu, Yuan-Chung Sheu and Hau-Tieng Wu. (2022). Asymptotic Analysis of Higher-order Scattering Transform of Gaussian Processes. *Electronic Journal of Probability* 27, 1-27.

Ionospheric studies with the LOFAR radio telescope

Maaijke Mevius[1]

(1) Netherlands Institute for Radio Astronomy (Astron), Dwingeloo, the Netherlands

Abstract
The LOFAR radio telescope is one of the world's largest low frequency radio telescopes consisting of many thousands of dual dipole antennas distributed over a European network of stations, with its core in the northern part of the Netherlands. The system is built to allow maximal flexibility in data acquisition, ranging from raw antenna time series data, single station beamformed data and the so-called interferometric mode: storing cross correlations between all stations. LOFAR operates at frequencies between 10 and 240 MHz. At these frequencies, the ionosphere is a major source of distortion for astronomical observations, which to a large extent can be removed by applying calibration techniques. Ionospheric calibration reveals a wealth of information on the ionospheric structures itself, especially at small spatial scales. In this presentation I will discuss the different observation modes of LOFAR and how we extract ionospheric information using a number of different techniques.

Radiofrequency interferences hunting: A case study on Global Navigation Satellite Systems Signals

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Abstract
As per our daily experience, Radio Frequency (RF) signals transmitted by Global Navigation Satellite Systems (GNSS) are exploited worldwide for radio navigation purposes. Furthermore, they are used as signals of opportunity in a variety of scientific activities, spanning from the remote sensing of waterways and humidity of the terrain to the monitoring of the upper layers of the atmosphere. Unfortunately, GNSS signals are susceptible to intentional or unintentional RF interferences (RFIs), which may alter the calculation of the positioning, velocity, and timing solutions of GNSS receivers up to denial of service. Unexpected effects can be observed for the computation of scientifically-relevant metrics such as the ionospheric scintillation indices. While the effects on positioning and navigation technologies are well known and documented [1], the actual observations of anomalous scientific data rarely are documented due to their perceived marginal impact on daily human activities. However, recent interference-hunting investigations have been reported about these signals that are contributing to question on the reliability of GNSS-related scientific products [3,4]. Such activities mainly consist of signals recording, replay, and real-time or post-processing analyses that require dedicated, Software Defined Radio (SDR) hardware and software solutions to guarantee the effectiveness and sufficient autonomy of the operations. Through the case study of anomalous scintillation indices computed by a GISTM receiver on the Island of Lampedusa [3,4], this talk highlights the main results of the analysis, characterization, and modeling of an unidentified, deliberate RFI acting on the L1/E1 GNSS signal bands, as it has been observed and captured through an experimental, SDR setup. Adverse impacts of the RFI on the amplitude scintillation indices estimated for space weather applications are discussed. The contribution discloses current limits and future research trends on interference detection and localization, and a demonstration of a novel SDR data recording and analysis system developed by Politecnico di Torino and Istituto Nazionale di Geofisica e Vulcanologia (INGV) is contextually provided to support future investigations.

[1] F. Dovis. (Ed.). (2015). GNSS interference threats and countermeasures. Artech House.
[2] C. Cristodaro, F. Dovis, N. Linty and R. Romero, "Design of a Configurable Monitoring Station for Scintillations by Means of a GNSS Software Radio Receiver," in IEEE Geoscience and Remote Sensing Letters, vol. 15, no. 3, pp. 325-329, March 2018, doi: 10.1109/LGRS.2017.2778938.
[3] A. Minetto, E. Pica, C. Cesaroni, F. Dovis, "Results of One-Year Observation of a Jamming Interferer Degrading Amplitude Scintillation Indices in GISTM Receiver," Proceedings of the 2023 International Technical Meeting of The Institute of Navigation, Long Beach, California, January 2023, pp. 966-979, doi:10.33012/2023.18619
[4] E. Pica, A. Minetto, C. Cesaroni and F. Dovis, "Analysis and Characterization of an Unclassified RFI Affecting Ionospheric Amplitude Scintillation Index over the Mediterranean Area," in IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, doi: 10.1109/JSTARS.2023.3267003.

Emprical Mode Decomposition with GP/Kernel methods

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Abstract
We present a kernel/Gaussian Process (GP) based approach (kernel mode decomposition) to empirical mode decomposition. It is based on iterations between (1) representing the signal with an additive GP (a sum of independent GPs), (2) conditioning on data to recover modes/patterns, (3) updating the kernel based on the activation of the underlying independent GPs after conditioning, (4) peeling off individual modes from the signal after recovery.
The proposed approach is interpretable and amenable to theoretical analysis, it achieves near-machine precision in the recovery of the modes when the amplitudes, frequencies, and waveforms of underlying modes are all unknown, and it is capable of handling situations where frequencies cross. We also show that the proposed approach can be seen as a more general framework aimed at programming kernels with regression networks and generalizing Gaussian Process Regression from the approximation of input/output functions to the completion of computational graphs.

[1] H. Owhadi, C. Scovel and G. R. Yoo. Kernel Mode Decomposition and the programming of kernels. Springer 2021.
Book: https://link.springer.com/book/10.1007/978-3-030-82171-5
Arxiv: https://arxiv.org/abs/1907.08592
Code: https://github.com/kernel-enthusiasts/Kernel-Mode-Decomposition-1D
[2] H. Owhadi Computational Graph Completion.
Research in the Mathematical Sciences 9 (2), 27 (2022)
Arxiv: https://arxiv.org/abs/2110.10323

Graph signal processing meets nonstationary signal processing

Naveed ur Rehman[1]

(1) Aarhus University, Denmark

Abstract

In this talk, a new method will be presented that enables the decomposition of multivariate signals into a set of constituent modes which can be interpreted in terms of their temporal, spectral, and topological characteristics – known as the *graph modes* [1]. The graph modes represent the finite number of oscillatory signal components and quantify the functional connectivity of graph vertices at multiple scales based on their signal content. We achieve that by combining the emerging field of graph signal processing and data-driven non-stationary signal processing. Specifically, a new variational optimization formulation is developed that includes necessary temporal, spectral, and topological requirements for the decomposition of multivariate signals into graph modes. The optimization formulation is solved using the alternating direction method of multipliers (ADMM) and the primal-dual optimization approach. The ability of the method to enable a joint analysis of the temporal and topological characteristics of time-varying graph signals at multiple frequency bands/scales is demonstrated on synthetic and real data sets.

[1] N. Rehman, “Time-varying graph mode decomposition”, arXiv:2301.03496v1, 2023

Nonconvexity of Sparsity Promoting Functions

Lixin Shen[1]

(1) Syracuse University, USA

Abstract
Sparsity promoting functions (SPFs) serve as a key ingredient for the sparse modeling. In this talk, we first briefly review some existing SPFs. We particularly focus on SPFs that are the ratio of the L1 and L2 norms and its variants. We then present algorithms for the applications of these SPFs in compressive sensing.

Some recent progress in nonlinear biomedical time series analysis

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(2) Department of Statistical Science, Duke University, Durham, NC

Abstract
In the clinical arena we are moving beyond snapshot health data. Physicians are now provided and confronted by multimodal physiological data collected over long stretches of time. The nonstationarity and heterogeneity nature of these datasets can impose a serious challenge for health care providers. I will discuss recent progress in dealing with such signals, including extracting actionable information by signal decomposition, uncertainty quantification, and others. Real world examples will be demonstrated.

RRCNN: A novel signal decomposition approach based on recurrent residue convolutional neural network

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(3) Georgia Institute of Technology, Atlanta, United States

Abstract
The decomposition of non-stationary signals is an important and challenging task in the field of signal time-frequency analysis. In the recent two decades, many signal decomposition methods led by the empirical mode decomposition, which was pioneered by Huang et al. in 1998, have been proposed by different research groups. However, they still have some limitations. For example, they are generally prone to boundary and mode mixing effects and are not very robust to noise. Inspired by the successful applications of deep learning in fields like image processing and natural language processing, and given the lack in the literature of works in which deep learning techniques are used directly to decompose non-stationary signals into simple oscillatory components, we use the convolutional neural network, residual structure and nonlinear activation function to compute in an innovative way the local average of the signal, and study a new non-stationary signal decomposition method under the framework of deep learning. We discuss the training process of the proposed model and study the convergence analysis of the learning algorithm. In the experiments, we evaluate the performance of the proposed model from two points of view: the calculation of the local average and the signal decomposition. Furthermore, we study the mode mixing, noise interference, and orthogonality properties of the decomposed components produced by the proposed method. All results show that the proposed model allows for better handling boundary effect, mode mixing effect, robustness, and the orthogonality of the decomposed components than existing methods.

Weak Adversarial Networks (WAN): A Computational Method for High-dimensional PDEs and Inverse Problems

Haomin Zhou[1]

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Abstract

We present a weak adversarial network approach to numerically solve a class of PDEs and inverse problems. The weak formulation of PDE is leveraged with deep neural networks and induces a minimax problem. The solution can be computed by finding the saddle points in the network parameters. As the parameters are updated, the network gradually approximates the solution. The proposed method is mesh-free without any spatial discretization and is suitable for problems with high dimensionality and low regularity on solutions. Theoretical justifications are provided on the convergence of the proposed algorithm. Numerical experiments on a variety of test problems demonstrate the promising accuracy and efficiency of this approach. This presentation is based on the joint work with Gang Bao (Zhejiang U.), Xiaojing Ye (Georgia State U.) and Yaohua Zang (Zhejiang U.) reported in the following papers.

[1] Gang Bao, Xiaojing Ye, Yaohua Zang, and Haomin Zhou, Numerical solution of inverse problems by weak adversarial networks, Inverse Problems, Vol 36, No. 11, 2020.

[2] Yaohua Zang, Gang Bao, Xiaojing Ye, Haomin Zhou, Weak adversarial networks for high-dimensional partial differential equations, Journal of Computational Physics, Volume 411, 15 June 2020.

POSTER SESSION

Analysis of tsunami signals with Fast Iterative Filtering and the IMFogram algorithm

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(2) Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy

Abstract
Signals from tide gauges and ocean-bottom pressure gauges play a fundamental role in analysis and real-time monitoring of tsunami waves. However, these records contain contributions by different physical phenomena, such as tides, local resonance effects, and seismic waves that, close to the earthquake source area, may interact and overlap with the tsunami. Usually, analysis of these time series is carried out by harmonic or wavelet analysis [1].

In the last three decades, a lot of attention has been devoted to the study of nonlinear and nonstationary time series, for which appropriate techniques need to be developed. Most of these consist of two steps: i) signal decomposition into simpler components and ii) time-frequency analysis on each component. Applications of some of these techniques to tsunamis may be found in [2], [3], [4].

In the present study, tsunami signals are analyzed through the (Fast) Iterative Filtering technique [5], [6] for the decomposition step, while the IMFogram algorithm [7] is used for the time-frequency analysis. It is shown how physical features of the signals are extracted from the tsunami time series and comparisons are made with similar techniques. Particular attention is given to tsunami time series recorded by tide gauges for Mediterranean events, where robust analysis methods are needed, among other reasons, to remedy the absence of deep sea sensors and the sparsity of coastal instruments.

[1] Heidarzadeh, M., and Satake, K. "Waveform and spectral analyses of the 2011 Japan tsunami records on tide gauge and DART stations across the Pacific Ocean." *Pure and Applied Geophysics* 170 (2013): 1275-1293.
[2] Vecchio, A., M. Anzidei, and V. Carbone. "New insights on the tsunami recording of the May, 21, 2003, Mw 6.9 Boumerdès earthquake from tidal data analysis." *Journal of geodynamics* 79 (2014): 39-49.
[3] Wang, Y. et al. "A method of real-time tsunami detection using ensemble empirical mode decomposition." *Seismological Research Letters* 91.5 (2020): 2851-2861.
[4] Wang, Y. and Satake, K. "Real-time tsunami data assimilation of S-net pressure gauge records during the 2016 Fukushima earthquake." *Seismological Research Letters* 92.4 (2021): 2145-2155.
[5] Cicone A., Liu J. and Zhou, H. "Adaptive Local Iterative Filtering for Signal Decomposition and Instantaneous Frequency analysis". Applied and Computational Harmonic Analysis, Volume 41, Issue 2, September 2016, Pages 384-411.
[6] Cicone, A. and Zhou, H. "Numerical Analysis for Iterative Filtering with New Efficient Implementations Based on FFT". Numerische Mathematik, 147 (1), pages 1-28, 2021
[7] Cicone, A., Li, W. S., & Zhou, H. (2022). New theoretical insights in the decomposition and time-frequency representation of nonstationary signals: the IMFogram algorithm. *arXiv preprint arXiv:2205.15702*.

New methods to analyse signals defined on spheres

R. Cavassi[1], A. Cicone[1], W. S. Li[2], E. Timko[2], and H. Zhou[2]

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(2) Georgia Institute of Technology, Atlanta, United States of America

Abstract

From a scientific point of view, this theme is extremely interesting. Geologists and astrophysics, for example, need to study signals defined on a sphere, maybe the most famous is the so called `Cosmic Microwave Background Radiation'. The problem is that, in this moment, there are very few tools to analyze such data and none of them has a focus on oscillatory behaviors.

The main idea of this project is to extend the Iterative Filtering technique to signals defined on spheres. Iterative Filtering is a technique which permits to study a signal through its decomposition in oscillatory components. To obtain this result we convolve, in an iterative way, the signal with another function called filter. Obviously, the shape and size of the filter have a strong impact on the decomposition but, since we use the convolution, it is possible to have some strong knowledge of the obtained functions.

However, there is not a unique definition of convolution for functions defined on spheres, because of the topological properties of this manifold. So, in our team we are trying to extend this method in two different ways. The simpler idea is to define new methods to evaluate local averages on this manifold.

On the other hand we are studying many possible convolutions on the sphere to determine which one presents our needed properties.

A Proposed Ionospheric Scintillation-Based Method to Detect Sub-centimeter Space Debris

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Abstract

Detection of space debris below the size limits of optical and radar-based methods (<1cm) is an open question. A new method of detecting orbital debris is being developed that uses debris-ionosphere interactions as a proxy for detecting the debris directly. Naturally stable plasma wave emissions, known as solitons, are emitted from debris plasma sheaths moving faster than the ion acoustic sound speed [1]. Existing proposed detection approaches of plasma solitons include incoherent scatter radar (e.g. EISCAT 3D [2]), spacecraft measurements (e.g. Swarm-E RRI instrument [3]), and active ionospheric research stations (e.g. HAARP). We propose a new detection method for plasma solitons based on scintillation measurements of GPS carrier frequency or another known radio transmission.

Plasma waves locally modify the electron density which in turn distorts radio waves in a highly frequency dependent manner that is described by the Appleton-Hartree equation. For frequencies above the ionospheric plasma frequency, this manifests as phase scintillation at the receiver where the amount of scintillation depends on the integral of electron density, known as the total electron count (TEC), in the beam. We estimate the magnitude of this modification to the TEC by a characteristic plasma soliton from simulation of the plasma with the Korteweg – De Vries equation superimposed on the International Reference Ionosphere (IRI) model and quantify the signal to noise ratio (SNR) necessary to detect this phase scintillation. We also show TEC data from the NOAA Continuously Operating Reference Stations Network with ground track of spacecraft flying overhead. Data is averaged spatially and temporally along the ground track. We compare bandpass filtered and unfiltered TEC data. It remains an open question as how best to establish a detection given the relatively sparse nature of the GPS TEC data compared to the size of the plasma waves.

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Estimation of spectral parameters from oblique Equatorial Electrojet echoes using a double skewed Gaussian model at JRO

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Abstract

Coherent echoes from the equatorial electrojet (EEJ) region are detected at the Jicamarca Radio Observatory (JRO) by using an array of 16 Yagi antennas with a main beam pointed obliquely to the west with an elevation of about 35 deg [1]. The spectrum of these observations are composed of two types of EEJ echoes (Type I and Type II) [2] from which we can estimate their main spectral parameters such as Doppler shift and spectral width independently for each type. Previously, the method applied to obtain these parameters was a standard fitting approach based on a double Gaussian model [3]. However, in some cases, the shape of the spectral measurements are not symmetric (resembling the shape of a skewed distribution). Based on simulations, we determined that the skewed shape of the oblique EEJ spectrum comes from the fact that the measured spectrum is the result of the sum of spectral contributions coming from different heights, with different Doppler shifts and spectral widths weighted by the antenna beam shape. The overall result is an asymmetric spectrum with a peak that does not coincide with the average Doppler shift. Thus, in order to account for this effect, we have implemented a double skewed Gaussian distribution model to fit the oblique EEJ measurements and estimate their spectral parameters. In this work, we present the results obtained in the simulation showing the skewed shape of the spectrum. Based on our simulations, we have also proved that the shift of the skewed Gaussian model can be interpreted as the Doppler Shift of the echoes. In addition, some examples of the new fitting procedure are shown in comparison with the classical Gaussian fitting where it can be seen the better agreement between the data and the double skewed Gaussian model.

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Graph model of phase lag index for connectivity analysis in EEG of emotions

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Abstract

Emotion recognition is useful in several fields, from medical diagnosis, driving a Brain-Computer Interface (BCI) [1, 3] or helping people with disabilities. During the last decades, many researchers have applied automatic strategies to identify emotional states based on electroencephalography (EEG) data. However, the task of emotion recognition is very difficult, and the results are often ambiguous. This work aims to perform brain connectivity studies of EEG data acquired by the UCSD [2] of four self-stimulated emotional classes (``relax'', ``anger'', ``happiness'', ``sadness'') using a graph model of the Phase Lag Index (PLI) [4], a measurement of the strength of the connections between electrodes insensitive to the volume conduction effect. This method for connectome generation and analysis shows that valuable information can be derived and used to help clarify the problem of automatic emotion recognition. Qualitative results show that for the analyzed emotions, connectivity analysis indicates relevant differences regarding both the active brain regions and the bandwidths involved in activation. In the same way, the proposed strategy allows separating useful from useless frequency bands. Furthermore, this method could demonstrate the common pattern between people or subjective patterns of emotions and discover the "fingerprints" of emotions. Future work will be focused on collecting more experimental data to expand the study of EEG signals of emotions through PLI-based graphs and to investigate fingerprint and subjective connectome patterns.

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An Open Architecture for Signal Monitoring and Recording Based on SDR and Docker Containers: A GNSS Use Case

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Abstract

Signal monitoring and recording station architectures based on software-defined radio (SDR) have been proposed and implemented since several years. However, the large amount of data to be transferred, stored, and managed when high sampling frequency and high quantization depth are required, poses a limit to the performance, mostly because of the data losses during the data transfer between the front-end and the storage unit. To overcome these limitations, thus allowing a reliable, high-fidelity recording of the signals as required by some applications, a novel architecture named SMART (Signal Monitoring, Analysis and Recording Tool) based on the implementation of Docker containers directly on a Network Attached Storage (NAS) unit is presented. Such paradigms allow for a fully open-source system being more affordable and flexible than previous prototypes. The proposed architecture reduces computational complexity, increases efficiency, and provides a compact, cost-effective system that is easy to move and deploy. As a case study, this architecture is implemented to monitor Radio-Frequency Interferences (RFI) on Global Navigation Satellite System (GNSS) L1/E1 and L5/E5 bands. The sample results show the benefits of a stable, long-term capture at a high sampling frequency to characterize the RFIs spectral signature effectively. [1]

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Approximation by non-Chebyshev Systems of Functions

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Abstract
Let $f_0, f_1, f_2, \dots, f_n\colon R^n \to R$ be continuous functions. By $span(f_1, \dots, f_n)$ denote the linear span of the functions $f_1, f_2, \dots, f_n$. Let us consider the following problem

$$||f_0 - p||_{C[a,b]} \to min_{p \in span(f_1,\dots,f_n)} .$$

In the poster we consider the problem for non-Chebyshev systems of functions $f_1, f_2, \dots, f_n$ .We suggest the algorithm for solution the problem when the system of functions $f_1, f_2, \dots, f_n$ is not Chebyshev. We estimate the rate of its convergence and consider the applications of the algorithm to the problems related to restricted systems [1] and exponential analysis [2].

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