FINESSE

Universidad de Alcalá

ITN –FINESSE

(Fiber NErvous Sensing SystEms)

A European Innovative Training Network

Summer School on
Distributed Sensing Methods

Universidad de Alcalá

Alcalá de Henares, Spain

11-13 September 2017

ITN FINESSE Training Event 2: Distributed Sensing Methods

Overview of FINESSE Training Event 2

The purpose of this training course is to offer to the participants the opportunity to attend a series of key lectures given by experts in the field of distributed fibre optics sensing. The course will offer a general introduction on all the theoretical concepts relevant in distributed sensing, from scattering physics to the ground science of all the necessary components and the overall performance of the systems and the system limitations as a function of the different parameters. In addition to this, the course will also introduce the FINESSE ESRs to some hands-on experience using experiments available in the UAH group. In particular, the trainees (split in three groups) will be able to handle (a) a conventional BOTDA system, being able to characterize by themselves the effects of the different system parameters (b) a coherent OTDR for the detection of vibrations and (c) a tuneable laser system for FBG interrogation.

TE2 programme at a glance

Time	Monday 11/09	Tuesday 12/09	Wednesday 13/09
9:30	**Light scattering in optical fibres** L Thévenaz (EPFL)	**Rayleigh-based distributed sensors** M. Gonzalez (UAH)	**Recent progress in phase-sensitive OTDR** H. Martins (FOCUS)
11:00	Coffee break	Coffee break	Coffee break
11:30	**Noise in distributed sensing schemes** M. Gonzalez (UAH)	**Making a good Brillouin distributed sensor** L. Thevenaz (EPFL)	**Quasi-distributed sensing using FBG technology** S. Sales (UPVLC)
12:45	**Nonlinear effects in optical fibers** S. Martin-Lopez (UAH)	**Recent progress in Brillouin distributed sensors** A. Dominguez (UAH)	**Qualification of DOFS** S. Delepine (ANDRA)
14:00	Lunch	Lunch	Lunch
16:00	**Raman-based distributed sensing** M. Soto (EPFL)	**Post-processing in distributed sensors** M. Soto (EPFL)	**Field deployment and applications of DOFS** E. Rochat (OMNI)
17:30	Free time	Free time	Free time
18:00			**EB meeting**
20:00	Social event	Social event	Social event

Detailed programme

Day 1: Monday 11/09

09.30 – 11.00: **Light scattering in optical fibres**
Luc Thévenaz – *Ecole Polytechnique Federale de Lausanne*
Abstract: The fundamentals of the 3 natural scattering processes in optical fibres – Rayleigh, Raman & Brillouin – will be addressed. The equations governing their response will be introduced and their dependence on external quantities such as temperature and strain will be highlighted.

11.00 – 11.30 **Coffee Break**

11.30 – 12.45: **Noise in distributed sensing schemes**
Miguel Gonzalez-Herraez – *Universidad de Alcalá*
Abstract: Noise is a fundamental problem in distributed sensing, which scales the performances that can be attained with any distributed sensing setup. This lecture will start by providing basic necessary definitions used regularly to quantify noise in optical setups (signal to noise ratio, NEP, sensitivity of a receiver), followed by an explanation of the fundamental noise contributions in optical sensing experiments (both electrical and optical noises will be addressed). Moreover, the necessary methodologies for noise analysis in different optical setups will be explained with particular emphasis on the limits that noise imposes in distributed sensing instrumentation.

12.45 – 14.00: **Nonlinear effects in optical fibers**
Sonia Martín López – *Universidad de Alcalá*
Abstract: Optical fibers become a nonlinear medium when the intensity of the light propagating through it is high enough. In that situation two different types of nonlinear effects can occur: Kerr effects and nonlinear scattering effects. Self and cross phase modulation (SPM and XPM), modulation instability (MI) and four wave mixing (FWM) are the main consequences of Kerr effect while Raman and Brillouin scattering are the leading nonlinear scattering processes in glass optical fibers. In this presentation, all these phenomena will be reviewed, pointing out their adverse and positive effects in communications and sensing.

14.00 – 16.00 **Lunch Break**

16.00 – 17.30: **Raman-based distributed sensing**
Marcelo Soto - *Ecole Polytechnique Federale de Lausanne*
Abstract: Raman scattering constitutes one of the most fundamental mechanisms exploited in optical fibre distributed temperature sensing. Making use of the thermally-activated spontaneous Raman scattering (SpRS) process, continuous measurements of a temperature profile over a sensing range of tens of kilometres can be obtained with high accuracy and metre-scale spatial resolution. In this lecture, the principle of Raman distributed fibre sensors and the most-common configurations will be described.

20:30 – **Social event: Welcome dinner**

Day 2: Tuesday 12/09

09.30 – 11.00: **Rayleigh-based distributed sensors**
Miguel Gonzalez-Herraez – *Universidad de Alcalá*
Abstract: This lecture will describe the most relevant Rayleigh sensing schemes, with particular emphasis in phase-sensitive optical time-domain reflectometry (phase-OTDR) and Optical Frequency Domain Reflectometry (OFDR). The main requirements and trade-offs will be addressed, with a comparative evaluation of the limitations of each sensing paradigm in terms of precision, sampling frequency, range and spatial resolution.

11.00 – 11.30 **Coffee Break**

11.30 – 12.45: **Making a good Brillouin distributed sensor**
Luc Thévenaz – *Ecole Polytechnique Federale de Lausanne*
Abstract: The principles of a Brillouin time-domain distributed sensor (BOTDA) will be introduced and the recipes for the implementation of a properly operating sensor will be presented. Attention will be drawn on the limitations and the effects distorting the response.

12.45 – 14.00: **Recent progress in Brillouin distributed sensors**
Alejandro domínguez López – *Universidad de Alcalá*
Abstract: Fiber sensing schemes based on Brillouin scattering, particularly sensors based on Brillouin Optical Time Domain Analysis (BOTDA) have become one of the most-established solutions to monitor large structures. A standard BOTDA sensor is typically able to inspect distances of 30-50 km with a spatial resolution of 1-2 m. However, of course the performance of this technique is bounded by certain fundamental limitations. In this lecture we will see a review of the procedures to successfully overcome such limitations and increase the performance of the sensors.

14.00 – 16.00 **Lunch Break**

16.00 – 17.30: **Post-processing in distributed sensors**
Marcelo Soto - *Ecole Polytechnique Federale de Lausanne*
Abstract: Signal processing has become one of the fundamental tools to enhance the performance of any kind of distributed optical fibre sensor. This lecture will introduce some of the most-used advanced techniques to enhance the signal-to-noise ratio (SNR) of distributed sensors. Special emphasis on pulse coding methods and image denoising algorithms will be discussed, and their potential to enhance the performance of different types of distributed fiber sensing will be presented.

18:00 – 20:30 **Social event: TE2 touristic visit**

Day 3: Wednesday 13/09

09.30 – 11.00: **Recent progress in phase-sensitive OTDR**
Hugo Martins – *FOCUS S.L.*
Abstract: We will review the latest developments in phase-OTDR technology, with emphasis on chirped-pulse phase OTDR. In addition, we will review several field applications of phase-OTDR systems, particularly in the detection of third party intrusions along very large infrastructures (e.g pipelines, railways).

11.00 – 11.30 **Coffee Break**

11.30 – 12.45: **Quasi-distributed sensing using FBG technology**
Salvador Sales – *Universitat Politecnica de Valencia*
Abstract: Distributed and optical fiber sensors have today demonstrated their capability. However, current state-of-the-art optical fiber sensors are only used for a limited number of applications. There is novel type of sensors based on Faint Long Gratings (FLOGs). Sensors based on stimulated Brillouin scattering (BOTDA/BOFDA) and those based on coherent Rayleigh backscattering (C-OTDR/C-OFDR) show the best performance in the field of the distributed sensors. However, they both suffer from intrinsic penalties in term of power efficiency and quality of the response. FLOGS sensors try to combine the advantages and are based on a mature technology: the fibre Bragg grating (FBG). This lossless fibre element has demonstrated its huge potentiality to realize highly sensitive point sensors.

12.45 – 14.00: **Qualification of DOFS**
Sylvie Lesoille Delepine – *Agence Nationale pour la Gestion des Dechets Radioactifs*
Abstract: Performances of sensing systems are highly dependent on the target application specificities and specifications. In the telecommunication industry, Telcordia standards are the reference qualification plans. They do not apply anymore when developing sensing systems for civil engineering industry, for medical industry, for aeronautics… When standards not fully cover the range of products and applications, qualification plans should be adapted. This talk aims to give the basics on qualification methodology: how to evaluate metrological performances, to perform reliability prediction with aging tests,... Several examples deployed in France for structural health monitoring of dams, power plants, radioactive waste repositories, will be detailed.

14.00 – 16.00 **Lunch Break**

16.00 – 17.30: **Field deployment and applications of DOFS**
Etienne Rochat – *Omnisens S.A.*
Abstract: Distributed optical fibre sensor are now applied worldwide in very diverse fields, including for instance oil and gas industry as well as power cable industry. In the oil & gas industry, distributed temperature (DTS) is used for leak detection, distributed strain (DSS) is used for pipeline deformation and ground movement measurement whilst distributed acoustic/vibration (DAS/DVS) is mainly used for third party intrusion monitoring. Pipeline from 100s to 1000s of kilometer are now instrument using optical fibres. In the power cable industry, DTS together with optical amplification on the longest cables is mainly targeting offshore wind and interconnectors, in combination with thermal cable models in order to manage dynamically the cable load whilst maintaining its lifetime. Strain is now being envisaged during cable installation whilst DTS and DVS/DAS are being tested for fault finding. The presentation focuses on selected cases studies of successful field deployments for both the onshore and offshore oil & gas industry and for the power cable industry.

18:00-20:00 **EB Meeting**

20:00 – 22:00 **Social event: TE2 Banquet**

Lecturer's biography (by alphabetical order)

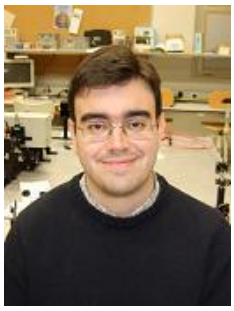
Sylvie Delepine-Lesoille – Agence National pour la Gestion des Dechets Radioactifs

Sylvie Delepine-Lesoille received her diploma degree from ENSTA engineering school, and a Master 2 in Physics, Laser-matter interaction in 1997. She was graduated PhD from Paris XI-Orsay University in 2000 after 3 years spent in Alcatel Research Center (France) on semiconductor flared resonator, to serve as EDFA pump laser at 1.48µm. She joined Photonetics-NetTest company to work on tunable lasers, both laboratory instruments and telecom components until 2002. From 2002 to 2008, she was a researcher at the Road and Bridge Laboratory, LCPC now called IFSTTAR, in France, working on optical fiber sensors for structural health monitoring. Since 2008, she is an R&D engineer in Andra, the French Agency for radioactive waste management. She develops or qualifies instrumentation systems for radioactive waste repository cell monitoring, such as distributed optical fiber sensing systems. She is co-author of about 32 papers and 9 patents.

Alejandro Domínguez López – Universidad de Alcalá

Alejandro Domínguez López holds a M.Sc. in Telecom Engineering by the University of Granada (2012), and a Ph.D. in Electronics by the University of Alcala (2017). During his Masters studies he spend one year at the Politecnico di Milano, Italy (2009-2010) and another one at the University of Miami, USA (2011-2012), where he finished his studies and received the Tzay Y. Young Award to the best Senior Project of the Dep. Of Electronics. After working as a consultant for INDRA in 2012, in 2013 he joined the Photonics Engineering Research Group at the University of Alcala, where he has worked in the development and optimization of long-range and high-resolution distributed optical fiber sensors. In this context, in 2016 he did a research internship at the Swiss Federal Institute of Technology (EPFL) where he collaborated to achieve state-of-the-art record results. He is co-author of 11 high impact journal papers and more than 15 international conference papers, as well as a co-author of a patent.

Miguel González-Herráez – Universidad de Alcalá



Miguel Gonzalez-Herraez received the M.Eng. and D.Eng. degrees from the Universidad Politecnica de Madrid, Madrid, Spain, in 2000 and 2004, respectively. In October 2004, he became an Assistant Professor at the Department of Electronics, Universidad de Alcala, Madrid, Spain, where he became an Associate Professor in June 2006. He is the author or coauthor of more than 100 papers in international refereed journals and more than 110 conference contributions. He has given several invited/plenary talks at international conferences. His research interests cover several aspects across photonics, mainly distributed optical fiber sensors and optical fiber-based light sources. He has received several important recognitions to his research career, including the European Research Council Starting Grant, the "Miguel Catalan" Prize for Young Scientists given by the Comunidad de Madrid, and the "Agustin de Betancourt" prize of the Spanish Royal Academy of Engineering. https://scholar.google.com/citations?user=c6SIO8sAAAAJ&hl=es

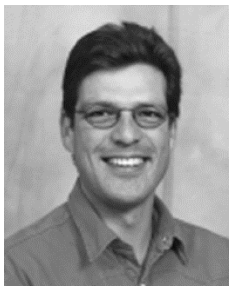
Sonia Martín López – Universidad de Alcalá

Sonia Martin-Lopez received the Ph.D. degree from the Universidad Complutense de Madrid, Madrid, Spain, in May 2006. The topic of her doctoral dissertation was on experimental and theoretical understanding of continuous-wave pumped supercontinuum generation in optical fibers. She had a predoctoral stay at the Nanophotonics and Metrology Laboratory, Ecole Polytechnique Federale de Lausanne, Lausanne, Switzerland. She has been involved as a Postdoctoral Researcher at the Applied Physics Institute and at the Optics Institute at the Spanish Council for Research for six years. She is currently a Postdoctoral Researcher at the Photonics Engineering Group, Universidad de Alcala, Madrid, supported by the "Ramon y Cajal" program. She is an author or coauthor of more than 140 papers in international refereed journals and conference contributions. Her current research interests include nonlinear fiber optics and distributed optical fiber sensors.

Hugo Martins – Fiber Optics Consulting, Services and Technologies

Hugo F. Martins received his Ph.D. degree in Physics under jointly-awarded PhD program in the University of Porto, Porto, Portugal and the University of Alcala, Madrid, Spain, in 2014. The topic of the doctoral dissertation was the use of Raman effect to assist distributed and remote fiber sensing. His research career was mainly focused on distributed optical fiber sensing, mainly the use of phase-sensitive optical time domain reflectometry for distributed vibration/intrusions and temperature/strain detection along large structures/perimeters. Dr. Hugo F. Martins is currently the technical director at FOCUS S.L., a company specialized fiber optic distributed sensing applications. Dr. Hugo F. Martins is an author or coauthor of more than 50 papers in international refereed journals and conference contributions and has received several important scientific recognitions, including the award of best PhD Thesis in Optics and Photonics of 2014 in Portugal by the "Sociedade Portuguesa de Óptica e Fotónica" (Portuguese Society of Optics and Photonics).

Etienne Rochat – Omnisens SA



Etienne Rochat received a master degree of engineering from the Swiss Institute of Technology (EPFL, Lausanne) and a PhD in science from the University of Neuchâtel. Prior to working for OMNISENS, Etienne worked as research scientist at ABB Corporate Research Centre (Switzerland), developing fibre sensors for remote pressure and temperature measurement in oil reservoir, then as research fellow at the University of Essex (UK) in non-conventional optical communication. Etienne Rochat joined OMNISENS in 2004 and worked originally as product manager for the company former trace gas analyser. In 2009, he became R&D manager for fibre optic distributed sensing, then head of engineering in 2010 and CTO in2013. As such, he is in charge of product research and development for the company monitoring solution, focusing on optical interrogators, sensing cables and novel applications. Etienne Rochat is the author of more than 50 papers and 10 patent families.

Salvador Sales – Universitat Politècnica de València

Telecommunications engineering degree (1992) and Ph.D. degree in optical communications (1995) both from the Universitat Politècnica de València (Extraordinary Doctoral Award from the Spanish Telecommunication Society, 1996). He has been working since 1992 in research projects related with optical communications and optical fibre sensors. I have been leading several European Union and national research projects in the field of optical communications and fibre sensors. Over 200 papers in SCI ranked journals and conference, including more than 10 invited in major international conferences, 7 patents, and cofounder the spin-off company CalSens SL in 2013. His main research interests include optoelectronic signal processing for optronic and microwave systems, optical fibre sensors, fibre Bragg gratings, WDM and SCM lightwave systems and semiconductor optical amplifiers.

Marcelo Soto – Ecole Polytechnique Federale de Lausanne

Marcelo A. Soto received his Ph.D. degree in Information and Communication Technologies from Scuola Superiore Sant'Anna, Pisa, Italy, in 2011. He is currently a Postdoctoral Researcher in the Group for Fibre Optics at EPFL Swiss Federal Institute of Technology of Lausanne, Switzerland, where he has been working on high-performance Brillouin and Rayleigh distributed fibre sensing, nonlinear fibre optics, optical signal processing, and optical Nyquist pulse generation. Dr. Soto is author or co-author of about 140 scientific publications, 1 book chapter and 8 patents. He is member of the Review Board of major international journals in optical fibre sensing and photonics, and member of the Technical Program Committee of two major scientific conferences in optical fibre sensing.

Luc Thévenaz – Ecole Polytechnique Fédérale de Lausanne

Luc Thévenaz received the M.Sc. degree and the Ph.D. degree in physics from the University of Geneva, Switzerland. In 1988 he joined the Swiss Federal Institute of Technology of Lausanne (EPFL) where he currently leads a research group involved in photonics, namely fibre optics and optical sensing. Research topics include fibre sensors, slow & fast light, nonlinear fibre optics and laser spectroscopy in gases. His expertise covers all applications of stimulated Brillouin scattering in optical fibres and he is known for his innovative concepts related to distributed fibre sensing. During his career he stayed at Stanford University, at the Korea Advanced Institute of Science and Technology (KAIST), at Tel Aviv University, at the University of Sydney and at the Polytechnic University of Valencia. In 2000 he co-founded the company Omnisens that is developing and commercializing advanced photonic instrumentation based on distributed fibre sensing. He is Fellow of both the IEEE and the Optical Society of America and Associate Editor of 3 major scientific journals.