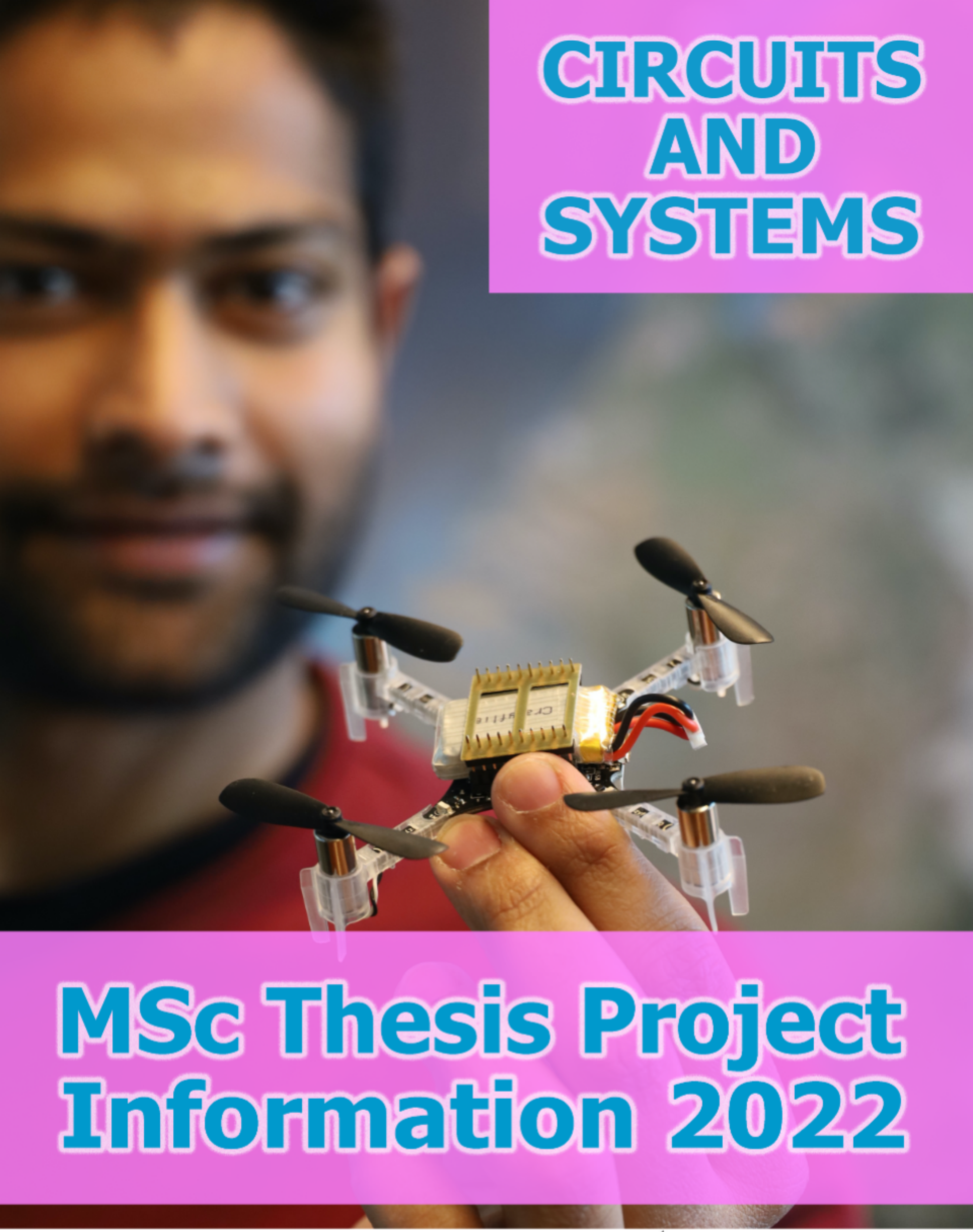


CIRCUITS AND SYSTEMS

MSc Thesis Project Information 2022

TU Delft

Faculty EEMCS

Delft University of Technology

cas.tudelft.nl

The CAS group

CAS covers signal processing theory and related system applications

Signals:	speech, audio, images, biomedical, communication, sensor, ...		
Models:	**EM, physics**	**stochastic**	**data collections**
	channel descriptions	signal descriptions	data descriptions
Methods:	**linear algebra** **tensors** **array signal proc.**	**estimation** **detection** **machine learning**	**graph signal proc.** **distributed proc.**
	compressed sensing source separation computational imaging	graphical models deep neural networks data fusion	network localization filtering on graphs distributed inference
Applications:	**communication** **sensing**	**biomedical**	**autonomous** **sensing systems**
	wireless, MIMO, 5G radar, sonar audio/acoustics radio astronomy	neuroscience, EEG cardiac, ECG MRI, ultrasound	self-driving cars drones, UAV satellite swarms sensor networks

Signal processing theory centers around ***signal processing for communication and array signal processing***, ***biomedical signal processing, computational imaging, distributed sensing, acoustical signal processing*** with applications in hearing aids, localization of sound sources, receiver algorithms for wireless communication, array signal processing (utilizing multiple antennas) for radar and radio astronomy, EEG, ECG, MRI, ultrafast ultrasound, ... ***Machine learning*** is an important tool we commonly use.

Autonomous sensing systems are a system-level focus of the group. Think of IoT, drones (UAVs), or satellite swarms. Topics are distributed inference, localization and clock synchronization, federated learning.

We have strong networks of co-operation with various companies, in the Netherlands, Europe and overseas. Such companies include Philips, NXP, Magma, Infineon, Magwel, Controlec, Thales, TNO, ASTRON, Holst Centre, Huawei, Oticon. We collaborate with several University Medical Centers (Rotterdam, Leiden, Utrecht, Amsterdam).

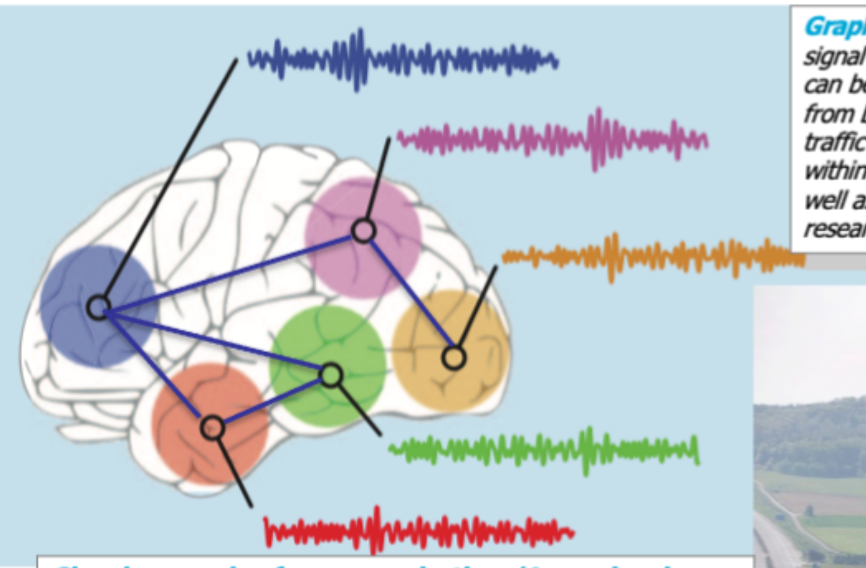
We also participate in multiple European and national research projects where we have research co-operations with other universities.

The group consists of 9 Professors, 4 postdocs, about 20 PhD students and 50+ MSc students.

We have a strong international orientation – considering cooperations as well as group members

Signal Processing for Communication

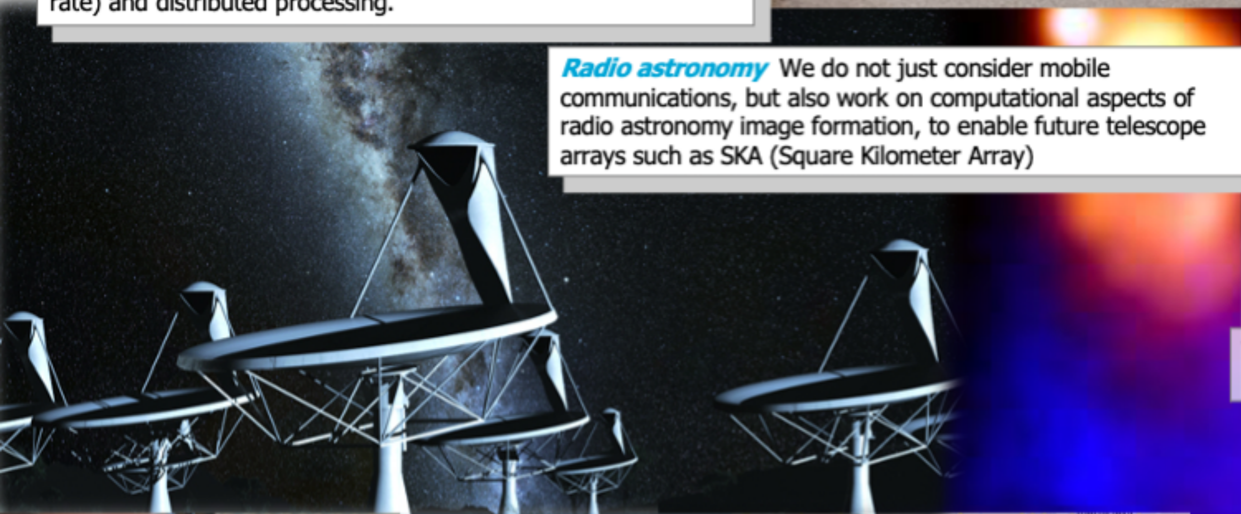
CAS offers a mix of research topics from highly mathematical and theoretical to practical hands-on work in the lab. Notwithstanding their diverse nature, they are highly interrelated and work towards some common goals of researching new things and demonstrating their effectiveness in practice. That is, in the CAS group, we enjoy doing new things that are both scientifically and practically relevant. And by actually working towards real implementations of our ideas, we stay connected to practice and learn a lot about what are interesting problems to solve. On the following pages you can read about our current research tracks.



Graph signal processing (GSP) *extends the field of classical signal processing to signals that have an irregular domain that can be characterized by means of a graph. Examples are signals from brain networks (fMRI, fUS, EEG, etc.), social networks and traffic networks. Our group has pioneered some key concepts within this field. We are currently developing new GSP theory as well as applying GSP to real data improving state-of-the-art research results.*

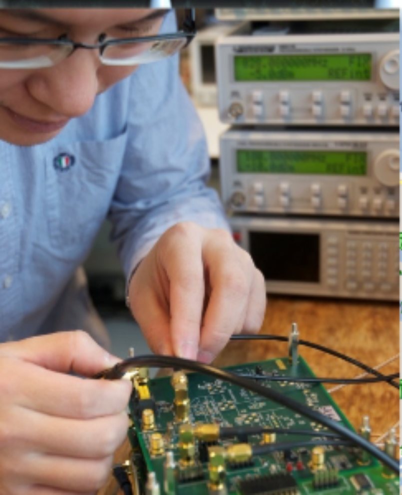
The SuperGPS projects aims to achieve reliable cm-level accuracy of cars using accurate timing estimation of UWB signals to enable autonomous driving applications

Signal processing for communications/Array signal processing refers to the parallel processing of signals from multiple antennas. This allows separating multiple signals, and can be used to increase the capacity or the robustness of mobile systems. We mainly work on advanced receiver algorithms and localization using multiple antennas and multiple nodes, and develop algorithms for "compressive sampling" (below Nyquist rate) and distributed processing.

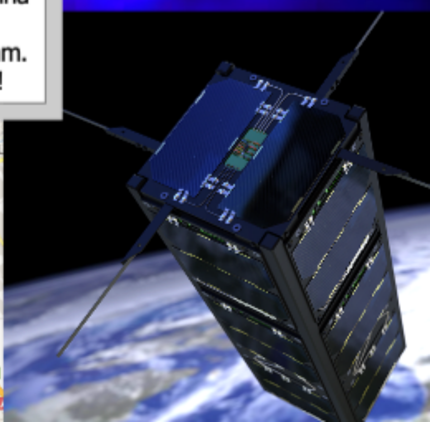


Radio astronomy We do not just consider mobile communications, but also work on computational aspects of radio astronomy image formation, to enable future telescope arrays such as SKA (Square Kilometer Array)

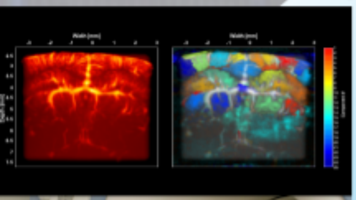
Time synchronization of clocks is key to many applications



Separation of overlapping ship transponder signals (AIS system), used for tracking ships. An experimental 4-antenna system allows to separate 4 overlapping signals at a time, allowing to resolve many more ships in the harbor of Rotterdam. One of our separation algorithms was actually sent into space!



Biomedical Signal Processing



Better understanding

High-quality multimodal data
biomarkers

Modalities:
Electroencephalography (EEG)
Wearables (EEG, ECG, ACM...)
Ultrasound (US), functional US
Video

translation

implementation

Clinical practice,
Real-life monitoring
Wearables

Unraveling the brain

How does the brain process visual or other information? How is it wired, how do different regions pass on information? How does the brain interact with the rest of our body? These questions are at the heart of better understanding various neurological diseases, including epilepsy.
To study these questions, high-quality and often multi-modal data collection is needed, such as EEG, functional MRI, or ultrasound. The ultimate goal is to *derive biomarkers* from the data, i.e. parameters that can differentiate healthy from pathological signals.

Example applications

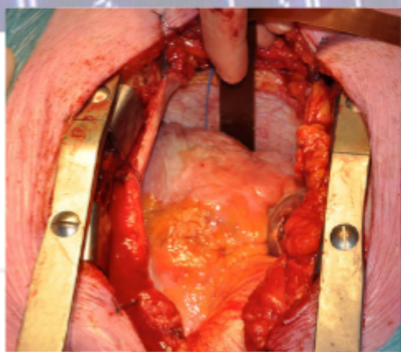
- Epileptic seizure prediction
- Vital signs extraction from video
- Study brain development using event-related potentials
- Mapping visual information processing in the brain
- Prostate cancer detection

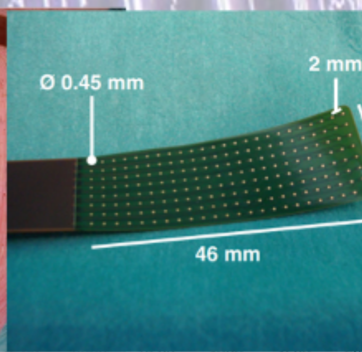
Signal Processing Challenge

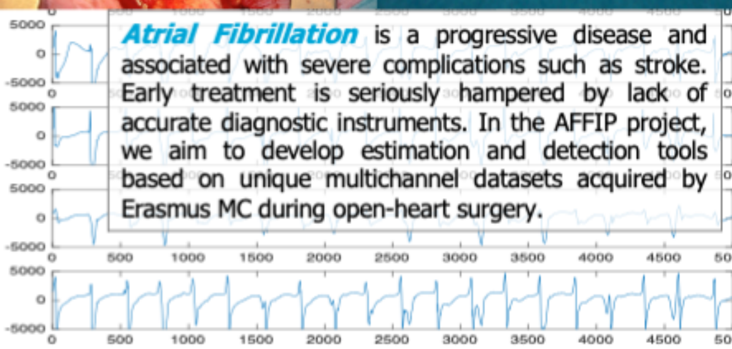
There are certain signal processing challenges common to various applications, even beyond neuroscience. Both (neuro)imaging and ultra-long term monitoring records very large amounts of data. The data inherently live in a *higher dimensional (tensor) space* and the pattern of interest is often hidden in the noisy mixture of physiological activity and artifacts. How to efficiently *learn from this big data*? How can we *fuse multimodal information*? How can we *separate signal from noise*?

Computational imaging

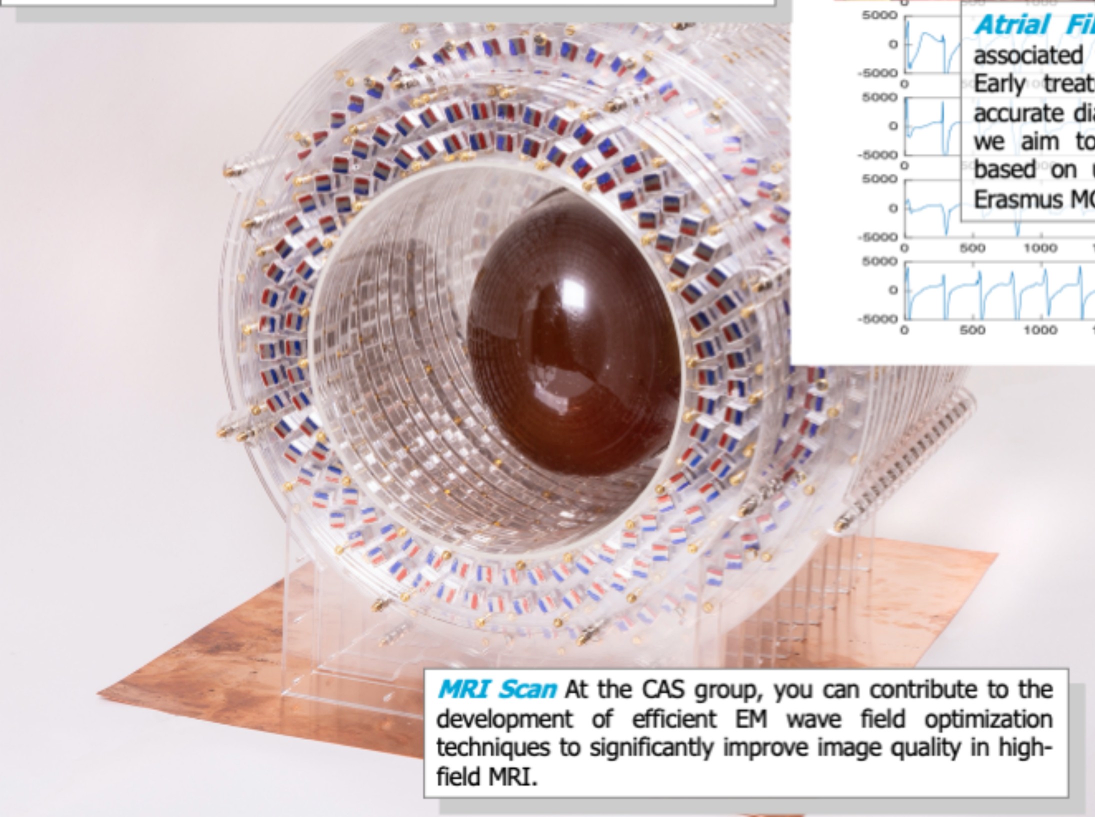
Reinventing MRI In collaboration with Leiden, Amsterdam and Utrecht University hospitals, we run several projects on MRI. Our work focuses on EM modeling and imaging and inversion techniques for improved functionality and reduced hardware costs. An interesting project is the development of a low-field MRI, using permanent magnets.

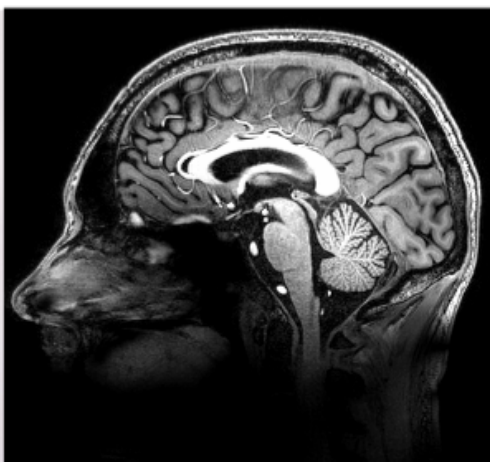






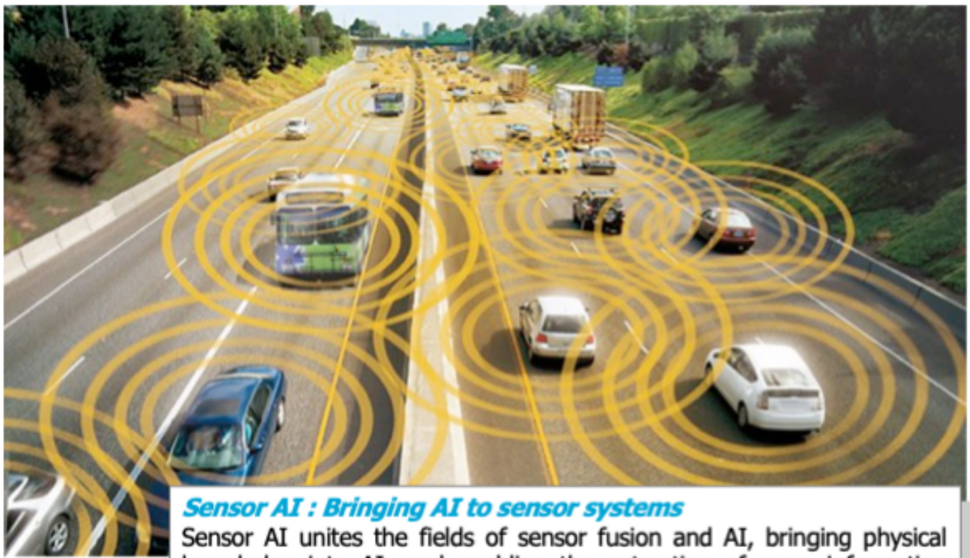
Atrial Fibrillation is a progressive disease and associated with severe complications such as stroke. Early treatment is seriously hampered by lack of accurate diagnostic instruments. In the AFFIP project, we aim to develop estimation and detection tools based on unique multichannel datasets acquired by Erasmus MC during open-heart surgery.





MRI Scan At the CAS group, you can contribute to the development of efficient EM wave field optimization techniques to significantly improve image quality in high-field MRI.

Distributed Autonomous Systems



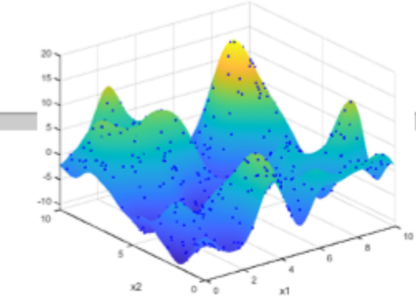
Sensor AI : Bringing AI to sensor systems

Sensor AI unites the fields of sensor fusion and AI, bringing physical knowledge into AI, and enabling the extraction of more information from available sensor data onboard networked systems. The Sensor AI Lab focuses on developing novel algorithms for distributed autonomous sensor systems e.g., automotives, UAVs, and satellites. This lab is part of the TU Delft AI Labs programme. The research topics include Scalable Gaussian Processes, Relative navigation, Human motion estimation and Distributed Learning

BSENS SORAI AILAB

Distributed Signal Processing

Due to the explosion in size and complexity of modern datasets (Big Data), it is increasingly important to be able to solve problems with a very large number of features or training examples. Hence, it is either necessary or at least highly desirable to have decentralized storage of these datasets and distributed algorithms for the problems. These solutions need to be parallelizable, asynchronous, easily scalable, be capable to exploit the possible (large) sparse geometry in the problem and need to be numerically robust against changes in the network topology. Applications can be found in distributed learning in wireless sensor networks, formation flying of satellites, or navigation of autonomous driving vehicles.



Autonomous navigation of drones

This research aims at developing optimal and resource-constrained algorithms for autonomous drone navigation including localization and synchronization for BVLOS scenarios and/or GPS-denied environments, by utilizing the onboard sensors, intermittently available RF signals from ground stations and/or in collaboration with other drones. Inferring from onboard sensors (e.g., IMU, Camera, LIDAR) entails employing sensor calibration and sensor fusion algorithms to enable environmental perception and detect and avoid (DAA).

ADACORSA

Acoustic Signal Processing

The research in the audio and speech signal processing group is focused on the development of the algorithmic and theoretical foundations of signal and information processing. The main research areas currently covered are multimedia data compression (speech, audio, video), single- and multi-channel speech enhancement, signal processing for large-scale sensor networks (localization, distributed signal processing), signal processing for hearing aids, and acoustical signal processing.

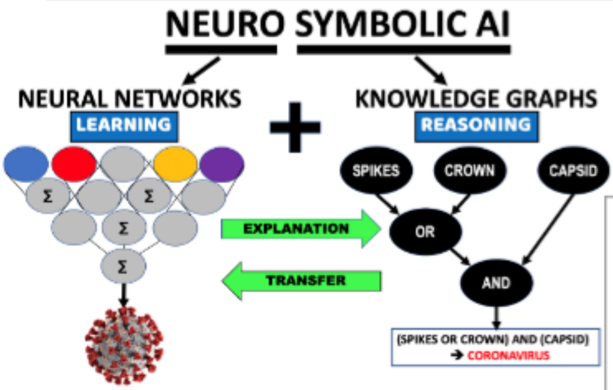
Signal Processing for Hearing Aids Together with Oticon A/S, we develop algorithms to improve the speech intelligibility, while preserving the ability to correctly localize the acoustic sources. We also develop models that can predict human speech intelligibility of processed noisy reverberant speech signals.

Speech reinforcement In train stations, airports or shopping malls, public address systems are often hard to understand due to reverberation or crosstalk between two announcement regions. We wish to pre-process the speech signal such that when it is played back in the environment, intelligibility is improved.

Next-Generation Machine Learning

At CAS we conduct research on novel approaches to build machine learning systems. We are particularly interested in neuro-symbolic systems that combine "slow" and "fast" thinking. Broadly speaking, one could view deep neural networks as a form of fast thinking, which rapidly propagate information through numerous layers of non-linear elements, while probabilistic graphical and logical systems represent slow thinking.

We develop novel methodologies for machine learning (mainly neuro-symbolic systems, which blend deep neural networks with symbolic processing) and a variety of applications in healthcare, climate research, robotics, and beyond. The machine learning group has ongoing collaborations with numerous local and international partners, such as MIT, NTU Singapore, Erasmus MC, Reinier de Graaf hospital, KNMI, Tuv Sud, and System X.

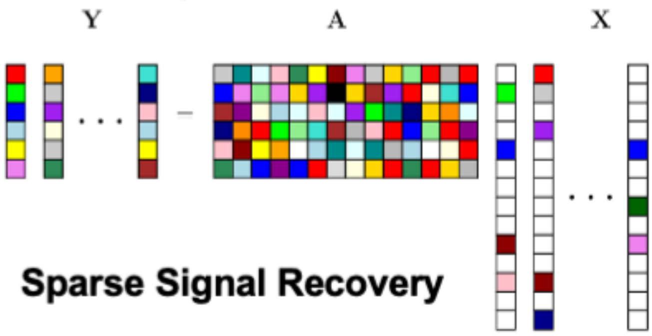


AI for predicting extreme weather Extreme weather effects such as the historic floods in southern France and the Netherlands have led to loss of life and long-term economic impacts. These meteorological disasters have shown us that weather forecasts need to become drastically more reliable, especially for extreme weather events.
We aim to develop mathematical tools for reliable modelling and prediction of extreme weather events. We are designing novel deep generative models following concepts from extreme-value theory, building upon our award-winning earlier research on extreme-value copula graphical models. To move toward this goal, we will apply statistical copulas that can tie extremal marginal distributions together to form a joint distribution of millions of extremal variables.

AI for the operating room One of our the projects is about **detecting medical instruments** in surgical nets by deep learning. Many surgical procedures are performed daily in operating rooms (ORs), where stress and haste are not uncommon. Surgical tools are misplaced during a procedure, posing a potential hazard to the treated patients or medical staff. This risk calls for monitoring whether tools are returned to their place of origin, i.e., the surgical basket or tool table. In another project, we attempt to develop tools to improve the efficiency and safety in Operating Rooms (ORs) by analyzing surgical processes and providing feedback. In particular, we are developing AI systems for **automated workflow analysis**, where observations are made and evaluated by algorithms rather than human experts.

Compressed Sensing

AI for network control Social network opinion dynamics is often manipulated by selfish agents such as paid vloggers, marketing agents, and election candidates. Their goal is to steer the network opinion to their advantage. These agents have limited access to the network due to physical and budget constraints, which can be modeled using sparse inputs. We investigate the optimal strategies of the agents to drive the network opinion to the desired state. We use a combination of Bayesian models and deep neural networks to solve the underlying sparse recovery problem.



Interpreting AI Despite the tremendous success in a wide range of applications, the theoretical understanding of neural networks is limited. The nested nonlinear structure of neural networks makes the analysis cumbersome. One of the fundamental problems related to learning neural networks is to understand the recovery guarantees of a neural network to estimate the parameters of a high dimensional distribution given a set of training data samples. We study provable guarantees and sample complexity of deep neural networks using tools from high dimensional statistics.

On the Integration of Acoustics and LiDAR

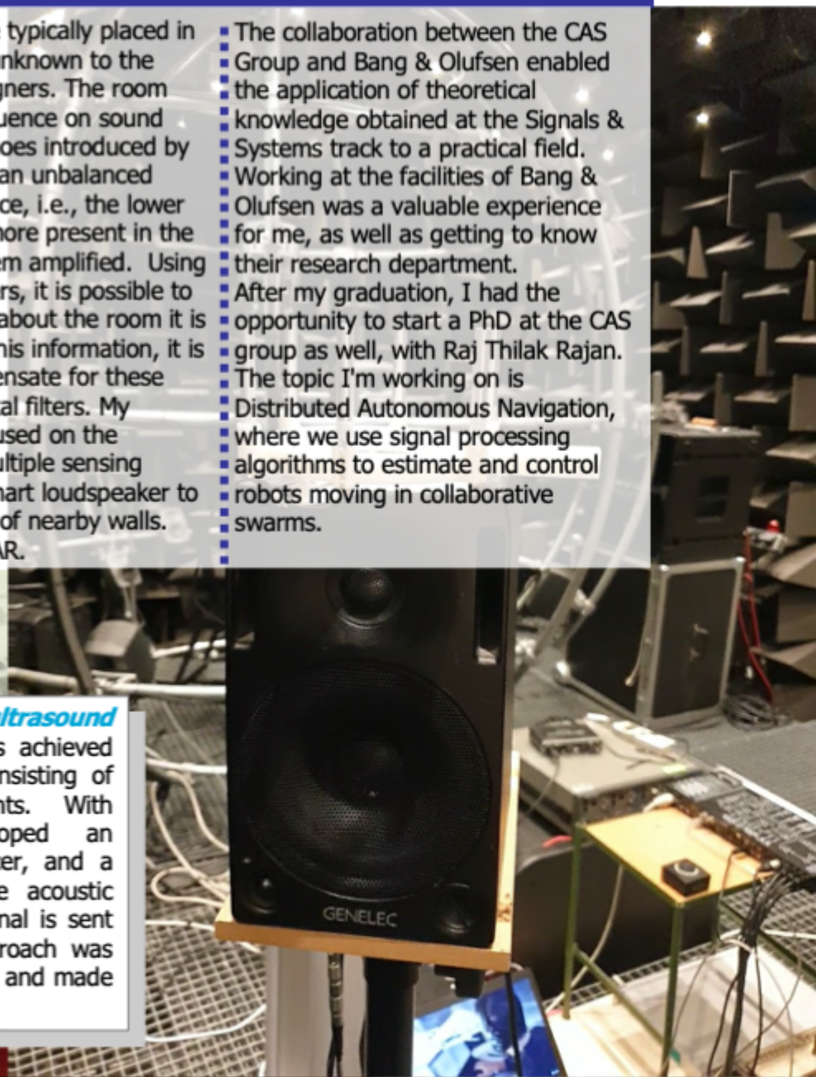
Here is an example of one of the topics that we work on. It is at the fore-front of technology, with a strong link to applications. Written by an MSc student who recently finished her MSc thesis project at the CAS group.

by Ellen Riemens

During my first year of the Signals & Systems program, I had a broad interest within the field of signal processing. I followed courses to learn about different application domains. When looking for an MSc thesis topic, I contacted several professors within the CAS group to explore topics. Jorge Martinez connected me to the research department of Bang & Olufsen in Denmark, where I researched the topic of finding certain acoustic properties of a room.

Loudspeakers are typically placed in an environment unknown to the loudspeaker designers. The room does have an influence on sound reproduction: echoes introduced by walls can lead to an unbalanced listening experience, i.e., the lower frequencies are more present in the reflection and seem amplified. Using smart loudspeakers, it is possible to infer information about the room it is located in. With this information, it is possible to compensate for these effects using digital filters. My research was focused on the exploitation of multiple sensing modalities in a smart loudspeaker to infer the location of nearby walls. Think e.g. of LiDAR.

The collaboration between the CAS Group and Bang & Olufsen enabled the application of theoretical knowledge obtained at the Signals & Systems track to a practical field. Working at the facilities of Bang & Olufsen was a valuable experience for me, as well as getting to know their research department. After my graduation, I had the opportunity to start a PhD at the CAS group as well, with Raj Thilak Rajan. The topic I'm working on is Distributed Autonomous Navigation, where we use signal processing algorithms to estimate and control robots moving in collaborative swarms.



Sparse sensing for ultrasound

Traditionally, 3D ultrasound is achieved using a 2D sliced crystal, consisting of 10,000 transducing elements. With Erasmus MC, we developed an alternative: a single transducer, and a plastic cap that scatters the acoustic waves such that a unique signal is sent into each direction. This approach was published in Science Advances and made international headlines!

The MSc thesis project

Your thesis project starts by contacting one of the professors at our group who can be your future advisor. This typically depends on your research interest and the match with the professor. Typically this is done 1—3 months before the actual start of your project. In a first meeting, we discuss your interests. The first important decision you have to make is if you want to do your graduation work at a company or at the university, in one of our research projects. In the first case, we will help you with finding a suitable place. In the other case, we will help you decide which project you should join. In any case, you'll receive more detailed information, which you can study at home. In subsequent meetings (and with your in-company supervisor if applicable), the actual project is defined, and a plan and time schedule is drafted. The project duration is usually 8-9 months, and is finished by writing a report and giving an oral presentation.

You will have regular meetings with the advisor, usually one of the professors. After 4 months a midterm presentation is scheduled, which records your activities of the first months, and contains a more detailed plan on the remaining 4 months of thesis work.

We don't just do theory: completing a design or implementing a tool is also a valid MSc project!

Criteria for a good mark are (1) amount of work, (2) quality/originality of the work, (3) independent working, (4) quality of the report, (5) quality of the presentation.

In many cases, the student also writes a conference paper based on the report. If it gets accepted, the student can attend the conference to present it!

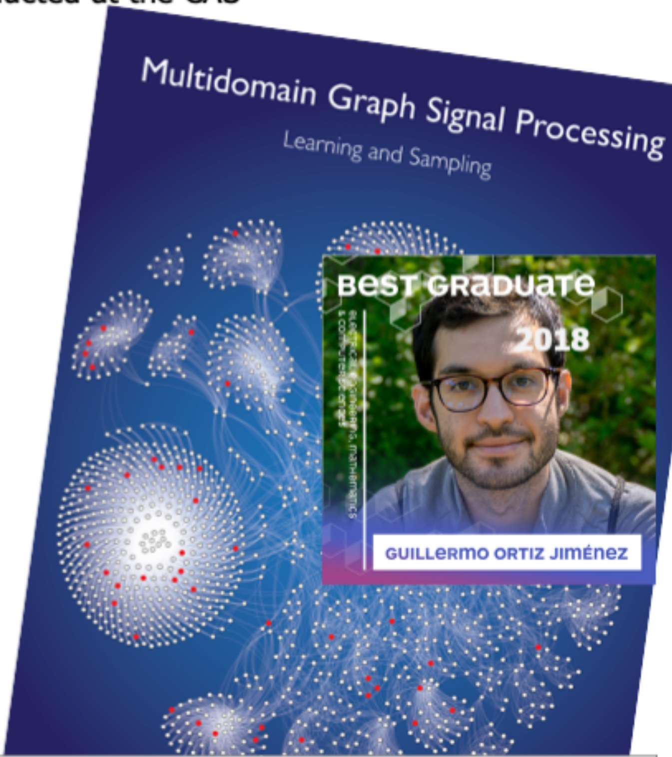
Students doing their MSc work either go to a company or work in the lab of our group. Combinations are also possible. For students working in our lab, the work is typically connected to one of our research projects.

See here for list of tentative actual thesis topics:
http://cas.tudelft.nl/Education/mscprojects.php

Thesis topic examples

To get an impression of the kind of thesis topics being conducted at the CAS group, see the list of recently finished theses below.

- Multidomain Graph Signal Processing
- Investigation of focal epilepsy using graph signal processing
- GNSS Chirp Interference Estimation and Mitigation
- Graph-aware anomalous network agent detection
- Model-based localization using vertical line arrays
- Clock skew invariant beamforming
- Calibration and imaging for future radio telescopes
- Bayesian learning applied to radio astronomy image formation
- Towards Sustainable Satellite Swarms
- Time Synchronization for Anchorless Satellite Networks
- Targetless Camera-LiDAR Calibration for Autonomous Systems
- Optimal Sensor Placement for Calibration-Involved Radio Astronomy Imaging Applications
- Loudspeakers as recording devices in public address systems
- On the Integration of Acoustics and LiDAR
- Room Geometry Estimation from Acoustic Echoes
- Deep Learning-Based Sound Identification
- Binaural beam-forming with dominant cue preservation for hearing aids
- Improving Ultrafast Doppler Imaging using Subspace Tracking
- Image Reconstruction for Multicoil Low-field MRI
- Accelerating (Compressed) SENSE Scans in MRI
- Correction of Field Inhomogeneities in Low-Field MRI During Image Reconstruction
- An automated ECG signal quality assessment method with supervised learning algorithm
- Atrial activation time estimation using cross-correlation between higher order neighboring electrodes
- Analyzing Functional Ultrasound Images of the Brain Using Tensor Decompositions
- Two-Dimensional Blood Flow Estimation in the Brain with Ultrafast Ultrasound
- Ultrasound Imaging Using a Single Element Transducer



After the MSC thesis...

After they graduate, most of our students easily find a job, e.g., at Philips Research Labs in Eindhoven, NXP, TNO, IMEC, Intel or ARM. The very best students may be offered a PhD research position, if available, or else we help with finding a position elsewhere. We have good contacts with prestigious schools such as Stanford, Berkeley, Cornell, and European institutes. Several of our students and staff have started companies, e.g., Innatera, Magma Design Automation, Ultrawaves, Eonic, Bit-by-Bit.

Some of the tools you might (learn to) use:

- Linear algebra
- Optimization
- Signal processing
- Electromagnetism
- Algorithms
- Analysis
- Software engineering
- C, C++, Matlab, Mathematica, Python, Perl, etcetera.
- and much more...

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