Editorial
Optical Fiber Sensor Technology and Applications

WELCOME TO this Special Issue of the IEEE SENSORS JOURNAL on Optical Fiber Sensor Technology and Applications.

Papers presented here are, in general, all expanded versions of selected papers originally presented in the Third European Workshop on Optical Fiber Sensors which took place early in July 2007. These original papers are available in SPIE Proceedings, Volume 6619.

The optical fiber sensor community has historically presented the major results of its work in a long series of optical fiber sensor (OFS) conferences, the first of which took place in London in 1983 and the nineteenth is due for April 2008 in Perth, Australia. These major conferences rotate around Europe, the Americas, and the Pacific separated by about 18 months. Recognizing that there are significant fiber sensor research and development programs within Europe, the community initiated the European Workshops to occur about halfway through the four and a half year gap between European venues for OFS to cater not only for the active European community but also to give the opportunity for younger researchers to participate. The workshop forum has also been slightly different from the standard conference with relatively few invited overview papers and the majority of the material presented in carefully organized theme workshops. Breakout groups within the conference are gathered to consolidate information from each poster session, and then meet in a plenary to compare notes. The next in this series of European Workshops is planned for Portugal in the Fall of 2010.

The concept of using optical fibers as the principal enabler in sensor technology goes back well over 40 years when the Fotonic™ sensor was patented in the mid 1960s as a device for precision measurement of the position of a surface with respect to a reference using simply a measurement of reflected light from the surface transmitted to and from in a bundle. The Fotonic™ sensor is still available as a commercial system some 40 odd years later. This sensor was conceived well before the landmark papers of Kao and Hockum, and Spitz proposing that fibers could be used in communications were published.

The mid 1970s saw the arrival of early single-mode fibers and with that the realization that interferometers based on fiber optics could perhaps be used as sensors. Consequently, interferometric principles from almost a century before attributed to Michelson, Mach–Zehnder, and Sagnac were eventually engineered into fiber-optic format and the result emerged as fiber-optic gyroscopes, hydrophones, seismic detectors, and extensometers all of which are in use today. Indeed on the physical measurement side for temperature, pressure, displacement, etc., these devices embrace the vast majority of the principles of current sensor technologies.

The major exception to this emerged around 1980 with the realization that Raman and Brillouin scatter could be used to measure temperature and strain fields. Furthermore, Raman scatter could be configured to measure temperature alone without interference from mechanical strain, and while the Brillouin system responded to both, there certainly were temperature stable applications. These techniques not only remove the need for interferometry or open path propagation in these important measurements, they are also open to the prospect for one of fiber-optic sensors most powerful tools, namely, distributed measurement. Here, simply installing a fiber in contact with the measurand field enables an interrogation unit to monitor strain and/or temperature as a function of position throughout the length of the fiber, which may extend to tens of kilometers. Depending on the processing, the gauge length of the effective sensor can vary from a few centimeters to a few meters. This very powerful tool is unique to fiber sensor technology.

The idea of fiber sensor networks emerged around the same time through which the optical power used to energize a remote point sensor (that is a sensor undertaking just a single measurement) could be divided among the many individual sensors and recombined at a single receiver interrogation unit thereby enabling a completely passive network. Since then, sensor counts up to several hundred have been achieved in such networks and many are operating in the commercial environment.

The other major contributor to measurements in the physical world has been the fiber Bragg grating which is simply a wavelength selective filter which responds to the environment within which it is operated through variations in mechanical strain or temperature. The principle of the Bragg grating dates back to the late 1970s and emerged as a candidate for main stream fiber sensing a decade or so later. Much has since been done in the use of arrays of Bragg gratings and also in simplifying while enhancing the accuracy of the basic Bragg grating interrogation units which must measure reflected wavelength with high precision.

Fiber-optic sensors have also found extensive application in chemical and biochemical measurements, predominantly through transducing a chemical change into some form or other of color modulation. Suitably stable illumination transmitted along the fiber to the sample is then collected and the changes in its properties accurately monitored. Direct absorption spectroscopy especially for gases has been a particularly successful technique and in some cases precise spectral measurements of the transmission and/or reflection and/or scatter properties of liquids and solids have also proved to have remarkably good discriminatory properties. Indeed there is an example of such a measurement in this volume. Occasionally too, nonlinear interactions such as Raman scatter, surface enhanced Raman, and photoluminescence have found niche applications.

So, the principles have been around for some considerable time. You may then ask what it is that keeps an enthusiastic, lively, and very productive research community interested in what appears to be a well rehearsed range of optical principles applied to sensing. The key of course lies in the "applied." Interfacing the application, the desired measurement, and the optical technique requires broadly based interdisciplinary knowledge

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and ability to communicate often complex technical issues from user to technologist. An appreciation of how fiber sensor technology might offer benefits to the very many other approaches to performing a similar measurement is also essential. Sensor technologies overall are a highly fragmented activity and it is this fragmentation which provides the stimulus. There is also the "what if" question when new related technologies begin to emerge and in recent times exciting optics in the guise of, for example, Bose Einstein condensates, photonic crystals, and slow light have raised the question "can these be applied to sensing using guided wave optics." Furthermore, the flexibility offered by the photonic crystal fibers and the performance of the available component set associated with fiber-optic systems gradually increases in performance so that high-quality amplifiers with outputs in the watts or even more can be configured in fibers and highly coherent single-mode laser diodes with modest tunability have also become available. These add yet more flexibility to the sensor engineers tool kit.

The contents of this issue then reflect this combination of basic themes with multiple nuance dependent upon the application direction sprinkled with a few explorations of new optical tools and emerging approaches to materials technologies—for example, nano particles—through which to enhance optical and chemical interaction.

In common with virtually every other sensor technology fiber-optic sensing is highly fragmented in both detail of implementation and application context. Recent market estimates put the total OFS world volume at around U.S. $1B per year with the most promising growth in distributed technologies. More details of this can be gleaned through the OIDA information services. Within this market volume there lie a dozen or so basic principles and 10–20 application sectors each one requiring different treatment. Unsurprisingly then much of the fiber sensor activity originates in small companies. Consequently, there is considerable opportunity for entrepreneurism and many examples of successfully transferring technology and knowledge from the academic environment into the commercial domain. Some elements of this will be evident from the papers in this issue.

Finally, we must thank our authors for their dedication and patience. Almost inevitably the emergence of a Special Issue takes longer than either authors or editors initially estimated and certainly desired. This has been no exception, in part due to the impressive amount of excellent papers presented, for which all the invited editors would like to convey their sincere apologies.

Some of the papers we have marked as invited in recognition of some particular feature. We should also thank Eileen Murray at the IEEE for her support in bringing the issue together and our many friends and acquaintances for contributing to our uniquely stimulating and constructively enjoyable community.

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Andrea Cusano received the M.S. degree (*cum laude*) in electronic engineering on November 27, 1998 and the Ph.D. degree in information engineering with tutor Prof. A. Cutolo from the University of Naples "Federico II," Italy. His Ph.D. thesis was focused on the development of fiber-optic optoelectronic sensor for Smart Materials applications.

On December 2002, he was nominated Permanent Researcher at the Engineering Department, University of Sannio, starting his research on December 30, 2002, in the Optoelettronic Division. Since 1999, his research is focused in the field of optoelectronic devices for sensing and telecommunication applications. He is coauthor of over 80 articles published on several high-level international journals, and of over 130 communications to international conferences. He is also coauthor of several chapters in international books focused on fiber-optic sensing systems. He is working also as Co-Editor for the publication of Special Issues focused on optical fiber sensors. He is coauthor of several national and European patents regarding the development of innovative fiber-optic sensors and systems for industrial applications. He is also cofounder of the spin-off society "OptoSmart S.r.l," whose core business is the developing of fiber-optic devices for the structural and environmental monitoring.

In 2006, Dr. Cusano won a national competition for the position of Associate Professor at the Optoelectronic Division of the University of Sannio. He acts also as referee of several high-level international journals, such as the IEEE PHOTONICS TECHNOLOGY LETTERS, the IEEE JOURNAL OF LIGHTWAVE TECHNOLOGY, the IEEE SENSORS JOURNAL, *Optical Engineering*, the IEEE TRANSACTIONS ON ULTRASONICS, FERROELECTRICS AND FREQUENCY CONTROL, SENSORS AND ACTUATORS A AND B, *Optics Express*, *Optics Communications*, and *Sensors*. Finally, he is Associate Editor of the *Sensors and Transducers Journal*, *Journal of Sensors*, *Open Optics Journal*, and *The International Journal of Biological and Environmental Monitoring*.

José Miguel López-Higuera (SM'93) was born in February 1954, in Ramales de la Victoria, Cantabria, Spain. He received the Telecommunication Technical Engineering degree from the Universidad Laboral de Alcalá de Henares, the Telecommunication Engineering degree and the Ph.D. degree in telecommunication engineering, with an extraordinary award, from the Universidad Politécnica de Madrid (UPM), Madrid, Spain.

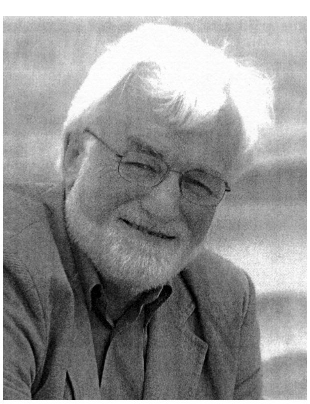
He founded and is the head of the Photonics Engineering Group, University of Cantabria. He fabricated the first lithium niobate integrated optic device in Spain. Presently, he works in the development of new devices and subsystems for optical communications and sensors, in photonic instrumentation, optical fiber sensor systems, and in materials detection and characterization using photonic techniques. He worked on more that 60 R&D&i projects acting as director in more than 50. He has written or co-written more than 400 publications in the form of books, chapters of books, papers, and conferences, both national and international, and obtained ten industrial publications (patents). He is the editor and coauthor of the book *Optical Sensors* (UC, 1998); of the *Handbook of Photonic Sensing Technology* (Wiley, 2002) (electronic edition in 2008), and the co-editor of the book *Engineering a High-Tech Business: Entrepreneurial Experiences and Insights* (SPIE Press, USA, 2008).

Prof. López-Higuera is a member of the SPIE and OSA. He received the Salvá i Campillo Prize in 2001 for the Most Original R&D Project in the area of Information and Telecommunications Technologies for the SISFOCDETIC Project co-funded by the European Union and Spanish Government. He has served as a member of the Steering Committees, Chairman or Co-Chairman, or as Technical Program Committee Member of International Scientific Events or Conferences (OFS, EWOF, WFOPC, ODIMAP, BGPP, etc.) or in high-tech companies (FiberSensing). He will also be the Technical Co-Chairman of EWOFS10 and Co-Chairman of the next OFS20.

Ignacio R. Matias (SM'03) received the M.S. and Ph.D. degrees in electrical and electronic engineering from the Polytechnic University of Madrid (UPM), Madrid, Spain, in 1992 and 1996, respectively.

He is currently a Professor with the Electrical and Electronic Engineering Department, Public University of Navarra, Pamplona, Spain. He has coauthored more than 100 books, book chapters, and journal papers mainly related to optical fiber sensors. He has been involved in more than 50 research projects holding more than a dozen patents and copyrights and promoting several spin-offs.

Prof. Matias has received several scientific and research awards. He is an Associate Editor of the IEEE SENSORS JOURNAL.



Brian Culshaw was born in Lancashire, U.K., on September 24, 1945. He graduated with a Degree in physics in 1966 and received the Ph.D. degree in electronic and electrical engineering specializing in microwave semiconductors from University College London (UCL), London, U.K., in 1969.

After a year at Cornell University, he joined Bell Northern Research (now Nortel) in Ottawa, and while continuing to work on microwave semiconductors, developed an interest in fiber-optic technology. Late in 1973, he returned to UCL and, after two years as a postdoc working on semiconductor device simulation, developed his interest in fiber-optic sensor technologies, their principles, and applications. He has administered several major research initiatives, particularly multipartner EU programs in sensing, measurement, fiber optics, and smart structures. In 1983, he became a Professor of Optoelectronics at Strathclyde University, Glasgow. He has reviewed research activities and proposals in the U.K. and elsewhere. He has also acted internationally in Ph.D. and Habilitation examinations. His research has encompassed fiber gyroscopes, hydrophones, spectroscopic analysis systems, and mechanical interferometric sensors.

Prof. Culshaw was *De Facto* Technical Chair of the First (1983) International Conference on Optical Fiber Sensors (OFSs), now a series regarded as the definitive meeting in the community. He Chaired the Tenth International Conference on OFSs in Glasgow and was Technical Co-Chair of the 17th International Conference on OFS in Bruges in 2005. He orchestrated, with SPIE in Bellingham, WA, the CD-ROM of the Series Proceedings which has recently been reissued. He also initiated European meetings in Smart Structures and the EWOFS workshop series in optical fiber sensor technology. Predominantly with SPIE, he has organized numerous other conferences and workshops in Europe, the U.S., and Asia. He was the 2007 President of SPIE. In the mid 1980s, he was the founding editor for the *International Journal of Optoelectronics*, and until mid 2004 was a Topical Editor for *Applied Optics*. He has edited for over a decade with A. Rogers of Surrey University, the Artech House series in *Optoelectronics*, now over 50 titles.