Research project

Photonic systems for sustainable applications

Abstract

We live in an unprecedented age in terms of human impact in our planet. This fact starts to compromise our civilization sustainability. Due to this, changes of the consumption models are necessary. New communication and information technologies offer potential and -demonstrated- solutions to enhance the efficiency in production and consumption of energy. These systems require huge sensor networks to monitor different parameters of interest, acting consequently using the information collected by the sensors. Photonic transduction mechanism, mainly based on optical fibres, shows outstanding characteristics to fulfil those requirements.

The research proposal linked to this Beatriz Galindo's call has the objective of developing novel and improved photonic sensors and high performance sensor networks based on optical fibres. Besides, these systems will be validated in real demonstrators in renewables energy generator systems and Smart Cities key parameters monitoring. Examples of these smart cities applications are traffic, wind turbines and electrical transformers monitoring, among others. These objectives are separated in three following working packages (WP).

WP1. New photonic systems for sensing: New sensing structures/systems based on optical fibre technologies will be developed, focused on electrical generation and transformation systems applications, including the design and development of the interrogation systems. New systems for traffic monitoring and health monitoring of asphalt structures will be also implemented.

WP2. High performance optical fibre sensor networks: It will be studied, designed and developed new optical fibre sensor networks capable to multiplex large amount of sensors for, mainly, future smart cities applications. Besides, it will be exploited the low loss characteristic of optical fibres to enhance remote monitoring systems, for instance, based on Raman random distributed feedback lasers.

WP3. Demonstrators: In collaboration with companies and institutions related to the research group, different demonstrators will be developed to carry out in field studies of the performance of the different systems developed during the research project. The developed systems will be validated in solar panels tracking systems, temperature monitoring inside electrical transformers and in traffic and structural health monitoring in asphalt structures.

1. Introduction

This research proposal was tailored for the possible incorporation of a new member into the Optical Communications and Electronic Applications Research Group in the Electric, Electronic and Communication Department of Universidad Pública de Navarra, which belongs to the Institute of Smart Cities of this University.

State of the art

As aforementioned, human action is compromising our civilization sustainability. It is expected that by 2050, around 70% of the world population will be settled in cities. The mitigation strategies to reduce the effects of such a situation will use, among others, new high efficiency control systems to control the impact of high-density settlements. Besides, another critical factor related with this is the electrical generation. Sustainable development was recognized as a societal challenge in the framework of the H2020 programme and the Spanish National Scientific and Technological research and Innovation plan 2017-2020. So much so that the new work programme 2018-2020 specifically highlight that, at least the 30% of the budget must be for sustainable development related projects. Hence, in this project it is presented different solutions for electrical transformers and solar generation and smart cities monitoring applications. Among them, traffic and structural health monitoring in/of asphalt structures. To develop these solutions, we will follow the next research lines: optical fibre transducers, optical fibre light sources, sensor networks and experimental infield demonstrators.

Since few decades, worldwide researchers have developed sensor systems based on controlling light propagation characteristics along optical fibres. Nowadays, there are available optical fibre sensors to monitor a number of physical and chemical parameters such as strain, temperature, vibrations, humidity, gas and biological components, among others [1]. The main transduction mechanism is the variation of the effective refractive index of the mode transmitted through the fibre. This variation changes the propagation characteristics of transmitted light, coding the parameter of interest [2]. Also, non-lineal effects can be utilized for sensors development. For instance, distributed optical fibre sensors based on Raman or Brillouin scattering [3-5].

Lately, new waveguides based on microstructures fibres have been demonstrated. These fibres can create special guiding conditions using a single material in combination with special structures such as hollow core or suspended core fibres [7], among others. This kind of fibres present outstanding characteristic for sensor development. In such a way, it can be engineered the optical guiding parameters to interact with the parameter of interest. To cite one, high-birefringent microstructured fibres for strain/displacement measurements with low temperature dependence because the utilization of a unique material in the fibre [8]. Other new trend is the nanowire creation by tapering standard fibres [9]. This kind of structure increases optical power transference to the evanescent fields and thus, achieves a higher interaction with surrounding elements by the fibre. In this way, the sensitivity of the new nanowire sensors is increased exponentially [10].

One of the main advantages of the optical fibre sensor technology is its large multiplexing capability in very simple networks. For instance, fibre Bragg grating sensors (FBGs) can be multiplexed by dozens in a single optical fibre [11]. Besides, the outstanding low loss characteristic of these media allows remote sensor monitoring (>50 km). Up to date, the Optical Communications and Electronic Applications Research Group from Universidad Pública de Navarra is heading the state of the art by multiplexing and interrogating a FBGs sensor network at 250 km [12]. On the other hand, new optical fibre technologies, designed for optical communications, can enhance even more this technology potential as monitoring system. The combination of optical fibres and opto-electric converters can bias and control optoelectronic devices remotely [13].

Finally, in line with the desired applications, this research plan will be centred on the specific issues and requirements identified.

Transportation systems are nowadays backbone of modern cities. Associated with this, however, there are traffic jams, air pollution, accidents, stressed drivers, pedestrian collisions and other effects. The cost of roads congestion, e.g., in Europe is estimated to be over €110 billion a year, which is equivalent to 1% of GDP [14,15]. Therefore, its mitigation has been the main priority of most infrastructure, traffic management and toll systems. One objective of this project is the development of new monitoring methods for these infrastructures based on optical fibre sensors. It has been demonstrated that sensors based on microstructured fibres and FBGs can be suitable devices for this task. They can provide the high performance characteristics, speed and remote capability that the monitoring of these asphalt structures deserve [16].

Another important topic associated with smart cities and smart grids is electrical generation and its control. Isolation failure in rotary electrical machines (motors and generators) supposes one of the main reasons of malfunction in this kind of universal machines. Approximately, 38% [17] of the beakdowns in this kind of machinery correspond to isolation failures in between the wires of the stator. Joint to the failures in ball bearings (40%), isolation faults supposes the main cause of lifetime reduction of this kind of machines. Hence, its monitoring is a critical aspect to predict and anticipate the faults and, thus, reach the maximum reliability levels. This issue is extensible to electrical transformers. There, isolating failures in the reelings (typically based on oil-immersed cellulose) are the main problem that reduce the lifetime by early aging of the isolation material.

Finally, solar energy is the world most growing renewable energy technology. In 2015 represented only the 1% of the world production. However, the 20% of the new installations were deployed using this technology. Scientist and specialist predict 3000 GW installed power in 2030 from the 73 GW installed nowadays [18]. Therefore, this is the energy generation technology that will grow most in the future. Its production is close to overcome the achieved using nuclear energy. On the other hand, the market is young and open to innovative solutions, such as new kinds of monitoring renewable energy plants. To maintain and accelerate this growing, it is necessary to enhance the monitoring underlying technologies. The goal is to increase the solar parks efficiency, reducing the operation cost. This will contribute to the climate changes objectives and to the transition to a low carbon emission economy. Furthermore, the remote monitoring would help to the introduction of the solar energy in new countries that faces new and more exigent installation conditions.

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2. Appropriateness to the Spanish Scientific, Technological and Innovation Strategy, to the H2020 European Commission Strategy, to the International Excellence Campus Iberus and the Societal Challenges.

The project here described is fully aligned with the Spanish's and European's research and development objectives and strategies. This is due to the objective of contributing with specific photonic solutions to overcome the societal challenges, explicitly identified by both research strategies.

This project proposal is focused on the sustainable development societal challenge. Specifically, in the frame of the "Plan Estatal de Investigacion Cientifica, Tecnica y de Innovacion 2017-2020" the following societal challenges are described: "clean, safe, sustainable and clean energy" and "smart, sustainable and integrated transportation". Besides, the proposal fits with the challenges defined in the EC H2020 Working Programme 2018-2020 in the following challenges: "Secure, clean and efficient energy"; "Smart, green and integrated transport" and "Climate action, environment, resource efficiency and raw materials". Additionally, in the new Working Programme it is literally stated: "Increased investment in sustainable development and climate related R&I".

On the other hand, Universidad Pública de Navarra (UPNA) belongs to the International Excellence Campus "Iberus", which has four main action axes. UPNA has an important role in the "Energy" axis. They are mainly related to the wind and solar electric generation. This project wants to contribute to this research line by developing enhanced and more efficient energy generation systems.

Appropriateness of the institutional environment (infrastructure)

The Beatriz Galindo grant, if approved, will be framed in the Optical Communications and Electronic Aplications Research Group (COAE), which belongs to the Electric and Electronic Engineering Department of Universidad Pública de Navarra. This research group has more than 25 senior researchers, further a relevant number of pre and post-doctoral researchers. The research is based on the synergies in between the following topics:

- Optical communications

- Optical fibre sensors
- Nanostructured optical devices
- Electronic and communications applications

Lately, this group has been contributed large amount of publications in international journals and presentations in international conferences. Besides, its members have been participated in many research projects founded by public institutions (Navarre´s Government, Spanish´s Government, and European Union), as well as R&D contracts with companies.

Most important activities, products, material resources and production infrastructure.

COAE researchers have access to a well-equipped R&D infrastructure including following laboratories: Optical Communications Laboratory, Sensors Laboratory and Photonics Laboratory. On the other hand, they have access to a computing and simulations laboratory. It has powerful computers specially set up to run specific software to simulate photonics devices, networks and systems. At the instrumentation level, the research group has a large selection of optical and electrical measurement instrumentation. It has also a large amount of optical and electrical components to set up the experiments. Finally, the group has access to the electronic fabrication tools from the Electric and Electronic Engineering Department.

R&D strategy

The research group has the following short-term strategy to enhance the technological transfer to the production framework. This is possible towards research contracts, patents, and the generation of technological start-ups. All of which without compromising the new scientific and technological knowledge generation and its communication in international journals and conferences.

Last technological developments carried out by the entity.

Following, some of the recent research projects carried out in the frame of the research group and related to this proposal are listed.

01/01/2017 –31/12/2019 Photonics sensors for safety and security (SENSA). Founded by Ministerio de Economía y Competitividad - 191.000€.

10/12/2014 – 9/12/2018 Advanced fibre laser and coherent source as tools for society, manufacturing and lifescience. Founded by COST Action MP1401 (European Commission) - 262.000 € (first two years).

01/10/2017- 01/092019 “Sistema de monitorización y diagnosis avanzada de máquinas eléctricas para mantenimiento según estado” Founded by Asociación de la Empresa de Navarra (AIN). - 4.500 €

01/06/2017- 30/04/ 2019 Desarrollo de seguidor solar bifila con sensorización de efectos del viento (WINDSOLAR). Research contract by the company Soluciones Técnicas Integrales Norland S.L. Founded by Gobierno de Navarra. Proyectos de I+D. Transferencia de Conocimiento. Project number: 0011-1365-2017-000122 - 96.703,87 €.

01/01/2014 –31/12/2016 Desarrollo de sensores de fibra óptica para seguridad y protección de infraestructuras (FOS4). Founded by Ministerio de Economía y Competitividad - 277.937 €.

01/11/2012 – 31/12/2014 Gestión ecológica de pilas de residuos de carbón de combustión mediante sensores de fibra óptica (ECOAL-MGT). Founded by European Comission - 185.418 €

01/11/2010-01/11/2014 Novel and Reliable Optical Fibre Sensor Systems for Future Security and Safety Applications (OFSeSa). Founded by COST Action TD1001 (European Comision) 501.676€ (all participants)

01/01/2011 –31/12/2013 Tecnologías para sensores de fibra óptica (TSEN) Founded by Ministerio de Ciencia e Innovación - 265.595 €.

Aditionally and due to the grant “Sistema de fabricación y medida en tiempo real de nanowires de fibra óptica”, from the ‘Convocatoria de infraestructura científico-tecnológica’ (2015). Founded by ‘Ministerio de Economía y competitividad’ - 133,790.39 € the group has an optical fibre microwire fabrication station that would be used during the development of this research project.

Patents and utility models

Recent patents from the research group and related to the project:

“Dispositivo y procedimiento para la medida de la distribución de magnitudes físicas en una fibra óptica” ES2392527, EP12785547. Inventors: Alayn Loayssa, Migues Sagües y Ander Zornoza. Priority date: 13/05/2011

“Sensor de medida de la distribución de magnitudes físicas en una fibra óptica y procedimiento de medida asociado” ES201430832, PCT/ES2015/070424. Inventors: Alayn Loayssa, Miguel Sagües y Javier Urricelqui. Priority date: 30/05/2014.

3. Methodology and work plan

Objectives

O1. To investigate novel techniques and technologies to improve optical fibre transducers. It will be focused on the sustainable development societal challenge.

O2. To investigate and to develop new laser and optical sensor network techniques and multiplexing technologies for smart cities applications.

O3. To validate the developed technology in real field demonstrators.

Tasks: Definition, temporal planning, results and risk management.

Next, the tasks related to this research project are presented. Is important to highlight that there exist an important teaching duty distributed along the duration of the contract. Therefore, this time schedule takes into account a workload distribution in research and teaching of 30%-70% respectively. Additionally, to provide a clearer idea about the time distribution of the different tasks, attached there is a Gantt chart that provides a graphical overview of the action.

Tasks related to objective 1:

T1.1 Design and development of a novel information coding system for FBG optical fibre sensors.

Hypothesis: Information in optical fibre sensors is coded in the intensity, wavelength, phase or polarization. This task proposes a novel codification method for dynamic measurements based on a novel “pseudo-digital” technique.

Time schedule: This task has a foreseen 6-month duration distributed along the first semester of the first year.

Results: New dynamic strain transducers based on novel codification of FBGs. [Patent]

Risks and mitigation: This is a low risk task. It will be taken into account the special FBGs´ inscription method. In the remote case, it should be studied an alternative FBGs fabrication by “femto-second” lasers inscription.

T1.2 New optical fibre transducers based on microwires fabricated by optical fibre tapering.

Hypothesis: Propagation mode delocalization along optical fibre tapers stimulates the evanescent fields. This increases the interaction of light with the surrounding media. Hence, the sensitivity of the sensor to the parameter of interest is enhanced. With this method, it will be developed new optical sensors sensitive to fluid elements (liquids or gases). New deposition techniques or femtosecond drilling can be used to increase the sensitivity of the transducers.

Time schedule: This task has foreseen 5-month duration distributed along the second semester of the first year.

Results: New enhanced sensitivity micro-structured transducers by optical fibre tapering.

Risks and mitigation: This is a low risk task. Due to the fragility of the structure, some handling issues can appear. If so, studies on how to embed the sensors to be protected would be carried out. This can extend the planned time.

T1.3 Development of new specialty optical fibres transducers.

Hypothesis: Longitudinal microstructuration surrounding the core of special optical fibres allows to control light propagation conditions. This control allows new and optimized optical fibre design for different usages. This will permit the enhancement of the propagation properties of transmitted light, allowing polarization, light confinement and dispersion control, among other features.

Time schedule: This task has foreseen 8-month duration distributed along the second and third year.

Results: New specialty fibre transducers based on new fibre designs.

Risks and mitigation: This is a medium risk task due to the dependence of other research centres for the development and fabrication of the specialty fibres. If the custom fibres do not bring the desired characteristics, it can be ask for the fibres re-fabrication. If not possible, the task will be develop by using commercial MOF fibres providing a reduced performance.

T1.4 Development of low cost optical fibre sensors interrogation systems.

Hypothesis: One of the main obstacles to a massive introduction of monitoring technologies based on optical fibres is the high cost of the interrogation systems. Usually, these systems requires expensive photonic and optoelectronics devices reducing this technology to some application niches. Therefore, this task proposes a low cost interrogation system based on optical signal processing by using low cost components.

Time schedule: This task has a foreseen 7-month duration distributed along the third year.

Results: New low cost optical fibre interrogation system. [Patent]

Risks and mitigation: This is a medium risk task. On the one hand, the final device could do not fulfil the minimum requirements. On the other, the design could fulfil the requirements but it might not be patentable. These risks can be mitigated by enhancing the design by increasing the components´ cost, always taking into account the competitors. If the system is not patentable, the developed system can be always used in publications or communications in conferences.

Tasks related to objective 2:

T2.1 Development of optical fibre sensor networks development based on the Raman non-linear effect.

Hypothesis: The availability of high power lasers coupled to optical fibres allows the development of the Raman non-linear effect in fibres. This effect is used to create amplification in the communication low loss spectral bands. Besides, different research groups have also used this effect to develop lasers and sensor networks. This effect present a unique characteristic that generates distributed cavities and thus, modeless emission. This task will exploit this effect to create remote high density multiplexing sensor networks by using wavelength and time division multiplexing techniques.

Time schedule: This task has a foreseen 9-month duration distributed along the second year.

Results: New multiplexing and monitoring structures by using Raman non-linear effect.

Risks and mitigation: This is a very low risk task because the physical effect involved in this task offers lot of research possibilities, presenting a very high development flexibility.

T2.2 Study on the output spectrum configurability by internal modulation of the Raman distributed cavity.

Hypothesis: Previous task is based on the longitudinal modeless characteristic of the Raman distributed feedback lasers. Due to this characteristic, it was demonstrated the modulation possibility of this kind of laser cavities without frequency restrictions. In this way, it can be understood that the cavity self-adapts to the modulation frequency and thus, by stimulating different propagation modes from the optical spectrum, it is possible to tailor the spectral output of the laser. This task has the objective of studying this effect and explore this application of sensor interrogation.

Time schedule: This task has foreseen 6-month duration distributed along the first semester of the fourth year.

Results: Novel reconfigurable spectral sources by internal modulation of random light sources.

Risks and mitigation: This is a medium risk task because the Raman non-linear effect present some instabilities at the high power requirements of these experiments, making challenging the practical use of this effect. Anyway, these are experiments linked to the previous task and would allow to a better comprehension of this effect, that has lot of impact on the scientific community.

T2.3 Development of power-by-light optoelectronic devices for optical networking.

Hypothesis: Currently, the scientific community is geared to increase the opto-electric conversion efficiency of electrical power converters. Actually, there are already commercialized fibre power-by-light solar cells with an efficiency of around 80%. They will allow the development of remote power-by-light optoelectronic systems. These devices can be used for optical networks such as large sensor networks suitable for smart cities applications and efficient electric generation. In this task, it will be developed switching, modulation and sensor hybridation systems.

Time schedule: This task has foreseen 7-month duration distributed along the fourth year.

Results: Design and prototypes of remote power-by-light devices. [Patent]

Risks and mitigation: This is a medium risk task due to the multidisciplinary dependence that involves electronic developers. Usually, the profile for this position is for photonic experts. To mitigate this risk of this task, other members from the research group, with electronics development experience would support the researcher.

Tasks related to objective 3:

T3.1 In field demonstrator for asphalt structures monitoring, using the developed technologies.

Hypothesis: The development of new optical fibre sensors installation techniques is crucial for its introduction in structural health monitoring applications. Specially, it exists interest on the study of new installation techniques in extreme media or materials. Asphalt pavement installation requires high temperatures (around 180 ºC) and high strain associated to the paver and compacting roller machines. This task aims to new protection methods for optical fibre sensor installation. Besides, it will be experimentally explored the installation of the sensors at different asphalt depths for traffic monitoring, weight in motion and structural health monitoring for preventive maintenance. In order to achieve this task, the team will be supported by a construction SME (Asfaltos y Construcciones del Baztan S.A.) and Pamplona´s City Hall.

Time schedule: Due to the dependency of this task to other institutions, the installation of the sensors is expected to be done during spring/summer of the third year. This task also have other sub task following listed:

T3.1.1 Optical fibre sensors embedment methods development for asphalt structures installation: 2-months along the second semester of the second year.

T3.1.2 Study of the different transducers to be used during the experiments: 2-months distributed during the second semester of the second year.

T3.1.3 Sensors materials purchase, planning and fabrication: 3-months distributed during the first semester of the third year.

T3.1.4 Sensor installation: Sensors installation is only one-day work. However, there is an uncertainty to the installation day, which depends on the partner institutions and the weather. Therefore, this day is expected to be accomplished along the spring-summer of the third year.

T3.15 Installed sensors data acquisition and processing: continuous process from the installation of sensors.

Results: Traffic monitoring system, vehicles parameter acquisition and asphalt structural health monitoring system.

Risks and mitigation: This is the longest task and the one with external non-academic partners. Due to this, this is a high-risk task. The risk is mainly concerned on the sensors selection, design and installation. The installation depends on the active involvement of different organizations and with a high economical cost. Thus, the installation day is unique and would not be repeated. This can be mitigated by preparing different sensor types and protection to ensure the best results.

4. Impact

Photonics is a Key Enabling Technology (KET) for Europe. The expected compound annual growth rate (CAGR) for photonics over the coming years is 8%. In specific areas, substantially higher (more than 20%) CAGR are predicted. Photonic Sensing is one of these areas. In addition, as the European Commissioner Günther Oettinger clearly stated at the 2016 Photonics 21 Annual Assemble in Brussels "Photonics provides a competitive edge for every industry and is key for their successful digitization" [1].

In this proposal the photonic sensing concepts, techniques and tools will be used to face a wide range of societal challenges targeted on applications related to sustainable development. For example, smart cities and electric generation efficiency. Applications that are included into the different National and European research and development plans. With this project, we expect to maintain and to improve:

1) The generation of new knowledge and technologies.

2) The transference of results.

3) The consecution of new R&D projects both with private and public Regional, National or European organizations.

4) The training of qualified personnel.

5) The competitiveness and position of the research group and the university in the international arena.

Quality and productivity indicators.

To measure our impact on the international EoArt, it has established objective indicators to be reached at the end of the third year. They are: at least 10 papers on SCI journals (75% inside the first Quartile, Q1); 8 papers on international conferences; at least the supervision of two students and the preparation and presentation of at least two new R&D projects proposals.

Dissemination Plan

Preliminary results will be presented in specialized conferences. Extended versions will be submitted for their publication as papers at international journals included in the JCR (preferably those included in the Q1). Following the guidelines of the Spanish Law of Science and European H2020, we will favor publication in open access journals (taken into account budget restrictions) and we will post pre-print, post-print or published versions in our institutional repository: Academica-E. We will also use social networking sites for researchers such as ResearchGate to give visibility to our papers. Additionally, other dissemination activities are intended within the members of the ongoing European COST Actions, the Platforms Photonics 21 and Fotónica 21, and others. It is also expected that the project results will enable the submission of new research proposals with companies in future European Calls.

Transference Plan

All results will be analysed by the project steering committee formed of professors from the research group and the researcher as they will be generated. Each result will be carefully considered for intellectual property protection before publication. There are different partner companies and institutions supporting this proposal that will support the exploitation of the results and will be consulted in each case. At the time of this proposal, three activities have been identified as probable candidates for patent filling: the FBG sensors coding system, the low cost sensor interrogation system and the power-by-light optoelectronic devices. If the steering committee agrees, the creation of new small spin-off could also be considered. In any case, the university and partners will sign exploitation agreements. As a clear indicator of transferences, it must by pointed out that the research group have created new spin-off companies such as Nadetech Innovations S.L. and Up technologies.

[1] "Photonics – a key enabling technology for Europe", KET working group on Photonics, (2011).