Signal-Processing Algorithms for Sensor Arrays

A Brief Review

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1) About me: Sergio Domínguez Gimeno

- **Sergio Domínguez Gimeno, 26 years old, PhD student**
- ***Electronics-Automation Engineering*** **degree**
- **Masters in *Innovation and Entrepreneurship in Health and Wellness Technologies***
- **Nowadays:**
  - Finishing my PhD in Electronics Engineering
  - I have been 3 years into the PhD
  - I hope finishing it this following year :D
- **This is my 4th conference**

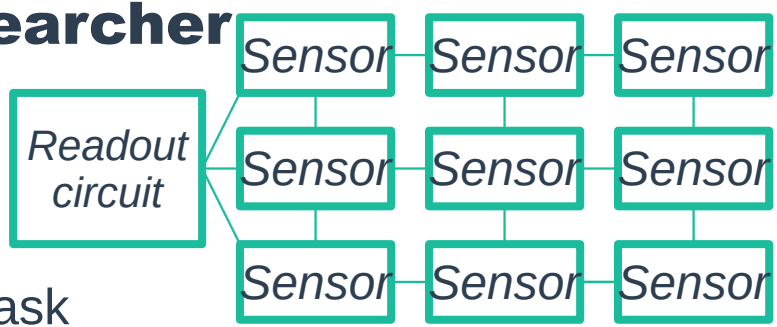
1) My research interests

- **Research topics:**
  - Resistive sensor arrays (RSA)
  - Algorithms for crosstalk solving in RSA (LSQR, neural networks, etc.)
  - Center-of-pressure readout improvement for fall-risk assessment
- **My research group's interests:**
  - Materials for non-expensive pressure sensitive mats (PSMs)
  - Algorithms for RSA non-idealities solving
  - Education quality
- **Currently active projects:**
  - Intelligent instrumentation and application in healthcare (with the University of Málaga)
  - EduQTech: the name of our research group → Reference group in Aragón (Spain)

IARIA

2) Introduction

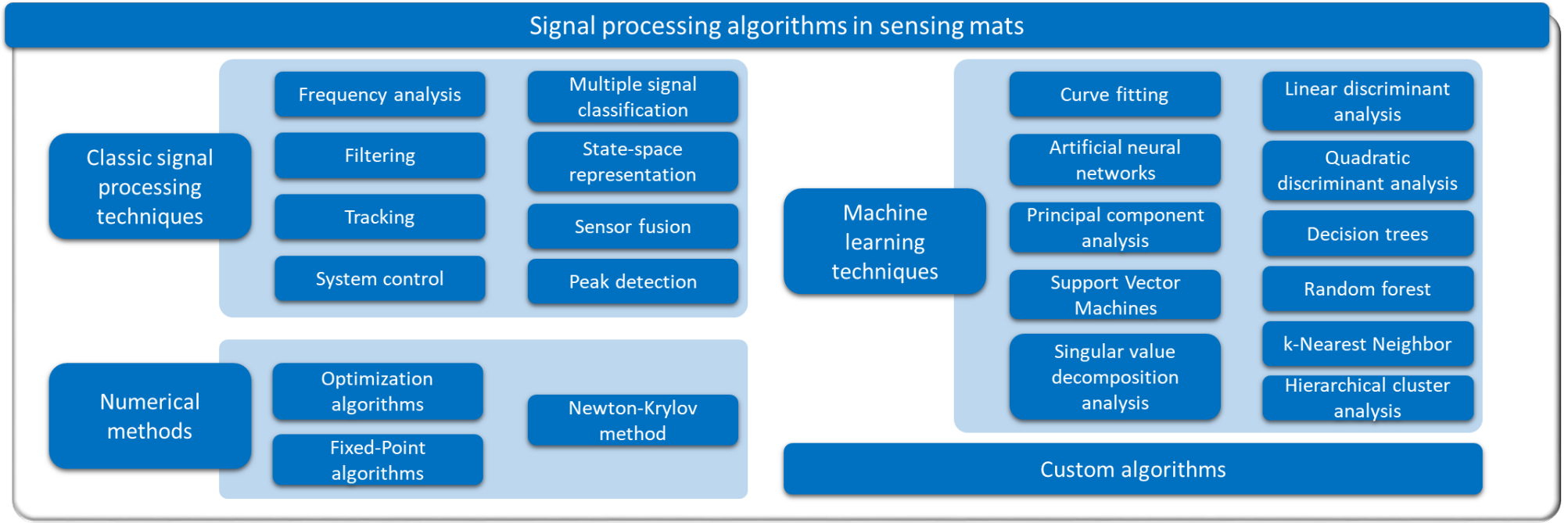
- **An entry point for any interested researcher**
- **Overview on the current state of the**
- **What are sensor arrays?**
  - Arrangement of sensors that work for the same task
  - Different technologies: resistive, capacitive, triboelectric, etc
- **Very different technolgies → Similarities in signal processing?**
- **Compendium of signal processing techniques in sensor arrays**



3) Search method and families of algorithms

- **PRISMA method:**
  - Searched in January 2023
  - Repeated in September 2023
- ***Web of Science* database**
- **Keywords searched in the title: *resistive, piezoresistive, capacitive, inductive, diode,* … + sensor + array**
- **322 papers → Title and abstract examined → 316 papers → Content is examined → 171 papers selected and analyzed**
- **For this work, only processing algorithms are studied.**

3) Search method and families of algorithms



4) Classic signal processing algorithms

1) **Fast Fourier Transform based algorithms:**
   - PSD, STFT, WT, DCT, etc.
   - Crack-Growth Index for SHM with CSA in [10]
   - Vibrating or frequency-based sensors, like CMUTs for VOC/VOL detection, vibrating solar panels of a satellite in [18]
   - Noise analysis
2) **Tracking algorithms: algorithms designed to follow an object in space**
   - Touchless hand tracking with a CSA in [20]
   - Surgical instruments with HSA in [7]
3) **Fusion algorithms:**
   - Mixing the signal of various sensors for enhanced capabilities, typical in IMUs.
   - Magnetometer-accelerometer-gyroscope fusion in [23].
4) **Others:**
   - Digital filtering: AC-power noise rejection [25] in a PSA, radiation waste location in [26] with a FSA
   - MUSIC (Multiple SIgnal Classification): for Structural Health Monitoring [12] with PSA
   - State-space representation: spatial vehicle launch [5] with an FSA-based IMU
   - Peak detection: number of strokes with ping-pong racket with PSA in [24]

5) Machine Learning techniques

1) **Curve fitting**
   - Frequently used to assess sensor responses and characteristics
   - Wind speed and direction with a PSA in [3].
2) **Neural Networks**
   - Touchless hand tracking with a CSA in [20]
   - Surgical instruments with HSA in [7]
3) **Principal component analysis**
   - Reduce dimensionality in classification tasks: VOCs and VOLs with CSAs [8][28]
4) **Support Vector Machines**
   - Extend the number of classification features considered: hand gesture in [29]
5) **K-Nearest Neighbor**
   - Identify different types of hits in the ping-pong racket
6) **Hierarchical Cluster Analysis**
   - VOC classification with cantilever resonator (CMUT) in [28]
7) **Decision trees and random forests**
   - Fast classification algorithms for anti-vandalism system basd on FSA [11]
8) **Singular Value Decomposition Analysis**
   - Separation of the dataset in several sets based on matrix factorization and eigenvalues. Detect objects immersed in sand in [35] with ECT.
9) **Linear/Quadratic discriminant analysis:**
   - Hand gesture recognition with a PRSA in [29]
   - Used together with SVM

6) Numerical methods

1)Least-Squares, Levenberg-Marquardt, Newton-Krylov and Fixed-Point interative method:

- All used for crosstalk correction in RSA in [1][36]
- LSQR is a high-accuracy time-consuming algorithm, while FP gets a good accuracy with less time.

2)Orthogonal Matching Pursuit

- Greedy search algorithm for PSA signal reconstruction → Gets an approximation of hard optimization problems
- PSAs can be used for SHM using sound waves that run inside materials
- SHM in [14] using PSAs

7) Classic statistical techniques and Custom algorithms

1)Classic statistical techniques

- Discriminant Factor Analysis
- Find sensor that performs the best within an array [27]

2)Custom algorithms: very application-specific algorithms

- Damage imaging in cylindrical pipes with FSA [37]
- Wind speed and direction detection algorithm with PRSA [38]
- Unexploded Ordnance detection with an ISA [39]

8) Discussion and Conclussion

1) **Curve fitting is the most popular analysis in sensor arrays**
2) **Machine learning techniques, such as neural networks, is the most popular group of processing algorithms (17,7%)**
   - They show a growing trend in recent times, due to the popularity of the new Large Language Models (Chat-GPT, Geminis, etc.).
   - Very versatile, but difficult to train: data obtention, training process, etc.
   - Currently being trained and run on GPU → Parallelization capability → Faster processing
3) **FFT algorithms are also very popular (17,3%)**
   - Lightweight-fast algorithms
   - Very useful for noise analysis, frequency response of sensors, sensor characterization, etc.
4) **Numerical methods is the fourth most common group of processing algorithms for sensor arrays**
5) **Found processing algorithms are as varied as the sensor arrays are.**
6) **AI models are expected to be used to solve different problems in the sensors field:**
   - Non-ideality modelling
   - Sensor design assistance

Thank you for your attention