Encoding optical FBG sensors to enhance the capacity of optical sensing systems

Cristian Andrés Triana Infante
Supervisors: Dr. Daniel Pastor Abellán,
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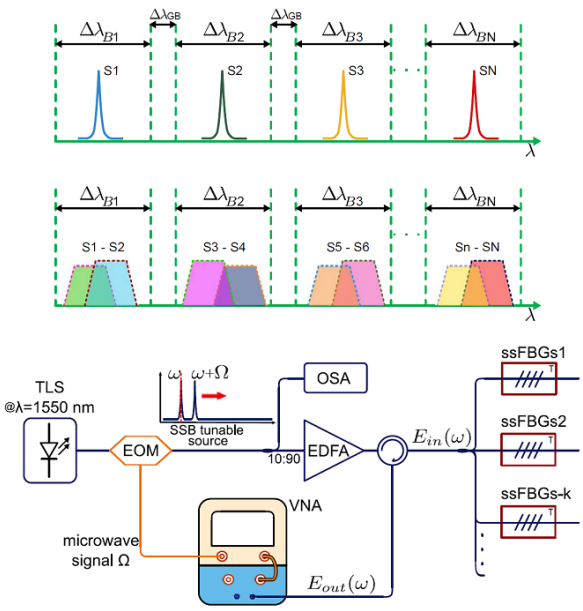
Defended on October 11th, 2018

This thesis investigates the application of coding concepts to the design of optical sensors based on Fiber Bragg Gratings (FBG). Specifically, the design, characterization and experimental validation of custom coded devices that can be designed and manufactured as Super Structured FBG devices (SSFBG) is presented. The objective of this thesis is to improve the overall capacity and performance of the classical optical sensor networks based on conventional FBG devices. The constrains in classical optical sensors networks multiplexed in wavelength are the limitation in the number of sensors supported by spectral bandwidth unit and by the fact that eventual spectral overlapping between spectrally adjacent sensors leads to situations of uncertainty or indeterminacy of the measured magnitude.

For this purpose, three coding methodologies of SSFBG devices have been proposed, with the aim of providing each sensor with additional information useful for the identification of each sensor even in spectral overlapping conditions. An encoded sensor based on FBGs is an FBG structure whose shape has been adapted to an orthogonal code-word, so that its central wavelength can be unequivocally distinguished from other signals in the spectrum. The design of the encoded SSFBG sensors is carried out by modifying the reflection spectrum of multiband FBG devices, and this is achieved by translating the orthogonal code-words into the terms of amplitude and phase of the FBG sensors. The amplitude coding of the SSFBG sensors consists of translating the code words "Optical Orthogonal Code-words "(OOC), developed for multiple-access communications systems by optical code division (OCDMA), in the reflection pattern of the devices. The amplitude and optical phase coding has been proposed also following two different approaches: in the first one, custom amplitude and phase codewords were specifically designed to exhibit orthogonal behaviour, and then a new interrogation technique based on a dual wavelength tunable source was specifically modelled and implemented in the lab to retrieve the differential optical phase codes imprinted on the SSFBG sensor devices. The second approach uses the "Discrete Prolate Spheroidal Sequences" (DPSS) sequences, which are mutually orthogonal sequences developed for communication systems. The use of these structures as orthogonal detection elements with specific phase and amplitude patterns was also proposed and demonstrated. The different designed and simulated devices were fabricated at the PRL's silica fibre Bragg Gratings fabrication facility and tested under spectral overlap conditions. The central wavelength of the sensors was successfully recovered in the three methodologies, and the detection system error and sensitivity was characterized in terms of the design parameters for all the en/decoding configurations.



THESIS SUMMARY

Distributed and Collaborative Processing of Audio Signals: Algorithms, Tools and Applications

Christian Antoñanzas Manuel
Supervisors: Dr. Miguel Ferrer Contreras, Dr. Alberto González Salvador
Defended on September 30th, 2019

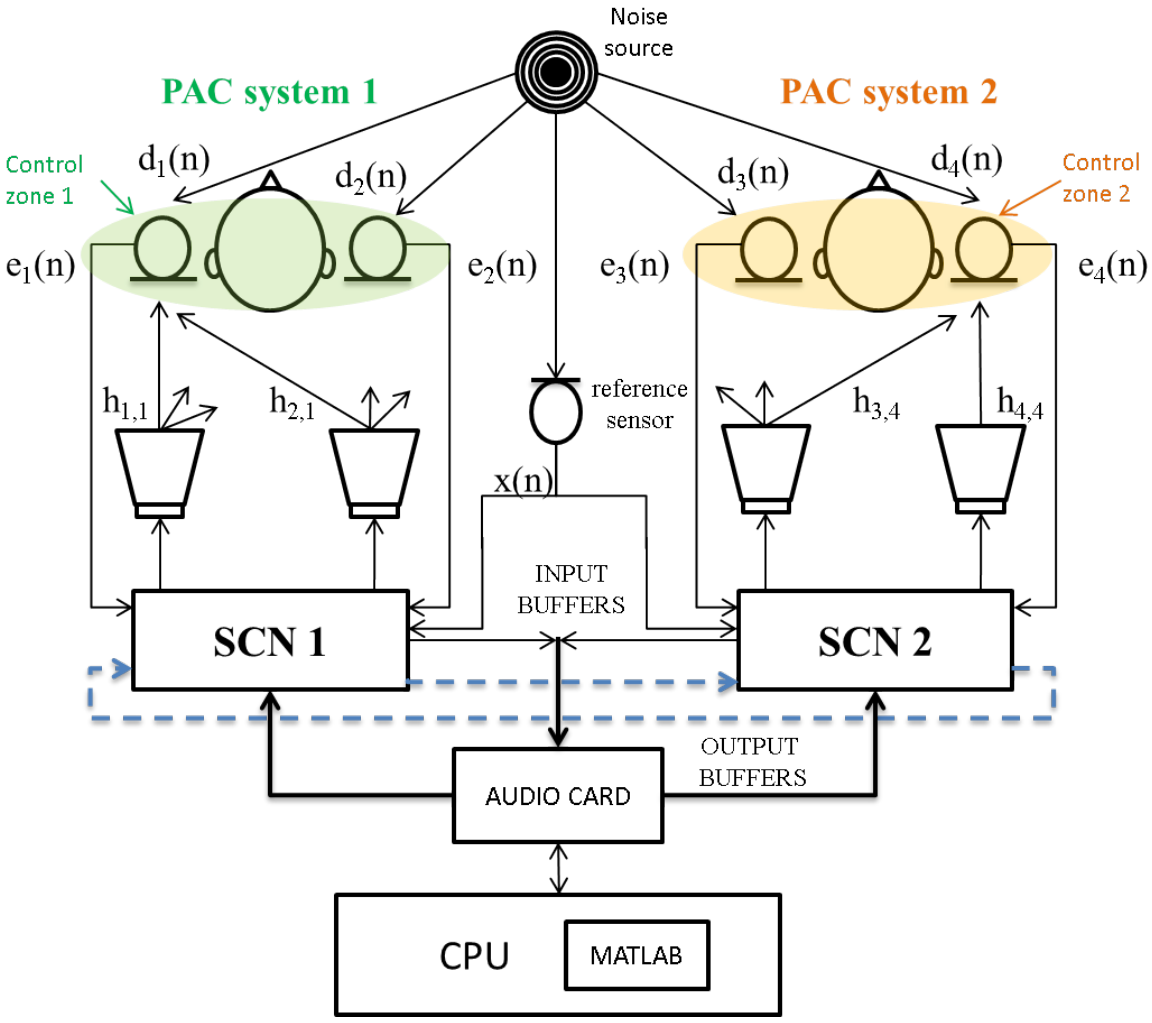
This thesis fits into the field of Information and Communications Technology (ICT), especially in the area of digital signal processing. Nowadays and due in part to the rise of the Internet of Things (IoT), there is a growing interest in wireless sensor net works (WSN), that is, networks composed of different types of devices specifically distributed in some area to perform different signal processing tasks. These devices, also referred to as nodes, are usually equipped with electroacoustic transducers, such as sensors or actuators, as well as powerful and efficient processors with communication capability. In the particular case of acoustic sensor networks (ASN), nodes are dedicated to solving different acoustic signal processing tasks, such as environmental sound monitoring, immersive audio, binaural hearing aids, noise-cancelling systems as well as audio teleconferencing. These audio signal processing applications have been undergone a major development in recent years due in part to the advances made in computer hardware and software. This has led to the development of powerful centralized processing systems that allow the number of audio channels to be increased, the control area to be extended or more complex algorithms to be implemented, thereby improving audio quality or creating independent control over several personal sound zones. In most cases, a distributed ASN topology can be desirable due to several factors such as the limited number of channels used by the sound acquisition and reproduction devices, the convenience of a scalable system or the high computational demands of a centralized fashion. All these aspects may lead to the use of novel distributed signal processing techniques with the aim to be applied over ASNs. To this end, one of the main contributions of this dissertation is the development of adaptive filtering algorithms for multichannel sound systems over distributed networks.

Note that, for sound field control (SFC) applications, such as active noise control (ANC) or active noise equalization (ANE), acoustic nodes must be not only equipped with sensors but also with actuators in order to control and modify the sound field. However, most of the adaptive distributed networks approaches used to solve soundfield control problems do not take into account that the nodes may interfere or modify the behaviour of the rest. This is an important issue which is tackled throughout this thesis. Therefore, other important contribution of this thesis is focused on analyzing how the acoustic system affects the behavior of the nodes within an ASN.

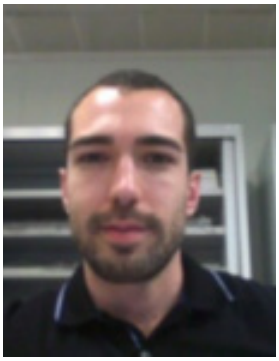
In cases where the acoustic environment adversely affects the system stability, several distributed strategies have been proposed for solving the acoustic interference problem with the aim to stabilize ANC control systems. These strategies are based on both collaborative and non-collaborative approaches. Implementation aspects such as hardware constraints, sensor locations, convergence rate or computational and communication burden, have been also considered on the design of the distributed algorithms. Moreover and with the aim to create independent-zone equalization profiles in the presence of multi-tonal noises, distributed narrowband and broadband ANE algorithms over an ASN with a collaborative learning and composed of acoustic nodes have been presented.

Experimental results are presented to validate the use of the distributed algorithms proposed in the work for practical applications. For this purpose, an acoustic simulation software has been specifically designed to analyze the performance of the developed algorithms. In this way, this simulation tool allows the transition between the initial formulation of any algorithm and its final programming on any digital signal processing platform.

Finally, the performance of the proposed distributed algorithms for multichannel SFC applications has been evaluated by means of a real practical implementation. To this end, a real-time prototype that controls both ANC and ANE applications by using collaborative acoustic nodes has been developed. The prototype consists of two personal audio control (PAC) systems composed of a car seat and an acoustic node, which is equipped with two loudspeakers, two microphones and a processor with communications capability. In this way, it is possible to create two independent noise control zones improving the acoustic comfort of the user without the use of headphones.



Design of photonic sensors based on cavities and new interrogation techniques

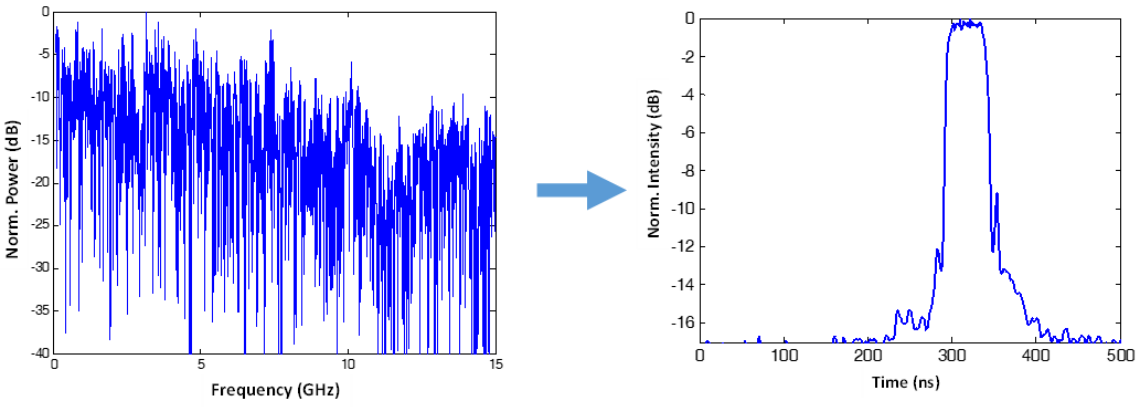


Javier Hervás Peralta
Supervisor: Salvador Sales Maicas
Defended on March 22nd, 2019

Optical sensors are photonic devices sensitive to different magnitudes that are used precisely to measure, in an absolute or a relative way, these magnitudes. These optical sensors are nowadays used to measure temperature, pressure, strain, humidity or the presence of a particular gas. In the past few decades a multitude of photonic sensors and different interrogation techniques have been developed, which had a great impact in dozens of different fields. One of the best examples is civil architecture, in which photonic sensors play a fundamental role in order to monitor the condition of the structures.

Despite of the good results showed by photonic sensors, the interrogation techniques used show different drawbacks. A large measurement time, low resolution or great complexity are some of them. In this doctoral thesis the design and characterization of a set of different photonic sensors based on the already known fiber Bragg gratings, along with the implementation of new interrogation techniques, are used in order to eliminate or at least reduce these problems. The interrogation techniques developed in this work are based on Microwave Photonics techniques, in which the interaction between optical and electrical signals is used to detect in this case the changes in a particular magnitude.

The techniques showed in this work have been designed in order to be as versatile and scalable as possible to have the opportunity to adapt to any requirement in different scenarios. In this work techniques that are able to interrogate hundreds or even thousands of sensors with great sensitivity and resolution can be found in addition to techniques that are developed to interrogate individual sensors with an enormous sensitivity. The work carried out in collaboration with the Swedish research institute RISE, based on the development of an electric field sensor based on poled fibers together with FBGs is also present.

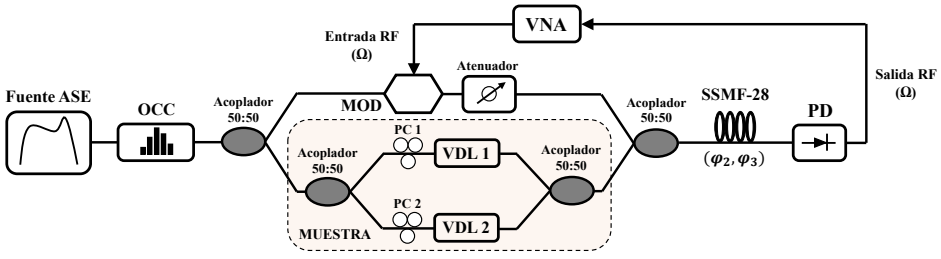


Microwave Photonics applied to Low Coherence Interferometry

Jesús Benítez González
Supervisors: Dr. José Mora Almerich, Dr. José Campany Francoy
Defended on May 21st, 2019
(Text in Spanish: Fotónica de microondas aplicada a la interferometría de baja coherencia)

Low Coherence Interferometry (LCI) is an optical technique for distance measurements, able to reach the micron scale of resolution in the axial direction of the sample. Its physical principle is based on the generation of an interference pattern which, after processing, can reveal the structural information of the sample studied. Among all the LCI applications, the medical field arises as one of the most relevant, mainly due to the non-invasive nature of the technique. In this sense, the Optical Coherence Tomography (OCT) is one of the most recognizable applications, where the acquisition of 2D and 3D images by using LCI enables the analysis and diagnosis of different biological tissues. Among other fields of application of this technique, we can highlight sensing and the optical components characterization. Nevertheless, LCI systems also suffer from some limitations related to compactness and cost-effectiveness, mainly when it is applied to the medical field where more complex structures are required. Furthermore, it also exists a strong limitation related to the interference pattern mostly due to its acquisition in the optical domain, where it is highly sensitive to vibrations and temperature variations.

On this basis, the main objective of this Ph.D. is focused in the study of the LCI technique and its combination with the field of Microwave Photonics (MWP). The benefits that MWP can offer to LCI are numerous, among which we can highlight the analysis of the interference pattern in the electrical domain instead of in the optical domain, or the possibility to make use of a more mature technology as the field of MWP is. The principle of operation of this technique, labelled as MWP-LCI, is based on the analysis of the interference pattern of the system when a certain sample is considered. The structural features of that sample generate different RF resonances where their position and width in the electrical spectrum are directly related to the different layers that compose the sample. In this way, the current Ph.D. is focused, firstly, in the demonstration of the existing analogy between the LCI and MWP-LCI techniques. Afterwards, several upgrade proposals are made to develop the most basic MWP-LCI structure. By the corresponding theoretical analysis of those proposals, it is demonstrated that the use of the MWP field allows the possibility to improve the limitations related to the first demonstrations carried out in MWP-LCI. Moreover, the experimental demonstrations associated to all the proposals are included, showing an excellent agreement with the theoretical results. Finally, the analysis is focused in the key elements that compose these structures: the sample, the optical source and the dispersive element. Through the different improvements applied to the MWP-LCI technique, we have been able to experimentally demonstrate a sensitivity level of 60 dB with resolutions of 27 µm in a working range that can easily exceed 1 cm.



THESIS SUMMARY

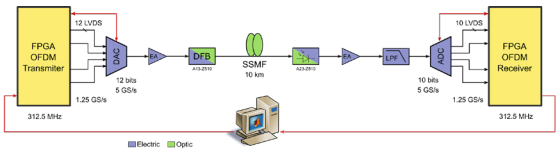
Algorithms and hardware architectures for OFDM implementation in optical communications system

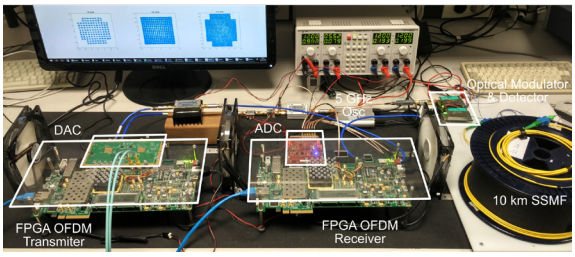
Julián Santiago Bruno
Supervisors: Dr. Vicenç Almenar Terré, Dr. Javier Valls Coquillat
Defended on March 14th, 2019
Text in Spanish: Algoritmos y arquitecturas hardware para la implementación de OFDM en sistemas de comunicaciones ópticos)

This doctoral thesis presents an in-depth exploration of the technical feasibility and achievable performance of a low-cost and high-speed optical communication system based on orthogonal frequency division multiplexing (OFDM) through the implementation of real-time digital signal processing algorithms over programmable logic devices (FPGA). Optical transmission systems based on intensity modulation and direct detection (IM/DD) is considered as one of the most interesting solutions for the deployment of the low-cost passive optical networks (PONs) that will be needed to cover the high traffic demand in the coming years. This demand is fueled, among others, by the significant increase of connected devices to the Internet, services and programs in the cloud, high definition video, etc.

The main objective of this thesis is to achieve the maximum bitrate and spectral efficiency of an IM/DD PON OFDM system (using a single band and a single wavelength). To this end, the hardware architecture of a high-speed real-time OFDM receiver, including all the necessary algorithms to perform the detection and demodulation of the OFDM symbols, has been implemented in a Virtex-7 FPGA device at a clock frequency of 312.5 MHz using a digital analog converter with a sampling rate of 5 GS/s. To reach the best possible performance, all the system bandwidth has been employed and the OFDM subcarriers have been loaded according to the characteristics of the electro-optical channel. An experimental platform for optical transmission through standard single-mode fiber (SSMF) has been developed to evaluate in real-time the performance of the implemented receiver. The main result of this thesis is the experimental validation of the proposed system that has achieved a bit rate of 19.63 GS/s and a spectral efficiency of 8.07 bit/s/Hz over 20 km SSMF. These results almost double the best performance published to date.

The receiver implementation included the design and development of several algorithms. First, it was designed a time synchronization algorithm (TSA) based on the cross-correlation between a known preamble and the received OFDM signal. This TSA has a good performance in low-SNR scenarios and its optimized design requires fewer resources than other synchronizers published in the literature. Second, a variable length parallel pipelined FFT processor has been implemented in a Virtex-7 device, it reaches a throughput of 10 GS/s with an efficiency (area/speed) higher than that of other published works. And finally, a channel equalizer working in the frequency domain to estimate and compensate channel distortions, which uses a known preamble to decrease the hardware complexity and increase the accuracy of the estimation, has been implemented. All the algorithms in this thesis have been developed to process 16 samples in parallel, thus reducing the required clock frequency (5 GHz/16) to acceptable values for the FPGA devices.





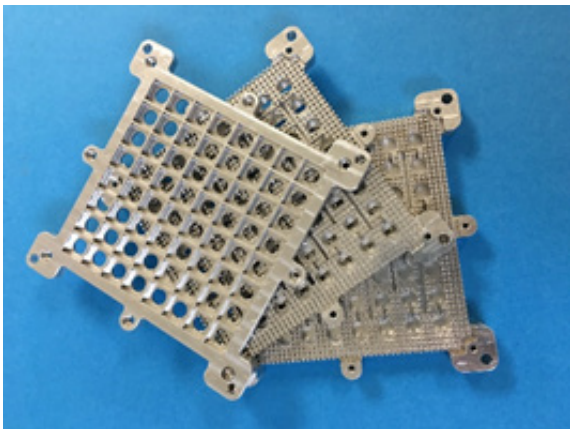
Gap Waveguide Array Antennas and Corporate-Feed Networks for mm-Wave band Applications

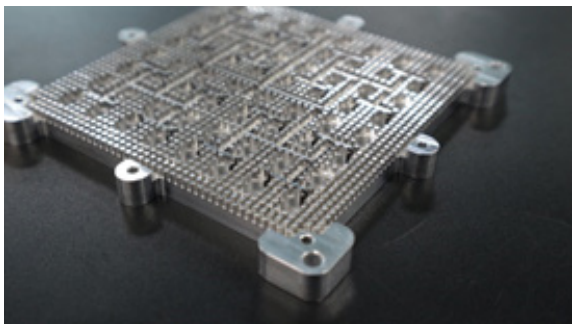
Miguel Ferrando Rocher
Supervisors: Dr. Alejandro Valero Nogueira,
Dr. Jose Ignacio Herranz Herruzo
Defended on December 18th, 2018

This thesis deals with topics of special interest regarding the design of antennas at the mm-wave band. Today, implementing passive components that operate in the mm-wave band and to ensure the appropriate metallic contact is challenging. Commonly, conventional planar transmission lines and hollow metallic waveguides are the usual solutions but they present high losses or they do not ensure a good metallic contact. So, new concepts must be explored.

Gap Waveguides (GWs), result suitably since they do not require metallic contact for shielding. Antenna arrays in Gap Waveguide Technology (GW) emerges as one promising candidate to naturally meet some of the mentioned needs. GW technology has demonstrated to be effective for mm-wave band devices because it enables full-metal distribution networks in a much simpler way than conventional waveguides. Very low distribution losses can be achieved preserving at the same time the assembly simplicity of multilayer microstrip feeding networks. This unique feature is a consequence of gap waveguides ability to safely confine the electromagnetic wave propagation through a contactless structure. During the last decade, there have been important advances in GW technology and a good number of gap waveguide-based arrays can be found in the literature.

This thesis goes a step further in the contribution to mm-wave gap waveguide antennas. Here, antennas with linear polarization as well as circular or dual polarization are proposed. Dual band antennas has also been explored. These contributions have been carried out with a focus on satellite communications on-the-move. In addition, new distribution networks have also been explored to obtain more compact, low-profile and lighter antennas.





Polymer optical fiber gratings for microwave photonics and communications applications

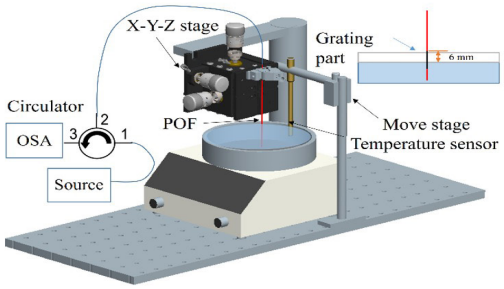
Rui Min
Supervisors: Dr. Beatriz Ortega Tamarit, Dr. Carlos Alberto Ferreira Marques
Defended on July 25th, 2019

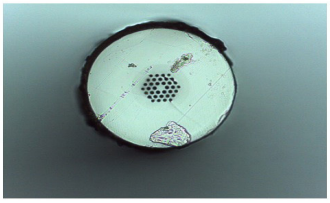
Polymer optical fibers (POFs) are optical fibers made of polymer materials with attractive characteristics compared with silica fibers, such as low Young's modulus, high failure strain, high flexibility and bio-compatibility.

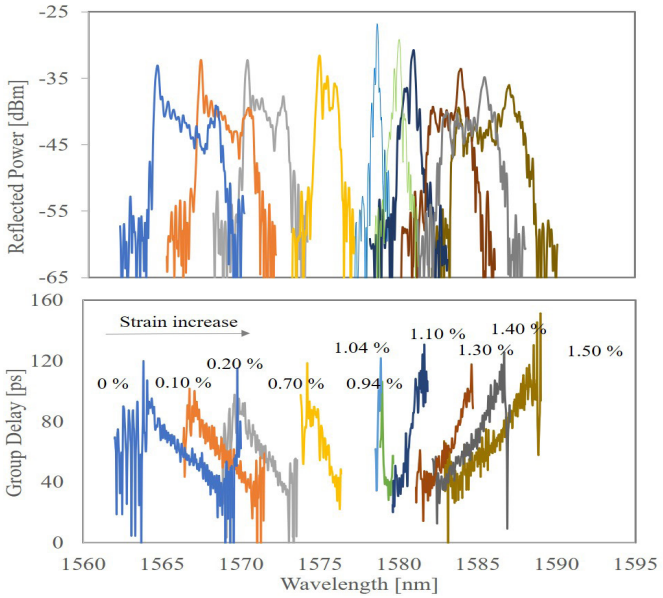
The present PhD thesis focus on the study, design, fabrication of fiber Bragg grating (FBGs) and long period gratings (LPGs) in POFs with the aim for microwave photonics, optical communication and bio sensing applications.

In this context, we fabricated uniform fiber Bragg gratings using different polymer materials, either in step index or microstructured fibers. Optimization of the FBG and LPG fabrication process was done by reducing the optical power, pulse duration and inscription time among other critical parameters and also the fabrication of polymer fiber gratings with different structures was demonstrated. We characterized stability, thermal, strain and humidity response of the fabricated gratings and finally demonstrated a variety of potential applications such as strain measurements, thermal detection and variable dispersion devices.

Although the advantages and characteristics of polymers have been successfully proved as promising for strain, temperature and humidity sensors and also for filters or variable delay lines in communications networks, several aspects require further research to make these devices real "off the shelf" sensors and filters in the next future.







Change detection techniques through remote sensing for sustainable development and desertification

Author: Soufiane Abdelaziz Azzouzi
Supervisor: Dr. Ana Vidal Pantaleoni
Defended on February 6th, 2019

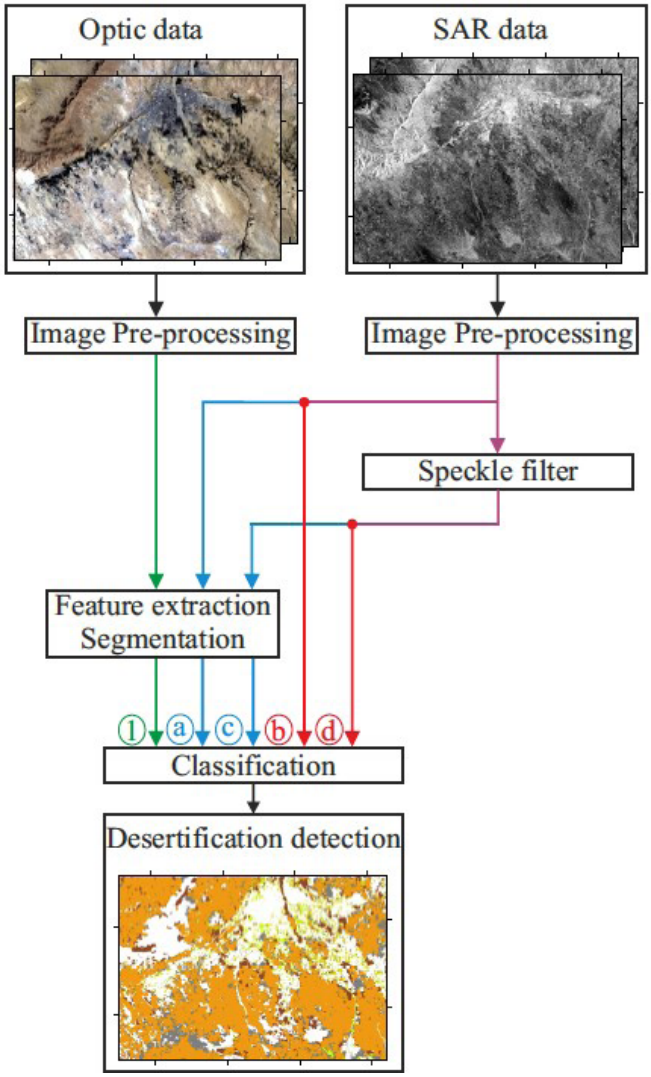
Over the last few years, the interest on the use of land use, land cover and its change in the time has grown. With the appearance of satellite images and Remote Sensing techniques, this type of Earth information can be obtained in a systematic way. In addition, the development of sensor technologies increases the availability of high and medium resolution images in the optical and microwave spectrum. On the other hand, the issue of desertification in arid zones is growing joined to the global awareness for climate change. For the last decades, the Algerian government has managed initiatives and programs to combat desertification in agricultural areas and cities located in the north of the country, near Sahara desert. Recently, they have started exploiting new sources of land cover information for this purpose. In general, land use and land cover monitoring methodologies require a high degree of human intervention for training and validation steps. The main focus of this Thesis is to develop change detection techniques through semiautomatic analysis of freely available optical and microwave images, with special emphasis on the detection of desertification in the north of Algeria.

Firstly, Change Vector Analysis is studied in two different zones in order to validate this change detection technique. For that purpose, supervised classification per pixel is employed with the selection of the appropriate classes for each scene information. In this step, comparison among different types of classifiers is done and Maximum Likelihood Classifier provides the better accuracy equal to 90,71 %. Quality evaluation is given by matrices of confusion and its derived parameters, such as global accuracy and kappa coefficient. A critical point in change detection methodology is optimal threshold selection. One possibility for it is given by the classical method Double-Window Flexible Pace Search. The results of change detection are given by transition matrices, change indexes and change maps.

Secondly, change detection applied to the issue of desertification in Algeria is studied using optical data. A methodology based on post classification comparison is developed to monitor the degradation of the Earth in a simple way. This method of change detection provides the best results with a value of 95,15 % in overall accuracy, after the comparison with Change Vector Analysis and considering different processing parameters in both methods. In this case, the Support Vector Machine classifier based on objects is the one that provides the best results with a remarkable global accuracy of 92,91 % and kappa coefficient equal to 0,91, after comparing the confusion matrices and their derived products. Consequently, a change detection method is designed and evaluated in the city of Biskra (Algeria) during a period of twenty-five years. The results are available in statistical format (transition matrices and change indexes) and in graphical format using change distribution maps. The excellent results are obtained with low human operator time.

Finally, taking into account the increasing availability of microwave images, the addition of radar images to the optical data in the previously selected desertification detection methodology is carried out. After evaluating different configurations, the integration of the radar image in vertical-vertical polarization without Speckle filtering after the segmentation step is chosen. This new strategy

employing optical and radar images provides a significant improvement over previous results (with a value of 97,05 % in global accuracy and 0,96 in kappa coefficient), since the properties of dry sand in the radar image make it more easily identifiable. This new semiautomatic method integrating different types of images reduces the analyst's work and produces an easily interpretable change detection report. The usefulness of this type of report lies in helping the Algerian government authorities to take appropriate actions to fight against land degradation.



The flowchart describes the algorithms used for the step of classification, where 1) is the standard classification, a) and c) fusion of the SAR and optical data before the process of segmentation, b) and d) fusion of the SAR and optical data after the segmentation step. And for each method you can apply the speckle filter or not. The approach achieves Land Use Land Cover change detection using Support Vector Machine and segmentation. The most useful change indices are obtained for the best methodology product. The simple improved methodology including radar images provides excellent results and it clearly outperforms the standard technique

Interoperability for the future European SmartCity ecosystem

Victor Fernández Pallarés
Supervisors: Dr. Juan Carlos Guerri Cebollada, Dr. Alicia Roca Martínez
Defended on June 26th, 2018.

Sustainable development of urban areas is a challenge of highest interest at global level. Never before could anyone have thought of the information as an asset of our society. The advent of the new technologies has provided us with a huge amount of unthinkable resources to manage the data generated by the city and it is leading to an imminent evolution of urban areas behavior.

Nowadays a proper management of the city is vital and depends on the continent, the amount and nature of the data to be treated and/or shared and the resources and infrastructures to be taken into consideration. The necessary model of the city we will face is due to a higher connectivity and interaction, without human intervention, among all the services that determine an urban center. This is what is making the current concept of city change towards the intelligent city or Smart City.

This new model of the city is characterized by a higher connectivity and interaction among all the services that determine an urban center. A feature of paramount importance is the mobility of the components of the city, as it is what supports the daily routine in the urban model. A very relevant element in this context is the Full Electric Vehicle (FEV), for all the reasons we have analyzed in our work. For a proper launching of the FEV it is needed to integrate it with the rest of infrastructures that influence the mobility in the city.

Our work has consisted of researching and designing an interoperability system to integrate the FEV in the Smart City. The first of our goals in this work has been to put the FEV in place into the SmartCity along with to optimize the energy supply to the FEVs. It has required to model the mobility of the FEVs in an area, to analyze the power consumption of the vehicles and control it from a centralized proactive information system center, to forecast the power demand in the city and to study the power supply availability in the network of charge stations. It has led us to the design of a model for the estimation of power supply availability in the network of Charging Stations (CS). So the system designed is able to manage, in a proactive way, the needs of the network in order to optimize costs and improve efficiency.

On the other hand, the second of our objectives has been to study how the factors involved in the mobility within the SmartCity can ensure that FEV mobility is carried out as planned and, with it, conveniently integrate the FEV in the urban mobility system. In other words, our goal has been to integrate the FEV management landscape, studied in the first part, with the other agents of mobility into the SmartCity, thus providing a comprehensive solution to the problem of integration of the FEV in the new European cities ecosystem. This requires optimizing the interaction between the FEV and the meteorological information, traffic and mobility services in the city such as public transport, parking and e-sharing, in addition to a necessary traffic forecasting strategy for the early decision-making.