Graz University of Technology
Signal Processing and Speech Communication Laboratory

SPSC

Signal Processing and Speech Communication Laboratory

SPSC Lab Report

1811 2011
200 YEARS TU GRAZ


SPSC
Signal Processing and Speech Communication Laboratory

Preface

Dear reader,

The Signal Processing and Speech Communication Laboratory (SPSC Lab) has been founded at Graz University of Technology (TU Graz) in the fall of the year 2000 and since then it has grown to a thriving research and education centre with over thirty scientists. The document you hold in your hands has been compiled for a double anniversary: The lab has completed its first decade while the university enters its bicentennial year and both organizations look into a bright future.

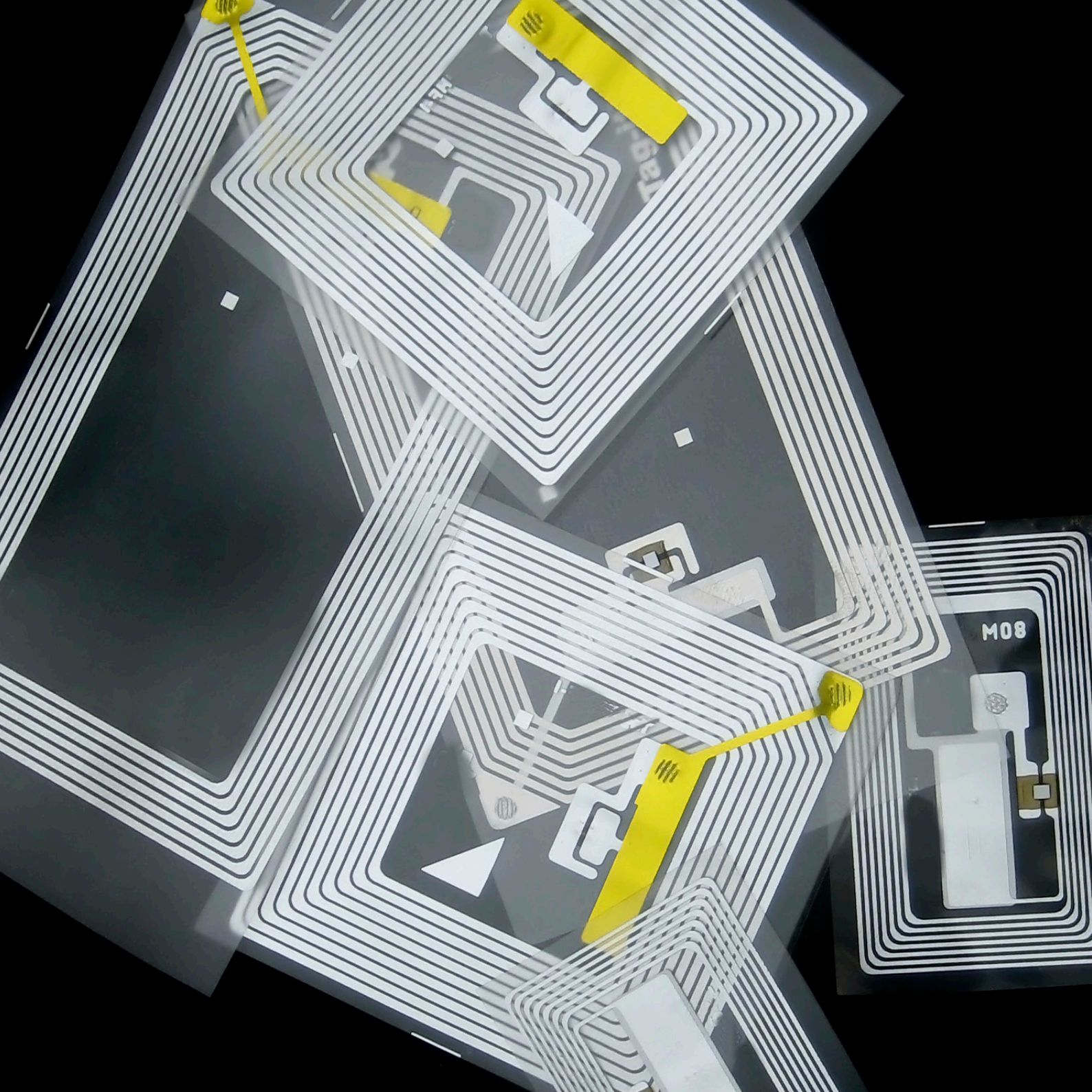
SPSC Lab is part of the Information and Communications Engineering section of the Faculty of Electrical and Information Engineering and we are active in four scientific areas: Nonlinear Signal Processing, Wireless Communications, Intelligent Systems, and Speech Communication. At university level, our research is well connected in the Field of Expertise *Information, Computing, and Communications Technologies* whereas our teaching contributes to several curricula in Electrical Engineering as well as to joint programs with Computer Science, Mathematics, Mechanical Engineering, and the University of Music and Performing Arts.

Cooperation is a hallmark of our success and so we take pride in holding leadership roles in long-term *cooperative research programs* such as the Christian Doppler Laboratory for Nonlinear Signal Processing, the Telecommunications Research Centre Vienna FTW, the Competence Network on Advanced Speech Technologies COAST, the COMET project Advanced Audio Processing AAP, and the FWF National Research Network Signal and Information Processing in Science and Engineering SISE.

This success has been made possible through the continuous support from our cooperation partners from industry and the public sector to whom we want to say: thank you! Thank you for these wonderful first ten years and, please, join us in our efforts to move ahead into a vibrant third century for our university.

November 2010 Gernot Kubin

How to use this document: Most of the printed material in this report has been selected from our website www.spsc.tugraz.at and it is intended as a teaser for your interest. Thus, to get further information on any of the topics, please access our website which provides a more complete description of our activities. Or - even better - please come to visit us!


M08

A Brief History of SPSC Lab

In Anno Domini 2000 the *Signal Processing and Speech Communication Laboratory* SPSC Lab was founded upon appointment of Gernot Kubin to a University Professorship for Nonlinear Signal Processing at Graz University of Technology. This was a belated outcome of the 1993 evaluation in Electrical Engineering which had covered all relevant university institutes and research institutions in Austria. Initially, the lab was a member of the Institute for Communications and Wave Propagation and its staff consisted of two Research and Teaching Associates, Christian Feldbauer from TU Graz and Dmitriy Shutin from Dnepropetrowsk State University, Ukraine.

In 2001 the lab was approached by the development centre of Infineon Technologies in Villach, Austria, to start a cooperative research project in *Nonlinear Signal Processing for xDSL systems* which resulted in a long-term strategic collaboration between these two partners which still continues its success story today. This allowed us to learn about hard real-world problems in nonlinear system identification and compensation which served as the driving force for fundamental research and to hone our algorithm engineering skills. Furthermore, the student lab was set up which provides 12 fully equipped work places for Digital Signal Processing (DSP) development and measurement. This was made possible by a combination of the starting grant received from the university and the close cooperation with the Institute of Technical Informatics which allowed us to join the *ELITE University Program* of Texas Instruments Europe. This program selects the top 3% of European higher-education institutions and provides premium support for and donations of complete DSP hardware and software environments. Finally, the *Intensive Program SoCware – System-on-Chip Design* was held in cooperation with several institutes from TU Graz and the local chip design companies Austria Micro Systems, Infineon Technologies, and Philips Semiconductors which led to the establishment of a SoC specialization in the Telematics Master's curriculum.

In 2002 we succeeded in the foundation of the *Christian Doppler Laboratory for Nonlinear Signal Processing*, a joint effort with our partner Infineon Technologies and later expanded by cooperation with the Austrian Research Centers ARC. Several projects have been run in this lab over the years, covering both wire-line and wireless communications, linearization methods using echo cancellation and pre-distortion, adaptation and realization concepts for nonlinear systems, error compensation for analog-to-digital-converters, novel structures for all-digital phase locked loops, as well as our first hardware realization steps in ultra-wideband UWB communications. In the same year, the first *international research scholarship holder* arrived at

A Brief History of SPSC Lab, cont´d

our lab, Tuan Van Pham from Danang University of Technology in Vietnam. He was the first of so far seven research scholars financed through the Austrian Academic Exchange Service ÖAD which all contribute to build our global alumni network. Finally, by the end of the year, the university financed staff grew to four by the appointment of the Senior Scientists Klaus Witrisal from TU Delft and Franz Pernkopf from the University of Leoben.

In 2003 Franz Pernkopf was awarded an *Erwin Schrödinger Fellowship* from the Austrian Science Fund FWF which led him as a visiting researcher to Oakland University and the University of Washington, Seattle. This started a series of Erwin Schrödinger Fellows from the SPSC Lab, with Heinz Köppl going to the University of California at Berkeley, Christian Feldbauer to KTH Stockholm and the University of Cambridge, Christian Vogel to ETH Zurich, and Dmitriy Shutin to Princeton University. According to FWF statistics, more than 50% of the scholarship holders eventually become full professors, so this appears like a promising career booster for our lab members. In teaching, close collaboration started with the Institute for Theoretical Computer Science through the establishment of *Computational Intelligence* as the first lecture course ever taught jointly by professors of the Faculties of Electrical & Information Engineering and of Computer Science.

In 2004 the Austrian University Act UG2002 led to a reorganization of the university and SPSC Lab became a standalone university institute with more than 20 scientists, continuing its cooperation with the other members of the Department of Communications and Wave Propagation. The lab was successful in winning its first grants within the EU 6th Framework Program for the projects *Services for NOmadic Workers SNOW* (with EADS France, SAP Germany, SBS Siemens Business Services Germany, Frauenhofer FIRST Germany, Loquendo Italy, and ARC Austria) and *Emergency Ultrawideband RadiO for Positioning and COMmunications EUROPCOM* (with Thales England/France, TU Delft, and IMST Germany).

In 2005 we initiated our first projects within the nationally funded FIT-IT program. While the project *Semantic Phonetic Automatic ReConstruction of dictations SPARC* won the prize for the best proposal in the first Semantic Systems call, the project *Measurable intelligent and secure semantic extraction and retrieval of multimedia data MISTRAL* was the first to unite 6 institutes of TU Graz within the Field of Expertise *Information, Computing, and Communications Technologies ICCT*. On a more regional level, the project *SonEnvir – A sonification environment for scientific data* was the first joint project of all four universities in Graz, funded by the Zukunftsfonds of the Land Steiermark. The

same year saw the introduction of the *Otto Nußbaumer Visiting Professorship in Smart Systems for a Mobile Society* with the appointment of W. Bastiaan Kleijn from the Royal Institute of Technology KTH Stockholm.

In 2006 a consortium consisting of Philips Speech Recognition Systems Vienna, Sail Labs Technologies Vienna, the Austrian Research Institute for Artificial Intelligence ÖFAI in Vienna, SPSC Lab, and several other partners succeeded in establishing the *Competence Network for Advanced Speech Technologies COAST*, an industrial research network funded by national and regional agencies within the K-net program. The network joined forces around the topic of automatic speech recognition as needed for dictation in medical documentation such as electronic medical records and for media mining in audiovisual broadcast archives. SPSC Lab took over the scientific leadership in this network and contributed to acoustic front-end processing, phonetic modeling and adaptation, and machine learning for single-channel speaker separation. As a dissemination event for the general public, the Voice Games at the traditional *Ball der Technik* demonstrated the technology of voice conversion in a joyful setting.

In 2007 we used an innovative scheme offered by the Christian Doppler Research Assocication and were among the first to open an *International Branch* of the Christian Doppler Laboratory for Nonlinear Signal Processing at Gottfried Wilhelm Leibniz University of Hannover. The branch was headed by Ilona Rolfes specializing in Radio-Frequency Engineering which allowed us to extend the industrial collaboration of the Christian Doppler Lab into this exciting field. This experience triggered the interest to join forces with 5 institutes of TU Graz within the ICCT Field of Expertise so as to found the *Radio-Frequency Competence Network of TU Graz*. As it first joint activity, this network submitted a proposal to the Austrian Council for Research and Technology Development RFT and won the necessary funds for a new professorship in Radio-Frequency Engineering including a large volume of specialized instrumentation. At the governing level of the university, Gernot Kubin was elected to President of the *University Senate*.

In 2008 the long-term relationship with *Telecommunications Research Vienna FTW* was developed to the next level. This center had been founded as a K-plus center in 1998 and close cooperation with SPSC Lab existed since its beginning. With FTW's successful application for a COMET K1 centre, TU Graz became a strategic partner of the centre and acquired shares

A Brief History of SPSC Lab, cont´d

of its operations company. This allowed closer coordination of the mutual strategies in the fields of telecommunications, traffic telematics, and energy systems which led to joint projects with new partner institutes from TU Graz. Another application to the COMET program was successful in initiating the K-project *Advanced Audio Processing AAP* which integrates three acoustics research institutions in Graz under one umbrella: IEM from the University of Music and Performing Arts, the DIGITAL Institute at Joanneum Research, and SPSC Lab. And at the national level, the Austrian Science Fund FWF approved the grant for a National Research Network *Signal and Information Processing in Science and Engineering SISE* which brings together stakeholders from mathematics, computational sciences, and signal processing in Vienna and Graz to push ahead fundamental research in distributed processing for sensor networks.

In 2009 one of our senior scientists, Klaus Witrisal, succeeded in obtaining his *Venia docendi in Wireless Communications* and was promoted to Associate Professor at TU Graz. At the same time, Dmitriy Shutin was offered a Junior Professorship at the University of Bochum in Germany which he turned down in favor of a research position at Princeton University. SPSC Lab received the inventors award from the Rector of TU Graz, being among the top 3 institutes of this university regarding *invention disclosures and patents*. And several months saw us busy with implementing our move to new premises on the ground floor of Inffeldgasse 16c which finally allowed us to consolidate our office space (which had been spread out over three buildings), leading to more efficient communication in the team.

In 2010 Franz Pernkopf was the next senior scientist at our lab to obtain his *Venia docendi in Intelligent Systems*. SPSC Lab alumnus Heinz Köppl was appointed to an *SNF Professorship in Computational Systems Biology at ETH Zurich* which illustrates the broad scope of signal processing as an interdisciplinary technology. Lab members were successful in receiving special awards from the Rector of TU Graz, this time for their best practice models in teaching evaluations (Martin Hagmüller) and inventory data acquisition (Andreas Lässer). The strategic partnership with *Telecommunications Research Vienna FTW* was strengthened by the opening of a TU Graz branch office hosted by SPSC Lab and led by our alumnus Christian Vogel. At the end of the year, Franz Pernkopf received the Young Investigator Award from the Land Steiermark.

And tomorrow we will further build on our highly motivated team of over 30 scientists and 4 support staff members. In the past ten years, we have successfully supervised *21 completed PhD theses* and authored over *300 international peer-reviewed publications* with more than a dozen best paper awards, and we have filed more than *20 patents*. So the perspectives for the start into the third century of our university are bright, with further growth possible through the *Sound of Music initiative*, i.e., a stronger integration of acoustics and audio engineering activities around the interuniversity research and teaching unit "Sound Studio", a *Speech & Language Technology initiative* with the Karl Franzens University Graz, the expansion of our application scenarios into the automotive industry, and the creation of start-up companies – our senior researcher Harald Romsdorfer just secured a top position in the "Best of Tech 2010" business plan competition.

Available at
www.ComputerScienceWeb.com
POWERED BY SCIENCE DIRECT®

ELSEVIER

Pattern Recognition Letters 24 (2003) 2839–2848

Pattern Recognition Letters

www.elsevier.com/locate/patrec

Floating search algorithm for structure learning of Bayesian network classifiers

Franz Pernkopf [a,*], [illegible] Leary [b,1]

[a] Institute of Communications [illegible] Have Propagation, Graz University [illegible] Inffeldgasse [illegible] Graz, 8010 Austria

[b] [illegible] of Automation, Univer[illegible] Le[illegible] 8700, Austria

[illegible] 3 February 2003; re[illegible] 10 Ju[illegible]

Abstract

This paper presents a [illegible] approach for lear[illegible] network struc[illegible] Bayesian network classifiers. A Bayesian network class[illegible] in combinatio[illegible] with the sear[illegible] allows simultaneous feature selection and determinatio[illegible] of the classifier.

The introduced search [illegible] conditional e[illegible] of previ[illegible] attributes and/or arcs from the network classifier. Hence [illegible] able to corre[illegible] work st[illegible] moving attributes and/or arcs between the nodes if they b[illegible] later st[illegible] the search. Class[illegible] results of selective unrestricted Bayesian network classifiers [illegible] naive Bay[illegible] classifiers and tree a[illegible] Bayes classifiers. Experiments on different data se[illegible] tive unrestricted Bayesian net[illegible] fiers achieve a better classification accuracy estimate in tw[illegible] red to augmented naive [illegible] rs, whereby in the remaining domains the performance is [illegible] the achieved net[illegible] structure [illegible] unrestricted Bayesian network classifiers is simpler.

Keywords: Bayesian network classifiers; Feature selection; floating search; [illegible]

1. Introduction

In classification problems the relevant attributes are often unknown a priori. Thus, many features are derived and the features which do not contribute or even degrade the classification performance [illegible] be removed. This step is performed during [illegible] selection. The main purpose of feature selection is to reduce the number of extracted features to a set of a few significant ones for classification while maintaining the classification rate. The reduction of the feature set size may even improve the classification accuracy by reducing estimation errors associated with finite sample size effects (Jain and Chandrasekaran, 1982). This behaviour of practical classification approaches is basically caused by insufficient modeling of the class-conditional probability

* Corresponding author. Tel.: +43-3168734436; fax: +43-3168734432.
E-mail address: pernkopf@inw.tugraz.at (F. Pernkopf).
[1] Tel.: +43-3842-402-9031.

0167-8655/$ - see front matter © 2003 Elsevier B.V. All rights reserved.
doi:10.1016/S0167-8655(03)00142-9

Original art by Franz Pernkopf

Research

The Research of SPSC Lab addresses fundamental and applied research problems in four scientific areas

- Nonlinear Signal Processing
- Wireless Communications
- Intelligent Systems
- Speech Communication

The interrelationship of the four scientific areas can be best explained with the example of *modern communication terminal devices* such as smart phones etc. Wireless communications provides access from the device to the communications network infrastructure. Speech communication provides a natural interface modality between the device and the human user. For the efficient realization and implementation, technologies such as nonlinear signal processing systems are needed. And to turn a plain communications terminal into a smart device, intelligent systems research provides the additional functionalities such semantic signal interpretation and identification, localization, and tracking of both the user and the device.

At university level, SPSC Lab contributes to the Field of Expertise *Information, Computing, and Communications Technologies ICCT* which is the largest out of five fields defining the research profile of Graz University of Technology.

The backbone of our strategic research is found in several long-term Research Programs where SPSC Lab often takes a leadership role. These programs extend over 4 or more years and are embedded into strategic partnerships, often supported by substantial third-party funding from private and public sources. The research programs are complemented by shorter-term research projects and by PhD theses research.

- Research Areas
- Research Topics
- Research Programs
- Research Projects
- PhD Theses
- Publications
- Contract Research
- Cooperative Research
- Researcher-in-Residence Program

Research Areas

Nonlinear Signal Processing

Nonlinear Signal Processing is an emerging discipline combining knowledge from signal processing, adaptive systems, nonlinear dynamical systems, statistics and information theory, computation, and mixed-signal processing systems realization. Nonlinearity shows itself as a *curse* in many physical system realizations where analog effects may deviate strongly from their idealized linear behavior. The modeling of these nuisance effects and their adaptive digital compensation is a key application of nonlinear signal processing in the realm of mixed-signal processing systems such as power amplifiers for wire-line and wireless communications. Nonlinearity can also be a *blessing* when it comes to the modeling, compression, and interpretation of information sources where deterministic nonlinear dynamics rivals with conventional statistical models in representing randomness of a source, i.e., its innovation or information content. This gives rise to more accurate signal models and to an understanding of information flow in computational algorithms and distributed signal processing networks. This research area strongly interacts with the art of algorithm engineering as an extension to circuit and system design, including the mapping on reconfigurable architectures.

Intelligent Systems

An intelligent system is able to perceive, learn, reason, and act in a prudent way. This involves various perception modalities such as input from cameras, microphones, sonar and other more exotic sensors. Furthermore, machine learning and pattern recognition techniques are important ingredients for reasoning under uncertainty in intelligent systems. One major aim is to extract relevant information from massive data in a semi-automatic fashion using computational and statistical methods. This interdisciplinary research is related to many fields throughout science and engineering, i.e., statistics, probability, and graph theory, optimization methods, logic, speech and image processing, control theory etcetera. The focus is on providing solutions for tasks where some kind of intelligence is inevitably essential. Application areas include bioinformatics, computer vision, natural language processing, speech processing, man-machine interfaces, expert systems, and robotics amongst others.

Wireless Communication

Wireless Communications is a multidisciplinary subject, requiring expertise in radio propagation, antennas, RF electronics, analog and digital (mixed-signal) signal processing, systems theory, some control theory, and many mathematical topics, as statistics, coding theory, queuing theory, game theory, and others. Continuously, new topics have been emerging over the past years. Only a few years back, concepts as orthogonal frequency division multiplexing (OFDM), multi-input multi-output (MIMO) systems, ultra-wideband (UWB) systems, cooperative communications, or cognitive radio have been considered as visionary but most likely unpractical ideas. Nowadays, many of those have found applications. They have been included in communications standards and they are being discussed in lecture courses on wireless communications.

Ultra-wideband (UWB) systems and techniques have become our key topic, potentially offering ultra-low-power wireless links that are robust against the ever-present multipath propagation in wireless channels. Based on UWB techniques, high-accuracy indoor localization, next-generation RFID systems, and ultra-wideband channel modeling have been the main research topics in Wireless Communications during the last years.

Speech Communication

Speech Communication covers speech production and speech perception of the sounds used in spoken human language. It is a highly interdisciplinary field that is studied by several academic disciplines including acoustics, psychology, speech pathology, linguistics, cognitive science, communication studies, computer science, and signal processing.

Research in Speech Communication at our lab focuses on automatic speech processing techniques for human-machine-interaction, for enhancing speech transmission, and for improving life quality of disabled persons. This involves research topics in speech signal processing, like speech analysis, speech enhancement and transmission, as well as research topics in automatic speech communication, like acoustic source localization, speech and speaker recognition, speech synthesis, and several language technologies. To this end, our lab provides the Speech Communication research area with an ideal combination of other research areas, like nonlinear signal processing, and intelligent systems.

Selected Research Topics

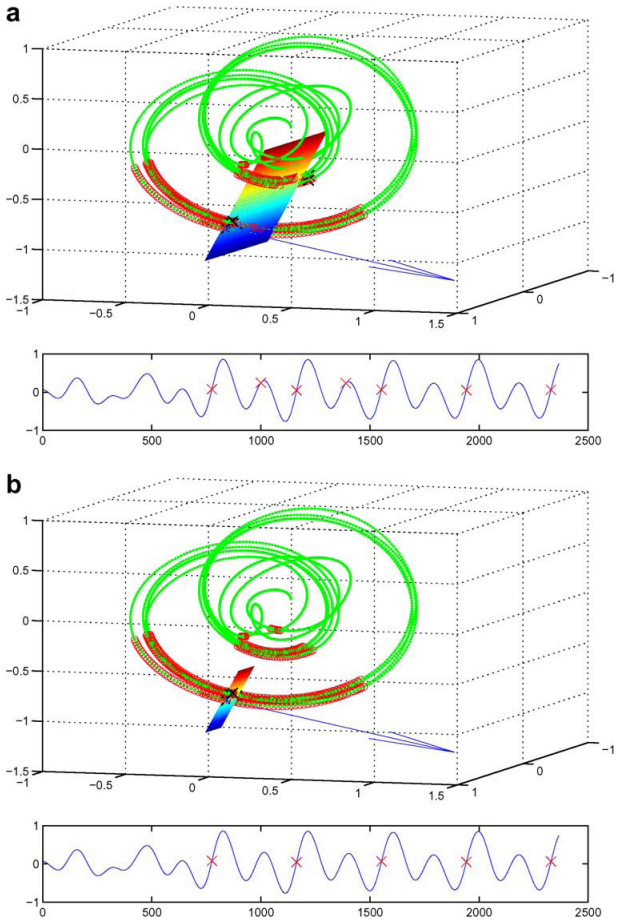
Nonlinear Modeling

Nonlinear Signal Processing

Nonlinear Modeling aims at a more accurate representation of physical reality where many systems are found to violate the basic prerequisite of linear models: the so-called *superposition principle* which states that the effect of the sum of multiple system inputs equals the sum of the effects of the individual inputs. This principle is often violated due to limitations in the maximum amplitude a physical quantity may reach, and due to basic physical laws which show a nonlinear relationship among the relevant variables of the problem domain. These nonlinear effects often become more prominent with the ongoing miniaturization of the electronic devices used for systems realization.

When choosing appropriate models, we can distinguish between physical or glassbox models and blackbox models. The former correspond to system descriptions in terms of parameterized equations and require substantial prior knowledge of the application domain. The latter rather provide *universally approximating structures* which are helpful to represent wide classes of nonlinear systems with minimum prior knowledge, which is compensated by the use of sophisticated model adaptation or learning algorithms.

Another distinction is between dynamical systems with fading memory, i.e., filter models and dynamical systems with non-fading



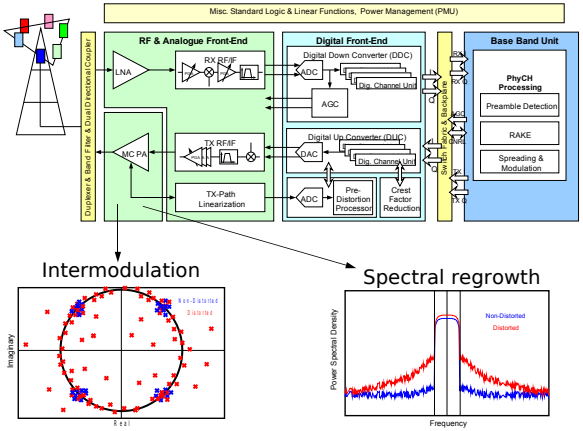
memory, i.e., oscillator models. While the latter can exhibit intricate behavior when operated in a chaotic regime, the former are well described by so-called Volterra Series representations and by Reservoir Computing representations. We have worked on many aspects of these models such as nonlinear oscillator identification from measured data, a new theory of Volterra series for mixed continuous- and discrete-time dynamical systems, model complexity reduction, the application of Reservoir Computing to wireless sensor networks and many others.

Adaptive Signal Processing & Control

Nonlinear Signal Processing

A well-understood special case of nonlinear signal processing is found in adaptive signal processing and control. In its classical setting, a parameterized linear system is used to represent a weakly nonlinear system around an operating point where the optimal parameterization is learnt from the observation of the system input and a desired system output using on-line parameter adaptation algorithms. This setting can be generalized to include parameterized nonlinear systems and to various learning architectures such as cascade system compensation in predistortion or equalization scenarios and parallel system compensation in echo cancellation.

The adaptation algorithms need to be able to handle real-world problems with often limited information from the observed signals, as is the case for blind adaptation algorithms and other underdetermined signal processing problems such as single-channel source separation. Furthermore, they need to achieve fast and accurate learning outcomes where the class of *Recursive Prediction Error methods* has recently been generalized to the nonlinear predistortion case. Finally, computational complexity and architecture often play a crucial role, e.g., when distributing the learning algorithm over sensor networks where the sensor nodes may play the triple role of sensing/communicating physical data, of forming the substrate for nonlinear models based on reservoir computing, and of implementing the model adaptation algorithm.

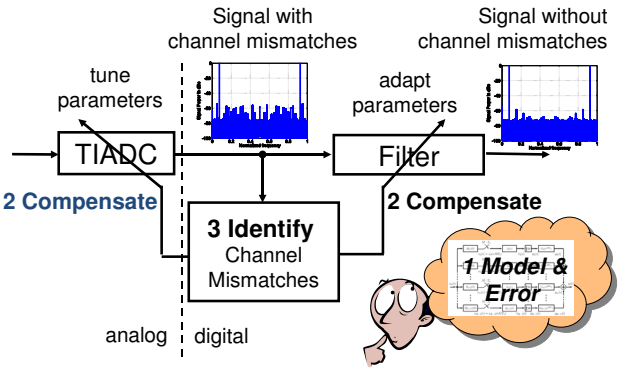


Selected Research Topics, cont´d

Circuits, Systems, Algorithms

Nonlinear Signal Processing

All signal processing systems need to be realized with analog circuits, digital hardware and/or software, or *mixed-signal systems* which constitute the combination of analog and digital subsystems. Such designs acknowledge that interaction with the physical environment is always analog while digital implementation becomes more and more advantageous in terms of hardware resources and power consumption. Going for *"Green ICT"*, therefore, often means to optimize a mixed-signal system design where digital methods assist the analog circuits to strike the best balance in system performance versus sustainable energy use.



On the digital side, the goal is best characterized as *algorithm engineering*, examples of which are found in our development of highly efficient multi-rate implementations of nonlinear filters and in the use of *reconfigurable computing architecture* where the challenge lies in the design of custom-precision number formats in both fixed point and floating point. Being able to choose an optimized computational precision according to the application requirements and the internal properties of a signal processing algorithm allows substantial savings in resources without sacrificing resources. In particular, such choices can even be based on the online estimation of the relevant information in observed data and derived algorithm variables where probabilistic models from machine learning provide the necessary online analysis.

Information Processing & Coding

Nonlinear Signal Processing

Information Theory is traditionally concerned with data transmission and compression and has not received as much intention for the description of signal processing systems. While traditional signal processing measures are related to signal energy and correlation, an information processing view should emphasize the amount of entropy generated by a signal model or the amount of entropy reduction resulting from an input-output system operation. While most linear systems fall in the class of *information allpasses* which do not increase or decrease the

entropy rate of the processed signals, nonlinear systems do. We study the impact of nonlinear systems on the information content of signals, exploit nonlinear models for signal compression and signal generation, including the recovery of lost information, and study the distributed analysis of sensor data under total capacity constraints.

Probabilistic Graphical Models

Intelligent Systems

Probabilistic graphical models unite probability and graph theory and allow to efficiently formalize both static and dynamic, as well as linear and nonlinear systems and processes. Many well-known statistical models, e.g. mixture models, factor analysis, hidden Markov models, Kalman filters, Bayesian networks, Boltzmann machines, the Ising model, just to name a few, can be represented in the framework of graphical models. This framework provides techniques for inference (sum/max-product algorithm) and learning. The flexibility in representing the structure of the considered phenomenon makes graphical models applicable in many research areas.

There are two basic approaches for learning graphical models in the scientific community: generative and discriminative learning. Unfortunately, generative learning does not always provide good results.

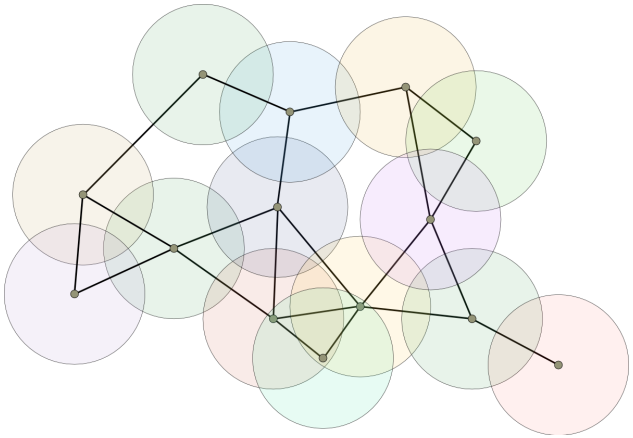
Discriminative learning is known to be more accurate for classification. In contrast to discriminative models (e.g. neural networks, support vector machines), the benefit of discriminatively learned generative graphical models (e.g. Bayesian networks) still maintains, especially, to work with missing variables by marginalizing the unknown ones. In particular, we have developed methods for generative and discriminative (e.g. max-margin) structure and parameter learning for Bayesian network classifiers. Furthermore, graphical models have been applied to various speech and image processing applications.

Wireless Sensor Networks

Nonlinear Signal Processing, Intelligent Systems, Wireless Communications

Wireless sensor networks (WSNs) have gained tremendous attention during the last years. They consist of small sensing devices capable to communicate with each other within short distances, but in a collaborative manner they can process data on a larger scale. WSNs are usually deployed randomly in a region under scrutiny and have tight energy and bandwith constraints such that the amount of data that can be transmitted and local computations that can be carried out is limited. In most applications, where a large number of nodes is deployed, either placed by hand or perhaps dropped by an airplane, nobody will go to replace the empty batteries which should highlight the need for energy efficient strategies.

Selected Research Topics, cont´d



Designed to make inferences about the environment which they are sensing, a major goal is to distribute the computational effort of the used inference algorithms among the nodes to save energy by *reducing the communication load for the individual sensors*. This is opposed to a centralized approach, where the measurements have to be transmitted to a fusion center (powerful base station) that then carries out the computations. Since many real world spatial-temporal phenomena (e.g. air pressure or temperature fields) tend to be very complex, transmission of the sensor information to a fusion center is impractical in terms of the whole network's lifetime which is due to the limited transmitting range, such that many nodes need to relay information from distant parts of the network to the fusion center. After mentioning not only the interesting properties but also the constraints that WSNs have to cope with, it should be clear why *distributed signal processing* and in particular *distributed learning* in WSNs has emerged to an internationally growing research direction.

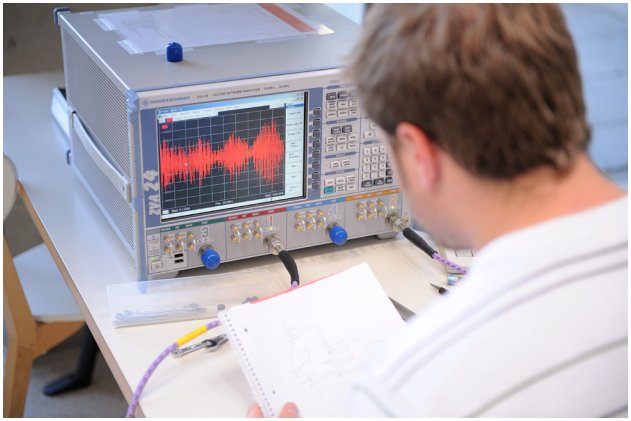
Ultra-Wideband Systems

Wireless Communications

The wealth of advantages derived from a large signaling bandwidth has motivated the considerable interest shown in the past years towards Ultra Wideband (UWB) communication systems. The possibility of extremely high data rates as well as high-accuracy ranging, together with the promise of low-power and low-complexity devices are some of the many features making UWB so attractive. However, UWB system design poses a number of new technical challenges, and traditional design guidelines are insufficient, or even misleading.

Whereas low-complexity UWB transmitters are very feasible, especially when considering the principle of impulse radio (IR) signalling, there is a number of processing tasks that, as a consequence of the large signal bandwidth, makes the implementation of conventional optimum receivers extremely complex, if feasible at all.

Noncoherent receiver concepts are among the candidate technologies to overcome this challenge, where analog circuits in the receiver frontend are employed to reduce the bandwith of

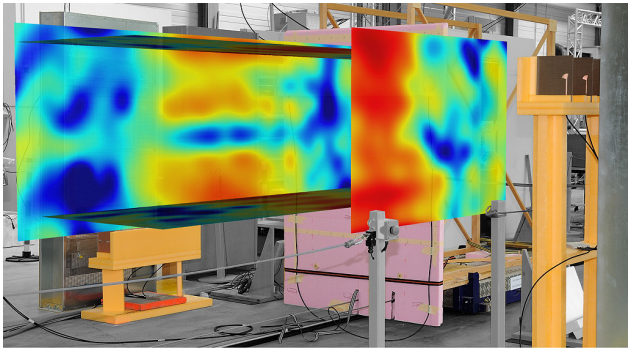


the input signal down to for instance symbol rate. Our group has broad experience in the design and analysis of noncoherent UWB systems. We also proposed novel receiver architectures, for example a multichannel autocorrelation receiver that is a noncoherent receiver frontend allowing for frequency discrimination and a memristor-based receiver that stores a received training signal and performs correlation with the data symbols in analog hardware.

RFID Systems

Wireless Communications

The automatic and simultaneous identification, localization, and tracking of targets using electromagnetic radiation started mainly as a military application in radar systems. In the early 1970s, commercial tracking of large and expensive goods emerged, followed by smaller items by the end of the 20th century. Since then, RF identification (RFID) became almost ubiquitous in commercial applications, e.g., tracking and identification of goods or electronic article surveillance.



Especially passive UHF RFID has come a long way since the first standardization in the early 2000s. Since then, it has become a widespread technology, with applications from supply chain management to laundry services. Even though it is a technically mature system, several problems remain elusive.

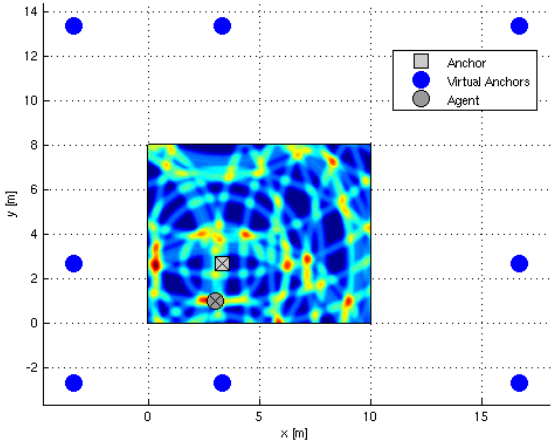
Selected Research Topics, cont´d

This list of ongoing research interests includes tag sensitivity (minimum operational power), self-jamming (carrier suppression), tag-based sensing, and positioning. With its main field of competence in signal processing and channel modeling, the SPSCs Lab contributions in these fields of research include channel and system modeling, positioning algorithms, as well as a large simulation framework available under GNU GPL.

Indoor Localization

Wireless Communications

In contrast to satellite-based outdoor positioning systems that have been around for several decades, indoor applications have not seen generic, robust solutions yet. The reason lies in fundamental technical and physical challenges. At a first glance, radio frequency (RF) signals seem to be a very promising measurement technology to provide the geometry-related raw data for the positioning system. They can penetrate materials, propagate over large distances, and transceivers can be implemented at low cost, small size, and with low power consumption. However, multipath propagation makes it extremely challenging to acquire precise distance or angle measurements in indoor environments. It is imperative to use (ultra)-wide bandwith (UWB) signals to be able to separate the direct signal from multipath components. And even if UWB signals are used, one faces the risk that the



line-of-sight signal is obstructed, which can lead to great offsets in the range or angle fixes.

Our research - next to fundamental work on ranging - has been focused on two approaches to cope with the non-line-of-sight challenge. Cooperative localization (in ad-hoc sensor networks) employs communication among sensor nodes to maximize the information available for solving the localization problem. The second approach proposes to actively exploit reflected multipath components. Assuming that the underlying geometry is known, each reflection yields additional information related to the mobile‘s location. A firm understanding of the (UWB) wireless channel is the basis for much of our research.

Channel Modeling

Wireless Communications

The physical basis for wireless communications is the radio channel whose properties are determined by the effects of multipath propagation. A basic description of the channel is easily found. The received signal is a sum of delayed and attenuated copies of the transmitted signal, due to reflections at any kind of objects in the propagation environment. But the technical implication of these meachanisms is tremendous. A simple narrowband signal, for example, undegoes signal fading due to the interfering multipath components and measures must be taken to avoid data loss. In fact, the whole field of wireless communications evolves from the properties of the multipath channel and techniques to ensure robust communication.

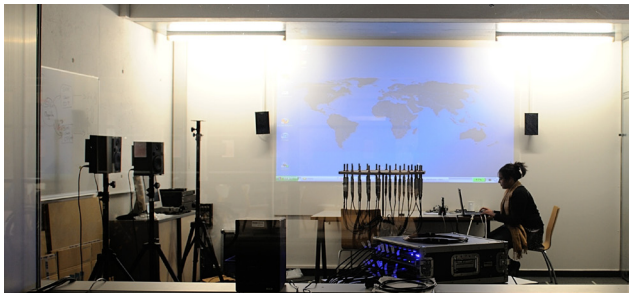
Our research in this topic concerns ultra-wideband (UWB) channels. Taking into consideration the correlation processing performed in the frontends of typical wireless receivers, we characterize the channel impact in a statistical sense. We obtain rather simple descriptions that are useful, e.g., for characterizing the fading in UWB systems, or inter-symbol or multiple-access interferences. The simplicity is due to the collapsed dimensionality of the received signal at the correlator output. The opposite holds for channel models for advanced localization systems. Here the propagation mechanisms have direct impact on the system performance, hence potentially very complex models are needed to characterize the impact of the radio channel.

Selected Research Topics, cont´d

Acoustic Source Localization and Separation

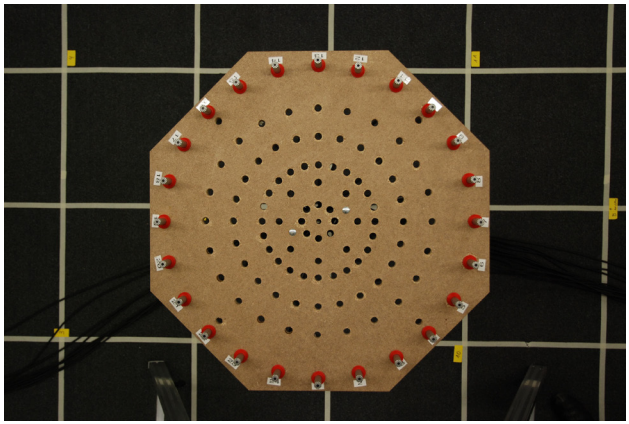
Speech Communication

Distant automatic speech recognition for use in human-machine-interaction as well as automatic event detection and localization used in e-Health surveillance and assistance applications require an automatic localization and separation of the acoustic source.



At our lab, research in Acoustic Source Localization and Separation covers localization of a single and of multiple concurrent acoustic sources using single-channel or multi-channel audio inputs. Given these audio inputs, we apply a combination of nonlinear signal processing and of machine learning concepts to achieve single-channel or multi-channel-based source separation using techniques like blind source separation, adaptive beamforming or fundamental frequency based source separation.

For recording of real-life audio databases, we have recently setup a special recording room equipped with a flexible setup of microphone arrays that allows us to record different meeting situations, assisted living simulations and other distant speech recognition tasks.



Language Technologies

Speech Communication

Research in Language Technologies at our lab is mainly motivated by challenges in automatic speech recognition back-end processing such as language modelling, modelling variation in pronunciation, or text alignment. Our text analysis methods comprise customizable phonetic and semantic similarity measures which have been evaluated on large industrial and scientific text

Selected Research Topics, cont´d

collections with respect to large vocabulary continuous speech recognition (dictation).

Currently, we focus our research on modelling dialect transformations at both, the sentence-level using grammatical transformations and the word-level with pronunciation transformations in close cooperation with our speech synthesis efforts.

Speech Analysis

Speech Communication

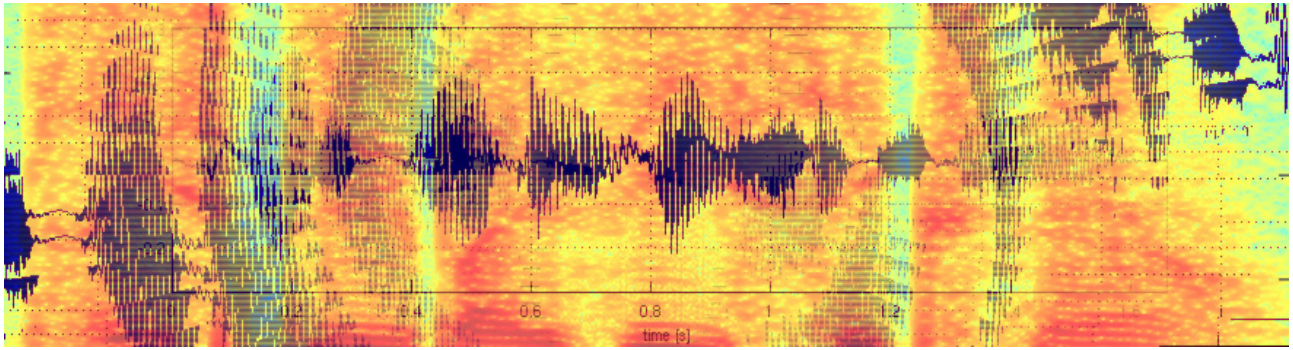
Our group is concerned with the development of algorithms for a wide range of important speech analysis tasks, both for single channel and multichannel speech. These tasks include voice activity detection, speech enhancement, pitch and multi-pitch tracking, phone segmentation and classification as well as speaker segmentation and identification.

We distinguish between two fundamentally different types of target applications. First, special emphasis is given to difficult environmental conditions, where the target speech signal is subject to cross-talk and embedded in various types of background noise. Second, we develop high-precision algorithms for semi-automatic analysis and processing of speech recorded in well-controlled studio conditions.

Speech Enhancement and Transmission

Speech Communication

Speech is only useful when it is transmitted from a speaker to a listener. Very often this is done in a telecommunication setting. If we want to transmit speech often there are restrictions that



include limited audio and/or network bandwidth. Therefore, one issue is to use the available resources - while maximizing the speech quality - by finding efficient speech coding and error concealment strategies. In a real-world-environment the speech signal cannot be picked up with perfect quality, e.g. when the speaker is driving a car. This results in efforts to enhance the speech quality for the listener. Tasks include noise suppression, where based on the statistics of the background noise, we try to remove those unwanted signal components from the noisy speech signal. Further, in a hands-free communication scenario, echo cancellation is used to subtract the signal from the loudspeaker that is picked up again by the microphone, which would otherwise be heard by the far-end speaker as echo of his voice. For low audio-bandwidth signals, artificial bandwidth extension can improve the audio signal quality considerably. Any enhancement effort can also deteriorate the desired speech sound, so minimizing this effect is an important task. Finally, the enhancement of speech as produced by humans suffering from voice pathologies is an important application area.

Speech and Speaker Recognition

Speech Communication

At our lab, automatic speech recognition research is focussed around front-end processing for robust speech recognition (noise reduction, voice activity detection, blind source separation, and speech quality assessment). Our algorithms have been tested in various ASR contexts, from command&control applications on embedded devices in industrial environments (SNOW) and air traffic control (ATCOSIM), to large vocabulary dictation systems (COAST-ROBUST). Furthermore, we provide state-of-the-art academic recognition setups for German and English research databases such as SpeechDat-II, TIMIT, or the Wall Street Journal Database (WSJ0).

With regard to our activities in the field of source separation and localization, our main interest is currently on distant speech recognition with single- and multi-channel recording conditions. Similarly, we provide expertise on single-channel narrow-band speaker recognition/verification.

Speech Synthesis

Speech Communication

Research in Speech Synthesis at our lab focuses on various advanced aspects of polyglot speech synthesis like mixed-lingual language technologies, polyglot prosodic modelling and polyglot speech signal processing techniques.

We focus our current research on extending the polyglot speech synthesis approach that was first developed to model multilingual and mixed-lingual environments, to be able to process multiregional pronunciation varities of German.

Research Programs

Telecommunications Research Vienna FTW

Period: 1998-2012

Funding Program: Competence Centers for Excellent Technologies COMET FFG, BMWFJ and BMVIT, ZIT

FTW is a K1 Competence Center for Excellent Technologies supported by the Austrian Government and the City of Vienna within the competence center program COMET, following a previous funding period as a Kplus competence centre. FTW was established in December 1998 and has grown into a nationally leading and internationally recognized center with over 70 people active in research and development of technologies for future communication systems. FTW closely cooperates with 6 partners from academia and 17 partners from industry. FTW enables people and companies in Europe to achieve their innovation potential inherent in new technologies for communication.

Since its beginning, SPSC Lab has closely collaborated with FTW and in 2008 Graz University of Technology became a strategic partner holding shares of the FTW operations company.

In 2010, a branch office of FTW has been opened in the premises of the SPSC Lab that further strengthens the ties between the two institutions and allows new cooperations with university institutes and with regional industrial partners from the three major application fields, i.e., telecommunications, transport, and energy.

The 7 strategic research topics of FTW are

- Channel Characterization
- Cross-Layer Transceiver Design
- Cooperative Communication
- Network Monitoring
- Quality in Communication Ecosystems
- Information Exploitation
- Context-Aware Interfaces and Systems

which are organized into 4 research areas:

- Signal & Information Processing
- Communication Networks
- Networked Services
- User-Centered Interaction & Communication Economics

www.ftw.at

Research Programs, cont´d

Christian Doppler Laboratory for Nonlinear Signal Processing

Period: 2002-2010

Funding Program: Christian Doppler Research Association CDG

The Christian Doppler Laboratory for Nonlinear Signal Processing addresses fundamental research questions arising from signal processing applications which are challenging due to their nonlinear aspects. We deliver theoretical analyses, develop and optimize new algorithms and, through their implementation, build awareness for their complexity, robustness, accuracy, and power consumption trade-offs. The Laboratory plays a leading role in the solution of signal processing problems where conventional methods fail. By entering into industrial partnerships, it thrives from and supports the bidirectional exchange of know-how and people between nonlinear science and the sweeping digital signal processing revolution. The Christian Doppler Laboratory is hosted by the SPSC Lab at TU Graz and receives support from the Christian Doppler Research Association and its industrial cooperation partners Infineon Technologies Villach and Austrian Research Centres ARC Vienna. In 2007, it was among the first labs to open an international branch at Leibniz University Hannover, headed by Ilona Rolfes who brings her specific competence in radio-frequency engineering to the industrial collaborations.

The research modules of the Laboratory are:

- Identification and equalization of nonlinearities in digital subscriber lines (xDSL)
- Digital correction of analog signal processing errors in fast time-interleaved analog-to-digital converters
- Digital predistortion of RF power amplifiers for UMTS Base-Stations
- Ultra Wideband Communications UWB
- Digital synthesizers for gigahertz-range fast frequency-hopping systems (all-digital phase locked loops)
- Reconfigurable radio frontends for wireless multistandard terminals with integrated antennas (implemented at the international branch in Hannover)

www.spsc.tugraz.at/cdlnsp

Competence Network for Advanced Speech Technologies COAST

Period: 2006-2010

Funding Program: K-net industrial cooperative research networks FFG and BMWFJ, ZIT Vienna and SFG

The competence network COAST is concerned with research and development in the field of speech recognition and speech interpretation with large lexicons for professional applications. The main research problems are:

- Development, improvement, and refinement of algorithms applied for speech recognition from the fields of statistics, acoustics, and signal processing, and their application specific parameterization.
- Application of new techniques of semantic interpretation using artificial intelligence to improve speech recognition results and their usability.
- Application-specific improvement and optimization of speech recognition, i.e., analysis of the question as to how speech recognition can optimally support concrete applications. The main focus here is on professional transcription of documents, messages, and meetings, as well as media mining for broadcast data.
- Testing of new speech recognition applications.

The establishment of COAST is a significant contribution to the strengthening of Austria‘s position in research and industrial applications of speech technology. Bringing together different disciplines – speech recognition, signal processing, and semantic interpretation – allows to address limitations of traditional statistical speech recognition; limitations which are currently hindering a broad, comprehensive application of speech recognition in audio/media mining, information input, and professional document creation. COAST is organized as an association (“Verein”) whose members are the industrial and scientific partners, i.e., Philips Speech Recognition Systems Vienna, Sail Labs Technologies Vienna, SPSC Lab, the Austrian Research Institute for Artificial Intelligence OFAI, NOA Audio Solutions Vienna, FH Technikum Vienna, Zydacron Graz, PCS Villach, and ebit Linz. The SPSC Lab has taken the scientific leadership in the COAST association. In 2009, Philips Speech Recognition Systems was acquired by the globally acting Nuance Communications USA, but still the research program will be completed as originally planned.

www.coast.at

Research Programs, cont´d

COMET K-Project Advanced Audio Processing AAP

Period: 2008-2012

Funding Program: Competence Centers for Excellent Technologies COMET FFG, BMWFJ and BMVIT, SFG

Advanced Audio Processing AAP is a K-Project in the COMET program of the Austrian government, co-sponsored by the provincial government and industrial partners. Advanced Audio Processing intends to develop its excellent core competencies in well defined areas:

- Acoustic multiple-input multiple-output (MIMO) systems
- Signal improvement and perceptual optimization.

These competencies are implemented by partners into industrial projects and products for chosen market segments. The combination of the development of sophisticated algorithms for audio signal processing and the ability to develop real-time solutions is in demand in numerous innovative application areas, which are covered by company partners, like professional audio and communication technologies, automotive applications, and applications in the entertainment industry. The expected results can be implemented in systems for in-car-communications, dictation and teleconferencing, as well as professional headphones and loudspeakers, and casino gaming machines.

Central aims are the consolidation and expansion of cooperation between scientific and industrial partners as well as the long-term und sustained establishment of an internationally recognized „audio signal processing center of excellence“ primarily located in Graz. The consortium consists of the following partners: Joanneum Research DIGITAL Institute, SPSC Lab, IEM at Graz University of Music and Performing Arts, AKG Acoustics, Atronic Austria, Philips Speech Processing, and austriamicrosystems AG.

www.comet-aap.at

National Research Network Signal and Information Processing in Science and Engineering SISE

Period: 2008-2013

Funding Program: National Research Networks of the Austrian Science Fund FWF

Distributed signals and data will be of great importance to our future daily life. The application of ubiquitous networked sensors, processing units, and distributed data sets will enhance the understanding of our world and its sustainable use. In this context, massive amounts of data have to be turned into concise and useful information, which demands groundbreaking new science at the intersection of mathematics, signal and information processing, communications theory, and scientific computing.

The network aims at developing new theories, algorithms, and implementations that enable the extraction, compression, transmission, and storage of information in large-scale distributed data sets. The focus is on distributed architectures which can be designed to be fault tolerant and scalable. The concepts and methods that will result from this basic research will be applicable to sensor and communication networks, distributed systems, cooperative wireless communications, machine learning, embedded system design, medicine, and molecular biology. The following key technologies are investigated:

- Signal and Information Representation
- Statistical Inference
- Nonlinear Dynamics and Machine Learning
- Information Networks
- Wireless Communications
- Distributed Computing and Information Processing
- Design Methodology

The network spans a consortium of groups from Vienna University of Technology, Vienna Telecommunications Research FTW, University of Vienna, and Graz University of Technology.

www.ftw.at/projects/nfn-sise


H { ∫ x(τ) · δ(t-τ) dτ }
H { δ(t-τ) } dτ
τ̂ = t - τ
x(t-τ̂) dτ̂
τ = time

Education

Our education activities are based on our research and come in various flavors. First of all, we teach courses for a broad range of university curricula which include the Bachelor and Master programs Electrical Engineering, Electrical Engineering and Audio Engineering (in cooperation with Graz University of Music and Performing Arts - KUG), Electrical Engineering and Business, Biomedical Engineering, Telematics, Software Development and Business Management, Computer Science, Technical Mathematics, Mechanical Engineering, and Production Science and Management.

Secondly, we are very active in the PhD program of the Doctoral School Information and Communications Engineering, advising up to 20 PhD students in our lab. This often comes with the hosting and supervision of international research scholarship holders at preDoc and postDoc levels.

Thirdly, we offer mentoring support at many levels, starting from internships for high-school and undergraduate students through curricular mentoring for Telematics Master's students and the Researcher-in-Residence Program where we provide a platform for medium to long-term collaboration for resident researchers from partner organizations.

Finally, Life Long Learning activities have included in-house courses for industrial partners, intensive programs and summer schools, as well as tutorials offered at major international conferences.

- Courses at Bachelor's level
- Courses at Master's level
- Master's Projects and Theses
- Mentoring
- Hosting and Supervision for Research Scholars
- PhD program/Doctoral School Information and Communications Engineering
- PhD theses
- Researcher-in-Residence Program
- Internships
- Life Long Learning

Courses

Bachelor Program

- **Signal Transformations**
  In cooperation with the Institute of Automation and Control
  Nicolaos Dourdoumas, Klaus Witrisal, Christoph Schörghuber, Bernhard Geiger
- **Signal Processing**
  Gernot Kubin, Bernhard Geiger, Paul Meissner, Klaus Witrisal
- **Fundamentals of Digital Communications**
  Klaus Witrisal
- **Computational Intelligence**
  In cooperation with the Institute of Theoretical Computer Science
  Gernot Kubin, Stefan Häusler, Paul Meissner
- **Introduction to Knowledge Processing**
  In cooperation with the Institutef of Theoretical Computer Science
  Stefan Häusler, Gernot Kubin, Paul Meissner, Michael Wohlmayr
- **Electrical & Information Engineering Seminar**
  Christian Feldbauer, Bernhard Geiger, Gernot Kubin, Paul Meissner, Franz Pernkopf
- **Introduction to Scientific Work**
  Christian Feldbauer, Bernhard Geiger, Paul Meissner, Franz Pernkopf
- **Bachelor Spezialization Laboratory**
  Christian Feldbauer
- **Speech Processing Seminar**
  Christian Feldbauer, Franz Pernkopf
- **Audio Signal Processing Seminar**
  Christian Feldbauer, Gerhard Graber, Werner Magnes, Franz Pernkopf, Christian Steger

Master Program

- **Adaptive Systems**
  Gernot Kubin, Christian Feldbauer
- **Mobile Radio Systems**
  Klaus Witrisal
- **Mixed Signal Processing Systems Design**
  Christian Vogel
- **Nonlinear Signal Processing**
  Gernot Kubin, Paul Meissner
- **Source Coding Theory**
  Christian Feldbauer
- **Speech Communication 1**
  Gernot Kubin
- **Speech Communication 2**
  Franz Pernkopf
- **Digital Audio Engineering 2**
  Martin Hagmüller

- **Linguistic Foundations of Speech and Language Technology**
  Rudolf Muhr (University of Graz)

- **Fundamentals of Telecommunication Economics**
  Peter Reichl (FTW)

- **Formal Methods for Systems and Synthetic Biology**
  Heinz Köppl (ETH Zurich)

- **Digital Signal Processing Laboratory**
  Christian Feldbauer, Bernhard Geiger, Paul Meissner, Franz Pernkopf

- **Speech Communication Laboratory**
  Franz Pernkopf, Stefan Petrik

- **Advanced Signal Processing Seminar 1 + 2**
  Christian Feldbauer, Franz Pernkopf, Klaus Witrisal, Gernot Kubin

- **Seminar/Project Signal Processing**
  Christian Feldbauer, Bernhard Geiger, Gernot Kubin, Paul Meissner, Franz Pernkopf, Klaus Witrisal

- **Seminar/Project Speech Communication**
  Christian Feldbauer, Bernhard Geiger, Gernot Kubin, Paul Meissner, Franz Pernkopf, Klaus Witrisal

- **Master Thesis Seminar**
  Wolfgang Bösch, Christian Feldbauer, Gerhard Graber, Otto Koudelka, Erich Leitgeb, Franz Pernkopf, Walter Randeu, Klaus Witrisal

PhD Program

- **PhD Student Seminar Information and Communications Engineering**
  Entire Faculty of Doctoral School Information and Communications Engineering

- **Signal Processing and Speech Communication 1 + 2**
  Gernot Kubin, Klaus Witrisal, Franz Pernkopf

Note:
As a rule, all courses in the Bachelor programs are taught in German whereas Master and PhD level courses are taught in English.

PhD Theses

- **Michael Baum**
  Improving automatic speech recognition for pluricentric languages exemplified on varieties of German, 2003
  Supervisors: Gernot Kubin; Zdravko Kačič, University of Maribor, Slovenia

- **Heinz Köppl**
  Nonlinear System Identification for Mixed Signal Processing, 2004
  Supervisors: Gernot Kubin; Martin Hasler, EPFL Lausanne, Switzerland

- **David Schwingshackl**
  Digital Enhancement and Multirate Processing Methods for Nonlinear Mixed Signal Systems, 2005
  Supervisors: Gernot Kubin; Wolfgang Mathis, University of Hannover, Germany

- **Christian Vogel**
  Modeling Identification and Compensation of Channel Mismatch Errors in Time-Interleaved Analog-to-Digital Converters, 2005
  Supervisors: Gernot Kubin; Håkan Johansson, Linköping University, Sweden

- **Erhard Rank**
  Oscillator-plus-Noise Modeling of Speech Signals, TU Vienna, 2005
  Supervisors: Wolfgang Mecklenbräuker, TU Vienna, Austria; Gernot Kubin

- **Christian Feldbauer**
  Sparse Pulsed Auditory Representations for Speech and Audio Coding, 2005
  Supervisors: Gernot Kubin; W. Bastiaan Kleijn, Royal Institute of Technology KTH Stockholm, Sweden

- **Peter Singerl**
  Complex Baseband Modeling and Digital Predistortion for Wideband RF Power Amplifiers, 2006
  Supervisors: Gernot Kubin; Hermann Eul, University of Hannover, Germany

- **Ed Schofield**
  Fitting Maximum-Entropy Models on Large Sample Spaces, Imperial College London, UK, 2007
  Supervisors: Stefan M. Rüger, Imperial College London, UK; Gernot Kubin

- **Dmitriy Shutin**
  Multipath Tracking and Prediction for Multiple-Input Multiple-Output Wireless Channels, 2006
  Supervisors: Gernot Kubin; Bernard Fleury, Aalborg University, Denmark

- **Florian Hammer**
  Quality Aspects of Packet-Based Interactive Speech Communication, 2006
  Supervisors: Gernot Kubin; Sebastian Möller, TU Berlin, Germany

- **Michael Pucher**
  Semantic Similarity in Automatic Speech Recognition for Meetings, 2007
  Supervisors: Gernot Kubin; Harald Trost, OFAI Vienna, Austria

- **Muhammad Sarwar Ehsan**
  Variable Delay Speech Communication over Packet-Switched Networks, 2007
  Supervisors: Gernot Kubin; Wai-Yip Geoffrey Chan, Queen's University, Kingston Ontario, Canada

- **Tuan Van Pham**
  Wavelet Analysis for Robust Speech Processing and Applications, 2007
  Supervisors: Gernot Kubin; Zdravko Kačič, University of Maribor, Slovenia

- **Jimmy Wono Tampubolon Baringbing**
  Low Complexity Ultra-Wideband (UWB) Communication Systems in Presence of Multiple-Access Interference, 2008
  Supervisors: Klaus Witrisal; Gernot Kubin; Gerard J.M. Janssen, TU Delft, The Netherlands

- **Yohannes Alemseged Demessie**
  Modeling and Mitigation of Narrowband Interference for Non-Coherent UWB Systems, 2008
  Supervisors: Klaus Witrisal; Gernot Kubin; Christoph Mecklenbräuker, TU Vienna, Austria

- **Christoph Krall**
  Signal Processing for Ultra Wideband Transceivers, 2008
  Supervisors: Klaus Witrisal; Gernot Kubin; Ilona Rolfes, University of Hannover, Germany

- **Jacobus Romme**
  UWB Channel Fading Statistics and Transmitted Reference Communication, 2008
  Supervisors: Klaus Witrisal; Gernot Kubin; Sergio Benedetto, Politecnico di Torino, Italy

- **Li Gan**
  Adaptive Digital Predistortion of Nonlinear Systems, 2009
  Supervisors: Emad Abd-Elrady; Gernot Kubin; Giovanni Sicuranza, University of Trieste, Italy

- **Stefan Mendel**
  Signal Processing in Phase-Domain All-Digital Phase Locked-Loops, 2009
  Supervisors: Christian Vogel; Gernot Kubin; Boris Murmann, Stanford University, USA

- **Martin Hagmüller**
  Speech Enhancement for Disordered and Substitution Voices, 2009
  Supervisors: Gernot Kubin; Jean Schoentgen, Université libre de Bruxelles, Belgium

- **Konrad Hofbauer**
  Speech Watermarking and Air Traffic Control, 2009
  Supervisors: Gernot Kubin; W. Bastiaan Kleijn, Royal Institute of Technology KTH Stockholm, Sweden

- **Stefan Petrik**
  Phonetic Similarity Matching of Non-Literal Transcripts in Automatic Speech Recognition, 2010
  Supervisors: Gernot Kubin; Harald Trost, OFAI Vienna, Austria

- **Michael Stark**
  Source-Filter Model Based Single Channel Speech Separation, 2010
  Supervisors: Franz Pernkopf; Gernot Kubin; Ioannis Stylianou, University of Crete, Heraklion, Greece

Support Staff

Karin Karner
Controlling

Andreas Läßer
IT Administration

Markus Köberl
IT Administration

Ilona Pölzl
Secreterial Help

Furthermore, we acknowledge continuous support by staff of the Institute for Communication Networks and Satellite Communications: *Werner Heid, Johanna Hofer, Andreas Merdonig, Gabriele Mörth, Marika Scheer, and Siegfried Stöllner.*

Senior Scientific Staff

Gernot Kubin
Professor
Nonlinear Signal Processing

Klaus Witrisal
Associate Professor
Wireless Communication

Franz Pernkopf
Associate Professor
Intelligent Systems

Christian Feldbauer
Senior Scientist
Information Theory for Signal Processing

Harald Romsdorfer
Senior Researcher
Speech Communication

Martin Hagmüller
Senior Researcher
Speech Signal Processing

Stefan Petrik
Senior Researcher
Spoken Language Technology

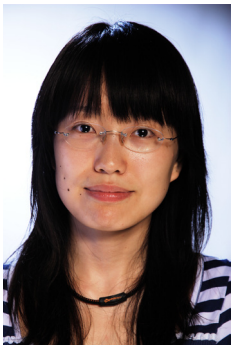
Christian Vogel
Senior Researcher in Residence (FTW Vienna/Graz)
Mixed Signal Processing Systems

Manfred Mücke
Senior Researcher in Residence (University of Vienna)
Reconfigurable Computing

PhD Students

Daniel Arnitz
Tag Localization in Passive UHF RFID

Thomas Buchgraber
Distributed Learning in Wireless Sensor Networks



Shuli Chi
Pulsed Transmitter for Base Stations

Bernhard Geiger
Information Theory for Signal Processing

Thomas Gigl
Low-Complexity Localization via Impulse-Radio UWB Signals

Tania Habib
Localization and Tracking of Speech Sources Using Circular Microphone Arrays

Katharina Hausmair
Pulsed Transmitters for Mobile Terminals

Christina Leitner
Nonlinear Methods for Speech Enhancement Using Multisensory Microphones

Paul Meissner
UWB Indoor Localization Exploiting Signal Reflections

Andreas Pedroß
NOFDM for UWB Communications

Robert Peharz
Sparse Learning of Graphical Models

Shahzad Saleem
Adaptive Calibration of Frequency Response Mismatches in Time Interleaved ADCs

Michael Soudan
Digitally Enhanced Data Converters

Sebastian Tschiatschek
Learning and Inference in Graphical Models

Thang Viet Huynh
Efficient Implementation of Speech Processing Algorithms on Reconfigurable Hardware

Michael Wohlmayr
Model Based Multiple Pitch Tracking of Speech

Bernd Lesser
Researcher in Residence
(University of Vienna)
MixSVM: Mixed-Precision Support Vector Machine Classification on FPGAs

Non-Resident PhD Students

Philipp Aichinger, Medical University Vienna, Vienna
Sebastian Egger, Telecommunications Research Vienna FTW, Vienna
Harald Enzinger, Graz
David Fischer, Austrian Academy of Sciences (ÖAW) Space Research Institute, Graz
Gerd Kotzian, European Organization for Nuclear Research (CERN), Geneva
Lukas Pfeifenberger, Commend International GmbH, Salzburg
Josef Prainsack, Infineon Technologies Austria AG, Graz
Robin Priewald, Swansea University, Wales UK
Bakti Putra, Telecommunications Research Vienna FTW, Vienna

Partners

We want to thank all our partners from academia, industry, research institutions, and the funding agencies for their continued support and look forward to fruitful cooperations in the future.

Academic Institutions

AALBORG UNIVERSITET
UNIVERSITY OF CAMBRIDGE
KATHOLIEKE UNIVERSITEIT LEUVEN
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE
ETH Eidgenössische Technische Hochschule Zürich Swiss Federal Institute of Technology Zurich
FH JOANNEUM
FACHHOCHSCHULE TECHNIKUM WIEN
Imperial College London
JKU JOHANNES KEPLER UNIVERSITY LINZ
KTH VETENSKAP OCH KONST
kunst uni graz
Leibniz Universität Hannover
LINKÖPINGS UNIVERSITET
LUND UNIVERSITY
Medical University of Graz
MEDICAL UNIVERSITY OF VIENNA INTERNATIONAL
Oakland UNIVERSITY
PRINCETON UNIVERSITY
Queen Mary University of London
RUHR UNIVERSITÄT BOCHUM
RUB
UNIVERSITÉ DE SHERBROOKE
THE UNIVERSITY OF CALIFORNIA 1868
Friedrich-Alexander-Universität Erlangen-Nürnberg
UNI GRAZ
UNIVERZA V MARIBORU
UNIVERSITY OF WASHINGTON 1861
universität wien
TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI VICTORIA UNIVERSITY OF WELLINGTON
TU Delft Delft University of Technology
WIEN TECHNISCHE UNIVERSITÄT WIEN Vienna University of Technology

Partners

Industrial Companies

Computer & Messtechnik Gmbh

XERXES electronics GmbH

Funding Agencies

Public Research Organizations

Third International EURASIP Workshop on RFID Technology

BEST PAPER AWARD

DANIEL ARNITZ

WITH THE PAPER ENTITLED

"TAG-BASED SENSING AND POSITIONING IN PASSIVE UHF RFID: TAG REFLECTION"

SEPTEMBER 7, 2010

ON BEHALF OF THE ORGANIZING AND TECHNICAL COMMITTEES

PROF. MARKUS RUPP | DR. EKATERINA MITROKOTSA | DR. JAVIER VALLS-ALONSO

ACCM AUSTRIAN CENTER FOR COMPUTATIONAL MECHATRONICS

n·t·h·f·s

IEEE AUSTRIA SECTION JOINT COMMITT CHAPTER

iμe

The

Best Student Contribution Award

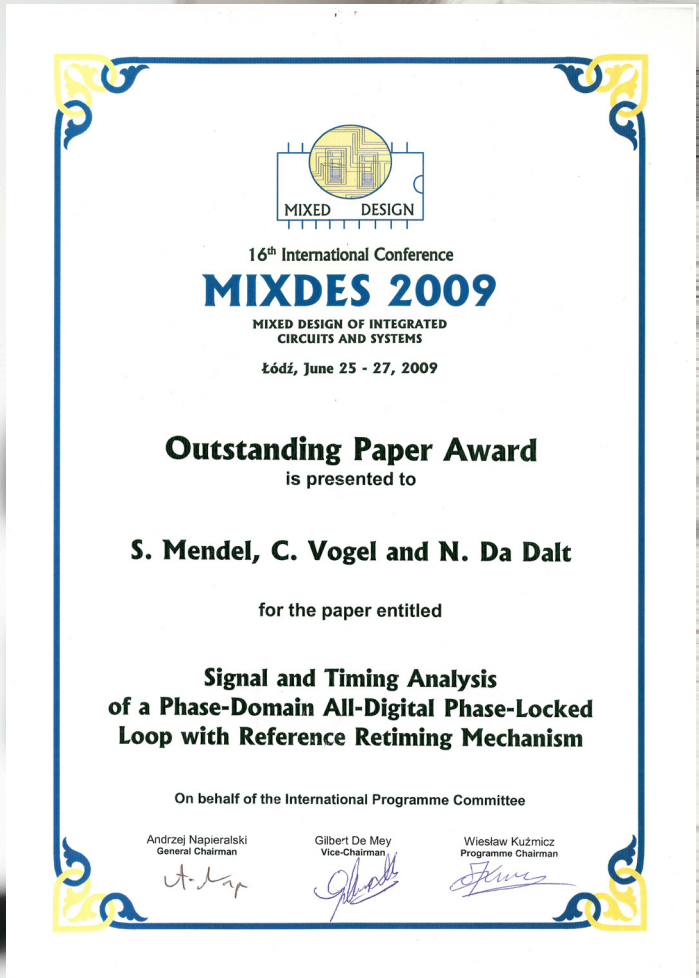
of the 5th IEEE UWB Forum on Sensing and Communication is awarded to

Paul Meissner

for his presentation entitled

Virtual Anchor Based Localization Using Ultra-Wideband Radio Signals (VALOUR)

a.Univ.-Prof. DI Dr. Christian Diskus | May 26, 2010, Austria | Univ.-Prof. DI Dr. Andreas Springer



MIXED DESIGN

16th International Conference

MIXDES 2009

MIXED DESIGN OF INTEGRATED CIRCUITS AND SYSTEMS

Łódź, June 25 - 27, 2009

Outstanding Paper Award

is presented to

S. Mendel, C. Vogel and N. Da Dalt

for the paper entitled

Signal and Timing Analysis of a Phase-Domain All-Digital Phase-Locked Loop with Reference Retiming Mechanism

On behalf of the International Programme Committee

Andrzej Napieralski, General Chairman | Gilbert De Mey, Vice-Chairman | Wiesław Kuźmicz, Programme Chairman

Hall of Fame

Erwin Schrödinger Fellowships

- **Franz Pernkopf**
  Description and Classification of 3-D-Surfaces
  Oakland University (USA), Department of Computer Science and Engineering and University of Washington, Seattle (USA)
  01.09.2003 - 31.08.2004 and 01.09.2005 - 31.01.2006

- **Heinz Köppl**
  Efficient I/O Representation of Nonlinear Systems
  University of California at Berkeley (USA), Department of Electrical Engineering and Computer Science
  01.09.2005 - 30.09.2006

- **Christian Feldbauer**
  Perceptual-Domain Coding of Speech and Audio
  Royal Institute of Technology KTH Stockholm, Department of Signals, Sensors and Systems, and University of Cambridge (UK), Department of Physiology 01.01.2006 - 31.12.2007

- **Christian Vogel**
  Digital Signal Processing for Data Converters
  ETH - Swiss Federal Institute of Technology Zurich (Switzerland), Signal and Information Processing Laboratory
  01.01.2008 - 30.06.2009

- **Dmitriy Shutin**
  Spatio-Temporal Nonlinear Learning with Echo State Wireless Sensor Networks
  Princeton University (USA), Department of Electrical Engineering
  01.10.2009 - 30.09.2011

Best Paper Awards

- **Peter Reichl*, Florian Hammer**
  Hot Discussion or Frosty Dialogue? Towards a Temperature Metric for Conversational Interactivity.
  8th International Conference on Spoken Language Processing (ICSLP/INTERSPEECH 2004), Jeju Island, Korea, 2004
  **Telecommunications Research Vienna (FTW)*

- **Peter Singerl**
  A New Approach for Efficient Modeling of Nonlinear Passband Systems for Communication Applications,
  IEEE RISP International Workshop on Nonlinear Circuits and Signal Processing (NCSP), Honolulu, USA, 2005

- **Christoph Krall, Klaus Witrisal, Heinz Köppl, Geert Leus*, and Marco Pausini***
  Nonlinear Equalization for a Frame-Differential IR-UWB Receiver
  IEEE International Conference on Ultra-Wideband (ICU), Zurich, Switzerland, 2005
  **Delft University of Technology*

- **Dmitriy Shutin, Gernot Kubin**
  Power Prediction of Multipath Components in Wireless MIMO Channels
  IEEE International Conference on Information, Communications and Signal Processing (ICICS), Bangkok, Thailand, 2005

Hall of Fame

- **Peter Singerl, Heinz Köppl**
  A Low-Rate Identification Method for Digital Predistortion Based on Volterra Kernel Interpolation
  IEEE Midwest Symposium on Circuits and Systems (MWSCAS), Cincinnati, USA, 2005

- **Bernhard Geiger, Thomas Gigl, Klaus Witrisal**
  Ranging in the IEEE 802.15.4a Standard Using Energy Detectors
  IEEE Region 8 Student Activities Committee, 2008

- **Christoph Krall, Christian Vogel**
  Digital Compensation of In-Band Image Signals Caused by M-Periodic Nonuniform Zero-Order Hold Signals
  IEEE UK/RI Best Paper Award, The 6th Symposium on Communication Systems, Networks and Digital Signal Processing, (CSNDSP), Graz, Austria, 2008

- **Bernhard Geiger, Thomas Gigl, Klaus Witrisal**
  Ranging in the IEEE 802.15.4a Using Energy Detectors
  4th IEEE UWB Forum on Sensing and Communications, Vienna, Austria, 2009

- **Stefan Tertinek, Christian Vogel**
  Reconstruction of Nonuniformly Sampled Bandlimited Signals Using a Differentiator-Multiplier Cascade,
  IEEE Transactions on Circuits and Systems I: Regular Papers, Vol.55, Issue 8, pp. 2273-2286, September 2008

- **Stefan Mendel, Christian Vogel, Nicola Da Dalt***
  Signal and Timing Analysis of a Phase-Domain All-Digital Phase-Locked Loop with Reference Retiming Mechanism,
  16th International Conference Mixed Design of Integrated Circuits and Systems (MIXDES), Lodz, Poland, 2009
  **Infineon Technologies Austria AG*

- **Thomas Gigl, Klaus Witrisal, Josef Preishuber-Pflügl*, Florian Trösch***
  Maximal Operating Distance Estimation Using IEEE 802.15.4a Ultra Wideband
  International Conference of Impact on Ubiquitous IT Co-Design to Industry (KOALA), Perth, Australia, 2010
  **CISC Semiconductor Design +Consulting GmbH, Austria*

- **Robert Peharz, Franz Pernkopf, Michael Stark, Yannis Stylianou***
  A Factorial Sparse Coder Model for Single Channel Source Separation
  Interspeech Technical Programm Committee, Makuhari, Japan 2010. Invited to submit expanded version to SPECOM (Speech Communication).
  **University of Crete*

- **Paul Meissner, Klaus Witrisal**
  Virtual Anchor Based Localization Using Ultra-Wideband Radio Signals (VALOUR)
  5th IEEE UWB Forum on Sensing and Communications, Linz, Austria, 2010

- **Daniel Arnitz, Ulrich Mühlmann*, Klaus Witrisal**
  Tag-Based Sensing and Positioning in Passive UHF RFID: Tag Reflection
  European Association for Signal Processing (EURASIP) Workshop on RFID Technology, La Manga del Mar Menor, Spain, 2010
  **NXP Semiconductors Austria GmbH Styria, Austria*

Honors

- **Martin Hagmüller, Gernot Kubin**
  ATC Maastricht Innovation Award,
  14th Annual Air Traffic Control (ACT) Maastricht Conference, The Netherlands, 2004

- **Christoph Steiner**
  GIT Award from the Austrian Association for Information and Communication Technology (GIT) for his graduation thesis, 2005 (Supervisor: Klaus Witrisal)

- **Heinz Köppl**
  Fred Margulies Award from the International Federation of Automatic Control (IFAC) for the best PhD thesis of the year, 2006

- **Heinz Köppl**
  GIT Award from the Austrian Association for Information and Communication Technology (GIT) for the best PhD thesis of the year, 2006

- **Christoph Krall**
  Award of Excellence, Federal Ministry of Science and Research (BMWF), Austria, 2008

- **Signal Processing and Speech Communication Laboratory**
  Inventors Award TU Graz 2010
  Top 3 institutes regarding invention disclosures and patents 07.2007 - 06.2009

- **Harald Romsdorfer**
  2nd Place "Best of Tech 2010" Austrian Businessplan Competition
  Centre for Advanced Technologies, Leoben, Styria for Businessplan titled "Synthetic Voices", 2010

- **Martin Hagmüller**
  Best Idea Award TU Graz, 2010
  Teaching Evaluation

- **Andreas Läßer**
  Best Practice Award TU Graz, 2010
  Inventory Data Acquisition

- **Franz Pernkopf**
  Förderungspreis des Landes Steiermark/ Young Investigator Award of the provincial government of Styria, Austria, 2010

Contact

Graz University of Technology
Signal Processing and Speech Communication Laboratory

Inffeldgasse 16c
A-8010 Graz
Austria
Tel: +43 316 873 7441
Fax: +43 316 873 4432
Email: spsc@tugraz.at
www.spsc.tugraz.at

Impressum

Medieninhaber & Herausgeber

Technische Universität Graz
Institut für Signalverarbeitung und Sprachkommunikation
Inffeldgasse 16c
A-8010 Graz
Austria

AutorInnen

Gernot Kubin, Andreas Läßer, Karin Karner, and the SPSC Team

Layout, Satz und Grafik

Andreas Läßer, Karin Karner

Druck

Medienfabrik Graz
Dreihackengasse 20
A-8020 Graz, Austria

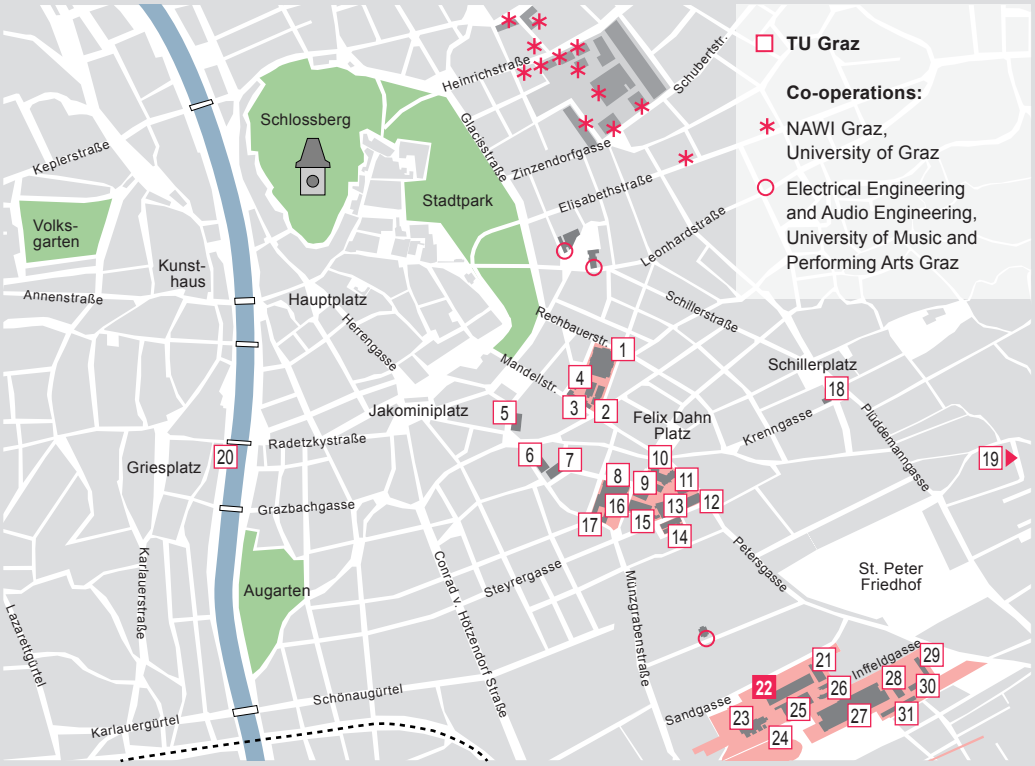
Bilder

Daniel Arnitz, Andreas Läßer, and the SPSC Team
iStockphoto

...

SCIENCE ▪ PASSION ▪ TECHNOLOGY

TU Graz
Graz University of Technology



1 Rechbauerstraße 12
2 Technikerstraße 4
3 Mandellstraße 9-15
4 Lessingstraße 25, 27
5 Schlögelgasse 9
6 Münzgrabenstraße 11
7 Kronesgasse 5
8 Kopernikusgasse 24
9 Stremayrgasse 16
10 Petersgasse 12
11 Petersgasse 14
12 Petersgasse 16
13 Steyrergasse 30
14 Steyrergasse 17-19, 21
15 Stremayrgasse 10
16 Stremayrgasse 9
17 Münzgrabenstraße 35a, 37
18 Krenngasse 37
19 Lustbühelstraße 46
20 Brückenkopfgasse 1
21 Inffeldgasse 12
22 Inffeldgasse 16
23 Inffeldgasse 24, 26
24 Inffeldgasse 31
25 Inffeldgasse 18
26 Inffeldgasse 10
27 Inffeldgasse 25
28 Inffeldgasse 21
29 Inffeldgasse 11
30 Inffeldgasse 15
31 Inffeldgasse 21a, 21b

22 Graz University of Technology
SPSC – Institute of Signal Processing and Speech Communication
Inffeldgasse 16c, 8010 Graz, Austria
spsc@tugraz.at
▶ www.spsc.tugraz.at

18|11|2011
200 YEARS TU GRAZ