

Signal Processing Group Overview



Prof. Dr.-Ing. Abdelhak M. Zoubir



Signal Processing Group
Technische Universität Darmstadt

Outline



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Research Projects

Current Research Projects

Past Research Projects

Teaching Activities

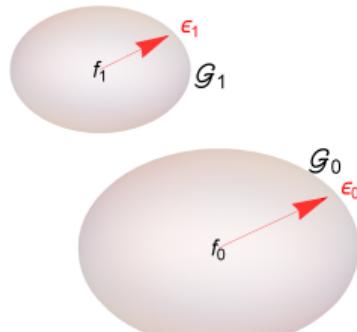
The SPG Laboratory

Current Research Projects

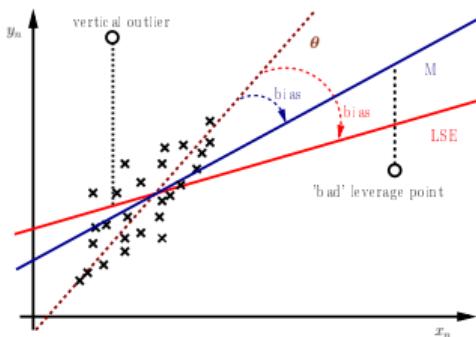
Robust Signal Processing



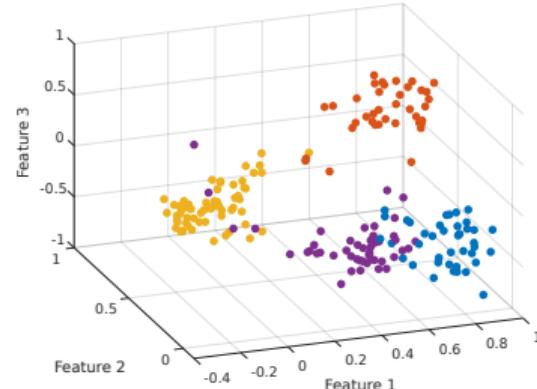
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(a) Detection



(b) Estimation



(c) Cluster Analysis

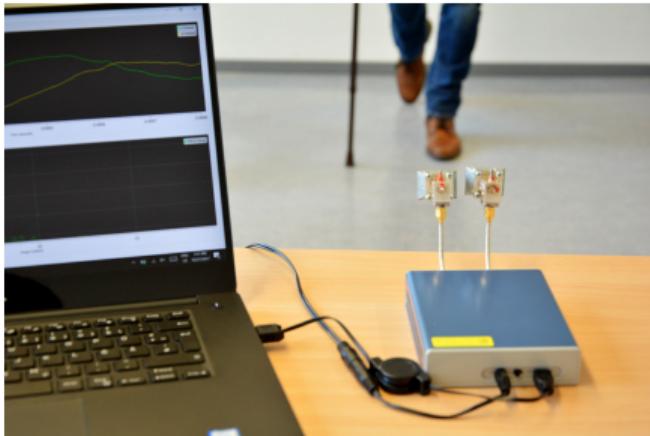
- ▶ Fundamental Research on Robust Detection, Robust Estimation and Robust Cluster Analysis
- ▶ **Challenges:** Uncertainty of the Distributions, Outliers in the Data

Radar-based Gait Analysis

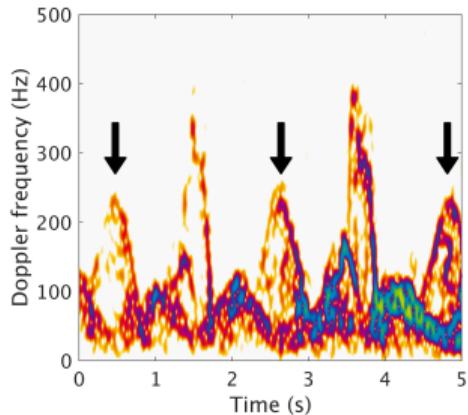
In cooperation with Villanova University, Villanova, USA.



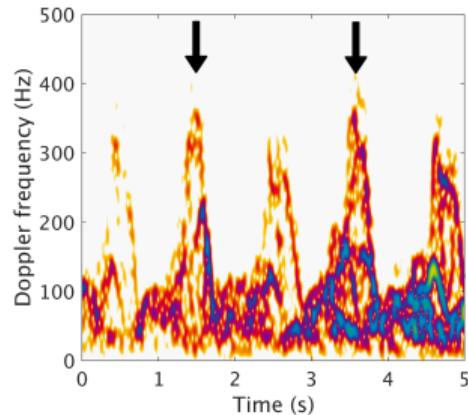
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(a) Experimental Setup



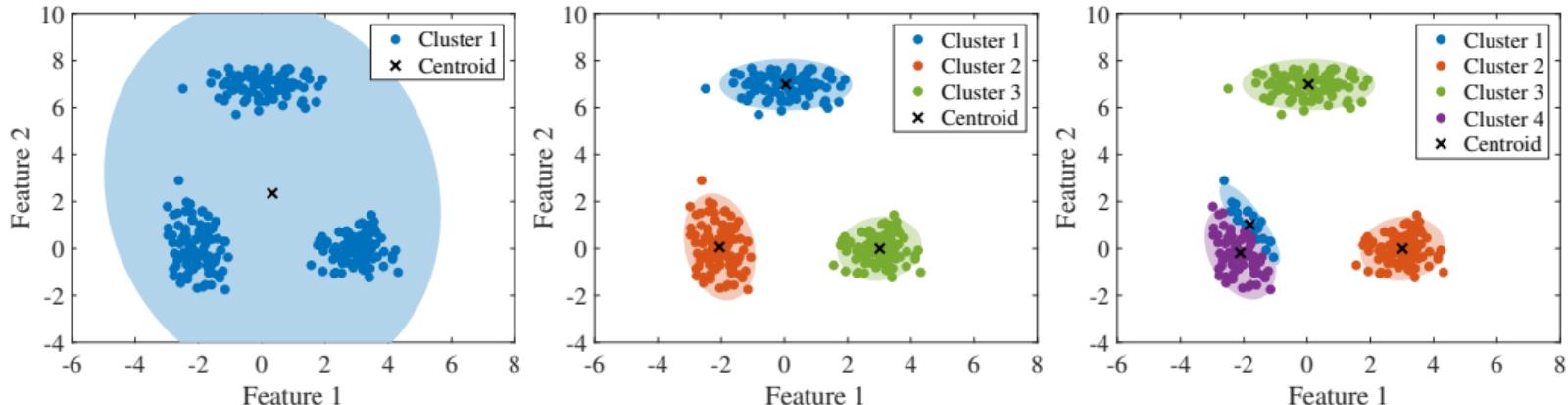
(b) Simulated Limping



(c) Walking with a Cane

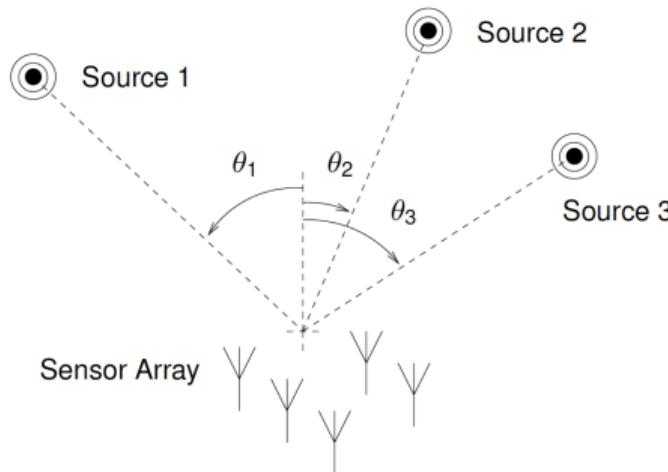
- ▶ Gait Classification Based on Radar Micro-Doppler Signatures
- ▶ Extraction of Medically Relevant Gait Parameters
- ▶ **Challenges:** Adequate Models, rich Doppler Spectrum

Robust Cluster Analysis

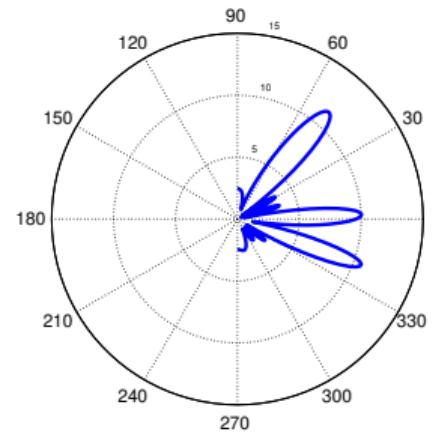


- ▶ Finding the Underlying Groupings (or clusters) in a set of Unlabeled Data.
- ▶ **Challenges:** Outliers in the Unlabeled Data set

Robust Statistics for Array Signal Processing



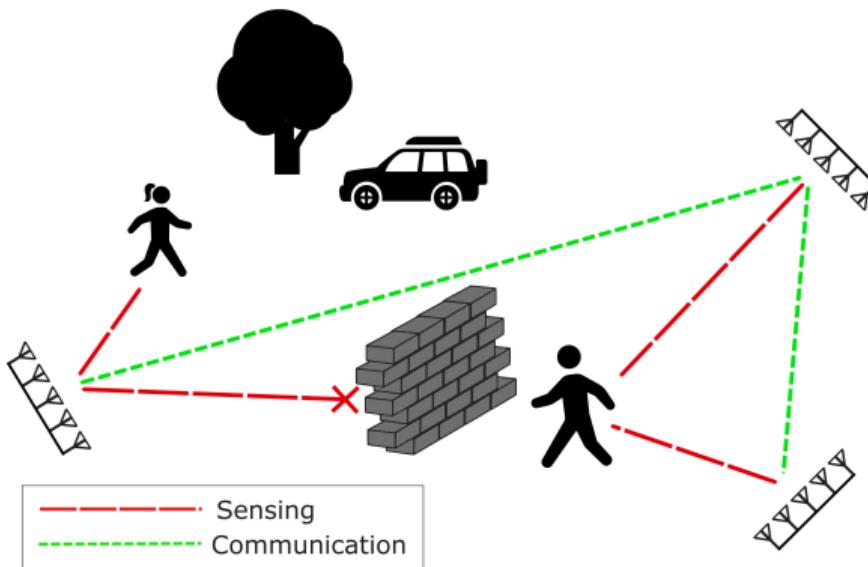
(a) DOA Estimation



(b) Beamforming

- ▶ Direction-of-Arrival (DOA) Estimation with Outliers
- ▶ **Challenges:** Conventional Beamforming Sensitive to Outliers

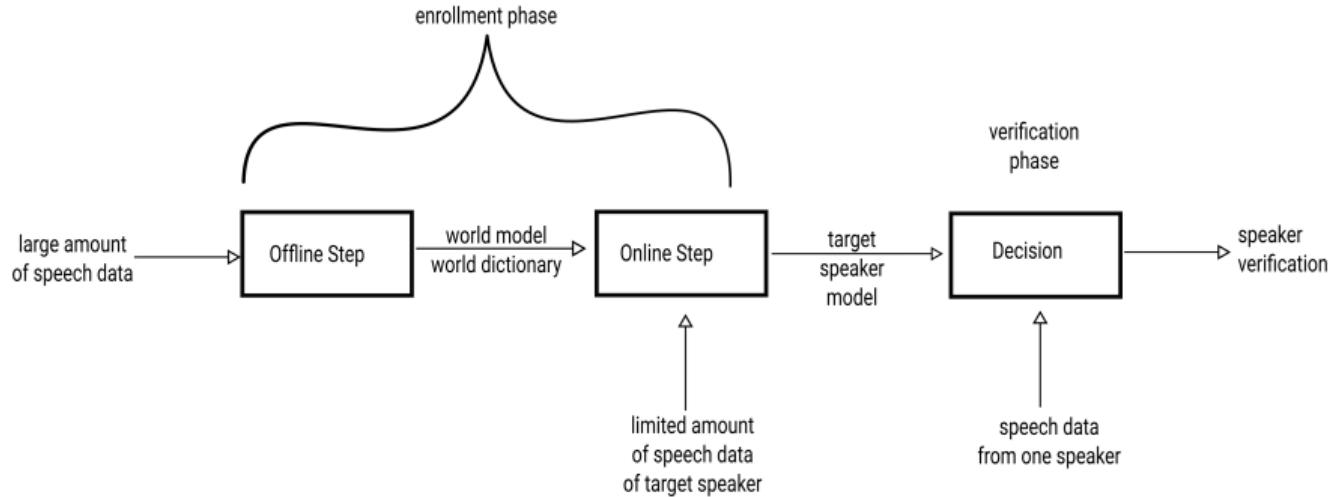
Joined Radar Communication



- ▶ Collectively Perform Detection, Localization or Parameter Estimation Tasks in Radar Sensor Networks
- ▶ **Challenges:** Enabling Efficient Communication Among Radar Nodes

Speaker Verification Under Limited Data Constraint

In cooperation with Sivantos GmbH, Erlangen.



- ▶ Online Learning of the Target Speaker Model
- ▶ **Challenge:** Limited Data of the Target Speaker

Biomedical Research

In cooperation with Roche Diagnostics Deutschland GmbH, Mannheim.



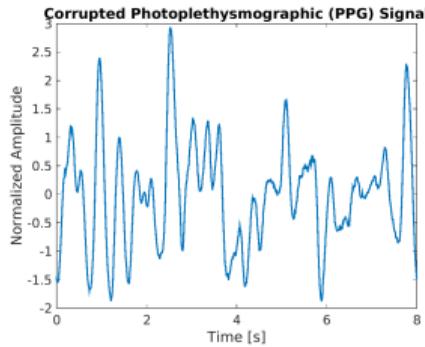
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(a) Blood Glucose Measurements



(b) Smartwatch with Photoplethysmographic (PPG) Sensor



(c) Recorded PPG Signal

- ▶ Biomedical Signals: Vital Signals, 2D or 3D Images of Organs or Audio Signals in Hearing Aids
- ▶ **Challenges:** Extract Accurately and in the Presence of Outliers, Information such as Heart Rate, Blood Pressure, Blood Glucose Concentration, Brain Activity, etc.

Biomedical Research

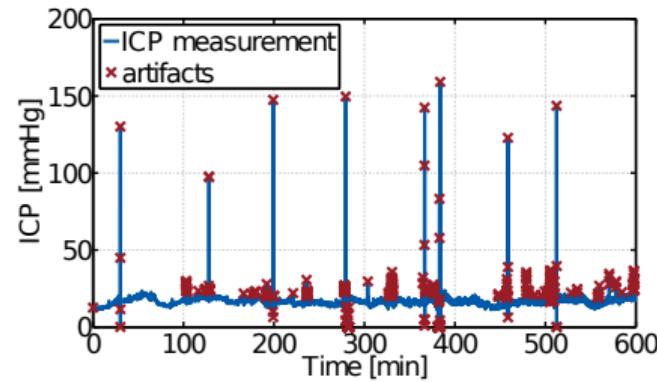
In cooperation with Roche Diagnostics Deutschland GmbH, Mannheim.



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(d) photo: ESA



(e) ten hour excerpt of a typical Intracranial Pressure (ICP) measurement

- ▶ Biomedical Signals: Vital Signals, 2D or 3D Images of Organs or Audio Signals in Hearing Aids
- ▶ **Challenges:** Extract Accurately and in the Presence of Outliers, Information such as Heart Rate, Blood Pressure, Blood Glucose Concentration, Brain Activity, etc.

curASig: High-Dimensional Robust Signal Processing

In cooperation with Prof. Muma (TU Darmstadt) and Prof. Wild (Unimedizin Main)



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- ▶ Interdisciplinary Project
- ▶ Extract Information from (High-Dimensional) Biomedical Data
- ▶ **Challenges:** Robustness Against Artifacts, Performance Guarantee, Tractability

curASig: High-Dimensional Robust Signal Processing

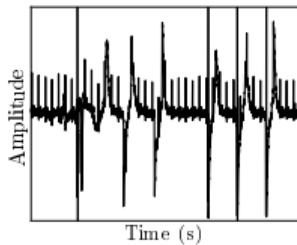
Robust Measures of Heart Rate Variability (HRV)



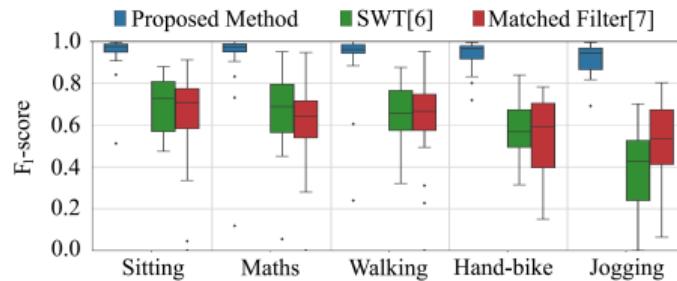
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(a) HRV as Variability in R-R interval



(b) ECG Signal with Motion Artifacts



(c) Comparison of Different Methods

- ▶ Visibility Graphs Enable the Mapping of a Time Series into a Graph which Leads to Improved Detection of Peaks
- ▶ New Biomarkers of Autonomous Dysfunction Based on Robust Measures of HRV
- ▶ Developing new Cross-Domain (Time, Frequency, Wavelet, ...) Approach Using Visibility Graphs

Large-Scale Spatial Inference

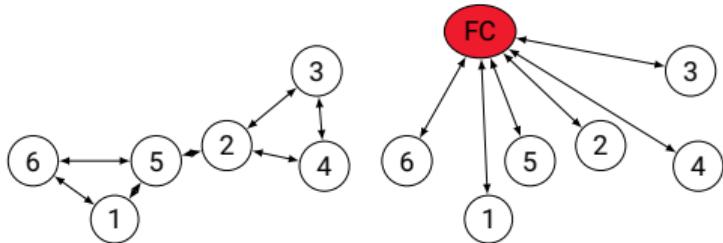


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- ▶ Powerful Localization of Abnormally Behaving Areas While Controlling the False Discovery Rate
- ▶ **Challenge:** Limited Sensor-to-Cloud Communication to Function in Large-Scale Sensor Networks

Low-Cost Wireless Sensor Network



(a) Distributed Network

(b) Centralized Network



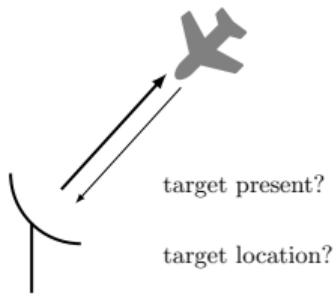
(c) Single Sensor



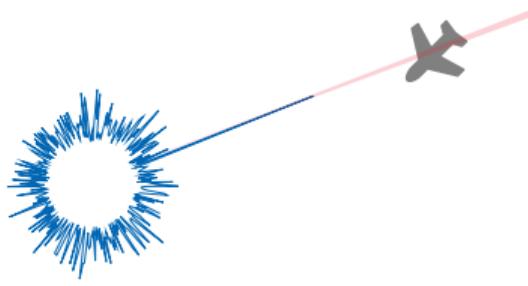
(d) Sensor Network Recording Data

- ▶ Record Data via Various Sensors: Temperature, Humidity, Microphone, Proximity, Gyroscope
- ▶ Detection and Localization of Anomalous Events (People Entering/Leaving Room, Open Window, Boiling Pot, Fire, ...)
- ▶ **Applications:** e.g. Smart Home, Smart Factory, Smart City
- ▶ **Constraints:** Sensor Battery Lifetime, Communication Bandwidth, Scalability

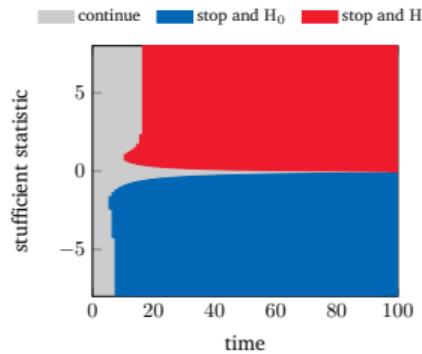
Sequential Joint Detection and Estimation



(a) Radar Scenario



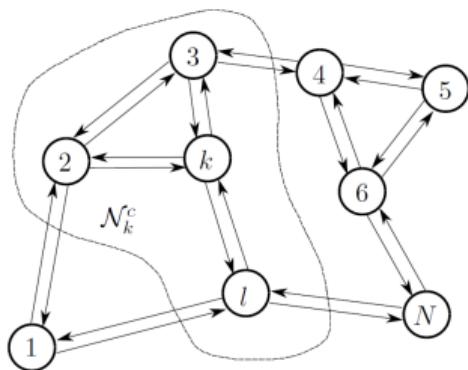
(b) Radar Pattern



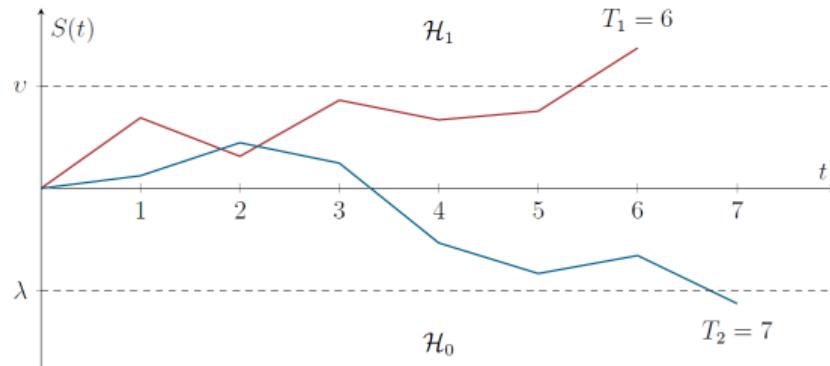
(c) Optimal Policy

- ▶ Jointly Infer Model and Model Parameter(s)
- ▶ Use on Average as few Samples as Possible
- ▶ **Applications:** Radar, Sonar, Communications, Biomedical Engineering

Robust Sequential Analysis in Networks



(a) Network with Neighborhood



(b) Exemplary Random Walks of Sequential Test Statistic

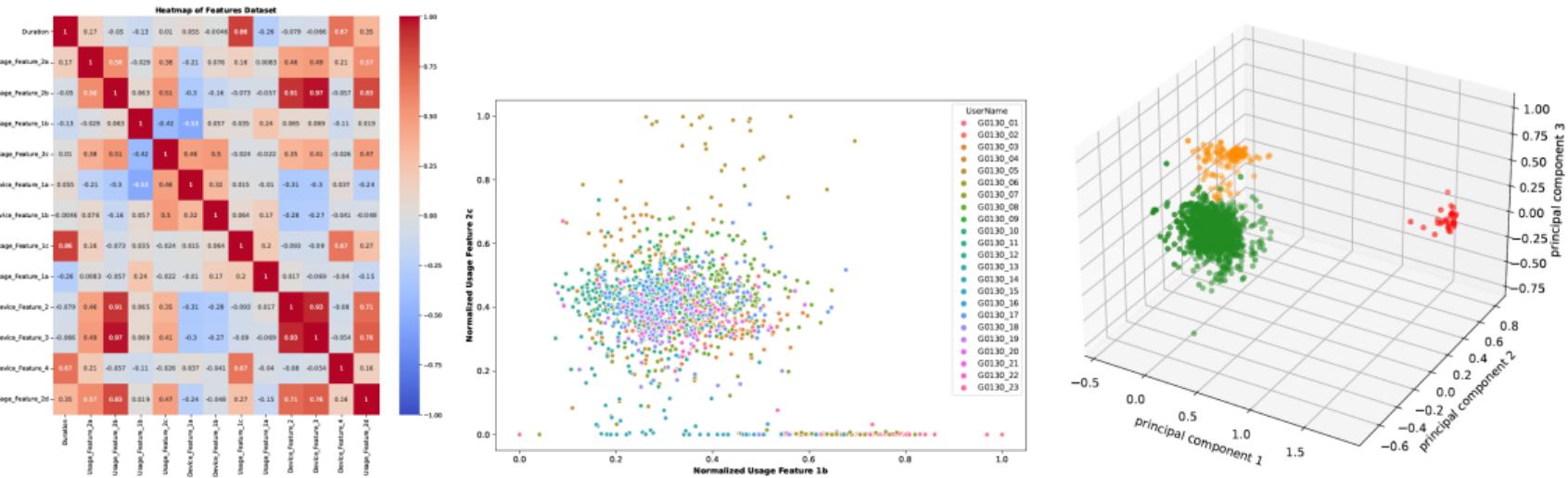
- ▶ Use as few Samples as Possible
- ▶ Achieve Good Performance under non-Gaussian Noise Environments (Real World Scenarios)
- ▶ **Challenge:** Find Robustness Criteria which hold in the Distributed and Sequential Case

Statistical Analysis of Personal Care Devices

In cooperation with Proctor & Gamble Service GmbH



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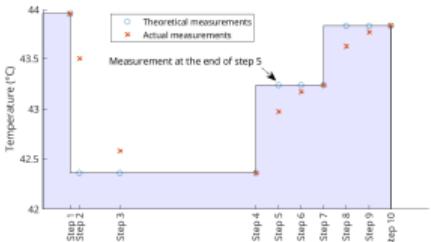


- ▶ Statistical Analysis of Consumer Behavior and Device Performance
- ▶ Challenges: High Dimensionality, Outliers due to Device Errors and Unpredictability of Human Nature

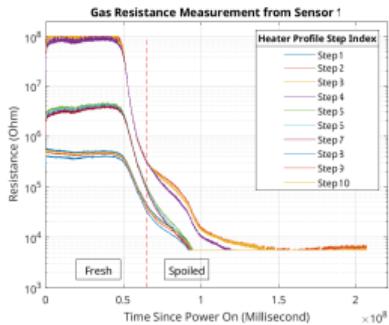
Robust Bootstrap in IoT



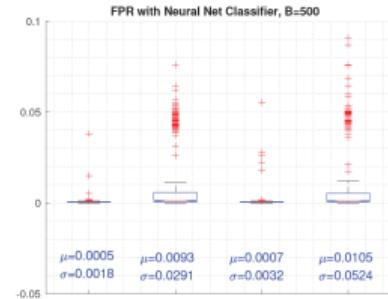
(a) Training e-nose



(b) Heater step



(c) Measurement



(d) Improvement on NN by
Stratified Out-of-Bag
Bootstrap

- ▶ Training a Good Detector by Measuring Volatile Organic Compounds (VOCs) in the Surrounding Air
- ▶ **Challenges:** Small Data Size, Mixed and Varying Environment During Deployment Reduce Accuracy.

Robust Bootstrap for Time Series Forecasting

With applications in the power sector

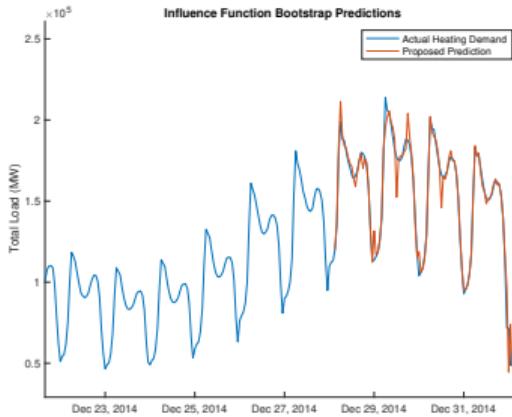


Figure: Heating Demand Prediction with the Influential Function Bootstrap with ARIMA-GARCH Composite Model

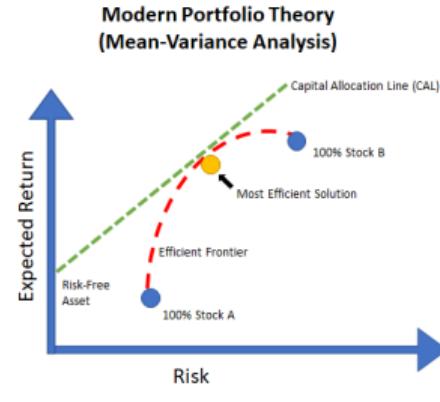
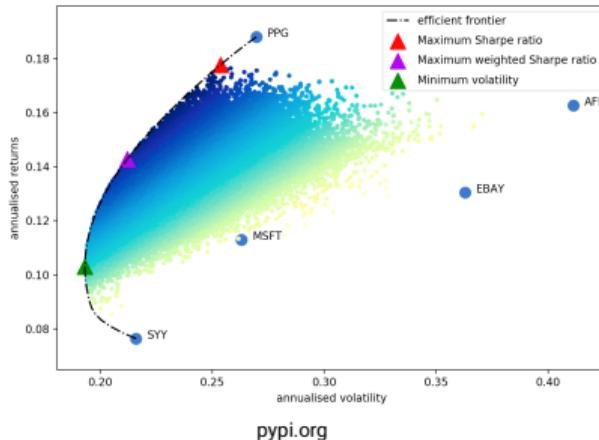
- ▶ Predicting Future Energy and Heating needs to Achieve Demand and Supply Equilibrium.
- ▶ **Challenges:** Complex Seasonality, Additive and Volatility Outliers.

Robust Bootstrap for Time Series Forecasting

With applications in the financial sector



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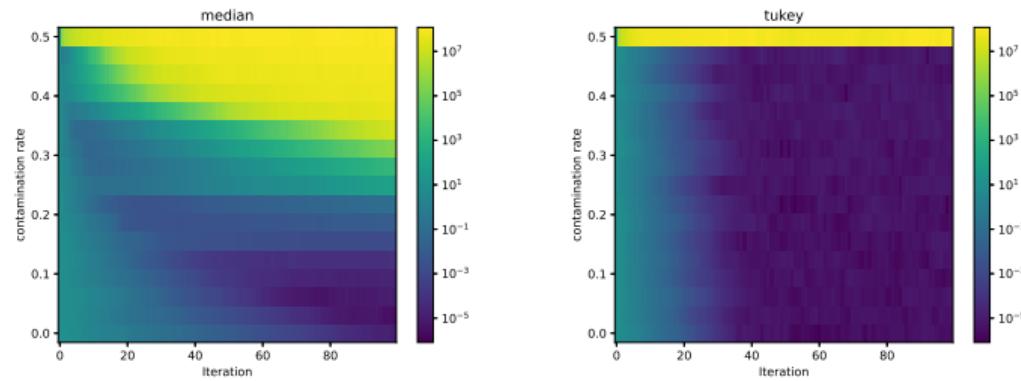


- ▶ Optimal Portfolio - Minimum Variance that can be Achieved for a Given Level of Expected Return
- ▶ **Challenges:** High Dimensionality, Volatility Outliers

Robust Aggregation in Distributed Learning



Autonomous Vehicles [smartcitiesworld.net]



Error for Different Aggregation Methods over Contamination Rate

- ▶ Robustly Exchange Data, to Allow for Coordination of Models Across a Collection of Agents
- ▶ **Challenges:** Sensor Failures, Malicious Intruders

Past Research Projects

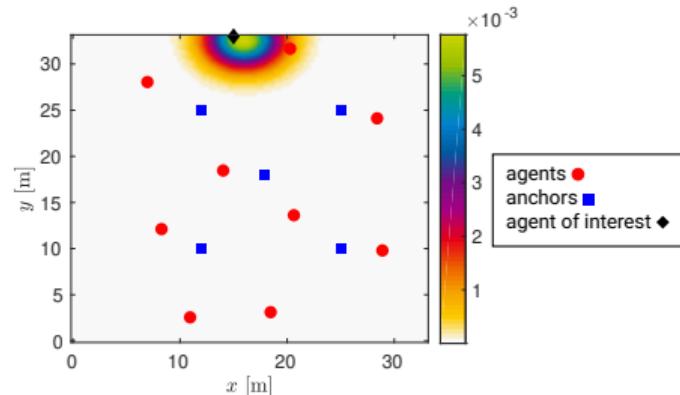
Cooperative Localization



(a) Localization



(b) Internet-of-Things



(c) Estimated Posterior

- ▶ Cooperative Localization With no Prior Knowledge or Calibration
- ▶ **Challenges:** Unknown Model Parameters, NLOS Propagation

Landmine Detection

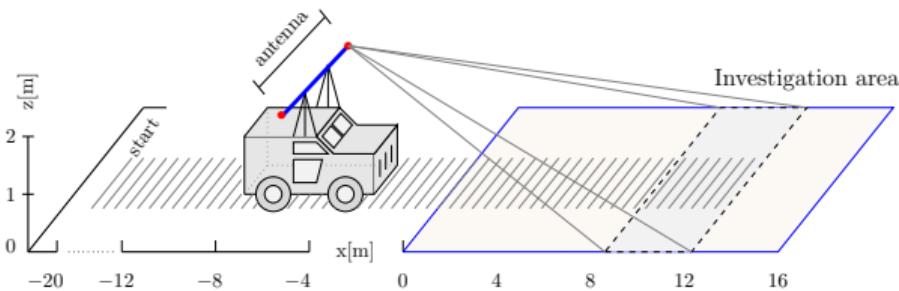
In cooperation with Temple University, Philadelphia, USA.



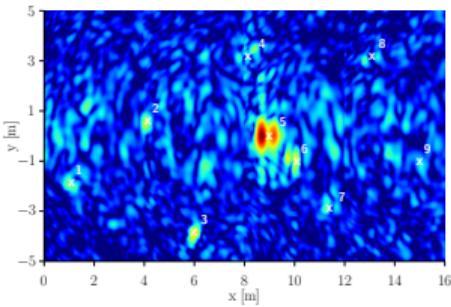
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(a) Anti-Personnel Mine



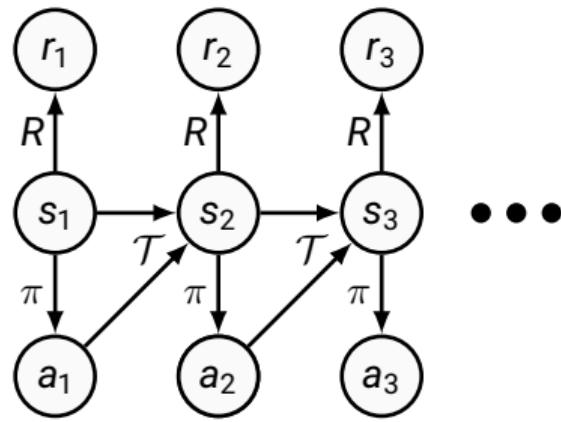
(b) Diagram of Forward-looking GPR System



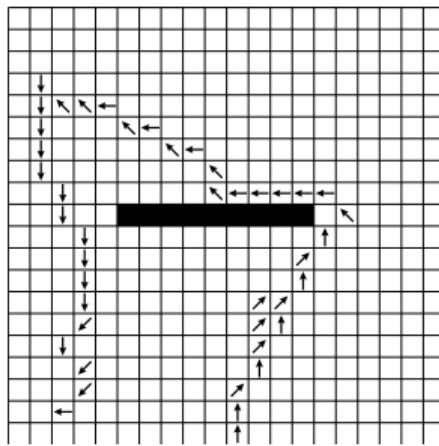
(c) Beamformed Image

- ▶ Landmines and Unexploded Ordnance Detection in FL-GPR Imagery
- ▶ **Challenges:** Environmental Changes, Clutter

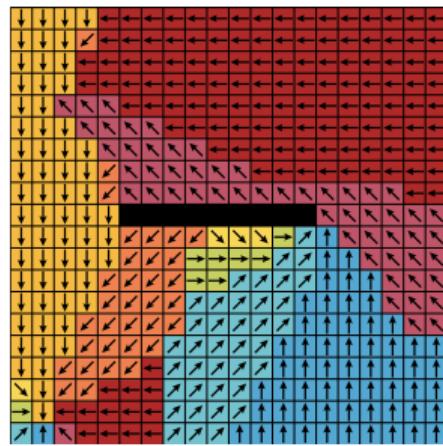
Inverse Reinforcement Learning



(a) Markov Decision Process



(b) Data Set



(c) Predictive Policy

- ▶ Learn Behavioral Model from Noisy Observations
- ▶ **Challenges:** Identify Target State, Infinite State Space, Scalability for Multi-Agent Systems

Synthetic Aperture Sonar

In cooperation with ATLAS ELEKTRONIK GmbH, Bremen.

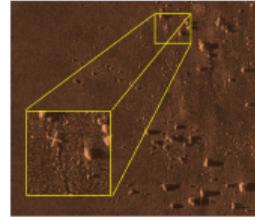


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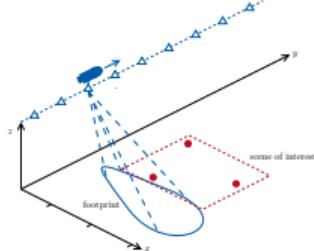
Scenario



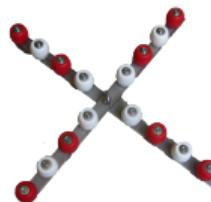
Reconstructed image



Autonomous underwater vehicle



Man-made object



Through-the-Wall Radar Imaging

In cooperation with Villanova University, Villanova, USA.



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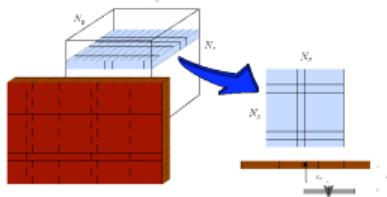
Laboratory set-up



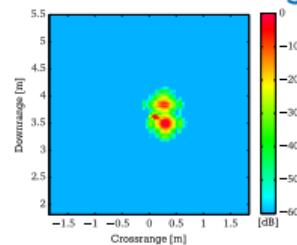
Human facing the wall



Scenario



CS beamforming

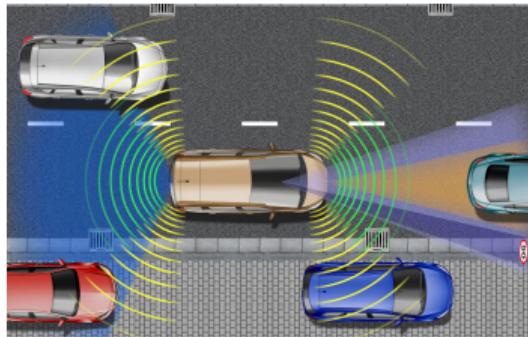


Automotive Applications

In cooperation with Adam Opel AG, Rüsselsheim.



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©GM Company

- ▶ Driver Assistance Systems Protect the Driver and the Passengers
- ▶ **Goal:** Develop Advanced Driver Assistance Systems (ADAS) that are able to act According to the Environment of the Vehicle
- ▶ **Challenge:** Efficient and Reliable Decision Making Based on High-dimensional Data

Teaching Activities

Courses Overview

Lectures

- ▶ Fundamentals of Signal Processing ([Prof. Dr.-Ing. Zoubir](#))
- ▶ Digital Signal Processing ([Prof. Dr.-Ing. Zoubir](#))
- ▶ Data Science I ([Dr.-Ing. Debes](#))
- ▶ Adaptive Filters ([Prof. Dr.-Ing. Puder](#))
- ▶ Speech and Audio Signal Processing ([Prof. Dr.-Ing. Puder](#))

Seminars

- ▶ Signal Detection and Parameter Estimation ([Prof. Dr.-Ing. Zoubir](#))
- ▶ Advanced Topics in Statistical Signal Processing ([Prof. Dr.-Ing. Zoubir](#))
- ▶ Data Science II ([Dr.-Ing. Debes](#))

Practicals

- ▶ Digital Signal Processing Lab ([Prof. Dr.-Ing. Zoubir](#))

Signal Processing in Other Groups

- ▶ Robust Data Science Group by Prof. Dr.-Ing. Muma
<https://robustdatascience.org>

- ▶ Communication Systems Group by Prof. Dr.-Ing. Pesavento
<https://www.nts.tu-darmstadt.de>

The SPG Laboratory

Signal Processing Laboratory

Biomedical Laboratory



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(a) Bitalino Kit



(b) AD Instruments BioAmp



(c) Data Acquisition

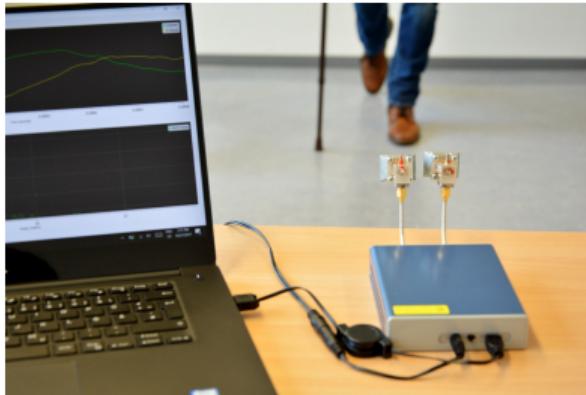
- ▶ Recording a variety of biomedical signals including blood pressure (dynamic and static), PPG, ECG, EEG, EMG, Respiration, EDA, arterial stiffness.

Signal Processing Laboratory

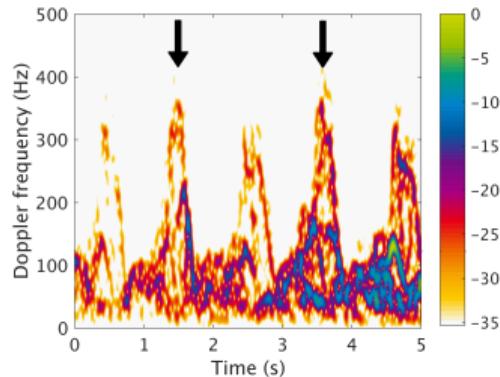
Radar Laboratory



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(a) 24 GHz Radar (2400AD by Ancortek)



(b) Mirco-Doppler Signature

- ▶ Recording radar return signals of human motions → micro-Doppler signature analysis

Signal Processing Laboratory

Synthetic Aperture Imaging



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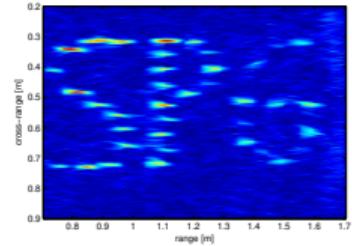
(a) Railed Synthetic Aperture Setup



(b) Ultra-sonic Sensors



(c) Objects in Target Area



(d) Reconstructed Image

Thank you for your attention!

More Information in
www.spg.tu-darmstadt.de