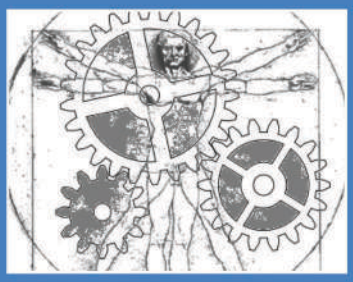
BodyPoweredSenSE

WEARABLE ICT FOR ZERO POWER MEDICAL APPLICATIONS



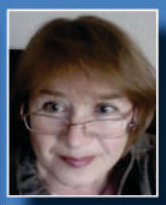
Prof. Pierre-André Farine, EPFL


Prof. David Atienza, EPFL


Dr. Danick Briand, EPFL


Prof. Thomas Gross ETHZ


Prof. Christofer Hierold, ETHZ


Dr. Maria Knyazeva, CHUV


Dr. med. Gabriele Wohlrab, KISPI

What it's about…

Developing smart, energy aware, user friendly wearable sensors and associated medical algorithms for the early diagnosis of Alzheimer's disease and childhood epilepsy, where the sensors derive power from the user's body energy (heat and motion) as well as from ambient light.

Context and project goals

Increasingly the analysis of a patient's physiological state requires long-term monitoring, during day to day activities, in order to precise a diagnosis or to evaluate the efficacy of an on-going treatment. Although wearable sensors can significantly benefit mankind in this long-term monitoring process, today's solutions invade the user's normal life as sensing platforms require removal, replacement and reconfiguration for battery recharging. Moreover, they are often too large, user-unfriendly and difficult to interpret their results.

Zero power medical devices can revolutionise human sensing, as new software and hardware architectures will lead to drastically lower power demands. Energy will then be harvested from natural sources (body heat, body motion, solar) such that recharging is no longer a prime necessity. Hence, users will experience a plug and play, near unperceivable, "forever on" usage pattern thereby enabling very long data capture periods not feasible today.

This project will support this zero power technology paradigm and apply them in realistic, demanding and extremely relevant use cases: the early prediction of Alzheimer's Disease (AD) in the elderly and the diagnosis of epilepsy (EP) in young children.

The research follows a layered approach starting with the design, development and fabrication of the natural energy harvesting sources. Then, in this project we will integrate them into a wearable platform, called ZPSense, in which the energy will be optimised in a global process to minimize the wastage of energy conversion and storage. The ZPSense platform will leverage very low power microprocessor and sensing circuitry optimised for bio-signals and fabricated to fit into highly ergonomic devices. A new approach to energy aware software design and multi sensor integration will ensure the ZPSense platform to operate at maximum quality of service for a given energy profile.

The ZPSense system will include a 24-channel EEG, a three-channel ECG and a novel patient environment monitor. It will interoperate on a body area network performing a multi-parametric analysis and fusion resulting in a more complex medical analysis than using three sensors separately. Using state of the art algorithms, the system will allow health care workers to more effectively diagnose AD and EP. The ZPSesnse system will be tested with real patients and will be thoroughly evaluated to determine their clinical and user satisfaction. Since care at home is the primary medical motivation, the industrial partners BodyPoweredSenSE will ensure a generic approach to health care at home, captured in a flexible friendly Home software application, as well as a user-centered design approach putting the user's needs at the centre of the ZPSense's ergonomic design.

How it differentiates from similar projects in the field

The fields of energy harvesting, energy aware computing, bio-medical wearable sensing, and medical diagnostic computational algorithm are all deeply researched topics at this time. This project is different in that it sums the needs and benefits of each of these fields into a synergistic whole. Every research aspect incorporates an understanding of the other and aims to deliver an overall superior solution technologically, medically and for the human benefit.

Quick summary of the project status

The energy harvesting work by SAMLAB and MNS has resulted in several prototypes being tested in the laboratory. TEGs have been integrated into headwear and the stretching piezo composite materials are being evaluated both on machines and to some extent on laboratory volunteers. The energy conversion to storage research of ESPLAB continues well with some silicon having been designed and a tape out due soon. The energy aware run time of NSG has been designed and design of the embedded clinical applications for ECG and EEG have begun as well as the design of a test hardware platform so that real time energy consumption during SMART sensing can be evaluated.

At the clinical level, NSG is working with KS to finalize the set of epilepsy detection algorithms and CHUV has begun testing EEG algorithms to detect localization patterns that could be used to detect degradation in neural pathways using low density EEG. ESL has begun work on system level networks and potential means to save energy through collaborative system behaviors.

Success stories

Presence in the media:

L'Express, Mercredi 17 juillet 2013, *Le corps producteur d'électricité*

Envirobot

AUTOMATED SURVEYING OF SURFACE WATER QUALITY
BY A PHYSICAL, CHEMICAL AND BIOLOGICAL SENSOR EQUIPPED
ANGUILLIFORM ROBOT

Prof. Jan Roelof van der Meer, UNIL

Prof. Richard Benton, UNIL

Prof. Martial Geiser, HESSO-VS

Prof. Hubert Girault, EPFL

Prof. Auke Ijspeert, EPFL

Prof. Philippe Renaud, EPFL

Dr. Kristin Schirmer, Eawag

What it's about…

Developing an aquatic robot which can "smell" polluting substances, using integrated biological and chemical sensors.

Context and project goals

Envirobot is an ambitious high end project with the major aim to develop and construct a demonstrator robot platform (the Envirobot) that samples and measures a set of relevant water quality parameters in surface water bodies by the incorporation of optical, physical, chemical and biological sensors. The Envirobot platform will be based on existing segmented anguilliform Amphibots, but with important adaptations in terms of energy use and efficiency, sensory decision programming, and communication possibilities. The Envirobot is invented to perform autonomous surveying or autonavigation. In autonomous surveying the robot will sample and analyze water bodies according to a preset path and defined number of waypoints.

During autonavigation, the robots must guide its movements and sampling on the basis of the sensory input. Autonavigation is challenging but extremely interesting, since Envirobot would be able to track and follow gradients of chemical pollution in water bodies. Envirobot will thus go significantly beyond what is currently feasible with automated buoys or sampling platforms.

The second major aim of the project consists in particular in the development and incorporation of a range of biological sensors useful for both functioning modes of the Envirobot. Biological sensors provide the best ecotoxicological information on water quality and can be both broadly responsive to any 'general distress' or very precise to quantify individual compound concentrations. By contrast, they have a wide range of response times (ms hours). Robust but slow response time biosensors (min hours) will consist of bioreporter bacteria or trout fish cell lines producing de novo fluorescence in response to pollutant stress, which will be used for water sample analysis during autonomous surveying. In order to produce rapid response time biosensors (ms min), which can actually guide the robot's movements, we will exploit:

1. bacterial chemotaxis towards and away from toxicants, and on toxicant induced changes in real time bioluminescence
2. electrophysiological or calcium (Ca) dependent fluorescence changes in signaling cascades employing insect chemoreceptors
3. real time observations of heart beat and leg movement frequencies of Daphnia magna (water flea) individuals.

All biological sensors are to be embedded in easy exchangeable microfluidics chambers with integrated life support, with optical or electrical detectors and with autosampling capacity, which will fit into body segments of the robot. Biological sensors are further complemented by a variety of miniaturized physical, optical and chemical sensors with rapid response times that can analyze a set of general water quality parameters.

How it differentiates from similar projects in the field

Aquatic robots are typically driven by telemetric operation. Here the project is integrating biological and chemical sensors into an existing aquatic robot that should permit the robot to operate and measure chemical pollution autonomously. The final goal is that the robot can seek and relocate its movement to the source of pollution based on continuous measurement inputs.

Quick summary of the project status

A new version of the anguilliform robot with larger modules and improved fabrication was conceived. Data communication between modules and sensors was established. First physico-chemical sensors were tested and implemented in individual robot modules. Robot swimming was improved and algorithms were developed to allow source tracking. Important progress was made with biological sensor elements. Rainbow trout gill cell lines could be maintained over long times in biochips and reacted very sensitively to a wide range of toxicants.

A method for automated heart-beat tracking was developed on single *Daphnia* individuals captured in microfluidic cages, that can be used to monitor distress upon pollutant exposure. A microfluidic impedance measurement system was designed to study the activity of ligand-induced voltage channels in *Xenopus* oocytes, which in the future can be implemented with a variety of channels.

Finally, bacterial systems were constructed and tested, which enable sensitive measurements of mercury ions. Progress was also made to quantitatively track bacterial cell movement in response to chemical exposures.

Success stories

The consortium is extremely dynamic, meeting in plenary every 3 months and with important key interactions between different groups. For example, development of *Xenopus* oocyte and fish gill cell microfluidics impedance (UNIL-CIG, Eawag and LMIS4), incorporation of bacterial sensors in microfluidics / electrochemical units (UNIL-DMF, LEPA and LMIS4), and robotic sensor implementation (BIOROB and HES-SO).

General "course" work has been incorporated to promote better understanding of mutual technical aspects (e.g., electrochemistry, modeling, voltage channels).

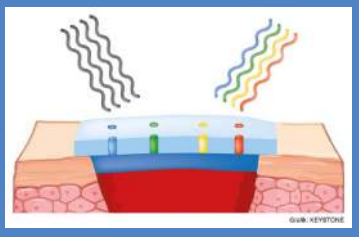
Produced video:

Measuring heart beat of Daphia: Uploaded movie on http://www.youtube.com/watch?v=fbTwfCm7eD0

Prof. Bradley Nelson, ETHZ

FlusiTex

FABRICATION OF FLUORESCENCE SENSORS INTEGRATED INTO A TEXTILE DRESSING FOR NON-INVASIVE LIFETIME BASED WOUND MONITORING



Dr. Luciano Boesel, EMPA

Dr. Stefano Cattaneo, CSEM

Dr. Michael Richter, EMPA

Prof. Brigitte von Rechenberg, UZH

What it's about…

Fabricating a sensing wound pad that can be used for non-invasive monitoring of the healing of chronic wounds, based on integrated fluorescence coupled (bio)sensors and fluorescence lifetime imaging using a TOF camera.

Context and project goals

FlusiTex will develop a wound dressing with an integrated sensing layer for non-invasive wound monitoring using fluorescence lifetime detection. The sensing strategy relies on a functionalized coating integrated onto commercially available wound dressings. Functionalization comprises fluorescence modified polymer hydrogels, enzymes embedded in fluorescence labeled polymer coatings, and functionalized nanoparticles that also serve as a component of the coating layer.

These sensing layers provide information on biochemically and physically relevant wound characteristics. A dedicated camera using a CMOS lock-in imager with fluorescence lifetime capability will be developed for periodically monitoring the response of the layers noninvasively, thus providing immediate feedback on the progression of wound healing at various points in time. Since the wound healing process is not yet fully understood, studies on factors relevant for the process will be conducted by a medical team in parallel with the development of the sensor-pad. The sensing elements will be integrated with a commercially available wound pad, and fabrication techniques will be developed to enable reliable large-scale production. The data from the embedded sensing elements will be collected by a specially developed fluorescence lifetime imager based on lock-in pixel technology and optimized to match the sensing needs, thus eliminating the for integrating expensive electronics with the wound pad. At the end of the project, a prototype of the system will be tested in vivo. A variety of companies have indicated strong interest in this project and will provide industrial expertise with the goal of joining the project at a later stage when technology transfer will follow, e.g. in the form of CTI projects.

The goal of the project is a (bio)sensing wound dressing suitable for read out using a fluorescence lifetime imager. While the wound pad to be developed is for use as a wearable wound-monitoring system, it can also be further extended to enable development of textile based environmental or food monitoring systems (a second application in the NanoTera research space). The technologies required to develop such a system are also congruent with the technology focus of Nano Tera projects; biotechnology, nanofabrication, biosensors and optical systems will be our main technology tools. The textile industry in Switzerland has suffered a dramatic decline in recent years due to the growing low-cost textile industry in Asia. This downturn can only be stopped and reversed by diversifying into high technology segments such as medical textiles, which have much higher margins than the conventional clothing segment. FlusiTex will enable the Swiss textile industry to enter untapped market segments by providing a state-of-the-art textile-based monitoring system.

How it differentiates from similar projects in the field

The approach to use multi-optical fiber sensing integrated into a wound pad for simultaneous monitoring of different parameters is novel. The data from the embedded sensing elements will be collected by a specially developed fluorescence lifetime imager based on lock-in pixel technology and optimized to match the sensing needs, thus eliminating the need for integrating expensive electronics with the wound pad.

For the first time, the response of the layers will be periodically monitored noninvasively and immediate feedback will be collected on the progression of wound healing at various points in time.

Quick summary of the project status

The project was successfully kicked off.

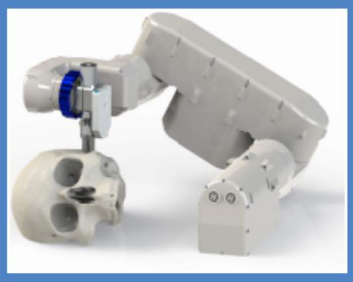
Hospital visits have been arranged to quantitatively study acute wounds on site. Chemicals to be detected to monitor wound healing have been chosen. We designed a strategy to synthesize the required enzyme-based FRET sensors and integrate those markers into commercially available wound pads.

“Fluorescence based wound monitoring pads with integrated biosensors may find broad application in strongly growing fields such as health care & medtech”

Prof. Stefan Weber, UniBE

HearRestore

IMAGE-GUIDED MICRO SURGERY FOR HEARING AID IMPLANTATION



PD Dr. Philippe Büchler, UniBE

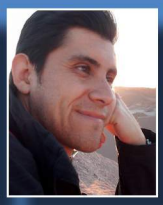
Prof. Marco Caversaccio, InselSpital

Dr. Olivier Chételat, CSEM

Dr. med. Patrick Dubach, InselSpital

Mr. Edo Franzi, CSEM

Dr. Kate Gerber, UniBE



Prof. Mauricio Reyes, UniBE

Prof. Andreas Stahel, BFH

Prof. Philippe Zysset, UniBE

What it's about…

Developing novel surgical and robotic technologies to drastically reduce the invasiveness and improve the outcome of hearing implant surgery.

Context and project goals

Hearing impairment or loss is among the most common reasons for disability. Worldwide, 27% of men and 24% of women above the age of 45 suffer from hearing loss of 26dB and more. Meaning that the person concerned can only hear sounds with a volume higher than 26dB, where whispering, quiet talking and loud radio music have sound pressures of 30dB, 50dB and 80dB respectively. In absolute numbers 80 to 100 million humans in the EU are suffering from hearing impairment.

While steady and extensive research is carried out to further improve and extend cochlea implant technology, the traditional surgical approach, foremost its invasiveness has not changed over the last three decades. In other surgical domains, the advancement of minimally invasive procedures advanced with the introduction and availability of suitable endoscopic and instrument and ultimately computer technology. Additionally, free-hand image guided surgery (IGS) and surgical robotics have been around since more than one decade increasing the surgeon's spatial orientation and thus reduction of uncertainty during surgical and interventional procedures. IGS is currently established as standard of care in Neuro-, head and orthopedic surgeries. While the propagation of such technologies into the aforementioned surgical disciplines is saturated, other clinical disciplines (i.e. abdominal) and interventions on a smaller geometric scale, so called as microsurgical procedures – have yet to be investigated.

Thus, in this project we will systematically explore and investigate approaches for micro-scale surgical image-guidance by utilizing the latest advancements of modern implants, imaging technology, as well as signal processing and computational power. The complex task of cochlear implantation is a prime example of a multi-scale system where research together with dedicated efforts in system integration can make a significant improvement in treatment options. Additionally, this scenario focuses on a relevant medical problem with an everincreasing importance due to the rise of the developed world. Unlike in the well-explored 'macro-surgical' application scenarios, the utilization of IGS in microsurgery requires extensive research far beyond existing knowledge. Thus, the project consortium intends to investigate a number of recent and promising research approaches that suggest feasibility and suitability for the mentioned application scenario, such as:

- Tracking of surgical instruments using nanometer scale tracking technology;
- Computer based planning of the implantation procedure using anatomical, physiological, and functional information derived from high resolution (80 µm) medical image data;
- Sub-millimeter accurate, reproducible and minimally-invasive patient-to-image registration;
- Numerical modeling of the drilling process for precise drill pose estimation;
- Utilization of Neuromonitoring to allow for safe and functional image guidance;
- Development of suitable clinical models and benchmarks in which efficacy and safety of image-guided cochlear implantation are demonstrated.

To enable such a project, a consortium of experts in nano-meter scale tracking, surgical robotics, medical image analysis, biomechanics, numerical bioengineering and clinical medicine has been created.

How it differentiates from similar projects in the field

This project is set apart from the competition in its approach to accuracy, safety and redundancy. The surgical robot is a platform technology which allows precise performance and monitoring of different stages of the surgery. Machining forces, integrated nerve stimulation/neuromonitoring, and image-guidance all culminate in an information rich environment to help guide the surgeon in the decision making process.

Quick summary of the project status and key results

Substantial progress has been made in all subtasks. The major highlight of the project is the successful transfer of the base technology to clinical use. The project was able to achieve regulatory clearance from both the local institutional review board (ethics commission) and the regulatory body Swissmedic for a first in man clinical trial. The trial will take place at the ENT department (clinical PI Prof. Caversaccio) of the University Hospital Bern.

Additionally, the consortium was able to launch a live animal study with collaboration from all four partner institutions. Preparation for the study required a large organizational effort and contributions from each of the project partners. The main goal of the study is to evaluate a new nerve stimulation probe, which will hopefully improve the accuracy of facial nerve detection.

In addition to this objective, the live animal study offers a unique opportunity for each of the project partners to make individual measurements with direct impact on their individual sub-tasks. As an example bone impedance, and drilling temperature measurements were both conducted within this framework.

Success stories

Awards:

A presentation of the scientific challenges and findings from the robot project was awarded with the “Hamlyn Medical Robotics Award 2013” during the prestigious Hamlyn Symposium on Medical Robotics, held at the Royal Society of Engineering in London in 2013.

Also, Mr. Juan Anso (PhD student at ARTORG center) received the distinction of ‘Best Master’s Thesis’ from the Biomedical Engineering department of the University of Bern for his work on facial nerve monitoring.

Presence in the media:

TV: Euronews “High Tech”: The project was showcased in a report on the spaceCoder technology.

Patents

B. J. Bell, T. Williamson, and S. Weber, “System and Method for estimating the spatial position of a tool within an object,” EP12168772.72012.

The above patent on process-based pose estimation was submitted previously, and was recently awarded. This patent is one of the foundations of a safety warning system which can alert the surgeon of impending contact between the drill and the facial nerve or other structures.

Other patents are in preparation.

Main publications

J. Ansó, B. Bell, N. Gerber, T. Williamson, K. Gavaghan, M. Caversaccio, S. Weber, Feasibility of Detection of the Facial Nerve Using EMG During Robotic Direct Cochlear Access, In International Journal of Computer Assisted Radiology and Surgery, Volume 8, Supplement 1 (pp. 101–107).

J. Ansó, C. Stahl, N. Gerber, T. Williamson, K. Gavaghan, K.M. Rössler, M-D. Caversaccio, S. Weber, B. Bell, Feasibility of Using EMG for Early Detection of the Facial Nerve During Robotic Direct Cochlear Access, Otol Neurotol. 2014 Mar;35(3):545-54. doi: 10.1097/MAO.0000000000000187.

J. Ansó, T. Wyss, M. Caversaccio, S. Weber, B. Bell, High Accuracy Functional Neuromonitoring to Preserve the Facial Nerve during Robotic Direct Cochlear Access using a custom made Concentric Stimulating Probe, 30th International Conference of Clinical Neurophysiology: Abstracts of Poster Presentations – Poster Session 8 – Intraoperative monitoring 1.

J. Ansó, T. Wyss, P. Büchler, A. Stahel, S. Weber, M. Caversaccio, B. Bell, Intraoperative Neuromonitoring of the Facial Nerve during Minimally Invasive Cochlear Implantation: A custom made Stimulating Probe, 13th International Conference on Cochlear Implants and Other Implantable Auditory Technologies.

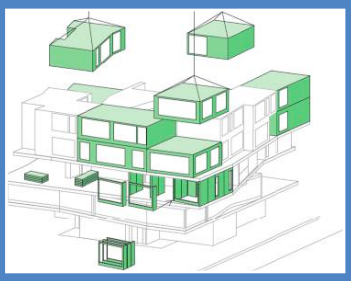
B. Brun[1], T. Williamson[1], M. Caversaccio2, S. Weber[1], B. Bell[1], Validation of custom active markers for use with a high accuracy tracking system, CURAC 2013.

“How could you develop such a robot and I don’t know about it!”

Renowned ENT surgeon
Prof. Dr. med. Olivier Sterkers, Paris

HeatReserves

DEMAND RESPONSE FOR ANCILLARY SERVICES: THERMAL STORAGE CONTROL



Prof. John Lygeros, ETHZ

Prof. Göran Andersson, ETHZ

Prof. Jan Carmeliet, EMPA

Prof. Moritz Loock, UniSG

Dr. Marek Zima, SwissGrid

What it's about…

Using thermal loads of buildings as reserves to enhance renewable energy integration.

Context and project goals

Control reserves are traded in the control reserve market and are today mainly covered by conventional generators. In Switzerland, control reserves are prominently provided by hydro power plants, which pump water to high altitudes in case of power surplus and release water through turbines in case of power shortage. Although in Switzerland the electricity production of wind and solar is currently limited, the need for ancillary services is significant also here, because of the nuclear phase-out as well as business opportunities with neighboring countries with substantial renewable generation such as Germany.

We propose to use thermal loads as additional means for ancillary services to account for the expected increase in renewables. To achieve this, we will develop appropriate demand response schemes for the thermal loads. One advantage of thermal loads is their ability to react locally, whereas control reserves from hydro power plants can lead to congestions in the transmission network. The increase in the number of ancillary service providers also leads to higher market liquidity. Finally, demand response can help to reduce electricity peaks. We propose two main options for providing ancillary services with thermal loads: first, control of Heating, Ventilation, and Air Conditioning (HVAC) systems of an aggregate of several office buildings; second, control of a large number of household appliances. These two options share a number of challenges, which can be categorized as follows:

Modeling and estimation: the challenges are due to modeling the fast dynamics of buildings given their complex HVAC systems as well as uncertainty in building parameters and weather forecasts; and due to modeling a large-scale and distributed population of household appliances in the power grid and (currently) very limited measurement possibilities for household appliances.

Control and communication: the models in both options are large-scale, distributed, hybrid (discrete and continuous modes of operations) and stochastic. Effective and tractable control schemes for these systems have to be developed. For office buildings the communication infrastructure is already in place (internet access of most building management systems), but privacy considerations put limitations on the information exchanged. For household appliances communication infrastructure still needs to be developed considering the trade-off between performance and investment costs.

Economic considerations and user incentives: even if all technical problems are solved, the crucial factor for a successful implementation of demand response will be whether users take part in the proposed schemes. This, to some extent, will be determined by economic incentives balancing benefits to the grid (Transmission System Operator) with potential losses or investments to the participants. To ensure user participation, we will investigate market structures, consumer behaviors and design incentives such as rewards, or lottery schemes.

Demand response options for both office buildings and for household appliances will be addressed by developing appropriate methodologies, tackling the computational complexity of the large-scale aggregated systems, validating the proposed methods in large-scale simulations, and finally case study implementations. The demand response schemes developed will provide additional ancillary services to the grid while optimizing energy use of each building/household unit. To tackle the multi-disciplinary problems, the project partners provide an outstanding mixture of expertise in the relevant areas of power grids, control theory, building simulations and economics. The expected outcome of the project is guidelines for Switzerland on the methodology and costs for implementation of demand response schemes for ancillary services and incentives for user participation in the schemes.

How it differentiates from similar projects in the field

The team consists of multi-disciplinary researchers from the fields of control theory (ETHZ-IfA), power systems (ETHZ-PSL), building systems (EMPA), grid operation (SwissGrid) and economics (St. Gallen). This allows for a holistic approach to address the proposed problem, including its technical, economic, and user acceptance implications.

Quick summary of the project status and key results

An integrated building modeling and simulation environment was developed in collaboration between ETH and EMPA. This platform is serving as a testbed for the control schemes developed.

In collaboration with Swissgrid, ancillary service requirements and the market structure were explored and the data from Swissgrid was used in the control schemes. The first round of the market study was conducted by St. Gallen, aiming to determine factors influencing user acceptance of thermal load demand response schemes. Six Semester and Master thesis were advised on topics of the project.

Collaborations with industrial partners of Cofely AG and Repower were established. Numerous papers were published in high impact journals and conference proceedings and four papers are submitted for publication. Ten presentations were given by the project partners in prestigious power and control conferences.

Success stories

Through a series of meetings with Swissgrid, several challenges and opportunities for participation of thermal loads in ancillary service market were identified.

Through collaboration of ETH Zürich partners with EMPA, a novel modeling and simulation platform for commercial buildings was developed. This platform contains a database of typical Swiss office buildings. It enables simulation of the buildings under various demand response schemes and can be used for accurate quantitative analysis of the developed strategies for the future of Switzerland ancillary service market.

A methodological framework was established, to estimate the amount of building reserves that can be robustly extracted. Several theoretical and practical challenges had to be resolved in the process. To the best of the team's knowledge, this is the first systematic approach to this problem. It is currently being extended and validated on the simulation platform described above. The consortium is hoping to be able to deploy this method on the NEST building later in the project.

Although several approaches have been proposed to enable the participation of populations of Thermostatically Controlled Loads (TCLs) in ancillary service markets, detailed quantitative analysis of the potential of these loads was lacking. The project addressed the Energy Arbitrage problem, that is, it answered the question of whether an aggregation of TCLs could make profit by participating in wholesale electricity markets. The results of the paper are the first to quantify the answer to this question. The key scientific findings were that the arbitrage potential for individual residential units are very small. Although the study was performed for participation in the wholesale electricity markets and with California market data, it is expected that the results would be similar for ancillary service markets in Switzerland, a topic we are currently investigating. The team's results suggest that there is a clear need for incentive design mechanism to engage consumers for participation in such demand response schemes. This further motivated and defined the tasks on economic analysis. They also suggest that minimal investment in communication infrastructure can be expected in this case, further motivating the development of advanced distributed control algorithms.

Main publications

M. Kamgarpour, M. Kamgarpour, C. Ellen, S. Esmaeil Zadeh Soudjani, S. Gerwinn, J. L. Mathieu, N. Müllner, A. Abate, D. S. Callaway, M. Fränzle and J. Lygeros, Modeling Options for Demand Side Participation of Thermostatically Controlled Loads, IREP Bulk Power System Dynamics & Control Symposium, Crete, Greece.

J. L. Mathieu, M. Kamgarpour, J. Lygeros, G. Andersson and D. S. Callaway, Arbitraging Intraday Wholesale Energy Market Prices with Aggregations of Thermostatic Loads, IEEE Transactions on Power Systems.

E. Vrettos, F. Oldewurtel, M. Vasirani, and G Andersson , Centralized and Decentralized Balance Group Optimization in Electricity Markets with Demand Response, IEEE Powertech Conference.

E. Vrettos, K. Lai, F. Oldewurtel, and G Andersson , Predictive Control of Buildings for Demand Response with Dynamic Day-ahead and Real-time Prices, European Control Conference.

E. Vrettos, and G Andersson , Combined Load Frequency Control and Active Distribution Network Management with Thermostatically Controlled Loads, IEEE International Conference on Smart Grid Communications.

E. Vrettos, J. L. Mathieu, and G Andersson , Demand Response with Moving Horizon Estimation of Individual Thermostatic Load States from Aggregate Power Measurements, American Conrtrol Conference.

E. Vrettos, J. L. Mathieu, and G Andersson , Control of Thermostatic Loads Using Moving Horizon Estimation of Individual Load States, IEEE Power Systems Computation Conference.

E. Vrettos, F. Oldewurtel, F. Zhu, and G Andersson , Robust provision of frequency reserves by office building aggregations, World Congress of the International Federation of Automatic Control.

Kuenzel, K., Loock, M., Cometta, C. , How punishment and reward increase customer acceptance of demand response in the energy industr, Academy of Management Meeting. – Philadelphia.

X. Zhang, S. Grammatico, G. Schildbach, P.J. Goulart, J. Lygeros, On the sample size of randomized MPC for chance-constrained systems with application to building climate control, European Control Conference.

X. Zhang, K. Margellos, P.J. Goulart, J. Lygeros, Stochastic Model Predictive Control Using a Combination of Randomized and Robust Optimization, Control and Decision Conference.

E. Vrettos, X. Zhang, F. Oldewurtel, M. Kamgarpour, J. Lygeros, G. Andersson, Exploring the Potential of Buildings in the Swiss Ancillary Service Market, Computational Optimisation of Low-Energy Buildings.

M. Kamgarpour, E. Vrettos, G. Andersson, J. Lygeros, Popluation of Thermostatically Controlled Loads for the Swiss Ancillary Service Market, Computational Optimisation of Low-Energy Buildings.

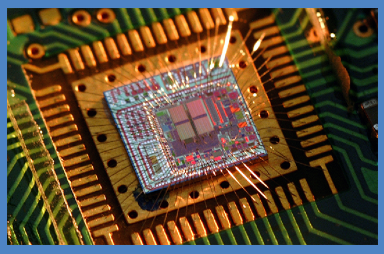
J. L. Mathieu, M. Kamgarpour, J. Lygeros, G. Andersson and D. S. Callaway, Energy Arbitrage with Thermostatically Controlled Loads, European Control Conference.

T. Borsche, F. Oldewurtel, G. Andersson, Scenario-based MPC for Energy Schedule Compliance with Demand Response, World Congress of the International Federation of Automatic Control.

T. Borsche, F. Oldewurtel, G. Andersson, Balance Group Optimization by Scenario-based Day-ahead Scheduling and Demand Response, IEEE Innovative Smart Grid Solutions Europe (ISGT-EU).

IcySoC

INEXACT SUB-NEAR-THRESHOLD SYSTEMS FOR ULTRA-LOW POWER DEVICES



Prof. Christian Piguet, CSEM

Prof. Luca Benini, ETHZ

Prof. Andreas P. Burg, EPFL

Prof. Christian Enz, EPFL

Thomas Lentsch, EM Microelectronics Marin

What it's about…

Developing an ultra-low-power platform based on an integrated circuit operated at very low supply voltage ("near- or sub-threshold") and using inexact computation blocks that provide approximate results tolerated by many applications like video or audio.

Context and project goals

The notion of exact computation, where outputs of the computational element (circuit) have precise deterministic values, as well as the fact that electronic chips are powered at nominal voltages for increased performances, have been pervasive in the computing domain for many decades owing to the overwhelming success of the integrated circuit design using reliable transistors, particularly in Complementary Metal-Oxide-Semiconductor (CMOS) technology. However, semiconductor industry is facing serious challenges today as diminishing transistor sizes driven by Moore's law are leading to increasing process variations and additional perturbations due to temperature and voltage fluctuations which threaten the circuit functionality. Owing to such widely anticipated hurdles to continued technology scaling - the promise of Moore's law - and a growing desire for reducing energy consumption, techniques and technologies such as inexact/approximate circuits and sub- or near-threshold circuits (supply voltage below or near the transistor threshold voltages) have gained prominence. The first radical approach realizes parsimonious or "adequately engineered" designs that trade accuracy at the hardware level for significant gains in energy consumption, area, and speed. The second approach offers the minimal power or energy consumption at the cost of increased delay and power variations. A large class of energy constrained systems, particularly in the domain of embedded portable multimedia and in domains of budding interest such as recognition, search and data mining, lend themselves readily for such a design philosophy. In fact, all of which can tolerate inaccuracies to varying extents or can synthesize accurate (or sufficient) information even from inaccurate computations.

Until now, these research works have been limited to application-specific instances of building blocks that were mostly ad-hoc targeting some specific examples and did not consider well-understood complete platforms based on these inexact and extreme low voltage components in sub- or near-threshold operation. In addition, research was conducted without a synergy between inexact computing and extreme low voltage circuits. It is therefore mandatory to consider at the same time the design of various inexact, approximate, sub- or near-threshold components and the platform consisting of these components. The platform design will be largely impacted by the usage of these components, in terms of parallelism, performances and robustness. One has to revisit the system design in terms of usage of hardware accelerators, heterogeneous or homogeneous processor cores and of communication or network-on-chip that has to be implemented for data transmission.

It has been demonstrated that inexact arithmetic blocks could provide a reduction up to 15X in delay, power and area product. Sub- or near-threshold circuits could provide a reduction of 6X in dynamic power when reducing the supply voltage from 1.0 V. to 0.4V. The platform design, while using very energy-efficient hardware accelerators, will contribute to the significant power reduction expected from the combination of the aforementioned techniques.

We will address practical issues by using the proposed techniques to fabricate prototype chips implementing large-scale error resilient systems and through physical measurements to validate and demonstrate evidence of the utility of these techniques both quantitatively (through well-defined application-specific quality metrics) and qualitatively, yielding perceptually discernible outputs (such as audio, image or video data).

How it differentiates from similar projects in the field

The project combines three techniques that are nicely complementary techniques: first, a multiprocessor platform (parallelization is mandatory to reduce power), second extreme low supply voltages down to 0.3 or 0.4 Volt (as power is proportional to Vdd^2, significant power reduction) and third, inexact arithmetic that also reduce significantly the power by reducing the required hardware.

Quick summary of the project status and key results

The consortium has a clear view of the architecture of the platform comprising multiprocessors, memories, network-on-chip and hardware accelerators.

The latter will be designed in inexact logic and the whole platform will be operated at very low supply voltages.

Several inexact arithmetic blocks have been identified and designed. A standard cell library at 0.4 Volt is currently designed.

Success stories

For the moment, IcySoC is still in the first phase of the project. The IcySoC project was presented in a Tutorial in the FTFC'14 workshop in Monaco, in which Christian Piguet and Andreas Burg were invited to present in details the project. These talks were well received and followed by a very interesting discussion with the audience.

Jeremy Schlachter has visited Rice Univ. for two weeks and has visited Avinash Lingamneni who was a former Ph.D. student in Rice/EPFL/CSEM working on inexact arithmetic.

Georgios Karakonstantis was invited to present research seminars on energy efficient approximate system design in University of Manchester and Queen's University (U.K.), Aarhus University (Denmark) and State-University of New York at Buffalo (U.S.A).

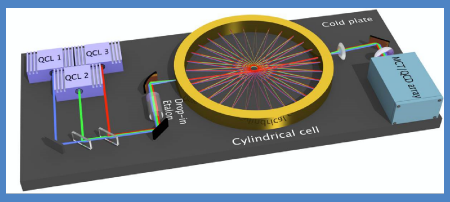
Main publication

G. Karakonstantis, A. Sankaranarayanan, M. M. Sabry, D. Atienza, A. Burg, A Quality-Scalable and Energy-Efficient Approach for Spectral Analysis of Heart Rate Variability, DATE 2014, Dresden, Germany, March 24-28, 2014.

Prof. Jérôme Faist, ETHZ

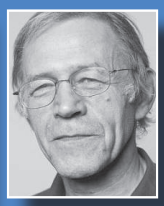
IrSens II

A MULTI-COMPONENT SENSOR FOR AIR POLLUTANTS AND GREENHOUSE GASES



Dr. Rolf Broennimann, EMPA

Dr. Lukas Emmenegger, EMPA



Prof. Herbert Looser, FHNW

Prof. Thomas Südmeyer, UniNE

What it's about…

Developing a laser based gas sensor for the simultaneous detection of up to ten components in environmental monitoring, medicine and industrial applications.

Context and project goals

Progress in sensor technologies and their applications has become a key ingredient for a sustainable development of today's society. Gas sensors, in particular, are essential to address some of the major challenges, such as air quality in urban areas and their effect on human health, as well as monitoring, predicting and reducing environmental impacts due to air pollutants and greenhouse gases. In this respect, mid-infrared (mid-IR) optical absorption techniques offer the possibility to realize highly sensitive detection of gases, which have inherently low molecular densities compared to liquids or solids.

In fact, the mid-IR spectral region contains the fundamental and most intense vibrational frequencies, which may be used to obtain an unambiguous signature of the targeted molecules, even at very low concentrations. The NanoTera project IRSens has explored the development of a technological platform for high sensitivity, portable and low-cost sensors based on new near- and mid-IR technologies such as VCSELs, quantum cascade lasers (QCL) and new optical elements. This project led to the industrialization of a hydrogen fluoride sensor based on near-IR VCSEL, a compact instrument measuring CO_2 isotopes with record precision, as well as the first detection of cocaine in saliva using mid-IR sensing techniques.

We, therefore, intend to leverage on these previous achievements to go several steps further by realizing new exceptional tools for gas monitoring in two strongly connected and complementary activities: the development of a highly specific and sensitive analyzer for nitrogen dioxide (NO_2) and an "all-in-one" spectrometer covering the ten major air pollutants and greenhouse gases. These two breakthrough instruments will exploit the developments of photonic elements with very low footprint and dissipation, made during IRSens, to create a new generation of high-precision and multi-species mid-IR sensors.

The first instrument will detect nitrogen dioxide, which is one of the most prominent air pollutants and a key substance in photochemical processes. The detection will be based on a miniaturized QCL based sensor for NO_2 that will be deployed on field. This sensor will be highly selective, unlike chemiluminescence, the standard method for NO_2 analysis, which is influenced by other nitrogen containing compounds because it is based on the reduction of NO_2 to NO prior to its detection.

The second instrument will detect the ten most relevant air pollutants (NO, NO_2, NH_3, SO_2, O_3, CO) and greenhouse gases (CO_2, H_2O, CH_4, N_2O) in a single instrument that does represents a "Holy Grail" for environemental sensing. It combines very broadband QCLs, having up to three DFBs for "multi-color" operation with novel optical arrangements, fast electronics and new laser driving schemes. This device will revolutionize air sensing and would be an excellent starting point for the future development of a medical breath analyzer.

To reach these ambitious goals, the group of ETH (Faist) will tackle the broadband, multi-color QCL; EMPA (Emmenegger) the optical and spectroscopic aspects of gas sensing; UNINE (Hofstetter) the detectors; EMPA (Brönimann) the electronics for laser driving and signal processing, and the University of Applied Sciences FHNW (Looser) the prototype system, spectral analysis software and the graphical user interface. Benchmarking and field validation will be performed in collaboration with the GAW World Calibration Center of the World Meteorological Organization and the Swiss National Air Pollution Monitoring Network who expressed their keen interest in our results. In addition, this research proposal has also attracted a strong industrial interest from ABB and AlpesLasers.

How it differentiates from similar projects in the field

The main difference between this project and others is the use of multi-color DFB lasers which allow obtaining several wavelength sources coming out from the same laser. This considerably decreases the complexity of the optical setup of the sensor.

The different wavelengths can be electrically controlled independently giving the possibility to sequentially address the different absorption lines. The integrated sensor will be based upon new developments for the optical cell, the quantum cascade detector, the controlling electronics and the signal processing.

Quick summary of the project status and key results

- Development of a new geometry for the multi-color DFB giving a better yield of independent single mode lasers and improving the dynamical range usable for spectroscopy.
- Low phase noise 400 MHz oscillator realized and FPGA based system, with ADC obtained with commercial available building blocks.
- QCL driver for the NO_2 platform developed.
- Definition of the targeted wavelength, resulting in the need for only 7 different wavelength instead of 9 in the original proposal
- New geometry for the optical cell for a longer optical path and better tolerance for misalignment
- New scheme for low dissipation driving of QCLs.

Success stories

Result

Development of a new geometry for the multi-color DFB lasers allowing a better yield for independent single mode emission samples

Award

IrSens prototype wins first runner-up innovation prize at SPIE Photonics Europe 2014.

The prototype analyzer developed within the IrSens project has been presented at the innovation village of SPIE Photonics Europe 2014 in Brussels. Markus Mangold from Empa won the first runner-up prize in the category "best innovation" for the prototype entitled "Portable mid-IR trace gas sensor for mobile applications".

The IrSens prototype is a truly portable MIR spectrometer based on direct absorption laser spectroscopy. Miniaturization-driven development of each building block and careful consideration of the power dissipation led to a high-sensitivity trace gas sensor with a footprint no larger than an A3 sheet of paper. The sensor is packaged to withstand weather conditions and is fully field deployable. The small footprint and ruggedized construction make it highly suitable for a variety of industrial, medical, and environmental applications.

Successful collaboration with industrial partner Alpes Lasers

An important step towards compact QCL based sensors is the miniaturization of each individual component. A close collaboration between Empa and the industrial partner Alpes Lasers SA, led to successful packaging of a QCL including a collimation lens into an HHL housing. The combined know-how of spectroscopy experts and laser developers allowed solving severe issues caused by unwanted back-reflections of light. The developed solution is a good example of how collaboration of research and industry strengthens the innovation in Switzerland.

Patents

- M. Mangold, B. Tuzson and L. Emmenegger, "Method for reducing fringes in laser spectroscopy measurements using an absorption mask in combination with multi-pass optical cells". Switzerland Patent 01884/12, 2012.
- J. Jágerská, M. Mangold, B. Tuzson and L. Emmenegger, "Time-multiplexed driving of multicolour lasers for quasi-simultaneous spectroscopic analysis," EP 14166907, 2014.

Main publication

M. Fischer, B. Tuzson, A. Hugi, R. Brönnimann, A. Kunz, S. Blaser, M. Rochat, O. Landry, A. Müller, L. Emmenegger, Intermittent operation of QC-lasers for mid-IR spectroscopy with low heat dissipation: tuning characteristics and driving electronics, Opt. Expr. 22, 7014-2027 (2014).

ISyPeM II

THERAPEUTIC DRUG MONITORING FOR PERSONALIZED MEDICINE

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Marco Bianchessi, STMicroelectronics

Dr. Thierry Buclin, CHUV

Prof. Christian Heinis, EPFL

Prof. Philippe Renaud, EPFL

Prof. Michael Schumacher, HES-SO

Prof. Jean-Manuel Segura, HES-SO

Prof. Yann Thoma, HES-SO

What it's about…

Developing a technological platform to improve medical practice by enabling personalized medicine via therapeutic drug monitoring, while reducing healthcare costs.

Context and project goals

Modern therapeutics must benefit from the development and large-scale implementation of convenient, user-friendly, miniaturized, integrated instruments enabling drug concentration monitoring and seamless pharmacokinetically guided dosage individualization. Technological advances during recent years make it possible to envisage a portable system, which would allow to perform drug concentration measurement in patients receiving critical treatments. The device should be offered at affordable cost to specialized clinics, and progressively to general practices or even to the patients themselves (as it is already the case for blood glucose determination). Translation of concentration measurement values into personalized treatment advices requires the integration of efficient and ergonomic computer tools into the system. These need to be coupled with communication capabilities, which are nowadays becoming a standard in many aspects of medical care, in order to be connected to reference pharmacokinetic-parameters databases.

The conception of our Point-Of-Care (POC) system is addressed to respond to three main objectives:

- perform the measurement of drug concentration in blood samples by an automated and compact analytical setup
- provide the medical doctor with information on the behavior of the patient within the population and accordingly suggest dosage adjustment
- collect drug usage and measurement data into a remote database, enabling further refinements in dosage adjustment procedures.

The aim of this project is to develop a sample-to-result POC system, which would include all the outlined functions. In particular, the system will be stand-alone and provide communication and elaboration functions in a configurable fashion in order to respond to different application needs.

The ISyPeM consortium holds a composite set of know-how and owned technologies to develop each technological component of the system, namely: a miniaturized blood sample preparation device, connected to a compact and low-cost analytical system with electronic readout for determining the drug concentration; an embedded elaboration software framework to determine dosage adjustment, manage population data and connect with remote databases; finally, a flexible and ergonomic graphical user interface to interact with the user at different levels of complexity.

How it differentiates from similar projects in the field

A comprehensive integrated approach to Therapeutic Drug Monitoring which combines innovative point-of-care compatible assays, prescription decision support and interoperability in a complex data-sharing scenario.

Quick summary of the project status and key results

The novel aptamer-selection protocol developed by CLSE in the framework of the ISyPeM I project led to the selection of highly specific probe molecules for Tobramycin, which demonstrated their functionality in serum samples.

Measurement system miniaturization let to drug detection on sample volumes down to 20µl both for label-based and label-free techniques (whole blood and serum samples respectively).

The software user-interface EzeCHiel for therapeutic drug monitoring features the possibility to visualize the concentration curve, percentiles for population data, patient specific parameters and works on an encrypted local database. Moreover, the interface between EzeCHiel and the system database at CHUV, MOLIS, has been defined.

Success stories

PRS signed: All partners signed a Product Requirements Specifications document prepared by the HES-SO Valais. This demonstrates the motivation of the consortium toward a commonly agreed target and in particular to ensure the functionality of the demonstrators.

EzeCHiel: start-up being launched soon: Partners at HEIG-VD and at CHUV will create a start up based on the EzeCHiel software.

The first demonstrator for drug monitoring at the point-of-care developed by CLSE-EPFL and STMicroelectronics and based on an STMicroelectronics property CMOS image sensor, is capable of determining Tobramycin concentrations in serum samples.

Presence in the media

“Le bon dosage en quelques minutes.”, E. Morisod, HES-SO Valais-Wallis Rapport d’activités 2013 (2013).

“Life Sciences HES-SO Valais//Wallis: Applied Research for Innovators.”, E. Heinzelmann, Biotechnet Column in Chimia 68 (2014) 449.

Patent

WO 2014/020479 A2 , April 10, 2014. “Post-CMOS Processing and 3D Integration Based on Dry-Film Lithography", C. Guiducci, Y.Leblebici, Y. Temiz.

Main publications

Verena Gotta, Stephane Bouchet, Nicolas Widmer, Peter Schuld, Laurent A. Decosterd, Thierry Buclin, Francois-Xavier Mahon, Chantal Csajka, Large-scale imatinib dose–concentration–effect study in CML patients under routine care conditions , Leukemia Research 38 (2014) 764–772, 2014 Elsevier Ltd.

F. M. Spiga, A. Bonyár, B. Ring, M. Onofri, A. Vinelli, H. Sántha, C. Guiducci, G. Zuccheri, Hybridization chain reaction performed on a metal surface as a means of signal amplification in SPR and electrochemical biosensors, Biosensors and Bioelectronics, 54, (2014), pp. 102-108.

E. Accastelli, G. Cappi, J. Buckley, T. Ernst, C. Guiducci, Comparison between front- and back-gating on silicon nanoribbons in real-time sensing experiments, Nanotechnology (IEEE-NANO), 2013 13th IEEE Conference on, vol., no., pp.517,520, 5-8 Aug. 2013.

A Fuchs, PharmD, M Guidi, PhD, E Giannoni, MD, D Werner, PharmD, PhD, T Buclin, MD, N Widmer, PharmD, PhD, C Csajka, PharmD, PhD, Population pharmacokinetic study of gentamicin in a large cohort of premature and term neonates, British Journal of Clinical Pharmacology, DOI: 10.1111/bcp.12444

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MagnetoTheranostics

FROM SUPERPARAMAGNETIC NANO-PARTICLES UNTIL TOOLS FOR DETECTION AND TREATMENT OF CANCER

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Dr. Olivier Jordan, UniGE

PD Dr. Niels Kuster, ETHZ

Prof. Matthias Stuber, CHUV

Prof. Harriet Thöny, InselSpital

Prof. Brigitte von Rechenberg, UZH

What it's about…

Developing a platform based on superparamagnetic nanoparticles for diagnosis and treatment of cancer.

Context and project goals

The use of superparamagnetic iron oxide nanoparticles as contrast agents is well known, additionally, such particles are used in as source for local heating of cancer (Hyperthermia, clinical tests). In these two applications, dextran coated nanoparticles are used; for example in imaging of the liver a passive accumulation of the particles occurs, whereas for hyperthermia the particles are injected directly into the tumor. Our work with such particles as well as that presented in the literature shows that the potential of superparamagnetic nanoparticles for medical application is much larger. Specific adsorption of the particles at tumor cells, organs or even as shown by EPFL at organelles inside cells, opens a very large field of diagnostic applications, especially as contrast agent for molecular imaging by MRI. Interestingly, particles used as contrast agent are also useful for hyperthermia applications because superparamagnetic nanoparticles have relaxation times which allow heating by applying alternating magnetic fields with field strengths and frequencies applicable to human bodies.

Unfortunately the magnetic properties of the nanoparticles used today - maghemite (gamma-Fe_2O_3) - has too low a specific absorption rate, so that heating with the typical amount of particles, which can be transported after systemic injection to the cell of interest, is too low. This means that as of today a combination of diagnosis (specific adsorption of nanoparticles) and concurrent therapy is not possible. However, we are convinced that with improved superparamagnetic nanoparticles and an alternating magnetic field with a frequency and magnetic field strengths well adapted to the magnetic properties of the particles we will be able to develop a platform enabling diagnosis and therapy of some type of cancer (theranosis) to be specified.

It is obvious that the long term aim of our project is extremely challenging. Therefore, we like to start this project with two approaches:

a) molecular imaging with specific adsorbed nanoparticles
b) hyperthermia with nanocomposites that later will be combined

For both applications we start with superparamagnetic iron oxide nanoparticles because each of the partners has experiences and were successful with this type of nanoparticles and additionally in one or more of the following research areas:

- Synthesis, surface modification and characterisation (including primary toxicity studies) of superparamagnetic particles for medical applications
- Engineering of ac-magnetic field generators and modelling of interaction of ac magnetic fields in human bodies
- Use of nanoparticles in diagnosis and therapeutic applications
- Working in complex multidisciplinary projects

Focusing on one type of cancer (prostate for example) the diagnostic tool will be developed for the detection of metastasis in lymph nodes, whereas the therapeutic development (hyperthermia with nanocomposites using a, magnetic field generator and software for temperature distribution prediction) is focused on the corresponding primary tumor. In parallel new nanoparticles will be developed which fulfill the materials as well as biological properties simultaneously and in an improved manner, so that at the end of the 4 years at least 2 applications of nanoparticles are ready for clinical research and furthermore the combined theranostic approach would be ready for a focused development together with clinics and equipment/software manufacturer.

How it differentiates from similar projects in the field

Today, most of the research work is done in the field of contrast agent or magnetic hyperthermia. Only very few research groups try to combine both applications. The reason is that the magnetic properties of the particles have to be well adapted to the application. The approach of MagnetoTheranostics is the controlled synthesis and coating of the particles which will allow multifunctional use of the injected particles.

Quick summary of the project status and key results

In the first year, the researchers were able to develop a synthesis method which allows them the manufacturing of superparamagnetic iron oxide nanoparticles with mean sizes between 7 and 25 nm.

Important is that the synthesis is carried out in water and therefore easy to scale up. The particles which show also a narrow size distribution were characterized in detail regarding their structure and magnetic properties and are now ready for further functionalization. Similar particles were used for the preparation of injectable formulation foreseen for the treatment of primary tumors.

On the biological and medical side of the project, the animal model was determined and the most promising antibodies/epitopes for a high specificity of particle adsorption were selected. To accelerate the development process, a model system was developed which allows a fast selection of functionalization methods and to investigate the behavior of nanoparticles in biological systems.

On the engineering side, the construction of the magnetic field generator has started. We fixed the frequency of the generator to 300 kHz and the applied magnetic flux density at 3 mT.

Success stories

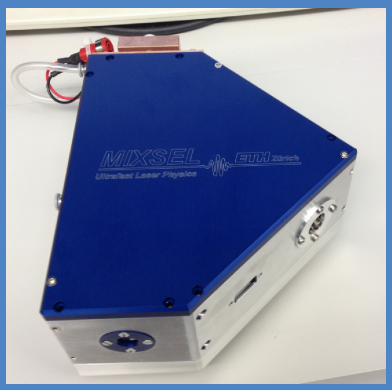
The most important success in the project is to have reached after a short period a common scientific language which bridges the gaps between physics, medicine and engineering. Especially to be underlined is the very close cooperation of young researchers from all partners covering all scientific fields of the project.

Regarding the scientific progress, it is important to mention the fast development of a very flexible particle synthesis process which allows the reproducible manufacturing of particles for all partners of the project at an early stage.

Prof. Ursula Keller, ETHZ

MIXSEL II

NOVEL SEMICONDUCTOR DISK LASERS FOR BIOMEDICAL AND METROLOGY APPLICATIONS



Dr. Gábor Csúcs, ETHZ

Dr. Deran Maas, ABB

Dr. Jacques Morel, METAS

Prof. Thomas, Südmeyer, UniNE

What it's about…

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Context and project goals

Following on from Nano-Tera Phase I project MIXSEL, we want to exploit our scientific leadership and consolidate our research efforts for real application demonstrations. We will continue to improve the VECSEL and MIXSEL sources towards prototype demonstrators for end-user demonstration in biomedical imaging, compact efficient white light generation for general high brightness illumination and frequency metrology applications. End-user demonstration will take place with our newly added university and industrial partners.

The high potential in metrology will be investigated and exploited by the University of Neuchatel, and two new partners, the Federal Office of Metrology (METAS) and the company ABB (financed by their own contribution). Biomedical imaging will be exploited together with the light microscopy and screening center (LMSC) at ETH Zurich and applications in high brightness illumination by Volpi AG. RUAG will be an end-user for applications in space missions. Industrial transfer of this technology is planned with the Swiss company TimeBandwidth Products AG (who previously secured IP for ultrafast optically pumped VECSELs and MIXSELs) and with Oclaro when larger scale production can be started.

Therefore the Phase II of the MIXSEL project will consolidate and continue with the most promising laser technology to achieve real application demonstrations. We will concentrate on optically pumped VECSELs and MIXSELs at a center wavelength of 950 nm to 980 nm where we achieved the best results. We will not focus on a specific wavelength demonstration because this can be done at a later stage. The wavelength range proposed here is typically used for bio-medical imaging and white light generation works even better at this shorter wavelength compared to 1.5 µm. During the initial MIXSEL project it also has become clear that electrically pumped VECSELs/MIXSELs will be limited in output power because of the design trade-offs between modelocking and power scaling. A key milestone demonstration of optically pumped MIXSELs and SESAM modelocked VECSELs is shorter femtosecond pulses in the range of 100 fs to 300 fs with more than 1 W average output power. We will develop prototype demonstrators for the target applications mentioned above.

How it differentiates from similar projects in the field

The project's SESAM-modelocked VECSEL and MIXSEL technology is world leading, still being the only group that has realized a MIXSEL. Furthermore it has been demonstrated that these semiconductor modelocked lasers have superior noise level performance compared to other semiconductor laser technologies. This, in combination with outstanding knowledge of frequency comb stabilization, should lead to the first fully stabilized frequency comb from a semiconductor modelocked laser.

Quick summary of the project status and key results

First demonstration of a femtosecond MIXSEL. This MIXSEL generated 620 fs pulses at 4.8 GHz repetition rate and 101 mW average output power. This MIXSEL has also been used to increase the repetition rate up to 100 GHz at an average output power of 127 mW and a pulse duration of 570 fs.

The team was able to detect for the first time the carrier envelope offset (CEO) frequency of a SESAM-modelocked VECSEL. This is the first step towards full stabilization of the frequency comb.

Success stories

In the period between the initial MIXSEL project and the new MIXSEL II project, a femtosecond MIXSEL generating 620 fs pulses at 4.8 GHz repetition rate and 101 mW average output power was demonstrated for the first time. Later on, this MIXSEL has also been used to stepwise increase the repetition rate up to 100 GHz at an average output power of 127 mW and pulse duration of 570 fs.

The team was able to detect for the first time the carrier envelope offset (CEO) frequency of a SESAM modelocked VECSEL. Amplifying and compressing the pulses from a SESAM-modelocked VECSEL was sufficient to generate a coherent octave spanning supercontinuum spectrum to detect the CEO frequency in an f-to-2f interferometer.

The researchers optimized the growth of VECSELs in the MOVPE reactor in the FIRST cleanroom at ETH Zurich. With this MOVPE growth it is now possible to build-in strain compensation in the VECSEL, which would lead to more reliable VECSELs necessary for prototypes. It furthermore reduced the dependence on the MBE growth.

JDS Uniphase, a world leader in the field of laser development, has acquired the industrial partner Time-Bandwidth Products. Together with JDSU the consortium is investigating the possibilities to develop an ultrafast semiconductor laser for industrial applications.

The journal "Light: Science and Applications" from the Nature Publishing Group (NPG) offered to write an invited review article about the semiconductor disk laser technology.

Presence in the media

The work also received strong media interest. An invited news article for LaserFocusWorld, a newsletter for the photonics industry, was written. Furthermore, the digital magazine 'Semiconductor Today' wrote an article about the project's latest results on electrically-pumped modelocked VECSELs.

- LaserFocusWorld, 04/07/2014 *MIXSEL: Ultrafast goes simple*
- SemiconductorToday, 04/08/2014, *Improving electrically pumped external-cavity mode-locking*

Award

Mario Mangold received the presentation award during the VECSEL conference at Photonics West 2014 in San Francisco.

Main publications

M. Mangold, V. J. Wittwer, C. A. Zaugg, S. M. Link, M. Golling, B. W. Tilma, and U. Keller, Femtosecond pulses from a modelocked integrated external-cavity surface emitting laser (MIXSEL), Opt. Express 21(21), 24904-24911 (2013).

B. W. Tilma, W. P. Pallmann, C. A. Zaugg, M. Golling, U. Keller, Sub-10-Picosecond Pulses from a Passively Modelocked Electrically Pumped VECSEL, Advanced Solid-State Lasers (ASSL 2013), Paris, France, Oct. 27 - Nov 1, 2013.

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B.W. Tilma, C.A. Zaugg, M. Mangold, S.M. Link, A. Klenner, M. Golling, U. Keller, High power ultrafast VECSELs and MIXSELs, 18th Annual Symposium of the IEEE Photonics Benelux Chapter, Eindhoven, The Netherlands, 25-26 Nov. 2013.

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"Modelocked semiconductor disk lasers: a new standard for compact, ultrafast, high power lasers"

NewbornCare

NEWBORN MONITORING BASED ON MULTIPLE VISION SENSORS

Prof. Pierre Vandergheynst, EPFL

Dr. Amina Chebira, CSEM

PD Dr. Jean-Claude Fauchère, USZ

Dr. Mathieu Lemay, CSEM

Dr. Jean-Marc Vesin, CSEM

Prof. Martin Wolf, (USZ)

What it's about…

Designing new contactless monitoring technologies for prematurely born babies.

Context and project goals

Modern societies are giving more and more priority to increase the quality of neonatal and post neonatal health sectors. The actual neonate sensor setup for heart and respiratory activities, and oxygen saturation is the following: gel electrodes to monitor the heart rate by electrocardiogram (ECG) and pulse oximeter to monitor arterial oxygen saturation (SpO2). The combination of the increasing number of parameters being monitored and the sensitivity of these sensors to body movement (especially the limbs) is responsible for the inacceptable high rate of false alarms, which in turn generates discomfort, stress and cardio-respiratory instability. These false alarms may also be the cause for caregiver desensitization which may dangerously lead to long response times for true alarms. Even if the problem is well known, it has not received new major incomes from the scientific community.

The NewbornCare project proposes to drastically reduce the false alarms of neonate vital sign monitoring by using a computer vision-based approach to accurately measure the heart and respiratory rates in a contactless fashion by combining variation enhancement techniques of both skin color intensity and body motion captured by an imaging sensor with robust tracking and segmentation algorithms. Moreover, the NewbornCare project also proposes to monitor arterial and brain tissue oxygen saturation of neonates using optical sensors (pulse oxymeter and near-infrared spectroscopy) integrated into a single sensor (based on expertise gained in promising NTF NeoSense project). Beside the development and implementation of versatile monitoring devices, the NewbornCare project aims at testing its applicability, specifically the smartphone application dedicated to neonate monitoring, in neonatal intensive care unit (NICU) scenarios. The NewbornCare project is aimed at showing the feasibility of implementing non-occlusive long-term monitoring strategies of multiple vital sign monitoring during neonate health care. This NICU validation will be headed by Prof. Dr. Fauchère at the Division of Neonatalogy, University Hospital Zurich.

The research conducted in NewbornCare will lead to a series of technological novelties, including:

- an embedded robust heart and respiratory rate monitoring system with a dedicated imaging,
- "smart" wireless body area network platforms linking the video with miniaturized multi-sensor devices located on the forehead of the neonates,
- high quality monitoring of arterial and brain tissue oxygen saturation based on miniature multi-sensor device integrated into a headband,
- an innovative multi-neonate monitoring tool for smartphones or tablets dedicated to NICU staff,
- a novel computer-aided diagnostic tool that detects and classify cardiac events based on learning methods,
- a beyond-state-of-the-art monitoring tool to estimate the blood flow over the entire neonate body.

How it differentiates from similar projects in the field

Current technologies rely exclusively on motion artifacts prone sensors.

NewbornCare, in contrast, focuses exclusively on novel contactless sensing technologies using vision based approaches.

Moreover, NewbornCare will also lead to the development of a new optical sensor to monitor arterial and brain oxygenation of neonates, crucial parameters that are not considered by current systems.

Quick summary of the project status and key results

The project is in its early phase, so the current achievements are related to precise measurements of lighting conditions in real conditions at an Intensive Care Unit so as to design the specifications of the NewbornCare vision sensors.

Existing computer vision algorithms have been tested and this pre-study confirmed that the original ideas proposed in this project are not covered by existing technology.

A new frequency tracking algorithm has been designed and evaluated on a publicly available dataset of neonates respiratory and heart signals.

Success stories

CSEM deployed a spectrometer at partner USZ site to precisely measure lighting conditions at the intensive care unit over the course of several days and continuously in time.

The insight gained into the intensity and spectrum of light during days and nights will help precisely design the vision components of NewbornCare.

ObeSense

MONITORING THE CONSEQUENCES OF OBESITY

Prof. Jean-Philippe Thiran, EPFL

Prof. David Atienza, EPFL

Dr. Olivier Dériaz, CRR-SUVA

Dr. Mathieu Lemay, CSEM

Dr. Urs Mäder, BFH

Dr. Etienne Pruvot, CHUV

Dr. René Rossi, EMPA

Prof. Nikos Stergiopulos, EPFL

Dr. Jean-Marc Vesin, EPFL

Prof. Martin Wolf, USZ

What it's about…

Joining the efforts of research groups in Switzerland involved in the monitoring of physiological markers to combine innovative and non-invasive sensors into single monitoring systems integrated in smart textiles for the long-term monitoring of overweigh/obese patients.

Context and project goals

Obesity is a medical condition associated with multiple health problems. Multiple clinical guidelines about the identification, evaluation and treatment of overweight and obesity and its related risks already exist. Importantly, these guidelines recommend the use of long-term monitoring systems that have not been adapted yet to the screening of large-scale populations to efficiently and simultaneously evaluate different physiological markers such as energy expenditure, hypertension, respiratory rate, stroke volume, heart rate and rhythm, etc. Indeed, physiological monitoring systems, if available, present multiple limitations, i.e. invasiveness, poor patient compliance, long-term skin intolerance, non-portable, limited power autonomy and memory, single-physiological marker oriented, sensitivity to motion artifacts, inaccurate estimates, etc.

The goal of the project is to join the efforts of research groups in Switzerland involved in the monitoring of physiological markers to combine innovative and non-invasive sensors into single monitoring systems to completely fulfill the guideline demands. The foreseen advanced sensors and their respective signal analysis algorithms are to be embedded into smart-textiles to provide advanced multi-parametric diagnostic tools for the management of obese patients in the different phases of their health condition: in clinical as well as ambulatory environments in order to improve patient life quality and reduce important health costs related to late prognostics.

How it differentiates from similar projects in the field

The main differentiators are:

- The central role of clearly defined medical application scenarios, driving the user requirements. Those three scenarios address clear medical needs, namely physical activity monitoring (prevention), monitoring at the hospital and post hospitalization monitoring (follow-up),
- The integration of multiple sensors into clinically usable (long-term) monitoring systems.

Quick summary of the project status

The three medical scenarios have been defined in detail, and the corresponding technical requirements have been set.

All the technical work packages are progressing well:

- Monitoring of respiratory rate and volume: transparent flexible polymer-optical fibers have been integrated in a smart T-shirt and have been successfully tested.
- Cardiac output: electrical impedance tomography (EIT) is being developed, and the systolic volume balance (SVB) method which requires information that can be extracted by a single pressure waveform, shows promising results.
- Energy expenditure: near infrared spectroscopy is being developed which aims at measuring the arterial and venous oxygen saturation as important parameters to determine energy expenditure. An application for mobile phones and tablets has been developed.
- Blood pressure: a non-occlusive sensor setup has been designed. Verification of the prototype and validation over 10 healthy subjects has been completed. Some modifications on the design were required based on bug report.
- Smart ECG T-shirts: a new design of comfortable electrodes has been proposed.
- Wireless body sensor network: two platforms are being developed, one being in feasibility phase of the ISO 13485 procedure.
- ECG analysis: several algorithms have been developed and validated.

Success stories

The coordination between the medical and technical teams, as well as among the technical partners, works perfectly well.

Presence in the media:

- Swiss TV show “36.9”, section “Avis d’expert” and radio show “CQFD” : Dr E. Pruvot (CHUV) and Dr M. Bertschi (CSEM) were interviwed on the work in ObeSense – http://avisdexpert.ch/videos/view/2601/1
- Newspaper “20minuten” : EMPA (L. Scherrer)
- Newspaper EmpaNews – November 2013

Main publications

F. Braun, M. Proença, M. Rapin, B. Grychtol, M. Bührer, P. Krammer, S. Böhm, M. Lemay, J. Solà, J.-Ph. Thiran, Comparing belt positions for monitoring the descending aorta by EIT, EIT 2014 International Conference, Gananoque, Canada.

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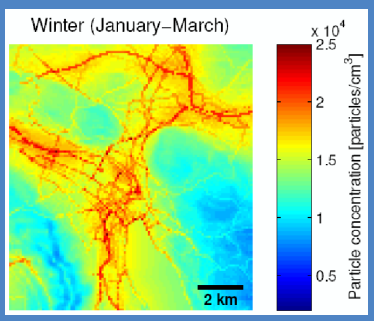
R. Braojos Lopez, I. Beretta, G. Ansaloni and D. Atienza , Hardware/Software Approach for Code Synchronization in Low-Power Multi-Core Sensor Nodes. , Design Automation and Test in Europe (DATE), March 2014.

R. Braojos Lopez, H. Mamaghanian, R. Vallejos, F. Javier, A. Dias Junior, G. Ansaloni, S. Murali and D. Atienza , Ultra-Low Power Design of Wearable Cardiac Monitoring Systems. , Design Automation Conference (DAC), June 2014.

Prof. Alcherio Martinoli, EPFL

OpenSense II

CROWDSOURCING HIGH-RESOLUTION AIR QUALITY SENSING



Prof. Karl Aberer, EPFL

Prof. Murielle Bochud, CHUV

Dr. Lukas Emmenegger, EMPA

Prof. Boi Faltings, EPFL

Prof. Andreas Krause, ETHZ

Dr. Michael Riediker, IST

Prof. Lothar Thiele, ETHZ

What it's about…

Providing high-resolution air quality maps through the integration of heterogeneous measurement sources in order to understand the health impacts of air pollution exposure.

Context and project goals

Novel sensing technologies can provide air quality data with unprecedented temporal and spatial resolution. This opens exciting new opportunities for the study of urban air quality and its impact on health. However, as opposed to traditional, expensive, and highly accurate air quality measurements, the use of dense networks based on low-cost sensors is largely unexploited.

An important issue for obtaining accurate and spatially highly resolved air pollution data is the tradeoff between high cost of accurate air pollution monitoring sensors and the number of such devices required for succinctly monitoring a given geographical area.

Crowdsourcing is a divide-and-conquer technique that has been successfully used for leveraging the intelligence of the crowd (or community) for solving many problems that require community participation (e.g., conducting online polls). Concretely, crowdsourcing can be defined as a participative online activity performed by a group of individuals (or intelligent machines) for mutual benefit between group members or for various other incentives (economic, social recognition, self-esteem, social responsibility), while the crowdsourcer will obtain and utilize the data collected by the user to his/her advantage.

In OpenSense II, we will leverage and improve methods developed in the framework of the Nano-Tera project OpenSense, particularly on: mobile monitoring of air pollution, sensor and communication platforms, calibration methods, sensor data gathering and visualization, statistical modeling, activity recognition, and personalized health recommendations. By adding the dimension of crowdsourcing and human-centric computation we will study possibilities to incentivize users to make available states based on physical measurements, such as location, motion and pollution, through their mobile personal devices or monitoring assets that they can install in their homes or on their cars.

Using a dispersion model we will compute high-resolution air pollution maps for the cities of Zurich and Lausanne. The model results will provide independent and validated information on air pollutant distributions and will thereby greatly help assess the quality of the sensor data and their suitability to measure city-scale air pollution levels. In addition, we will study concrete applications that measure the impact of long- or medium-term exposure to air pollution on human health and evaluate the potential of crowdsourcing for providing feedbacks to users.

How it differentiates from similar projects in the field

- Combining the information from a dense sensor network with high-resolution dispersion modeling is a new approach for assessing air pollution levels and human exposure in the complex urban environment
- The systematic evaluation of a large variety of low- and medium-cost sensors for air pollution monitoring in on-line and real-world settings is unique and of high value for a wide range of stakeholders
- Involving private citizens as both providers of data and users of health recommendations is a novel contribution and will effectively close the loop between data gathering and the end-user.

Quick summary of the project status

- Upgrading the ten sensor nodes deployed in Zurich with new electrochemical-based CO and NO_2 sensors from AlphaSense.
- Deployment and validation of thirteen sensor nodes in Lausanne.
- Evaluating the performance of low-cost gas sensors based on field experiments.
- Design and development of an active-smart sampling system.
- Development of a novel rewarding mechanism, called the Divergence-based Bayesian Truth Serum.
- Development of a novel incentivizing mechanism called SeqTGreedy.
- Evaluation and preparation of the GRAMM/GRAL model system for its application to the cities of Zurich and Lausanne
- Exploration of the association of short-term exposure to PM10 with systolic blood pressure, diastolic blood pressure, and pulse pressure in two Swiss population-based studies.
- Analysis of renal function data (from SKIPOGH and CoLaus studies) and its association with PM10 levels.

Success stories

Award:

Best paper award PerCom 2014

Presence in the media:

There was a large media coverage about the generated high-resolution pollution maps for Zurich:

- Newspapers and radio: NZZ, Tagesanzeiger, Blick, 20Minuten, radio stations, ETH News (Jan. 2014)
- Television: Tele TOP (broadcast in the region of Zurich and Northeast Switzerland, Jan. 2014)
- BAFU Magazin Umwelt 2/2014 (May 2014)

An article on the project was included in the June-July 2014 issue of the internal journal of the TL (Transports publics de la règion lausannoise).

Main publications

David Hasenfratz, Olga Saukh, Christoph Walser, Christoph Hueglin, Martin Fierz, and Lothar Thiele, Pushing the Spatio-Temporal Resolution Limit of Urban Air Pollution Maps, Proceedings of the 12th International Conference on Pervasive Computing and Communications (PerCom 2014).

David Hasenfratz, Silvan Stuerzenegger, Olga Saukh, and Lothar Thiele, Spatially Resolved Monitoring of Radio-Frequency Electromagnetic Fields, Proceedings of the 1st International Workshop on Sensing and Big Data Mining (SenseMine 2013).

T. Guo, T. G. Papaioannou and K. Aberer, Model-View Sensor Data Management in the Cloud, IEEE International Conference on Big Data (BigData).

J. Eberle, Z. Yan and K. Aberer, Energy-Efficient Opportunistic Collaborative Sensing, IEEE 10th International Conference on Mobile Ad-Hoc and Sensor Systems (MASS).

E. C. Un, J. Eberle, Y. Kim and K. Aberer., A model-based back-end for air quality data management., ACM conference on Pervasive and ubiquitous computing - UbiComp '13.

Y. Kim, J. Eberle, R. Hanninen, E. C. Un and K. Aberer., Mobile observatory: an exploratory study of mobile air quality monitoring application, ACM conference on Pervasive and ubiquitous computing - UbiComp '13.

R. Gwadera, M. Riahi and K. Aberer., Pattern-wise trust assessment of sensor data., 15th IEEE International Conference on Mobile Data Management.

B. Agir, T. G. Papaioannou, R. Narendula, K. Aberer and J.-P. Hubaux., User-side adaptive protection of location privacy in participatory sensing, Geoinformatica, vol. 18, num. 1.

Adish Singla, Andreas Krause, Incentives for Privacy Tradeoff in Community Sensing, AAAI Conference on Human Computation and Crowdsourcing (HCOMP), 2013.

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Gagan Goel, Afshin Nikzad, Adish Singla, Mechanism Design for Crowdsourcing Markets with Heterogeneous Tasks, AAAI Conference on Human Computation and Crowdsourcing (HCOMP), 2014.

G. Radanovic and B. Faltings, Incentives for Truthful Information Elicitation of Continuous Signals, Proceedings of the 28th AAAI Conference on Artificial Intelligence (AAAI'14).

D.-H. Tsai, I. Guessous, M. Riedkier, F. Paccaud, J.-M. Gaspoz, J.-M. Theler, G. Waeber, P. Vollenweider, M. Bochud, Short-term Effects of Particulate Matters on Blood Pressure in the Swiss Population-based Bus Sante and Colaus Studies, Journal of Hypertension, 2014.

Prof. Ernst Meyer, UniBas

PATLiSci II

RAPID SENSING OF CANCER

Prof. Katharina Glatz-Krieger, USB

Dr. Harry Heinzelmann, CSEM

Dr. Paul Bernard Henrich, USB

Prof. Roderick Lim, UniBas

Dr. Marko Loparic, UniBas

Prof. Nico de Rooij, EPFL

PD Dr. Rosanna Zanetti-Dällenbach, USB

What it's about…

Developing a measurement module for a scanning force microscope to perform parallel force spectroscopy for identification of cancer cells by their elastic properties and chemical recognition of related biomarkers by nanomechanical sensing.

Context and project goals

The aim is to develop rapid diagnostic tools for cancer. Highly parallelized mechanical sensors are used to investigate biopsy samples in a fast and reliable way. A large number of force vs. distance curves is acquired on the biopsy sample to get enough statistics for a representative value of the elasticity (Young's modulus) of the cells under investigation. This process is highly automated, which will make the application by the medical doctor easier compared to the optical analysis of histologic specimens. The required time for this type of diagnosis will be reduced from 3 hours to minutes. Therefore, the medical doctor will receive the information promptly and will be able to decide about the therapy. In addition to the elasticity mapping, rapid biomarker tests will be developed to complement the information about the status of the tumor.

Two case studies will be done in collaboration with collaborators from hospitals.

- Diagnosis of breast cancer
- Diagnosis of melanoma cancer.

The reduction of turnaround times is achieved by the simpler specimen preparation (no histologic cuts), the automation of the data acquisition, faster approach cycles, and the parallelization. 1d-arrays of passive probes will be implemented with suitable parallelized deflection sensors. Compared to the current state-of-art, where only one probe is used to acquire 10'000 force vs. distance curves, these arrays will reduce the data acquisition by an order of magnitude. The use of optimized, large bandwidth preamplifiers and smaller cantilevers will further reduce the acquisition time of force vs. distance curves. The data acquisition and processing will deliver quantitative elasticity numbers. Rapid biomarker tests will complement the information about the status of the tumor and help the medical doctor to decide about the future therapy.

How it differentiates from similar projects in the field

In contrast to competitors, the project combines two complementary methods (force spectroscopy mapping for cell stiffness and nanomechanical cantilever sensing for biomarker detection) into a single instrumental platform, which can be handled easily.

Analysis of clinically relevant material such as biopsies instead of cultured cells or chemically synthesized biomolecules. No amplification, labeling and spiking required. Transition from proof-of-principle experiments to a clinically relevant approach.

Quick summary of the project status and key results

The project profits from its predecessor PATLiSci where basic concepts of parallel force spectroscopy and nanomechanical biomarker sensing have been validated.

Here the consortium will fabricate and use optimized cantilever arrays for both parallel force spectroscopy and nanomechanical sensing. First conclusive results on discrimination of breast cancer cells from unaffected cells in tissue using a single cantilever have already been demonstrated. Investigation of RNA in melanoma and wild type cells shows clear difference in nanomechanical bending response of functionalized cantilevers, in particular the BRAF mutation which is essential for selection of appropriate treatment measures.

Presence in the media

M. Loparic, M. Plodinec, R. Lim and R. Sum. Potentielle medizinische Anwendungen des Atomic Force Microscope. Schweiz Med Forum 13 830 (2013)

Roderick Lim, “Swiss Nanoscience Institute - Die Erforschung der Nanowelt an der Universität Basel” http://www.youtube.com/watch?v=ixkkfVQ2kmo

Patent

Previously existing patent on force spectroscopy on tissue samples (ARTIDIS): Plodinec, Lim and Loparic. US Patent 8,756,711 B2.

Main publication

Marija Plodinec and Roderick Y.H. Lim, Nanomechanical Characterization of Living Mammary Tissues by Atomic Force Microscopy, Mammary Stem Cells: Methods and Protocols, Springer Humana Press.

“Squeeze out information on your cells!”

Prof. Christophe Moser, EPFL

SHINE

SOLAR HYDROGEN INTEGRATED NANO ELECTROLYSIS

Dr. Julien Bailat, CSEM

Dr. Artur Braun, EMPA

Prof. Sophia Haussener, EPFL

Prof. Demetri Psaltis, EPFL

What it's about…

Developing an efficient and cost effective hydrogen production system that uses only sunlight and water as inputs.

Context and project goals

This project aims to develop a hydrogen production system using sunlight in an integrated manner with earth abundant materials mimicking natural photosynthesis. PhotoElectroChemical (PEC) systems use semi-conductor materials to absorb photons from the sun to generate a potential high enough (>1.2 V) to split water and produce hydrogen and oxygen at an integrated electrolysis cell. A major advantage of PEC systems over systems composed of photovoltaic panels (PV) in conjunction to a separate electrolyzer is their integral approach, i.e. the PV cell is part of the electrolyzer. This provides opportunities not only for cost reduction but also for improvement in the efficiency of the electrochemical reaction.

There are currently small-scale pilot production sites where hydrogen is produced with solar power in Switzerland. For example, the Michelin research center near Fribourg has 55 m^2 of photovoltaic panels with 15% efficiency. The electricity generated by the solar panels powers a potassium hydroxide electrolyzer running at 75% efficiency, producing hydrogen gas compressed at a pressure of 30 bars. The solar-to-fuel efficiency of such a pilot plant is thus 11.2%. The plant produces 1.56 kg of H_2 gas per day during the summer, which represents 52 kWh of energy. This is a large energy density, more than 20 times that of the best lithium ion batteries when accounting for the mass of the pressurized hydrogen composite container.

In 2010, an artificial photosynthesis program funded by the US Department of Energy received $122 million for 5 years, whose mission is to develop manufacturable solar fuel generators with earth abundant elements yielding sun to fuel efficiencies over 10% (ten times the fuel efficiency of natural crops). In Switzerland, Michelin since 2001 and Belenos since 2008 have teamed up with PSI to develop fuel cells and production of hydrogen gas with photovoltaic energy. Other research programs are underway in the EU, such as the German Research Foundation's SPP 1613 (2011).

We believe that leveraging the existing silicon photovoltaic knowhow in Switzerland and focusing on a system's engineering approach for manufacturing hydrogen via PEC will provide the tools to become an important player in a renewable-based fuel economy. Specifically, we propose a system's engineering approach for realizing a PEC system with:

- Photoharvesting electrodes based on amorphous and crystalline silicon cells developed in Prof. Ballif's group at CSEM which develops stable processes,oriented towards industry.
- PEC cell design inspired by fuel cell technology.
- Operation under concentrated sunlight.

Because of sunlight concentration (>10x), the reactor PV cells are smaller, more efficient and cheaper since less silicon semi-conductor material is used. Michelin research center is bringing a considerable practical experience in fuel cell and electrolysis in this project. The proposed system will make use of the full energy content of the solar spectrum by using the visible part of the spectrum (400 – 1000 nm) to illuminate the PV cell and the rest of the spectrum to self-align the concentrator and heat water to create water vapor near room temperature for the feedstock of the PEC cell. It is expected that the results of this project will provide the design tools and the technology blocks to produce efficient and cost effective sun-to-fuel systems.

How it differentiates from similar projects in the field

Much research effort has been devoted to the development of components of an integrated photo-electro-chemical system (PEC), but relatively little attention has been paid to the engineering-design aspects of viable solar-fuel generators.

Driven by physical and technoeconomic models, SHINE's systems engineering approach uses concentrated irradiation, thin film silicon cells and membrane electrode assembly water splitting units, optimized for an integrated operation, in order to obtain high sun to fuel efficiency at a low cost.

Quick summary of the project status and key results

In the first year of the project, SHINE has developed the foundations to achieve viable solar-hydrogen generations. These achievements include:

- Multi-physics, technoeconomic and energy life-cycle models that identify optimal design parameters for the fabrication of practical solar-hydrogen generators.
- Fabrication of a passive self-tracking solar-concentrator system with angular ranges above +/- 20°.
- Microfluidic units for water vapor generation, solar-thermal energy harvesting for photoelectrochemical reaction enhancement and water electrolysis from both liquid and vapor phase.
- Development of multi-junction microcrystalline and amorphous Si cells with open circuit voltages above 2.1 V (high voltages are required to drive the water splitting reaction) and efficiencies above 11%.
- Development of nickel based catalyst for water oxidation, and water electrolysis cells based on membrane electrode assemblies.

Success stories

SHINE members, Volker Zagolla and Christophe Moser, at EPFL developed the first self-tracking solar-concentrator in the world.

Presence in the media:

Work by SHINE members, Florent Boudoire and Artur Braun, at EMPA featured at RTS

Main publications

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S. M. Hosseini Hashemi, J. W. Choi, D. Psaltis, Solar thermal harvesting for enhanced photocatalytic reactions, Phys. Chem. Chem. Phys., 2014,16, 5137-5141.

S. M. Hosseini Hashemi, J. W. Choi, D. Psaltis, Effect of Solar Thermal Energy on Photoreactions' Rate, Proceedings of the Conference on Lasers and Electro-Optics 2014.

S. Tembhurne, M. Dumortier, S. Haussener, Heat transfer modeling in integrated photoelectrochemical hydrogen generators using concentrated irradiation, Proceedings of the 15th International Heat Transfer Conference, IHTC-15, August 10-15, 2014, Kyoto, Japan.

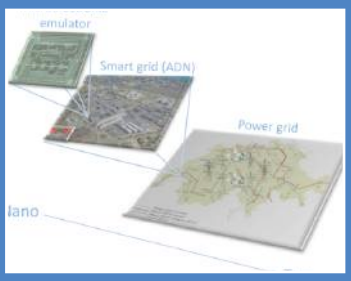
Volker Zagolla, Eric Tremblay, and Christophe Moser, Proof of principle demonstration of a self-tracking concentrator, Opt. Express 22, A498-A510 (2014).

V. Zagolla ; M. Schmidlin ; E. Tremblay ; C. Moser, Demonstration and future potential of a self-tracking phase change actuator, Proc. SPIE 8981 (doi:10.1117/12.2037623).

Prof. Maher Kayal, EPFL

SmartGrid

SMART GRIDS, SMART BUILDINGS AND SMART SENSORS FOR OPTIMIZED AND SECURE MANAGEMENT OF ELECTRICITY DISTRIBUTION USING DEDICATED MICROELECTRONIC ICS AND REAL TIME ICT



Prof. Alexandra Andersson, HESSO-VS

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Prof. Mario Paolone, EPFL

What it's about…

Developing of new technologies dedicated to the real time monitoring and management of smart grids with validation in the EPFL campus

Context and project goals

The emerging concept of Smart grid is to be realized by renovating the existing power systems in a way that introduces intelligence in different levels of it. Part of this intelligence has to deal with a large demand for real-time and best decision-making. In order to keep the reliability of the power system and to improve its efficiency, the decision-making is essentially tied to the optimization of such system at different levels. Additionally, a solution to the optimization problem is of interest only if it meets stringent time frame demands dictated by the need of real-time operation of the smart-grid. A distributed intelligence system can cope with all these requirements: It is able to compute at each level of the hierarchy of the smart grid, from the large-scale bulk grid down to each individual building.

Nowadays, smart sensing is well integrated into power grids. However, the mass of data that need to be exchanged and managed is impressive. The amount of information to be processed grows due to the increasing number of controlled devices inserted into the grid. A large amount of data needs to be collected, analyzed simultaneously and results must be provided with strict time constraints.

These considerations lead to the idea that some of the major operation problems of distribution networks, such as voltage and power flow controls, can be solved in a distributed manner that helps to relieve the information-processing burden and enhance the system security while preventing critical events. In particular, new electronic integrated circuits can be used to run an emulation of a power system faster than real-time in a distributed configuration. The capability of evaluating different scenarios instantaneously enables a modification of the paradigm of the power system control and optimization. The additional analysis speed gained allows dealing with the growing needs for flexibility in greenenergy oriented grids.

In the frame of this project, it is proposed to create a new environment for an optimized and secure management of electricity distribution using dedicated mixed-mode microelectronic Integrated Circuits (ICs) and a real-time layer of Information and Communication Technology (ICT).

This new concept will make uses of the power systems (both medium- and low-voltage levels) of the EPFL campus as a test platform where the different research groups integrate their competences, cross-interact and deploy the technologies they developed. Indeed, the EPFL power system, characterized by a total number of 40 medium-to-low voltage substations, a maximum absorbed power of 30 MW, the presence of active power injections composed by 2MW photovoltaic panels installation integrated with a 6 MW combined heat and power generation units, represents a realistic 1:1 scale infrastructure with the strategic advantages of being framed within a research environment.

How it differentiates from similar projects in the field

This project is addressing the real time monitoring with dedicated electronics of the smart grid starting from the human needs using environmental sensors going through the optimization of buildings power consumption including the monitoring of the stability and the security of all the system at high level.

The human behavior observation is adding regulation parameters and can provide a new paradigm in the optimization in real time of power grid.

Quick summary of the project status

- Development of a phase measurement unit (PMU) prototype with a Phasor Data Concentrator (PDC). This functionality has been integrated within the PMU calibrator as well as into the real-time state estimator.
- IP based communication infrastructure for Smart Grid with Security architecture has been developed to transport PMU measurements to the state estimator. The entire network uses the IPv6 protocol.
- Development of enhanced linear Kalman Filte-SE processes integrating PMUs in quasi steady-state conditions.
- Faster than real time transient stability analysis of power network electronics emulation has been developed.
- Architecture of the smart building management platform has been designed and tested. This is done in order to integrate the demand side management of buildings within the active distribution network (ADN).
- Since May 2014, a preliminary version of the EPFL active distribution network (AND) process is successfully running.

Main publications

G. Lilis, T. Kyriakidis, G. Lanz, R. Cherkaoui, M. Kayal, On the effect of integration algorithms on reduced accuracy computational architectures, ECESCON 7, Thessaloniki, Greece, 2014.

G. Lanz, T. Kyriakidis, R. Cherkaoui, M.Kayal, Mixed-Signal Power System Emulator Extension to Solve Unbalanced Fault Transient Stability Analysis, PSCC 18, Wroclaw, Poland , 2014.

G. Lilis, T. Kyriakidis, G. Lanz, R. Cherkaoui, M. Kayal, Pipelined Numerical Integration on Reduced Accuracy Architectures for Power System Transient Simulations, 16th International Conference on Computer Modelling and Simulation (UKSim), Cambridge, United Kingdom, 2014.

Pignati M., Zanni L., Sarri S., Cherkaoui R., Le Boudec J., and Paolone M., A Pre-Estimation Filtering Process of Bad Data for Linear Power Systems State Estimators using PMUs, Power System Computation Conference (PSCC), 2014 IEEE.

L. Zanni, M. Pignati, S. Sarri, R. Cherkaoui, M. Paolone, Probabilistic assessment of the process-noise covariance matrix of discrete Kalman filter state estimation of active distribution networks, International Conference of Probabilistic Methods Applied to Power Systems (PMAPS), Jul. 2014, in press.

M. Paolone, M. Pignati, P. Romano, S. Sarri, L. Zanni, R. Cherkaoui, A Hardware-in-the-Loop Test Platform for the Real-Time State Estimation of Active Distribution Networks using Phasor Measurement Units, Proc. of the Cigré SC C6 Colloquium, Yokohama, Japan, Oct. 6-9, 2013.

T.T. Tesfay, J.-P. Hubaux, J.-Y. Le Boudec and P. Oechslin, Cyber-secure Communication Architecture for Active Power Distribution Networks, 29th ACM Symposium on Applied Computing, 2014.

N. Gast, J.-Y. Le Boudec and D.-C. Tomozei, Impact of demand-response on the efficiency and prices in real-time electricity markets, Proceedings of the 5th international conference on Future energy systems - e-Energy '14, pp. 171-182, 2014.

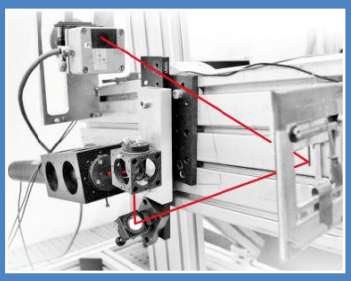
N. Gast, D.-C. Tomozei and J.-Y. Le Boudec, Optimal Generation and Storage Scheduling in the Presence of Renewable Forecast Uncertainties, Ieee Transactions On Smart Grid, Vol. 5, Nr. 3, pp. 1328-1339, 2014.

K. Christakou, D.-C. Tomozei, J.-Y. Le Boudec and M. Paolone, GECN: Primary Voltage Control for Active Distribution Networks via Real-Time Demand-Response, Ieee Transactions On Smart Grid, Vol. 5, Nr. 2, pp. 622-631, 2014.

Prof. Bert Müller, Uni Basel

SmartSphincter

SMART MUSCLES FOR INCONTINENCE TREATMENT



Dr. Lukas Brügger

PD Dr. Philippe Büchler, UniBE

PD Dr. Franc Hetzer, Spitäler SH

Dr. Urs Sennhauser, EMPA

What it's about…

Realizing artificial muscles for the treatment of severe fecal incontinence by building hundred thousands of low-voltage, dielectric, electrically activated polymers layers with nanometer thickness.

Context and project goals

One of the largest markets, still under-developed by medical device companies, is the treatment of urinary (UI) and fecal incontinence (FI). The demographic changes in western countries will lead to a significant increase of incontinent people. For instance, FI affects nearly 10% of people over 60 years of age, and about 2 million people in Europe have daily severe FI, which is one of the most devastating of all physical disabilities, since it affects self-confidence and personal image, and usually leads to social isolation. The success of current treatments is disappointing because of numerous complications including infections that often require device removal and the extended use of diapers. The aim of the proposal is to realize prototype devices acting as artificial muscle, termed anal sphincter, to finally treat patients with severe FI. The device should replace the destroyed natural muscle function using low-voltage electrically activated polymers (EAPs) controlled by implemented pressure sensors and the patient.

The unique artificial fecal EAP-based sphincter system is driven by an integrated microprocessor, powered by an energy harvesting device and an implantable battery, rechargeable by transcutaneous energy transfer (TCT) controlling the fluid flow intentionally by the patient and automatically with pressure gauges. The remote control will allow the physician to perform patient-specific adjustments. The ring-like sphincters should be optimized with respect to its macroscopic shape concerning function and comfort applying statistical shape models, with respect to its surface architecture and chemistry to prevent infections and achieve implantation procedures as simple as possible.

In vitro and bench tests should verify reliability of the entire device before it will be implanted in minipigs. Histological investigations should demonstrate that the applied forces do not significantly affect the surrounding tissue. The expected benefits for the patient and their physicians are:

- recovery of continence
- short hospitalization periods because of the relatively simple treatment and post-op individual adjustments
- guaranteed reliability (minimal failure rates)
- electronically controlled by integrated sensors and managed by the patient.

The consortium is a competent, multidisciplinary team, distributed across Switzerland, active in fields ranging from medicine via microelectronics towards biomaterials science with recent experience in the development of sophisticated urinary sphincters.

How it differentiates from similar projects in the field

First, the researchers in the project carefully analyzes the human anatomy to define the target specifications for a biomimetic design.

Second, they determine the biomechanical parameters using advanced experimental setups and sophisticated imaging and software tools.

Third, they include the time response to realize a nature-analogue implant.

Fourth, the implant design includes multiple actuators to allow tissue recovery in a periodical manner.

Fifth, the unique, low-voltage, dielectric actuators enable sensing and guarantee an energy efficient operation.

Quick summary of the project status

Main achievements so far include:

- Finding two promising alternatives to conventional stiff metal electrodes for the multilayer dielectric electrically activated polymer actuators (see Success Story below)
- Developing a cantilever bending method which verified the mechanical deformation of the first actuators as a function of applied voltage to a precision of 0.03 %
- Validating the ability to power the actuators for 10 days without recharge from available ISO-compliant lithium ion cells
- Confirming through a pre-pilot study that a combination of manometry and luminal imaging will provide sufficient information to build a statistical shape model of the human anal sphincter.

The consortium has now successfully applied to the ethical committee of the Canton of Bern for a full pilot study involving 10 male and 10 female participants.

Looking towards the future, the team has designed a system for fabricating multiple layers of nanometer-thin actuators using physical vapor deposition in ultra-high vacuum, and is currently proceeding with its realization.

Success stories

At the start of the project the reviewers pointed out that the stiffness of the actuator (dielectric electrically activated polymer) is given by the nanometer-thin conductive (metal) layers and not by the stretchable elastomer layers, although the elastomer layer is typically an order of magnitude thicker. The team concurs with the reviewers that the stiffness of conventional metal electrodes makes achieving strains of 10 % a formidable challenge. Fortunately, it is now possible to see some promising alternatives to the gold films currently in use. During the first year, the PhD-student T. Töpper introduced liquid metals, which could master the challenge. Another PhD-student, Bekim Osmani experimentally realized parallel wrinkles to allow the actuator to stretch in one predefined direction.

Liquid metals show a high flexibility and the ability to follow strain without stiffening the structure, making them a current focal point of research in microelectronics for flexible micro scale wires or antennas. Combined with a low resistivity, fluid metals are of high interest as flexible contact electrodes for electrically activated elastomer (EAP) actuators. In order to achieve the target of multi-layer stack actuators, the team has grown an actuator consisting of 4 µm polydimethylsiloxane (PDMS) embedded in 50 nm gallium electrodes by molecular beam deposition. The actuation efficiency and flexibility of the liquid metal electrodes will be characterized using the custom-built EAP cantilever bending apparatus. In addition, the sheet resistance of fluid gallium (at temperatures >30 °C) and solid gallium (at temperatures <30 °C) on PDMS will be measured with respect to surface strains of up to 100 % to demon-strate the high capability of fluid gallium as a flexible electrode which remains conductive under high actuation strains.

Parallel wrinkles are formed on the surface of uniaxial pre-stretched elastomer films due to compressive strains between the film and the elastomer substrate. The periodicity and amplitude of the wrinkles can be predicted for different film coating materials and film thicknesses. Pre-stretched PDMS layers with a chromium film show a periodicity of 5.5 µm, and for polytetrafluoroethylene or indium films it is expected to be of an order of magnitude lower. By adjusting the amplitude of these electrode carriers the consortium will fabricate EAP actuators for strains larger than 10%.

Presence in the media:

- Uni News 18.04.2013
- In TV documentation “Gesundheit heute: Mit Nanotechnologie gegen Arterienverkalkung“ of 04.01.2014 our PhD students Elisa Fattorini, Bekim Osmani and Tino Töpper were showing our laboratory.

Main publication

Florian M. Weiss, Tino Töpper, Bekim Osmani, Carla Winterhalter, and Bert Müller, Impact of electrode preparation on the bending of asymmetric planar electro-active polymer microstructures, Proc. of SPIE 9056 (2014) 905607.

Prof. Stéphanie Lacour, EPFL

SpineRepair

HYBRID CMOS-POLYMER NEURAL INTERFACES FOR RESTORATION OF SENSORIMOTOR FUNCTIONS AFTER SPINAL CORD INJURY

Prof. Grégoire Courtine, EPFL

Prof. Andreas Hierlemann, ETHZ

Prof. Silvestro Micera, EPFL

Dr. Alain-Serge Porret, CSEM

Prof. Janos Vörös, ETHZ

What it's about…

Developing a novel spinal cord (SC) neuroprosthesis by integrating soft tissue-like materials, implantable customized electronic hardware and SC stimulation protocols with robotic rehabilitation training to facilitate functional recovery after spinal cord injury.

Context and project goals

This project proposes to optimise, manufacture, assemble and validate a fundamentally different technology to produce an electrical stimulation neuroprosthetic system based on ultra-compliant microelectrode arrays, embedded low-power analog electronics and efficient telemetry unit.

We focus on a cutting-edge spinal cord neuroprosthesis designed to facilitate motor control and functional recovery in rats paralyzed after spinal cord injury. The spinal neuroprosthesis builds upon pioneering work from our group using a combination of robotic training, epidural electrical stimulation and monoamine agonists in rats to restore impressive locomotor capacities, provided the spinal cord injury spared a few cortical axonal projections.

Based on these exciting results, we propose to integrate an autonomous spinal neuroprosthesis with a high density of surface electrodes and embedded electronics that will allow for the definition and evaluation of unique electrical stimulation patterns thereby providing guidelines for adaptive stimulation strategies to restore, efficently and durably, locomotion after spinal cord injury.

How it differentiates from similar projects in the field

The project implements unique soft neurotechnologies and customized electronic hardware, which to date are not developed by other groups.

Quick summary of the project status and key results

So far, the project has

- demonstrated a chronic, wired, soft spinal cord neuroprosthesis for SC rat model,
- developed novel stretchable wiring based on Ag nanowires,
- defined the layout of the implantable electronic hardware,
- designed the CMOS stimulator,
- modeled current stimulation strategies,
- conducted the first characterization of locomotion enabled by the multielectrode array implants in spinal rats.

Success stories

SpineRepair is an engineering project with a focused application to restore motor functions after spinal cord injury. The success of the project as a whole relies on the integration and communication of the team, which gathers material scientists, electrical engineers, bioengineers and neuroscientists.

A common vision and language has been established throughout the consortium, which will surely help to reach the ultimate goal: to implement and validate a wireless spinal cord neuroprosthesis in SC animal models.

Presence in the media (Courtine Lab)

TEDGlobal, Edinburgh, June 2013

Le Monde, August 2013

CQFD, Radio-Télévision Suisse, March 2014

Patents

- **Patent 1 by G. Courtine** (patent filed to EPO, MBP13367-EP)

  “System to deliver adaptive electrical spinal cord stimulation to facilitate and restore locomotion after a neuromotor impairment”. The patent covers the description and therapeutic use of a closed-loop system for real-time control of epidural electrical stimulation after neuromotor disorders. The system spans the inter-connected devices required for online monitoring of motor performance, and the algorithms for adapting stimulation parameters in order to improve rehabilitation.

- **Patent 2 by SP Lacour, IR Minev** (patent filed to EPO in May 2014)

  “Dry encapsulation method for electrode arrays”. The method enables the electrical passivation of electrode arrays with elastomeric dielectric films of arbitrary thickness. The passivation layer may contain circular (or any shape) openings at arbitrary locations for the purpose of creating vias or exposing active electrode sites.

- **Patent 3**

  EPFL : Raspopovic Stanisa, Petrini Francesco Maria, Capogrosso Marco, Bonizzato Marco, Micera Silvestro

  “Bidirectional limb neuro-prosthesis” P2670PC0P / 13-280 ar/ab

Main publications

Capogrosso M, Wenger N, Raspopovic S, Musienko P, Beauparlant J, Bassi Luciani L, Courtine G and Micera S, A Computational Model for Epidural Electrical Stimulation of Spinal Sensorimotor Circuits, The Journal of Neuroscience, December 4, 2013 33(49): 19326-19340.

Wenger N*, Martin Moraud E*, Raspopovic S, Bonizzato M, DiGiovanna J, Musienko P, Morari M, Micera S* and Courtine G*, Closed-loop neuromodulation of spinal sensorimotor circuits controls refined locomotion after complete spinal cord injury., Science Translational Medicine, in press.

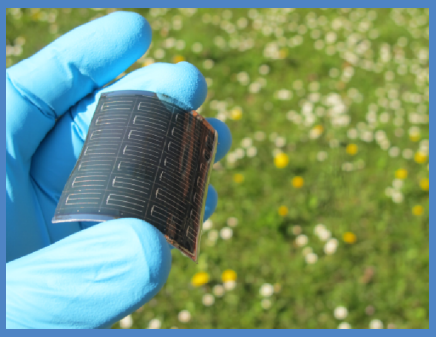
David Borton, Marco Bonizzato, Janine Beauparlant, Jack DiGiovanna, Eduardo M. Moraud, Nikolaus Wenger, Pavel Musienko, Ivan R. Minev, Stéphanie P. Lacour, José del R. Millán, Silvestro Micera, Grégoire Courtine, Corticospinal neuroprostheses to restore locomotion after spinal cord injury, Neuroscience Research, 2014, 78, 21-29.

Moraud, E.M.; Wenger, N.; Gandar, J.; DiGiovanna, J.; Musienko, P.; Courtine, G.; Micera, S., A real-time platform for studying the modulatory capacity of epidural stimulation after spinal cord injury, Neural Engineering (NER), 2013 6th International IEEE/EMBS Conference on , vol., no., pp.1449,1452, 6-8 Nov. 2013.

Prof. Christophe Ballif, EPFL

Synergy

SYSTEMS FOR ULTRA-HIGH PERFORMANCE PHOTOVOLTAIC ENERGY HARVESTING



Dr. Julien Bailat, CSEM

Prof. Anna Fontcuberta I Morral, EPFL

Prof. Michael Grätzel, EPFL

Prof. Ayodhya N. Tiwari, EMPA

What it's about…

Developing energy harvesting systems with ultra-high efficiencies.

Context and project goals

This project aims to realize photovoltaic (PV) energy harvesting systems based on tandem solar cells with efficiencies beyond those achievable with state-of-the-art industrial single-junction cells by combining the unique technological components – record cells absorbing various parts of the solar spectrum – recently realized by Swiss research institutes. By themselves, the new multi-junction cells will be highly complex systems, and will open opportunities for tomorrow's electricity power plants and for consumer electronic applications, including e.g. watches and powering of low-consumption electronics. The project is supported by key players of the PV field (Meyer Burger) and of the watch and electronic industries (Swatch Group R&D and EM Marin).

For decades, the PV market has been dominated by wafer-based crystalline silicon (c-Si) solar cells with lab record efficiencies of 25%, and production efficiencies of 17-22%. As these values are already close to the theoretical limit of single-junction c-Si cells, further improvements will not be possible by incremental technological innovation. One of the most promising approaches to overcome this limit is to combine two single-junction cells with different optical band gaps to form tandem solar cell systems. This concept has been successfully employed for concentrator PV systems using expensive III-V semiconductors and for thin film Si solar cells, such as a-Si/c-Si tandem cells with limited efficiencies. Highly efficient tandem cell systems involving c-Si or copper indium gallium selenide (CIGS) bottom cells have so far not been successfully realized, mainly due to the difficulty to find a suitable wide-band gap top cell that delivers the necessary photocurrent while exhibiting excellent electrical properties.

Recently, the situation drastically changed with the emergence of highly efficient wide-band gap thin-film solar cells that deliver high photocurrents, based on perovskite or II-VI absorbers. In addition, low-band gap cells based on CIGS compounds have recently reached efficiencies beyond 20%, thus are nearly as efficient as the best c-Si cells. In parallel, heterojunction c-Si solar cells with record efficiencies in the infra-red have been demonstrated. We believe that these recent developments from Swiss labs enable industrially relevant tandem systems with efficiencies beyond 30%.

The project consortium has vast experience and top-notch infrastructures required to fabricate state-of-the-art devices for all these high-efficiency PV technologies, and each group is worldleading in one or several of them. Each of these technologies will be adapted and optimized to be integrated into tandem cells. Specifically, PV-lab at EPFL will develop dedicated a-Si/c-Si heterojunction bottom cells and versatile µc silicon test templates, EMPA chalcogenide cells with tuneable band gaps such as CIGS and kesterite cells, and LPI at EPFL perovskitesensitized solar cells. As a more explorative effort, LMSC at EPFL will also implement GaAs nanowire cells in tandem devices with the potential to surpass the thermodynamic efficiency limit for conventional solar cells. These experimental efforts will be supplemented with optical simulations to ensure optimal device design. Finally, the broad PV-related capabilities of the project consortium are leveraged for up-scaling and the development of PV energy harvesting demonstrator systems for indoor and outdoor applications, an activity that will be led by CSEM.

How it differentiates from similar projects in the field

High-efficiency, low-cost tandem devices are on the agenda of many research groups. Yet, with its very broad knowledge base, long-standing experience with technology transfer, and record devices in many photovoltaic technologies including solar cells based on GaAs nanowires, a-Si/c-Si heterojunctions, chalcogenides, and metallorganic halide perovskites, the Synergy consortium is well positioned to lead the development of ultra-high efficiency tandem cells in this highly competitive environment.

Quick summary of the project status and key results

The Synergy project will realize photovoltaic energy harvesting systems with efficiencies beyond those achievable with state-of-the-art industrial solar cells.

The systems developed in this project have the potential to provide both the terawatts of sustainable energy needed for future generations as well as to enable a next generation of ubiquitous wearable and electronic applications with integrated power source. This will have a strong impact on the Swiss watch and electronic industries. In addition, these systems have the potential to revolutionize the PV market, and, as a consequence, also the Swiss energy landscape.

Moreover, the Synergy project will help to maintain the competitiveness of the Swiss solar industry in a highly challenging market environment, thus securing and generating jobs.

Finally, this project will also strengthen the interaction between world-leading Swiss research institutes and contribute to the education and training of engineers and scientists specialized in the area of renewable energy technologies.

Success stories

- Perovskite and low-temperature TiO_2 layers were fabricated at LPI and provided to PV-Lab for optical characterization, including absorption and ellipsometry measurements.
- For tandem devices, it is crucial that the absorber material of the top cell is highly transparent at photon energies below its bandgap. The absorption edge of perovskite layers was measured by photo-thermal deflection and Fourier transform photocurrent spectroscopy, and a steep absorption edge with very low sub-bandgap absorption was found. These findings thus confirm that perovskite-absorber layers are highly suited for tandem cells. A paper about these findings was published [S. de Wolf et al., J. Phys. Chem. Lett., 2014, 5 (6), pp 1035–1039].
- Empa investigated the potential of Perovskite/CIGS tandem cells and confirmed by a combination of calculations and experimental results their potential for high efficiencies.
- LPI developed a low-temperature TiO_2 deposition process that was successfully employed for the fabrication of highly efficient perovskite single-junction cells.

Main publication

Stefaan De Wolf, Jakub Holovsky, Soo-Jin Moon, Philipp Löper, Bjoern Niesen, Martin Ledinsky, Franz-Josef Haug, Jun-Ho Yum, and Christophe Ballif, Organometallic Halide Perovskites: Sharp Optical Absorption Edge and Its Relation to Photovoltaic Performance, J. Phys. Chem. Lett., 2014, 5 (6), pp 1035–1039, dx.doi.org/10.1021/jz500279b.

UltraSoundToGo

HIGH PERFORMANCE PORTABLE 3D ULTRASOUND PLATFORM

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Prof. Luca Benini, ETHZ

Prof. Jean-Yves Meuwly, CHUV

Prof. Joseph Sifakis, EPFL

Prof. Lothar Thiele, ETHZ

Prof. Jean-Philippe Thiran, EPFL

What it's about…

Developing a prototype of next-generation, high-quality, mobile ultrasound imaging device.

Context and project goals

Ultrasound imaging is an important biomedical technique for analyzing soft tissues in the human body, with both diagnostic and therapeutic applications. Ultrasound images are formed by emitting ultrasound waves in the medium of interest and recording the backscattered waves on an array of transducers. Conventional 2D ultrasound image beamforming techniques are then used to create an image from the received echoes. Ultrasound imaging is the most widely-used medical imaging technique, because of its relative low cost, non-invasiveness and non-use of ionizing radiation, i.e. lack of adverse effects. It is widely used in prenatal care, for mammography and for many other applications (cardiac, renal, liver and gallbladder analysis, imaging of muscles and superficial structures such as testicles, thyroid, etc.). Because of the real time nature of ultrasound, it is often used to guide surgical procedures. Furthermore, ultrasound is increasingly used in remote diagnosis cases where teleconsultation is required. The worldwide outreach of ultrasound diagnostic for prenatal care and for mammography would be widely improved by the construction of high-performance and safe portable devices, especially for emergency, prenatal care and mammography.

Yet, ultrasound imaging has limitations. The quality of the resulting images is often poor compared to more expensive procedures, such as Computed Tomography and Magnetic Resonance Imaging. Also, the image acquisition relies on manually rubbing a probe on the patient's body, and experience and skill are required for the best diagnostic results - as opposed to the other imaging techniques, where the medical personnel is not in direct physical contact with the patient. For both reasons, trained sonologists must be in charge of operating the ultrasound scanners, rather than more generic personnel. Moreover, ultrasound imaging devices are usually bulky and power-hungry, making them non-portable and unsuitable for field operation in absence of a stable power supply. Miniaturized, lower-power ultrasound imaging devices exist, but they provide medium quality at best.

UltrasoundToGo intends to develop a high-performance, low-power signal processing platform for ultrasound imaging applications, targeting future 3D portable ultrasound systems. The motivation of this work is to provide the means for achieving a portable medical system that can provide high-quality images while being battery operated, and thus much more usable in medical emergencies and developing countries or areas where energy availability is sporadic. The improved image quality and the flexibility of the platform are intended to make ultrasound imaging devices much easier to use also by non-specifically-trained personnel. UltrasoundToGo also envisions telemedicine scenarios, where high-quality images could be effortlessly and safely scanned by general practitioners and sent to specialists for analysis.

UltrasoundToGo will rely on innovation from both the hardware and software side. From the hardware side, UltrasoundToGo will improve on existing industrial and academic works by leveraging cutting-edge programmable chips - off-the-shelf parts and new architectures - to provide high-bandwidth signal processing and advanced computing capabilities in a low-power envelope, compatible with battery operation. From the software viewpoint, UltrasoundToGo will innovate in the signal processing and image processing departments, leveraging a highly-parallel algorithmic approach for optimal platform utilization and efficiency. One of the distinctive features of the system will be to support a qualified software deployment and maintenance model whereby new real-time control and analysis algorithms can be downloaded on the platform infield, under end-user control. This model is supported by a formally well-defined and sound programming model and verification methodology for guaranteeing correctness and quality of results.

How it differentiates from similar projects in the field

The project investigators bring significant expertise in the latest chip architectures and programming paradigms, and intend to use them to devise a highly optimized platform that can process ultrasonic echoes more efficiently than any existing device.

Areas of research include improvements in image quality, reductions of system cost, enhancements in portability, and new programming methods aimed at guaranteed imaging performance.

Quick summary of the project status and key results

During the first year, the partners have kicked off the project, recruited the necessary researchers, and organized periodic meetings to track the progress of the collaboration. External consultants in Switzerland and Italy have been brought on board to contribute their expertise from the medical and application viewpoints.

Hardware development platforms were procured, with initial work performed on them.

A reference Matlab flow was developed to act as the starting hub for the project; this Matlab flow models the image reconstruction pipeline, and can be step-by-step replaced by software or hardware implementations of specific functions.

An early version of compressive sensing applied to ultrasonic imaging was developed, as well as a novel image reconstruction technique that reduces pressure on the hardware memory interface.

From the software implementation side, a QoS-aware flow and a parallel beamforming algorithm were prototyped.

Success stories

For many of the research groups in the project, the main background is in engineering rather than in biomedical applications. During the first year of the project, significant expertise was acquired by constant interactions with professionals in the field, leading to relevant training opportunities for junior and senior staff alike.

Additionally, the difficulties in acquiring the initially expected hardware platform led to useful and constructive discussions among all the groups, resulting in a newly collaboratively-defined path towards the final demonstrator. Development along this new axis has been steady and productive.

Main publications

Pirmin Vogel, Andrea Bartolini, Luca Benini, Efficient Parallel Beamforming for 3D Ultrasound Imaging, GLSVLSI'14 Proceedings of the 24th edition of the great lakes symposium on VLSI, Houston, Texas, USA, pp. 175-180, May 2014.

Stefanos Skalistis, Alena Simalatsar, Modeling of Reconfigurable Medical Ultrasonic Applications in BIP, Proceedings of the 5th Workshop on Medical Cyber-Physical Systems, Dagstuhl, Germany, pp. 66-79, 2014.

WearableMRI

WEARABLE MRI DETECTOR AND SENSOR ARRAYS

Prof. Klaas Prüssmann, ETHZ

Prof. Qiuting Huang, ETHZ

Prof. Gerhard Tröster, ETHZ

What it's about…

Advancing magnetic resonance imaging (MRI) by introducing elastic, lightweight signal detectors that patients can wear like a piece of clothing.

Context and project goals

This project aims to advance the technology of magnetic resonance imaging (MRI), which is one of the most widely used imaging modalities in medical diagnostics and research. The variety of anatomical and functional features, processes, and diseases that can be visualised with MRI is steadily increasing. However, the technique also faces fundamental limitations with respect to its sensitivity, speed, and fidelity of the dynamic magnetic fields involved. One effective way of addressing the sensitivity and speed limitations is parallel data acquisition with RF detector arrays. However, current rigid detector setups exploit this potential only partly and are limited in terms of ergonomics. Mechanical rigidity compromises sensitivity because is prevents adjustment to individual sizes and shapes of target anatomies. It also prevent changes in posture, such as the flexion of joints, and impairs patient comfort. Fixed detector electronics incur suboptimal performance as effective loads vary from patient to patient, taking a further toll on effective sensitivity.

The main goal of this project is to address these issues jointly by developing wearable, adaptive detector arrays with miniaturized on-detector receivers. In this concept, mechanical adaptiveness will be achieved by stretchable and elastic detector loops that automatically conform to the individual anatomy and posture. Arrays of elastic detector loops will be complemented by adaptive electronics that sense effective port impedances and automatically adjust variable matching networks for optimal sensitivity yield. On-detector reception will be accomplished with an integrated circuit and optical conversion for safe, digital signal transmission.

To address the limited fidelity of magnetic field evolutions during MRI scans, the recent concept of concurrent magnetic field sensing with NMR field probes will be expanded. Field sensing introduces tolerance to field imperfections and perturbations by enabling data correction upon image reconstruction as well as feedback control during scans. NMR field probes yield RF signals of the same nature as the primary MRI signals. Therefore, the second goal of this proposal is to integrate the chip receiver to be developed into NMR field probes to enable modular, scalable arrays of high-accuracy field sensors. Such sensor arrays will be assembled both in rigid form, to enhance the basic field monitoring applications, and in wearable configurations. The latter will offer the additional functionalities of bulk motion tracking during MRI scans and the observation of subtle field fluctuations related to physiological processes inside the body.

How it differentiates from similar projects in the field

Advancing MRI detection is the aim of numerous research and development efforts in academia and the healthcare industry around the world.

What renders this project unique in this field is the radical step from rigid, cage-like detectors to wearable assemblies that conform to the patient. To master this transition, the project faces unique challenges of mechanical and electronic adaptiveness along with those of miniaturization.

Quick summary of the project status and key results

The first year of this project has been dedicated to system design considerations and the definition of interface specifications, concept studies for the flexible detector frontend and the optical link, design of the integrated receiver, and the development of a PCB-based evaluation platform.

At this point, the system design for the first demonstrator is completed. Concerning the detector frontend, main conclusions on the geometry and mode of construction as well as the matching and preamplification strategy have been drawn. For the wearable optical link a viable solution has been identified and tested using a micro-machined non-magnetic optical bench. The first version of the integrated circuit design is almost completed after major efforts to accommodate challenging specifications in terms of dynamic range, sensitivity and clocking.

The evaluation platform is essentially completed and has already been demonstrated in practice, receiving high-fidelity MR signals from conventional detectors with non-integrated in-magnet digitization and optical transmission.

Success stories

One highlight of the past year was the first successful signal acquisition with the PCB-based platform for in-magnet digitization and optical signal transmission. Jonas Reber, doctoral student in the project, gave a highly attended presentation of these results at the Annual Meeting of the International Society for Magnetic Resonance in Medicine, the premier peer-reviewed conference in MRI technology.

A second highlight has been the invitation by ETH Zurich president Ralph Eichler to present our MRI activities to the ETH council upon its annual consultations with the ETH board. The entire council spent a full hour in the MRI labs and received our presentation of the WearableMRI project very positively.

Main publications

Reber J, Marjanovic J,Brunner DO, Schmid T, Moser U, Dietrich BE, Barmet C, Pruessmann KP, In-Bore Broadband Array Receivers with Optical Transmission, Proceedings of ISMRM 2014, #619.

Marjanovic J, Reber J, Brunner DO, Weiger M, Dietrich BE, Schmid T, Moser U, Barmet C, Pruessmann KP, Dead Time Reduction with a Variable Rate Broadband Receiver – Applications to Zero Echo Time Imaging, Proceedings of ISMRM 2014, #927.

“Make yourself comfortable. Detector clothes boost the utility and ergonomics of MRI”

Prof. Qiuting Huang, ETHZ

WearMeSoC

MULTI FUNCTIONAL WEARABLE WIRELESS MEDICAL MONITORING BASED ON A MULTI CHANNEL DATA ACQUISITION AND COMMUNICATION MANAGEMENT SYSTEM ON A CHIP

Prof. Peter Achermann, UZH

Prof. Jürg Blaser, USZ

Prof. Konrad Bloch, USZ

Dr. Laurence Jacobs, REMSMED

Prof. Urs Schwarz, USZ

Dr. David Tschopp, ACP

Prof. Gregor Zünd, USZ

What it's about…

Developing a chip that will enable very small wearable medical monitors with wireless connectivity to small phones and tablets.

Context and project goals

For both in- and outpatient applications the electronic interface to typical sensors and electrodes is still embodied in size and weight that prevents it from being used in the convenient and flexible way expected by new visions of healthcare provision. Integration of the plethora of functionalities required in a wearable medical monitor, including the management of wireless connectivity and its power consumption, holds the key to the breakthrough required for clinical and user acceptance of many continuous use cases.

A highly integrated system on a chip (SoC) will be developed in this project, starting from a multi-channel data acquisition integrated circuit already developed by the principal investigator ETH recently. The new SoC will improve existing design by incorporating on chip many of the conceptual design innovations such as DC connectivity and mains interference cancellation that are currently realized off-chip on a large FPGA. It will more-over incorporate multi-channel transimpedance and charge amplifiers for current, charge and optical sensors. Temperature sensors and actuating functions for stimulation will also be incorporated to make the IC truly multi functional, therefore useable in as many future applications as possible.

Experience from previously engineering portable medical monitors shows that what limits miniaturization even in single function applications is the large variety of critical support functions that need to be realized with separate commercial chips, especially when wireless connectivity is involved. The latter's high power consumption mandates a large battery, unless data transmission can be managed to occur at high rate but in bursts. Frequency and duration of such bursts must be adaptable dependin g on the use cases. The management of data buffering, storage, interaction between on-chip and off-chip memories and intelligent control of the wireless modem so that it stays connected to the base unit or station even when little transmission is taking place, requires highly sophisticated digital logic and control functions to be integrated on chip. This doesn't exist today and will be realized in the proposed project. Battery and power management circuits for the operation of all the ICs on the monitor PCB, control and data interface between the SoC and the wireless modems and memory, management of a small display (LCD or LED) are all to be integrated before the targeted size (match box) and weight (25g) become reachable.

This interdisciplinary project consists of partners from engineering, biomedical signal processing specialists who can advance automated diagnostics for early warning as well as scientific understanding, and clinical researchers who have already worked on convincing use cases that require miniaturized monitors. Their input to the system engineering and SoC definition, drawing from rich experience in using larger portable monitors to actually carrying out case studies previously, will be invaluable to the success of the SoC. The design of the latter is such a complex as well as costly task that it cannot afford frequent specification changes and addition of functionalities. Nevertheless, continual validation by the clinical team using both the prototype existing at the start of the project, the intermediate prototype developed during the project and the final demonstrators will be of crucial importance to achieving the ambitious goals set by this proposal.

Medical research carried out in their own right in the use cases will advance our understanding of sleep disorders and therapy, oximetry and ECG monitoring of cardiac surgical patients in postoperative wards, verification of onset of dementia, physiological responses to adverse environments such as high altitude, air travel and oxygen deprived working environments. Two commercial partners will contribute their knowhow in diagnostics and engineering during the project. They are also motivated to exploit the results of the project and help them reach the market.

How it differentiates from similar projects in the field

This interdisciplinary project consists of partners from engineering, biomedical signal processing specialists who can advance automated diagnostics for early warning as well as scientific understanding, and clinical researchers who have already worked on convincing use cases that require miniaturized monitors. Their input to the system engineering and SoC definition will be invaluable to the success of the SoC.

Quick summary of the project status and key results

The project got to a good start. The prototyping hardware platform is ready and has been evaluated by medical partners. The design of the SoC started and progresses well. The development of oximetry interface electronics has led to the start of the project's own IC intended to be optimized for resilience to motion artefacts.

Success stories

Affordable EMG-based hand gesture recognition system developed with the analog front-end IC "Cerebro":

The analog front-end IC Cerebro developed in the predecessor project PlaCiTUS has been successfully implemented in a hand gesture recognition system for an arm prosthesis. The performance of the developed system matches up to a state-of-art high-end active sensor platform at much lower cost. Thus is opens up the path to affordable and accurate prosthesis devices.

Reference: S. Benatti, B. Milosevic, F. Casamassima, P. Schönle, P. Bunjaku, S. Fateh, Q. Huang, L. Benini, EMG-based Hand Gesture Recognition With Flexible Analog Front-End, submitted for publication at the Biomedical Circuits and Systems Conference (BioCAS)

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P. Schönle, F. Schulthess, S. Fateh, R. Ulrich, F. Huang, T. Burger and Q. Huang, A DC-Connectable Multi-Channel Biomedical Data Acquisition ASIC with Mains Frequency Cancellation, Proceedings of the European Solid-State Circuits Conference (ESSCIRC), pp. 149-152, Bucharest, Romania, Sep 2013.

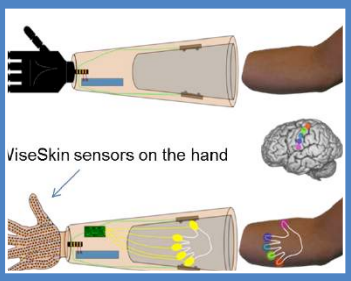
H. Kröll, St. Zwicky, B. Weber, Ch. Roth, Ch. Benkeser, A. Burg, Q. Huang, An Evolved EDGE PHY ASIC Supporting Soft-Output Equalization and Rx Diversity, accepted for publication at the European Solid-State Circuits Conference (ESSCIRC) 2014.

Peter Achermann and Leila Tarokh, Human sleep and its regulation, Kosmos 63 (2(303)): 173-180 (2014).

Stadelmann K, Latshang TD, Lo Cascio CM, Tesler N, Stoewhas AC, Kohler M, Bloch KE, Huber R, Achermann P., Quantitative Changes in the Sleep EEG at Moderate Altitude (1630 m and 2590 m). , PLoS.One. 2013.(In Press) IF: 3.73.

WiseSkin

WISE SKIN FOR TACTILE PROSTHETICS

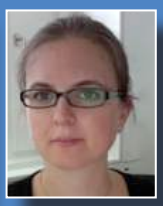


Dr. John Farserotu, CSEM


Prof. Jean-Dominique Decotignie, CSEM


Prof. Christian Enz, CSEM/EPFL


Prof. Volker Koch, BFH


Prof. Stéphanie Lacour, EPFL

What it's about…

Providing a non-invasive solution for restoration of a natural sensation of touch by embedding miniature tactility sensors into the cosmetic silicone coating of prostheses, which acts like a sensory "skin".

Context and project goals

Amputation of a hand or limb is a catastrophic event resulting in significant disability with major consequences for amputees in terms of daily activities and quality of life. Although functional myoelectric prostheses are available today (e.g. hand), their use remains limited due, in part, to a lack of sensory function in the prostheses. At the same time, as the world population both grows and ages, the number of people living with disabilities, such as persons who have lost limbs for whatever reason e.g. trauma, diabetes or cancer, also increases. A sense of tactility is needed for providing feedback for control of prosthetic limbs and to perceive the prosthesis as a real part of the body, inducing a sense of "body ownership". Today, there is no solution for restoration of a natural sense of touch for persons using prosthetic limbs.

WiseSkin provides a solution for restoration of the sensation of touch. It embeds tactility sensors into the cosmetic silicone coating of prostheses, which acts like a sensory 'skin' providing the sensation of touch, enabling improved gripping, manipulation of objects and mobility (walking) for amputees. Flexibility, freedom of movement and comfort demand unobtrusive, highly miniaturized, ultra-low power (ULP) sensing capabilities built into the 'skin', which is then integrated with a sensory feedback system. The focus is on non-invasive (external actuation) sensory feedback mechanisms. The main elements of the project are:

- flexible, skin-like, material embedded with tactility sensors
- miniature, flexible, soft-MEMS based sensors (e.g. pressure, shear)
- ULP, event driven wireless communication (radio and protocol) between the sensors and processing / control module
- a conformal, stretchable powering system based on a metallic mesh grid
- use of the metallization layers as a waveguide
- a system for sensory feedback based on a tactile display (i.e., on the amputation stump or the back) using miniature actuators / electrodes
- Proof-of-Concept demonstrator (i.e., tested on volunteers) combined with brain imaging to investigate neural mechanisms of tactile perception

WiseSkin pushes the forefront of technology in miniature, ULP sensor and communication devices, materials and sensory feedback systems; putting nano-tera research at the forefront. It enhances the competitiveness of Swiss organizations in these domains, helping to open the door for Swiss industry to capture an early and substantial share in the market for advanced, high-density body sensor networks towards artificial skin and tactile robots. Importantly, WiseSkin enables new prosthetic products, with improved functionality, hopefully offering improved quality of life for amputees.

How it differentiates from similar projects in the field

Today, there is no solution for restoring a natural sense of touch to persons using prosthetic limbs.

Additionally, the WiseSkin approach targets the ability to cover large areas (i.e. much more than a sensor node at the tip of a finger).

Quick summary of the project status

Accomplishments include:

- Development of the first sample of the artificial skin with dual layers for powering and waveguide and test
- Paper presented at the International Symposium on Medical Information and Communication Technology 2014 (ISMICT 2014) concerning the number and location of sensors and the power budget.

Main publication

C. Antfolk, V. Kopta, J. Farserotu, J-D. Decotignie, C. Enz, The WiseSkin Artificial Skin for Tactile Prosthetics - A power budget investigation, Presented at the International Symposium on Medical Information and Communication Technology 2014 (ISMICT 2014), Florence Italy, Digital Object Identifier : 10.1109/ISMICT.2014.6825229.

X-Sense II

MEMS ACOUSTIC DETECTORS FOR NATURAL HAZARD WARNING SYSTEMS

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Dr. Jan Beutel, ETHZ

Prof. Alain Geiger, ETHZ

Prof. Christofer Hierold, ETHZ

Dr. Hugo Raetzo, FOEN

Prof. Andreas Vieli, UZH

What it's about…

Developing novel sensing, processing and communication systems for detecting destructive processes such as a rock face collapsing, leading to severe natural hazards.

Context and project goals

X-Sense II contributes to the reduction of this growing gap between supply and demand by technological development and scientific advance. It investigates a complete data chain from custom designed sensor technology over networking, data-based storage and processing towards new discoveries in environmental sciences and new, more effective technologies for early warning.

Steep bedrock in high-alpine regions such as the European Alps is influenced by seasonal frost or permafrost. Knowledge of processes and factors affecting slope instability is essential for detecting and monitoring potentially hazardous slopes. In the attempt to understand or anticipate movement, a combination of differing sensed variables and sensing modalities is usually employed. This includes displacement (GPS, crack meters), seismic/acoustic signals, repeat imagery, and environmental data such as temperatures, precipitation etc.

The current state of the art in sensing systems is based on continuous oversampling and subsequent filtering of the digital data acquired to extract meaningful information. The significant power and data rates associated to important modalities such as GPS and acoustic emission inherently

- necessitate heavy infrastructure in the field for energy harvesting,
- require large amount of data to be stored and communicated and
- impose the difficulty to differentiate signals relevance from the noise generated by other phenomena.

This big data problem effectively constitutes a showstopper with respect to wide applicability.

X-Sense II will follow a new path by exploiting advances in MEMS technology to achieve a trigger-based duty-cycling of complex sensing systems by monitoring acoustic events. This partial relocation of signal analysis and decision-making from the computing domain to the sensor itself will enable close to zero standby-power. The sensing device will be based on a new class of mechanical switches which is highly sensitive and frequency selective. The potential of such an approach is huge and will be explored in X-Sense II: Use the triggering signal to wake up other types of sensor at the same or other locations as well as using the detailed frequency-dependent triggering information as a new modeling input for geoscientific investigations and early warning. This new approach needs scientific advances in MEMS sensor design as well as event-based sensing architectures, adaptive communication and distributed control. In addition, it will only be successful if based on a close interaction between engineering sciences, geosciences, industry and public stakeholders. The analysis of comprehensive acoustic field measurements will provide a characterization of the signals to be used as triggers. The multi-scale approach of X-Sense II, which combines various sensing modalities, is a key factor of success. Measuring displacement with crack meters in rock faces and with continuous GPS on more gentle slopes, is a proxy for the high-magnitude low-frequency hazards under investigation because cumulatively, it can lead to slope failure.

How it differentiates from similar projects in the field

The current state of the art in sensing systems is based on continuous oversampling and subsequent filtering of the digital data acquired to extract meaningful information. The significant power and data rates associated to important modalities such as GPS and acoustic emission inherently

- necessitate heavy infrastructure in the field for energy harvesting,
- require large amount of data to be stored and communicated and
- impose the difficulty to differentiate signals relevance from the noise generated by other phenomena.

Quick summary of the project status

The current state of the art in sensing systems is based on the principle of continuous oversampling and subsequent filtering of the digital data acquired to extract meaningful information describing the processes to be observed.

X-Sense II will exploit advances in MEMS technology to achieve a trigger-based duty-cycling of complex sensing systems by monitoring acoustic events. This partial relocation of signal analysis and decision-making from the computing domain to the sensor itself will enable close to zero standby-power. The sensing device will be based on a new class of mechanical switches which is highly sensitive and frequency selective. The potential of such an approach is huge and will be explored in X-Sense II: Use the triggering signal to wake up other types of sensor at the same or other locations as well as using the detailed frequency-dependent triggering information as a new modeling input for geoscientific investigations and early warning.

Success stories

- The field site for pilot experiments has been identified. Scouting of the detailed location has been done jointly on June 11, 2014. Installation was planned shortly thereafter.
- Successful launch of the PERMOS Continuous GPS Pilot Program as a result of the technology transfer of the GPS sensors system developed in X-Sense to authorities and other research groups.
- A number of publications involving members of different groups have been achieved. This shows the active interdisciplinary collaboration in X-Sense II.

Presence in the media:

- Agnes Fazekas: *Am Puls der Gletscher*. Natur - Das Magazin für Natur, Umwelt und besseres Leben., Februar 2014.
- Agnes Fazekas: *Das Knacken der Alpen*. Spiegel Online, Januar 2014.
- Christian Thiele: *Auf Allen Gipfeln ist Not*. GQ Magazin, Condé Nast Verlag GmbH, München, December 2013.

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Marco Zimmerling, Federico Ferrari, Roman Lim, Olga Saukh, Felix Sutton, Reto Da Forno, Remo S. Schmidt and Marco André Wyss, Poster Abstract: A Reliable Wireless Nurse Call System: Overview and Pilot Results from a Summer Camp for Teenagers with Duchenne Muscular Dystrophy, Proceedings of the 11th ACM Conference on Embedded Networked Sensor Systems (SenSys 2013), Rome, Italy, p. 52:1-52:2, November 2013.

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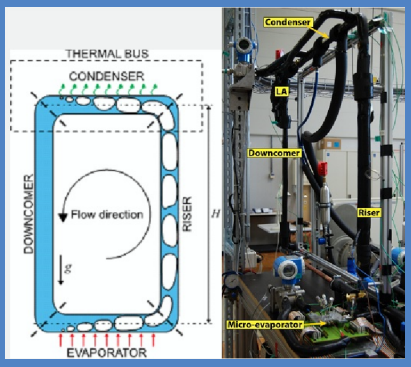
Felix Sutton, Reto Da Forno, Roman Lim, Marco Zimmerling and Lothar Thiele, Demonstration Abstract: Automatic Speech Recognition for Resource-Constrained Embedded Systems, Proceedings of IPSN 2014, Berlin, April 2014.

Prof. David Atienza, EPFL

YINS

ENERGY- AND THERMAL-AWARE DESIGN OF MANY-CORE HETEROGENEOUS DATACENTERS



Prof. Luca Benini, ETHZ

Dr. Edouard Bugnion, EPFL

Prof. Babak Falsafi, EPFL

Marcel Ledergerber, Credit Suisse

Dr. Fabrice Roudet, Eaton Manufacturing

Patrick Segu, BrainServe

Prof. Lothar Thiele, ETHZ

Prof. John Thome, EPFL

What it's about…

Developing new technologies and optimization methodologies to develop next-generation energy-efficient datacenters.

Context and project goals

Energy efficiency in datacenters is of strategic importance to Switzerland, as over 75% of the Swiss economy is service-based and depends on information technology (IT), which makes Switzerland one of top spenders of IT per capita. IT is also witnessing a major paradigm shift towards Cloud Computing with datacenters emerging as a key backbone of services at scale, making energy dissipated in datacenters a key concern even with moderate increases in IT electricity demands. In particular, because of Switzerland's decision to abandon nuclear energy by 2034, improvements in energy efficiency are imperative to make up for half of the electricity otherwise furnished by nuclear power. Meanwhile, in Switzerland many IT departments for enterprises, research, and governmental organizations alike are at capacity with regards to their electricity budget. Thus, the only feasible solution to achieve energy sustainability is to drastically increase the power efficiency of data centers.

The design of datacenters today is a really complex process, where important opportunities exist both within and across various server and infrastructure components. Server software, system and silicon technologies as well as infrastructure for cooling and power delivery have historically been designed in isolation with an over provisioning of resources to guarantee a desired quality of service. Unfortunately, due to the diverse nature of workloads and demands on resources, such over provisioning results in prohibitive levels of waste in energy and efficiency. Modern volume server software and hardware is broadly based on designs primarily derived from the desktop market and are ill-suited for serviced-oriented server workloads. Similarly, while most datacenters make use of air-cooling technologies to ensure the correct running of the servers, air-cooling is reaching fundamental physical limits in efficiency with a continued increase in server density requiring innovation in cooling technologies.

In YINS, we propose to develop a radically new thermal-aware design approach for next generation energy-efficient datacenters. This new design approach tightly integrates the cooling infrastructure definition with holistic system-level power, performance and thermal management. This vertically-integrated system-level management paradigm goes beyond hardware and software boundaries by redesigning the entire datacenter to maximize performance given a target power, area and cost budget. Therefore, we propose to develop new server technologies based on Fully Depleted Silicon On Insulator (FDSOI) and specialized server architectures. Finally, these novel architectures interact with new on-chip microfluidic cooling delivery at server-level and passive thermosyphon cooling systems for the rack and room-level, as well as energy recovery strategies for the complete datacenter.

To realize its vision, YINS requires inter-disciplinary research at the boundaries of multiple scientific domains, as well as developing and integrating innovations in critical research areas, namely, computer systems, circuits and semiconductor technologies, and cooling technologies, large-scale simulation, software synthesis and optimization, statistical network modeling and model predictive control theory. Therefore, the YINS consortium includes six world-renown academic partners from EPFL and ETHZ covering key research areas of computer, electrical and mechanical engineering, and three key industrial partners in Switzerland for datacenter design and large-scale IT banking services provisioning (Credit Suisse, Eaton and BrainServe), and three third-party industrial partners (Constellium, Friotherm and Osmoblue).

How it differentiates from similar projects in the field

The vertically-integrated system-level management paradigm that YINS targets for datacenters goes beyond competitors in the field by performing inter-disciplinary research at the boundaries of multiple scientific domains.

It integrates innovations in several research areas, namely, computer engineering and cooling design, large-scale computing system simulation, software generation and optimization, statistical network modeling and model predictive control theory.

Therefore, YINS includes six world-renown academic partners from EPFL and ETHZ covering these key research areas and three key industrial partners in Switzerland for datacenter design and large-scale IT banking services provisioning (Credit Suisse, Eaton and BrainServe).

Quick summary of the project status

- The team has started developing an architectural simulating infrastructure for the modelling of heterogeneous large scale computing systems running computational kernels.
- The project validated the application of on-chip microfluidic fuel cell networks for joint cooling and power supply (i.e., localized power generation and delivery) of memories in multi-core computing servers.
- Joker, a framework for answering different "what-if" workload deployment configuration questions in data centers has been developed.
- Bulk Memory Page Access Prediction and Streaming (or BuMP) have been introduced to improve energy efficiency for in-memory workloads.
- A thermosyphon loop test bench has recently been developed and installed in the LTCM laboratory facilities.
- Analytical models and metrics relevant to the design and optimization of datacenters have been identified.

Success stories

A new wireless energy monitoring device and management system for datacenters has been developed to help companies. This new system, called Power Monitor System and Management (PMSM), has been developed by the ESL-EPFL partner of YINS, and the new system is able to monitor and track the energy consumption by racks of servers and, even better, can help redistributing workload among servers to optimize energy use. PMSM has been already installed in two Credit Suisse datacenters and has been reported to enable cut power demand by 30 to 50 percent.

Within YINS, LTCM-EPFL members presented the first two-phase cooling prototype at server level. This prototype demonstrated that two-phase cooling can improve heat removal efficiency while requiring a lower flow rate (for lower operation cost) and enabling better temperature uniformity across the server chips. Their technology is showcased on the cover of the Electronics Cooling, a high-profile magazine dedicated to thermal management in electronics industry. In addition, Nicolas Lamaison, Jackson Marcinichen and John Thome have been awarded the Best Paper Award at InterPACK. The authors showcase in this work for the first time the need for transient modeling and control of on-chip liquid cooling in servers and propose, the use of online models for effective and accurate cooling control, which we will explore further in YINS in the coming reporting periods.

Presence in the media:

The "Power System Monitoring and Management (PMSM) device and system, developed at ESL-EPFL in cooperation with Credit Suisse, has been cited at Clean Technica, SNS Analytics International.

Main publications

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Francesco Beneventi, Andrea Bartolini, Pascal Vivet, Denis Dutoit, Luca Benini , Thermal analysis and model identification techniques for a logic+ WIDEIO stacked DRAM test chip, DATE 2014.

Roberto Diversi, Andrea Tilli, Andrea Bartolini, Francesco Beneventi, Luca Benini, Bias-Compensated Least Squares Identification of Distributed Thermal Models for Many-Core Systems-on-Chip, Circuits and Systems I: Regular Papers, IEEE Transactions on , vol.PP, no.99, pp.1,14, doi: 10.1109/TCSI.2014.2312495.