PLAN DE INVESTIGACIÓN

DOCTORANDO:

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PROGRAMA DE DOCTORADO: “Electroquímica: Ciencia y Tecnología”

DIRECTOR: Dr. Toribio Fernández Otero.

TÍTULO DE LA PROPUESTA DE TESIS: Development of self-sensing systems comprising polymeric artificial muscles

RESUMEN DE LA PROPUESTA:

Skeleton muscles and tendons are able to sense their relative position and the required force while they contract and expand via specific organs. Actuation and sensing occur at the same time. Similar abilities were discovered for electroactive materials based on conducting polymers which sense temperature, electrolyte concentration, and trailed mass while moving[1–3]. Dual sensing-actuating artificial muscles based on these materials driven by electrochemical reactions announce the development of self-sensing devices. Several sensors and a faradaic motor work simultaneously in one uniform device driven by the reaction of the constitutive material, like skeleton muscles do[4]. The integration of dual sensing artificial muscles into devices could reduce the complexity, the size and the control effort of nowadays technology.

The aim of the project is the investigation of novel materials for dual sensing-actuating artificial muscles and the development of a proof of concept for industrial applications. Electroactive materials are synthesized and characterized, in particular basic conducting polymers such as polypyrrole and its composites with reasonable life time, reproducibility and stability. With these electroactive materials, dual sensing-actuating artificial muscles are fabricated and tested under different experimental conditions. Furthermore, novel configurations of these motors are designed and tested. Based on the experimental results theoretical descriptions are derived, characteristic material values are determined and the existing proprioceptive model[1–3] is adopted in terms of real world environment. In the second phase of the project a functional demonstrator is developed and fabricated as a proof of concept. Based on the updated proprioceptive model and the application requirements a control system for self-sensing

systems is developed and the demonstrator is designed. The demonstrator will show the potential of dual sensing-actuating polymeric artificial muscles for future technology.

OBJETIVOS ESTIMADOS DEL TRABAJO:

The aim of the project is the investigation of novel materials for dual sensing-actuating artificial muscles and the development of a proof of concept for industrial applications.

ESTADO DEL ARTE DEL PROBLEMA:

The discovery of the first electrically conductive polymer by Alan J. Heeger, Alan G. MacDiarmid and Hideki Shirakawa 50 years ago [5] initiated a new scientific field and the fast exploration of other polymers of this kind.

After the discovery of reversible volume variations of conducting polymers due to ion and solvent exchange driven by redox reactions [4,6–9] for charge balance and osmotic balance inside the material, researchers attempt to utilize the effect to develop soft polymeric motors [10]. Since then, different actuator configurations in milli and micro range have been studied with multilayer actuators being the most studied [11–20]. In addition, mechanical conducting polymer sensors (produce voltage or current in response of force/displacement) have been described and analysed [21–28]. For characterization and control, complex physical models have been developed including mechanical, electrical [29,30] and electromechanical [28,31–34] descriptions. However, most of them neglecting the underlying electrochemical mechanisms.

In contrast, the electrochemical proprioceptive model recently developed by the group of Professor Otero utilises the electrochemical origin of actuation to reveal proprioceptive properties of these polymeric motors. While the position of the electrochemical artificial muscles is controlled by the consumed charge and the motion rate by the applied current [35], the muscle senses any mechanical, chemical and thermal variations [2,3,36–38]. Polymeric motors based on conducting polymers are self-sensing electro-chemo-mechanical motors.

Self-sensing systems have been designed using several smart materials such as dielectric elastomers [39–41], IPMCs [42,43], shape memory alloys [44], piezoelectric [45–47] and magnetostrictive materials [48] which function as one resistance or capacitance sensor of an entity. In contrast, in electro-chemo-mechanical actuators based on conducting polymers [2,3,36] several sensors (consumed energy by the driving reaction) and actuator are present in a physically uniform device. Alternation of sensing and actuation mode or partial separation of actuation and sensing region[26] are not required because the self-sensing artificial muscles sense simultaneously the working condition during actuation. Control and communication (sensing and control signals) can be established via the same wire, in parallel to vertebrate muscles (motor neurons). Hence, the latter inherit the potential of designing biomimetic robotic systems with the lowest complexity level. Electrochemical full-polymeric sensing-muscles allow the construction and theoretical description of artificial primitive proprioceptive devices [49,50].

PLAN DE TRABAJO CON UNA ESTIMACIÓN DE CALENDARIO Y METODOLOGÍA QUE SE VA A UTILIZAR:

1st year

- State of art of the field
- Material synthesis and characterization for proprioceptive motors (with focus on composites conducting polymers and carbon nanotubes and basic conducting polymers) with reasonable life cycle and stability for commercial applications with high reproducibility
- Fabrication and testing of proprioceptive motors under different experimental conditions
- Study of different materials assessing their possible used as artificial muscles
- Publication of the attained results

2nd year

- Choice of a material to develop a control system
- Developing of a control system
    - Design of a control system
    - Building of the control system
    - Implementation of the control system
    - Improvement of the control system
    - Sensorless position control
- Developing of a methodology to compare different materials and their possible use as artificial muscles
- Development of control system for dual sensing and actuation devices
- Improvement of the theoretical model for artificial proprioception
- Publication of the attained results if appropriate

3rd year

- Design and fabrication of demonstrator for functional device for industrial applications comprising sensing and actuation properties as proof-of-concept
- Publication of the attained results if appropriate
- Writing and presentation of the thesis

INVESTIGACIÓN BIBLIOGRÁFICA:

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PUBLICACIONES MÁS RELEVANTES REALIZADAS EN EL ÁMBITO DE ESTUDIO:

The PhD candidate participated in papers accepted in international magazines

- Otero, T. F., Schumacher, J., & Pascual, V. H. (2016). Construction and coulodynamic characterization of PPy-DBS-MWCNT/tape bilayer artificial muscles. RSC Advances,6(72), 68538-68544
- Otero, T. F., Schumacher, J. Electrochemical synthesis and characterization of self-supported polypyrrole-DBS-MWCNT electrodes. Journal of Electroanalytical Chemistry.
- Otero, T. F., Pascual, V.H, Martinez-Soria, L., Schumacher, J., Valero, L. "Electrochemical and sensing properties of self-supported Ppy-PVS films". To be submitted

The PhD candidate has also participated in congresses communications:

Authors: Johanna Schumacher, Toribio F. Otero, Victor H. Pascual, Jose G. Martinez, Laura Valero.
Title: Polypyrrole-carbon nanotube composite/tape bilayer sensing-muscles: electrochemical and electrochemo-dynamical characterization at different sweep rates
Participation type: Oral communication and poster
Congress: VI International Conference on Electrochemically Active Polymer (EAP) transducers and artificial muscles
Venue: Helsingor (Denmark) June 2016

Authors: Victor H. Pascual, Toribio F. Otero, Jose G. Martinez, Laura Valero, Johanna Schumacher
Title: Electrochemical reactions from conducting polymers sense available electrochemical energy: sweep rate influence
Participation type: Oral communication and poster
Congress: VI International Conference on Electrochemically Active Polymer (EAP) transducers and artificial muscles
Venue: Helsingor (Denmark) June 2016

Authors: Jose G. Martinez, Toribio F. Otero, Victor H. Pascual, Laura Valero, Johanna Schumacher
Title: A single electro-chemo-physical equation explains dual sensing and actuating properties of conducting polymer actuators: theoretical description of sensing-motors
Participation type: Oral communication and poster
Congress: VI International Conference on Electrochemically Active Polymer (EAP) transducers and artificial muscles
Venue: Helsingor (Denmark) June 2016

Authors: Johanna Schumacher, Toribio F. Otero, Víctor H. Pascual, José G. Martinez
Title: Characterization of PPy-DBS-MWCNT/tape bilayer sensing-muscles at different scan rates
Participation type: Oral communication
Congress: XXXVII Reunión del Grupo de Electroquímica de la Real Sociedad Española de Química.
Venue: Alicante (Spain) July 2016

Authors: Victor H. Pascual, Toribio F. Otero, Jose G. Martinez, Laura Valero, Johanna Schumacher
Title: Electrodos y dispositivos de polipirrol - dodecilbencenosulfonato sienten las condiciones electroquímicas de trabajo.
Participation type: Poster
Congress: XXXVII Reunión del Grupo de Electroquímica de la Real Sociedad Española de Química.
Venue: Alicante (Spain) July 2016

Authors: Johanna Schumacher, Toribio F. Otero, Victor H. Pascual,
Title: Dual sensing-actuation artificial muscle based on polypyrrole-carbon nanotube composites
Participation type: Oral communication
Congress: SPIE, Electroactive Polymer Actuators and Devices (EAPAD) 2017
Venue: Portland (USA) March 2017

Authors: Victor H. Pascual, Toribio F. Otero, Johanna Schumacher
Title: Properties of polypyrrole polyvinilsulfate films for dual actuator sensing systems
Participation type: Oral communication
Congress: SPIE, Electroactive Polymer Actuators and Devices (EAPAD) 2017
Venue: Portland (USA) March 2017

Authors: Victor H. Pascual, Toribio F. Otero, Johanna Schumacher
Title: Biomimetic reactions in conducting polymers for artificial muscles: sensing working conditions
Participation type: Oral communication
Congress: SPIE, Electroactive Polymer Actuators and Devices (EAPAD) 2017
Venue: Portland (USA) March 2017

Authors: Victor H. Pascual, Toribio F. Otero, Johanna Schumacher
Title: PPy/DBS films for artificial muscles: Dependency of the mechanical properties with the oxidation state

Participation type: Oral communication
Congress: EuroEAP 2017, 7th international conference on Electromechanically Active Polymer (EAP) transducers & artificial muscles
Venue: Cartagena (Spain) June 2017

Authors: Victor H. Pascual, Toribio F. Otero, Johanna Schumacher
Title: Precise tip positioning of self-sensing polymeric actuators
Participation type: Oral communication
Congress: EuroEAP 2017, 7th international conference on Electromechanically Active Polymer (EAP) transducers & artificial muscles
Venue: Cartagena (Spain) June 2017

COMPLEMENTOS DE FORMACIÓN:

"MICACT Training School on Dielectric Elastomer Transducers". École Polytechnique Fédérale de Lausanne(Switzerland) 8th,9th&10th September 2015 (30 hours)

"MICACT Training School on Modelling and Ionic EAPs". University of Tartu (Estonia) 25th-29th January 2016 (35 hours)

"MICACT Training School on Modelling and Ionic EAPs". University of Tartu (Estonia) 25th-29th January 2016 (35 hours)