Silicon nitride photonics for optogenetics: Design and fabrication of \textit{in vitro} and \textit{in vivo} multi-electrode-optrode arrays for optogenetics

**Micro-optoelectronic neural implant**
- Width: 100 µm
- Thickness: 30 µm
- 24 electrodes
  - 10 \times 10 \text{ µm}^2
  - Tetrode configuration
- 12 optical outputs
  - 6 for blue
  - 6 for amber
  - 6 \times 20 \text{ µm}^2

**Successful \textit{in vivo} optical stimulation**
- Implanted in mouse brain
- Recorded neural activity

**Micro-optoelectronic neural implant**
- Miniature laser diode
- Weight < 3 g
- Heat management

**Technology**
- 100 µm \times 30 µm
- 24 electrodes
- 12 optical outputs
  - 6 for blue
  - 6 for amber
  - 6 \times 20 \text{ µm}^2

**N\textsubscript{sites}/cross-section**
- Best of 22 after 2009

**Major publication**
Video Interpretation: from Classification to Online Detection

Introduction
Over the last years, the amount of video data has grown exponentially. It is not feasible anymore to analyze all this data by hand. Video interpretation methods can automatically find concepts in videos to summarize them or extract relevant parts. We introduce some new strategies for three problems:

- Action recognition: a video contains only one human action that has to be identified, and nothing else,
- Object recognition: a video contains one object that has to be identified, and nothing else,
- Online action detection: a continuous video stream might contain interesting actions that need to be detected and identified as soon as possible.

Action recognition
Traditionally, the first step in action recognition is the detection of interesting points in videos, features. These features should contain as much information as possible that can be used to identify the actions. We introduce two new features: spatio-temporal dense interest points, and dense interest trajectories. These strategies outperform the standard features in applications where a low feature density is required.

Object recognition
Video object recognition strategies usually look for key frames in the video, where the object is clearly visible, and then apply still image recognition methods on these key frames only. All motion information is discarded. We demonstrate that this motion information is useful, and that standard action recognition methods can be used to capture this information.

Online action detection
Online action detection is a problem that has not yet received much attention. A good strategy would be useful, though, in applications where anticipation of dangerous situations is essential. An example is shown in the figure.

We collected a dataset for online action detection and designed a framework for evaluation. Adaptations of standard action detection methods to the online setting are proven to be insufficient. Nevertheless, LSTMs (‘long short term memory’), a class of neural networks, seem very suited for this problem. They receive their inputs frame by frame and give an output after every frame. Their output needs to adapt fast enough, though, to detect actions when they have only just started.

The LSTM has two tasks: it should interpret the high-dimensional video input, and it should model (short and long term) temporal connections between the actions. Our experiments suggest that the LSTM has difficulties performing both tasks at the same time. We therefore designed a two-stream architecture, where every stream focuses on one task, and demonstrated an improvement over the standard LSTM. The results are still low, though. The problem of online action detection is far from solved.

Publications
De Geest, R., Tuytelaars, T., Dense interest features for video processing. ICIP 2014.
De Geest, R., Tuytelaars, T., Improving LSTM for online action detection. WACV 2018.
The power of model order reduction in vibroacoustics and its applications in model-based sensing

Introduction / Objective
Vibroacoustic numerical modelling techniques are widespread as they enable the accurate prediction of the sound and vibration characteristics of a particular product or system. However, the amount of effort and time that is required to compute the resulting sound and vibrations is often prohibitively large. In the first part of the thesis this problem is addressed by developing highly efficient model order reduction strategies. The availability of small and accurate numerical models is leveraged in the second part of the thesis, where model-based sensing strategies are developed to enable the virtual measurement of quantities that are difficult or expensive to measure directly.

Research Methodology
The use of model order reduction methods drastically reduces computation times while making almost no concessions to the model accuracy. This work proposes solutions to retain the stability of the original model in the reduction process. Also, the reduction process is automated to make it available to non-experts, and even a strategy for parallel time domain simulation is developed. Both theoretical derivations and numerical experiments are presented.
Efficient numerical models are combined with experimental measurements in the second part of the thesis. Inverse identification methods are used to derive physical properties from experimental sound and vibrations measurements. State estimation techniques are used to produce virtual microphone measurements at locations where no physical microphone is installed.

Results & Conclusions
The developed automatic and stable model order reduction techniques are shown to yield accurate and small numerical models, which can be evaluated at a very low cost. Such models be used to assess the performance of virtual prototypes instead of relying on expensive and time-consuming physical prototypes. For example, the sound of a new guitar design can be predicted using these methods, without the need to actually construct a physical prototype.

The use of such reduced-order models in model-based sensing enables the virtual measurement of system properties. It has become possible to "listen" to the properties of a vibrating structure. By combining numerical models with a few experimental measurements, virtual microphone sensing allows us to accurately evaluate the sound at places where there is no actual microphone. This technique even makes it possible to measure the entire sound field!

Major publication
Adaptive resolution approach in simulation of complex polymer structures

Introduction / Objective
The study of polymer-based composites is a challenging multiscale problem, involving multiple time and length scales. From specific interface interactions to macroscopically observable mechanical failure, the time and length scales range from femtosecond and sub-angstrom to years and metres, respectively. Computer simulations predicting the behaviour at the largest scales from the finest atomistic details remain impossible in the foreseeable future. Therefore, coarse-grained models are usually used, which approximate the material behaviour at the level of interest, but at the expense of losing information. This thesis tackles two of the main problems in the molecular simulation of polymeric materials:
- simulation of chemical reactions at the coarse-grained level
- reverse mapping to the fine-grained level.

Research Methodology
The work presented in this thesis is mainly devoted to advancing methods that allow us to run a virtual experimental setup. We focused our tasks specifically around complex polymer systems, such as polymer networks and hyperbranched polymers.

The specific aims of this work were to deliver and validate computational tools, which can be composed into a computational experiment, showed in figure 1. In figure 2, the reverse mapping process is shown.

Results & Conclusions
As a result of this project, two computational tools were prepared.
- A comprehensive software package for modelling chemical reactions at a coarse-grained scale. We validated the results by simulating polymerization of two systems: hyperbranched polymer and polyethylene terephthalate and comparing with the existing experimental data as well as with the theory.
- A generic reverse mapping method for complex polymer systems. The key points of the method are its generality and dependency on only one tuning parameter. We tested the correctness on various of systems, starting from a set of dodecane chains and ending with complex polymer networks.

Major publication
The Value of Energy Flexibility
An Assessment of Residential Aggregator Services

Introduction / Objective
Aggregators bring together residential, commercial and small industrial demand response (DR) and distributed generation as a Virtual Power Plant (VPP) to actively participate in electricity markets or enter demand response program offered by the operators of the system. Two main barriers for Aggregator Services have been identified: Knowledge of VPP characteristics and determining the value of aggregator services. This leads to the main research question is: How can the value of aggregated flexibility be assessed?

Phase 1: How to Simulate a Residential VPP
Developed residential device and behaviour models with following requirements:
1. High Resolution (< 1 Minute)
2. Intelligent Control
3. Configurable
4. Scalable
5. Validated

Phase 2: Black Box Forecasting of VPP Characteristics
Implemented a forecasting model which is able to determine the flexibility characteristics of a VPP using no low level data. Performed a sensitivity analysis of model on broad range of VPP makeups determined which performed with low error of under 10% for all residential VPPs.

Phase 3: Value Assessment of Aggregated Flexibility
Defined mathematical determination and methodology to assign value to flexibility. Performed three types of experiments to assess various influences on value.
1. Impact of VPP Characteristics
2. Impact of Market Makeup and Environment
3. Assessment of Trading Strategies.

Contributions to Industry
VPP Models:
• Used to test new DR Algorithm
• Investigate Aggregated DR for most Smart Grid Services
Black Box Capacity Forecasting Model:
• Reduce Risk and Guarantee of Services
• Improve Optimization and DR Control Strategies

Value Assignment:
• Justify Business Case and Competitiveness
• Determine which Smart Grid Services to Offer
Value Potential:
• Assess Performance of DR Algorithm
• Recommend Improvements to increase profits

Major publication
Introduction / Objective
Osteoporosis is a bone disease associated with aging. It is defined by low bone mass and compromised bone strength, leading to increased risk of fractures. Osteoporosis results from sex hormone deficiency as well as reduced mobility with aging, leading to a negative balance in the bone remodeling process. Bone remodeling is controlled by mechanosensitive osteocytes that reside in lacunae. It has been shown that the shape of osteocytes and their lacunae vary with aging and in different bone diseases. However, it remains unknown whether changes in lacunar morphology can really underlie the altered bone mechanoresponsiveness and whether this is (one of) the pathways involved in age-related bone loss. Therefore, the focus of this thesis was on the role of osteocyte lacunar shape on the bone mechano-biological response.

Research Methodology
In order to reach this aim, we investigated potential age-related variations in the morphology of the osteocyte lacunar network in fibulae of young and old mice using high-resolution desktop micro-computed tomography (μCT). We related lacunar shape to microscopic bone strains using μCT image-based micro-finite element (μFE) modeling. In order to investigate whether lacunar morphology affects the osteocyte mecharesponsive we studied the response of osteocytes to mechanical loading in mechanically loaded fibula of two groups of mice having different lacunar morphology by quantification of loading-related changes in sclerostin and β-catenin expression in osteocytes, as determined using immunohistochemistry.

Results & Conclusions
With aging the shape of the osteocyte lacunae changes from elongated towards round; in addition, the lacunae reduce in size. A direct mechanical consequence is that local strain concentrations in the bone tissue around the lacunae will reduce in magnitude. Hence, osteocytes located in smaller and more round lacunae in aged bones will experience lower local tissue strains than those in larger and thinner lacunae in young bones. Due to the reduced tissue strains, the osteocytes respond with a loading-induced reduction in β-catenin expression and an increased expression of sclerostin, even if the mechanical loading remains the same. The reduction of β-catenin expression leads to a reduction in bone formation; at the same time, the increase in sclerostin expression limits bone formation too, because of its anti-anabolic effect. This causes an imbalance in the bone remodeling process with a net loss of bone resulting in osteoporosis.

Major publication
3D freehand ultrasound data acquisition and processing to obtain clinically-relevant muscle and tendon parameters in static and dynamic conditions in children with spastic cerebral palsy

Introduction / Objective

Medical imaging modalities are frequently used to acquire and assess large volumetric datasets of the musculoskeletal system in children with movement disorders, such as spastic cerebral palsy (SCP). One of these modalities is ultrasonography (US), an affordable, subject-friendly and accessible modality. However, the conventional 2D US has a limited field of view, and is operator dependent. A new modality called three-dimensional freehand ultrasonography (3DfUS), overcomes some of the previous limitations. The combination of an US system with pose sensors allows entire visualization of certain lower limb muscle and tendons. However, 3DfUS is not currently applicable for clinical use.

Research Methodology

This doctoral thesis aims to establish a clinically applicable 3DfUS framework, capable of obtaining reliable outcome parameters of muscles and tendons in children with SCP. This multidisciplinary project is organised into three main steps:

1. create a framework for 3DfUS that is clinically applicable and with a verified validity
2. Validate the data acquisition and processing of static condition measurements
3. Validate the data acquisition and processing of dynamic condition measurements, including a semi-automatic tool for the data processing

Results

- An open source software for applying 3DfUS was developed (Py3DFreeHandUS) and validated, with volume and length accuracies within 3%
- The reliability for estimating clinically relevant outcome parameters is sufficient to detect the variations expected in children with SCP
- A tool to reducing deformation during the acquisition was conceived and revealed to reduce volume estimation errors.
- Larger errors in estimating fascicle lengthening were found with respect to muscle belly lengthening
- A method to semi-automatically track the muscle-tendon junction displacement was validated in a SCP cohort

Conclusions

- A clinically applicable 3DfUS framework was established for estimating musculoskeletal alterations in children with SCP
- The framework has been already applied in over 150 children, and will be further developed in an ongoing TBM project

Major publication

Ab-initio investigation of amorphous semi-conductors

Introduction / Objective
With the developments of smartphones, computers, television and more recently of virtual reality, flat panel displays have become a commodity with ever-improving quality. Since the most fundamental building block of these circuits is the semiconductor material used, their improvement can lead to substantial progress. In this framework, amorphous oxide semiconductor materials such as amorphous Indium-Gallium-Zinc-Oxide (a-IGZO), have attracted much attention. The material present outstanding semiconductor properties for an amorphous material, is transparent and processable at low temperature (<350C) on very large areas, enabling the creation of transparent circuitry on flexible plastic substrate. However, the lack of fundamental understanding of a-IGZO complexifies its use. The objective of this work was to improve our comprehension of the semiconducting properties of this complex amorphous material and search for alternative material presenting p-type behaviors that could be combined with a-IGZO which only presents a n-type conductivity.

Research Methodology
The research was conducted through first-principles simulations (DFT) able to model materials at the atomic level by solving, approximately, the Schrodinger equation. Since the major difficulty for the study of amorphous phases is the creation of amorphous structures, different methods were developed for their creation. A new formalism for the study of defects in amorphous materials as well as a new method to study the conductivity of amorphous semiconductors were also introduced.

Results & Conclusions
I propose that defects in amorphous indium-gallium-zinc-oxide (a-IGZO) can be divided in two categories: point defects and "non-stochiometric" defects. Point defects are defined as local and abnormal changes in the electronic and atomic structure of the material. The locality of these defects is particularly important because the structure of an amorphous material is only locally defined. In a-IGZO for instance, the structure is characterized by the bond between the metals and the oxygen atoms. As a result, a bond between two oxygen atoms, for instance, is a well-defined points defects. In opposition, a vacancy, which is commonly considered as a point defect in a crystalline material, is not well defined in a amorphous phase. Indeed, because an amorphous structure is only locally defined, the effect of the addition (or removal) of an atom can be averaged throughout the structure. Consequently the number of atoms in the structure may be changed with negligible impact on the local structure of the material, i.e. without formation of a point defect. Since adding or removing atoms from the stochiometric structure create defects, but are not well defined point defects, these are defined as "non-stochiometric" defects. They always dope the material if they break the charge balance between the cations (metals) and anions (oxygen).
A-IGZO is a very poor hole conductor. Whenever holes form in the valence band states, they are trapped in polarons, and if the density of holes is sufficient, peroxides (oxygen-oxygen single bond) form to capture these holes. These are difficult to break at low electron concentration, effectively acting as a doping source.
The conception of an amorphous p-type material is very difficult because of the difficulty to obtain highly delocalized s-orbitals at the top of the valence band. Counterintuitively, the best delocalization is obtained by combining s, p and d orbitals at the top of the valence band.

Major publication
Precipitation estimation from weather radar measurements: statistical analysis of convective storms and extreme rainfall

Introduction / Objective
The study of precipitation estimation, which has been based so far on rain gauge measurements, can now benefit from more than 10 years of high resolution radar measurements. Accurate rainfall estimations are needed for the verification of weather and climate models and for the management of flood risks. Unfortunately radar measurements are not yet widely used due to the many sources of error and the computational challenges.

Research Methodology
The archived volumetric data of the Wideumont C-band weather radar are used to improve the knowledge of precipitation in Belgium. Convective storms producing high precipitation are identified and tracked in the 3D radar data. Surface rainfall intensity is obtained by a careful processing of the radar measurements and a combination with rain gauges. New insights are obtained thanks to:

- An in-depth analysis of the convective storms characteristics
- An independent and extended verification of the rainfall estimates
- A regional analysis of rainfall extremes based on the radar estimates

Results & Conclusions

- The distribution of convective activity indices (number of storms, area coverage and total mass) and individual storm properties (volume, mass, top, duration, speed) follows a power law with significant diurnal, monthly and annual variations.
- Artifacts in raw radar images (CAP) are reduced by the removal of non-meteorological echoes and by mitigating overestimation due to hail. The best rainfall estimation is obtained by using a vertical profile of reflectivity and spatial merging with gauges (EDK).
- For 1 hour extremes, the regional approach allows to reproduce the results of rain gauge records and to reduce the model uncertainty. The remaining differences between the radar and the gauge can be explained by estimation errors and sampling.

Major publication

Introduction and Objective

Cultural serial transnational World Heritage is extremely complex and needs new systematic methods for their management and monitoring. This doctoral thesis proposes the integration of monitoring in the nomination process of these types of properties using Geospatial Content Management Systems (GeoCMS) illustrated with the Silk Roads as a case study. This involves the definition of a conceptual framework for strengthening the monitoring process supporting a preventive conservation approach, while also building stakeholder capacity.

Research Methodology

The proposed monitoring framework, supported by continuous capacity building to stakeholders, includes:

• A cyclic approach containing the three pillars of the World Heritage Outstanding Universal Value;
• A values-based risk management approach. The Nara Grid (Van Balen 2008) and additional contributions from a wider group of stakeholders (“who”) are applied to systematically assess heritage values (“why”) and identify heritage attributes (“what”) and risk assessment (Waller 2003) is applied as a preventive conservation tool;
• Workflows for (digital) documentation, as well as data standards and methods for nomination and monitoring, of serial transnational World Heritage (“how”);
• A data model to build a monitoring tool developed and implemented as a GeoCMS under a User Centered-Design approach. The GeoCMS aids to compile, store, manage and share information online during the preparation of the nomination dossier and the monitoring process, while at the same time it uses the capabilities of a Geographic Information System (“where”).

Results and Conclusions

Results showed that the integration of a values-based risk management approach into a management system provided for a more accurate and earlier detection of the symptoms of damage. The use of the Silk Roads CHRIS, a GeoCMS, facilitated the implementation of risk assessment for serial transnational World Heritage properties by standardizing the information, as well as of the monitoring process with common techniques in remote sensing such as satellite imagery.

The system was effectively used as a tool to support the Central Asian countries in the preparation of two Silk Roads nomination dossiers. The underlying methodologies support the large number of stakeholders in their efforts to preserve the values of their shared cultural heritage, to jointly understand and trust the information, to train professionals, to increase scientific knowledge, and lastly, to produce the World Heritage nomination dossier.

Major publications

Long-term energy-system optimization models - Capturing the challenges of integrating intermittent renewable energy sources and assessing the suitability for descriptive scenario analyses

Introduction / Objective
Energy-system optimization models (ESOMs) are used to support policy making by analyzing different transition pathways of the entire energy system. To limit the time needed to solve these models, a low level of temporal and technical detail are typically employed, i.e., variations in demand and supply of electricity are represented in aggregated energy terms and the technical constraints faced by thermal power plants when changing their power output are not considered. Given the increasing penetration of intermittent renewable energy sources (IRES), such as wind turbines and solar PV panels, these modeling simplifications might induce high errors.

Research Methodology
Methodological modeling exercises have been set-up to analyze the impact of the low level of temporal and technical detail used in ESOMs, for a varying penetration of IRES.

Results & Conclusions
Impact of the low level of temporal and technical detail:
1. Both the low level of temporal and the low level of technical detail lead an overestimation of the uptake of IRES (light grey area) and an overestimation of the use of baseload plants (dark grey area)
2. The low level of temporal detail has the highest impact on the results
3. The traditional temporal representation leads to smoothing of the variability of IRES

Improving the temporal representation:
1. By using the data of a small number of representative days, smoothing of electricity generation by IRES can be avoided and accuracy increased
2. A novel method is developed to select a representative set of days, which is more accurate than methods available in the literature

Improving the technical representation:
1. Reduced formulations of the technical constraints faced by thermal power plants have been proposed (clustered unit commitment constraints)
2. These reduced formulations are shown to be sufficiently accurate, while reducing the computational cost by a factor of 5-600 with respect to a model with integrated clustered unit commitment constraints
3. Care should be taken when incorporating technical constraints. Different sources of flexibility should be represented.

Major publications
Introduction / Objective

Adequate reliability of power systems is crucial due to the criticality of reliable, but affordable electricity supply for society. Nowadays, power system reliability is managed using a deterministic reliability management approach based on the N-1 criterion. This N-1 approach does not aim at cost-optimality and is challenged by the evolutions in power systems. Probabilistic reliability management on the contrary takes into account risks related to power system uncertainties and enables system operators to make decisions based on socio-economic principles. However, adequate performance evaluation is required to convince system stakeholders to move towards alternative reliability management. The objective of this work is to contribute to the fundamental understanding of the evaluation of short-term reliability management.

Research Methodology

- A study of available quantitative and qualitative performance indicators and the development of a multi-dimensional performance metric
- The design and development of a modular and generic quantification framework
- A study of performance evaluation techniques
- The development of indices to quantify inequality and inequity between consumers in terms of reliability
- An assessment of reliability management using value of lost load data with different levels of detail based on an economic model and numerical analysis
- A study of controllable factors of short-term reliability criteria using the developed multi-dimensional performance analysis

Results & Conclusions

- The multi-dimensional performance of a reliability management approach and criterion comprises its practicality and applicability and its technical, social and economic acceptability
- Evaluation of the decision-making trajectory and the resulting real-time system state is required, while considering both normal and failure states
- The proposed inequality indices can help power system stakeholders to suppress public opposition against decisions crucial to ensure and improve the performance of power systems.
- Data issues and increased complexity of probabilistic reliability management ask for intermediate steps between the N-1 approach and a fully probabilistic approach, implying a trade-off between efficiency, reliability and equality

Major publication

Characterization of passive acoustic dampers with orifices using linear and nonlinear numerical models

Introduction / Objective
Passive acoustic dampers with perforations in the shape of Helmholtz resonators, perforated plates, and liners, are one of the most commonly used solutions to suppress noise propagation. They can be found inside vehicle exhaust systems, in aircraft nacelles as wall treatment or in air conditioning systems in buildings. The damping mechanisms involved can differ significantly depending on the geometry of the perforations, the amplitude of the incoming acoustic excitation and the operating conditions, notably in presence of flow. Due to the large variety of conditions encountered by silencers and the difficulties to reproduce and monitor them in experimental setups, numerical prediction schemes represent an appealing alternative.

Research Methodology
Considering the number of applications that can benefit from improved design tools and an overall better understanding of the complex physics involved in sound wave absorption by perforated silencers, the research activities focus on:

- Development of novel numerical techniques to characterize the aero- and vibro-acoustic behavior of perforated silencers in complex working conditions.
- Application of these numerical methods to a selected set of acoustic resonators and orifices under various conditions to characterize the damping mechanisms involved and identify potential parameters that can be included in the modeling and design of future passive silencers.

Results & Conclusions
In this dissertation, the following innovative methods are developed:

- An efficient frequency-domain high-order Finite Element Method solver for the linearized Navier-Stokes equations for problems of acoustic wave propagation through non-uniform flow regions. This linear approach is further applied to characterize the influence of local sheared flows, temperature profiles, and flow turbulence on the acoustic behavior of perforates.
- A methodology based on the Computational Fluid Dynamics solution of incompressible flow equations to study the nonlinear behavior of Helmholtz resonator.
- A coupled vibro-acoustic Finite Element Method model with a patch-impedance approach for the study and optimization of passive noise control devices based on flexible micro-perforated panels.

Major publications
Improving Efficiency in Illumination Algorithms using Stochastic Visibility Evaluation and Line Sampling

Introduction / Objective

The use of computer graphics has become commonplace in industry, games, films, architectural visualizations, etc. However, there is an ever-increasing demand for more realism and graphical fidelity. To achieve this realism, current state-of-the-art illumination algorithms are based on ray tracing, which simulates the physical transport of light. Even though ray tracing is conceptually simple, the underlying problem is a recursive integral equation. Solving this integral equation is usually done using stochastic methods which leads to variance on the numerical outcomes and noise in the rendered images. In this dissertation, we aim to reduce this noise by improving the efficiency of the stochastic methods.

Research Methodology

In this dissertation, we aim to reduce this noise by improving the efficiency of the illumination algorithms. First, we introduced a stochastic visibility estimator to evaluate the visibility between two points in a three-dimensional scene. While the visibility between two points is traditionally evaluated by testing all the geometrical primitives, we improve the efficiency by only testing a random subset of the primitives while still converging to the correct solution (Figure 1a). Second, we leverage cheap geometrical proxies to accelerate the visibility evaluation. To evaluate the visibility, we stochastically choose either to test a cheap geometry proxy or the full geometry, while remaining unbiased (Figure 1b). Finally, we propose to use line samples instead of point samples to evaluate the direct illumination. By analytically integrating the contribution of a line sample, we reduce the dimension of the direct illumination integral, which reduces the noise and can lead to higher orders of convergence (Figure 1c).

Results & Conclusions

Using stochastic visibility results in a trade-off between speed and noise. For simple scenes, the reduction in speed is not compensated by an equal reduction in noise. Therefore, this technique is only viable in scenes with very complex geometry. Similarly, the use of geometrical proxies only has merits in scenes containing very complex geometry. Finally, line sampling reduces the noise in an image, and when the offsets of the lines are sampled using an appropriate distribution (i.e. low-discrepancy or stratified) the convergence speed is increased at the expense of more costly visibility evaluations.

Major publication

Design and Evaluation of Feedback Control Algorithms for Implantable Hearing Devices

Introduction / Objective
This thesis presents three different tasks related to the development of a feedback control strategy for a novel hearing device as follows: 1) the feedback characterization in two novel implantable hearing devices; 2) the presentation of new algorithms for feedback control and their comparison with the state of the art; 3) the subjective and objective evaluation of the developed algorithms in terms of sound quality.

Research Methodology
The feedback characterization measurements of the two implantable hearing devices have been performed on fresh frozen cadaver heads.

The algorithmic derivation discusses two novel adaptive feedback cancellation (AFC) algorithms, the frequency-domain prediction-error-method-based adaptive filter (FD-PEMAF) relying solely on frequency-domain operations for both filtering and prefiltering, and the PEM-based frequency-domain Kalman filter (PEM-FDKF) algorithm, replacing the standard frequency-domain adaptive filter with a frequency-domain Kalman filter (FDKF).

Finally, a subjective listening test was designed in order to investigate the sound-quality degradation caused by different AFC algorithms, including the PEM-FDKF. Additionally, the subjective results were compared to the performance obtained using a batch of different objective measures.

Results & Conclusions
For the implantable hearing devices: there exist a specimen-dependent feedback, as well as a strong effect due to incorrect implantation; nonlinearity of the actuator was measured at high levels and the presence of a structure-borne mechanical feedback component was assessed.

The FD-PEMAF provides comparable performance to the considered baselines, reducing the total computational complexity. The PEM-FDKF combines good decorrelation properties, by means of the PEM-based signal prewhitening, fast convergence, good tracking behavior, and low computational complexity by means of the FDKF.

Additionally, The PEM-FDKF performs significantly better, in terms of sound-quality preservation, compared to the two considered baselines. The comparison between the subjective perceptual sound-quality scores and the results obtained with a batch of existing objective scores showed that a good subjective-to-objective correlation is obtained.

Major publications

Design, Autonomous Control and Flight Testing of a Multicopter Unmanned Aerial Vehicle (for Close-Range Inspection of Fruit Orchards)

Introduction / Objective
Unmanned Aerial Vehicles (UAV) are currently flying over fruit orchards performing fruit inspection. If they were to fly through the fruit orchard corridors and use sideward looking cameras, individual leaves and fruit could also be inspected with high spatial resolution. To be (commercially) viable two main challenges can be identified: (i) the design and construction of a suitable rotorcraft UAV for narrow corridors and (ii) the autonomous navigation of this rotorcraft UAV through the fruit tree corridors.

Research Methodology
A compound multicopter class was defined which uses large (efficient) propellers to lift most of the multicopter’s weight while (small fast responsive) propellers control its motion. By also “stretching” the vehicle longitudinally, the resulting design achieves lower (overall) disk loading, higher propulsive efficiency, higher payload capacity and longer flight endurance for a given width. Tools were developed that aid this compound design.

A modular and generic constraint-based task specification approach and UAV flight control system architecture was developed that is capable of simultaneously performing several tasks: human-machine shared control, (dynamic) obstacle avoidance and (visual) object (marker or corridor) and trajectory tracking in unknown environments, both in- and outdoor.

Results & Conclusions
The fruit inspection UAV is capable of flying autonomously through the fruit orchard corridors and image fruit using sideward looking cameras that capture the fruit with a 2mm image spatial resolution. This enables automated individual fruit inspection and quality assessment. The flight control system was extensively and experimentally validated both in- and outdoor and successfully navigated the UAV through the fruit orchard in more than 90% of the attempts.

Major publication
Deterministic and probabilistic determination of dynamic soil characteristics

Introduction / Objective

Characterisation of shallow soil layers is important for the study of different problems in civil and geophysical engineering, such as the prediction of ground borne vibrations in the build environment or the calculation of site amplification. This research addresses the quantification of the uncertainty on the soil parameters, determined by means of in situ experiments, focusing on the inversion of multi-modal Rayleigh dispersion and attenuation curves obtained with the multichannel analysis of surface waves (MASW) method (figure 1).

Research Methodology

The circle fit method is proposed for the determination of the Rayleigh phase velocity and attenuation coefficient. The inversion can be performed using local gradient based search algorithms. Analytical expressions are formulated for the sensitivities to the soil parameters.

In order to quantify the parameter uncertainty, a full framework for a Bayesian inversion procedure, combining the uncertainty on the test results as well as a priori available information about the soil characteristics is implemented in this PhD, using advanced Markov Chain Monte Carlo sampling methods.

Results & Conclusions

The Bayesian inversion procedures results in a soil profile with maximum a posteriori (MAP) likelihood and an ensemble of soil profiles representing the posterior probability density function of the dynamic soil characteristics such as the shear wave velocity (figure 2). These soil profiles can be used to quantify the uncertainty on the vibration transfer functions of the site.

Major publication

Study of Dust Explosion Characteristics and their Determination

Introduction / Objective
Safety is of major importance when working with combustible dusts as they can give rise to explosions. The risk for dust explosions can best be assessed by determining the explosion characteristics of the dust. Important characteristics are flame speed, maximum pressure rise, maximum rate of pressure rise and minimum ignition energy. This work aims to assess these parameters in a new way and to develop new insights into the dust explosion mechanism.

Research Methodology
- The flame structure and propagation speed of zirconium and lycopodium dust in air were computed in the Hartmann tube using high speed camera.
- The flow velocity prior to ignition was studied using the particle image velocimetry (PIV).
- A model is developed based upon the chemical and the physical properties of one single dust particle to compute the minimum ignition energy.

Results & Conclusions
- A powder such as lycopodium has a combustion that result in an irregular shape and clusters. A powder such as zirconium creates a well-defined flame which makes it possible to define the flame boundary easily.
- In our theoretical model for minimum ignition energy, the spark energy is released in a small volume between the electrodes in which dust particles are present. The heat is released instantaneously and dissipates outside this volume.
- Despite some limitations when it is applied to coals, the model predicts the MIE for dusts rather well. It is proposed to apply 40-60% energy loss when applying the model.

Major publication
Polymer Microwave Fiber (PMF) Communication Links

Introduction / Objective
Since the last decade, opportunities have been risen to integrate entire radio systems – operating at mm-Wave frequencies – in one single transceiver chip. This is merely made possible through the continuous scaling of nanometer CMOS technology. The high carrier frequency increases the absolute bandwidth, resulting in high-speed communication links. Based on a combination of three low-cost elements – (1) standard CMOS transmitters and receivers, (2) on-chip integrated antennas and (3) low-loss polymer fibers – a novel physical layer for multi-gigabit communication systems is proposed in this thesis. The result is a communication technique that is competitive with copper wireline and fiber-optics.

Research Methodology
The PMF polymer fibers that we tend to use have low insertion losses at mm-Wave frequencies and are therefore suitable for communication over several meters distance. Furthermore, the high carrier frequency enables to integrate the antenna on the chip or in the package and enables high bandwidth resulting in high data rates. This doctoral dissertation discusses the opportunities, the design issues and the performance of multi-gigabit PMF communication links. We propose to package the mm-Wave transceiver chips using flip-chip packaging instead of wire-bonding. Two 120-GHz simplex PMF communication links are implemented in a 40-nm bulk CMOS technology. The directive channel, the coupler and the CMOS circuitry are described in detail. As a proof of concept, four different simplex demonstrators are presented. Every demonstrator setup is built with a specific purpose to showcase the abilities and opportunities and to valorize the PMF communication. Finally, bidirectional communication is discussed. An orthogonal behaviour between up and downlink has to be exploited to achieve two-way communication.

Results & Conclusions
A 15-m long PMF link with measured data rates up to 1.5 Gbps is presented. Data rates up to 17.7 Gbps are measured over a link distance of 1 m with a BER < 10^{-12}. The maximum product of data rate and distance is 60.8 Gbps × m over a distance of 8 m, resulting in an energy efficiency of only 1.2 pJ/bit/m. For in-band full-duplex operation, the maximum measured data rate is 6.2 Gbps.

Major publications
Asymptotics for orthogonal polynomials and high-frequency scattering problems

Introduction / Objective
The goal of this thesis is to exploit asymptotic behaviour in computational science, and in particular in high-degree orthogonal polynomials / quadrature and high-frequency acoustic scattering problems. Asymptotics are much more efficient than standard algorithms for computing these, like the recurrence relation and Boundary Element Methods.

Research Methodology

Jacobi-, Laguerre- and Hermite-type polynomials/quadrature:
- Weight function: generalised and classical
- Asymptotic expansion: obtain all terms
- Expansions cover the whole complex plane

Adaptive asymptotic compression for scattering problems:
- Capture local contributions to integrals from BEM with window function
- Discover asymptotic information adaptively to the geometry
- Efficient and robust algorithm improves condition number

Results & Conclusions

Efficient, fully explicit and automatic construction of higher order asymptotic expansions of orthogonal polynomials and Gaussian quadrature rules as $n \to \infty$.

Major publications

Daan Huybrechs and Peter Opsomer. *High-frequency asymptotic compression of dense BEM matrices for general geometries without ray tracing*. 2017, In revision
Design of automotive sound packages for the mid-frequency range

Introduction and objectives
Design of sound packages for the mid-frequency range is challenging:
- Lack of clear performance metrics
- Mix of structureborne and airborne contributions
- Many parameters (geometry, input, material, attachment)
  ➔ Objective: Have tools and guidelines to design sound packages

Research methodology
The methodology consists in 4 steps:
1. Selection of mid-frequency performance metrics
2. Development of an exploration framework for the mid-frequency performance of sound packages
3. Application on a structureborne case
4. Validation of the exploration framework

Results and conclusions
1. Metrics have been selected to quantify transmission and structureborne back-coupling performances.
2. A greedy exploration framework has been developed:
   - Objective: Be able to translate a performance target into a sound package property by “performance maps”
3. Application on a structureborne case allows to extract performance maps and conclude on guidelines:
4. Validation of the framework has been performed by measurements of 47 specifications in a dedicated set-up.

Major publication
Deformation behavior of Al-Al and Al-Cu laminated materials produced by Accumulated Extrusion

Introduction / Objective
Severe Plastic Deformation (SPD) helps in producing metals with enhanced microstructural and mechanical properties. It has the ability to produce ultra fine grained (UFG) and nano-structure metals at a bulk scale and therefore has a great scope in advanced engineering applications. Accumulated Extrusion (AccumEx) is a new SPD technique that has been introduced in this thesis. The aim of this thesis is to evaluate AccumEx as a SPD technique and understand the evolution of the microstructure, texture and mechanical properties of the materials processed by AccumEx.

Research Methodology
- AccumEx was applied to two material systems - Al-Al (Similar) and Al-Cu (Dissimilar). The microstructure, texture and mechanical properties of the deformed materials were characterized.
- The deformation field imposed by AccumEx on Al-Al was derived using the embedded pin technique.
- The saturation behavior of UFG Al-Al laminates at ultra high strains was studied using ex-situ plane strain compression tests coupled with EBSD characterization.
- AccumEx was directly compared with Equal Channel Angular Pressing (ECAP) in terms of the obtained final material properties.

Results & Conclusions
AccumEx produced an UFG microstructure in Al for both Al-Al and Al-Cu laminates, while a coarser microstructure in the Cu part of the Al-Cu laminates. The mechanical properties deteriorated after 4 passes for Al-Al and after 2 passes for Al-Cu. Shear induced delamination defects reduced the robustness of the material. In Al-Cu system, the interaction between Al and Cu played a crucial role.

The deformation field of AccumEx contained a gradient in shear strain across the thickness from surface to center. They accumulated as the number of deformation passes increased. The B-H fibre, a new texture fibre was identified and proposed as an indication of the presence of shear or shear gradient.

Grain size saturation can be visualized as an effect of few sequential microstructural events which involved shortening of grains, disappearance of grains and grain boundaries and re-arrangement of grain neighbors. Two mechanisms were identified as drivers for the microstructural modifications - grain splitting, pinching and triple junction motion. The local deformation mode at the level of the microstructure was identified to be a combination of plane strain compression + shear with its axis around TD + extension along TD.

A comparison study between AccumEx and ECAP showed that AccumEx was very effective in producing a rapid grain refinement and strengthening of the material. However, at ultra high strains, the robustness of the material is compromised which limits its ability as a SPD process only till medium high strains.

Major publication
Introduction / Objective

Switched-mode power converters are used in various applications, such as computer and office equipment, consumer electronics, networking and telecom equipment and industrial electronics. The main advantage of switched-mode power converters is the high conversion efficiency they provide. One of their most important disadvantages is the high level of electromagnetic emissions they generate, which can exceed the limits specified in the regulations.

The objective of this dissertation is to develop a design methodology for switched-mode power converters with an improved electromagnetic compatibility. The ability to improve the electromagnetic compatibility early in the design stage reduces the design cost and time to market.

Research Methodology

The methodology is based on mathematical combination of the results of the decoupled electromagnetic and circuit simulations of the analyzed converter. The electromagnetic simulations are used to model the radiation characteristics of the converter. The circuit simulations are used to model the electrical characteristics of the converter.

Decoupled electromagnetic and circuit simulations allow to simplify the simulation domains, which speeds up the simulations and enables parameterized analysis of:

- input decoupling network, which is a critical part for the electromagnetic compatibility of these type of converters,
- small loop above finite image plane, which is a simplified model of radiation of these type of converters.

A procedure for calculation of radiated emissions from the measurements performed by a transverse electromagnetic cell and a hybrid coupler is developed. It is used to validate the methodology.

Results & Conclusions

The application of the methodology is demonstrated on the example of a synchronous buck converter. The converter is based on the integrated circuit NCP5369 from ON Semiconductor. The predicted radiated emissions of the converter are compared to the radiated emissions calculated from the measurements performed by a transverse electromagnetic cell and a hybrid coupler and a good agreement is obtained.

Major publication

Valorization of coffee byproducts via biomass conversion technologies

Introduction / Objective
Coffee is one of the world’s most prominent agricultural products, mainly used as a beverage. Processing of coffee generates different byproducts. The main focus of this PhD research is to investigate the potential for valorization of coffee byproducts via biomass conversion technologies. The main objectives of the study are the evaluation of the impact of waste water produced by wet coffee processing industries and waste processing technologies are screened specifically for their potential in processing coffee waste.

Research Methodology
To evaluate the impact of effluents from traditional wet coffee processing plants on the downstream water quality, samples were collected from 11 rivers/streams associated with wet coffee processing plants. Effluent quality parameters for these plants were measured before intake, during processing and after effluent discharge. Bioethanol production from different coffee waste fractions has now been studied by acid or acid and enzymatic hydrolysis. The fermentation was conducted using two different yeasts (baker’s yeast and lignocellulosic yeast). Further purification of the fermented filtrate was carried out by an alcohol selective pervaporation membrane at 4 temperatures (23, 30, 40 and 50 °C). Besides, composting and co-composting of coffee husk and pulp with source separated municipal solid waste was studied. Finally, comprehensive study was conducted on the pyrolysis of the different fractions of coffee waste (coffee husk, pulp, parchment, silver skin and spent coffee ground) was performed.

Results & Conclusions
The measured values of effluent parameters significantly deviate from both the Ethiopian-EPA and US-EPA surface water quality guidelines. Husk hydrolysis using acid and cellulolytic hydrolysis and fermentation with lignocellulosic yeast GSE16-T18 followed by pervaporation was found to be viable for producing an acceptable ethanol yield (figure 1.1). The composting results indicate that coffee husk and pulp can be composted alone or co-composted with source separated municipal solid waste yielding very mature and stable compost with good quality. The pyrolysis results indicate that more char and activated carbon could be produced from pyrolysis of coffee pulp than from any other fraction of coffee waste. In particular, the coffee waste fractions silver skin and parchment were found to yield higher bio-oil yield than the other coffee waste fractions.

Major publication
MOBILITY RESOURCE OWNERSHIP
CONCEPTS, DATA ANALYSIS AND MODELING

Introduction / Objective
Transport systems are evolving from a stable and conservative mix of options towards portfolios of instantly accessible mobility services. One of the effects of such disruptive changes is that our capabilities to forecast transport systems are getting limited. The central topic of this research lies in predicting demand for mobility services and ownership accommodating mobility behavior predictors.

Research Methodology
The proposed model, which exploits the maximum random utility concept in a discrete choice context, forecasts mobility resource ownership of people (e.g., whether they own only a car, or they are better off with a car and a bicycle). The predictions are based on personal travel patterns spanning over multiple days. The particular focus was devoted to the following topics:

- Developing, estimating and applying the mobility resource ownership model using a real-world data.
- Identifying the travel behavior determinants in personal travel patterns using the robust statistics.
- Transferring the required data sets to a geo-spatial context lacking travel behavior data using Statistical Matching.
- Framing the model in a supply and demand interactions using a Stackelberg leadership structure.

Results & Conclusions

The mobility determinants were identified

The model was plugged in a supply and demand framework of multimodal systems

Major publication
Climate variability and change in Europe and the Middle East

Introduction / Objective
This PhD research deals with the challenge researchers and organizations involved in water resource management are confronted with to create and design local alternatives to reduce adverse impact of climate variability and change. The overall objective is to contribute to a better understanding of how climate variability and change may impact hydrological conditions in Europe and the Middle East. The specific objectives of this thesis are 1) to analyze the decadal variability of extreme precipitation in Europe and the Middle East, 2) to detect the atmospheric drivers of extreme precipitation variability in Europe and the Middle East, 3) to investigate the impact of climate change in Belgium for precipitation, evapotranspiration and water availability, and 4) to examine the impact of climate change in the Middle East for precipitation, dryness and drought.

Research Methodology
To scrutinize the atmospheric processes that transport large amounts of moisture for an extreme precipitation event and to potentially improve seasonal prediction systems considering multiple interacting controls that govern extreme precipitation occurrence, the concurrent and lagged relationships between extreme precipitation quantiles and slowly-varying modes of climate variability were investigated through bivariate and multivariate analyses. The climate change impact and the associated uncertainties were statistically analyzed using climate models with a wide range of spatial (2.8-~400 km) and temporal (15min-daily) scales.

Results & Conclusions
The results show that European extreme precipitation in all seasons is mostly modulated by the winter atmospheric circulations over the Atlantic and Pacific and the summer atmospheric circulations over the Mediterranean Sea (Fig. 1). The analyses for the Middle East reveal an intensification of extreme precipitation events for the late 21st century for all seasons. A drier spring and a wetter autumn is expected based on seasonal precipitation projections (Fig. 2). A longer drought periods are also projected for most of the Middle East region.

The climate change results indicate that wet season will get wetter and dry season drier in Belgium, resulting in an increased risk of summer droughts and winter floods.

Major achievement
The 2016 Ernest du Bois Prize from King Baudouin Foundation for the best PhD thesis on the theme of water availability and the protection of the water resources in the world.
Cochlear implant artifact suppression in EEG measurements

Introduction / Objective
Cochlear implants (CIs) aim to restore hearing in severely to profoundly deaf adults, children and infants. Electrically evoked auditory steady-state responses (EASSRs) are neural responses to continuous modulated pulse trains, and can be objectively detected at the modulation frequency in the electro-encephalogram (EEG). EASSRs can potentially be used to determine appropriate stimulation levels during CI fitting, without behavioral input from the subjects. EASSRs are distorted by electrical artifacts, caused by the CI's radiofrequency link and by the electrical pulses used to stimulate the auditory nerve. CI artifacts may also be present at the modulation frequency, leading to inaccurate EASSR detection and unreliable EASSR amplitude and phase estimations. The insights provided in this thesis and the developed CI artifact suppression methods may assist researchers and clinicians to record EASSRs in the presence of CI. These responses may then be used to improve CI rehabilitation or CI stimulation strategies, leading to a better quality-of-life for all patients with a CI.

Research Methodology
CI artifacts are characterized based on the CI artifact duration and based on the CI artifact amplitude growth function (AGF). Furthermore, three methods for CI artifact suppression to enable reliable estimation of EASSR parameters are developed and evaluated on EEG data acquired in CI subjects.
- Independent component analysis (ICA)
- Template subtraction (TS)
- Kalman filter (KF) based EASSR parameter estimation

Results & Conclusions
The CI artifacts are larger and longer in recording channels closer to the implant. Advanced CI artifact suppression methods are needed to measure EASSRs in ipsilateral channels and in infants and children.
- ICA based CI artifact suppression: in some cases, CI artifacts are successfully removed, although mixed results are obtained in other cases.
- TS based CI artifact suppression: reliable EASSR amplitudes, phases and latencies are obtained. The template construction recording duration can be reduced to 60 s, while reliable EASSR parameter estimations are still obtained.
- KF based EASSR parameter estimation: reliable EASSR amplitudes, phases and latencies are again obtained for a high signal-to-noise ratio (SNR) dataset, without the need for additional data collection.

Example of a CI artifact for S8, with a CI at the right side, measured with 37 Hz AM 900 pps pulse trains at a subthreshold stimulation amplitude. Left: time and frequency domain signals. Right: spatial distribution of spectral power at the modulation frequency. No neural response is expected to be present, as subthreshold stimulation levels were used.

Major publications
Selective laser melting of aluminum, Hastelloy X, tool steel and cobalt-chrome: Compositional modification and use of base plate preheating

Introduction / Objective
Selective laser melting (SLM) is an emerging additive manufacturing production technique for metals, offering a perfect solution for production of small series of parts and parts with complex geometries. One of the main drawbacks at this point is the limited number of materials that are processable using SLM. Specific knowledge that is acquired within SLM of one material can not be automatically transferred to SLM of another material, which highly complicates the material development.

In this research, four different materials are investigated in order to broaden the material palette for SLM.

Research Methodology
Each of the four materials that are subject for this research, possesses its own challenges and requires a different focus.

• High strength aluminum alloys have great industrial interest because of their good strength to weight ratio. These alloys, however, suffer from major cracking issues when processed through SLM. This problem is tackled by changing the alloy composition on the one side and by application of base plate preheating on the other side.

• The nickel alloy Hastelloy X also suffers from crack formation which can be minimized using base plate preheating.

• H13 tool steel is well processable by SLM but has a low martensitic transformation temperature. Therefore, its properties are highly influenced by the base plate preheating temperature applied during SLM.

• For CoCr, a wide variety of in- and post-process treatments were examined in order to fully characterize CoCr SLM parts.

Results & Conclusions
Addition of Zr to high strength aluminum alloys results in extensive grain refinement of the material as shown in Figure 1. Since a fine grained microstructure is less susceptible to crack formation, crack free parts could be obtained after minor compositional modification.

Figure 2 shows the effect of base plate preheating on the stress-strain curves of H13 tool steel parts. The bainitic microstructure in parts produced at 400ºC guarantees best ultimate tensile strength of as-built SLM parts.

Major publications
Virtual torque sensing: A model-based approach for indirect measurement of dynamic operational loads on mechatronic powertrains

Introduction / Objective

Mechatronic powertrains are found in a wide variety of industrial and commercial applications such as wind turbines, production machines and vehicles. Optimizing such powertrains' design and operation requires detailed knowledge about their dynamic behaviour and operational loads. Dynamic load torque is a key quantity of interest in this respect, but due to its intrusive nature, but an operational measurement, using a torque sensor is almost never feasible. Therefore, this work has aimed for the indirect measurement of a dynamically varying load torque acting on a mechatronic powertrain.

Research Methodology

The proposed approach is one of model-based state estimation. A lumped-parameter physical model describes both the electrical dynamics of the actuator and the mechanical dynamics of the driveline. This work assumes no prior knowledge on the load torque, but instead treats it as an unknown system input. Kalman-filter based joint state/input techniques allow online estimation of the load torque by combining the non-linear multi-physical model with measurement data from the electrical and the mechanical domain. Before demonstrating this approach, several questions are to be addressed:

- Which modelling approach and estimator algorithm to use?
- How to determine suitable sensor types and locations?
- How to validate and demonstrate a virtual torque sensor?

Results & Conclusions

This work has demonstrated accurate virtual torque sensing in the frequency range of 0 to 200 Hz, based on a lumped-parameter torsional driveline model. It has indicated how the required instrumentation depends on which (high-)dynamic content is to be identified in the load torque estimate. A novel mechatronic powertrain setup has been developed for validation, featuring a double cardan driveline and a reference torque sensor. The use of acceleration measurements ($y_{\text{acc}}$) instead of speed measurements ($y_{\text{vel}}$) allows to increase the virtual sensor bandwidth significantly ($10 \rightarrow 200$ Hz). With the former, the reference ($T_L$) is followed closely, independently of the input model uncertainty $Q_{uu}$.

Major publication