Biosystems & Biorobotics

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Soft Robotics: Trends, Applications and Challenges

Proceedings of the Soft Robotics Week, April 25–30, 2016, Livorno, Italy

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Biosystems & Biorobotics

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Aims & Scope

Biosystems & Biorobotics publishes the latest research developments in three main areas: 1) understanding biological systems from a bioengineering point of view, i.e. the study of biosystems by exploiting engineering methods and tools to unveil their functioning principles and unrivalled performance; 2) design and development of biologically inspired machines and systems to be used for different purposes and in a variety of application contexts. The series welcomes contributions on novel design approaches, methods and tools as well as case studies on specific bioinspired systems; 3) design and developments of nano-, micro-, macrodevices and systems for biomedical applications, i.e. technologies that can improve modern healthcare and welfare by enabling novel solutions for prevention, diagnosis, surgery, prosthetics, rehabilitation and independent living.

On one side, the series focuses on recent methods and technologies which allow multiscale, multi-physics, high-resolution analysis and modeling of biological systems. A special emphasis on this side is given to the use of mechatronic and robotic systems as a tool for basic research in biology. On the other side, the series authoritatively reports on current theoretical and experimental challenges and developments related to the “biomechatronic” design of novel biorobotic machines. A special emphasis on this side is given to human-machine interaction and interfacing, and also to the ethical and social implications of this emerging research area, as key challenges for the acceptability and sustainability of biorobotics technology.

The main target of the series are engineers interested in biology and medicine, and specifically bioengineers and bioroboticists. Volume published in the series comprise monographs, edited volumes, lecture notes, as well as selected conference proceedings and PhD theses. The series also publishes books purposely devoted to support education in bioengineering, biomedical engineering, biomechatronics and biorobotics at graduate and post-graduate levels.

About the Cover

The cover of the book series Biosystems & Biorobotics features a robotic hand prosthesis. This looks like a natural hand and is ready to be implanted on a human amputee to help them recover their physical capabilities. This picture was chosen to represent a variety of concepts and disciplines: from the understanding of biological systems to biomechatronics, bioinspiration and biomimetics; and from the concept of human-robot and human-machine interaction to the use of robots and, more generally, of engineering techniques for biological research and in healthcare. The picture also points to the social impact of bioengineering research and to its potential for improving human health and the quality of life of all individuals, including those with special needs. The picture was taken during the LIFEHAND experimental trials run at Università Campus Bio-Medico of Rome (Italy) in 2008. The LIFEHAND project tested the ability of an amputee patient to control the Cyberhand, a robotic prosthesis developed at Scuola Superiore Sant’Anna in Pisa (Italy), using the tf-LIFE electrodes developed at the Fraunhofer Institute for Biomedical Engineering (IBMT, Germany), which were implanted in the patient’s arm. The implanted tf-LIFE electrodes were shown to enable bidirectional communication (from brain to hand and vice versa) between the brain and the Cyberhand. As a result, the patient was able to control complex movements of the prosthesis, while receiving sensory feedback in the form of direct neurostimulation. For more information please visit http://www.biorobotics.it or contact the Series Editor.

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Introduction

Cecilia Laschi, Fumiya Iida, Jonathan Rossiter, Matteo Cianchetti and Laura Margheri

Soft Robotics is now considered one of the most promising frontiers for robotics research and technological innovation. The enormous growth of this field in the last few years has been evidenced by a large increase in the number of publications, special issues in journals, focused sessions and workshops at international conferences, summer schools, competitions, EU funded projects, as well as new laboratories, companies and faculty appointments.

Being "soft" is more and more a characteristics needed in robotics systems, especially in those that have to interact with humans or within particular environments. The importance of soft body parts appears clear if taking a look at many natural organisms, where softness, compliance, and embodied intelligence are useful characteristics for reducing the complexity of behaviour control [1]. The vast majority of natural organisms are soft-bodied indeed, and even those with stiff skeletons are predominantly made of soft materials. Caterpillars, octopuses, manta-ray, some fishes and snakes, birds, plants, and others, have therefore inspired engineers for the design and development of new soft technologies and soft systems, as well as for implementing new strategies for terrestrial and underwater locomotion or flying (examples can be found in [2–10]).

The field of soft robotics is highly multi-disciplinary, linking know-how from material science, mechanical/electrical engineering, control engineering, chemistry, physics, computer science, biology and many more.

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There are several cases where soft technologies and integrated soft systems could revolutionize the use of robotic devices, especially in applications where elastic versatility and safe human-robot interaction are needed.

Industrial robotic arms, agriculture robots, surgical robots, robots for search and rescue, wearable systems, exoskeletons and rehabilitation devices can benefit from the use of soft and variable-stiffness components to increase their capacities to interact safely, dependably and effectively with humans and the physical environment.

Soft robotics has the potential for allowing the development of a radically new generation of machines with better performance in the real world, and greater adaptability in a variety of tasks [11].

The interdisciplinary characteristics of soft robotics, the high number of research laboratories in Europe and worldwide that are working in its various subfields (smart materials, biomimetics, embodied intelligence, etc.) and the more recent interest of industrial stakeholders, have arisen the necessity for the creation of a common forum to help researchers to combine their efforts and to maximize the opportunities and materialize the potential impact of soft robotics.

Following this need, RoboSoft, the EU-funded FET-Open Coordination Action (CA) for Soft Robotics (http://www.robosoftca.eu/), started on October 1, 2013 to pose the basis for consolidating the soft robotics community and for enabling the accumulation and sharing of crucial knowledge needed for scientific and technological progress in this field.

RoboSoft has been running for 3 years coordinated by The BioRobotics Institute of the Scuola Superiore Sant'Anna (Italy) in partnership with the ETH Zurich (Switzerland), the University of Cambridge (UK), and the University of Bristol (UK) and it has organized a series of scientific and technical events and activities to unify and extend the community of soft roboticists, to educate a young scientific community of students, to promote the visibility of soft robotics towards stakeholders and special interest research groups and to provide opportunities for better exploiting the potential of soft robots and technologies in future ICT.

Research laboratories and institutions at European and international level working in the field of Soft Robotics have been involved and supported for taking part in the scientific initiatives of the Coordination Action as Members of the RoboSoft Community.

Their representatives are experts in various scientific and technological areas related to soft robotics (smart materials, soft actuators and sensors, control architectures, energy storage, harvesting soft devices, stretchable electronics, biology) and during the periodic meetings they participated in consultations aimed at discussing new challenges, milestones, to redefine theories and techniques, and to provide research roadmaps within a single coherent vision for soft robotics.

RoboSoft has created a large network of scientists and industries and has established strong collaborations with other initiatives worldwide that are dedicated to the promotion of soft robotics, such as the IEEE Robotics and Automation Society (RAS) Technical Committee on Soft Robotics, or education-related initiatives, such as the Soft Material Robotics IGERT at Tufts University and the Marie Sklodowska-Curie Initial Training Network SMART-E.

RoboSoft is now a pillar for the community of soft robotics because of the several events and initiatives organized for merging people, for helping the scientific discussion and for promoting soft robots.

The main events organized by RoboSoft were the annual Plenary Meetings for Community Members, the Schools for Ph.D. students, a series of workshops, special sessions and exhibitions at major robotics conferences, a number of dedicated academia-industry meetings and other initiatives for cross-fertilization with other scientific communities.

The flagship event dedicated to the soft robotics community was launched by RoboSoft in 2015 and named the "Soft Robotics Week", a week totally dedicated to Soft Robotics, featuring a unique concentration of several scientific, cultural and educational events.

International experts across multiple fields in the scientific community of soft robotics, industrial leaders, young researchers and students, met together to present current research and technologies of soft robotics, discuss the challenges and expected milestones, provide research roadmaps and identify the needed supporting actions for this field.

This book represents the proceedings of the second edition of Soft Robotics Week, held in Livorno from April 25 to 30 2016 and presents the current state of soft robotics, collecting the major research lines and novel technologies and approaches presented and discussed during the event by the RoboSoft Community.

The main themes are related to soft robot legged locomotion, soft robot manipulation, underwater soft robotics, biomimetic soft robotic platforms, plant-inspired soft robots, flying soft robots, soft robotics in surgery, as well as methods for their modelling and control.

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Soft Bionics Hands with a Sense of Touch Through an Electronic Skin

Mahmoud Tavakoli, Rui Pedro Rocha, João Lourenço, Tong Lu and Carmel Majidi

Abstract Integration of compliance into the Robotics hands proved to enhance the functionality of under-actuated hands for prosthetic or industrial applications. An appropriate design of the finger geometry with compliant joints allows the fingers to adapt to the shape of the object, and the soft and compliant skin allows for a higher contact area and contact friction. In this article, we describe how these properties were exploited for the development of compliant hands that are simple, efficient and easy to control. We also discuss integration of soft pressure and bending sensors into the digits of these hands.

1 Introduction

About a quarter of the motor cortex in the human brain (the part of the brain which controls all movement in the body) is devoted to the muscles of the hands. This shows the complexity of the human hand, which is composed of 34 muscles. It is clear that individual control of many of the hands joints and thus muscles requires considerable effort from the brain. However many of the tasks, such as grasping, is pretty instinctive for humans and does not involve a considerable brain effort.

Neuroscientists research shows that to control the complicated hand mechanism for a grasping action, the human brain does not control each joint and muscle individually, but utilizes some predefined motion pattern or synergies [1]. Therefore, as stated by Bicchi et al., all joint configurations belong to the s-dimensional manifold, where s expresses the number of synergies" [2]. This means that only a limited number of the vast possible joint configurations are used by humans.

The term synergy comes from the Attic Greek word synergia from synergos, meaning "working together". A grasping synergy, thus makes the control of the hand "easier" for the brain. On the other hand, if we consider the human hand as a rigid

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