Faculty of Engineering, department ELEC:
Fundamental Electricity and Instrumentation

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Editor: Ann Pintelon
Faculty of Engineering – Dept. ELEC
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1. Introduction to the department ELEC

1.1 INTRODUCTION TO THE LONG TERM STRATEGY OF THE DEPARTMENT ELEC

‘ELEC’ stands for "Fundamental Electricity and Instrumentation” (in Dutch: “Algemene Elektriciteit en Instrumentatie”) and the name corresponds to the educational and research tasks and objectives of the department. The main research activity of the department is the development of new measurement techniques using advanced signal processing methods, embedded in an identification framework. When we make a measurement, we have to make a number of decisions:

- Firstly, a model structure for the considered part of reality is proposed (e.g. for a resistance measurement, Ohm’s law can be selected, describing the relation between the voltage across the resistor and the current through it).
- Next, a number of measurements is made (e.g. a number of current and voltage measurements).
- Finally, the quantities of interest are extracted from these measurements by matching the model to the data. Often an intuitive approach is used.

However, in the presence of measurement errors this can lead to a very poor and even dangerous behaviour: the user wouldn't remark that something is going seriously wrong. This is the major motivation for the development of the identification theory. It offers a systematic approach to ‘optimally’ fit mathematical models to experimental data, eliminating stochastic distortions as much as possible. As such it can be considered as the modern formulation of the measurement problem, and for that reason the identification approach is the “fil rouge” in most of the activities of the department.

Each measurement (or identification session) consists of a series of basic steps:

- Collect information about the system;
- Select a (non) parametric model structure to represent the system;
- Select the model parameters to fit the model as well as possible to the measurements (this requires a “goodness of fit” criterion);
- Validate the selected model.

Most of the research activities of the department are related to one of these problems, but this does not narrow our focus. At this moment we deal with a very wide scope of application

- Systems covering the frequency range from a few mHz up to 50 GHz,
• Linear systems, non-linear systems and time-varying systems
• Lumped systems and distributed systems.

We applied the measurement and modelling techniques to the identification of electrical machines (frequency range 0.01 Hz till 1 kHz, linear models, 2 inputs and 2 outputs), mechanical vibrating systems (frequency range below 5 kHz, linear or non-linear, up to 2 inputs/2 outputs), electronic circuits and filters (frequency range up to 5 MHz, linear and non-linear models, single input/single output or multiple input/multiple output), underwater acoustics (frequency range up to a few MHz, 1 input and 2 outputs), distributed systems (telecommunication lines, up to a few hundred MHz), microwave applications (frequency range up to 50 GHz, non-linear, 6-port measurements). We have also applied those methods to the analysis of biological samples used as records of global climate change. For some of these applications the efforts are focused on the development of new measurement instruments (measurement of telecommunication lines, non-linear microwave analyser), for others we focused completely on the development of new data processing and modelling techniques, or even worked on the underlying fundamental theoretical aspects.

To cover this wide application range, we make use of an extensive measurement park. Most of it nowadays consists of VXI-or PXI-based data-acquisition systems, although we have also some classical instruments like network and spectrum analysers. All these instruments are computer controlled in a Matlab environment.

1.2 RESEARCH TEAMS OF ELEC

There are no formal research groups in the department ELEC. There are 3 research teams that cooperate intensively with each other.
• Team A: Data driven modeling (Rik Pintelon)
• Team B: Applied signal processing for engineering, telecommunications and Microwave systems (Gerd Vandersteen, Yves Rolain and Leo Van Biesen)
• Team C: Structured low-rank approximation (Ivan Markovsky)

1.3 RESEARCH TOPICS OF THE DEPARTMENT ELEC

• Automatic Measurement Systems
• Telecommunication:
  o application of information theory in data telecommunication by wire problems (xDSL)
  o environmental G.I.S. development
  o 4G communication
  o navigation techniques
  o positioning Techniques using the cellular network (focus on GSM)
Introduction to the department ELEC

- proactive Location-based Services (LBS) using multiple positioning technologies
  - System identification and parameter estimation
    - linear, nonlinear systems systems
    - time invariant, time-varying and parameter-varying systems
    - Experiment design
    - Time and frequency domain system identification
    - Development and distribution of a system identification toolbox
  - Applied Signal Processing for Engineering:
    - instrumentation setup contributions
    - instrumentation calibration contributions
  - Structured Low-rank approximation
    - system identification in the behavioral setting
    - data-driven signal processing and control
    - tensor approximation methods
  - Modelling high frequency nonlinear systems
  - Medical Measurements and Signal Analysis
  - Linear and nonlinear modelling techniques for medical and high-frequency applications
The mixed girls/boys team was founded in 2010, sponsored by the ELEC department. It quickly became clear that some practice might come in handy, and the weekly ELEC futsal training sessions were born. Everyone was and is welcome to join, and we only play the sport to have some fun.

Over the years, ELEC was complemented with some fine new Phd. students, who were not completely tired and fat yet. The combination with the weekly training sessions allowed our team to rise from the very bottom of the competition to at least an above-average rating. Practice makes perfect!

Also, it turns out ice cream is a pretty good motivator...
1.5 STAFF OF ELEC (2018)

1.5.1 General Director of the dept. ELEC

Leo Van Biesen was born in Elsene, Belgium, on August 31, 1955. He received the degree of Electro-Mechanical Engineer from the Vrije Universiteit Brussel (VUB), Brussels in 1978, and the Doctoral degree (PhD) from the same university in 1983. Currently he is a full senior professor. He teaches courses on fundamental electricity, electrical measurement techniques, signal theory, computer-controlled measurement systems, telecommunication, underwater acoustics and Geographical Information Systems for sustainable development of environments. His current interests are signal theory, modern spectral estimators, time domain reflectometry, wireless local loops, xDSL technologies, underwater acoustics, and expert systems for intelligent instrumentation. He has been chairman of IMEKO TC-7 from 1994-2000 and President Elect of IMEKO for the period 2000-2003 and the liaison Officer between the IEEE and IMEKO. Prof. Dr. Ir. Leo Van Biesen has been president of IMEKO until September 2006. He is also member of the board of FITCE Belgium and of USRSI Belgium.

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1.5.2 Professor members of the dept. ELEC

Mariya Ishteva is an applied mathematician working in an engineering environment. Since January 2017 she is a research professor (10%) and a postdoc (90%) at Dept. ELEC of Vrije Universiteit Brussel. She has been affiliated with the department since January 2013, including one year as an FWO Pegasus Marie Curie fellow. She works on structured matrix and tensor low-rank approximations and their application for representing, modeling and extracting information from complex data. Her main research interests are in the fields of (multi)linear algebra, system identification, machine learning, data mining, and optimization.

Mariya received a BSc degree in Computer Science in 2002 from Sofia University, Bulgaria and MSc degree in Mathematics in 2005 from University of Karlsruhe (TH), Germany. She defended her PhD thesis in December 2009 at Katholieke Universiteit Leuven, Belgium. Afterwards she was a postdoc at Universite catholique de Louvain, Belgium in 2010 and at Georgia Institute of Technology, USA in 2011 and 2012.

Mariya was an evaluation panel member for the agency for innovation by science and technology (IWT), in 2013 and in 2014. She co-organized three minisymposia, one special session, one mini-course, and one seminar series. She reviewed papers for fourteen journals and six conferences. Mariya received the best poster award at the Belgian-French-German Conference on Optimization, Belgium in 2009.

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Ivan Markovsky obtained Ph.D. in Electrical Engineering from the Katholieke Universiteit Leuven in 2005. Since then, he is teaching and doing research in control and system theory at the School of Electronics and Computer Science (ECS) of the University of Southampton and the Department of Fundamental Electricity and Instrumentation (ELEC) of the Vrije Universiteit Brussel, where he is currently an associate professor. His research interests are structured low-rank approximation, system identification, and data-driven control, topics on which he has published 70 peer-reviewed papers, 7 book chapters, and 2 monographs. He is an associate editor of the International Journal of Control and the SIAM Journal of Matrix Analysis and Applications. In 2011, Ivan Markovsky was awarded an ERC starting grant on the topic of structured low-rank approximation.

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Rik Pintelon was born in Gent, Belgium, on December 4, 1959. He received a master's degree in electrical engineering in 1982, a doctorate (PhD) in engineering in 1988, and the qualification to teach at university level (geaggregeerde voor het hoger onderwijis) in 1994, all from the Vrije Universiteit Brussel (VUB), Brussels, Belgium. In 2014 he received the degree of Doctor of Science (DSc) from the University of Warwick (UK) for publications with the collective title "Frequency Domain System Identification: A Mature Modeling Tool". From 1982 to 1984 and 1986 to 2000, Dr. Pintelon was a researcher with the Belgian National Fund for Scientific Research (FWO-Vlaanderen) at the Electrical Engineering (ELEC) Department of the VUB. From 1984 to 1986 he did his military service overseas in Tunisia at the Institut National Agronomique de Tunis. From 1991 to 2000 he was a part-time lecturer at the department ELEC of the VUB, and since 2000 he is a full-time professor in electrical engineering at the same department. Since 2009 he is visiting professor at the department of Computer Sciences of the Katholieke Universiteit Leuven, and since 2013 he is a honorary professor in the School of Engineering of the University of Warwick. His main research interests include system identification, signal processing, and measurement techniques. Dr. Pintelon is the coauthor of 4 books on System Identification and the coauthor of more than 200 articles in refereed international journals. He has been a Fellow of IEEE since 1998. Dr. Pintelon was the recipient of the 2012 IEEE Joseph F. Keithley Award in Instrumentation and Measurement (IEEE Technical Field Award).

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Yves Rolain (1961, Belgium) received the Electrical Engineering (Burgerlijk Ingenieur) degree in July 1984, the degree of computer sciences in 1986, and the PhD degree in applied sciences in 1993, all from the Vrije Universiteit Brussel (VUB), Brussels, Belgium. He was a research professor at the VUB in the department ELEC, and since 2014 he is a full-time professor in electrical engineering at the same department. He became a fellow of the IEEE in 2006 and received the IEEE I&M Society award in 2005. His main interests are microwave measurements and modelling, applied digital signal processing and parameter estimation / system identification.

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Leo Van Biesen was born in Ebene, Belgium, on August 31, 1955. He received the degree of Electro-Mechanical Engineer from the Vrije Universiteit Brussel (VUB), Brussels in 1978, and the Doctoral degree (PhD) from the same university in 1983. Currently he is a full senior professor. He teaches courses on fundamental electricity, electrical measurement techniques, signal theory, computer-controlled measurement systems, telecommunication, underwater acoustics and Geographical Information Systems for sustainable development of environments. His current interests are signal theory, modern spectral estimators, time domain reflectometry, wireless local loops, xDSL technologies, underwater acoustics, and expert systems for intelligent instrumentation. He has been chairman of IMEKO TC-7 from 1994-2000 and President Elect of IMEKO for the period 2000-2003 and the liaison Officer between the IEEE and IMEKO. Prof. Dr. Ir. Leo Van Biesen has been president of IMEKO until September 2006. He is also member of the board of FITCE Belgium and of USRSI Belgium.

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Gerd Vandersteen was born in Belgium in 1968 and received the degree in electrical engineering from the Vrije Universiteit Brussel (VUB), Brussels, Belgium, in 1991. In 1997, he received his PhD in electrical engineering, entitled "Identification of Linear and Nonlinear Systems in an Errors-in-Variables Least Squares and Total Least Squares Framework", from the Vrije Universiteit Brussel/ ELEC. During his postdoc, he worked at the micro-electronics research centre IMEC as Principal Scientist in the Wireless Group with the focus on modeling, measurement and simulation of electronic circuits in state-of-the-art silicon technologies. This research was in the context of a collaboration with the Vrije Universiteit Brussels. From 2008 on, he is working as Prof. at the Vrije Universiteit Brussels/ELEC within the context of measuring, modeling and analysis of complex linear and nonlinear system. Within this context, the set of systems under consideration is extended from micro-electronic circuits towards to all kinds of electro-mechanical systems. From 2011 on, he is director of the Doctoral School of Natural Sciences and (Bioscience) Engineering (NSE)

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1.5.3 Postdoc. members of the dept. ELEC

**Philippe Dreesen** was born on January 31, 1982 in Bree, Belgium. In 2007 he received the MSc degree in Electrical Engineering (Burgerlijk Werktuigkundig-Elektrotechnisch Ingenieur, richting Elektrotechniek, option Dataverwerking en Automatisatie) from KU Leuven, Belgium. In September 2013 he received a PhD degree from KU Leuven with a doctoral thesis on the topic of solving systems of polynomial equations with the use of linear algebra methods. Currently he is a postdoctoral researcher with the Vrije Universiteit Brussel, Belgium. His research interests are in the fields of (multi-)linear algebra, polynomial algebra, system identification and machine learning.

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**John Lataire** was born in Brussels, Belgium, in 1983. He received the Electrical Engineer degree in electronics and information processing and the Ph.D. degree in engineering sciences (Doctor in de Ingenieurswetenschappen) from the Vrije Universiteit Brussel, Brussels, in 2006 and 2011, respectively. From October 2007 to October 2011, he was on a Ph.D. fellowship from the Research Foundation—Flanders (FWO). Since August 2006, he has been working as a Researcher with the Department ELEC-VUB, Brussels. His main interests include the frequency domain formulation of the identification of dynamic systems, with a specific focus on the identification of time-varying systems, and the use of kernel-based regularization in a bayesian framework.

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**Hannes Maes** was born in Hasselt (Belgium) on May 17, 1990. He received the degree of Electrical Engineer in Electronics and Information Processing in July 2012 and his PhD in Engineering Sciences from the Vrije Universiteit Brussel, Brussels, in 2012 and 2017 respectively. His PhD thesis is entitled 'Low Frequency Forced Oscillation Technique in Clinical practice' and can be downloaded from http://vubirelec.be/knowledge/publications/list-of-phds. His main interests include respiratory mechanics, forced oscillation technique, instrumentation and system identification. Since 30/09/2018 he has left the department ELEC.

**Koen Tiels** was born in Halle (Belgium) in 1987. He received the degree of master in Electromechanical Engineering in July 2010 and the degree of Doctor in Engineering (Ph.D.) in March 2015, both from the Vrije Universiteit Brussel (VUB), Brussels, Belgium. He is currently a post-doctoral researcher at the Electrical Engineering (ELEC) Department of the VUB. His main interests are in the field of nonlinear system identification. Since 1/2/2018 he has left the department ELEC for a post-doc position at the University of Uppsala, Sweden.

**Matthijs Van Berkel** was born in 's-Hertogenbosch, the Netherlands, on June 11, 1983. He received his TSO degree in Industriële wetenschappen from TI Sint-Jansberg, Maaseik, 2003. In the same year he began his studies in Mechanical Engineering (ME) at the Eindhoven University of Technology in the Netherlands, where he received his M.Sc. degree (with great appreciation) in Control Systems Technology (ME) in 2010. In 2011, he started his PhD on the "Estimation of heat transport coefficients in fusion plasmas", which he defended at the Eindhoven University of Technology in 2015. During his PhD he was a member of the Tokamak Physics group at the Dutch Institute For Fundamental Energy Research (FOM DIFFER). Moreover, in 2013, he received a short-term postdoctoral fellowship from the Japan Society for the Promotion of Science (JSPS) to conduct research at the National Institute for Fusion Science, Toki, Japan, where he stayed one year. Since August 2015, Matthijs is a postdoc at the ELEC department, continuing his work in the fields of system identification, heat transport, and nuclear fusion plasmas.

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**Maral Zyari** was born in Tehran, Iran in 1986. She graduated as an Electrical Engineer in Electronics and Information Processing in July 2013 at Vrije Universiteit Brussel (VUB). In September 2013 she joined the department ELEC as a PhD student. Her main interests are RF circuit design and modeling and her current research is about identifying reflections in high frequency structures. Since 23 October 2018 she obtained the Ph.D. degree in engineering sciences.

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1.5.4 PhD scholarships ELEC

**Piet Bronders** was born in Suva (Fiji) in 1991. He graduated as an Electrical Engineer in Electronics and Information Technology in 2014 at the Vrije Universiteit Brussel (VUB). In October 2014 he joined the department ELEC as a PhD student. His main interest is NL RF circuit design and measurement. His current research topic is the design and modelling of RF power amplifiers.

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**Cedric Busschots** was born in Leuven (Belgium) in 1990. In 2012, he obtained the degree of 'industriel ingenieur in de elektronica-ICT' at Lessius Mechelen - Campus De Nayer. He continued at the VUB and ULB, and graduated in 2015 with a degree in electromechanical engineering. In August 2015 he joined the ELEC department as a PhD student. His research focuses on system identification using microcontrollers.

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**Gaia Cavallo** was born in Rome (Italy) in 1991. In July 2017, she obtained the MSc degrees of 'Biomedical Engineering' and 'Systems and Control' at the Delft University of Technology, the Netherlands. In December 2017 she joined the ELEC department as a PhD student. Her research focuses on time-varying system identification of human biomechanical properties.

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**Jan Decuyper** was born in Jette (Belgium) in 1991. He graduated as an Electromechanical Industrial Engineer (Renewable Energy) at the Erasmus Hogeschool Brussel in 2013. In October 2013, he joined the department of INDI as a phd student. As of February 2014, he became a member of the ELEC department. His main research interests are in the field of modelling systems that are subjected to vortex-induced vibrations. Since 1/2/2018 he has left the department ELEC.

**Alireza Fakhrizadeh Esfahani** was born in Esfahan (Iran). He graduated in Electrical Power Engineering. He continued his studies in Technomathematics (Applied Math.) at Master level in Finland and graduated in 2012. He joined the ELEC Department in Sept. 2013. His research area is System Identification under supervision of Prof. Johan Schoukens. He is interested in System Identification, Nonlinear Dynamics and Control. At the moment he is studying the structure detection of nonlinear systems. Since 1/2/2018 he has left the department ELEC.

**Jeroen De Geeter** was born in Jette (Belgium) in 1989. He graduated as a Software Engineer in 2015 at the Vrije Universiteit Brussel (VUB). After graduating, he worked as a software developer before joining the ELEC department in November 2017 as a PhD student. His research focuses on system identification using tensors.

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Leonidas Niyonkuru was born in Maramvya, Burundi on the 17th March 1968. He received the degree of Master of Science in Telecommunication in June 1995 from the Bonch-Bruevich Saint Petersburg State University of Telecommunication in Russia. He worked as teacher assistant at University of Burundi from July 1999 to December 2008. He worked with ECONET wireless Burundi from December 2008 to March 2012. He returned to university of Burundi in March 2012. He joined the department ELEC as a PhD student in February 2015. His research focuses on carrier aggregation intermodulation distortions in 4G and 5G mobile network.

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Dries Peumans was born in Ukkel (Belgium) in 1992. In 2015, he graduated as an Engineer in Electronics and Information Technology at the Vrije Universiteit Brussel (VUB). Afterwards he joined the department ELEC as a PhD researcher. His research focuses on nonlinear modelling and the design of analog circuits.

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Gustavo Quintana Carapia was born on August 31st, 1978, in Atlacomulco, Mexico. He obtained his diploma in Electronics Engineering from the Autonomous University of the State of Mexico in 2002. From 2002 to 2006, he worked as head of the outside plant office of the telephone company in Toluca city. In 2015, he received his degree in Electronics Engineering from the Toluca Institute of Technology. Since March 2016, he is a PhD researcher at the Department of Fundamental Electricity (ELEC) of the VUB. His research interests include model-free methods for dynamic measurements and control.

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Mark Vaes was born on September 19th, 1985 in Marche-en-Famenne (Belgium). He graduated as an Industrial Engineer in Electromechanics at the Erasmushogeschool Brussel. In February 2013 he joined the ELEC department as a PhD student. His main interests are in the field of system identification of linear and nonlinear systems.

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Evi Van Nechel was born in Asse (Belgium) on May 15, 1991. She graduated as an Electrical Engineer in Electronics and Information Technology at the Vrije Universiteit Brussel in July 2014. In October 2014, she joined the department of ELEC as a PhD student. Her main research interests are in the field of RF design and modeling of microwave structures.

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Sandra Vásquez was born in Bogota, Colombia, in 1985. She obtained her diploma in Electronics Engineering from the National University of Colombia in 2008. From 2009 to 2012, she worked as project engineer in the HVAC sector (Heating, Ventilation and Air Conditioning) and the oil industry. In 2015, she received her M.Sc. degree in Electronics and Information Technology Engineering from the Vrije Universiteit Brussel (VUB) and the Université Libre de Bruxelles (ULB). Since August 2015, she is a PhD researcher at the Department of Fundamental Electricity (ELEC) of the VUB and the Control Engineering Department (SAAS) of the ULB. Her research interests include the modeling of Linear Parameter Varying (LPV) systems and the fault diagnosis in wind turbines.

Phone: +32 (0)2 629 29 49  
e-mail: savasque@vub.be
Francisco Williams Riquer was born in 1992 in Veracruz, Mexico. He graduated as Mechatronic engineer from the Tecnológico de Monterrey Campus Puebla (Mexico) in 2014. In 2018 he obtained a Master of Sciences in Mechatronics by the Hamburg University of Technology and a Master of Arts in Technology Management by the Northern Institute of Technology Management. Since December 2018, he is a Ph.D. researcher at the Department of Fundamental Electricity and Instrumentation (ELEC) of the VUB. His research interests include system identification of linear and nonlinear systems, optimal and robust control, control of nonlinear systems, and time-delayed systems.

Phone: +32 (0)2 629 28 44  
e-mail: Francisco.Williams.Riquer@vub.ac.be

1.5.5 Technical and Administrative Staff

Johan Pattyn was born in 1974 (Belgium). After 2 years of engineering studies he joined the navy to become a radar technician. Since december 2009 he is with the department ELEC of the Vrije Universiteit Brussel (full time tenure). He is responsible for Rapid PCB Prototyping and also is involved in the maintenance and repair of the instruments and circuits for the students lab's.

Phone: +32 (0)2 629 29 52  
e-mail: Johan.Pattyn@vub.be

Ann Pintelon was born in October 1963 (Belgium). In 1985 she received the Ms degree in Physical Education (VUB). Since 1990 she has been with the department ELEC at the Vrije Universiteit Brussel (full time tenure). She is mainly responsible for the scientific reports of the department ELEC (annual report, web-pages ELEC, ...); the management of the infocentre (library, publication list, ...); the administrative organisation of conferences, workshops; hosting of visiting researchers; financial administration; preparing budgets; follow-up staff contracts....

Phone: +32 (0)2 629 27 67  
e-mail: Ann.Pintelon@vub.be

Sven Reyniers was born in 1973 (Belgium). He has several years of ICT - experience in multinationals, including several international missions (France, Germany). Since 2006, he is working at the Vrije Universiteit Brussel (full time tenure) at the department ELEC. As system and network administrator he is responsible for the health and availability of the department servers and network.

Phone: ++32 (0)2 629 29 52/29 45  
e-mail: Sven.Reyniers@vub.be
1.5.6 Professors Emeriti

Alain Barel was born in Roeselare, Belgium, on July 27, 1946. He received the degree in Electrical Engineering from the Université Libre de Bruxelles, Belgium, in 1969, the Postgraduate degree in telecommunications from Rijks Universiteit Gent (State University of Gent), Belgium, in 1974, and the doctor of applied science from the Vrije Universiteit Brussel in 1976. He worked as assistant and Lecturer at the Vrije Universiteit Brussel (VUB). From 2006 until September 2011 he has been 10% active at the department as Professor emeritus and teaches microwaves, and until September 2012 been active as a voluntary researcher at the dept. ELEC.

e-mail: abarel@vub.ac.be

Michel Gevers was born in Antwerp, Belgium, in 1945. He obtained an Electrical Engineering degree from the Université Catholique de Louvain, Belgium, in 1968, and a Ph.D. degree from Stanford University, California, in 1972. He holds a Honorary Degree from the Vrije Universiteit Brussel and the University of Linköping, Sweden, and a few other titles. He has been President of the European Union Control Association (EUCA) from 1997 to 1999, and Vice President of the IEEE Control Systems Society in 2000 and 2001. Between 1990 and 2010 he has been the coordinator of the Belgian Interuniversity Network DYSCO (Dynamical Systems, Control, and Optimization) funded by the Federal Ministry of Science. His research interests are in system identification and its interconnection with robust control design, optimal experiment design, data-based control design, optimal control and filtering, and realization theory. He has published about 250 papers and conference papers, and two books: "Adaptive Optimal Control - The Thinking Man's GPC", by R.R. Bitmead, M. Gevers and V. Wertz (Prentice Hall, 1990), and "Parametrizations in Control, Estimation and Filtering Problems: Accuracy Aspects", by M. Gevers and G. Li (Springer-Verlag, 1993). Until September 2012 he was 20% active at the department ELEC as Professor emeritus, and now still active as a voluntary researcher at the dept. ELEC.

Ronny Van Loon (1940-2012) obtained a degree in Physics at the ULB, and a PhD in Science at the VUB. He joined the VUB in 1970 as assistant, then Professor at the Faculty of Applied Science. In parallel with the teaching activities, he had research and logistic activities as a medical physicist at the university hospital AZ-VUB: from 1982 on in the Radiotherapy department focusing on EC granted projects in Hyperthermia, from 1989 on in the Radiology department involved in dosimetry and quality assurance. He directed the subgroup QUARAD ("Quality in Radiology"), a team involved in dosimetry, radiation protection and quality improvement in radiology. This group is acting in Belgium as reference centre for the Quality Assurance of the technical aspects of breast cancer screening. Prof. Van Loon was the Past-President of the Belgian Hospital Physicist Association, and member of the Board of the "Federal Agency of Nuclear Control" and the "Belgian Society of Radioprotection". He was delegate of the VUB in the VLIR-cooperation and Development Cell, and coordinates a cooperation project in Hanoi (Vietnam) and in VLIR International Training programme on Medical Physics. Until September 2005, he was still 10% active at the department ELEC as professor emeritus. He also contributed to the IAEA's (International Atomic Energy Agency) teaching programs on radiation protection in medical applications of ionizing radiation. He was scientific advisor at the "Belgian Museum of Radiology", Brussels, and he was active as a voluntary researcher at the dept. ELEC. In October 2008, he received the title of "Doctor Honoris Causa" from the Hanoi University of Technology.

On 20 December 2012, prof. dr. em. Ronald Van Loon suddenly passed away. We will remember him as a warm friendly and very wise colleague, who remained actively involved at the faculty of Engineering and the university. He always defended his opinion and his philosophical beliefs. He was loyal to the basic philosophy of the Vrije Universiteit Brussel: the principle of "free inquiry", based on a text of Henri Poincaré, and the principle that the institution must be managed according to the model of democracy.
1.5.7 List of phone numbers and e-mail addresses from active members

<table>
<thead>
<tr>
<th>NAME</th>
<th>PHONE</th>
<th>E-MAIL</th>
</tr>
</thead>
<tbody>
<tr>
<td>P. BRONDERS</td>
<td>+32(0)2 629 28 68</td>
<td><a href="mailto:Piet.Bronders@vub.be">Piet.Bronders@vub.be</a></td>
</tr>
<tr>
<td>C. BUSSCHOTS</td>
<td>+32(0)2 629 27 56</td>
<td><a href="mailto:Cedric.Busschots@vub.be">Cedric.Busschots@vub.be</a></td>
</tr>
<tr>
<td>G. CAVALLO</td>
<td>+32(0)2 629 28 44</td>
<td><a href="mailto:Gaia.Cavallo@vub.be">Gaia.Cavallo@vub.be</a></td>
</tr>
<tr>
<td>J. DE GEETER</td>
<td>+32(0)2 629 28 44</td>
<td><a href="mailto:Jeroen.De.Geeter@vub.be">Jeroen.De.Geeter@vub.be</a></td>
</tr>
<tr>
<td>PH. DREESEN</td>
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<td><a href="mailto:Philippe.Dreesen@vub.be">Philippe.Dreesen@vub.be</a></td>
</tr>
<tr>
<td>M. ISHTEVA</td>
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<td><a href="mailto:mariya.ishteva@vub.be">mariya.ishteva@vub.be</a></td>
</tr>
<tr>
<td>J. LATAIRE</td>
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<td><a href="mailto:John.lataire@vub.be">John.lataire@vub.be</a></td>
</tr>
<tr>
<td>I. MARKOVSKY</td>
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<td><a href="mailto:Ivan.Markovsky@vub.be">Ivan.Markovsky@vub.be</a></td>
</tr>
<tr>
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<td>+32(0)2 629 29 79</td>
<td><a href="mailto:Niyonkuru.Leonidas@vub.be">Niyonkuru.Leonidas@vub.be</a></td>
</tr>
<tr>
<td>J. PATTYN</td>
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<td><a href="mailto:Johan.Pattyn@vub.be">Johan.Pattyn@vub.be</a></td>
</tr>
<tr>
<td>A. PINTELON</td>
<td>+32(0)2 629 27 67</td>
<td><a href="mailto:Ann.Pintelon@vub.be">Ann.Pintelon@vub.be</a></td>
</tr>
<tr>
<td>R. PINTELON</td>
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<td><a href="mailto:Rik.Pintelon@vub.be">Rik.Pintelon@vub.be</a></td>
</tr>
<tr>
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</tr>
<tr>
<td>G. QUINTANA CARAPIA</td>
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</tr>
<tr>
<td>S. REYNIERS</td>
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<td><a href="mailto:Sven.Reyniers@vub.be">Sven.Reyniers@vub.be</a></td>
</tr>
<tr>
<td>Y. ROLAIN</td>
<td>+32(0)2 629 29 44</td>
<td><a href="mailto:Yves.Rolain@vub.be">Yves.Rolain@vub.be</a></td>
</tr>
<tr>
<td>M. VAES</td>
<td>+32(0)2 629 29 46</td>
<td><a href="mailto:Mark.Vaes@vub.be">Mark.Vaes@vub.be</a></td>
</tr>
<tr>
<td>E. VAN NECHEL</td>
<td>+32(0)2 629 29 49</td>
<td><a href="mailto:evi.van.nechel@vub.be">evi.van.nechel@vub.be</a></td>
</tr>
<tr>
<td>L. VAN Biesen</td>
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<td><a href="mailto:Lvbiesen@vub.be">Lvbiesen@vub.be</a></td>
</tr>
<tr>
<td>G. VANDERSTEEN</td>
<td>+32(0)2 629 29 44</td>
<td><a href="mailto:Gerd.Vandersteen@vub.be">Gerd.Vandersteen@vub.be</a></td>
</tr>
<tr>
<td>S. VASQUEZ</td>
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<td><a href="mailto:savasque@vub.be">savasque@vub.be</a></td>
</tr>
<tr>
<td>F. WILLIAMS Riquer</td>
<td>+32(0)2 629 28 44</td>
<td><a href="mailto:Francisco.Williams.Riquer@vub.ac.be">Francisco.Williams.Riquer@vub.ac.be</a></td>
</tr>
<tr>
<td>M. ZYARI</td>
<td>+32(0)2 629 29 49</td>
<td><a href="mailto:mzyari@vub.be">mzyari@vub.be</a></td>
</tr>
</tbody>
</table>

1.5.8 Industrial Partnership

- ir. Frank LOUAGE, MSc Zobeida Cisneros Barros; Address System N.V.
- Dr. ir. Luc PEIRLINCKX, TomTom, Belgium, Cap Gemini, Belgium
- ir. Serge TEMMERMAN, SEBA service NV (measuring instruments for telecom. cables)
- Dr. Frank UYTDENHOIJEN, Banana-Telecom
- Dr. ir. Marc VANDEN BOSSCHE, Dr. ir. Frans Verbeyst; NMDG Engineering bvba
- Dr. Lieven Philips, Dr. Adnan Al-Adnani, Dr. Lee Barford; Agilent Technologies

1.5.9 National and international contacts in 2018

1.5.9.1 Visiting professors/researchers

- **Leonard BATURUMINI**, Université du Burundi, Bujumbura, Burundi: visits in the frame of the VLIR cooperation:
- **Yvan BAUDOIN**, KMS Brussels, meeting in the frame of organization of ISCMR’2018, Mons, September 2018: 16/08/2018
- **Stephane CHRETIE**, National Physical Laboratory, London, UK: Research collaboration and seminar at ELEC ”Multi-Kernel Unmixing And Super-Resolution Using The Modified Matrix Pencil Method”: 19/10/2018
• **Antonio FAZZI**, Grand Sasso Science Institute (GSSI), Italy, Visit in the framework of a joint VUB-GSSI research project "Approximate common factor computation with applications in systems and control theory": 01/10/2018 - 30/11/2018

• **Francesco FERRANTI**, Institut Mines-Télécom (IMT) Atlantique, France: Member of Jury PhD Maral Zyari: 23/10/2018-24/10/2018

• **Gaspard NGENDAKUMANA**, Université du Burundi, Bujumbura, Burundi: visit in the frame of the VLIR cooperation: 17/04/2018 – 13/05/2018

• **Indira NOVILOS**, ESPOL, Ecuador (PhD alumnus ELEC): meeting about new VLIR projects with ESPOL: 22/02/2018

• **Paul OLAMBA KALONDA**, Faculté Polytechnique, Université de Kinshasa: meeting in the frame of a new VLIR project with Unikin, DR Congo: 26/10/2018

• **Konstantin USEVICH**, CNRS, France: Research collaboration in the framework of the FWO projects G028015N "Decoupling multivariate polynomials in nonlinear system identification": 17/04/2018-20/04/2018

• **Patrice YAMBA**, Faculté Polytechnique, Université de Kinshasa, DR Congo: meeting in the frame of VLIR cooperation Burundi and DR Congo: 15/02/2018 & 12/03/2018

• **Erliang ZHANG**, Zhengzhou University, China: 21/01/2018 – 03/02/2018, Measuring and modelling of dynamic systems

### 1.5.9.2 Scientific missions 2018

- **Piet BRONDERS**
  
<table>
<thead>
<tr>
<th>Date</th>
<th>Date</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>04/06/2018</td>
<td>09/06/2018</td>
<td>IEEE MTT-S International Microwave Symposium (IMS), Honolulu, Hawaii: presentation of paper “Multi-Delay Rational Modeling of Lumped-Distributed Systems”</td>
</tr>
<tr>
<td>08/06/2018</td>
<td>16/06/2018</td>
<td>2018 IEEE/MTT-S International Microwave Symposium - IMS, Philadelphia, PA, USA. Presentation of paper “Measurement &amp; Extraction of the Low-Frequency Dynamics of an Envelope Tracking Amplifier using Multisine Excitations”</td>
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</tbody>
</table>

- **Cedric BUSSCHOTS**
  
<table>
<thead>
<tr>
<th>Date</th>
<th>Date</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>05/10/2018</td>
<td>05/10/2018</td>
<td>Participating at World of Technology &amp; Science, Utrecht, The Netherlands</td>
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</table>

- **Gaia CAVALLO**
  
<table>
<thead>
<tr>
<th>Date</th>
<th>Date</th>
<th>Event</th>
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</thead>
<tbody>
<tr>
<td>09/07/2018</td>
<td>11/07/2018</td>
<td>18th IFAC Symposium on System Identification (SYSID 2018), Stockholm, Sweden. Presentation of poster “Nonparametric Identification of Time-Varying Human Joint Admittance”</td>
</tr>
</tbody>
</table>

- **Jeroen DE GEETER**
  
<table>
<thead>
<tr>
<th>Date</th>
<th>Date</th>
<th>Event</th>
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</thead>
</table>
Annual report ELEC 2018

02/07/2018 07/07/2018 14th international conference on latent variable analysis and signal separation, LVA/ICA 2018 Guildford, UK. Presentation of paper “Decoupling Multivariate Functions Using Second-Order Information and Tensors”

27/08/2018 31/08/2018 Participating in EURASIP summer school, Louvain, Belgium

Philippe DREESEN

09/04/2018 13/04/2018 Participation to 2018 Workshop on Nonlinear System Identification Benchmarks, University of Liège, Belgium
04/05/2018 08/05/2018 SIAM Conference on Applied Linear Algebra, Hong Kong. Presentation of paper “Decoupling Multivariate Polynomials: Comparing Different Tensorization Methods.”
09/04/2018 13/04/2018 Participating in NL Benchmarks Workshop, ULiege, Liege, Belgium
27/08/2018 31/08/2018 EURASIP summer school, Louvain, Belgium. Presentation of paper “Nonlinear singular value decomposition”

Mariya ISHTEVA

27/08/2018 31/08/2018 Participating in EURASIP summer school, Louvain, Belgium
26/11/2018 28/11/2018 Participation to IAP DYSCO Study Day, Belgium, Louvain

John LATAIRE

27/03/2018 29/03/2018 Participation to 37th Benelux Meeting on Systems and Control, Soesterberg, The Netherlands
09/07/2018 11/07/2018 Participation to 18th IFAC Symposium on System Identification (SYSID 2018), Stockholm, Sweden.
28/11/2018 28/11/2018 Participation to IAP DYSCO Study Day, Belgium, Louvain

Ivan MARKOVSKY

18/01/2018 18/01/2018 Université Catholique de Louvain, Louvain-la-Neuve: meeting of the steering committee of the Graduate School in Systems and Control
26/01/2018 26/01/2018 University of Antwerp, meeting with Annie Cuyt in the frame of the FWO project
12/02/2018 16/02/2018 University of Southampton, meeting with Prof. M. Niranjan, E. Rogers, S. Gunn & T. Blumensath about applications of system identification in rehabilitation engineering
08/05/2018 08/05/2018 Technische Universiteit Delft, The Netherlands. Member committee doctoral candidate B. Günes.
29/05/2018 29/05/2018 Participation annual editorial board meetings of the International Journal of Control, London, UK
31/05/2018 01/06/2018 International Conference on Approximation and Matrix functions, Université de France, Lille. Invited lecture “Structured low-rank approximation approach to sum-of-exponentials modeling”
19/06/2018 21/06/2018 Visit to Gran Sasso Science Institute, L’Aquila, Italy: meeting with Joint PhD student Antonio Fazzi on “Approximate common factor computation with applications in systems and control theory”.
02/07/2018 07/07/2018 14th international conference on latent variable analysis and signal separation, LVA/ICA 2018 Guildford, UK. Presentation of papers “Applications of polynomial common factor computation in signal processing” and “Using Hankel Structured Low-Rank Approximation for Sparse Signal Recovery”
12/07/2018 31/07/2018 Visit Technical University of Sofia, meeting with Prof. Tsonyo Slavov in the frame of joint PhD student
<table>
<thead>
<tr>
<th>Date</th>
<th>Event Description</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>23/09/2018</td>
<td>27th ERNSI Workshop on System Identification, Pembroke College, Cambridge, UK.</td>
<td>Presentation of poster: &quot;Dynamic measurement: application of system identification in metrology&quot;</td>
</tr>
<tr>
<td>30/10/2018</td>
<td>National Physics Laboratory, London, UK: Presentation &quot;Dynamic measurement: application of system identification in metrology&quot;</td>
<td></td>
</tr>
</tbody>
</table>

- **Dries PEUMANS**

- **Rik PINTELON**
  - 14/05/2018 17/05/2018 I2MTC 2018, IEEE International Instrumentation & Measurement Technology Conference, Houston Texas: Presentation of poster “Time-variant frequency response function measurement of multivariate time-variant systems operating in feedback”
  - 07/05/2018 09/05/2018 Microsymposium at Technische Universiteit Eindhoven, The Netherlands.
  - 09/07/2018 11/07/2018 18th IFAC Symposium on System Identification (SYSID 2018), Stockholm, Sweden. Presentation of paper “Impact of the Missing Data Pattern, the Oversampling, the Noise Level and the Excitation on Nonparametric Frequency Response Function Estimates”

- **Leo VAN BIESEN**
  - 25/01/2018 28/01/2018 Visit to BIPM, Paris. Participating in BIPM meeting
  - 30/08/2018 09/09/2018 XXII IMEKO World Congress, Belfast, Ireland. Board meetings IMEKO.
  - 14/10/2018 22/10/2018 Université du Burundi, Bujumbura: meeting with Prof. Dr. ir. Leonard Batururimi in the frame of the VLIR project.

- **Gerd VANDERSTEEN**
  - 30/01/2018 30/01/2018 FITCE event "The walls have ears – Big Brother is hearing you“ in Ghent
  - 11/04/2018 16/04/2018 University of Seville, Spain. Member committee doctoral candidate Fabio Passos.
  - 30/04/2018 30/04/2018 FITCE training social media – Londerzeel, Belgium

- **Evi VAN NECHEL**
  - 08/06/2018 16/06/2018 91st ARFTG Microwave Measurement Conference (ARFTG), Philadelphia, PA, USA. Presentation of paper "Extracting Improved Figures of Merit for Characterizing Nonlinear Devices using Multisine Excitation Signals"

- **Sandra VASQUEZ RODRIGUEZ**
  - 27/03/2018 29/03/2018 37th Benelux Meeting on Systems and Control, Soesterberg, The Netherlands: presentation of paper “Identification of LTI models from concatenated data sets”

- **Maral ZYARI**
1.6 FUNCTIONAL ORGANISATION OF THE DEPT. ELEC

Head of department ELEC
L. Van Biesen

Technical assistance
- Electronic Design assistance
- Mechanical Design assistance
- Didactical Design assistance
- Purchase Electronic Components
- Purchase General Components
- Instrument Maintenance
- Instrument Inventory & Loan serv.
- Office/ Lab. accommodation

J. Patyn

Administration
- Centralization
  Correspondence
  Personnel files
- Thesis printouts
- Administration
  Purchases
  Contracts
- Office material stock
- General secretariat
- Financial
  Administration of
department ELEC
- Financial plan

J. Pattyn

InfoCenter
- Instrument and accessory overview
J. Pattyn

A. Pintelon

Education
- Courses
  Educational staff
- Labs and Exercises
  Scientific staff
- Lab-exercises
  Coordinator
  Gent
  Vandesteen
- Lab assistance
  J. Pattyn

Professor staff (ZAP)

Research Organization
- Coordination
  Thesis/PhD follow-up
  Industrial contacts
  Job students follow-up
  Staff follow-up
- Research work
  Research staff

Professor Staff and Postdoc

Support to other bodies, internal or external to the VUB
- IEEE Instrumentation & Measurement Society, Adcom
  R. Pintelon, Y. Rolain, G. Vandesteen, J. Lataire
  associate editors
- IMEKO:
  L. Van Biesen, President, Liaison Officer to IEEE
  IMEKO General Council
  L. Van Biesen, Chairman
  IMEKO Technical Board:
  L. Van Biesen, member
  IMEKO Editorial Board:
  L. Van Biesen, member
  IMEKO VSC:
  L. Van Biesen, member
- ELSEVIER - IMEKO Journal "Measurement"
  L. Van Biesen, associate editor
- Faculty of Electrical Engineering
  L. Van Biesen, Chairman Council Bachelor Studies
  R. Pintelon, chairman PhD council
  Y. Rolain, chairman IT council
  W. Delcourte, support of system administrator
- The Royal Academies of Science and the Arts of Belgium
  Section "Technical Sciences": J. Schoukens
  Member of National Committee of Radio-Electricity:
  L. Van Biesen
- VUB-DIVIB faculty educational council for Bachelor in
  Engineering Science studies
  L. Van Biesen; chairman

Personnel
- Job students
- Follow-up
- Scholarships
- Research contracts
- Contract renewal
- Visiting researchers/professors

Public Relations
- Annual Report
  internet - ELEC home page

Computer Support
- PC workstations ELEC
  Y. Rolain
  J. Patyn
  S. Reyniers
- Support network ELEC
  Y. Rolain
  J. Patyn
  S. Reyniers

National/international contacts
- Organisation of workshops,
  conferences, ...
  Research staff

A. Pintelon

A. Pintelon
1.7 LIST OF THE MOST IMPORTANT MEASUREMENT EQUIPMENT

1.7.1 Signal Generators

- HP E1445A VXI Arbitrary Waveform Generator, f_{max} < 40 MHz (3x)
- HP E1340A VXI Arbitrary Waveform Generator, f_{max} < 42 MHz (3x)
- Synthesizer/Function Generator, Agilent 33120A (2x)
- NI 5411 AWG
- Noise Source, HP 346B, 10 MHz-18 GHz
- Agilent, 4142B, DC power supply
- HP E1434A VXI Arbitrary Waveform Generator, 4 channel source, f_{max}: 65 KHz
- HP, Signal Generator, HP 83650B, 45 MHz - 40 GHz
- Tektronix, AWG710, 4 GHz
- Tektronix AWG 7052, 5GHz Arbitrary Waveform Generator
- Rhode & Schwarz, Vector Signal Generator, SMIQ06B, 300 kHz - 6.46 GHz
- Agilent 33250A, NI 5411, 2x AWG 33220A
- Agilent 81101A, Pulse generator, 50MHz

1.7.2 Spectrum Analyzers, Impedance Analyzers, Network Analyzers

- 2 channel Dynamic Signal Analyzer, HP 3562, 100 kHz (2x)
- Impedance Analyzer, HP 4192A, 5 Hz - 13 MHz
- Vector Impedance Meter, HP 4193 A, 0.4 - 110 MHz
- Spectrum Analyzer, R&S FSU, 20 Hz- 67 GHz
- μwave Network analyzer, E8364B, 10 MHz - 50 GHz
- μwave Network analyzer, N5242A, 10 MHz – 26.5 GHz 4 port
- Noise Gain Analyzer, Eaton 2075 B, 10 MHz – 1800 MHz
- Network Analyzer, HP 8753 C, 300 kHz - 6 GHz
- Spectrum Analyzer, HP 8565 E, 9 kHz - 50 GHz
- PNA Network Analyzer, Agilent, 5 0MHz - 50 GHz
- Impedance Analyzer, Agilent E4991A, 10MHz - 3GHz
- Anritsu BTS Master MT8222A, High Performance, Handheld Base Station Analyzer
1.7.3 Digitizers

- 4 channel digitizer, Nicolet 490, 200 MHz, 8/12 bit
- 4 channel Digital Sampling oscilloscope, HP 54120T, 20 GHz, 11 bit
- 1 channel, HP E1430A VXI ADC 10 MHz, 16 bit (10x)
- 1 channel, HP E1437A VXI ADC 20 MHz, 16 bit (4x)
- 2 channel, HP E1429B VXI ADC 20 MHZ, 12 bit (2x)
- 8 channel, HP E1433A VXI ADC 196 KHz
- 2 NI 5911 flexres digitizer
- TDS 3032 digital phosphor oscilloscope, Agilent D5060321 300MHz, TDS 2001C 50 MHz
- 6 NI Elvis II

1.7.4 Miscellaneous

- Dual programmable filter, Difa PDF 3700, 100 kHz
- Dual adjustable filter, Wavetek, 100kHz
- Logic state analyser HP 1645A
- µwave power meter, HP436A, 10 MHz- 18 GHz
- 4 VXI racks +4 MXI controllers + Digital cards
  (2x Agilent E4841A + 1 Agilent E4805A)
- HP E1450, VXI timing module
- HP E1446A, VXI power module generator
- Wafer Probe Station
- Polytec Optical Fibre Vibrometer
  Velocity range (Doppler interferometer): 1, 5, 25, 125, 1000 mm/s/V
  Displacement range (Fringe Counter): 2, 8, 20, 80, 320, 1280, 5120 □m/V
- 2 PXI mainframes + MXI controller + embedded controller
- Custom-built measurement setup for making geo-referenced GSM network measurements
- 4 hTC P3600 smart phones (equipped with 2G, 3G, Bluetooth, WiFi and GPS)
- 2 JRC DGPS 200

1.7.5 Underwater Acoustics

- Raytheon V860 echo sounder
- B&K hydrophones, amplifiers etc.
- Panametrics transducers (500 kHz, 1MHz)
- D-GP5 Beacon Receiver KODEN (KBR-90)
- 1 water tank + positioning system
- Anritsu BTS Master MT8222A, High Performance, Handheld Base Station Analyzer

## 1.8 FINANCIAL SUPPORT (ACTIVE PROJECTS UNTIL 31/12/2018)

<table>
<thead>
<tr>
<th>Sponsor (project leader)</th>
<th>Duration project</th>
<th>Activity</th>
<th>Approx. amount (in €)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAS12 (L. Van Biesen/R. Pintelon)</td>
<td>2017-2018</td>
<td>Core Funding dept. ELEC</td>
<td>34.074</td>
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<tr>
<td>DOZ284 (G. Vandersteen)</td>
<td>2016-2018</td>
<td>Education: Methodological approach for project-based education</td>
<td>10.000</td>
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<tr>
<td>FWOD1758 (I. Markovsky, M. Ishteva, Ph. Dreesen, K. Usevich, J. Schoukens)</td>
<td>2015-2018</td>
<td>Decoupling multivariate polynomials in nonlinear system identification</td>
<td>252.000</td>
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<tr>
<td>FWOD1825 (Y. Rolain)</td>
<td>2017-2020</td>
<td>A Novel Wave-Based Stochastic Calibration Framework for High-Frequency Measurement and Modeling</td>
<td>232.000</td>
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<tr>
<td>FWOD1827 (I. Markovsky, M. Ishteva, Ph. Dreesen)</td>
<td>2017-2020</td>
<td>Block-oriented nonlinear identification using Volterra series</td>
<td>192.000</td>
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<tr>
<td>FWOD1867 (R. Pintelon, J. Lataire)</td>
<td>2018-2021</td>
<td>Identification of nonlinear continuous-time systems from noisy input – noisy output observations</td>
<td>394.000</td>
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<tr>
<td>FWOD251 (I. Markovsky)</td>
<td>2018-2021</td>
<td>Structured Low-Rank matrix / tensor approximation: numerical optimization-based algorithms and applications</td>
<td>790.000</td>
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<tr>
<td>FWOTO-232 (G. Vandersteen)</td>
<td>2016-2020</td>
<td>PhD Scholarship Dries Peumans &quot;BLA-based Design and Analysis of VCO-based Sigma-Delta Modulators&quot;</td>
<td>59.880</td>
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<tr>
<td>FWOTO899 (R. Pintelon)</td>
<td>2018-2022</td>
<td>PhD Scholarship Gaia Cavallo &quot;Identification of Time-Varying Joint Impedances for the Application to Bionic Devices&quot;</td>
<td>59.880</td>
</tr>
<tr>
<td>Legal Expertise (L. Van Biesen)</td>
<td>Since 1995</td>
<td>Expert to the court</td>
<td>Confidential</td>
</tr>
<tr>
<td>License Identification Toolbox (J. Schoukens)</td>
<td>Since 1994</td>
<td>Identification Toolbox</td>
<td>Confidential</td>
</tr>
<tr>
<td>NDA29 (L. Van Biesen)</td>
<td>Since 2004</td>
<td>Cellular positioning</td>
<td>Confidential</td>
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<tr>
<td>NDA65 (Y. Rolain)</td>
<td>Since 2005</td>
<td>Mutual non-disclosure agreement (NDA) : project for a RDS TMC receiver box</td>
<td>Confidential</td>
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<td>NDA240 (G. Vandersteen)</td>
<td>2008-2018</td>
<td>NDA – Secrecy Agreement</td>
<td>Confidential</td>
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<tr>
<td>NDA384 (L. Van Biesen)</td>
<td>2011-2018</td>
<td>NDA – Non Disclosure Agreement</td>
<td>Confidential</td>
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<td>OZR2877 (R. Pintelon)</td>
<td>2015-2019</td>
<td>Bench Fee voor Joint PhD VUB-ULB, Vasquez Rodriguez Sandra Paola</td>
<td>4000</td>
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<td>OZR2980 (L. Van Biesen)</td>
<td>2016-2018</td>
<td>Sabbatical Leave Johan Schoukens &quot;Identification of Structured Nonlinear Models&quot;</td>
<td>75.000</td>
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<td>OZR-METH1 (since 1/10/2016 R. Pintelon)</td>
<td>2007-2021</td>
<td>Center for Data Based Modelling and Model Quality Assessment</td>
<td>6.751.100</td>
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<tr>
<td>VLIR-UOS Phase 3 (L. Van Biesen)</td>
<td>2011-2023</td>
<td>The VLIR Institutional cooperation with Université du Burundi, Burund: New communication and information technologies</td>
<td>2700/year</td>
</tr>
</tbody>
</table>
### 1.9 AWARDS

#### 1.9.1 Grade of Fellow (IEEE)

The Institute of Electrical and Electronic Engineers, Inc. elected the grade of fellow to:

- Michel Gevers: for contributions to the understanding and identification of linear multivariable systems (1990)
- Johan Schoukens: for contributions to frequency domain system identification and the integration of measurement, signal processing and estimation theory (1997)
- Rik Pintelon: for fundamental research in frequency domain system identification and its applications in instrumentation, control and signal processing (1998)
- Yves Rolain: for contributions to measurement and modeling of nonlinear microwave devices (2005)

#### 1.9.2 Grade of Senior member (IEEE)

- Leo Van Biesen: In recognition of professional standing (1990)
- Gerd Vandersteen: In recognition of professional standing (2007)
- Wendy Van Moer: In recognition of professional standing (2007)

#### 1.9.3 Awards from IEEE Instrumentation and Measurement Society (US)

- Yves Rolain received the Recipient of the 2004 IEEE Instrumentation and Measurement Society award "For Contributions to Nonlinear Circuit technology".
- Johan Schoukens: IEEE Society Distinguished Service Award For technical and professional leadership of the IEEE Instrumentation and Measurement Society as Technical Program Co-Chair of IMTC/96 and author of conference papers on an annual basis, Associate Editor of the IEEE Transactions on Instrumentation and Measurement and member of the Society of Administrative Committee
- Wendy Van Moer received the "2006 Outstanding Young Engineer Award" from the IEEE Instrumentation and Measurement Society for outstanding contributions to nonlinear circuit theory.
• Rik Pintelon received the “2010 TIM Outstanding Associate Editor Recognition” for the meticulous, objective, professional and timely manner by which responsibilities while overseeing the review processes of numerous papers in 2010 are conducted.

• Wendy Van Moer received the “TIM Outstanding Associate Editor Recognition” in 2010 and 2011 for important contributions to TIM: for the meticulous, objective, professional and timely manner by which responsibilities while overseeing the review processes of numerous papers in 2010 are conducted.

• Rik Pintelon On behalf of the IEEE Transactions on Instrumentation and Measurement (TIM) administrative committee and the Instrumentation and Measurement Society (IMS) Publications Committee sincerely thanks Rik Pintelon for his meticulous, objective, professional and timely manner by which he conducted his responsibilities while overseeing the review processes of numerous papers in 2011. Therefore, we acknowledge your important contributions to TIM by recognizing Rik Pintelon as a 2011 TIM Outstanding Associate Editor.

• Yves Rolain received the "Best Reviewer Award" of the IEEE Transactions on Instrumentation and Measurement in 2010, 2011, and 2012

• Kurt Barbé received the “2011 Outstanding Young Engineer Award” from the IEEE Instrumentation and Measurement Society for the innovative application of statistical techniques and signal analysis in biomedical measurements.

• Lee Gonzales Fuentes received the IEEE Graduate Fellow" from the IEEE Instrumentation and Measurement Society for her project “Kernel density estimators for the disturbing noise in sampling oscilloscopes”.

• Kurt Barbé received the "TIM Outstanding Associate Editor Recognition" of the IEEE Transactions on Instrumentation and Measurement in 2012

• Kurt Barbé received the ‘Best Reviewer Award’ of the IEEE Transactions on Instrumentation and Measurement in 2009 and 2012

• John Lataire received the 2016 J. Barry Oakes Award “for fundamental contributions to the frequency domain measurement and identification of time-invariant systems” (May 2017)

• Rik Pintelon received In appreciation of outstanding service to the IEEE Transactions on Instrumentation and Measurement and Recognition as one of Transactions “Outstanding Reviewers of 2017”

1.9.4 Award from IEEE Control Systems Society

Michel Gevers: Distinguished Member of the IEEE Control Systems Society in recognition of exceptional service to the Society and the profession (1997)
1.9.5 Grade of Fellow (IFAC)

Michel Gevers: For fundamental contributions to system identification and its connection to control (2006)

1.9.6 Belgian Francqui Chair ULB


Linear models are at the basis of many engineering activities. The aim of this course is to identify these models from experimental data. In real life, nonlinear distortions violate the ideal linear framework. Two solutions are discussed to extend the classic linear modelling approach. First the linear framework will be extended to include these distortions using best linear approximations and nonlinear noise sources. Alternatively, the nonlinear distortions will be explicitly modelled.

Lectures (see pdf-files at http://wwwtw.vub.ac.be/elec/ELECcourse.htm):

- Inaugural: System Identification from data to model
- Lesson 1: Frequency Response Function Measurements
- Lesson 2: Impact of Nonlinear Distortions on the Linear Framework
- Lesson 3: System Identification (pdf-file)
- Lesson 4: Identification of Linear Systems
- Lesson 5: Identification of Nonlinear Systems

1.9.7 Awards granted by the VUB, on the proposition of the department ELEC

- Title of Doctor Honoris Causa to Prof. P. Eykhoff (Technische Universiteit Eindhoven) on April 4, 1990 (VUB, Brussels)
- Medal of Excellence to William Hewlett and David Packard on March 3, 1995 (VUB, Brussels)
- Medal of Excellence to Joseph F. Keithley on June 4, 1996 (Gothic Town Hall of Brussels)
- Title of Doctor Honoris Causa to Prof. M. Gevers (Université Catholique de Louvain - CESAME) on November 28, 2001 (VUB, Brussels)

1.9.8 Distinguished Service Award from IMEKO

The International Measurement Confederation extends to Prof. Leo Van Biesen this Distinguished Service Award:
• As recognition and appreciation for his valuable contribution to the international exchange of scientific and technical information relating to developments in measuring techniques, instrument design and manufacture and in the application of instrumentation in scientific research and in industry.

• For his continuous support in IMEKO as member of several TCs, delegate of the Belgian Member Organization to the General Council, President Elect and Chairman of the Technical Board from 2000 to 2003, President of the Confederation from 2003 to 2006 and Past President and Chairman of the Advisory Board from 2006 to 2009.

1.9.9 Joseph F. Keithley Award in Instrumentation and Measurement: IEEE Technical Field Award

Prof. Rik Pintelon received the 2012 Joseph F. Keitley Award in Instrumentation and Measurement, for outstanding contributions in electrical measurements.

Rik Pintelon has played a pioneering role in introducing system identification to the instrumentation and measurement field as a modern approach to solving measurement problems. System identification involves using statistical methods to build mathematical models of dynamical systems using measured data.

Dr. Pintelon's innovative methods have found important use in a diverse range of areas, including measurement and modeling of metal corrosion and deposition, electric machines, inner-ear dynamics, and analysis of civil engineering structures. Dr. Pintelon also developed a frequency domain approach to system identification and pushed for its adoption within the control systems community. In 1991, he and his colleagues were successful in developing the Frequency Domain System Identification (FDIDENT) Toolbox for the popular MATLAB program, which exposed his work to a large audience. Dr. Pintelon also published a highly cited book on system identification in 2001 (System Identification: A Frequency Domain Approach, IEEE Press), with a second edition that appeared in spring 2012.

1.9.10 Doctor Honoris Causa

Prof. Em. Michel Gevers received the title of "Doctor Honoris Causa" from the Vrije Universiteit Brussel in November 2001 and from the Linköping University (Sweden) in 2010.

Prof. Em. Ronny Van Loon received the title of "Doctor Honoris Causa" from the Hanoi University of Technology, in October 2008, for his personal contributions to the VLIR HUT IUC program in particular and the development of Hanoi University of Technology in general over the past 10 years. Thanks to his tremendous efforts as a key promoter since the
establishment in 1998, the VLIR IUC programs with HUT has vigorously developed and reaped fruitful achievements, significantly contributing to the expansion of international network and international academic exchange at Hanoi University of Technology.

Prof. Dr. ir. Johan Schoukens received the title of "Doctor Honoris Causa" from the Budapest University of Technology (Hungary) in May 2011.

1.9.11 Member of the “Royal Flemish Academy of Belgium for Science and the Arts”

Prof. Dr. ir. Johan Schoukens has been elected in December 2009 as member of the "Royal Flemish Academy Of Belgium For Science And The Arts" for the section "Technical Sciences".

1.9.12 Paper/presentation awards (since 2002)


Carine Neus received at the Symposium on Communications and Vehicular Technology in the Benelux (2008) the "Best Paper Award" for the paper "Challenges for Loop Identification and Capacity Estimation of DSL with Single Ended Line Testing".

Carine Neus received from IMEKO the "Best Paper Award" for the paper "Feasibility and problems of DSL loop topology identification via single-ended line tests” presented at the 16th IMEKO TC4 International Symposium and 13th International Workshop on ADC Modelling and Testing, Florence, Italy (September 2008)


Mussa Bshara and Leo Van Biesen received the "Top Six Achievement Award "Winning Paper" for the paper "Potential Effects of Power Line Communication on xDSL Inside the Home Environment" presented at the VIII Semetro. 8th International Seminar on Electrical Metrology João Pessoas, Paraiba, Brazil June 17 - 19, 2009
Mussa Bshara and Leo Van Biesen received the “Best Paper Award” for the paper “Fingerprinting-based Localization in WiMAX networks depending on SCORE measurements”, presented at the Fifth Advanced International Conference on Telecommunications, AICT 2009, Venice/Mestre, Italy, May 24-28, 2009.


Yves Rolain received the “Automated RF techniques group best paper award” from IEEE in 2010.

John Lataire received the “Best Junior Presentation Award 2010” at 29th Benelux Meeting on Systems and Control in Heeze, The Netherlands. He received the DISC trophy for the presentation of the paper “Frequency Domain Least Squares Estimator of Time-Varying systems”.


Lee Gonzales. The journal paper: "Cognitive Radios: Discriminant Analysis for Automatic Signal Detection in Measured Power Spectra” was certified as Finalist for the EMBS Best Paper Award in Transactions Publications by the IEEE Engineering in Medicine and Biology Society Benelux Chapter 2013, in December 5th 2013.


Kurt Barbé (2013) received the ‘Andrew R. Chi Best Paper Award 2013’ of the IEEE Transactions on Instrumentation and Measurement for the paper “Analyzing the Windkessel model as a potential candidate for correcting oscillometric blood pressure measurements” by Kurt Barbé, Wendy Van Moer and Danny Schoors.

Rik Pintelon, Ebrahim Louarroudi, and John Lataire (2014) were awarded the IEEE Instrumentation and Measurement Society 2014 Andy Chi Best Paper Award at the At the 1²MTC-2015 conference in Pisa, Italy. The prize-winning paper was titled 'Detecting and quantifying the nonlinear and time-variant effects in FRF measurements using periodic excitation'.

Rik Pintelon (2015) received at SYSID-2015, October 19-21, Beijing, China, a ‘Certificate of Recognition’ for his plenary talk 'Identification of Time-Varying Systems'.

1.9.13 Master thesis awards

Diane De Coster received in October 2011 from FWO the "Barco High Tech Awards for Master thesis", for her master thesis entitled "Ontwerp en realisatie van een geminiaturiseerde elektronische lock-in detectiemodule voor het meten van biomoleculen in fotonische 'lab-on-a-chip' systemen".

Maarten Schoukens received in March 2011 from IMEC the "IMEC-award for the best Master thesis at the faculty of Engineering, at the Vrije Universiteit Brussel" for his master thesis entitled "Ontwerp en realisatie van een compensatie voor niet-lineaire RF vermogenversterkers".

Egon Geerardyn received in March 2012 from IMEC the "IMEC-award for the best Master thesis at the faculty of Engineering, at the Vrije Universiteit Brussel" for his master thesis entitled "A simulation Method for Pin-pointing the Dominant Nonlinear Contributors in CMOS Circuits".

Adam Cooman received in March 2013 from IMEC the "IMEC-award for the best Master thesis at the faculty of Engineering, at the Vrije Universiteit Brussel" for his master thesis entitled "Design and Analysis of an On-chip Programmable Op-amp Based Filter".
1.10 INTERNATIONAL/NATIONAL CONFERENCES/WORKSHOPS ORGANISED BY THE DEPT. ELEC

**International conferences**

- International Instrumentation and Measurement Technology Conference (IMTC), Brussels (Belgium), 4-6 June, 1996
- 16th International IFAC Symposium on System Identification (IFAC-SYSID), Brussels (Belgium), 11-13 July, 2012
- Annual Symposium of the IEEE EMBS and IM Benelux Chapter and National Day on Biomedical Engineering, Brussels, Belgium, 5-6 December 2013

**International workshops**

- 22nd Benelux meeting on Systems and Control, Vossemeren (Lommel), 19-21 March, 2003
- 26th Benelux meeting on Systems and Control, Vossemeren (Lommel), 13-15 March, 2007
- 30th Benelux meeting on Systems and Control, Vossemeren (Lommel), 15-17 March, 2011
- ERNSI’2014, 21-24 September 2014, Ostend, BELGIUM
- Workshop on Nonlinear System Identification Benchmarks, Brussels, Belgium, 24/04/2017 - 26/04/2017

**National workshop**

- IAP DYSCO study day, Palais des Académies, Brussels, November 22, 2013
2. Short Description of the Research Projects

2.1 THE CENTER FOR MODEL-BASED SYSTEM IMPROVEMENT - FROM COMPUTER-AIDED ENGINEERING TO MODEL-AIDED ENGINEERING: STRATEGIC RESEARCH PROGRAM OF THE VUB (SRP-19)

Gerd Vandersteen, Yves Rolain, Piet Wambacq (ETRO), Maarten Kuijk (ETRO)

The vision of this SRP is to develop a Model-Aided Engineering (MAE) paradigm by expanding the Computer-Aided Engineering (CAE) techniques in a way that it unifies design, modelling, analysis, and measurements into a single paradigm. This MAE targets the support of the complete life cycle of the device: starting from the conceptual design phase (design and analysis using models), over the use of the device (measurement, modelling, calibration, and compensation), until the end of the device lifetime (fault detection).

The long-term strategic plan is to modify existing and develop new modelling techniques specifically for this aim, and to apply these methods in the design and life cycle of the system. This demands an interdisciplinary collaboration in various domains

- **State-of-the-art designs** are essential to test the assumptions made and to prove the applicability of the concept.

- **MAE-specific modelling and analysis tools** are developed and matched specifically to design-time and runtime needs. These are required to compensate for the design imperfections, to speed up the design of complex systems, to monitor the performance, and to integrate novel device structures into a larger design context.

- **Measurement techniques** assess the performance of the system, both at design and runtime. They must be specifically tailored to provide useful design information to the designer rather than raw measurement data, and must enable both the compensation of non-ideal behavior and fault detection.

The scientific goal is to extend MAE to include time-varying systems, parameter varying systems, and large-signal stability analysis. The innovative aspects are summarized below.

- **Designs** are planned in the domains of mm-wave (transceivers/radar) and sub-nanosecond demodulating optical sensors applications. Both require high quality, high frequency synthesizers and stable high-frequency/high-speed power amplification. This MAE-centric application domain strengthens the focus of the project.

- **Modelling and analysis** techniques developed in the past focused on the integration of time-invariant systems in the design methodology. These systems have characteristics that
do not change over time. However, many practical systems contain time variations; either by design (e.g. frequency converters) or just variations over time (e.g. aging). The aim is to extend the current work by adapting and integrating state-of-the-art time-varying system models and large-signal stability analysis methods. Time-varying identification was initiated and developed at ELEC under the guidance of Prof. Rik Pintelon. These techniques will be adapted for and included in the MAE paradigm.

The stability analysis aims to tackle the spectral purity analysis of (phase-locked loop and injection locked) oscillators and the stability analysis of (power) amplifiers driven by large, possibly modulated signals.

- **Measurements techniques** for time-varying systems form a major measurement challenge for a system whose behavior evolves over time. The development of specific measurement techniques and their corresponding model extraction is a major research and implementation challenge to enable an accurate run-time measurement / calibration / compensation scheme.

### 2.1.1.1 Major scientific results

The **Distortion Contribution Analysis** (DCA) speeds up the (micro)-electronic design by pinpointing the dominant nonlinear contributions in a complex system (PhDs of Adam Cooman (2016), Dries Peumans). The published results are focused on (nonlinear) time-invariant systems use the Best-Linear-Approximations (BLAs) for linear time-invariant systems. Contrary to existing state-of-the-art techniques, this DCA only requires classical transient and small signal analyses. The state-of-the-art techniques require the knowledge of the Volterra theory and the modelling of the individual transistors. The future research within the requested SRP will be extended to the DCA of Periodic Time-Varying (PTV) systems, and for the design high-efficiency power amplifiers (Researcher: Piet Bronders). This must enable to use the DCA on complex PTV system such as complete transmitters/receivers.

**Block oriented modelling of nonlinear time-invariant systems** is intensively used to capture the dominant nonlinear behavior of nonlinear systems. The PhD of Maarten Schoukens (2015) nicely describes the use of the BLAs determined at different excitation levels in order to extract in the structure of the nonlinear model.

**System identification when data is missing** is an active research topic to adapt the identification methods to practical applications when data is unavailable due to failing sensors/measurements. We achieved a major scientific breakthrough in the modelling of linear time-invariant system when samples are missing in the output signal (PhD of Diana Uglyumova). Using the extended local polynomial method (LPM), it is now possible to estimate the linear dynamic response of multiple-input multiple-output systems, and additionally, the missing data values including the uncertainties on all the estimates. One of the advantages of the extended LPM is that it even works if many samples are missing (e.g. 10% and more), and that there is no need for any deterministic or stochastic pattern in the missing data pattern. The future research within the requested SRP will extend towards time-varying systems when data is missing.
Meta-modelling is often used during design in order to replace time-consuming simulations or measurements with a model which depends on different design parameters. State-of-the-art methods where recently deduced, starting from electromagnetic field simulations. The aim of the recent research was to apply these methods on RF filter synthesis problems (joint PhD of Matthias Caenepeel with INRIA-France in 2016), and on novel microwave structures to be used within RF filter design (Evi Van Nechel). The aim is to extend the research activity towards the time-varying electrical and thermal modelling of GaN RF power transistors starting from simulations and measurements.

Parameter extraction of partial differential equations describing a combined diffusion - advection problem is an important topic within both plasma physics and hydrology (joint PhD in 2015 and post-doc of Matthijs van Berkel). The newly developed methods start from a realistic statistical framework and determine the parameters of the partial differential equations in the frequency domain. The transition from time to frequency domain is enabled by the local polynomial method. The main advantage of this approach over state-of-the-art methods is that it provides uncertainty bounds on the estimates and that it enables the detection of modelling errors.

The Forced Oscillation Technique (FOT) is an active research domain in medical instrumentation. The aim is to measure the lung impedance (defined as the ratio of pressure and air flow) of the longs for diagnostic purposes. The recent breakthrough in Forced Oscillation Techniques enables now the measurement of the lung impedance in the 0.1 to 10Hz frequency range (PhD Hannes Maes and Cedric Busschots). The main issue is that the natural breathing is in the same frequency region than the signals of interest. After improving the measurement setup, the focus was put onto the signal processing techniques to make the measurements more resilient to the breathing perturbations. This was done using modelling and regularization techniques in order to separate the natural breathing and the lung’s response to the excitation.

Clinical measurements where started in collaboration with the UZ Brussels. Measurements on patients revealed an important time-varying behavior which depends on the breathing of the patient. The requested SRP will be used to improve the medical measurements using the extension of the MAE towards time-varying systems.

2.2 TELECOMMUNICATION: APPLICATIONS

2.2.1 Carrier aggregation intermodulation distortions in Advanced Systems

Leonidas NIYONKURU: PhD student, Gerd VANDERSTEEN and Leo VAN BIESEN:
Funding: VLIR-UOS (Vlaamse Interuniversitaire Raad-Universitaire Ontwikkelingssamenwerking)

Achieving greater throughput requires increasing bandwidth. However, due to frequency’s scarcity, the necessary bandwidth may not be available in one contiguous band. LTE Advanced use multiple bands for one user: that is carrier aggregation [1]. However power amplifier’s efficiency is only possible in the nonlinear mode, in which multiple bands will lead to intermodulation (IMD) distortions. The consequence can be severe desensitization of own receiver. The predistortion is one of the method used for mitigating intermodulations.
Some of the predistortion methods follow the following steps: extract the IMD to be mitigated from the output, demodulate it, modulate it again at IMD carrier and add it (with opposite phase) to main signal before amplification [2]. There will then be cancellation between IMDs generated in the power amplifier by the main signal and those reintroduced from output. However that cancellation will be possible if those 2 IMDs has opposite phases.

In this project we analyse the consequences of carrier aggregation intermodulation distortions in LTE-Advanced and we design and implement (hardware implementation) an IMD carrier generator, which will output a linear combination of used frequency carriers.

References:


2.3 SYSTEM IDENTIFICATION AND PARAMETER ESTIMATION

2.3.1 Decoupling noisy multivariate polynomials in nonlinear system identification

Philippe Dreesen, Mariya Ishteva, I. Markovsky, Konstantin Usevich (CNRS, France)

Funding: Fund for Scientific Research (FWO-Vlaanderen – G028015N)

In the field of system identification, one special type of nonlinear models are the so-called block-oriented models, and more specifically the Wiener-Hammerstein models. When identifying parallel Wiener-Hammerstein systems, a multiple-input-multiple-output polynomial should be decoupled, that was obtained from noisy measurements. In this work, an earlier developed decoupling algorithm developed for the noiseless case is extended to the noisy case.

The starting point of the research is a multivariate polynomial function under the influence of noise, whose coefficients are approximated. It is also assumed that the covariance matrix on these coefficients is known at the start of the decoupling process. We wish to decouple this function by finding two transformation matrices and a set of univariate polynomials, such that the given function can be expressed as a linear combination of univariate polynomials in linear forms of the input variables.

The earlier developed algorithm uses first-order derivative information of the given multivariate function and involves the so-called Canonical Polyadic Decomposition (CPD) of a tensor, which is,
loosely spoken, a generalization of the singular value decomposition for two-dimensional matrices to multidimensional arrays of numbers. In this work, a weight matrix based on the covariance matrix is added to the CPD. Three different weight matrices were tested: a diagonal weight matrix, block-diagonal weight matrix and a full weight matrix.

Results vary depending on the added noise. Also the full weight matrix, even though containing more information than the remaining weight matrices, is ill-conditioned, which may produce unexpected results in some cases.

References


2.3.2 Identifying parallel Wiener-Hammerstein systems by decomposing Volterra kernels

Mariya Ishteva, Philippe Dreesen, David Westwick (University of Calgary), Ivan Markovsky, Konstantin Usevich (CNRS, France)

This project is funded by FWO project G090117N, 'Block-oriented nonlinear identification using Volterra series'

To capture the nonlinear effects of the real world, the focus of system identification is shifting from linear to nonlinear dynamical models. Every nonlinear dynamic system with fading memory can be approximated with arbitrary precision by its Volterra kernel description, which generalizes the concept of the finite impulse response to the nonlinear case, in much the same way as a Taylor series expansion for function approximation. However, the Volterra series provides a non-parametric representation, which lacks physical and intuitive interpretation. To take advantage of the Volterra representation while aiming for an interpretable block-oriented model, we study ways to impose the desired structure using tensor techniques.

We successfully generalized [1], [2] an existing tensor technique [3], [4] for identifying Wiener-Hammerstein systems to identifying the more challenging but more powerful parallel Wiener-Hammerstein systems. Tensor techniques, and in particular well-designed structured canonical
polyadic decompositions, thus once again proved useful in the system identification community. The next step is to make the algorithm numerically stable and robust to noise.

References


2.3.3 Measuring nonlinear distortions: from test case to an F-16 Fighter

M. Vaes\textsuperscript{1}, Y. Rolain\textsuperscript{1}, B. Peeters\textsuperscript{2}, J. Debille\textsuperscript{2}, T. Dossigne\textsuperscript{3}, J.P Noël\textsuperscript{1}, C. Grappasonni\textsuperscript{3}, G. Kerschen\textsuperscript{3}

\textsuperscript{1} Vrije Universiteit Brussel (VUB), Dept. ELEC  
\textsuperscript{2} Siemens Industry Software, Leuven, Belgium  
\textsuperscript{3} Aerospace and Mechanical Engineering Department University of Liège, Belgium

\textit{Funded by the Flemish Government (Methusalem project)}

What are the similarities and differences between the behavior of a small vibrating test system and an F-16 fighter? To find it out, we compare measurements of the test system to measurements from the bolted connection of the wing and the missile of a F-16 Fighter Falcon from the Belgian air force. These measurements were done during a ground vehicle test (GVT) campaign. Essentially, the behavior of these systems match, even though the test system is only the heart of a self-study kit for nonlinear system identification and the F-16 is a complex real life mechanical structure. This clearly shows the added value of an experiment driven nonlinear educational system identification package. It provides safe small-scale toy examples for hands-on exercices that react like real systems. We believe that this practical approach lowers the gap between learning system identification concepts and applying it on real systems.
Methodology

The mechanical systems are first excited by a multisine signal with a low measured amplitude. The frequency response function (FRF) is a rather smooth curve with resonance frequencies. When the amplitude is slightly increased, the FRF does not change. The system behaves like a typical linear time invariant (LTI) system (Figure 1, dark grey). Increasing the amplitude of the input signal further makes the FRF depart from this value for both systems as the nonlinear distortions pop up.

In Figure 1 the resonance frequency of the FRF is shifting to the left for both systems. This shows a softening effect. Note also the increased noise and amplitude change.

Adapting the input signal empowers detection, quantification, and qualification of nonlinear distortions and the measurement noise. What is the gain? Interpretation of these FRF’s leads to a better understanding of both systems and can be of great importance for the practitioner. Odd nonlinear distortion can be detected which lies at the origin of the changes in both dynamics of the system (Figure 2).

An example where this knowledge is of great importance is in the case of GVT campaigns. In GVT mostly, LTI-based methods are used to identify the resonance frequencies and predict flutter of an aircraft. If the system contains odd nonlinear distortions, this becomes very dangerous to assess dampings as the dynamics of the system is changed.

An F-16 and the test system look pretty much alike indeed, the kit prepares practitioners to tackle real-world problems.

References:
2.4 IDENTIFICATION OF TIME-AND PARAMETER-VARYING SYSTEMS

2.4.1 Nonparametric identification of linear dynamic errors-in-variables systems

Erliang Zang (School of Mechanical Engineering, Zhengzhou University, China) and Rik Pintelon

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The present work handles the nonparametric identification of linear dynamic systems within an errors-in-variables framework, where the input is arbitrary, and both the input and output disturbing noises are white with unknown variances. Using the property that the frequency response function and the system leakage term can be locally approximated very well by a low-order degree polynomial, a frequency domain estimator is developed, which gives consistent estimates for the frequency response function and the input-output noise variances. The consistency and uniqueness of the estimator are theoretically analyzed under mild conditions, and uncertainty bounds are also provided. The proposed method is finally validated on a simulated linear dynamic system.

The approach is illustrated on a simulated six degree lumped mechanical system, which is described by $G(z^{-1}) = \sum_{r=1}^{12} b_r z^{-r} / (1 + \sum_{r=1}^{12} a_r z^{-r})$ where $b_1 = 0.3484$, $b_2 = -2.8544$, $b_3 = 10.4983$, $b_4 = -22.4986$, $b_5 = 30.1250$, $b_6 = -24.0652$, $b_7 = 7.2967$, $b_8 = 6.6918$, $b_9 = -9.7056$, $b_{10} = 5.6571$, $b_{11} = -1.7170$, $b_{12} = 0.2234$, $a_1 = -10.6221$, $a_2 = 52.7688$, $a_3 = -162.0841$, $a_4 = 342.7932$, $a_5 = -525.8495$, $a_6 = 599.9538$, $a_7 = -512.9843$, $a_8 = 326.2764$, $a_9 = -150.5710$, $a_{10} = 47.8665$, $a_{11} = -9.4145$ and $a_{12} = 0.8667$.

The sampling frequency $f_s = 2^{13}$ Hz. The input is a bandlimited white noise by using a lowpass digital Butterworth filter with normalized (by $f_s/2$) cutoff frequency 0.85. The noise-free input–output signals are perturbed by normally distributed noises, and the SNR is same for both input and output. The estimator’s performance is illustrated using Monte Carlo simulations. A total of 400 Monte Carlo simulations are performed and the estimated results are averaged accordingly. The polynomial degree $R = 2$, the width of the frequency window is fixed to 2 Hz. To enable the start of the algorithm, the FRF $G(j\omega)$ is initialized by the LPM with defined parameter settings, the iteration of the other parameters of the polynomial models begins from zero. The input–output noise variances are supposed to be situated within limited bounds, e.g., $\sigma_0^2 \in [0.025, 0.25]$ and $\sigma_1^2 \in [1, 10]$ for SNR = 10 dB, starting values are obtained by minimizing a cost function.

Figures 4 and 5 show the results. It can be seen that the estimated input-output noise variances $\hat{\sigma}_u^2$ and $\hat{\sigma}_y^2$ are close to the true values 5.93 and 0.09, respectively. Also, the residuals of the nonparametric FRF estimate of the proposed method (see Fig. 5, dashed black line) are significantly smaller than those of the local polynomial method neglecting the input noise (see Fig. 5, green
dashed line). The predicted standard deviation also coincides with the actual sample standard deviation of the hundred Monte-Carlo runs.

Fig. 4: Contour plot for the cost function evaluated on a dense grid of $\sigma_U^2$ and $\sigma_T^2$ ($\sigma_0^2 = [5.93,0.09]$).

Fig. 5: Nonparametric estimate of the FRF. Blue solid line: true FRF, black solid dashed line: sample standard deviation, red+: predicted standard deviation, green thin dash-dotted line: residual error from the local polynomial method that neglects the inputs noise, black thin dotted line: residual error from the present method.
2.4.2 Linear parameter-varying modeling and decentralized fault diagnosis for large sets of interacting subsystems

Prof. Rik Pintelon, Prof. Michel Kinnaert, Sandra Vásquez

1. Control Engineering department (SAAS) of the ULB

Funding: FNRS - Fonds de la Recherche Scientifique

Fault Detection and Isolation (FDI) systems aim at the early detection and localization of faults. They are the key for the establishment of condition-based maintenance on industrial processes, which allows for cost reduction, and a safer and more reliable operation. The research on FDI has been mostly done on a centralized approach, where the information of the supervised system is gathered in a central node. However, this approach becomes unfeasible on large-scale systems due to limitations on computational power or communication infrastructure. Here a decentralized approach is necessary (see Figure 3), since the fault diagnosis is decomposed into different sub-problems aiming at the supervision of smaller parts of the system (subsystems). This lowers the technical requirements, and improves the reliability and security [1].

This project aims at developing a model-based decentralized FDI system, for a process made of large sets of interacting subsystems. A relevant example of such a process is a wind farm, where the turbines are interacting with each other through the wake effect [2]. This project addresses the next challenges:

- How to identify Linear Parameter-Varying models [3, 4] for the subsystems from available data (accounting for the dynamic dependence on operating conditions). Continuous-time frequency domain identification [5, 6] will be used since (i) a continuous-time model is closer to the physics than a discrete-time model, and (ii) the modeling can be done in a user defined frequency band.

- How to extend to a decentralized framework the FDI methods currently developed in a centralized way [7, 8], while dealing with the interactions of the subsystems and optimizing the computational load and data exchange. Both additive and multiplicative faults will be considered.

The case study will be wind farms, with focus on the supervision of energy production, and the temperature of certain components of the turbines (see Figure 4).

**Figure 3. Concepts of centralized and decentralized fault diagnosis (figure inspired by [1]):**
Figure 4. Concept of the proposed FDI system for wind farms

References


2.4.3 Identification of time-varying biomechanical systems

Gaia Cavallo, John Lataire, Rik Pintelon,
in collaboration with Mark Van de Ruit, Winfred Mugge, Alfred Schouten, Jan-Willem van Wingerden (Delft University of Technology, The Netherlands)

Funding: FWO, Methusalem

This project aims at extracting models of human joints in a data driven manner. This is done in collaboration with the biomechanics group at the TU Delft, where experimental setups have been instrumented to apply force and position disturbances to joints (ankle, wrist and shoulder). Based on measurements of the force and position, the mechanical impedance of the joint can be estimated.

The dynamic properties of a human joint are continuously modulated by the central nervous system, to be adapted to the task at hand. For instance, while walking, the leg is stiff during stance phase and slack during the swing phase. The perceived impedance of the joint are a.o. determined by the joint angle, muscle activation level, and muscular fatigue, all of which are variable in time. From a dynamic systems' perspective, this means that the system is time-varying.
Applications where the identification of time-varying models of human joints is relevant and are foreseen for future research include:

- the understanding of movement disorders, linked to abnormal control of the reflexive component of joint admittance,
- the design, tuning and control of prosthetic and orthotic devices, to adapt their dynamic properties and mimic the intended human joint behaviour.

Preliminary results for the identification of the time-varying wrist joint have been obtained, by using the skirt decomposition method, and a kernel based parametric method. They were applied to angular and torque measurements on a human wrist, to which an angular position perturbation was applied, see left figure. The human subject was requested to follow a sinusoidal force trajectory (facilitated via visual feedback on a screen), which resulted in a fairly controllable time variation of the muscular properties.

The skirt decomposition method allows to extract a nonparametric model of the time-varying impedance of the system. This gives an estimate of the evolution of the resonance frequency (middle figure), which is related to the evolution of the stiffness of the muscle.

The kernel method gives a parametric model, thus giving a smoother result, in which the sinusoidal variation of the stiffness is clearly visible, in the right figure.
2.4.4 FRF measurements subject to missing data: quantification of noise, nonlinear distortion, and time-varying effects

R. Pintelon, J. Lataire, and G. Vandersteen

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This work has been accepted for publication in the IEEE Transactions on Instrumentation and Measurement.

Quantifying the level of nonlinear distortions and time-varying effects in frequency response function (FRF) measurements is a first step towards the selection of an appropriate parametric model structure. In this project we tackle this problem in the presence of missing data, which is an important issue in large-scale low-cost wireless sensor networks. The proposed method is based on one experiment with a special class of periodic excitation signals.

In many scientific disciplines parametric models are identified from experiments on dynamical systems either to get insight into complex physical phenomena, or for computer aided design, fault detection/monitoring, prediction and control [1]. Choosing the appropriate model structure of the parametric model is one of the most difficult steps in the identification procedure. A nonparametric procedure allowing the user/scientist to decide which type of dynamical model structure is most appropriate for a particular application would be very helpful in this respect.

A first step towards the solution of this difficult problem is presented in [2]: via an experiment with a random phase multisine, which is a special periodic signal, the time-varying frequency response function, the noise level, the level of nonlinear distortions and the time-varying effects are estimated nonparametrically. It allows one to decide which of the following dynamical models is best suited to describe the measurements: linear time-invariant (LTI), linear time-varying (LTV), nonlinear time-invariant (NLTI), or nonlinear time-varying (NLTV). In addition, it gives insight into the complexity of LTI and LTV dynamics via the best linear time-invariant and best linear time-varying approximations, respectively.

In this project we extend the results of [2] to measurements subject to missing data. The proposed approach is based on a non-trivial combination of the algorithm for estimating the time-varying frequency response function using random phase multisines [2] and the missing data algorithm for frequency response functions using periodic excitations [3].
The whole procedure is illustrated of the following time-varying bandpass filter

\[ \begin{align*}
C_1 & \quad R_1 \\
R_2 & \quad C_2 \\
R_3 & \quad y(t) \\
p(t) & \quad (33 \text{ mVrms}) \\
\text{u}_0(t) & \quad (97 \text{ mVrms})
\end{align*} \]

Figure 5. Transient response \( y(t) \) (33 mVrms) of a second order time-varying bandpass filter to two periods of a random phase multisine \( u(t) \) (97 mVrms). During the experiment the gate voltage \( p(t) \) decreases linearly from -1.612 V to -1.661 V. The electronic circuit consists of a high-gain operational amplifier (CA741CE), a JFET transistor (BF245B), three resistors \( (R_1 = R_2 = 10 \, k\Omega \text{ and } R_3 = 470 \, k\Omega) \), and two capacitors \( (C_1 = C_2 = 10 \, nF) \).

Figure 6 shows the estimated frequency response functions \( G_p(j\omega), p = 0, 1 \), of the time-varying FRF \( G(j\omega, t) = \sum_{p=0}^{1} G_p(j\omega) f_p(t) \), where \( f_p(t) \) are Legendre polynomials, for 20% clipping and 30% randomly missing data patterns of the output signal \( y(t) \).

It can be seen that the estimates (black lines), their noise (green lines), and the total (red lines) variances coincide, except for the total variance of the 20% clipping above 20 kHz. From the right column of Figure 6 it follows that the error of the missing data estimates (gray lines) are of the level...
of their predicted total uncertainty (noise and nonlinear distortion). The maximal error (first frequency excluded) on $\hat{\sigma}_0$ and $\hat{\sigma}_1$ is, respectively, -56.8 dB and -65.0 dB for the 20% clipping, and -58.2 dB and -63.1 dB for the 30% random pattern.

Figure 7 compares the estimated and the true missing data. It follows that the ratio of the rms value of the estimation error and the rms value of the missing samples is about $4 \times 10^{-3}$ for both missing data patterns. This estimation error is mainly due to the nonlinear distortions.

Figure 7. Comparison of the estimated and the true missing data. Top row (only one 1 out of 8 missing samples are shown): true (black x) and estimated (red o) samples – Measurement example. Bottom row (all missing samples are shown): difference between the true and estimated samples (red lines) and the predicted standard deviation (black lines). Left column: 30% randomly missing data (32 mVrms) with an estimation error of 0.14 mVrms. Right column: 20% clipping (58 mVrms) with an estimation error of 0.24 mVrms.

References


2.4.5 Local bending stiffness identification of beams using simultaneous Fourier-series fitting and shearography

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In this project, we present a novel method for the identification of the local bending stiffness of beams. We use shearography to capture measurements of vibrating beams, so the input data for the identification is the modal slope – the differential of the modal shape. The modal slope is fitted by two Fourier-series functions, one of which is derived from a thin-beam model. The local bending stiffness is identified as the one corresponding with the best match between the measured and the two fitted modal slopes. This identification method, which we call simultaneous Fourier-series fitting, is demonstrated on numerically-generated inputs, as well as on experimental measurements. We use a flat, concave and convex beam, as well as beams with locally varying bending stiffness mimicking local damage to verify the method. It is shown that the method gives accurate results and is robust to noise. Additionally, it has advantageous properties that make it useful and practical: using this method, it is possible to perform the identification from only a sub-region of a beam and even without specifying the boundary conditions

**Reference**


2.5 STRUCTURED LOW-RANK APPROXIMATION

2.5.1 Data driven fast measurements

*Gustavo Quintana-Carapia* and *Ivan Markovsky*

**Funded by FWO**

**Introduction**

Measurement techniques have fundamental speed and accuracy limitations. The speed and precision of a measurement device used in monitoring and control tasks determines the quality of the available data, which in turn limits the accuracy of models derived from the data. In this project, we develop a method that overcomes the hardware constraints. The method performs calculations in real-time to speed up, by digital signal processing, measurement tasks.
Title: Problem formulation

The metrology problem of speeding up a measurement device is modeled as an input estimation problem for a dynamical system with step input. The input step level is the unknown (to-be-measured) quantity, the output is the known (measured) quantity, and the input-output relation represents the unknown measurement process dynamics see Figure 8.

Problem: Given output observations of a stable linear time-invariant system with known dc-gain $G$, generated by a step input $u = \bar{u}s$, where $s$ is the unit step function, find the input step value $\bar{u}$.

Data-Driven Fast Measurement method (DDFM)

A dynamic compensator performs on-line identification and model based design. The proposed method called DDFM is a model-free approach that bypasses the parameter identification and compensator design and finds directly the quantity of interest $\bar{u}$, see Figure 9.

The quantity of interest $\bar{u}$ is computed directly from the data by solving, recursively, the following system of linear equations [2]:

$$\begin{bmatrix} G \\ \vdots \\ G \end{bmatrix} \mathcal{H}(\Delta y) \begin{bmatrix} \bar{u} \\ l \end{bmatrix} = \begin{bmatrix} y(n + 1) \\ \vdots \\ y(T) \end{bmatrix}$$

Where $n$ is the system order, $\Delta y(t) = y(t) - y(t - 1)$, and $\mathcal{H}(\Delta y)$ is the block-Hankel matrix with $n$ columns.

Practical implementation

The DDFM algorithm is implemented on a digital signal processor (NXT Lego brick), see Figure 10. As a test bed we use temperature measurement, but this method can be applied to multivariable dynamical systems and is capable of performing sensor fusion.
In Figure 11 the estimation error $\varepsilon = \bar{u} - \hat{u}$ is shown as a function of time, for a particular experiment. Here $\bar{u}$ is the steady state value and $\hat{u}$ is the current prediction of $\bar{u}$. In this experiment, the following methods are compared:

1. direct (raw) measurement of the sensor,
2. estimate of the measured quantity, obtained by the DDFM method,
3. estimate of the measured quantity, obtained by the Kalman filter.

Note that the Kalman filter is designed using a model of the measurement process. This model is obtained using all the collected data. On the other hand, the instantaneous value of the DDFM prediction is calculated online using the (previously) measured values.

References


2.5.2 Uncertainty analysis of a subspace-based input estimation method for dynamic measurements.

Gustavo Quintana Carapia, Ivan Markovsky, Rik Pintelon, Péter Zoltán Csurcsia (VUB INDI Department, Siemens PLM Software), and Dieter Verbeke (VUB INDI Department)

A measurement is an experimental procedure to determine the value of a physical magnitude. The true value of the to-be-measured quantity is unknown and the measurement result is an estimation
of the true value. The difference between the true value and its estimate cannot be absolutely determined. Therefore, there is an uncertainty associated with the result of any measurement. Moreover, the accuracy and availability of the estimation depends on the sensor dynamics. A data-driven method that estimates the value of an unknown input by processing the sensor transient response suggested that a measurement can be performed in less time than classical model-based approaches.

The data-driven estimation method estimates the true value of a step input of level \( u \) by processing the transient response \( y \) of a sensor of order \( n \) and dc-gain \( G \). The perturbation noise \( \varepsilon \) is additive normally distributed so that the measured transient response is \( \tilde{y} = y + \varepsilon \). The estimation of the step input level is obtained as the solution of the minimization problem

\[
\hat{x} = \arg \min_x \| \tilde{y} - \tilde{R}x \|_2
\]

where \( \hat{x} = [\hat{u} \quad \hat{y}]^T \), \( \tilde{y} = [\tilde{y}(n+1) \quad \ldots \quad \tilde{y}(T)]^T \), and \( \tilde{R} = [1 \quad 0 \quad H(\Delta \tilde{y})]^T \). Since the Hankel matrix \( H(\Delta \tilde{y}) \) is constructed from the differences of the measured transient response \( \Delta \tilde{y}(t) = \tilde{y}(t+1) - \tilde{y}(t) \), the measurement noise perturbs not only \( \tilde{y} \) but also \( \tilde{R} \). This is a structured errors-in-variables problem.

We study the statistical properties of the data-driven estimation method (1) to know the estimate uncertainty. The aim of the statistical analysis is to provide confidence bounds on the uncertainty associated with the estimate in practical measurements. We obtain analytical expressions for the prediction of the estimate bias and variance. The analytical solution to the problem (1) is approximated by a Taylor expansion. The first two moments of the estimate \( \hat{x} \) are analyzed. The resulting expressions are functions of the measurement noise variance and of the exact transient response data and predict the bias and variance of the estimate.

We validate the prediction formulas using Monte Carlo simulation and using real data measured from a weighing sensor in an experimental setup. The bias and variance of the estimate give insight on how these parameters are related with the signal-to-noise ratio and the processed number of samples of the sensor transient response.

![Figure 12. Relative errors of the estimate bias (left) and variance (right) observed in the Monte Carlo simulation.](image)

The Monte Carlo averages (MC) of the estimate bias and variance parameters is accurately predicted (p) by the formulas. The relative error between the empirical (e) and the predicted (p) bias and variance parameters increases as it is expected for decreasing signal-to-noise ratio.
2.5.3 Data-driven signal processing using the nuclear norm heuristic

Philippe Dreesen and Ivan Markovsky

Funding: Fonds de la Recherche Scientifique (FNRS) and Fonds Wetenschappelijk Onderzoek (FWO Vlaanderen) under Excellence of Science (EOS) Project no 30468160 “Structured low-rank matrix / tensor approximation”

Applications in signal processing and control theory are typically model-based and proceed in two steps. In the 'modeling' step, a mathematical model is built from the measured noisy data. In the 'design' step, the model is used to solve a specific application problem. In this project, we will explore 'data-driven methods', in which modeling and design are combined into a single task. By combining modelling and design into a single 'direct' problem, better solutions can be found than by solving the two problems separately.

The tools that we employ are structured low-rank matrix approximation and structured low-rank matrix completion. In the context of linear dynamics, low-rank matrices come with a specific structure that captures time-invariance and linearity, namely the (block) Hankel matrix (having repeated elements along the anti-diagonals). Removing noise from signals is related to finding the nearest low-rank Hankel-structured matrix, viz. the nearest LTI system that explains the observed data. Low-rank matrix completion appears in two ways: Firstly, there can be missing data because of sensor outages or problematic communication channels. Secondly, data completion can be used to find entire unknown signals, which allows us to come up with data-driven variants of classical problems such as system simulation (input u is given, output y is unknown), output tracking control (output y is given, input u is unknown), or for building a Kalman filter which supports missing elements in the data set.

![Diagram of Given Data, Matrix Completion Problem, and Prediction](image)

We investigate the use of the nuclear norm for the above problems. Our initial findings on the data-driven simulation problem suggest that, when using an adequate rescaling of the given data, the exact data-driven simulation problem can be solved by replacing the original structured low-rank matrix completion problem by a convex optimization problem, using the nuclear norm heuristic.

References

2.5.4 Applications of polynomial common factor computation in signal processing and systems theory

I. Markovsky, A. Fazzi*, and N. Guglielmi*
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Funding: FWO and FWO-EOS

We consider the problem of computing the greatest common divisor of a set of univariate polynomials and present applications of this problem in system theory and signal processing. One application is blind system identification: given the responses of a system to unknown inputs, find the system. Assuming that the unknown system is finite impulse response and at least two experiments are done with inputs that have finite support and their Z-transforms have no common factors, the impulse response of the system can be computed up to a scaling factor as the greatest common divisor of the Z-transforms of the outputs. Other applications of greatest common divisor problem in system theory and signal processing are finding the distance of a system to the set of uncontrollable systems and common dynamics estimation in a multi-channel sum-of-exponentials model.

References


2.5.5 Using structured low-rank approximation for sparse signal recovery

I. Markovsky, P.-L. Dragotti (Imperial College London)

Funding: FWO and FWO-EOS

Structured low-rank approximation is used in model reduction, system identification, and signal processing to find low-complexity models from data. The rank constraint imposes the condition that
the approximation has bounded complexity and the optimization criterion aims to find the best match between the data—a trajectory of the system—and the approximation. In some applications, however, the data is sub-sampled from a trajectory, which poses the problem of sparse approximation using the low-rank prior. This paper considers a modified structured low-rank approximation problem where the observed data is a linear transformation of a system’s trajectory with reduced dimension.

We reformulate this problem as a structured low-rank approximation with missing data and propose a solution methods based on the variable projections principle. We compare the structured low-rank approximation approach with the classical sparsity inducing method of 1-norm regularization. The 1-norm regularization method is effective for sum-of-exponentials modeling with a large number of samples, however, it is not suitable for identification of systems with damping.

Reference


2.5.6 Sum-of-exponentials modeling via Hankel low-rank approximation with palindromic kernel structure

I. Markovsky and D. Toon Verbeke (VUB-INDI)

Funding: FWO and FWO-EOS

Estimation of a sum-of-damped-exponentials signal from noisy samples of the signal is a classic signal processing problem. It can be solved by maximum likelihood as well as suboptimal subspace methods. In this paper, we consider the related problem of sum-of-exponentials modeling, in which the model is constrained to have no damping. This constraint is difficult to impose in the subspace methods. We develop solution methods using an equivalent Hankel matrix low-rank approximation formulation. A necessary condition for the model to have no damping is that a vector in the kernel of the Hankel matrix has palindromic structure. Imposing this necessary condition in solution methods is trivial. Simulation results show that even for a relatively high noise-to-signal ratios the necessary condition is in fact also sufficient, \ie, the identified model has no damping. Another contribution of the paper is a method for sum-of-exponentials modeling based on circulant embedding: low-rank approximation of a circulant matrix constructed from the given data. This method imposes the constraint that the model has no damping plus an addition constraint that the model frequencies are on the discrete-Fourier transform’s grid.

Reference

2.5.7 Learning Kalman filtering with Lego mindstorms

I. Markovsky

Funding: FWO and FWO-EOS

Research shows that, in learning science and engineering, guided project work leads to deeper understanding of theoretical concepts (as well as acquisition of hands-on skills) than the classical approach of textbook reading and attending lectures. In an approach to education based on project work, the role of the teacher is to create a stimulating learning environment and to supervise the students in accomplishing their objectives. The main challenge is to come up with projects that are engaging, diverse, and feasible in view of limited time and resources. In this paper, we describe such a signal processing project. The task is to improve the speed and accuracy characteristics of a sensor by real-time signal processing. It turns out that this is an application of Kalman filtering however the students need to identify a model of the sensor and implement the Kalman filter on a DSP. The project consists of three main tasks: 1) mathematical formalization of the problem, 2) development of solution methods, and 3) implementation and testing of the methods. The testing is done on an inexpensive laboratory setup, using the Lego Mindstorms educational kit in combination with a temperature sensor. The learning outcomes are understanding of model representations, system identification, and state estimation, as well as implementation in MATLAB and C of real-time signal processing algorithms. Possible extensions include data fusion of multiple sensors, adaptive signal processing, and applications to other sensors.

Reference:


2.5.8 Compressed ultrasound signal reconstruction using a low-rank and joint-sparse representation model

Miaomiao Zhang*, Ivan Markovsky, Colas Schretter (VUB-ETRO), Jan D’hooge*

*Katholieke Universiteit Leuven

Funding: FWO and FWO-EOS

With the introduction of very dense sensor arrays in ultrasound imaging, data transfer rate and data storage can become a bottle neck in ultrasound system design. To reduce the amount of sampled channel data, we proposed a new approach based on the low-rank and joint-sparse model that allows to explore the correlations between different ultrasound channels and transmissions. With this method, the minimum number of measurements at each channel can be lower than the sparsity in compressive sensing theory. The accuracy of reconstruction is less dependent on the sparse basis. An optimization algorithm, based on simultaneous direction method of multipliers, is proposed to efficiently solve the resulting optimization problem. Results on different data sets with different experimental settings show that the proposed method is better adapted to the ultrasound signals and can recover the image with fewer samples (e.g. 10\% of the samples), while maintaining adequate image quality.
Short Description of the Research Projects

References


2.5.9 Realization and identification of autonomous Wiener systems via low-rank approximation

Ivan Markovsky, P. Dreesen

Wiener systems are nonlinear dynamical systems, consisting of a linear dynamical system and a static nonlinear system in a series connection. Existing results for analysis and identification of Wiener systems assume zero initial conditions. In this paper, we consider the response of a Wiener system to initial conditions only, we consider autonomous Wiener systems. Our main result is a proof that an autonomous Wiener system with a polynomial nonlinearity is equivalent to a finite-dimensional linear system. The order of the equivalent linear system is \((n + d)\)-choose-\(d\) — the number of combinations with repetitions of \(d\) elements out of \(n\) elements — where \(n\) is the order of the linear subsystem and \(d\) is the degree of the nonlinearity. The relation between the eigenvalues of the equivalent linear system and the linear subsystem is given by a rank-1 factorization of a symmetric \(d\)-way tensor. As an application of the result, we outline a procedure for identification of autonomous Wiener systems.

2.6 MODELLING HIGH FREQUENCY NONLINEAR SYSTEMS

2.6.1 Developing wave-based calibration for vector network analyzers

Yves Rolain, Gerd Vandersteen

Funding: FWO

2.6.1.1 current state-of-the-art in RF calibration

Calibration is an essential part of any RF, microwave and millimeter wave measurement process. The accuracy of a bare-bones high-frequency measurement instrument is jeopardized by the influences of non-idealities, cabling and instrument drift. To maximally remove these systematic errors, calibration has been introduced together with the instrumentation benches.

This work concentrates on the calibration of a vector network analyzer (VNA). The aim of this instrument is to characterize the behavior of a system operating at microwave frequencies. The calibration is meant to increase the accuracy of the measurement process, by removing the systematic errors.
Calibration methods for VNA calibration have been constantly developed in the literature since the introduction of the VNA in the sixties. This resulted in a wide variety of methods, whose diversity is dictated by their dependence on the type and the amount of standards used.

Standards can be impedances (1-port), transmission lines (2-ports) or complete circuits (1-port and 2-ports). They can be exactly known, partially known or unknown-but-repeatable and do depend on the technology used (connectorized, probed, free space). Generally speaking, a minimal set of standards is selected to solve for the calibration coefficients analytically. The class of ‘auto-calibrating’ methods exploits the redundancy in the measurements to some extent to avoid exact prior knowledge of the standards (TRL [1], Unknown thru [2], LRM [3]...), but still requires a standard-specific solution for each set of standards.

Taking one step backward to locate the similarities between the state-of-the-art methods, it becomes clear that the common basis is

- Calibration of the S-parameters only: Both the device and the instrument are assumed to be Linear and Time-Invariant systems (LTI). Knowing the S-parameters is hence equivalent to knowing the system. Calibration of the S-parameters is therefore sufficient, and the standards are characterized by their S-parameters.

- Single frequency calibration: LTI systems support the superposition principle, hence the calibration can be solved on a frequency-by-frequency basis. Note that all measurement frequencies have to be calibrated separately.

- Non-Parametric calibration: The calibration is known only at the calibration frequencies only. There is no knowledge about the behavior in between calibration frequencies.

- The calibration depends on the standard set: Each standard set results in a new method, which has to be fully characterized and tested. This limits the flexibility.

- The calibration is based on analytic expressions: Imposing minimal standard sets leads to equations that can be solved analytically, at the cost of losing the uncertainty estimation of the calibration.

While the basic assumptions underpinning the VNA calibration are unchanged since the sixties, three quantum leaps happened in RF measurements: differential system measurements, non-linear system measurements and parameter-varying (time-varying or temperature-varying) system measurements. Both classes allow the system behavior to deviate from linearity in some way. It is no longer allowed to use superposition to characterize the response to an arbitrary excitation as a sum of sinewave responses. Despite the increased complexity of measurements performed (differential, non-linear, time-varying), the initial linear S-parameter calibration has mainly remained unchanged. The extension in the calibration that was needed for nonlinear characterization resulted merely in an add-on to the S-parameter calibration addition, using a separate standard element such as a pulse generator ([4],[5]). For parameter varying systems, the calibration will have to be known on a much denser frequency grid.

S-parameters are no longer sufficient to characterize a nonlinear or time-varying DUT. Calibrated waves are the new natural measurable quantity rather than their calibrated ratios. A shift of the
calibration paradigm from S-parameter to wave-based calibration is therefore needed. Realizing this shift to waves answers the call for characterization under multi-line spectral excitation, which results in either an increased spectral resolution (time-variation) or a wider spectral bandwidth (nonlinearity) of the waves present at the ports of the DUT. Measuring at excited frequencies only is no longer sufficient.

This calls for a new paradigm in calibration. Instruments have evolved away from a single-sine single-frequency measurement in different ways as summarized below:

- Excitation spectra are dense and wide banded: Arbitrary waveform generators create spectrally dense excitation spectra over wide modulation bandwidths. Time-varying and nonlinear DUTs expand the bandwidth and increase the resolution even further. The number of calibration frequencies therefore increases by at least 2 orders of magnitude.

- Measurements are fast: Acquiring 10 frequency sweeps per second moves to mainstream, resulting in access to vast amounts of (repeated) data.

- Setups are agile: Frequency is no longer the only variable that is swept in a measurement. Dependence on signal power, port impedances, bias settings under large signal operation, or temperature in time-varying systems is also characterized and swept.

- Ad-hoc calibration kits pop up: specific measurements require specific calibration kits (e.g. on-wafer) to ensure accuracy. These home-made standards have a lower quality than commercial counterparts and are not specified a priori. Their uncertainty also needs to be propagated.

### 2.6.1.2 Goal of this project: methods overview

“Wave-based calibration for nonlinear and parameter-varying system measurement and identification enables accurate, validated measurement and modeling with uncertainty bounds included”

Changing the basic assumptions underpinning the calibration framework will generate a quantum leap in calibration. This evolution is mandatory to keep up with the changes in the measurement instrumentation. The framework will be developed along 5 main axes

- Develop a generic N-port calibration framework to embed flexible user-determined standard set selections in a single estimation framework.

- Validate the calibration using a stochastic N-port framework including measured experimental noise properties, (measured) reconnection errors, and (simulated) standard uncertainties.

- Construct ‘user calibration kits’ based on a user-specified mix of custom-built and commercial standards. Custom built elements will be characterized by a device model and an uncertainty model, with minimal user interaction. An accurate calibration uncertainty boundary will result.

- Develop a minimum mean square error calibration framework to help the user to maximally identify and minimize the influence of parasitic problems by the identification of custom
standard sets. This will maximally circumvent the technological limitations of the user setup.

- Develop an “optimal” calibration to complete set of standards with new standards that maximally decrease the uncertainty on the DUT measurements.

- Develop an identification-friendly calibration. Even small abrupt (noisy) changes in the error terms over the frequency lead to model extraction problems. A combined, single step, instrument calibration and device estimation framework will be developed to maximize model quality while maximally maintaining the calibration accuracy.
2.6.2 Identifying Reflections in High Frequency Structures

Maral Zyari, Yves Rolain, Francesco Ferranti (IMT Atlantique, Brest – France)

Funding: IRMO

The goal of this work is to improve the modeling of Lumped Distributed Structures (LDSs) by obtaining a sensible accuracy with a reasonably low number of model parameters while identifying the reflections present.

First, a model suite consisting of three model classes with increasing complexity is introduced. The complexity of the models is chosen proportionally to the complexity of the LDS under study. A sum of delayed damped complex exponentials (Cisoids) is used to obtain initial values for the delays by simultaneous estimation of the delays caused by the structure's transmission lines and the reflections imposed by the lumped elements.

This work provides an important contribution to the modelling and identification of LDSs while providing a model suite that can be applied to a wide range of applications.

Additionally, an adaptive sampling technique to shorten the time needed for a tuner calibration has been proposed. The adaptive technique allows for a strong reduction of the calibration time while keeping the accuracy at a high level. The proposed method decomposes the necessary 2D sampling of vertical and horizontal movements of the tuner probe into two 1D sampling and modeling procedures. It has been applied to the passive tuner and the different numerical results confirm the accuracy and efficiency of the proposed approach, and its potential for an adaptive and automated extraction measurement technique using adaptive excitation.

![Figure 13. A general schematic diagram of the systems under study as a lumped/distributed structure. Transmission lines (TL) are tapped with the unknown elements or circuits (L). This example structure contains single and multiple reflection. The incident (a) and the reflected (b) are depicted. The case of the multiple reflection is illustrated by solid arrows while the single reflection case is depicted by dashed arrows.](image-url)
Overview of the contributions

- A model suite has been proposed that models LDSs. It consists of three models with different complexity that can provide accurate models and stay parsimonious in the number of model parameters [1].
- A fully rational model (the Koga multi-delay model) has been implemented that can estimate multiple reflections with one set of parameters [2].
- The model suite has been successfully applied to SI application examples [3].
- An adaptive sampling technique has been proposed and implemented to perform faster calibration procedures on passive impedance tuners [4].

The examples and the results are available in the recently published PhD Thesis that is available on the ELEC website: https://vubirelec.be/knowledge/publications/list-of-phds

References:


2.6.3 BLA-based Design and Analysis of VCO-based Sigma-Delta Modulators

Dries Peumans and Gerd Vandersteen

Funding: FWO scholarship

Nonlinear system theory is involved. The available theoretical frameworks depend on the assumed system properties and the applied signals. An example is the Volterra theory framework which uses a series expansion of the system’s behaviour around an operating point. This operating point can be fixed (classical Volterra theory), periodically varying, or can consist of an expansion around a reference signal. Volterra series expansions have the advantage to be a direct extension of the linear system theory, but have the disadvantage that they often lead to complex expressions and that they can only describe weakly nonlinear systems.

Various techniques exist to reuse the linear frameworks in system theory, system design, identification, and control using approximative models of the nonlinear system. Examples of such techniques include (but are not limited to) the Describing Functions (DF) and the Best-Linear Approximations (BLA) framework.
The DF framework allows to approximate the input-output relationship of static nonlinear blocks (including saturation and/or hysteresis phenomena) by a linear gain which is function of the excitation signal’s characteristics. The DF considers a class of excitations which are combinations of input signals comprising a constant operating point, a single-sinusoid input (SIDF), a two-sinusoid input (TIDF) or a random input (RIDF). Furthermore, the DF assumes that the filtering characteristic of the overall system filters signals such that the output signal assumptions are a good approximation of the reality.

The theory around the DF allows the analysis/design of not only (nonlinear) control loops, but also the study of limit cycles within autonomous nonlinear systems. Throughout the years, the DF has been proven beneficial for the nonlinear analysis of oscillators [11, 12, 13] and sigma-delta modulators. However, the DF has two main drawbacks: its potential to measure frequency dynamics is limited and it does not give insight in the (unmodelled) residuals/nonlinear distortion.

The Best-Linear Approximation framework almost starts from the dual viewpoint: it approximates the linearised dynamic behaviour (in least-squares sense) from a (strongly) nonlinear system assuming a Gaussian-like input signal. Different BLA extraction techniques exist (robust method, fast method and local polynomial method) using multisine excitations (a subset of Gaussian-like inputs) which enable the measurement of the linear dynamic behaviour under a wideband excitation, and allows the separation of the steady state and transient response, additive measurement noise and even/odd nonlinear distortions. Lately, the BLA has been successfully extended towards non-autonomous (periodically) time-varying systems. Using the BLA and the characterized distortion levels, a Distortion Contribution Analysis (DCA) can be performed to pinpoint the dominant sources of nonlinear behaviour. The disadvantage of exclusively working with Gaussian-like signals is the impossibility to analyse (periodically) autonomous systems.

It can be concluded that the BLA and the DF start from a different point of view and result into complementary application domains. In particular cases, the BLA and DF are related to each other. However, no general theory exists for the linear approximation for both autonomous and non-autonomous nonlinear dynamical systems, which combines concepts from both the BLA and DF. The aim of this PhD is to develop and illustrate such a theory to more effectively analyse and design complex nonlinear systems.

References


2.7 HIGH FREQUENCY DESIGN AND CHARACTERIZATION

2.7.1 Model driven design of high performance microwave structures

Evi Van Nechel, Yves Rolain, John Lataire

Microwave filters are steadily evolving towards the use of more complex transmission line structures as building blocks. This is needed to cope with the highly demanding specifications of modern telecommunication equipment.

The design procedures that are used to realize these filters however have not evolved at the same pace. They still rely on the use of lossless, analytical models that are borrowed from standard line structures to approximate more complex, lossy structures. The lack of accuracy that results from this crude approximation is then filled using massive numerical optimization based on EM simulations. This process is both time-consuming and blocks the intuitive insight in the operation of the device. The loss of physical insight makes it harder for the designer to make proper design choices and can lead to designs that are too sensitive.

To circumvent these disadvantages, we propose to introduce model driven design. This is done by using 2 different approaches:

1. Introducing an accurate equivalent circuit model into the design procedure

An accurate equivalent circuit model is extracted for an elementary section of the considered microstripstructure. The discrete parameters of the model are related to the geometrical parameters of the structure. We will maintain the analytical models from the classical design procedure and extend them to make the procedure sufficiently accurate, thereby eliminating the need for optimisation.

2. Introducing metamodeling into the design procedure

The geometrical parameters of the complete microstripstructure are linked to the filter characteristics or the filter specification parameters through metamodels. The metamodels are then used in the optimization process instead of the computationally expensive EM simulations, resulting in an accurate and efficient optimization directly on the structure of interest. Using a metamodeling-based design a designer needs more than 5000 times less CPU time compared to an EM-optimization-based design.

After designing a modulated RF device, the nonlinear behavior of the system needs to be characterized. Several widely used Figures of Merit (FOM) exist for this purpose. To improve the time and effort necessary to extract the traditional FOMs, we are working at an alternative that is based on the Best Linear Approximation.

Reference

[1] Yves Rolain, Maral Zyari, Evi Van Nechel, Gerd Vandersteen. A measurement-based error-vector-magnitude model to assess non linearity at the system level. IEEE MTT-S International Microwave Symposium (IMS), Honolulu, Hawaii, 4-9 June 2017, pp. 1429-1432
2.8 MEDICAL MEASUREMENTS AND SIGNAL ANALYSIS

2.8.1 Estimation of respiratory impedance at low frequencies using the forced oscillation technique

Hannes Maes and Gerd Vandersteen

Funding: the Science Foundation Flanders (FWOAL662) and Center for model-based system improvement - From Computer-Aided Engineering to Model-Aided Engineering (SRP19)

The forced oscillation technique (FOT) is a non-invasive measurement technique to characterize the impedance of a respiratory system (Zrs). Zrs is defined as a frequency dependent ratio of pressure at the airway opening (pao) to air flow (qe) induced by Zrs.

It is emphasized in [1] that measurement and analysis of Zrs at lower physiological frequency ranges (< 10 Hz) is most sensitive to normal physical processes and pathological structural alterations. This work aims at measuring Zrs on spontaneously breathing patients at lower frequency ranges using FOT.

A pressure generating device with a low output impedance ZD is developed [2] and is used for measurements on patients with COPD, asthma and without respiratory complaints.

![Diagram](image)

**Figure 14: Measurement of Zrs.** pe: wanted pressure excitation, ZD: output impedance of device, pao: pressure at airway opening, qao: flow at airway opening, consisting of the addition of response qe of respiratory system Zrs with breathing flow qb.

The main difficulty in the measurement of Zrs is the presence of the breathing flow qb which overlaps with qe in the low frequencies (Figure 14).
Elimination of the breathing disturbance from the estimation of Zrs has been done by means of nonlinear breathing models in [3] and by regularization techniques in [4]. Additionally, a measurement technique using adaptive excitation signals has been deployed and has proven to be effective during clinical trials at UZ Brussel. The technique has been patented under the name “Improved methods for determining respiratory properties and system therefor” and the results are available in the recently published PhD Thesis that is available on the ELEC website.

References:


3. Development cooperation

3.1 DEVELOPMENT COOPERATION IN CURRICULA BUILDING AND ACADEMIC RESEARCH

The department ELEC has a long tradition in development cooperation with universities and institutes in the South. Projects with funding from the Belgian government for Development Cooperation already were undertaken from the eighties of last century with the Moi University in Eldoret Kenya, Anton de Kom University in Paramaribo, Surinam and ESPOL in Guayaquil, Ecuador.

With the support of the VLIR (Flemish Interuniversity Council) Prof. Leo Van Biesen from ELEC became leader (promoter) in two development cooperation projects in central Africa. Both projects, described in more detail in the next sections, aim to contribute in the rebuilding of the academic and/or professional education programmes, in improving the research facilities and in the formation by Master degrees and/or PhD of future academic staff personnel. Such projects belong either to the funding group of the VLIR Own Initiative group with partners in the countries of the development cooperation priorities of the Belgian Federal and Community governments with a medium term duration between 3 to 5 years, either to the VLIR Institutional University Cooperation programme (IUC) that facilitates a 12-year partnership between a university in the South and Flemish universities and university colleges. These programmes support the partner university in its triple function as provider of educational, research-related and societal services. It aims, as such, at empowering the local university as to better fulfil its role as development actor in society.

3.2 UIC PROJECT WITH THE UNIVERSITY OF BURUNDI, BUJUMBURA, BURUNDI

The VLIR Institutional cooperation with Université du Burundi, Burundi, is a project with a duration and 12 years that started in 2011. The Flemish programme coordinator is Prof. Filip Reyntjens (University of Antwerp) and the local programme coordinator is Prof. Samuel Bigawa. The project consists of 5 major subprojects and 1 subproject responsible for the management and reporting. Prof. Leo Van Biesen (ELEC) is promoter of subproject 5 that deals with new communication and information technologies and support to the library. The local project leader is Prof. Léonard Batururimi.

The 5 subprojects are listed below:

1. Strengthening teaching and research capacity in basic sciences and pharmacy.
2. Contribution to the improvement of medical education, research and to the quality of health care in the community
3. Rural development and food security in the provinces of Ngozi and Kayanza
4. Capacity building for teaching and research in the Faculty of Law
5. New communication and information technologies and support to the library
The Université du Burundi (UB) is the only public university of the country and is located in the capital Bujumbura. It started an IUC programme in 2010 that fully subscribed to the PRSP (Poverty Reduction Strategy Papers) development priorities of a post-conflict area. In this context the University of Burundi is to be reinforced in its role of development actor towards society through interventions of higher education and research. As such, a partnership with the Flemish universities and university colleges is established and sustainable scientific cooperation implemented.

The IUC programme encompasses 5 thematic projects, basic sciences, rural health, food security, development of the Rule of Law and ICT and library development. Most of the projects are campus-based but projects 2 and 3 operate in the North of the country in the provinces of Ngozi, Kirundo and Muyinga. The partnership proudly carries the label 'Kubadilishana Mawazo, Kugeuza Maisha' or 'Sharing minds, Changing lives' in Kiswahili.

For more information on the programme, you can also visit the UB - VLIR-UOS website (http://www.vliruos.be/en/ongoing-projects/overview-of-ongoing-projects/iuc/institutional-cooperation-with-universit%C3%A9-du-burundi-(ub),-burundi/).

The local promoter of subproject 5, Prof. Léonard Batururimi, and the Dean of the faculty of engineering at the University of Burundi, Prof. William Sahinguvu, visited the department ELEC in 2013 for 2 weeks. Eloge Bapfunya received a 3 months training in ICT and telecom at the departments ELEC and ETRO of the VUB and Egide Nshimirimana is following the Master in Applied Computer Science at the engineering faculty of the VUB.

The yearly envelope of subproject 5 is about 75 k€.
4. Education

4.1 THE INTRODUCTION OF THE BACHELOR-MASTER STRUCTURE

Since the academic year 2004-2005 the "bachelor - master" structure (replacing the candidate - licentiate structure) has been introduced. The initiative for this thorough interference in the programmes of higher education was the Bologna Declaration. The Ministers of Education of 31 European Countries gave in 1999 the start to uniform the higher education in Europe. Although the Bologna process creates convergence, the fundamental principles of autonomy and diversity are still respected. The aim of the Bologna Declaration is to improve in Europe the exchangeability of degrees, the free mobility of students, quality assurance and a flexible study package by introducing credit systems.

4.2 BRUFACE (WWW.BRUFACE.EU/EN/)

Brussels Faculty of Engineering (in short "Bruface") is an initiative of the two universities in the centre of Brussels. The Université Libre de Bruxelles (ULB) and the Vrije Universiteit Brussel (VUB) jointly offer a broad spectrum of fully English taught master programmes in engineering.

Starting from the academic year 2011-2012 Université Libre de Bruxelles and Vrije Universiteit Brussel jointly organise the following English taught Master of Science (MSc) programmes

- MSc in Architectural Engineering
- MSc in Chemical and Materials Engineering
- Options Materials, Process Technology
- MSc in Civil Engineering
- MSc in Electromechanical Engineering
- Options Aeronautics, Energy, Mechatronics-Construction, Vehicle Technology and Transport
- MSc in Electronics and Information Technology Engineering

The Université Libre de Bruxelles (ULB) and the Vrije Universiteit Brussel (VUB) are both active in several international higher education networks including T.I.M.E.\(^1\) and UNICA\(^2\).

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\(^1\) Top Industrial Managers Europe: is a network of 51 leading Engineering Schools and Faculties and Technical Universities which offers, through a system of voluntary bilateral agreements between its members, promotion and recognition of academic excellence and relevance to the international labour market in the form of Double Degrees in engineering and in related fields.

\(^2\) Is a network of 42 Universities from the Capital cities of Europe, with a combined strength of over 120,000 staff and 1,500,000 students. Its role is to promote academic excellence, integration and co-operation between member universities throughout Europe.
### 4.3 COURSES LECTURED IN THE FACULTY OF ENGINEERING

#### 4.3.1 Regular Courses, Bachelor Degree (academic year 2016-2017)

<table>
<thead>
<tr>
<th>Lectures and practical courses</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Applied Electricity</strong> - Prof. Yves Rolain and Prof. R. Pintelon (Network Theory)</td>
<td>7</td>
</tr>
<tr>
<td>2 major goals are to be attained:</td>
<td></td>
</tr>
<tr>
<td>1) Getting insight in the use of mathematical tools to describe the most important experimental classical laws. One starts from the 4 equations of Maxwell. It is demonstrated that when including the law of Lorentz, which expresses the interaction between electrical sources and mechanical forces, any electrical problem can be solved. To achieve this task an introduction on Newtonian potentials is given. Using the theory of Helmholtz, it is shown that the approach of potentials yields an adequate and concise method to tackle electrical problems. This potential theory is also of use in other physical domains then electricity, such as mechanics and hydraulics, and, therefore, this theory is kept as fundamental as possible. The mechanism of conduction in conductors is studied using Ohm’s law in local and global form. The resistance is studied as well as the current and voltage distributions in a conductor (calculus methods of Hopkinson). Attention is always drawn on the methods to predict the responses and influences when an electrical source (in scalar or vector form) is applied to a physical system. A mathematical model describing a battery is studied. The same approach to model the sources is also treated for magnetic and dielectric media, whereby an energetic balance is deducted.</td>
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<tr>
<td>2) Introduction to network analysis and theory.</td>
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<tr>
<td><strong>Applied Statistics</strong> - Prof. G. Vandersteen</td>
<td>3</td>
</tr>
<tr>
<td>The theory and exercises deal with the following topics</td>
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<tr>
<td>Introduction</td>
<td></td>
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<tr>
<td>Dealing with probabilities: why do you need a course on statistics</td>
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<tr>
<td>Stochastic variables: characterization; physical interpretation</td>
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<tr>
<td>Probability density functions: description; physical interpretation; relations</td>
<td></td>
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<tr>
<td>Calculation of uncertainty bounds</td>
<td></td>
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<tr>
<td>Estimation of parameters</td>
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<tr>
<td>Hypothesis testing</td>
<td></td>
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<tr>
<td>Box plot: description, basic idea, applications</td>
<td></td>
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<tr>
<td><strong>Electromagnetism</strong> - Prof. Y. Rolain</td>
<td>6</td>
</tr>
<tr>
<td>Starting from the very general Maxwell equations, we end up with the differential equations that govern the behaviour of the electrical field in free space. This simple differential equation is subsequently solved using simple mathematical functions in different geometries and field configurations. These use-cases contain both real engineering problems and fair approximations of more complex situations. This includes but is not limited to the propagation of electromagnetic waves in free space, or in a guiding structure. Examples used in the course are the coaxial cable, the rectangular metal waveguide and the flat dielectric waveguides. The dissipative behaviour of the electrical field results in an in-depth analysis of the Skin-effect in plane and cylindrical conductors. A lot of time and effort is spent to cover the theory and the practical applications of the transmission lines. A whole collection of techniques are explained theoretically and are next illustrated in the tutorials, the exercises, and the laboratory work. Some examples are: the S-parameters, the reflection coefficient, the VSWR, the reflectometric setup, and the single- and double-stub matching techniques. Finally some energetic concepts of the propagation of the electromagnetic fields in the free space are touched. The vector of Pointing is used to introduce the basics of the theory of the antennas and to calculate the power balance of a radio propagation. The course is split in the Lectures and practical work.</td>
<td></td>
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<tr>
<td><strong>Information and Communication Technology</strong> - Prof. G. Vandersteen</td>
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</tr>
<tr>
<td>This work college has multiple aims. First, it is the goal to build a bridge between the highly theoretical courses and the practical applications in order to stimulate the future engineers. Second, it is the aim that the students get in touch with electronics, photonics and information theory (EIT), and in addition has some knowledge about control theory. This will enable the students to make an educated choice about what they want to study later on. A last goal is to inform the non-EIT students about some fundamental aspects on EIT and control theory.</td>
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<tr>
<td><strong>Network Analysis and Synthesis</strong> (3rd Bachelor) - Prof. R. Pintelon</td>
<td>7</td>
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<tr>
<td>Part 1: Linear networks and Nonlinear networks</td>
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<tr>
<td>Part 2: Synthesis of filters</td>
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<tr>
<td><strong>System and Control Theory</strong> - Prof Yves Rolain (system theory) and Prof Rik Pintelon (control theory)</td>
<td>6</td>
</tr>
<tr>
<td>Part 1: Introduction to system theory. Describing the behaviour of linear dynamic systems (continuous time, discrete time) in the time domain and in the frequency domain. It is also shown how these descriptions can be combined with information from measurements (sampling, discrete Fourier transform, reconstruction).</td>
<td></td>
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<tr>
<td>Part 2: analysis (calculus with block diagrams, state equations, time response frequency response, root locus, Nyquis diagram, Bode plot) and design of feedback controllers (state feedback controllers, compensation regulators such as PD, lead, PI, lag, and PID). The course ends with a number of practical examples such as de operational amplifier, de voltageregulator, and the compact disc player; and with an introduction to digital and nonlinear control,</td>
<td></td>
</tr>
</tbody>
</table>

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3 The language of tuition of the bachelor courses is Dutch
4.3.2 Regular Courses, Master Degree (academic year 2016-2017)

<table>
<thead>
<tr>
<th>Lectures and practical courses</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced Control Theory - Prof. R. Pintelon</td>
<td>4</td>
</tr>
<tr>
<td>This course describes basic concepts and techniques for the analysis and design of a number of advanced model based controllers: amongst others robust controllers (H-infinity), internal model controllers, and feedforward controllers. To limit the complexity of the maths, the course is limited to the simplest class of systems: linear single input single output systems. Moreover, the course does not put the emphasis on maths but on the hands on experience: design, implementation, and critical evaluation of the advanced controllers. Therefore the course also provides practical insight that is very useful to design and implement the controllers.</td>
<td></td>
</tr>
<tr>
<td>Advanced Measurement and Identification - Prof. Y. Rolain, Dr. J. Lataire</td>
<td>4</td>
</tr>
<tr>
<td>Engineers and scientists build models to understand, describe, predict and control the behaviour of the environment. In order to create these models it is necessary to combine the mathematical models with (noisy) measurements. In this advanced course, we will explore the consequences of having systems which do not satisfy the basic assumptions made when making frequency response function measurements. That is, we will learn how to deal with nonlinearities and time variations. Also, an introduction is given to the measurement of very high frequency signals and systems, and to the use of recursive identification techniques. In addition to a sound theoretical basis, we will also provide the students with hand on experiences in the labs.</td>
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</tr>
<tr>
<td>CAE-tools for the Design of Analog Electronic Circuits – Prof. G. Vandersteen</td>
<td>4</td>
</tr>
<tr>
<td>Analysis and design of analog electronic circuits is done using computer aided engineering (CAE) tools. The methods used comprise dc analysis, ac analysis, transient analysis, harmonic balance analysis, shooting method, large-signal / small signal analysis,... It is evident that every tool is optimized to analyze a specific type of circuit or analysis. Take for example the transient simulation which is available in SPICE. This transient simulator is not suited for analyzing nonlinear microwave circuits or for the noise analysis in mixers. To solve this problem, simulation techniques such as harmonic balance were developed. Harmonic balance assumes that all signal are either periodic or quasi-periodic. This makes harmonic balance unsuited for non-quasi-periodic signals, but makes the technique superior for the analysis of nonlinear microwave circuit and the noise analysis of mixer. The aim of the course is to teach the future engineer the pros and cons of the different available simulation tools. This way, he/she should be able to judge which CAE-tool is the most appropriate for solving his/her design or analysis problem. Besides the choice of the analysis tool, there is also the problem of setting the simulation parameters correctly. This requires some background in the actual implementation of the simulations techniques. Hence, a theoretical background of the different simulation techniques must be given in the course. In addition to the theoretical background of the different simulation techniques, there is also the question of the actual implementation of the simulations tools. This course is designed to give the students the necessary background to be able to use these tools correctly. This requires some background in the actual implementation of the simulations techniques. Hence, a theoretical background of the different simulation techniques must be given in the course. In addition to the theoretical background of the different simulation techniques, there is also the question of the actual implementation of the simulations tools. This course is designed to give the students the necessary background to be able to use these tools correctly.</td>
<td></td>
</tr>
<tr>
<td>Capita selecta Telecom – Prof. G. Vandersteen</td>
<td>3</td>
</tr>
<tr>
<td>The content changes year by year since the selected subjects in telecommunication are chosen in function of the industrial expectations and realisations. Subjects treated in the recent years are e.g.: xDSL and ADSL and VDSL2 in particular, GSM (GPRS) networks, Wi-Fi and meshed networks, RFID, UMTS, WiMAX, SACD coding versus Dolby or DTS, GNSS, Tetra, IP-TV, UWB...</td>
<td></td>
</tr>
<tr>
<td>High-frequency Electronics and Antennas -Prof. Y. Rolain</td>
<td>4</td>
</tr>
<tr>
<td>This course introduces the analysis, the design and the measurement of electronic circuits operating at RF and microwave frequencies.</td>
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<tr>
<td>Identification of Dynamical Systems – Prof. R. Pintelon</td>
<td>4</td>
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<tr>
<td>This course describes the various steps one has to go through for obtaining a linear dynamic model of a process. It starts with the choice (design) of the measurement setup, the choice (design) of the excitation signal, the choice of the simulation techniques (such as harmonic balance), the estimation of the parametric model (identification toolboxes in Matlab), till finally the model selection and the model validation. Hereby the influence of each error source (stochastic measurement errors, systematic measurement errors, non-linear distortions, time-variant effects, model errors...) on the final result is studied in detail. Each step is illustrated thoroughly by means of real life examples.</td>
<td></td>
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<tr>
<td>Industrial Measurement Environments - Prof. Y. Rolain</td>
<td>4</td>
</tr>
<tr>
<td>This course is dedicated to industrial metrology. The learning objective consists in the study of the building blocks of instrumentation in metrology (measurements) and to adapt those to industrial requirements and environments. Since the content of this course is highly based on technology, it evolves strongly. Therefore, the students will receive updated information on standards and specific realisations, which are demonstrated by on site industrial plant visits. After completion of the course, the students should be able to analyse industrial measurement problems, to conceive and to plan metrological installations, to integrate and to network them.</td>
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<tr>
<td>Measurement and Identification- Prof. Y. Rolain, Dr. J. Lataire and Dr. Ph. Dreesen</td>
<td>4</td>
</tr>
<tr>
<td>Engineers and scientists build models to understand, describe, predict and control the behaviour of the environment. In order to create these models it is necessary to combine the mathematical models with (noisy) measurements. In this course general methods are given in order to obtain good measurements, and to use this data to build a model.</td>
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<tr>
<td>Measuring and Modelling of Nonlinear Systems –</td>
<td>3</td>
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<tr>
<td>Linear system theory is a simple but very successful description of nature although most systems are nonlinear. For that reason it is important for an engineer to know how the presence of nonlinear distortions can be detected.</td>
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</table>

*The language of tuition of the Master courses is English and/or Dutch*
On the basis of this information, she/he should decide if linear system theory is still applicable to solve his problem. On the other hand, some systems are intrinsic nonlinear. Till recent, it was very hard to measure these characteristics. New measurement equipment allows nowadays to characterize also these nonlinear systems. For that reason it is necessary that our engineers have a sufficient background to access these new possibilities. Applications exist in the mechanical, electrical, electronic and microwave fields. This course offers a good basis to recognize, understand and deal with such nonlinear problems.

**Physical Communication - Prof. G. Vandersteen**
Problems with radio communications: used frequencies, propagation paths, and modulation methods. Advanced study of AM modulations (conventional AM, DSB, SSB, VSB, QAM), angle modulations (WBFM, NBFM, PM), digital modulations (FSK, PSK, DMT). Study of the properties of transmission channels and SNR studies of demodulators. Many practical circuits and schemes are treated. Study of the atmosphere as channel for radio and satellite communications. Bundle profiles of antennas and (linear) antenna-arrays. Study of reflection, transmission, diffraction, refraction and scattering...

**RF/Microwave Design Techniques: from Datasheet to Product - Prof. Y. Rolain and Prof. G. Vandersteen**
The step from a prototype to a commercial product is larger than seen at first sight. To cut the price of the final product, it is important.
The aim of this course is to close in the gap between the theoretical knowledge on RF/microwave design, and the design of a commercial product. Starting from the knowledge on electromagnetics and RF/microwave amplifier design, all design aspects of complete RF/microwave systems are covered in the course. This includes the system-level design, the design of different RF/microwave sub-systems (such as mixers, amplifiers, hybrids, filters, antennas...), their design for manufacturability (production tolerances, Design Rule Checking (DRC) ) and their protection to the manipulation by the user (e.g. ESD-protection).

**Signal Theory - Prof. G. Vandersteen and Prof. I. Markovsky**
Signals and information and signal classification, the terminology, the elements in a communication system, the kind of signals: the deterministic ones, stochastic signals, periodic signals. Use of basic functions and integral transformations:
The properties of stochastic signals. Statistical averages, ensembles and realisations, mixed signals, wide sense stationary signals and ergodic signals. Markov processes. Spectral analysis applied to stochastic processes. The theorem of Wiener-Kinchine, the periodogram, the properties of the autocorrelation function. The telegraph signal, the binary synchronous NRZ-signal. White Gaussian noise. The Karhunen-Loève series. Estimation of signals in the sense of the least squares. The orthogonality principle, the Wiener filter. Linear detection of signals: the 'Matched Filter'.
Modulation methods. Amplitude modulation. AM-modulators, modulators with a quadratic law and of the switching type. Detection of AM-signals (synchronous detection, detection with diodes, the envelope detector. The double sideband AM (DSB), single sideband AM-modulation (SSB), the vestigial sideband (VSB). The PLL. Application of AM-modulation: the colour television and the PAL -system. Frequency modulation. Decomposition of angle modulated signals into sinusoids and determination of the bandwidth of FM. SECAM and stereo radio. FM-demodulators. Pre- and the-emphasis filters.
Information theory. The auto-information, the entropy. The entropy of a discrete and of a continuous source. The conditional entropy. The trans-information and the capacity of a transmission channel. The symmetric Binary Channel (BSC).
Redundancy of a channel. Fundamental coding theorems of Shannon. Development of codes with unequal length and optimised coding.

**Voice Image Coding Media and Systems - Prof. I. Markovsky**
Part 1:
Chapter 1: introduction to telephony. The telephone set, general description, the transmission of the signals. The side-tone circuitry, the complete telephone set, making a connection, the bell circuitry, and the switchboard.
Chapter 2: characteristic parameters of transmission lines. The line types and their parameters. Aerial lines, cable lines and coaxial cables. The influence of the frequency on the characteristic impedance and the propagation factor (attenuation and phase). Improvement of the quality of cables. Practical telephony cables are treated (Belgacom, BT, France Telecom, KPN, ETSI-models).
Chapter 4: Telephony using carriers.
Digital Subscriber Line. Digital technologies are studied. HDSL, ADSL and SDSL modems are treated. Cross-talk problems are examined (NEXT, FEXT). De theoretical channel capacity for ADSL, SDSL and VDSL are derived and compared to practical measurements.
Chapter 6: Markovian processes. The infinite switching channel, the switching board with losses. The finite switching board with a queuing line.
Part 2:
Relying on the codes, which have been studied in the Signal Theory course and which have been optimised with respect to (average) code length and do take into account the entropy of the source, block-coding and convolutional codes are studied theoretically and are applied in practical examples.
Following applications are treated: the Radio-Data-System (RDS), as an example of syndrome decoding, NICAM (digital stereophony) to illustrate companding, TeleText, the CIRS-coding in the Compact Disc (CD). Theory of a cellular radio applied in depth towards the GSM.
Introduction to underwater acoustical communications.
4.4 DESIGNING SYSTEMS FROM CONCEPTS: THE PING-PONG TOWER PROJECT

The design of complex systems demands that engineers possess significant set of abstract system-level thinking skills. Engineering students therefore need to be exposed to the art of solving problems systematically and have to learn the limitations and the backsides of ad-hoc methods, to ensure that they should only turn to these methods as last resort alternatives.

To start the process of system-based thinking early, we use an experience based learning project during the students’ fourth semester to awaken them to a systematic engineering approach. This project is taken by all engineering students at our university. As a consequence, all the students are taught the crucial concepts that can lead to the inclusion of sustainable development in engineering practice irrespective of their final specialization in electronics, mechanics, chemistry....

A feasible toy engineering problem is proposed that includes a lot of practical engineering problems: The process to be controlled is the stabilization of the height of a Ping-Pong ball floating in a user-controlled airflow inside a transparent Plexiglas tube. Although students get a strong guidance towards good engineering practice, they have to choose the method and decide on the practical implementation themselves.

Pedagogically speaking, the major advantage of this project is that the students gain a lot of engineering attitudes. Firstly, they gain hands-on experience in a wide range of engineering applications: digital electronics, analog electronics, power electronics, control engineering, signal processing, optical system design, and computer engineering all have their role to play in the project. Secondly, they gain the insight that system-level thinking leads to complexity reduction and problem partitioning, and therefore allows to solve large-scale problems that would remain untracktable otherwise. They learn that walking the lines of a systematic design framework leads to well-understood, high-quality, reproducible and reusable results.

In the next section, we situate the project in the engineering study. Afterwards, we explain the different steps the student should take. Then we describe which engineering attitudes the students gain throughout this project.

4.4.1 Situating the project

At the Vrije Universiteit Brussel, all engineering students follow the same courses during their first four semesters of their bachelor education. In order to help the engineering students to choose
between different specializations, they are confronted with four different engineering problems in their fourth semester, one in civil engineering, one in chemical engineering, one in mechanical engineering and one in electronic engineering.

The ping pong tower project has a number of inherent advantages due to its broad range of possible solutions. The solutions that can be built

- are a combination of analog and digital electronics;
- use both hardware and software solutions;
- have the dynamics of the system are in a practical range, making it possible to demonstrate instabilities;
- involve no safety risks due to the use of low voltages;
- make it possible to introduce the students to control theory.

4.4.2 The project

The students need to control the height of a Ping-Pong ball in a tube by means of a fan which blows air in the tube. They need to set and measure the height using a PC. Every group needs to present its work in a scientific way by the end of the project to train their scientific presentation skills.

The goal is that the teams build up a complete solution starting from available basic building blocks:

1. A variable speed fan blows air into a Plexiglas tube whose diameter is 4 mm larger than the Ping-Pong ball.
2. An example interface between the PC and a PIC-based microcontroller board which has a USB connection to the PC. The firmware of the microcontroller board contains the implementation of an analog-to-digital convertor and a PID controller with user adjustable gains besides the present USB interface to the PC. The simple PC program allows the user to set the wanted height and read the actual height of the Ping-Pong ball from the microcontroller board.
3. Various pre-existing modules are available since – due to the limited timeframe – it is impossible that the students build everything from scratch. The pre-existing modules are an ultrasonic position sensor module, a fan power steering module, a microcontroller board and a simple PC program.

4.4.3 From concept to working system

The key idea is to illustrate the usefulness of a top-down design for the control of complex systems. The students are thought to first reason at the system level using simple system models. Next, good engineering practice rules are to be used to specify the modules separately. Then, the selected modules are designed separately from a set of discrete components. The final challenge is to combine everything in a performing system.
During the first one and a half day, the students try to understand the problem by slicing it into smaller sub-problems. During the next day, they decide on their strategy and implementation. The next two days, they spend on implementing their different blocks. The final one and a half day before the presentation, they need to combine the different sub-blocks and tune their controller.

### 4.4.3.1 Step 1: Understanding the problem

What is a system? This question is the key problem tackled in this phase. Therefore, the students get a short introduction to the system-level concept.

They discover the usefulness of a block diagram of their complete system to support high-level reasoning. They partition the problem into different logical blocks with a smaller complexity. They also have to think about the analog and/or digital interfaces between the different blocks. This brings them to a block diagram like Figure 1 the figure below.

For the first time in their education, the students have to deal with

- the sensors and sensor data,
- the controller,
- the power steering stage for the fan,
- interfacing the digital data between a PC and a microcontroller, and
- the design of a user-friendly interface on the PC.

![Figure 15. A possible block diagram for the problem.](image)

In order to be able to interconnect all the blocks, they need to decide on the interfaces between the different blocks. Therefore, they write down specifications for the different blocks. The interface specifications of the pre-existing modules are given in a datasheet format. These specifications let the students reflect on the interconnection and make them acquainted with datasheets. The power steering module – for example – has two different inputs: an analog voltage and a digital PWM input that are both controlling the output voltage. They have to decide which type of signal they are going to use and consider the influence of their choice to the rest of the system.

The students experience that most design problems do not have a unique solution, unlike what they found from their courses in mathematics. Although the control loop will always look the same at
system level, the block diagrams of the different groups can differ. Some groups implement for example the controller in the PC program, which moves the interface between the PC and the system directly to the controller input. Such choices have a large impact. The students learn to weight off the different advantages and disadvantages, and learn to slice a complex problem into tractable and independent, co-operating blocks.

4.4.3.2 Step 2: Strategic thinking

Due to the limited timeframe and their lack of practical experience, it is not possible for every group to build up a complete solution from scratch. Therefore, depending on the number of students in the group, two to three blocks are selected for a design from scratch, depending on the student’s own interest. This allows training their negotiation skills and expressing their leadership. They use the pre-existing modules for the other blocks.

The groups define work packages that fit the workload of two students for the next three days. Since they work in teams of two students, they all feel engaged in the project. They can make their own contribution to the project without being overshadowed by one brilliant student in the group who would otherwise be designing the complete project.

Every team then focuses on the design strategy of their specific block. They have the freedom to choose their approach freely. The sensor – for example – can be realized under different forms: an ultrasonic height sensor, an optical scan line, an image-based webcam sensor, … They are also encouraged to propose their own solutions, although the feasibility needs to be checked beforehand.

4.4.3.3 Step 3: Creating the different blocks

When they develop a specific block, they learn that the system-based approach used before can be reused. The specific problem is further split into different sub-blocks until they reach the level where building and understanding each part becomes straightforward. Then, each element is realized and tested to meet the prescribed specifications. Afterwards, those elementary parts are combined into subsystems.

For the ultrasonic sensor, this system-based approach results in the design of a transmitter, a receiver and a signal processing unit. The transmitter generates a pulsed 40 kHz signal together with its envelope. The receiver cleans up the measured reflected burst and generates a discrete envelope of the received signal. The signal processing unit measures the time T between the transmitted and reflected burst, which is proportional to the distance L between the sensor and the Ping-Pong ball.

The system-based approach can be recycled ones more. For example, the pulse transmitter in the ultrasonic sensor can be split into different blocks: the 40 kHz oscillator, the envelope generator, the masking of the oscillator by the envelope and the driver for the loudspeaker. These different blocks are basic electronic building blocks that the students already studied or can be found easily in references on electronic circuits or on the internet.
When the different basic building blocks are combined, the students experience the concepts of loading and interference. The loading of a circuit requires the design of an output driver such that it matches the input characteristics of the next block. The interference is minimized by a careful routing of the power line, proper decoupling and filtering of the appropriate signals.

During this step, they learn to iteratively use the system-level approach to end up with a hierarchical design and how elementary building blocks in electronics or informatics can be combined into a subsystem that meets the specifications. They also experience that the basic building blocks seen in introductory courses are used in real systems.

**4.4.3.4 Step 4: Going back to the system level**

Now that the separate blocks are operational, the challenge lies in their combination, i.e. by suppressing the interference and overcoming the loading of the different blocks.

Finally, system-level testing is performed. Once the system is reaching specs, it becomes time to close the control loop. Here, students encounter feedback loops for the first time. This shows them the power of feedback control and nicely illustrates the properties of the different control actions: The proportional gain which lacks accuracy, the derivative action for speed improvement and the integral action for error removal and the consequent instability.

First – by playing manually with the gains of the different actions – the students discover the advantages and disadvantages of the different actions. Second – by the end of the day – the students are explained how the relay test works. This allows them to obtain a working controller without any heuristic search.

Hence, the way is now opened for them to understand the usefulness and the power of the otherwise so abstract control theory. They learn to evaluate the control behaviour by looking at the tracking behaviour and the disturbance rejection.

During this step, they learn how to combine different blocks to a larger system and also to evaluate and tune the system’s performance by measurements.
To finalize their effort and tune their controller, they need one and a half day.

4.4.3.5 Step 5: Presentation
During the last half day, the groups have to demonstrate their system to the groups and give a scientific presentation of their solution. This presentation trains their communication skill. It also enables them to learn about other implementations from other groups.

4.4.3.6 Conclusion
The project is mainly intended to help the students to make an informative choice about their engineering specialization, and also teaches them a fundamental engineering concept: design a complex control system.

The system-level systematic framework enables the engineer to develop well-understood, high-quality, reproducible and reusable results.

4.5 COURSES LECTURED IN THE FACULTY OF SCIENCE AND BIO-ENGINEERING

<table>
<thead>
<tr>
<th>Lectures and practical courses</th>
<th>Credits</th>
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<tbody>
<tr>
<td>Berekenbaarheid en informatietheorie⁵ - Prof. L. Van Biesen</td>
<td>6</td>
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<tr>
<td>Computability and Information Theory</td>
<td></td>
</tr>
<tr>
<td>1st Year Master of Sciences in Engineering: Computer Science (compulsory)</td>
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<tr>
<td>Geographical Information Systems - Prof. L. Van Biesen</td>
<td>3</td>
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<tr>
<td>2nd Year Master of Ecological Marine Management (compulsory)</td>
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<tr>
<td>2nd Year Master of Sciences in Engineering: Applied Computer Science (optional)</td>
<td></td>
</tr>
<tr>
<td>2nd Year Master of Science Ecological Marine Management (compulsory)</td>
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<tr>
<td>Theory of Computation and Information Theory - Prof. L. Van Biesen</td>
<td>6</td>
</tr>
<tr>
<td>1st Year Master of Sciences in Engineering: Computer Science (compulsory)</td>
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<tr>
<td>Analyse, WPO⁶: Dr. Mariya Ishteva</td>
<td>14</td>
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<tr>
<td>Analysis, Exercises</td>
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<tr>
<td>1st Year Bachelor of Science in Engineering</td>
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<tr>
<td>Complexe Analyse, WPO⁷: Dries Peumans and Evi Van Nechel</td>
<td>5</td>
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<tr>
<td>Complex Analysis, Exercises, Exercises</td>
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<tr>
<td>2nd Year Bachelor of Sciences in Engineering and physics</td>
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<tr>
<td>Aanvullingen van de Wiskunde (3rd Bachelor), Lecturer: Prof. S. Caenepeel, Exercises: Dr. M. Ishteva</td>
<td>3</td>
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</table>

4.6 NATIONAL AND INTERNATIONAL COURSES

4.6.1 National courses (since 2003):

4.6.1.1 Identificatie van systemen (Identification of Systems)
Organised by: University of Gent, “Instituut voor permanente vorming”
Location: IVPV - UGent, Technologiepark, 9052 Gent-Zwijnaarde

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⁵ The language of tuition of this course is Dutch
⁶ The language of tuition of this course is Dutch
⁷ The language of tuition of this course is Dutch
Meten en modelleren is een basisactiviteit van vele ingenieurs: modellen worden gebruikt tijdens het ontwerp, in simulatoren en in eindproducten. Het modelleringsproces is een complexe activiteit die in 4 grote delen kan worden opgesplitst: verzamelen van de experimentele data; opstellen van een model; in overeenstemming brengen van een model en data; validatie van de resultaten.

Systeemidentificatie biedt een systematische, optimale oplossing en wordt in deze module bestudeerd, met als toepassing the identificeren van dynamische systemen. Hierbij wordt de klemtoon gelegd op het aanbrengen van de ideeën, ondersteund door uitgewerkte Matlab illustraties.

De behandelde topics zijn

- **Systeemidentificatie: wat? waarom?**
  Een verhelderend voorbeeld
  Goede schatters/slechte schatters, wat mag je ervan verwachten?

- **Niet-parametrische identificatie van frequentieresponse functies**
  Basisidee: van tijdsignaal tot frequentierespons (FRF)
  Experiment design: keuze van de excitatiesignalen, ruisgevoeligheid, uitmiddelen
  Nietlineaire distorties: detectie, kwalificatie en quantificatie

- **Parametrische identificatie van de transferfunctie**
  Basisidee: van data tot model
  Tijdsdomein- en frequentiedomein-identificatie

- **Identificatie van tijdsvariërende systemen**
  Basisidee
  Balans volgsnelheid/ruisgevoeligheid

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**4.6.1.2 Courses lectured at the Katholieke Universiteit Leuven (KULeuven)**

- **Rik Pintelon:** "Identificeren van lineaire dynamische systemen" 18 HOC, 36 WPO (4 credits): keuze o.o. in de Master in de wiskundige ingenieurstechnieken

- **Dr. Philippe Dreesen:** "System Identification and Modeling" (3 credits):

- **Master in de ingenieurswetenschappen: wiskundige ingenieurstechnieken**

- **Master in de ingenieurswetenschappen: bouwkunde**

- **Master in de wiskunde**

- **Master in de ingenieurswetenschappen: wiskundige ingenieurstechnieken, programma voor industrieel ingenieurs of master industriële wetenschappen (aanverwante richting) (na toelating)**

- **Yves Rolain:** "Meten en modelleren" keuze o.o. in de Master in de wiskundige ingenieurstechnieken
4.6.1.3 **Open course program-IMEC academy: DSP concept explained with well-chosen exercises.**

**Organised by:** imec-leuven  
**Location:** imec, Leuven, Belgium  
**Lectured by:** Johan Schoukens and Yves Rolain  
**Dates:** November 14th, 28th, December 5th, 19th, 22nd (2011)

The course is a basic theoretical introduction to the concepts of digital signal processing.

- Introduction to system theory and signal processing impulse response and transfer functions of linear systems; stability-causality; poles and zeros; sampling DFF=FFT – all with Matlab exercises.
- Introduction to measurement and modelling of linear systems (measurement of the frequency response function; choice of excitation; the effect of noise and leakage; estimation of the parametric model) – including Matlab exercises.
- Handling non-linear distortion: detection; classification and qualification of linear distortion – including Matlab exercises.
- Design of digital filters and systems (basic choices and non idealities: filter examples; compression and expansion ...) – including Matlab exercises.
- Wrap-up: further Matlab exercises applying the techniques on integrated problems. Analysis of implemented filters; evaluating non-linear distortions (impact of quantizing noise).

4.6.1.4 **Measuring, Modeling Identification and design of (non)linear systems**

**Organised by:** imec-leuven  
**Location:** NXP Semiconductors, Nijmegen, The Netherlands  
**Lectured by:** Johan Schoukens, Gerd Vandersteen and Yves Rolain  
**Dates:** April 9-12, June 12-14 (2013)

4.6.1.5 **System Identification in the real world (J. Schoukens)**

**Location:** VUB  
**Organised by:** IAP-Graduate School in Systems, Optimization, Control and Networks (SOCN)  
**Dates:** February 24, 27 and March 3, 6, 10, 12, 2015

- Lesson 1: System Identification: from data to model
- Lesson 2: Nonparametric identification of linear dynamical systems
- Lesson 3: Impact of nonlinear distortions and time-varying behavior on the linear identification framework
- Lesson 4: Identification of linear systems
- Lesson 5: Identification of nonlinear systems: Guest speakers: Koen Tiels and Maarten Schoukens
Lesson 6: Dealing with time varying systems: Guest speakers: Rik Pintelon, Ebrahim Louarroud, John Lataire

4.6.2 International courses (since 2003):

4.6.2.1 Characterisation of Multiport Systems through 3-port LSNA Measurements
Location: Seminar at NIST, Boulder, CO, December 2003
Lectured by: Wendy Van Moer
# attendees: 20

4.6.2.2 The use of multisines
Location: Seminar at NIST, Boulder, CO, December 2003
Lectured by: Daan Rabijns
# attendees: 20

4.6.2.3 GIS training in SEAFDEC, Thailand
Location: Samut Prakan SEAFDEC/Training Department, Thailand, Bangkok, 2005
Lectured by: Tesfazghi Ghebre Egziabeher
The theme of the course was interrelated to the use of Geographic Information System for Fishery Management. Participants of the course were members of the Southeast Asian Fisheries Development and Training Centre (SEAFDC/TD), who were professionally engaged in the fishing industry.

4.6.2.4 Measuring, Modeling, and Designing in a Nonlinear Environment
Location: tutorial workshop organized at I2MTC08, Vancouver, Canada, May 2008
Lectured by: Yves Rolain, Ludwig De Locht, Rik Pintelon, Johan Schoukens, Wendy Van Moer
Topics:
- Best linear approximation and design: A perfect marriage (L. De Locht)
- Measurement of the Best Linear Approximation of Nonlinear Systems (W. Van Moer)
- Impact of nonlinear distortions on the linear framework (J. Schoukens)
- Frequency Response Function Measurement in the Presence of Nonlinear Distortions (R. Pintelon)

4.6.2.5 VUB - doctoral school on Identification of Nonlinear Dynamic Systems
Location: Dept. ELEC, Vrije Universiteit Brussel, Building K, 6th floor
Lectured by: Rik Pintelon, Johan Schoukens, Gerd Vandersteen, Yves Rolain
# attendees: Since 2010 an average of 25 attendees.
The department ELEC of the VUB, organized a 4 weeks doctoral school during springtime (May-June) to give an intensive training on advanced modelling and simulation techniques of (non)linear dynamic
systems, starting from experimental data. Half of the time has been spent on courses/exercises, the other half on a project to get hands-on experience. The material taught during the courses and exercises has been put into practice during a clearly defined project, in order to get hands-on experience. The course covered the following topics:

- A basic introduction to system identification,
- Identification of dynamic systems,
- Measuring and modelling of nonlinear systems,
- Simulation tools for nonlinear systems,
- Design and characterization of high-frequency (nonlinear) systems (optional: intended for those with an interest in microwave systems).

**4.6.2.6 Mini-course on System identification in the behavioral setting: A low-rank approximation approach**


*Lectured by:* Ivan Markovsky

**4.6.2.7 SOCN course Low-rank approximation and its applications,**

*Dates and location:* March 12, 13, 14, 19, 20, 21, 2014, K.U.Leuven, 20 attendees

*Lectured by:* Ivan Markovsky

*Description*

Established data modeling approaches are often derived in a stochastic setting. An alternative deterministic approximation approach, known in the systems and control literature as the behavioral approach, has been developed since the 80’s by Jan C. Willems and co-workers. The behavioral approach differentiates between the abstract notion of a model and the concrete notion of a model representation. This distinction proves to be important for developing a coherent theory and effective algorithms for system identification, analysis, and control. The course presents a behavioral approach to system identification.

The highlight of the course is the low-rank approximation problem, which is a practical tool for modeling in the behavioral setting. A matrix constructed from the data being rank deficient implies that there is an exact low complexity linear model for that data. Moreover, the rank of the data matrix corresponds to the complexity of the model. In the generic case when an exact low-complexity model does not exist, the aim is to find a model that fits the data approximately. The corresponding computational problem is low-rank approximation. In the case of linear time-invariant dynamical models, the data matrix is, in addition, Hankel structured and the approximation should have the same structure.
Once the approximate system identification problem is formulated as a low-rank approximation problem, it is solved by generic methods. Except for a few special cases, however, low-rank approximation problems are nonconvex and a global solution is expensive to compute. In the course, we present methods based on local optimization, which lead to fast and effective algorithms. The cost function evaluation has the system theoretic interpretation of Kalman smoothing.

In addition to the theory and algorithms for exact and approximate system identification, the course presents examples from system theory (model reduction and distance to uncontrollability), computer algebra (approximate common divisor computation), and machine learning (recommender systems). Software implementation of the developed methods makes the theory applicable in practice. An essential part of the course are exercises, which give hands-on experience with the presented theory and methods.

**4.6.2.8 Nonlinear Distortion analysis of circuits and systems**

*Date and location:* tutorial workshop organized at ISCAS2014, Melbourne, Australia, 1/6/2014

*Lectured by:* Gerd Vandersteen and Adam Cooman

*Attendees:* 16

*Description:*

This tutorial aims to demystify the nonlinear distortion analysis of circuits and systems. Combining capability of analyzing large circuits through simulation-based methods and the analytical insight provided by symbolic methods enables the analysis of the nonlinear behavior of complex systems. The simulation-based methods make it possible to pinpoint the dominant nonlinearities, while the symbolic method can be used afterwards to get an analytical insight in the nonlinear behavior. This will be demonstrated using a large set of practical examples. The tutorial first introduces the necessary notions on Volterra theory, starting from classical linear system theory. The analytical expressions provided by Volterra result in a better understanding of the behavior of the system. The complexity of the resulting expressions, however, limits this technique to simple systems. Second, the tutorial introduces the Best-Linear-Approximation (BLA) paradigm, which represents the nonlinear system as a linear transfer function and additive nonlinear distortion components. It enables the separation of the various linear and nonlinear contributions and is able to pinpoint the dominant nonlinear distortions in a complex system and this in a hierarchical way. The main drawback of the simulation-based methods is, however, the reduced analytical insight. Finally, the power of both methods is illustrated on applications. Starting from a single-transistor circuit (a common source amplifier), the circuits’ complexity gradually increases over OPAMPs (different topologies), sigma-delta modulators and a receiver architecture. Both the symbolic method and the simulation-based methods are used side-by-side to gain insight in the nonlinear distortion properties of the system. All results are finally cross-checked and compared with publication results available in the literature.
4.6.2.9 Measuring dynamic systems in the presence of nonlinear distortions and time varying behavior: Going beyond the Linear Time-Invariant framework in instrumentation and measurement

Date and location: I2MTC 2015 International Instrumentation & Measurement Technology Conference, Pisa (Italy): 3 h tutorial on May 11 2015

Lecturers: John Lataire, Ebrahim Louarroudi, Rik Pintelon and Johan Schoukens

Many real life measurement problems boil down to the characterization of a dynamical system. In most instruments, for example, dynamic signal analyzers, the linear time-invariant (LTI) paradigm is used to model these systems. However, nowadays the linear and the time invariance behavior are more and more challenged. The ever increasing demand for higher performance and efficiency pushes the systems in a nonlinear operation mode so that nonlinear models are required for their design and control. Also the time invariance assumption does no longer hold in many biomedical applications. For that reason it becomes very urgent to extend the successful LTI approach to address these new challenges. The model quality and the model building cost are becoming limiting factors for further technological developments, and a new generation of instruments is needed to provide the basic information in the engineering labs.

In this tutorial, we offer a systematic approach to deal with nonlinear and time-varying systems. We will learn

- how to recognize the presence of nonlinearities and time-variations
- how to quantify the level of these effects
- how to include these effects in mathematical models
- many real life examples will be given, amongst others:
  - detection and analysis of nonlinear vibrations on a ground vibration test of an F-16 fighter
  - characterization of a micro-wave power amplifier
  - cell impedance measurements on a beating hart
  - study of pit corrosion of metals

4.6.2.10 Presentations On System Identification

Lectured by: Johan Schoukens
Location: University of Warwick,
Dates: 9-10 November 2015

- Presentation 1: Why do you need system identification?
- Presentation 2: Identification of (linear) dynamical systems: A case study
- Presentation 3: A statistical framework for system identification

4.6.2.11 VUB - ELEC workshop on System Identification 2017

Location: Dept. ELEC, Vrije Universiteit Brussel, Building K, 6th floor
Lectured by: John Lataire, Rik Pintelon, Gerd Vandersteen, Yves Rolain, Koen Tiels, Maarten
The VUB-ELEC department was proud to organize the 2017 edition of the workshop on System Identification (a biennial event), as a continuation of 9 successful editions of the ELEC Doctoral School on the Identification of Nonlinear Dynamic Systems (with a slightly altered format).

System identification is the engineering discipline which aims at constructing mathematical models of physical systems, based on measured data. The purpose of these estimated models can be very broad: to gain physical insights into the system, to build a robust controller, to detect anomalies, to compensate for unwanted behaviour, to predict future outcomes, etc... Since 1989, the VUB-ELEC department has gathered a lot of experience in system identification.

The ELEC workshop on System Identification brings together researchers in System Identification and researchers/industrials who are in need of modelling tools based on measured data. As a participant, you will have the opportunity to learn from, and collaborate with experts in (frequency domain) system identification to solve your own modelling problem.

System identification has applications in a lot of engineering disciplines. Some examples below.

**Electrochemical impedance spectroscopy**

This includes the detection and characterisation of corrosion of metals, and the characterisation of the state-of-charge (SOC) and state-of-health (SOH) of batteries.

**Power electronics**

Heavy duty electrical machines involve the use of highly nonlinear electronic components in complex control loops. Reliable models of these components are crucial for the predictability and thus the safety of these devices.

**(HF/RF) electronic circuits**

The requirements on (HF/RF) electronic circuits like amplifiers and mixers is becoming increasingly stringent, such that advanced modelling and identification tools are required for design and distortion compensation purposes.

**Mechanical applications**

In robotics, a position dependency of the dynamic behaviour can be observed, which can be captured by using nonlinear or time-varying identification tools. In the study of structural vibrations (modal analysis), the modelling tools must take into account the possible variations of the load (think of a bridge with a variable density of cars driving on top, or a wind turbine subject to different wind speeds).
Biomedical applications

Making black box models of (parts of) living creatures is very challenging, and involves the appearance of many nonlinear and parameter-varying effects. Think of the influence of moisture on the mechanical and electrical properties of biological tissues, or the dependence of the dynamics of joints on the muscular activity.

4.6.2.12 SOCN Graduate School “Sequential Monte Carlo Methods”

Location: VUB, Green Room, ground floor of the U-residence
Lectured by: Thomas Schön
Dates: This 15-hour course has taken place in 6 sessions over four days on October 3, 4, 5, 6, 2017

The aim of this course is to provide an introduction to the theory and application of computational methods for inference in nonlinear dynamical systems, as well as more general problems. More specifically we will introduce sequential Monte Carlo (SMC) methods and Markov chain Monte Carlo (MCMC) methods and show how these can be used to solve challenging learning (system identification) and state estimation problems in nonlinear dynamical systems. We will also briefly discuss SMC in a more general context, showing how it can be used as a generic tool for sampling from complex probability distributions.

List of topics:

- Probabilistic modeling of dynamical systems
- Filtering and smoothing
- The Monte Carlo idea and importance sampling
- Particle filtering / Sequential Monte Carlo
- Basic convergence theory for particle filters
- Likelihood estimation and maximum likelihood parameter learning
- Bayesian parameter learning
- Particle Markov Chain Monte Carlo
- Generic SMC / SMC Samplers
- Prerequisites: Basic understanding of probability theory, statistics and numerical computations.
5. Bibliography

5.1 BOOKS

b1. **Identification of Linear Systems: A Practical Guideline to Accurate Modeling**
J. Schoukens, R. Pintelon
The book is concentrated on the problem of accurate modelling of linear time invariant systems. These models can be continuous time (Laplace-domain) or discrete time (Z-domain). The complete experimental procedure is discussed: how to create optimal experiments (optimization of excitation signals), how to estimate the model parameters from the measurements, how to select between different models, etc. These problems are thoroughly discussed in the first section of the book. A profound theoretical development of the proposed identification algorithm is also made in this section. The second part consists of detailed illustrations of the proposed algorithms on practical problems: modelling an electronic, electrical, acoustic, mechanical system. Finally the book is completed with a practical guideline to help the user making the correct choices.
The book is intended for all those dealing with "practical" modelling problems and have to combine measurements and theory. A second group of interested people are those involved with identification theory.

b2. **System Identification: A Frequency Domain Approach**
Rik Pintelon, Johan Schoukens
How does one model a linear dynamic system from noisy data? This book presents a general approach to this problem, with both practical examples and theoretical discussions that give the reader a sound understanding of the subject and of the pitfalls that might occur on the road from raw data to validated model. The emphasis is on robust methods that can be used with a minimum of user interaction.
*System Identification: A Frequency Domain Approach* is written for practising engineers and scientists who do not want to delve into mathematical details of proofs. Also, it is written for researchers who wish to learn more about the theoretical aspects of the proofs. Several of the introductory chapters are suitable for undergraduates. Each chapter begins with an abstract and ends with exercises, and examples are given throughout.

b3. **Exact and Approximate Modeling of Linear Systems: A Behavioral Approach**
Ivan Markovsky, Jan C. Willems, Sabine Van Huffel, Bart De Moor
Society for Industrial and Applied Mathematics, 2006
Exact and Approximate Modeling of Linear Systems: A Behavioral Approach elegantly introduces the behavioral approach to mathematical modeling, an approach that requires models to be viewed as sets of possible outcomes rather than to be a priori bound to particular representations. The authors discuss exact and approximate fitting of data by linear, bilinear, and quadratic static models and linear dynamic models, a formulation that enables readers to select the most suitable representation for a particular purpose. This book presents exact subspace-type and approximate optimization-based identification methods, as well as representation-free problem formulations, an overview of solution approaches, and software implementation. Readers will find an exposition of a wide variety of modeling problems starting from observed data. The presented theory leads to algorithms that are implemented in C language and in MATLAB.

b4. **System Identification A frequency Domain Approach - second edition**
Rik Pintelon, Johan Schoukens
System Identification is a general term used to describe mathematical tools and algorithms that build dynamical models from measured data. Used for prediction, control, physical interpretation, and the designing of any electrical systems, they are vital in the fields of electrical, mechanical, civil, and chemical engineering. Focusing mainly on frequency domain techniques, System Identification: A Frequency Domain Approach, Second Edition also studies in detail the similarities and differences with the classical time domain approach. It highlights many of the important steps in the identification process, points out the possible pitfalls to the reader, and illustrates the powerful tools that are available.
Readers of this Second Edition will benefit from:
- Matlab ® software support for identifying multivariable systems that is freely available at the website http://booksupport.wiley.com
- State-of-the-art system identification methods for both time and frequency domain data
- New chapters on non-parametric and parametric transfer function modeling using (non-)period excitations
- Numerous examples and figures that facilitate the learning process
- A simple writing style that allows the reader to learn more about the theoretical aspects of the proofs and algorithms
Unlike other books in this field, System Identification: A Frequency Domain Approach, Second Edition is ideal for practicing engineers, scientists, researchers, and both master's and PhD students in electrical, mechanical, civil, and chemical engineering.

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8 More publications of the department ELEC can be found on:
http://cris.cumulus.vub.ac.be/portal/
b5. **Substrate Noise Coupling in Analog/RF Circuits**  
Stephane Bronckers, Geert Van Der Plas, Gerd Vandersteen, Yves Rolain  
Substrate noise coupling - the coupling of signals from one node to another via a substrate - is a frequent problem that occurs in integrated circuits. It is critical that today's engineers address this issue and this book shows them how. The book offers detailed guidance on the impact of substrate noise on a wide range of circuits operating from baseband frequencies up to mm-wave frequencies. This unique reference presents case studies to illustrate that careful modeling of the assembly characteristics and layout details is required to bring simulations and measurements into agreement. Practitioners learn how to use a proper combination of isolation structures and circuit techniques to make analog/RF circuits more immune to substrate noise.

b6. **Low Rank Approximation: Algorithms, Implementation, Applications.**  
Ivan Markovsky  
Matrix low-rank approximation is intimately related to data modelling; a problem that arises frequently in many different fields. Low Rank Approximation: Algorithms, Implementation, Applications is a comprehensive exposition of the theory, algorithms, and applications of structured low-rank approximation. Local optimization methods and effective suboptimal convex relaxations for Toeplitz, Hankel, and Sylvester structured problems are presented. A major part of the text is devoted to application of the theory. Applications described include:
- system and control theory: approximate realization, model reduction, output error, and errors-in-variables identification;  
- signal processing: harmonic retrieval, sum-of-damped exponentials, finite impulse response modeling, and array processing;  
- machine learning: multidimensional scaling and recommender system;  
- computer vision: algebraic curve fitting and fundamental matrix estimation;  
- bioinformatics for microarray data analysis;  
- chemometrics for multivariate calibration;  
- psychometrics for factor analysis; and  
- computer algebra for approximate common divisor computation.

b7. **Mastering System Identification in 100 Exercises**  
Johan Schoukens, Rik Pintelon, Yves Rolain  
Systems identification is a general term used to describe mathematical tools and algorithms that build dynamical models from measured data. Mastering System Identification in 100 Exercises takes readers step by step through a series of MATLAB® exercises that teach how to measure and model linear dynamic systems in the presence of nonlinear distortions from a practical point of view. Each exercise is followed by a short discussion illustrating what lessons can be learned by the reader. The book, with its learn-by-doing approach, also includes:  
- State-of-the-art system identification methods, with both time and frequency domain system identification methods - including the pros and cons of each  
- Simple writing style with numerous examples and figures  
- downloadable author-programmed MATLAB® files for each exercise—with detailed solutions  
- Larger projects that serve as potential assignments  
Covering both classic and recent measurement and identifying methods, this book will appeal to practicing engineers, scientists, and researchers, as well as master's and PhD students in electrical, mechanical, civil, and chemical engineering.

Ivan Markovsky  
Springer, 2019 (ISBN 978-3-319-89620-5)  
This book is a comprehensive exposition of the theory, algorithms, and applications of structured low-rank approximation. Local optimization methods and effective suboptimal convex relaxations for Toeplitz, Hankel, and Sylvester structured problems are presented. A major part of the text is devoted to application of the theory with a range of applications from systems and control theory to psychometrics being described. Special knowledge of the application fields is not required. The second edition of "Low-Rank Approximation/ is a thoroughly edited and extensively rewritten revision. It contains new chapters and sections that introduce the topics of:
- variable projection for structured low-rank approximation;  
- missing data estimation;  
- data-driven filtering and control;  
- stochastic model representation and identification;  
- identification of polynomial time-invariant systems; and  
- blind identification with deterministic input model.

The book is complemented by a software implementation of the methods presented, which makes the theory directly applicable in practice. In particular, all numerical examples in the book are included in demonstration files and can be reproduced by the reader. This gives hands-on experience with the theory and methods detailed. In addition, exercises and MATLAB®/Octave examples will assist the reader quickly to assimilate the theory on a chapter-by-chapter basis.

"Each chapter is completed with a new section of exercises to which complete solutions are provided."

Low-Rank Approximation (second edition) is a broad survey of the Low-Rank Approximation theory and applications of its field which will be of direct interest to researchers in system identification, control and systems theory, numerical linear algebra and optimization. The supplementary problems and solutions render it suitable for use in teaching graduate courses in those subjects as well.
5.2 JOURNAL PAPERS (2018)

**j616. Nonlinear state-space modelling of the kinematics of an oscillating circular cylinder in a fluid flow**
Jan Decuyper, Tim De Troyer, Mark Runacres, Koen Tiels, Johan Schoukens
The flow-induced vibration of bluff bodies is an important problem of many marine, civil, or mechanical engineers. In the design phase of such structures, it is vital to obtain good predictions of the fluid forces acting on the structure. Current methods rely on computational fluid dynamic simulations (CFD), with a too high computational cost to be effectively used in the design phase or for control applications. Alternative methods use heuristic mathematical models of the fluid forces, but these lack the accuracy (they often assume the system to be linear) or flexibility to be useful over a wide operating range. In this work we show that it is possible to build an accurate, flexible and low-computational-cost mathematical model using nonlinear system identification techniques. This model is data driven: it is trained over a user-defined region of interest using data obtained from experiments or simulations, or both. Here we use a Van der Pol oscillator as well as CFD simulations of an oscillating circular cylinder to generate the training data. Then a discrete-time polynomial nonlinear state-space model is fit to the data. This model relates the oscillation of the cylinder to the force that the fluid exerts on the cylinder. The model is finally validated over a wide range of oscillation frequencies and amplitudes, both inside and outside the so-called lock-in region. We show that forces simulated by the model are in good agreement with the data obtained from CFD.

**j617. Improved Tactile Resonance Sensor for Robotic Assisted Surgery**
David Oliva Uribe, Johan Schoukens, Ralf Stroop
This paper presents an improved tactile sensor using a piezoelectric bimorph able to differentiate soft materials with similar mechanical characteristics. The final aim is to develop intelligent surgical tools for brain tumour resection using integrated sensors in order to improve tissue tumour delineation and tissue differentiation. The bimorph sensor is driven using a random phase multisine and the properties of contact between the sensor's tip and a certain load are evaluated by means of the evaluation of the nonparametric FRF. An analysis of the nonlinear contributions is presented to show that the use of a linear model is feasible for the measurement conditions. A series of gelatine phantoms were tested. The tactile sensor is able to identify minimal differences in the consistency of the measured samples considering viscoelastic behaviour. A variance analysis was performed to evaluate the reliability of the sensors and to identify possible error sources due to inconsistencies in the preparation method of the phantoms. The results of the variance analysis are discussed showing that ability of the proposed tactile sensor to perform high quality measurements.

**j618. Modeling the nonlinear cortical response in EEG evoked by wrist joint manipulation**
Vlaar, M.P., Birpoutsoukis, G., Lataire, J., Schoukens, M., Schouten, A.C., Schoukens, J., & Van der Helm, F.C.T
Joint manipulation elicits a response from the sensors in the periphery which, via the spinal cord, arrives in the cortex. The average evoked cortical response recorded using electroencephalography was shown to be highly nonlinear; a linear model can only explain 10% of the variance of the evoked response, and over 80% of the response is generated by nonlinear behavior. The goal of this study is to obtain a nonparametric nonlinear dynamic model, which can consistently explain the recorded cortical response requiring little a priori assumptions about model structure. Wrist joint manipulation was applied in ten healthy participants during which their cortical activity was recorded and modeled using a truncated Volterra series. The obtained models could explain 46% of the variance of the evoked cortical response, thereby demonstrating the relevance of nonlinear modeling. The high similarity of the obtained models across participants indicates that the models reveal common characteristics of the underlying system. The models show predominantly high-pass behavior, which suggests that velocity-related information originating from the muscle spindles governs the cortical response. In conclusion, the nonlinear modeling approach using a truncated Volterra series with regularization, provides a quantitative way of investigating the sensorimotor system, offering insight into the underlying physiology.

**j619. Grey-box state-space identification of nonlinear mechanical vibrations**
Jean Philippe Noel and Johan Schoukens
International Journal of Control, Vol. 91, No. 5, pp. 1118-1139
The present paper deals with the identification of nonlinear mechanical vibrations. A grey-box, or semi-physical, nonlinear state-space representation is introduced, expressing the nonlinear basis functions using a limited number of measured output variables. This representation assumes that the observed nonlinearities are localised in physical space, which is a generic case in mechanics. A two-step identification procedure is derived for the grey-box model parameters, integrating nonlinear subspace initialisation and weighted least-squares optimisation. The complete procedure is applied to an electrical circuit mimicking the behavior of a single-input, single-output (SISO) nonlinear mechanical system and to a single-input, multiple-output (SIMO) geometrically nonlinear beam structure.

**j620. Data driven discrete-time parsimonious identification of a nonlinear state-space model for a weakly nonlinear system with short data record.**
Many real world systems exhibit a quasi linear or weakly nonlinear behavior during normal operation, and a hard saturation effect for high peaks of the input signal. In this paper, a methodology to identify a parsimonious discrete-time nonlinear state space model (NLSS) for the nonlinear dynamical system with relatively short data record is proposed. The capability of the NLSS model structure is demonstrated by introducing two different initialisation schemes, one of them using multivariate polynomials. In addition, a method using first-order information of the multivariate polynomials and tensor decomposition is employed to obtain the parsimonious decoupled representation of the set of multivariate real
efficient multidimensional regularization for Volterra series estimation

Georgios Birpoutsoukis, Péter Zoltán Csurcsia, Johan Schoukens
Mechanical Systems and Signal Processing, 104 (2018), pp. 896-914

This paper presents an efficient nonparametric time domain nonlinear system identification method. It is shown how truncated Volterra series models can be efficiently estimated without the need of long, transient-free measurements. The method is a novel extension of the regularization methods that have been developed for impulse response estimates of linear time invariant systems. To avoid the excessive memory needs in case of long measurements or large number of estimated parameters, a practical gradient-based estimation method is also provided, leading to the same numerical results as the proposed Volterra estimation method. Moreover, the transient effects in the simulated output are removed by a special regularization method based on the novel ideas of transient removal for Linear Time-Varying (LTV) systems. Combining the proposed methodologies, the nonparametric Volterra models of the cascaded water tanks benchmark are presented in this paper. The results for different scenarios varying from a simple Finite Impulse Response (FIR) model to a 3rd degree Volterra series with and without transient removal are compared and studied. It is clear that the obtained models capture the system dynamics when tested on a validation dataset, and their performance is comparable with the white-box (physical) models.

Improved FRF Measurements of Lightly Damped Systems Using Local Rational Models

Dries Peumans, Cedric Buuschts; Gerd Vandersteen, Rik Pintelon

Lightly damped systems exhibit strong resonances which should be accurately characterized to prevent potential harmful damage in real-world applications. Characterizing these resonances using frequency response function (FRF) measurements is challenging due to long transient behavior and spectral leakage. Local modeling techniques exist which remedy these difficulties, but they introduce a bias or do not use an appropriate model structure. In this paper, we solve these problems by developing two local rational modeling techniques that remove the bias on the FRF measurement. The proposed techniques involve the use of the bootstrapped total least squares estimator on the one hand and the incorporation of prior knowledge of the pole locations on the other hand. Furthermore, the performance of both techniques is demonstrated by measuring the flexural vibrations of a steel beam.

A systematic approach to optimize excitations for perturbative transport experiments

M. van Berkel, A. de Cock, G.M.D. Hogeweij, H.J. Zwart, G. Vandersteen

In this paper, techniques for optimal input design are used to optimize the waveforms of perturbative experiments in modern fusion devices. The main focus of the paper is to find the modulation frequency for which the accuracy of the estimated diffusion coefficient is maximal. Mathematically this problem can be formulated as an optimization problem in which the Fisher information matrix is maximized. First this optimization problem is solved for a simplified diffusion model, while assuming a slab geometry and a semi-infinite domain. Later, the optimization is repeated under more general conditions such as a cylindrical geometry, finite domain, and simultaneous estimation of multiple transport coefficients. Based on the results of these optimizations, guidelines are offered to select the modulation frequency and to determine the optimality of the corresponding experiment.

Nonparametric identification of linear dynamic errors-in-variable systems

Erliang Zhang, Rik Pintelon
Automatica, 94 (2018), pp. 416-425

The present work handles the nonparametric identification of linear dynamic systems within an errors-in-variables framework, where the input is arbitrary and both the input and output disturbing noises are white with unknown variances. Using the property that the frequency response function and the system leakage term can be locally approximated very well by a low-order degree polynomial, a frequency domain estimator is developed, which gives consistent estimates for the frequency response function and the input-output noise variances. The consistency and uniqueness of the estimator are theoretically analyzed under mild conditions, and uncertainty bounds are also provided. The proposed method is finally validated on a simulated linear dynamic system.

Heat flux reconstruction and effective diffusion estimation from perturbative experiments using advanced filtering and confidence analysis

M. van Berkel, T. Kobayashi, G. Vandersteen, H.J. Zwart, H. Igami, S. Kubo, N. Tamura, H. Tsuchiya, M.R. de Baar, the LHD Experiment Group
Nuclear Fusion, Vol. 58, No. 9, 2018, 11 pages

The heat flux is one of the key parameter used to quantify and understand transport in fusion devices. In this paper, a new method is introduced to calculate the heat flux including its confidence with high accuracy based on perturbed measurements such as the electron temperature. The new method is based on ideal filtering to optimally reduce the noise contributions on the measurements and piece-wise polynomial approximations to calculate the time derivative. Both methods are necessary to arrive at a heat flux and effective diffusion coefficient with high accuracy. The new methodology is applied to a measurement example using electron cyclotron resonance heating block-wave modulation at the Large Helical Device showing the merit of the newly developed methodology.

Model-Driven Design of Microwave Filters Based on Scalable Circuit Models

Evi Van Nechel, Francesco Ferranti, Yves Rolain, John Lataire
Most microwave filters are currently designed using direct electromagnetic (EM) optimization. This method holds several disadvantages regarding the provided physical insight to designers and duration of the optimization process. To circumvent these drawbacks, we propose a filter design based on scalable circuit models. This model-driven design competes with EM optimization by maintaining the accuracy of the optimization results while providing a very significant speedup and gaining physical insight on the EM working mechanism of the filter of interest. This paper discusses the advantages of using the proposed model-driven design by the illustration on a defected ground structure filter. A scalable equivalent circuit model is used in the design procedure to provide physical insight to the designer and to speed up the design process enormously.

### j627. Separation of transport in slow and fast time-scales using modulated heat pulse experiments (hysteresis in flux explained)


Nuclear Fusion, Vol. 58, No. 10, 2018, 17 pages

Old and recent experiments show that there is a direct response to the heating power of transport observed in modulated ECH experiments both in tokamaks and stellarators. This is most apparent for modulated experiments in the Large Helical Device (LHD) and in Wendelstein 7 advanced stellarator (W7-AS). In this paper we show that: (1) this power dependence can be reproduced by linear models and as such hysteresis (in flux) has no relationship to hysteresis as defined in the literature; (2) observations of hysteresis (in flux) and a direct response to power can be perfectly reproduced by introducing an error in the estimated deposition profile as long as the errors redistribute the heat over a large radius; (3) non-local models depending directly on the heating power can also explain the experimentally observed Lissajous curves (hysteresis); (4) non-locality and deposition errors can be recognized in experiments and how they affect estimates of transport coefficients; (5) from a linear perturbation transport experiment, it is not possible to discern deposition errors from non-local fast transport components (mathematically equivalent). However, when studied over different operating points non-linear-non-local approaches are derived which should be distinguishable from deposition errors in the deposition profile. To show all this, transport needs to be analyzed by separating the transport in a slow (diffusive) time-scale and a fast (heating/nonlocal) time-scale, which can only be done in the presence of perturbations.

### j628. Distortion Contribution Analysis with the Best Linear Approximation

Cooman A., Bronders P., Peumans D., Vandersteen G. and Rolain Y.


A Distortion Contribution Analysis (DCA) obtains the distortion at the output of an analog electronic circuit as a sum of distortion contributions of its sub-circuits. Similar to a noise analysis, a DCA helps a designer to pinpoint the actual source of the distortion. Classically, the DCA uses the Volterra theory to model the circuit and its sub-circuits. This DCA has been proven useful for small circuits or heavily simplified examples. In more complex circuits however, the amount of contributions increases quickly, making the interpretation of the results difficult. In this paper, the Best Linear Approximation (BLA) is used to perform the DCA instead. The BLA represents the behaviour of a sub-circuit as a linear circuit with the unmodelled distortion represented by a noise source. Combining the BLA with a classic noise analysis yields a DCA that is simple to understand, yet capable to handle complex excitation signals and complex strongly nonlinear circuits.

### j629. Experimentally driven demystification of system identification for nonlinear mechanical systems

M. Vaes, Y. Rolain, J. Pattyn and G. Vandersteen

IEEE Instrumentation and Measurement Magazine, 21(2), pp. 16-25

The goal of this work is to develop a low cost hardware-based demonstrator for system identification (SI) methods that can be used in a self-paced training kit by students as well as practicing engineers. The focus lies on hands-on training with a high return on effort. The training starts from experiments that are performed on the demonstrator, a real system that is introduced here. It can easily be used at home by the trainee without the need for external support or expensive equipment. The advantage for the SI community is that the steep learning curve, that often scares potential users of advanced SI methods, is flattened while the practical applicability of these methods is demonstrated altogether. The joint use of teaching material and hardware-based illustration provides enough knowledge, understanding and confidence to apply the methods on industrial scale systems. The first test case, which is presented here, is a mechanical setup. It consists of a nonlinear mass-spring-damper system built using commonly available components for a total cost of less than 50 Euro. When applying a signal with a low amplitude to the designed system, it almost perfectly behaves as a Linear Time Invariant (LTI) device. This is only true when sufficient the amplitude of the input signal is very small. Increasing the amplitude introduces weak and intuitive nonlinear distortions. This regime of operation is used to illustrate the analysis and estimation methods in a framework that closely approximates the theoretical assumption of periodic in, same period out (PIPSO) systems. Increasing the amplitude even further challenges the trainees intuition even more. A sweep up and sweep down sine test shows that the system becomes bistable around the resonance peak which shifts in frequency with increasing amplitude of the input signal. These phenomena are typical for a nonlinear vibrating system containing jumps. The main payback for the trainee is the knowledge that well known Frequency Response Function (FRF) measurement of the mechanical system can indeed be used as an enabler for the nonlinear SI. The experiments show the need for the detection, quantification and qualification of nonlinear effects. Existing high return local linearization methods [1][2] are introduced and applied directly to the system under test. The major advantage of these real experiments lies in the direct visual feedback provided to the user under a directly usable and understandable format. A first presentation of the setup to test groups already involved in SI seems to indicate that the approach can strongly stimulate, motivate, attract and help potential users.

### j630. Revealing Time-Varying Joint Impedance With Kernel-Based Regression and Nonparametric Decomposition

Mark van de Ruit, Gaia Cavallo, John Lataire, Frans C. T. van der Helm, Winfred Mugge, Jan-Willem van Wingerden, Alfred C. Schouten

IEEE Transactions on Control Systems Technology: accepted for publication, D.O.I. 10.1109/TCST.2018.2881664
During movements, humans continuously regulate their joint impedance to minimize control effort and optimize performance. Joint impedance describes the relationship between a joint’s position and torque acting around the joint. Joint impedance varies with joint angle and muscle activation and differs from trial-to-trial due to inherent variability in the human control system. In this paper, a dedicated time-varying system identification (SV) framework is developed involving a parametric, kernel-based regression, and nonparametric, “skirt decomposition,” SV method to monitor the time-varying joint impedance during a force task. Identification was performed on single trials and the estimators included little a priori assumptions regarding the underlying time-varying joint mechanics. During the experiments, six (human) participants used flexion of the wrist to apply a slow sinusoidal torque to the handle of a robotic manipulator, while receiving small position perturbations. Both methods revealed that the sinusoidal change in joint torque by activation of the wrist flexor muscles resulted in a sinusoidal time-varying joint stiffness and resonance frequency. A third-order differential equation allowed the parametric kernel-based estimator to explain on average 76% of the variance (range 52%-90%). The nonparametric skirt decomposition method could explain on average 84% of the variance (range 66%-91%). This paper presents a novel framework for identification of time-varying joint impedance by making use of linear time-varying models based on a single trial of data.

Precompensation of Supply Dynamics of Dynamic Power Supply Transmitters Using a Linear Parameter-Varying Model

Piet Bronders, John Lataire, Thierry Coppens, Guillaume Paillancy, Sebastian Gustafsson, Yves Rolain, Gerd Vandersteen
IEEE Transactions on Microwave Theory and Techniques, 10 pp. (early access on-line: 10.1109/TMTT.2018.2876261)
The use of a linear parameter-varying framework is proposed as a viable design tool for dynamic power supply transmitters. Accurate synchronization between the low- and high-frequency paths of these devices is an essential requirement for obtaining optimal results. Using this framework, the estimation of the low-frequency dynamics of the supply path is made possible for actual operational conditions. A precompensation model can, as a result, be designed to compensate for these unwanted dynamics, improving both the linearity and the energy efficiency of the resulting device. Moreover, the procedure does not require access to any internal nodes and can be implemented digitally without modification of the existing hardware. A measurement example demonstrates the advantages and improvements that become possible with the proposed technique.

An ODE-based method for computing the Approximate Greatest Common Divisor of polynomials.

A. Fazzi and N. Guglielmi and I. Markovsky
Computing the greatest common divisor of a set of polynomials is a problem which plays an important role in different fields, such as linear system, control and network theory. In practice, the polynomials are obtained through measurements and computations, so that their coefficients are inexact. This poses the problem of computing an approximate common factor. We propose an improvement and a generalization of the method recently proposed in Guglielmi, N., Markovsky, I.: An ODE based method for computing the distance of coprime polynomials. SIAM J. Numer. Anal. 55, 1456-1482 (2017), which restates the problem as a (structured) distance to singularity of the Sylvester matrix. We generalize the algorithm in order to work with more than 2 polynomials and to compute an Approximate GCD (Greatest Common Divisor) of degree $k > 0$; moreover we show that the algorithm becomes faster by replacing the eigenvalues by the singular values.

Active Fault Diagnosis on a Hydraulic Pitch System Based on Frequency-Domain Identification

Sandra Vásquez, Michel Kinninger, Rik Pintelon
IEEE Transactions on Control Systems Technology: early access
The blade pitch system is a critical subsystem of variable-speed variable-pitch wind turbines that is characterized by a high failure rate. This paper addresses the fault detection and isolation (FDI) of a blade pitch system with hydraulic actuators. Focus is placed on incipient multiplicative faults, namely hydraulic oil contamination with water and air, bearing damage resulting in increased friction, and drop of the supply pressure of the hydraulic pump. An active model-based FDI approach is considered, where changes in the operating conditions (i.e., mean wind speed and turbulence intensity) are accounted through the identification of a linear parameter-varying model for the pitch actuators. Frequency-domain estimators are used to identify continuous-time models in a user-defined frequency band, which facilitates the design of the FDI algorithm. Besides, robustness with respect to noise in measurements and stochastic nonlinear distortions is ensured by estimating confidence bounds on the parameters used for FDI. The approach is thoroughly validated on a wind turbine simulator based on the FAST software that includes a detailed physical model of the hydraulic pitch system. This paper presents the design methodology and validation results for the proposed FDI approach. We show that an appropriate design of the excitation signal used for active fault detection allows an early fault diagnosis (except for oil contamination with water) while ensuring a short experiment duration and an acceptable impact on the wind turbine operation.
This paper proposes a technique for extracting multiple measurement-based figures of merit with a single measurement taken from 1 measurement setup. Separate estimates of the linear term, the noise term and the in-band and out-of-band nonlinear distortion allow to calculate the signal-to-noise and distortion ratio, noise power ratio, adjacent channel leakage power ratio, etc. Those are extracted in least squares sense for a class of modulated excitation signals resembling real communication signals like LTE. The proposed method allows to split the linear dynamics from the nonlinear distortion, power ratio, etc. Those are extracted in least squares sense for a class of modulated excitation signals resembling real nonlinear distortion allow to calculate the signal-to-noise and distortion ratio, noise power ratio, adjacent channel leakage power ratio, etc. This paper proposes a technique for extracting multiple measurement-based figures of merit with a single measurement taken from 1 measurement setup. Separate estimates of the linear term, the noise term and the in-band and out-of-band nonlinear distortion allow to calculate the signal-to-noise and distortion ratio, noise power ratio, adjacent channel leakage power ratio, etc. Those are extracted in least squares sense for a class of modulated excitation signals resembling real communication signals like LTE. The proposed method allows to split the linear dynamics from the nonlinear distortion.
resulting in improved measures that are closer to the actual definitions of these figures of merit. The new measurement approach is compared with the classical one. Experimental results validate the proposed technique.

**c1045. A comparison between structured low-rank approximation and correlation approach for data-driven output tracking**

S. Formentin and I. Markovsky
18th IFAC Symposium on System Identification (SYSID 2018), Stockholm, SWEDEN, 9-11 July 2018, pp. 1002-1007

Data-driven control is an alternative to the classical model-based control paradigm. The main idea is that a model of the plant is not explicitly identified prior to designing the control signal. Two recently proposed methods for data-driven control—e.g., a method based on correlation analysis and a method based on structured matrix low-rank approximation and completion—solve identical control problems. The aim of this paper is to compare the methods, both theoretically and via a numerical case study. The main conclusion of the comparison is that there is no universally best method: the two approaches have complementary advantages and disadvantages. Future work will aim to combine the two methods into a more effective unified approach for data-driven output tracking.

**c1046. Impact of the Missing Data Pattern, the Oversampling, the Noise Level and the Excitation on Nonparametric Frequency Response Function Estimates**

R. Pintelon, J. Lataire, G. Vandersteen and D. Ugryumova
18th IFAC Symposium on System Identification (SYSID 2018), Stockholm, SWEDEN, 9-11 July 2018, pp. 533-538

Nonparametric frequency response function estimation (FRF) is a first important step towards successful parametric modelling of the dynamics. In some application such as, for example, low-cost wireless sensor networks, sensors are subject to failure (clipping, outliers) and the transmission errors of the wireless communication can be as high as 30%. Hence, nonparametric estimation of the FRF in the presence of missing data is an important issue. In this paper we study the impact of the missing data pattern, the missing data fraction, the oversampling (w.r.t. the bandwidth of the system), the signal-to-noise ratio and the type of excitation on the bias and variance of the FRF estimates.

**c1047. Nonparametric Identification of Time-Varying Human Joint Admittance**

G. Cavallo, M. van de Ruit, A.C. Schouten, J.W. van Wingerden, J. Lataire
18th IFAC Symposium on System Identification (SYSID 2018), Stockholm, SWEDEN, 9-11 July 2018, pp. 521-526

In this study, a nonparametric method, developed in Lataire et al. (2012), is applied to the identification of linear time-varying human joint admittance. The aim of the method, denoted Shirt Decomposition method, is to reconstruct the time-varying system function. The main contribution of the paper is to evaluate the possibilities and limitations of the method for the identification of linear time-varying human joint admittance in simulation. The proposed method delivers an estimate of linear time-varying joint admittance from a single experimental trial, provided that a multisine is used as excitation signal. The trade-off between i) the frequency resolution of the dynamics, and ii) the allowable complexity of the time variation is explored.

**c1048. Bioimpedance Parameter Estimation using Fast Spectral Measurements and Regularization**

Roberto G. Ramírez-Chavarría, Gustavo Quintana-Carapia, Matias I. Müller, Robert Mattila, Daniel Matatagui, Celia Sánchez-Pérez

This work proposes an alternative framework for parametric bioimpedance estimation as a powerful tool to characterize biological media. We model the bioimpedance as an electrical network of parallel RC circuits, and transform the frequency-domain estimation problem into a time constant domain estimation problem by means of the distribution of relaxation times (DRT) method. The fredholm integral equation of the first kind is employed to pose the problem in a regularized least squares (RLS) form. We validate the proposed methodology by numerical simulations for a synthetic biological electrical circuit, by using a multisine signal in the frequency range of 1kHz to 853kHz and considering an error in the-art regularization.

**c1049. An adaptive modeling method for the calibration if passive tuners**

Maral Zyari, Francesco Ferranti, Yves Rolain
2018 IEEE MTT-S International Conference on Numerical Electromagnetic and Multiphysics Modeling and Optimization (NEMO), Reykjavik, Iceland, 8-10 Aug. 2018, 4pp

We propose a new modeling technique that can be used for an efficient and adaptive calibration of passive microwave tuners based on mechanical probes that can move horizontally (X) and vertically (Y). The proposed technique adaptively samples the (X, Y) space and builds a model for the scattering parameters of the tuner as a function of the X and Y position variables at different frequencies. The method samples the (X, Y) space in an automated way and selects the sample distribution to obtain a desired accuracy. The required user interaction is limited, the user needs to choose the desired frequencies and modeling accuracy for the calibration. Pertinent numerical results based on measurements validate the proposed approach.

**c1050. A Unified, Wave-Based Calibration framework for Vector Network Analyzers**

Indy Magnus, Yves Rolain, Gerd Vandersteen

An adaptive modeling method for the calibration of passive microwave tuners is presented. The method is wave-based and based on the Green’s function of the electromagnetic problem. The main advantage of this approach is that it is not limited to be used with a specific material composition. The method is validated using measurements. The results show a good agreement with the measurements. The method is also shown to be applicable to a wide range of materials.
The state of the art in Vector Network Analyzer calibrations shows the existence of a separate calibration method and algorithm for each possible combination of standards used during the calibration. In this work, we propose a single, unified calibration framework that can handle most current calibrations using one framework and one algorithm only. The method uses raw wave measurements only, which enables the integration of any potential calibration element and a subsequent power and/or phase calibration as is required for nonlinear VNA measurements.

**c1051. Ultrasound signal reconstruction from sparse samples using a low-rank and joint-sparse model.**
M. Zhang, I. Markovsky, C. Schretter, and J. D’hooge
2018 IEEE International Ultrasonics Symposium (IUS), Kobe, Japan, October 22-25, 2018, 4pp.
With the introduction of very dense sensor arrays in ultrasound (US) imaging, data transfer rate and data storage can become a bottleneck in ultrasound system design. To reduce the amount of sampled channel data, several strategies based on compressive sensing (CS) have been proposed. However, the reconstruction accuracy of CS-based methods is highly dependent on the sparse basis and the number of measurements for each channel cannot be lower than the sparsity thereby limiting the data reduction rate. Therefore, we propose to use a low-rank and joint-sparse model to represent US signals and exploit the correlations between adjacent receiving channels. Results show that the proposed method is better adapted to the ultrasound signals and can recover high quality image approximations from as low as 10% of the samples.

**c1052. Ultrasound signal reconstruction from sparse samples using a low-rank and joint-sparse model.**
M. Zhang, I. Markovsky, C. Schretter, and J. D’hooge
With the introduction of very dense sensor arrays in ultrasound (US) imaging, data transfer rate and data storage can become a bottleneck in ultrasound system design. To reduce the amount of sampled channel data, several strategies based on compressive sensing (CS) have been proposed. However, the reconstruction accuracy of CS-based methods is highly dependent on the sparse basis and the number of measurements for each channel cannot be lower than the sparsity thereby limiting the data reduction rate. Therefore, we propose to use a low-rank and joint-sparse model to represent US signals and exploit the correlations between adjacent receiving channels. Results show that the proposed method is better adapted to the ultrasound signals and can recover high quality image approximations from as low as 10% of the samples.

### 5.4 ABSTRACTS (2018)

**a378. Identification of LTI models from concatenated data sets**
Sandra Vásquez, Michel Kinaert and Rik Pintelon
37th Benelux Meeting on Systems and Control, Soesterberg, The Netherlands, March 27 - 29, 2018, pp. 20
For some industrial applications, experimental data is available in the form of several data sets corresponding to the operation of the plant under the same conditions. An example of such an application is the condition monitoring of a wind turbine based on SCADA data. Here, one is interested in the identification of a turbine’ subsystem for a specific wind condition. However, long records of a given operating condition might be difficult to obtain. Hence, one needs to select multiple short data-records from the operational data to identify the system. In this case, identification approaches where missing data are treated as unknown parameters [1, 2] are not feasible due to the large amount of lost data. Then, the best option is to concatenate the data sets, and introduce additional parameters to handle the transient effects [3]. Our aim is to verify the consistency of the estimates when considering this last approach. To this end, we performed a Monte Carlo simulation to prove consistency when dealing with AR and ARX model structures.

**a379. Decoupling multivariate functions: exploring multiple derivative information**
Jeroen De Geeter, Philippe Dreesen, Mariya Ishteva
37th Benelux Meeting on Systems and Control, Soesterberg, The Netherlands, March 27 - 29, 2018, pp. 120
Descriptions of nonlinear systems often involve a set of multivariate real functions. While very flexible, this has the downside of having a large number of parameters which makes gaining insight based on such models very difficult. When decoupling a set of multivariate real functions, these functions are expressed as a linear combination of univariate functions - removing cross terms. Such a decoupled representation may give more insight into the problem, reduce the number of variables or may be useful to simplify a complex system.

**a380. Identification of the Time-Varying Human Joint Impedance for the Application to Bionic Devices**
Gaia Cavallo, Mark van de Ruit, Alfred C. Schoute, John Lataire
37th Benelux Meeting on Systems and Control, Soesterberg, The Netherlands, March 27 - 29, 2018, pp. 130
The neuromuscular system continuously regulates the properties of the human joints according to the environmental conditions and the task to perform. The result is a change of the joint impedance, a mechanical description of the dynamic behavior of the joints. When the variation of the lower limbs' joint impedance is abnormal, for example after a stroke, cerebral palsy or limb amputation, the execution of motor tasks is affected. Disabilities can be alleviated by prostheses (in the case of amputations) or orthoses for external support to a limb), termed bionic devices. The ultimate goal of bionic devices is to replicate the dynamic behavior of the joints in concert with the human's intention, such that the device is
Decoupling Multivariate Polynomials: Comparing Different Tensorization Methods
Philipp Dreesen, Mariya Ištěva, Konstantin Usevich
SIAM Conference on APPLIED LINEAR ALGEBRA, Hong Kong Baptist University, Hong Kong, 4-8 May 2018, pp. 78

Decoupling multivariate polynomials is a useful tool for obtaining an insight into the workings of a nonlinear mapping, to perform parameter reduction, or to approximate nonlinear functions. It is well-known that multivariate polynomials have a close connection to symmetric tensors, and it turns out that a decoupled representation can be obtained by performing the symmetric canonical polyadic decomposition. When considering a multivariate polynomial vector function, this leads to a coupled symmetric CPD. Another well-studied tensor-based method proceeds by collecting the first-order information of the polynomials in a set of operating points, which is captured by the Jacobian matrix evaluated at the operating points. The polyadic canonical decomposition of the three-way tensor of Jacobian matrices directly returns the desired information.

Time-variant frequency response function measurement of multivariate time-variant systems operating in feedback
Pintelon, R., E. Louarroudi, and J. Lataire
Poster presented at I2MTC 2018, IEEE International Instrumentation & Measurement Technology Conference, Houston Texas

The classical time-invariance assumption is often not (exactly) met in real-life applications. As a natural extension of the frequency response function (FRF), the time-variant FRF (TV-FRF) provides quick insight into the complex dynamics of time-variant systems. Recently, a procedure has been proposed to estimate nonparametrically the TV-FRF from known input, noisy output measurements of time-variant systems operating in open loop. However, in many applications, feedback is present either due to an explicit control action or due to the interaction between a nonideal actuator and the system under test. The extension of the open-loop approach to noisy input, noisy output measurements of time-variant systems operating in closed loop requires the deconvolution of the time-variant impulse response of the cascade of two time-variant systems. In this paper, this nontrivial problem is solved for a particular class of time-variant systems. The robustness of the approach with respect to the system assumption is demonstrated via simulations and measurements on an electronic circuit.

Nonparametric Identification of the Wrist Impedance Under Time-Varying Conditions
Gaia Cavallo, Mark van de Ruit, Alfred C. Schouten, John Lataire
Poster presented at the 7th IEEE RAS/EMBS International Conference on Biomedical Robotics and Biomechatronics, Enschede, The Netherlands, 27-29 August 2018

The human neuro-muscular system behaves as an optimal controller and it constantly regulates the properties of the human limbs to optimize effort and performance, while guaranteeing stability. Under a mechanical perspective, the result is the regulation of the human joints' impedance, defined as the dynamical relationship between an applied angular displacement of the joint and the resulting torque acting about it. The change of the joint impedance during daily tasks can tell a great deal about the underlying neuromuscular system and it can be used as a model to mimic in prosthetic devices, to render their design more natural-looking and versatile.

Using Hankel Structured Low-Rank Approximation for Sparse Signal Recovery
I. Markovsky and P.-L. Dragotti
Poster presented at the Dolomites Research Week on Approximation (DRWA18), Alba di Canazei, Trento, Italy, September 10-14, 2018

Structured low-rank approximation is used in model reduction, system identification, and signal processing to find low-complexity models from data. The rank constraint imposes the condition that the approximation has bounded complexity and the optimization criterion aims to find the best match between the data---a trajectory of the system---and the approximation. In some applications, however, the data is sub-sampled from a trajectory, which poses the problem of sparse approximation using the low-rank prior. This paper considers a modified structured low-rank approximation problem where the observed data is a linear transformation of a system's trajectory with reduced dimension. We reformulate this problem as a structured low-rank approximation with missing data and propose a solution method based on the variable projections principle. We compare the structured low-rank approximation approach with classical sparsity inducing method of $\ell_1$-$\ell_1$-norm regularization. The $\ell_1$-$\ell_1$-norm regularization method is effective for sum-of-exponentials modeling with a large number of samples, however, it is not suitable for identification of systems with damping.
5.5 WORKSHOPS (2018)

w299. Enhancing Envelope Tracking Power Amplifier understanding using the wonderful properties of LPV
Piet Bronders, Dries Peumans, John Lataire and Gerd Vandersteen
Presentation of poster at 27th ERNSI Workshop on System Identification, Pembroke College, Cambridge, UK, 23-26 September 2018
The inclusion of a High-Frequency Power Amplifier (PA) is a crucial component of any wireless communication set-up. Its job, as the name suggests, is to amplify all in- and outgoing wireless traffic. If omitted, the communication signals would simply be too weak to be of any use. One does not want to waste any unnecessary energy during this process and, one way to do this, is to regulate the supply level of the PA. Such an arrangement is commonly known as Envelope Tracking (ET). Modelling the behaviour of such a device in actual operational conditions is an important step towards achieving even better performance. Identifying such a device gives rise to models that are both Multiple-Input Multiple-Output (MIMO) and Linear-Parameter Varying (LPV) with, in the most extreme case, multiple scheduling parameters. Furthermore, to mimic actual operational behaviour, the device will be excited by carefully designed multisines which, combined with the versatility of the Best Linear Approximation (BLA), result in models which are also valid for the eventual communication signal. Validation of the proposed framework is done on two simulation examples. Firstly, a so-called Class B PA in which only the supply level of the device is modulated, is identified using a MIMO LPV model with just a single scheduling parameter. Secondly, a Class A PA, wherein both bias and supply voltage are modulated, is considered and introduces the concept of multi-scheduling to the identification procedure.

w300. Dynamic measurement: application of system identification in metrology
Ivan Markovsky
Presentation of poster at 27th ERNSI Workshop in System Identification, Pembroke College, Cambridge, UK, 23-26 September 2018
Dynamic measurement takes into account the dynamical properties of the sensor. Dynamic measurement is identification(-like) problem however, the goal is to estimate the steady-state value ML estimation structured total least squares.

w301. Exposing resonances using the Bootstrapped Total Least Squares estimator
Dries Peumans, Antonin De Vestel, Cedric Busschots, Yves Rolain, Rik Pintelon and Gerd Vandersteen
Presentation of poster at 27th ERNSI Workshop in System Identification, Pembroke College, Cambridge, UK, 23-26 September 2018
Almost all mechanical systems are in one way or another susceptible to resonant behaviour. This resonant behaviour should be accurately characterised to prevent unwanted mechanical oscillations which could in turn lead to mechanical failure. It is therefore of utmost importance to accurately characterise these mechanical resonances. In the past, advanced local rational modelling techniques have been introduced which effectively estimate the non-parametric Frequency Response Function (FRF) for Multiple-Input, Multiple-Output (MIMO) systems. Unfortunately, most of these existing techniques derive the local rational model parameters using a biased estimator. We developed a local rational modelling technique which removes the bias from the estimation procedure and is also applicable to MIMO systems. At its core, this technique uses the Bootstrapped Total Least Squares (BTLS) estimator, which not only provides a consistent estimate of the common-denominator rational model, but also allows us to generate accurate uncertainty bounds on the FRF matrix. The performance of the proposed technique was verified by characterising the resonant behaviour of the tailplane of a glider.

w302. Identification of a class of nonlinear systems through an LTV approach - Application to an RRR-robot
John Lataire, Rik Pintelon, Tom Oomen
Presentation of poster at 27th ERNSI Workshop in System Identification, Pembroke College, Cambridge, UK, 23-26 September 2018
Nonlinear systems are appearing in all engineering applications. Deriving models for these systems is important for instance for prediction and control.

w303. Time-variant frequency response function measurement in the presence of missing data
Rik Pintelon, Diana Ugryumova, Gerd Vandersteen, Ebrahim Louarroudi, John Lataire
Presentation of poster at 27th ERNSI Workshop in System Identification, Pembroke College, Cambridge, UK, 23-26 September 2018
Time-variant systems are systems with dynamic properties which evolve with time. Examples include: a swinging pendulum with a varying rope length, a civil construction with a varying distribution of the load,... This poster considers that input-output measurements of the time-varying system are available, where some samples of the output are missing. An approach is proposed to estimate the time-varying frequency response function non-parametrically. The problem is formulated as a MISO LTI estimation, with a local polynomial approximation of the linear blocks. This results in a linear least squares problem. It appears that the method is very robust to missing data.

w304. Using Hankel Structured Low-Rank Approximation for Sparse Signal Recovery
I. Markovsky and P.-L. Dragotti
Presentation at workshop on “Sparse Approximation with Exponential Sums and Applications”, Goettingen, 26–27 November
Structured low-rank approximation is used in model reduction, system identification, and signal processing to find low-complexity models from data. The rank constraint imposes the condition that the approximation has bounded complexity and the optimization criterion aims to find the best match between the data—a trajectory of the system—and the approximation. In some applications, however, the data is sub-sampled from a trajectory, which poses the problem of sparse approximation using the low-rank prior. This paper considers a modified structured low-rank approximation problem where the observed data is a linear transformation of a system's trajectory with reduced dimension. We reformulate this problem as a structured low-rank approximation with missing data and propose a solution method based on the variable projection principle. We compare the structured low-rank approximation approach with the classical sparsity inducing method of $\ell_1$-norm regularization. The $\ell_1$-norm regularization method is effective for sum-of-exponentials modeling with a large number of samples, however, it is not suitable for identification of systems with damping.

5.6 SCIENTIFIC LECTURES (2018)

**sL50. System identification in the behavioral setting**
Ivan Markovsky
Presentation at the Seminar of the Department of Electrical Engineering, TU Eindhoven, The Netherlands, 14 March

**sL51. The no free lunch principle in data modeling**
Ivan Markovsky
Invited lecture at the BioTensors workshop, Leuven, Belgium, 27–31 August

**sL52. Structured low-rank approximation approach to sum-of-exponentials modeling**
Ivan Markovsky
Invited lecture at the International conference on Approximation and Matrix Functions, University of Lille, France, 1 June 2018

**sL53. Dynamic measurement: application of system identification in metrology**
Ivan Markovsky
Presentation at National Physics Laboratory, London, UK, 30 October 2018

5.7 SEMINAR PRESENTATIONS ORGANISED BY THE DEPT. ELEC (2018)

1. **Identification of the Time-Varying Human Joint Impedance for the Application to Bionic Devices**
Gaia Cavallo (ELEC) – April 13, 2018

The neuromuscular system continuously regulates the properties of the human joints according to the environmental conditions and the task to perform. The result is a change of the joint impedance, a mechanical description of the dynamic behavior of the joints. When the variation of the lower limbs' joint impedance is abnormal, for example after a stroke, cerebral palsy or limb amputation, the execution of motor tasks is affected. Disabilities can be alleviated by prostheses (in the case of amputations) or orthoses (for external support to a limb), termed bionic devices. The ultimate goal of bionic devices is to replicate the dynamic behavior of the joints in concert with the human's intention, such that the device is perceived as a natural extension of the human body. A model of the changes of the joint impedance during daily tasks is required, and system identification can be used as a tool to obtain such a model.

2. **Uncertainty analysis of a subspace-based input estimation method for dynamic measurements.**
Gustavo Quintana Carapia (ELEC) – June 15, 2018

A measurement is an experimental procedure to find the value of a physical magnitude. The true value of the to-be-measured quantity is unknown and a measurement result is an estimation of the true value. The distance between the true value and its estimate cannot be absolutely determined. Then, there is an uncertainty associated with the result of any measurement. Moreover, the accuracy and availability of the estimation depend on the sensor dynamics. A data-driven method that estimates the value of an unknown input by processing the sensor transient response showed an improvement in time compared to classical model-based approaches. To assess the uncertainty associated with the data-driven method estimate, I performed a statistical analysis of the method. The aim of the statistical analysis is to give confidence bounds on the uncertainty associated with the estimate in practical measurements. The bias and variance of the estimate were studied to get insight on how these parameters relate to the signal-to-noise ratio and to the number of samples processed. I obtained analytical expressions that predict the estimate bias and variance. The bias and variance prediction formulas were validated using Monte Carlo simulation. A practical setup for weighing mass generates real data that was used to evaluate the prediction formulas in experimental conditions.
3. **Decoupling multivariate functions: exploring multiple derivative information**

Jeroen De Geeter (ELEC) – June 21, 2018

Descriptions of nonlinear systems often involve a set of multivariate real functions. While very flexible, this has the downside of having a large number of parameters which makes gaining insight based on such models very difficult. When decoupling a set of multivariate real functions, these functions are expressed as a linear combination of univariate functions - removing cross terms. Such a decoupled representation may give more insight into the problem, reduce the number of variables or may be useful to simplify a complex system. Using the canonical polyadic decomposition, of a tensor containing first order information of the function, this decoupled representation can be found. However, there are a number of drawbacks to this method. For example, it cannot find an equivalent function for systems described by a single function. Therefor, I developed a method that tries to mitigate these problems by leveraging the relationship between the decompositions of function evaluation, first and second order information.

4. **Identification Of Autonomous Wiener Systems**

Ivan Markovsky (ELEC) – September 4, 2018

We show that the behavior of an autonomous Wiener system, consisting of an order-n linear time-invariant (LTI) subsystem and a degree-d polynomial nonlinearity, is included in the behavior of an LTI system of order (n + d)-choose-d --- the number of combinations with repetitions of d elements out of n elements. The eigenvalues of the embedding system are products of up to d eigenvalues of the linear subsystem. Based on this result, we propose the following three-step identification procedure:

1) identify the embedding LTI system from the given output data,
2) compute the linear subsystem, and
3) compute the nonlinear subsystem.

Step 1 is a classical LTI identification problem, however, there are two practical challenges. First, the order of the system is high even when n and d are small. Second, due to a wide range of dampings and frequencies, some eigenvalues of the system can not be computed numerically in a finite precision arithmetic, even when the data is exact (noise free).

Step 2 is a rank-1 factorization of a symmetric d-way tensor constructed from the eigenvalues of the identified LTI system. Although this problem can be solved by d singular value decompositions, there is a practical challenge of dealing with missing values due to the numerically unidentifiable eigenvalues.

Step 3 of the identification procedure is a structured data fusion problem, for which there are existing theoretical results and computational methods.

5. **Multi-Kernel Unmixing And Super-Resolution Using The Modified Matrix Pencil Method**

Stephane Chretien (National Physical Laboratory, London) - October 19, 2018

In this talk, we consider a generalization of the usual super-resolution problem that we call the multi-kernel unmixing super-resolution problem. Assuming access to Fourier samples, we derive an algorithm for this problem which is able to estimate the source parameters of each group, along with precise non-asymptotic guarantees.

Our approach involves estimating the group parameters sequentially in the order of increasing scale parameters. Each step involves Mairra’s modified matrix pencil method, and a fine study of perturbation bounds for generalised eigenvectors.

Applications to various engineering problems will also be presented.

Bio: Stephane Chretien studied at Ecole Normale Superieure (Cachan) and obtained his PhD in Electrical Engineering from the Universite Paris Sud Orsay in 1996, where he worked on successive projection methods for nonconvex set theoretic feasibility problems in signal processing. He then joined the University of Michigan (Ann Arbor) as a post-doctorate where he developed a Kullback-Proximal framework for the analysis of estimation algorithms in statistics and machine learning with application to Positron Emission Tomography. He then went back to France as a researcher in the NUMOPT team at INRIA where he studied numerical methods for nonsmooth optimization and EM-types algorithms for clustering. In 1999, he joined the Mathematics for Decision team in Brussels, where he studied network flow problems and convex relaxations for urban traffic modelling and control. In 2000, he was appointed Assistant Professor in the Mathematics Laboratory (Probability and Statistics) at the Universite de Franche Comte, Besancon where he studied efficient algorithms for Compressed Sensing, time series analysis and clustering, and contributed theoretical results on sparse recovery and finite random matrices. He joined the National Physical Laboratory (Mathematics and Modelling) in September 2015. He is now with the newly created Data Science Division, working on medical and industrial applications. His research focuses on time series analysis, machine learning, clustering, image segmentation, genetics, scheduling, combinatorial optimization, etc.

5.8 PATENTS

1. **TDR Based Transfer Function Estimation of Local Loop**

   Tom Bostoen, Patrick Boets, Leo Van Biesen, Thierry Pollet and Mohamed Zekri
   European Patent Office, Application No./Patent No. 01400832.0-1246

2. **Method and Apparatus for Identification of an Access Network by Means of 1-Port Measurements**

   Tom Bostoen, Thierry Pollet, Patrick Boets, Mohamed Zekri and Leo Van Biesen
3. Method and Apparatus for Identification of an Access Network by Means of 1-Port Measurements
   Tom Bostoen, Thierry Pollet, Patrick Boets, Mohamed Zekri and Leo Van Biesen

4. Method for Matching an Adaptive Hybrid to a Line
   Tom Bostoen, Patrick Boets, Leo Van Biesen and Thierry Pollet
   European Patent Office, Application No./Patent No. 03292891.3

5. Interpretation system for interpreting reflectometry information
   T. Vermeiren, Tom Bostoen, Leo Van Biesen, Frank Louage, Patrick Boets

6. Interpretation system for interpreting reflectometry information
   T. Vermeiren, Tom Bostoen, Leo Van Biesen, Frank Louage, Patrick Boets

7. Localisation of Customer Premises in a Local Loop Based on Reflectometry Measurements
   Tom Bostoen, Thierry Pollet, Patrick Boets, Leo Van Biesen

8. Localisation of Customer Premises in a Local Loop Based on Reflectometry Measurements
   Tom Bostoen, Thierry Pollet, Patrick Boets, Leo Van Biesen

   Tom Bostoen, Thierry Pollet, Patrick Boets, Leo Van Biesen

10. Signal Pre Processing for Estimating attributes of transmission Line
    Tom Bostoen, Thierry Pollet, Patrick Boets, Leo Van Biesen

11. A method for determining bit error rates
    Vandersteen Gerd, Verbeeck Jozef, Rolain Yves, Schoukens Johan, Wambacq Piet, Donnay Stephane

12. A method for determining signals in mixed signal systems
    Wambacq Piet, Vandersteen Gerd, Rolain Yves, Dobrovolny Petr

5.9 DOCTORAL DISSERTATIONS

PhD1. Etude de la Production et des Conditions de Propagation d'Ondes de Choc Créés par un Plasma de Décharge
      Jean Renneboog
      Doctoral Dissertation, Universit Libre de Bruxelles, 1967
PhD2. **Bijdrage tot het Verwekken en Meten van Nauwkeurig Bepaalde Fazeverschuivingen**
Alain Barel
Doctoral Dissertation, Vrije Universiteit Brussel, April 1976
*Jury: G. Maggetto (VUB), Verlinden (VUB), Hoffman (RUG), C. Eugène (UCL)*
*Promoter: J. Renneboog (VUB)*

PhD3. **Maximum Informatie Extractie door middel van een Optimaal Frequentie Domein Experiment**
Guy Vilain
Doctoral Dissertation, Vrije Universiteit Brussel, March 1983
*Jury: G. Maggetto (VUB), A. Barel (VUB), J. Cornelis (VUB), C. Eugène (UCL), Kerkhof, J. Vereeken (VUB), G. Vansteenkiste (VUB)*
*Promoter: J. Renneboog (VUB)*

PhD4. **Foutdetectie op Electrische Lijnen met behulp van een Digitale Behandeling van het Reflectogram**
Leo Van Biesen
Doctoral Dissertation, Vrije Universiteit Brussel, April 1983
*Jury: G. Maggetto (VUB), A. Barel (VUB), Baert (RUG), C. Eugène (UCL), Goossens, Kirschvink, J. Tiberghien (VUB)*
*Promoter: J. Renneboog (VUB)*

PhD5. **Parameterestimatie in Lineaire en Niet-Lineaire Systemen met Behulp van Digitale Tijdsdomein Metingen**
Johan Schoekens
Doctoral Dissertation, Vrije Universiteit Brussel, February 1985
*Jury: G. Maggetto (VUB), A. Barel (VUB), P. Eykhoff (TU Eindhoven), C. Eugène (UCL), Hoffmann (RUG), Spriet (RUG), O. Steenhaut (VUB), G. Vansteenkiste (VUB)*
*Promoter: J. Renneboog (VUB)*

PhD6. **Active Microstrip Antennas**
Russell Dearnly
Doctoral Dissertation, Vrije Universiteit Brussel, June 1987
*Jury: G. Maggetto (VUB), L.P. Ligthart (TU Delft), G. Szymbanski (Tech. University of Poznan), J. Tiberghien (VUB), A. Van De Capelle (KUL)*
*Promoters: J. Renneboog (VUB), A. Barel (VUB)*

PhD7. **Analysis and Application of a Maximum Likelihood Estimator for linear Systems**
Rik Pintelon
*Jury: G. Maggetto (VUB), A. Barel (VUB), P. Eykhoff (TU Eindhoven), A. van den Bos (TU Delft), J. Vandewalle (KUL)*
*Promoters: J. Renneboog (VUB), J. Schoukens (VUB)*

PhD8. **Time Division Multiplexing in Optical Fiber Networks**
Danny Sevenhans
Doctoral Dissertation, Vrije Universiteit Brussel, June 1988
*Jury: G. Maggetto (VUB), P. Kool (VUB), E. Stijns (VUB), R. Blondel (Universit de Mons), P. Bulteel (Atea), C. Eugène (UCL), Baert (RUG)*
*Promoters: J. Renneboog (VUB), A. Barel (VUB)*

PhD9. **Design of Optimal Input Signals with Minimal Crest Factor**
Edwin Van der Ouderea
*Jury: G. Maggetto (VUB), F. Delbaen (VUB), P. Eykhoff (TU Eindhoven), R. Pintelon (VUB), J. Renneboog (VUB), A. van den Bos (TU Delft), J. Vandewalle (KUL)*
*Promoter: J. Schoukens (VUB)*

PhD10. **Channel Multiple Access Protocols for a Hydrological Multihop Packet Radio Network**
Thomas J. Odhiambo Afullo
Doctoral Dissertation, Vrije Universiteit Brussel, June 1989
*Jury: G. Maggetto (VUB), L. Van Biesen (VUB), J. Tiberghien (VUB), P. Van Binst (VUB), A. Van Der Beken (VUB)*
*Promotor: A. Barel (VUB)*

PhD11. **Steady-State Analysis of Strongly Nonlinear Circuits**
Eli Van Den Eijnde
PHD12. **Knowledge-Based Spectral Estimation**  
James Ambani Kulubi  
Jury: G. Maggetto (VUB), R. Pintelon (VUB), A. Barel (VUB), W. Verhelst (VUB), O. Steenhaut (VUB), Hoffman (RUG)  
Promoter: L. Van Biesen (VUB)

PHD13. **Radar Cross Section Reduction using Multiple-Layer Strip Gratings**  
Gert Van Der Plas  
Jury: G. Maggetto (VUB), R. Van Loon (VUB), A. Van de Capelle (KUL), D. De Zutter (RUG), P. Delogne (UCL)  
Promoters: A. Barel (VUB), E. Schweicher (KMS)

PHD14. **Automated Diagnosis for Arbitrary Digital Circuits**  
Patrick Bakx  
Jury: G. Maggetto (VUB), M. Goossens (VUB), A. Barel (VUB), M. Verlinden (VUB), V. Jonckers (VUB), P. Vandeloo (UIA)  
Promoter: L. Van Biesen (VUB)

PHD15. **Measuring Nonlinear Systems - A Black Box Approach for Instrument Implementation**  
Marc Vanden Bossche  
Jury: G. Maggetto (VUB), R. Milard (T.U. Leeds), P. Eykhoff (TU Eindhoven), D. De Zutter (RUG), Rik Pintelon (VUB), D. Ritting (Hewlett Packard - USA)  
Promoters: A. Barel (VUB), J. Schoukens (VUB)

PHD16. **Identification of Multi-Input Multi-Output Systems using Frequency-Domain Models**  
Patrick Guillaume  
Doctoral dissertation, Vrije Universiteit Brussel, June, 1992  
Jury: G. Maggetto (VUB), A. Barel (VUB), M. Van Overmeire (VUB), P. Eykhoff (TU Eindhoven), M. Gevers (UCL), J. Vandewalle (KUL)  
Promoters: J. Schoukens (VUB), R. Pintelon (VUB)

Hugo Van hamme  
Doctoral dissertation, Vrije Universiteit Brussel, June, 1992  
Jury: G. Maggetto (VUB), A. Barel (VUB), F. Delbaen (VUB), M. Vanden Bossche (Hewlett Packard Belgium), A. van den Bos (TU Delft), B. De Moor (KUL), L. Ljung (University of Linköping)  
Promoters: R. Pintelon (VUB), J. Schoukens (VUB)

PHD18. **Identification of Linear Systems from Amplitude Information only**  
Yves Rolain  
Jury: G. Maggetto (VUB), A. Barel (VUB), F. Delbaen (VUB), P. Eykhoff (TU Eindhoven), A. van den Bos (TU Delft), K. Godfrey (Univ. of Warwick, UK), J. Vandewalle (KUL)  
Promoters: J. Schoukens (VUB), R. Pintelon (VUB)

PHD19. **The Use of the Method of Moments in Designing NMR Antennas**  
Guido Annaert  
Doctoral dissertation, Vrije Universiteit Brussel, December, 1993  
Jury: G. Maggetto (VUB), R. Van Loon (VUB), R. Luypaert (VUB-AZ), R. Turner, C. De Wagter (RUG), P. Van Hecke (AGFA-GEVAERT N.V.), M. Lumori (VECO)  
Promoters: A. Barel (VUB), M. Osteaux (VUB-AZ)

Luc Peirlinckx  
Doctoral dissertation, Vrije Universiteit Brussel, June 1994  
Jury: G. Maggetto (VUB), A. Barel (VUB), L. Bjørnø (TU Denmark), P. De Wilde (VUB), H. Leroy (KULAK), J. Van Campenhout (UG), J.P. Sessarego (CNRS-LMA, France)  
Promoters: L. Van Biesen (VUB), R. Pintelon (VUB)
### PhD21. Radar Cross Section Calculations of Three-Dimensional Objects, Modelled by CAD
Isabelle De Leeneer

*Jury:* G. Maggetto (VUB), V. Stein, D. De Zutter (UG), A. Van De Capelle (KUL), R. Van Loon (VUB)
*Promoters:* A. Barel (VUB), E. Schweicher (KMS)

### PhD22. Design and Realization of Low Crest Factor Broadband Microwave Excitation Signals
Tom Van den Broeck
Doctoral Dissertation, Vrije Universiteit Brussel, September 1995

*Jury:* G. Maggetto (VUB), J. Tiberghien (VUB), L. Martens (UG), R. Pollard (University of Leeds), M. Vanden Bossche (Hewlett Packard Belgium)
*Promoters:* A. Barel (VUB), J. Schoukens (VUB)

### PhD23. Accurate Experimental Modelling of Bounded Wave Propagation in Viscoelastic Materials
Dayu Zhou
Doctoral Dissertation, Vrije Universiteit Brussel, October 1995

*Jury:* G. Maggetto (VUB), P. Guillaume (VUB), L. Bjorna (TU Denmark), H. Leroy (KULAK), M. Lumori (VECO), J.P. Sessarego (CNRS-LMA, France), I. Veretennicoff (VUB)
*Promoters:* L. Van Biesen (VUB), L. Peirlinckx (VUB)

### PhD24. Calibration of a Measurement System for High Frequency Nonlinear Devices
Jan Verspecht
Doctoral Dissertation, Vrije Universiteit Brussel, November 1995

*Jury:* G. Maggetto (VUB), J. Schoukens (VUB), A. Cardon (VUB), M. Vanden Bossche (Hewlett Packard, Belgium), L. Martens (RUG), B. Nauwelaers (KUL), U. Lott, A. Roddie, R. Pintelon (VUB), I. Veretennicoff (VUB)
*Promoter:* A. Barel (VUB)

### PhD25. Performance with dielectric resonators at microwave frequencies for studying the pairing state in high-Tc superconductors
Andrei Mourachkine

*Jury:* W. Van Rensbergen (VUB), G. Van Tendeloo (VUB), J. Drowart (VUB), N. Klein (IFF, Julich), V. Gasumyants (St. Petersburg)
*Promoters:* A. Barel (VUB), S. Tavernier (VUB), R. Deltour (ULB)

### PhD26. Identification of Linear and Nonlinear Systems in an Errors-in-Variables Least Squares and Total Least Squares Framework
Gerd Vandersteen
Doctoral dissertation, Vrije Universiteit Brussel, April 1997

*Jury:* G. Maggetto (VUB), A. Barel (VUB), M. Gevers (UCL), L. Ljung (University of Linköping), A. van den Bos (TU Delft), J. Vandewalle (KUL)
*Promoters:* R. Pintelon (VUB), J. Schoukens (VUB)

### PhD27. Frequency Domain Identification of Transmission Lines from Time Domain Measurements
Patrick Boets

*Jury:* G. Maggetto (VUB), A. Barel (VUB), M. Goossens (VUB), R. Pintelon (VUB), D. Baert (RUG), C. Eugène (UCL), J. Capon (Belgacom), J. Verspecht (Hewlett Packard, Belgium)
*Promoter:* L. Van Biesen (VUB)

### PhD28. Nonparametric Identification of Nonlinear Mechanical Systems
Stefaan Duym

*Jury:* G. Maggetto (VUB), R. Pintelon (VUB), A. Barel (VUB), J. Vandewalle (KUL), J. Swevers (KUL), K. Worden (Univ. of Sheffield)
*Promoters:* J. Schoukens (VUB), M. Van Overmeire (VUB)

### PhD29. Design of Digital Chebyshev Filters in the Complex Domain
Rudi Vuerinckx

*Jury:* G. Maggetto (VUB), A. Barel (VUB), F. Grenez (ULB), I. Kollár (TU Budapest), McClellan (Georgia Institute of Technology), R. Pintelon (VUB), W. Verheist (VUB)
*Promoters:* J. Schoukens (VUB), Y. Rolain (VUB)

### PhD30. Caching in Dataflow-Based Instrumentation & Measurement Environments
Eli Steenput


PhD40. **Measurement and modelling of the noise behaviour of high-frequency nonlinear active systems**

Geens Alain

Doctoral Dissertation, Vrije Universiteit Brussel, May 2002

Jury: G. Maggetto (VUB), J. Vereecken (VUB), R. Pintelon (VUB), D. Van Hoenacker (UCL), J.C. Pedro (Universidade de Aveiro, Portugal), A. Barel (VUB)

Promoter: Y. Rolain

PhD41. **Model Based Calibration of D/A Converters**

Vargha Balázs

Doctoral Dissertation, Vrije Universiteit Brussel, June 2002

Jury: G. Maggetto (VUB), J. Vereecken (VUB), A. Barel (VUB), B. Bell (NIST, USA), I. Kollar (TUB, Hungary), Y. Rolain (VUB), G. Vandersteen (VUB-IMEC)

Promoters: Johan Schoukens, István Zoltán (TUB)

PhD42. **Frequency Response Function Measurements in the Presence of Non-Linear Distortions**

Kenneth Vanhoenacker

Doctoral Dissertation, Vrije Universiteit Brussel, June 2003

Jury: G. Maggetto (VUB), J. Vereecken (VUB), A. Barel (VUB), P. Guillaume (VUB), H. Sol (VUB), J. Swevers (KUL), H. Van der Auweraer (LMS International)

Promoter: Johan Schoukens

PhD43. **Identification of Nonlinear Systems using Interpolated Volterra Models**

József G. Németh

Doctoral Dissertation, Vrije Universiteit Brussel, June 2003

Jury: A. Barel (VUB), T. Dobrowiecki (Budapest University of Technology and Economics), M.P. Kennedy (University College Cork), R. Pintelon (VUB)

Promoters: Johan Schoukens, István Kollár (TUB)

PhD44. **Identification of block-oriented nonlinear models**

Philippe Crama

Doctoral Dissertation, Vrije Universiteit Brussel, June 2004

Jury: G. Maggetto (VUB), J. Vereecken (VUB), P. Guillaume (VUB), L. Ljung (Linköping Universitet, Sweden), M. Verhaegen (TUD, The Netherlands), J. Vandewalle (KUL), A. Barel (VUB), R. Pintelon (VUB)

Promoters: Johan Schoukens, Y. Rolain

PhD45. **Identification of the Time Base in Environmental Archives**

Fjo De Ridder

Doctoral Dissertation, Vrije Universiteit Brussel, December 2004

Jury: W. Baeyens (VUB), A. Barel (VUB), A. Berger (UCL), Ph. Lataire (VUB), G. Munhoven (Université de Liège), D. Paillard (Centre d’Etudes de Saclay, Orme des Merisiers, France), J. Schoukens (VUB), J. Vandewalle (KUL), J. Vereecken (VUB)

Promoters: R. Pintelon, Frank Dehairs

PhD46. **Optimisatie van patiënt dosissen, gekoppeld aan beeldkwaliteit, in de vasculaire radiologie**

Lara Struelpens

Doctoral Dissertation, Vrije Universiteit Brussel, January 2005

Promoter: R. Van Loon, co-promotors: H. Bosmans (KUL), F. Vanhavere (SCK-CEN)

PhD47. **Modelling, Designing and Developing a Multidisciplinary Geodatabase GIS with the Implementation of RDBMS in conjuction with CAD and different GIS applications for the development of Coastal/Marine Environment**

Tesfazghi Ghebre Egziabeher

Doctoral Dissertation, Vrije Universiteit Brussel, September 2005

Jury: E. Vandijck (VUB), F. Canters (VUB), A. Barel (VUB), S. Wartel (Royal Belgian Institute of Natural Sciences), L. Peirlinckx (Phonetics Topographics, Belgium)

Promoters: L. Van Biesen and Marc Van Molle (Geography dept., fac. of Sciences)

PhD48. **Modeling of Substrate Noise Impact on CMOS VCOS on a Lightly-Doped Substrate**

Charlotte Soens


Promoters: M. Kuijk, Y. Rolain, P. Wambacq,

PhD49. **Evaluation of deep-sub-quarter micron CMOS technology: low noise amplifiers, oscillators and ESD reliability**

Dimitri Linten


Promoters: Y. Rolain, P. Wambacq and M. Kujik

Jury: G. Maggetto, J. Vereecken, A. Barel, M.I. Natarajan (Mentor IMEC), I. Smedes (Philips Semiconductors), M. Tiebout (Infineon)

PhD50. **Verification and Correction of Test Signals with a Spectrum Analyzer**

Daan Rabijns

Doctoral Dissertation, Vrije Universiteit Brussel, March 2006

Promoters: G. Vandersteen, J. Schoukens

Jury: P. Lataire, J. Vereecken, I. Kollar (Budapest Univ. of Techn. & Economics), D. DeGroot (CCNi Measurement Service), P. Guillaume, W. Van Moer

PhD51. **Impact and Mitigation of Analog Impairments in Multiple Antenna Wireless Communications**

Jian Liu


Promoters: A. Barel, J. Stiens, G. Vandersteen

Jury: P. Lataire, J. Vereecken, L. Van der Perre (IMEC), V. Öwall (Lund University, Sweden), W. Van Moer

PhD52. **Development and evaluation of a numerical method for the identification of a physical system described by a partial differential equation: a case study**

Kathleen De Belder


Promoters: R. Pintelon, J. Schoukens

Jury: Ph. Lataire, J. Vereecken, J. Sweeck (KUL), P. Guillaume, H. Van der Auweraer (LMS International), H. Sol, P. Roose (Cytec)

PhD53. **Contributions to Large-Signal Network Analysis**

Frans Verbeyst


Promoter: Y. Rolain

Jury: J. De Ruyst, Jean Vergeet, Alain Barel, Don DeGroot (CCNi Measurement Services, Andrews University, Michigan, USA), Rik Pintelon, Roger Pollard (University of Leeds, UK), Johan Schoukens, Steve Vnlanduit

PhD54. **Contribution to severe weather and multimodel ensemble forecasting in Belgium**

David Dehenuauw

Doctoral Dissertation, Vrije Universiteit Brussel, November 2006

Promoters: A. Barel, H. Decleir


PhD55. **A system identification view on two aquatic topics: phytoplankton dynamics and water mass mixing**

Anouk de Brauwere


Promoters: Willy Baeyens, Johan Schoukens

Jury: Robert Finsy, Frank Dehairs, Rik Pintelon, An Smeyers-Verbeke, Joos Vandewalle (KUL), Eric Deleersnijder (UCL), Karlne Soetaert (NIOO-KNAW), Johannes Karstensen (University of Kiel)

PhD56. **Ultra-Wideband transceiver for low-power low data rate applications**

Julien Ryckaert


Promoters: Yves Rolain, Piet Wambacq (IMEC)

Jury: Annick Hubin, Rik Pintelon, Gerd Vandersteen, J. Rabaey (University of Berkley, USA), M. Tiebout (Infineon Germany), Christof Debaes, C. Desmet (IMEC)

PhD57. **Measuring, modeling and realization of high-frequency amplifiers**

Ludwig De Locht


Promoters: Yves Rolain, Gerd Vandersteen

Jury: Annick Hubin, Rik Pintelon, Wendy Van Moer, Danielle Vanhoenacker (UCL), Andrea Ferrero (Politecnico di Torino), Christof Debaes (VUB), Marc Vanden Bossche (NMDG Engineering)

PhD58. **Body Area Communications: Channel characterization and ultra-wideband system-level approach for low power**
Andrew Fort
Promoters: Leo Van Biesen, Piet Wambacq (IMEC)
Jury: Annick Hubin, R. Pintelon, G. Vandersteen, Y. Hao (Univ. of London), C. Desset (IMEC)

PhD59. Algorithms for identifying guaranteed stable and passive models from noisy data
Tom D’Haene
Promoter: Rik Pintelon
Jury: Gert Desmet, Jean Vereecken, Patrick Guillaume, Paul Van Dooren (UCL), Tom Dhane (UGent), Martine Olivi (INRIA), Gerd Vandersteen

PhD60. Identification of Nonlinear Systems Using Polynomial Nonlinear State Space Models
Johan Paduart
Promoters: Johan Schoukens, Rik Pintelon
Jury: Annick Hubin, Jean Vereecken, Steve Vanlanduit, Lennart Ljung (Linköping University), Jan Swevers (KUL), Yves Rolain

PhD61. GSM-based Positioning: Techniques and Application
Nico Deblauwe
Doctoral Dissertation, Vrije Universiteit Brussel, June 2008
Promoters: Leo Van Biesen, Prof. Dr. Claudia Linnhoff-Popien (Ludwig-Maximilians-Univ. Munchen)
Jury: Dirk Lefeber, Rik Pintelon, Peter Schelkens, Wendy Van Moer, Luc Vandendorpe (Universit Catholique de Louvain), Luc Martens (Universiteit Gent), Fredrik Gustafsson (Linköping University)

Anna Marconato
Doctoral Dissertation, Vrije Universiteit Brussel - Università degli Studi di Trento, March 2009
Promoters: Prof. Dario Petri, Johan Schoukens, Bruno Caprile
Jury: Annick Hubin, Gerd Vandersteen, Michel Verleysen (UCL), Davide Anguita (University of Genova), Anne Nowé

PhD63. A framework for the analysis and modelling of substrate noise
Stephane Bronckers
Doctoral Dissertation, Vrije Universiteit Brussel, June 2009
Promoters: G. Van der Plas, G. Vandersteen
Jury: A. Hubin, voorzitter, R. Pintelon, P. Wambacq, M. Nagat, (Kobe University, Japan), F.J. Clement, (Coupling Wave Solutions, France), W. Schoenmaker (Magwel, Belgium)

PhD64. Identification and use of nonparametric noise models extracted from overlapping subrecords
Kurt Barbé
Doctoral Dissertation, Vrije Universiteit Brussel, September 2009
Promoters: Rik Pintelon, Johan Schoukens
Judging-committee: Annick Hubin, Patrick Guillaume, Gerd Vandersteen, Lennart Ljung (Linköping University), Jérôme Antoni (Univ. de Technologie de Compiègne), Joos Vandewalle (KULeuven), Steve Vanlanduit

PhD65. Model Fitting in Frequency Domain Imposing Stability of the Model
László Balogh
Doctoral Dissertation, Vrije Universiteit Brussel, October 2009
Promoters: Rik Pintelon, István Kollár (TUBudapest)
Jury: Johan Schoukens, Patrick Guillaume, Joos Vandewalle (KULeuven), Steve Vanlanduit, Barnabás Garay (TUBudapest)

PhD66. CMOS building blocks for 60 GHz Phased-Array receivers
Karen Scheir
Promoters: Piet Wambacq, Yves Rolain
Jury: A. Hubin, R. Pintelon, G. Vandersteen, J. Long (TUDelft, Nederland), K. Halonen (Helsinki University of Technology, Finland), C. Debaes

PhD67. Localization in wireless networks and co-existence of broadband services
Mussa Bshara
Doctoral Dissertation, Vrije Universiteit Brussel, June 2010
Promoter: Leo Van Biesen
Jury: J. Tibergheen, R. Pintelon, P. Schelkens (IBBT), F. Gustafsson (linkoping Universitet), G. Vandersteen, P. Boets (Alcatel-Lucent-bell), L. Vandendorpe (UCL)

PhD68. Advanced calibration and Instrumentation setups for nonlinear RF devices
Liesbeth Gommé
Doctoral Dissertation, Vrije Universiteit Brussel, August 2010
Promoter: Yves Rolain
Jury: A. Hubin, R. Pintelon, G. Vandersteen, K. Godfrey (University of Warwick), D. Barataud (University of Limoges), M. Vanden Bossche (NMDG Engineering)

PhD69. A Bayesian Model To Construct A Knowledge Based Spatial Decision Support System For The Chaguana River Basin
Indira Nolivos Alvarez
Doctoral Dissertation, Vrije Universiteit Brussel, October 2010
Promoters: Leo Van Biesen, Pilar Cornejo (ESPOL, Ecuador)
Jury: J. Tiberghien, R. Pintelon, W. Bauwens, Pedro Girao (Universidade Tecnica de Lisboa), Rony Swennen (KUL), Ann Now

PhD70. Best Linearized models for RF systems
Koen Vandermot
Doctoral Dissertation, Vrije Universiteit Brussel, October 2010
Promoter: Yves Rolain
Jury: W. Bauwens, R. Pintelon, G. Vandersteen, D. Vanhoenacker (UCL), T. Dhaene (Universiteit Gent), M. Vanden Bossche (NMDG Engineering)

PhD71. Time series reconstruction of environmental proxy records
Veerle Beelaerts
Doctoral Dissertation, Vrije Universiteit Brussel, January 2011
Promoter: Rik Pintelon, Frank Dehairs
Jury: W. Bauwens, H. Terryn, J. Schoukens, J. Vandewalle (KUL), G. Munhoven (Universiteit de Liège), D. Paillard (Lab. des Sciences du Climat et de l'environnement, Centre de Saclay, France), M. Elskens

PhD72. Multirate Cascaded ΔS Converters for Wireless Applications
Lynn Bos
Doctoral Dissertation, Vrije Universiteit Brussel, January 2011
Promoters: G. Vandersteen, Dr, ir. J. Ryckaert
Jury: P. Guillaume, H. Terryn, P. Warnbacq, P. Rombouts (Universiteit Gent), K. Makinwa (Delft University of Technology), B. Murmann (Stanford University)

PhD73. Use and modeling of overtone resonances in FBAR resonators operating at RF frequencies
Mohamed Reda Amin El-Barkouky
Doctoral Dissertation, Vrije Universiteit Brussel, January 2011
Promoters: Y. Rolain, P. Wambacq
Jury: D. Lefebber, H. Terryn, G. Vandersteen, B. Otis (University of Washington, Seattle, USA), J. Vandewalle (KUL)

PhD74. Nonlinear and Dynamical Models for Temperature Reconstructions from Multi Proxy Data In Bivalve Shells
Maite Bauwens
Doctoral Dissertation, Vrije Universiteit Brussel, March 2011
Promoters: Johan Schoukens and Frank Dehairs
Jury: Alan Wanamaker (Iowa State University, USA), Luc André (ULB-MRAC), Fjo De Ridder, Rik Pintelon, Willy Baeyens, Mark Elskens

PhD75. Reflectometric Analysis of Transmission Line Networks
Carine Neus
Doctoral Dissertation, Vrije Universiteit Brussel, March 2011
Promoters: Leo Van Biesen, Yves Rolain
Jury: Annick Hubin, Ludwig De Locht, Patrick Boets (Alcatel-Lucent, Belgium), Luc Martens (U-Gent), Tomas Nordström (TTW Telecommunication Research Center Vienna, Austria)

PhD76. Frequency Domain Measurement and identification of Linear, Time-varying Systems
John Lataire
Doctoral Dissertation, Vrije Universiteit Brussel, March 2011
Promoter: Rik Pintelon
Jury: Jérome Antoni (Université Compiègne, France), Lennart Ljung (University of Linköping, Sweden), Paul Van den Hof (Delft University of Technology, The Netherlands), Johan Schoukens, Patrick Guillaume, Herman Terryn, Steve Vanlanduit.

PhD77. Nonlinear dynamic systems: blind identification of block-oriented models, and instability under random inputs
Vanbeylen Laurent
PhD78. Study of 3D position determination of the interaction point in monolithic scintillator blocks for PET
Zhi Li
Promoters: Stefaan Tavernier, Gerd Vandersteen
Jury: Johan Schoukens, Michel Defrise, Karl Ziemons (University of Aachen, Germany), Jose Perez (Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, Spain)

PhD79. Some practical applications of the best linear approximation in nonlinear block-oriented modelling
Lieve Lauwers
Promoter: Johan Schoukens
Judging committee: Gert Desmet, Herman Terryn, Kurt Barbé, Keith Godfrey (University of Warwick), Joos Vandewalle (KULeuven), Steve Vanhoutte

PhD80. Design and evaluation of channel models for DSL applications
Wim Foubert
Doctoral Dissertation, Vrije Universiteit Brussel, November 2011
Promoters: Leo Van Biesen and Yves Rolain

PhD81. Digital Basedband Modeling and Correction of Radio Frequency Power Amplifiers
Per Landin
Doctoral Dissertation, KTH School of Electrical Engineering, Stockholm, Sweden - Vrije Universiteit Brussel (cotutelle), June 2012
Promoter: Wendy Van Moer

PhD82. Frequency Domain Based Performance Optimization of Systems with Static Nonlinearities
David Rijlaarsdam
Promoters: Maarten Steinbuch (TUE) - Johan Schoukens, P.W.J.M. Nuij (co-promoter TUE)

PhD83. Tackling two drawbacks of polynomial nonlinear state-space models
Van Mulders Anne
Doctoral Dissertation, Vrije Universiteit Brussel, June 2012
Promoter: Johan Schoukens
Jury: Hugo Sol, Herman Terryn, Gerd Vandersteen, Håkan Hjalmarsson (KTH), Thomas Schön (Linköping Sweden), Jan Swevers (KUL), Patrick Guillaume

PhD84. Signal Shaping and Sampling-based Measurement Techniques for Improved Radio Frequency Systems
Charles Nader
Doctoral Dissertation, University of Gävle, Sweden - Vrije Universiteit Brussel (cotutelle), August 2012
Promoters: Prof. Niclas Björsel (University of Gävle); Prof. Wendy Van Moer (Vrije Universiteit Brussel)
Jury: Prof. Hedie Ottevaere, Prof. Herman Terryn, Prof. Kurt Barbé, Dr. Lee Barford (Agilent Technologies); Prof. Håkan Hjalmarsson (KTH Royal Institute of Technology); Prof. Gurvinder Virk Singh (University of Gävle); Dr. Marc Vanden Bossche (NMDG)

PhD85. Modelling and Optimization of Algorithms for Multiuser Multicarrier systems
Cordova Junco Hernan Xavier
Doctoral Dissertation, Vrije Universiteit Brussel, October 2012
Promoter: Leo Van Biesen

PhD86. Identification in Nuclear and Thermal Energy. Moderator Temperature Coefficient Estimation via Noise Analysis and Black-Box Modeling of Heat Transfer
Griet Monteyne
Doctoral Dissertation, Vrije Universiteit Brussel, April 2013
Annual report ELEC 2018

Promoter: Gerd Vandersteen, Peter Baeten
Jury: Christophe Demazière (Chalmers University of Technology, Sweden), Saqib Javed (Chalmers University of Technology, Sweden), Jan Swevers (KUL), Steve Vanlanduit, Johan Deconinck, John Lataire, Johan Schoukens

PhD87. Closing the design gap between system-level and component-level Electro Static Discharge (ESD)

Mirko Scholz
Doctoral Dissertation, Vrije Universiteit Brussel, May 2013
Advisors: Gerd Vandersteen, Dimitri Linten (IMEC)
Jury: Maarten Kuijk, Johan Deconinck, Piet Wambacq, Dr. Vladislav Vashchenko (Maxim IC), Harald Gossner (Intel)

PhD88. Study of the Best Linear Approximation of Nonlinear Systems with Arbitrary Inputs

Wong, Hin Kwan Roland
Doctoral Dissertation, Vrije Universiteit Brussel - University of Warwick, UK (co-tutelle), June 2013
Advisors: Prof. em. Dr. Keith R. Godfrey (University of Warwick), Prof. Dr. ir. Johan Schoukens, Prof. Dr. Nigel G. Stocks (University of Warwick)
Jury: Steve Vanlanduit, Tadeusz Dobrowiecki (Budapest University of Technology and Economics), Johan Deconinck, Gerd Vandersteen, Peter R. Jones (University of Warwick), Jérôme Antoni (Université de Lyon)

PhD89. Frequency Domain Measurement and Identification of Weakly Nonlinear Time-Periodic Systems

Ebrahim Louarroudi
Doctoral Dissertation, Vrije Universiteit Brussel, September 2014
Advisors: Rik Pintelon and John Lataire
Jury: Jérôme Antoni (University de Lyon, France), Keith Godfrey (University of Warwick, UK), Frans van der Helm (Delft University of Technology, Nederland), Ivan Markovsky, Steve Vanlanduit, Johan Deconinck, Gerd Vandersteen

PhD90. Glucose Estimation At Physiological Levels Employing Electrochemical Impedance Spectroscopy and Gas Sensors

Oscar Javier Olarte Rodríguez, Vrije Universiteit Brussel, December 2014
Advisors: Wendy Van Moer, Yves Van Ingelgem, Kurt Barbé
Jury: Clara Ionescu (Ghent University), Sergio Rapuano (University of Sannio, Italy), Jose Chilo (Högskolan i Gävle, Sweden), Chris van Schravendijk (Diabetes Research Center VUB), Heidi Ottevaere, Johan Deconinck

PhD91. Wiener system identification with generalized orthonormal basis functions

Koen Tiels, Vrije Universiteit Brussel, March 2015
Advisors: Johan Schoukens
Jury: Fouad Giri (University of Caen Basse-Normandie), Peter S.C. Heuberger (Technische Universiteit Eindhoven), Anna Marconato, Steve Vanlanduit, Johan Deconinck, Gerd Vandersteen

PhD92. Identification of Parallel Block-Oriented Models starting from the Best Linear Approximation

Maarten Schoukens, Vrije Universiteit Brussel, May 2015
Advisors: Yves Rolain, Gerd Vandersteen
Jury: Lennart Ljung (University of Linköping, Sweden), Fouad Giri (University of Caen Basse-Normandie), Joos Vandewalle (KULeuven), Rik Pintelon, Annick Hubin, Johan Deconinck, Francesco Ferranti

PhD93. Estimation of Heat Transport Coefficients in Fusion Plasmas

Matthijs van Berkel, Technische Universiteit Eindhoven, June 2015
Advisors: M.R. De Baar (TUE), Gerd Vandersteen

PhD94. Identification From Partially Missing Data and Modeling of Distillation Columns

Diana Ugyryumova, Vrije Universiteit Brussel, July 2015
Advisors: Gerd Vandersteen, Rik Pintelon
Jury: Daniel E. Rivera (Arizona State University, USA), Steve Vanlanduit, Keith E. Godfrey (Warwick University, UK), Johan Deconinck, Michel Kinnnaert (ULB), Ebrahim Louarroudi

PhD95. Nonparametric identification of linear time-varying systems

Péter Zoltán Csurscia, Vrije Universiteit Brussel and Budapest University of Technology and Economics (co-tutelle), October 2015
Advisors: Johan Schoukens, István Kollár (Budapest University of Technology and Economics)
Jury: István Vajk (Budapest University of Technology and Economics), Keith Godfrey (University of Warwick), Jérôme Antoni (Université de Lyon), Steve Vanlanduit, Johan Deconinck, John Lataire

PhD96. System Identification in Highly Non-Informative Environment

Sándor Kolumbán
Doctoral Dissertation, Vrije Universiteit Brussel and Budapest University of Technology and Economics (co-tutelle), January 2016
PhD97. **Modeling and identification of Linear Parameter-Varying systems**

Jan Goos  
Promotor: Rik Pintelon  
Co-promotor: John Lataire  
Jury: Jan Swevers (KUL), Roland Tóth (TUE), Marion Gilson-Bagrel (Université de Lorraine), Patrick Guillaume, Johan Deconinck, Francesca Ferranti

PhD98. **Development of User-Friendly System Identification Techniques**

Geerardyn Egon  
Doctoral Dissertation, Vrije Universiteit Brussel, August 2016  
Advisors: Johan Schoukens and Tom Oomen (Eindhoven University of Technology)  
Jury: Patrick Guillaume, Johan Deconinck, Koen Tiels, Jérôme Antoni (University of Lyon), Tomas McKelvey (Chalmers University of Technology), Bart Peeters (Siemens Industry Software – LMS)

PhD99. **Modeling Techniques for the efficient design of microwave bandpass filters**

Matthias Caenepeel  
Doctoral Dissertation, Vrije Universiteit Brussel, October 2016  
Advisors: Yves Rolain, Martine Olivi, Fabien Seyfert  
Jury: Annick Hubin, Johan Deconinck, Koen Tiels, Jérôme Antoni (University of Lyon), Tomas McKelvey (Chalmers University of Technology), Bart Peeters (Siemens Industry Software – LMS)

PhD100. **Distortion Analysis of Analog Electronic Circuits using Modulated Signals**

Adam Cooman  
Advisor: Gerd Vandersteen  
Jury: Heidi Ottevaere, Roger Vounckx, Piet Wambacq, Fabien Seyfert (INRIA-APICS), Fabio Filicori (Università di Bologna), Raymond Quéret (Université de Limoges)

PhD101. **D-Optimal Input Design for the Identification of Structured Nonlinear Systems**

Alexander De Cock  
Doctoral Dissertation, Vrije Universiteit Brussel, May 2017  
Advisor: Johan Schoukens  
Jury: Roland Scharf, Annika Raatz, Steve Vanlanduit, Tobias Hemsel, Lars Panning-von Scheidt, Jérôme Antoni, Roger Vounckx, Gerd Vandersteen

PhD102. **Differentiation of Soft Biological Tissues and Phantoms using a Piezoelectric Tactile Sensor for Applications in Brain Tumor Resection**

David Oliva Uribe  
Doctoral Dissertation, Vrije Universiteit Brussel and Leibniz Universität Hannover (co-tutelle), July 2017  
Advisors: Jörg Wallaschek, Johan Schoukens  
Jury: Roland Scharf, Annika Raatz, Steve Vanlanduit, Tobias Hemsel, Lars Panning-von Scheidt, Jérôme Antoni, Roger Vounckx, Gerd Vandersteen

PhD103. **Data-driven Discrete-time Identification of Continuous-time Nonlinear Systems and Nonlinear Modelling of Li-Ion Batteries**

Rishi Relan  
Doctoral Dissertation, Vrije Universiteit Brussel, October 2017  
Advisor: Johan Schoukens  
Jury: Joeri Van Mierlo, Roger Vounckx, Mark Runacres, Koen Tiels, Tomas McKelvey (Chalmers University), Hugues Garnier (Université de Lorraine), Dhammika Widanalage (University of Warwick)

PhD104. **Low Frequency Forced Oscillation Technique in Clinical Practice**

Hannes Maes  
Doctoral Dissertation, Vrije Universiteit Brussel, October 2017  
Promotor: Gerd Vandersteen  
Co-promotor: John Lataire  
Jury: Heidi Ottevaere, Roger Vounckx, Sylvia Verbanck, Ebrahim Louarroudi (Atlas Copco Airpower), Raffaele Dellac (Politecnico di Milano), David W. Kaczka (University of Iowa, USA)

PhD105. **Nonlinear State-Space Modelling of the Kinematics of an Oscillating Cylinder in a Fluid Flow**

Jan Decuyper
Annual report ELEC 2018

PhD106. Multivariate polynomial decoupling in nonlinear system identification
Gabriel Hollander
Doctoral Dissertation, Vrije Universiteit Brussel, December 2017
Advisors: Johan Schoukens, Philippe Dreesen
Jury: Steve Vanandacht, Mariya Isteva, Ivan Markovsky, Thomas Schön (Uppsala University, Sweden), Konstantin Usevich (Université de Lorraine, France), David Westwick (University of Calgary, Canada)

PhD107. Volterra Series Estimation in the Presence of Prior Knowledge
Georgios Birpitsoukis
Doctoral Dissertation, Vrije Universiteit Brussel, January 2018
Advisors: Johan Schoukens
Jury: David Westwick (University of Calgary, Canada), Tadeusz Dobrowiecki (Budapest University of Technology and Economics, Hungary), Xavier Bombois (CNRS, France), Mark Runacres, Patrick Guillaume, Roger Vounckx, Péter Csurcsia

PhD108. Structure Discrimination and Identification of Nonlinear Systems
Alireza Fakhrizadeh Esfahani
Doctoral Dissertation, Vrije Universiteit Brussel, January 2018
Advisors: Johan Schoukens
Jury: Patrick Guillaume, Roger Vounckx, Philippe Dreesen, Keith Worden (University of Sheffield, UK), Gaetan Kerschen (Université de Liège), Bart Peeters (SIEMENS)

PhD109. Identifying Reflections in High Frequency Structures
Maral Zyari
Doctoral Dissertation, Vrije Universiteit Brussel, October 2018
Advisors: Yves Rolain, Francesco Ferranti
Jury: Annick Hubin, Roger Vounckx, Gerd Vandersteen, Daniëlle Van Hoenacker (UCL), Mattias Thorsell (Chalmers University of Technology), Giulio Antonini (Università degli studi dell’Aquila)

5.10 THESIS TOT HET BEHALLEN VAN HET AGGREGAAT VAN HET HOGER ONDERWIJS

1. System Identification. A Frequency Domain Modeling Approach
Johan Schoukens
Geaggregeerde van het hoger onderwijs, Vrije Universiteit Brussel, 1991
Judging-committee: G. Maggetto (VUB), G. Baron (VUB), G. Vansteenkiste (VUB), P. Eykhoff (TU Eindhoven), A. van den Bos (TU Delft), J. Vandewalle (KUL), M. Gevers (UCL)
Promoters: J. Renneboog (VUB), A. Barel (VUB)

2. Frequency Domain Identification of Linear Time Invariant Systems
Rik Pintelon
Geaggeerde van het hoger onderwijs, Vrije Universiteit Brussel, 1994
Judging-committee: G. Maggetto (VUB), A. Cardon (VUB), G. Baron (VUB), P. Eykhoff (TU Eindhoven), M. Gevers (UCL), A. van den Bos (TU Delft), J. Vandewalle (KUL), G. Van Steenkiste (RUG)
Promoter: A. Barel (VUB)
5.11 DOCTOR OF SCIENCE

   Rik Pintelon
   Doctor of Science, University of Warwick, October 20, 2014

2. System Identification in a Nonlinear Environment
   Johan Schoukens
   Doctor of Science, University of Warwick, October 20, 2014
6. Location of the university (VUB) and the dept. ELEC

Getting to the department ELEC of the "Vrije Universiteit Brussel"

6.1 ARRIVAL BY CAR:

Take the "Ring" and exit at the crossing with the motorway E411 direction centre of Brussels. At the end of the motorway, take the viaduct (go straight on), and at the second traffic lights, turn on right ("Triomflaan"), the VUB is situated on the left side of this road, starting from entrance 6 (see map 6.6.2)

6.2 FROM THE BRUSSELS NATIONAL AIRPORT AT ZAVENTEM:

Brussels International Airport is at Zaventem, 14 km from the city centre.

- Information can be obtained by phone: Tel +32 2 753 42 21 / +32 2 723 31 11
- Flight information: Tel +32 900 70 000 (7 a.m. - 10 p.m.)
- www.brusselsairport.be

From the airport, every 20 minutes the rail shuttle quickly takes you to the North Station in the centre of Brussels. At the North Station ("Bruxelles Nord"), you take the train to Etterbeek (direction Etterbeek or Louvain La Neuve) and get off the train in Etterbeek, which is 10 min. walking distance from the VUB. You only pay € 6.00 for a standard jump ticket (a taxi or cab from airport to the University is about € 50.00).

More information and timetables of the Belgian railways: www.b-rail

6.3 FROM BRUSSELS SOUTH AIRPORT (CHARLEROI)

Situated to the south of Brussels, approximately 60 km away, Brussels-South Charleroi airport mainly houses low-cost airlines. www.charleroi-airport.com

A bus links Charleroi Brussels-South and the Gare du Midi railway station in Brussels more than 20 times a day.

The timetables are organised to coincide with Ryanair airline flights.

- Brussels to Charleroi: The shuttle departure point is situated at the junction of rue de France and rue de l'Instruction (follow "Thalys" exit at the Gare du Midi station).
6.4 ARRIVAL BY TRAIN:

Change in “Bruxelles Nord” and take the train to Etterbeek (direction Etterbeek or Louvain La Neuve).

Info timetables: www.belgianrail.be/en

6.5 ARRIVAL BY SUBWAY:

Take line 5 direction “Hermann-Debroux” and get off at “Petillon”, which is also 10 min. walking distance from the VUB.

More information about Brussels subway: www.stib.be

The dept. ELEC is located in building K, 6th floor.

Address: Vrije Universiteit Brussel, Department ELEC, Pleinlaan 2, Building K, 6th floor, B-1050 Brussels, Belgium

Secretariat:
phone: +32 (0)2 629 27 67, e-mail: Ann.Pintelon@vub.ac.be
Telefax: +32 (0)2 629 28 50
www-environment: wwwir.vub.ac.be/elec/

6.6 MAPS

6.6.1 Location of the campus in the Brussels agglomeration
6.6.2 Map of the surroundings of the campus

6.6.3 Campus map (3D)