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 candidate
- *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

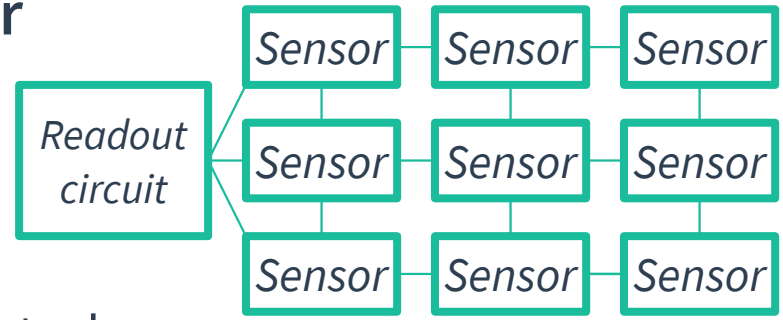
IARIA

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)

2) Introduction

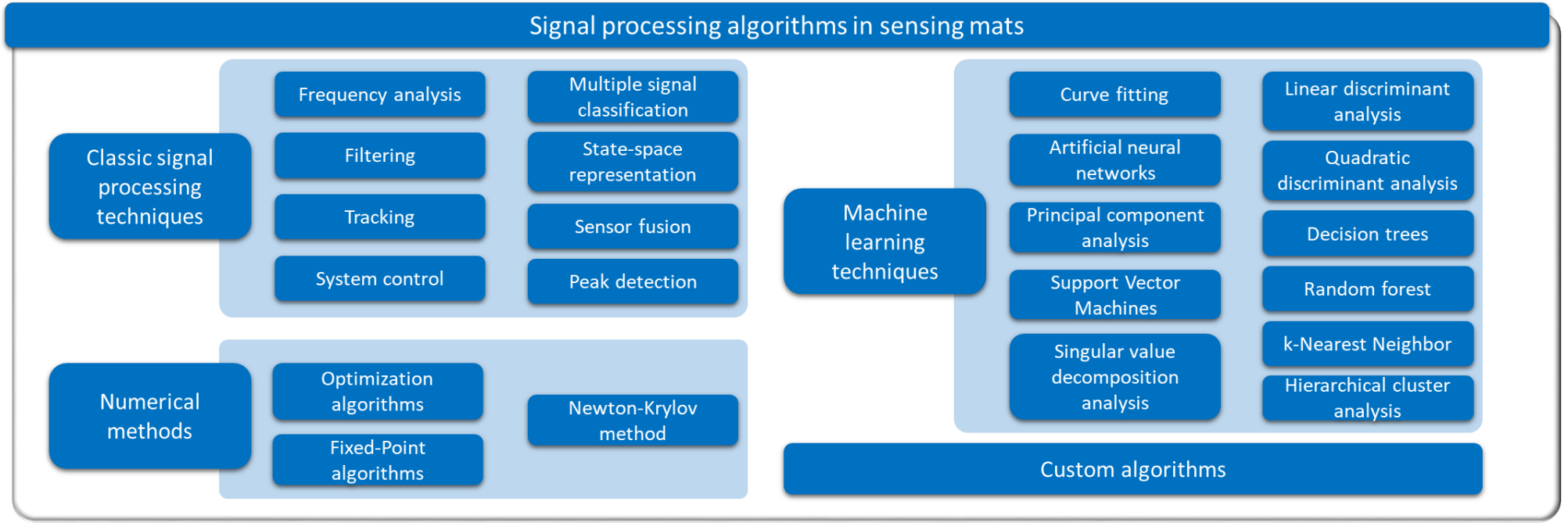
- An entry point for any interested researcher
- Overview on the current state of the art
- What are sensor arrays?
  - Arrangement of sensors that work for the same task
  - Different technologies: resistive, capacitive, triboelectric, etc
- Very different technolgies → Similarities in signal processing?
- 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 TSA in [3].

2) Neural Networks

- Touchless hand tracking with a CSA in [20]
- Obtaining cardiac pulse with CNN and BSA in [13]

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:

- Separate groups of input data using linear or quadratic functions
- Hand gesture recognition with a PRSA in [29]

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 [14]

7) Classic statistical techniques and Custom algorithms

1) Classic statistical techniques

- Discriminant Factor Analysis
- Find sensor that performs the best within an array with Discriminant Linear Analysis [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