# SEVENTH FRAMEWORK PROGRAMME
# THEME ICT-2013.9.1
# Challenging current Thinking, FET-Open

# RoboSoft working paper

**Grant Agreement number: 619319**
**Project acronym: RoboSoft**
**Project title: A Coordination Action for Soft Robotics**
**Funding Scheme: Coordination and support action**
**Start date of the project: October 1, 2013**
**Duration of the project: 36 months**
**Project's coordinator: Cecilia Laschi, Scuola Superiore Sant'Anna**

**Deliverable Number: D3.2.1 RoboSoft working paper**
**Due date: September 30, 2014**
**Actual submission date: September 30, 2014**

**WP3 Leader: SSSA – Scuola Superiore Sant'Anna**
**Involved Partners in the WP: ETH Zurich, UOB**

**Project website: [www.robosoftca.eu](http://www.robosoftca.eu)**

Version 5.0, September 2014

## Table of Contents

# 1. Introductory note

## 1.1 Context

The **Future and Emerging Technologies (FET) Open** scheme supports Coordination and Support Actions for creating the best conditions within which FET research can flourish and achieve the transformative impacts to which it aspires. One purpose of such actions fosters the emergence of new research communities involving a broad diversity of disciplines that are expected to: (1) catalyze transformative effects on the communities and practices for high-risk and high-impact research and on the mechanisms to support the global nature of such research; (2) establish new, engaged and risk-taking research communities prepared to develop new and non-conventional approaches for addressing future challenges in science and society.

**Soft robotics** is an interdisciplinary field in robotics linking know-how from material science, mechanical/electrical engineering, control engineering, chemistry, physics, computer science, biology and medicine.

Taking a syntactic approach, "soft robotics" is considered a subset of "robotics" because of its qualification. However, even in its present state, we see that it is actually much more than a mere "subfield" of robotics, where some specific aspects of robotics are investigated in greater detail. Looking at the research community, there are many people that are not from robotics, control, or artificial intelligence, but from material science, continuum physics, soft-matter physics, and will include computational sciences as well. Many of them will not view themselves as belonging to a subfield of robotics. Also, looking at the potential, "soft robotics" is really an overarching, interdisciplinary endeavor, rather than a subfield: it is the combination of these fields that bears the true potential of soft robotics.

There are many differences between soft, and traditional, robotics technologies in term of functional capability, accuracy, adaptiveness, speed and robustness, safety, load capacity and others. Moreover, classical control architectures and standard robotic control tools (e.g. inverse kinematics or predictive control) are usually not directly applicable. New types of control and design paradigms are needed to develop useful soft robots. These could include distributed architectures and a corresponding approach that incorporate various, various machine learning approaches, as well as cognitive modelling.

There is strong growth in the field of soft robotics evidenced by a large increase in the number of publications, special issues in journals, focused sessions and workshops at international conferences, summer schools, EU funded projects and new faculty appointments.

Despite this growth, the soft robotics community is still scattered and there is a need for an efficient network for scientists and roboticists to collaborate on new technologies and scientific paradigms.

**RoboSoft**, the **EU-funded FET-Open Coordination Action (CA) for Soft Robotics** (FP7-ICT-2013-C project #619319), is creating a framework to consolidate the soft robotics community and is enabling the accumulation and sharing of crucial knowledge needed for scientific and technological progress in this field.

## 1.2 Role of the RoboSoft Community

**RoboSoft** (http://www.robosoftca.eu/) started on October 1, 2013 and it is coordinated by Prof. Cecilia Laschi (The BioRobotics Institute, Scuola Superiore Sant'Anna, Pisa, Italy) in partnership with the ETH Zurich (Switzerland) and the University of Bristol (UK).

RoboSoft aims at creating and consolidating a scientific community of roboticists working in the field of soft robotics and at attracting those researchers and developers that might potentially benefit from soft robotics, but are not yet working in the field.

For this objective the RoboSoft Consortium brings together European and international institutions who work in the field of soft robotics to become "members" of the "**RoboSoft Community**" and to take part to the scientific initiatives.

Currently, the RoboSoft Community Members counts 21 institutions and research laboratories (see Annex I of this document for the full list or visits http://www.robosoftca.eu/robosoft-community/community-members for the continuously updated list) whose researchers participate in all the RoboSoft events and activities (plenary meetings, workshops, summer schools, events for cross-fertilization with other scientific communities, joint publications, etc.) and can benefit of the use of the RoboSoft resources, channels and initiatives to promote their research and technological results.

Most importantly, the RoboSoft community members are involved in consultations to discuss challenges and the expected milestones of soft robotics, and to provide research roadmaps for the field. This way the possible supporting actions that should be provided by the European Commission can be identified, in order to generate the body of knowledge and of scientific and technological standards to effectively materialize the potential impact of soft robots, for current societal challenges (industry/manufacturing, new jobs, elderly care, health sector, search and rescue, etc.).

The participation and the contribution of the members to the consultations is reported through the **RoboSoft working papers**, joint publications, and through the book series on soft robotics released at the end of the RoboSoft CA.

This working paper represents the result of the first consultation of the RoboSoft community members held during the First RoboSoft Plenary Meeting (March 31 – April 1, 2014, Pisa, Italy) and during the months after the event.

At the meeting, the community members were divided into 3 Working Groups (WGs) to discuss diverse highly relevant topics, and in particular related to:

- **Smart Materials, Soft Actuators and Soft Sensors** (WG coordinated by Barbara Mazzolai);
- **Control Architectures and Paradigms for Soft Robots** (WG coordinated by Helmut Hauser);
- **Energy Storage, Harvesting Soft Devices and Stretchable Electronics** (WG coordinated by Jamie Paik).

The working paper paragraphs are organized following a series of questions prepared by the RoboSoft Coordinator, the partners and the Advisory Board, to be used by the WGs coordinators to guide the discussion. After parallel brainstorming sessions of the WGs, all the participants re-joined and the results were presented in a wrap-up session followed by a plenary discussion.

The consultation was targeted to the soft robotics community with the aim to identify major challenges for research and technologies in soft robotics, as well as new topics and instruments to be implemented for FET initiatives in the next funding phase to tackle them.

Experts were therefore invited to present an analysis of current technologies and their limitations, of the grand challenges and of what research topics should be included in the next work-programme. They were also asked to propose preferred means to implement the research (whether the projects should be big or small, or whether networking or coordination should be fostered) as well as which role should play high-tech companies, SMEs, large industries in the participation in frontier research.

## 1.3 General comment. Soft Robotics: a definition is needed

There is a shared requirement of a consolidated **definition of soft robotics** and of what can be defined as “soft”.

“Soft” may refer to the structural compliance of a robot, which means that the softness is generated by the geometrical arrangements of hard materials – so that structural strains are magnified compared with local material deformation (e.g. compliant mechanisms).

Nevertheless, these robots still have major limitations due to the complexity of their electromechanical bodies and the complexity of their control system, especially during manipulation of objects and materials that are soft, or with a particular shape.

On the other side, “soft” may refer to an inherent material compliance that involves bulk material properties – including soft matter (e.g. elastomers, polymers, gels; see Ewoldt, 2014). In this second approach, which is mostly shared within the RoboSoft Community, the robots are made of soft materials that undergo large deformation during their normal use.

In the first case the control is embedded in the body made of different materials and structures, while in the second case the control is embedded directly in the materials itself (as described also in Pfeifer and Bongard, 2007).

Many of these traits are found in natural organisms so there is a mutually beneficial relationship between studies of biological systems and soft robotics. The vast majority of animals are soft bodied, and even animals with stiff skeletons are predominantly made of soft materials. For example, the human skeleton typically contributes only 11% of the body mass of an adult male, whereas skeletal muscles contributes an average 42% of body mass. Even if bones, with a Young’s Modulus of 20-30 GPa, are rigid structures rather than a compliant material, they are still “soft” compared to metal structures used in rigid robots.

Although findings from research on natural organisms morphology and function has strong implications for soft robotics, this field is not the same as biorobotics: even if bio-inspiration is important, it shouldn’t become a limitation. What is important is that bio-inspiration can be a rich source of solutions for a smarter design and for a better development of soft robots.

For example, it is noticeable that completely soft animals tend to be small because it is difficult for them to support their own body weight without a skeleton. All of the large soft invertebrates are found either in water (squid and jellyfish) or underground (giant earthworms), where their body is supported by the surrounding medium. Additionally, the high deformability and energy-absorbing properties of soft tissues prevent them from exerting large inertial forces and limit how fast soft animals can move from place to place (Kim et al. 2013). This does not prevent different parts of the body from moving quickly under low loads. These considerations make it likely that terrestrial soft robots bigger than a mouse or rat will incorporate stiff components for better performance, taking advantage of high flexibility. Similar limitations would apply to soft robots and necessitate careful selection of materials to match size as well as function. Another important aspect of soft robotics is that soft technologies can be more easily combined with tissue engineering to create hybrid systems for various applications (i.e. medical, see also Kim et al. 2013).

One of the major advantages of soft robots is that they can safely interact with humans and natural environments, so generally speaking, a possible definition of Soft Robotics could be "A branch of Robotics that encompasses solutions that interact with environment relying on inherent or structural compliance".

In the following some examples of deformable structures are provided and an attempt is made to classify them as structural or inherently compliant, under the big umbrella of soft robots.

The first one is a gripper made of joints and flexible materials (the design is inspired by fin tails, source: Festo MultiChoiceGripper, http://www.festo.com/cms/en_corp/13706.htm, Figure 1) and it grasps without damaging the objects because the shape of the whole mechanism changes (but not of the bulk material). Therefore, considering the surface of the gripper even though the materials with which it is made are rigid, it undergoes 'large' deformations when interfacing a delicate object like an egg and that is why it is more 'safe' and it does not break it, i.e. it conforms to the 3D structure of the egg.

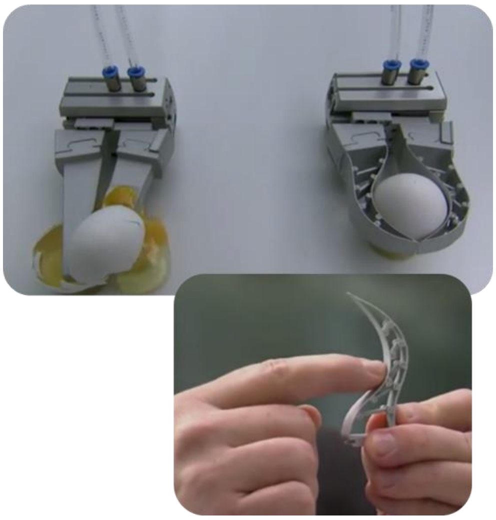

**Figure 1 Festo MultiChoiceGripper**

The second case is the approach of granular jamming (source: Brown et al, PNAS 2010, Cornell Univ). A gripper handles objects without damaging them because the shape at gripper/object interface changes. This can be interpreted as a "quasi-inherent compliance" where the flexible "shell+granular medium+vacuum" can be considered as a whole.

**Figure 2 JamBot Universal Jamming Gripper, Brown et al, PNAS 2010**

The third one represents the “inherent compliance”, in fact the robotic hand holds objects without damaging them because the shape of the bulk material changes. This approach uses soft pneumatic fingers (source: Worcester Polytechnic Inst, ,2013, http://www.youtube.com/watch?v=ebBWUzIXsms, Figure 3).

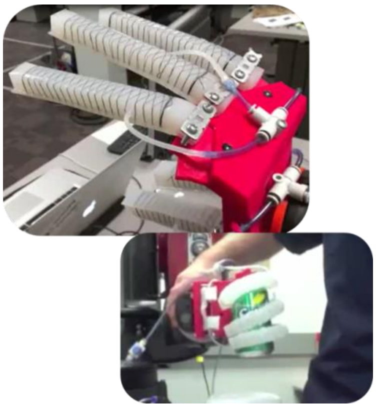

**Figure 3 Soft pneumatic fingers, Worcester Polytechnic Inst, 2013**

In a fourth case represents still “inherent compliance” through a miniaturized gripper built from extremely soft material like hydrated gel. These soft actuators can gently manipulate objects both in air and in liquid solutions (source: Palleau et al, 2013).

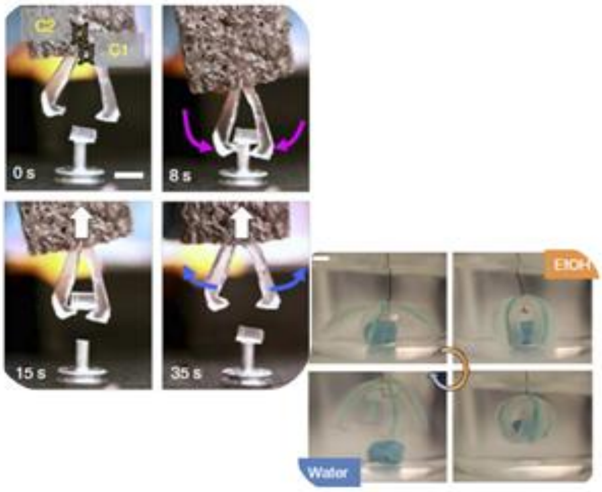

**Figure 4 Soft tweezers (left) and soft gripper (right) made from hydrogels handling small parts of polydimethylsiloxane. Image from Palleau *et al*, Nature Comm., 2013.**

On the basis of the above statements, the RoboSoft community proposed and agreed on the following definition of Soft Robotics:

> ***"Soft robot/devices that can actively interact with the environment and can undergo 'large' deformations relying on inherent or structural compliance"***

## 2. Main scientific and technological challenges for frontier research in soft robotics that need to be tackled in the next 10-20 years, nature of the challenges (vision-driven and high-risk, embryonic or foundational), and bottlenecks that need to be addressed in the medium term

### Smart Materials, Soft Actuators and Soft Sensors

At the light of recent significant improvements in the field of smart materials, soft actuators, and soft sensors, the design and development of the body structure of a robot can be properly carried out by adapting known technologies. However in a long term vision, there is a strong need for well-defined design rules, such as how to build a robot based on specific tasks, as well as of new manufacturing technologies and processes.

Additive manufacturing and 3D rapid prototyping, for instance, should be adapted for integrated processes of new soft/functional materials. The range of commercial soft printable materials, which is currently very limited, should be substantially enriched with actual exploitable soft materials. In addition there is a need for benchmark data on already available soft materials, for both physical and chemical characteristics.

Currently available compliant, soft materials that are able to change own intrinsic features dynamically (including geometrical, mechanical, chemical and electrical properties) are not well characterized and are generally not sufficiently robust for deployment in active robots. Therefore, one of the major challenges is the development of materials that allow adaptability, conformability and softness and that, at the same time, remain robust and do not degrade in the environment. These new soft actuation systems need to be developed with sufficient power density to make them practical. Another interesting challenge is to make soft responsive materials (for example based on functional, hierarchical and/or micro & nanostructured composites) capable of working as actuators and sensors at the same time and to serve as computational resource that can be exploited in the context of control, e.g. as a pure physical feedback control loop. Considering the potential advantages in exploiting intrinsic material properties, it would be also very useful to develop design strategies to extract maximum benefit from the intrinsic properties.

### Control Architectures and Paradigms for Soft Robots

While the exploration of smart materials, soft actuators and sensors is striving, the research on appropriate control paradigms is still struggling to keep up. Most of the currently used control approaches applied to soft robots (if they are actively controlled at all) are either very simple and rely on classical theoretical control approaches or they are based on the approach that "somehow" control is implicitly included in the morphology of the soft machines (e.g., the control on how to shape the balloon gripper in Figure 2). The reason is that soft robotic systems are highly complex and non-trivial to control. Typical properties are strong nonlinearities, a high-dimensional (potentially infinite) state space, bifurcation behavior, underactuation, and delayed communication all of which are difficult to handle individually and constitute a serious problem when combined.

There exists some work that uses classical control approaches pushed to its limits in trying to cope with soft structures, but it is clear that we need substantial extensions of these classical tools. Especially, more research in the area of over-redundant and under-actuated systems and in that of soft material modelling is required. In particular, a unified modelling framework is needed, able to represent the *passive dynamic behaviour* of both traditional elastic materials and the next generation of active soft materials.

In addition, we even need a fundamentally different approach in control. One promising concept is called morphological computation (also sometimes referred to morphological control when the involved computation is used for controlling the system, see Füchslin et al. 2013), where the computation required for the control is (partly) outsourced to the physical body of the robot. It has been shown that a “clever” morphology can simplify drastically the control of the system. While there exist numerous examples that demonstrate the validity of this approach (see Pfeifer and Bongard 2007) there exists very little theoretical work so far (see Hauser et al. 2011 and 2012). It will be a big challenge to define a unifying theoretical framework for morphological computation that is able to describe, model and help to execute control for generally soft structures. In the same context it will be highly beneficial to derive design guidelines to help us to build soft robots. Furthermore, as the complexity of soft systems grows it will be necessary to include in such a framework a distributed control paradigm that is able to cope with different time horizons and to coordinate distributed actions along the body and hierarchical structures, a concept usually referred to "orchestration." Another big challenge in the context of morphological computation is to understand how much of the computational load (and which type of computation) should and could be offloaded to the physical body (typically refer to as the "embodiment trade-off", i.e. efficiency vs. flexibility, etc.).

As research on smart materials will provide us eventually with tools to let us grow and self-assemble soft-robotic structures we are facing another challenge with respect to control. We have to develop and incorporate control paradigms that are able to cope with such "design by emergence." For example, as the behavioral dynamics of an embodied system is a result of interactions among a particular control structure, body dynamics and the environment, the term "guided self-organization" may become important, i.e. how to guide a self-organizing system towards desirable behaviors, while maintaining its non-deterministic dynamics with emergent features (Nurzaman et al., 2014). The notion of embodiment itself has been expanded to include soft materials and body morphology (Pfeifer et al. 2014)

Finally, we believe the development of any control technique for soft robots will benefit from an interdisciplinary approach. It will be a challenge to inspire communities outside robotics, e.g., biology, physics, material science, neuroscience, information and computer science, etc. to contribute novel ideas. RoboSoft is one tool working to take this challenge.

Soft robotics also raises high challenge for modelling. In fact, even if there exists well established theories as mechanics of continuous media, in robotics we need to extract minimal models exploitable for analysis, control and to help goal oriented design in particular toward control. In this respect, it will require a big effort to build generic modelling tools suited to soft robotics. As it has been done in conventional robotics, where rigid-body mechanics are used to build a general modelling framework, we need in soft robotics a similar approach that is based on continuous mechanics and that addresses the basic issues of robotics: geometry, kinematics, dynamics.

### Energy Storage, Harvesting Soft Devices and Stretchable Electronics

Stretchable and soft electronics, especially regarding energy storage or harvesting are in their infancy to be directly adapted into conventional systems. Due to the fast evolutions of diverse robots with soft material bodies, the need for more complete softness is increasing. As mentioned in the previous paragraphs, larger communities are searching for solutions toward active components (actuators and sensors). However, in order to achieve more comprehensive softness, it is imperative to have soft electronics such as power source, energy storage, energy harvesting devices that would eventually be integrated into the soft robot body via stretchable circuits.

The challenge of achieving a practical solution remains as current efforts (low voltage OFET, hybrid energy harvesters, chemical reaction) are limited by the effectiveness (quantity of energy, applicability, duration of storage, repeatability etc).

It is also important to note that via points and interconnections between electronics, robot bodies and the circuitries must be considered during the hardware integration: the connections between active and passive parts and electronics need to be robust and soft. One approach is to standardize soft components (to serve as a library of components) so that the interconnections remain simple and straight forward without additional modification but also it is important to define new non-conventional fabrication processes allowing scalability of individual parts and mass-production of new stretchable and soft electronics elements.

## 3. Which could be the “killer applications” for soft robotics?

Soft robots can interact and operate in environments that are difficult for rigid-structure robots; in particular they are generally safe and hard to damage.

Soft robotics technologies have the potential to make a strong impact in applications requiring **adaptive interaction** with objects and with the environment, and where the robot can exploit a **shape guided behaviour** (demonstrating that morphology is crucial to simplify control (i.e., the previously mentioned concept of morphological computation).

The major fields that may represent “**killer applications**” for soft robots are:

– **Medical field**: surgical tools (e.g. probes, endoscopes, etc.), being more flexible and compliant means they are safer because they are able to adapt to human bodies, and to access and operate in small domains; Band-Aid sensors with its own electronics; rehabilitation/prosthetics (soft-hard wearable robotics). However, compliance might be negotiated with accuracy for the considered field, so that direct application of soft robots is not trivial; prostheses that allow a more natural movement and are more comfortable to carry; HRI in a medical context (e.g., autistic children, Alzheimer, etc.)

– **Exploration in unstructured environment** (underwater, space, catastrophic scenarios): soft robots may have more capabilities to adapt to the environmental changing conditions and are potentially more energy efficient in locomotion and, therefore, potentially more autonomous;

– **Wearable robotics and textile engineering** (close to skin or covering surfaces); adaptive robotic body with embedded functionality;

- **Industrial field**: especially in all the cases in which interaction with humans is required, or where it is necessary **handling / assembly / manipulation** of fragile products;
- **Manufacturing food field**: such for example to test ripeness of fruits, to handle delicate products;
- **Agriculture**: especially where delicate manipulation is required;
- **Social oriented-technology**: soft robots have a more human-like interaction because of softness;
- **Gaming industry**: soft robots are safe to interact (kids).

## 4. Research topics to be included in the next work programmes to foster research addressing the challenges identified

General topics that should be included:

- **new manufacturing processes for soft robotics** (e.g. 3D printing of functional/soft materials);
- **novel paradigms/principles for robots design** (including basic research challenges for actuators, sensors, smart materials, control and their integration in full systems);
- modelling, and development of (bioinspired) **functional/active materials** for targeting high-level integration of actuation (distributed/integrated actuators) and sensors (sensor morphology) with control. including self-healing, self-repairing and self-adapting systems;

There should also be a focus on soft robotic applications, and self-assembling for **safe HRI**, **safe soft wearable robotics** and **robotics for unstructured environments**.

## 5. Funding 'instruments' the EC should employ in order to support the research in soft robotics, and to be useful to maximize the opportunities and materialize the huge potential impact of soft robotics technologies (small projects < 3M€ - 3yrs or large projects ~4-6 M€ - 4-5 yrs., coordination actions, support of stakeholders, specific actions, specific course, competitions, new infrastructures…)

Most contributors consider that all of these instruments are potentially very useful for supporting soft robotics. They are indicated for different challenges depending from the complexity: for example large projects could be useful to fund new manufacturing technologies or to integrate various aspects of soft robotics (i.e., control, actuators, sensors, materials, etc.) into robotics systems.

Therefore, **a good mixture of both small and large projects is necessary** as they can serve different purposes and can address realistic “simple” goals in combination with long term goals.

**Small “Flagship” or IP-like projects** can line up also other ideas for new small projects to provide deeper investigation on certain level and to look at one specific aspect.

It is also **important to get industry more involved** and to be more attractive to the industries.

There is also the need for **robotics infrastructures** dedicated to soft robots with real world test beds to provide engineering support for testing demonstrators, their performance and robustness, and to assess robotics metrics and benchmarks. Such infrastructures could represent facilities for open access for academia and industry and for end users, where you can find the structure (devices, professional tools, instruments, facilities) and the better know-how (experts, scientists/researchers/roboticists).

Another important instrument to be promoted, both at European and global level, is the support to joint initiatives for benchmarking, such as public robot competitions.

Together with research and innovation projects, it will be very important to continue **specific coordination and supporting actions** and implement tools to organize activities/events to open and push soft robotics, as well as to continue consultation to define following calls.

The instrument of ITNs will be important as well, since researchers that are trained in the highly interdisciplinary approach of soft robotics will be required to tackle the upcoming challenges of the next generation.

## 6. International collaboration and synergies outside the EU necessary for the research, organisations and exploitation of results

Most contributors, both from European and non-European countries, consider the collaboration with global partners very important for the research activities and for the exploitation of the research results. Therefore, promoting calls dedicated to **International R&D programmes and coordination actions** with countries active in soft robotics (e.g. USA, Japan, etc.) will be useful.

In addition, it would help to enlist the support of **major Science Foundations,** together with opening **new IEEE societies** (while it is only 2 years old, the Robotics and Automation Society Technical Committee on Soft Robotics, has already 426 members: as the Technical Committee grows so fast, it can be used as a reason why in the future an IEEE society may be necessary).

In addition to promoting and supporting existing academic journals dedicated to the field (e.g., *Soft Robotics*, Mary Ann Leibert, Inc. publishers) the creation of **new International ISI Journals** will help to provide new channels for disseminating soft robotics technologies.

## 7. Roles of high-tech companies, SMEs, large industries in the participation in frontier research

It is very important and timely to get industries (high-tech companies, SMEs, large industries) more involved and connected with research laboratories working in the field of soft robotics to get input on the directions relevant to future ICT markets and thus to reduce the gap towards commercialization of soft robots.

The participation of industries in research activities would serve to provide ideas for real applications for soft robots and would open the possibility to look at new fields of applications and identifying overlooked needs.

Soft robots have the potentiality to open new fields and new markets and to reduce production costs, but enabling technologies are needed (e.g., material for 3D printers, production tools, injection moulding). High-tech companies participating in research activities would serve for specific tasks, such as the development of hardware needed, system integration and field testing, and in general for the exploitation of the results at the end of the projects.

Specific resources could serve to support start-up of new spin-off companies in the final stage of a project, not only to provide services to the new company but also as a seed-capital to be invested if the project achieves the expected results.

## 8. Annex I: RoboSoft Community Members and PI (March 2014)

1. **Tufts University** - Barry Trimmer
2. **Center for Micro-BioRobotics IIT@SSSA** - Barbara Mazzolai
3. **Heron Robots** - Fabio Bonsignorio
4. **Institut de Recherche en Communications et Cybernétique de Nantes** - Frederic Boyer
5. **UZH - AI Lab** - Helmut Hauser
6. **University of Tsukuba - Flexible Robotics Lab** - Hiromi Mochiyama
7. **Edinburgh University** - Adam A. Stokes
8. **Tallin University** – Centre for Biorobotics - Maarja Kruusmaa
9. **Cornell University** - Robert Sheperd
10. **Seul National University** - KyuJin Cho
11. **Osaka University** - Koh Hosoda
12. **EPFL - Laboratory of Intelligent Systems** - Dario Floreano
13. **EPFL - Reconfigurable Robotics Laboratory** - Jaimie Paik
14. **Carnegie Mellon University** - The Robotics Institute - Yong-Lae Park
15. **The Chinese University of Hong Kong** - Michael Wang
16. **University of Tokyo** - Takao Someya
17. **Fraunhofer IZM** - Thomas Loher
18. **University of Wollongong** - Gursel Alici
19. **Vrije Universiteit Brussel** - Francis Berghmans
20. **Max Planck Institute for Intelligent Systems** - Metin Sitti
21. **Università degli Studi di Trento** - Massimiliano Gei

## 9. Annex II: Contributors (in alphabetical order for each working group)

### Smart Materials, Soft Actuators and Soft Sensors Working Group

1. Addinall Raphael, Fraunhofer IPA
2. Baldoli Ilaria, The BioRobotics Institute
3. Beccai Lucia, Italian Institute of Technology
4. Brodbeck Luzius, ETH Zurich
5. Calabrese Luigi, University of Trento
6. Cianchetti Matteo, The BioRobotics Institute
7. Conn Andrew, University of Bristol
8. Follador Maurizio, Italian Institute of Technology
9. Gei Massimiliano, University of Trento
10. Ghilardi Michele, University of Pisa
11. Jeronimidis George, University of Reading
12. Knoop Espen, University of Bristol
13. Licofonte Alessia, The BioRobotics Institute
14. Manti Mariangela, The BioRobotics Institute
15. Margheri Laura, The BioRobotics Institute
16. Mattoli Virgilio, Italian Institute of Technology
17. Mazzolai Barbara, Italian Institute of Technology (*WG Coordinator*)
18. Must Indrek, University of Tartu
19. Poldsalu Inga, University of Tartu
20. Popova Liyana, Italian Institute of Technology
21. Ranzani Tommaso, The BioRobotics Institute
22. Russo Sheila, The BioRobotics Institute
23. Sadeghi Ali, Italian Institute of Technology
24. Schubert Bryan, EPFL
25. Sheperd Robert, Cornell University
26. Signori Francesca, Italian Institute of Technology
27. Simaite Aiva, LAAS
28. Sinibaldi Edoardo, Italian Institute of Technology
29. Tonazzini Alice, Italian Institute of Technology
30. Tramacere Francesca, Italian Institute of Technology

### Control Architectures and Paradigms for Soft Robots Working Group

1. Bonsignorio Fabio, Heron Robots
2. Boyer Frédéric, Ecole des Mines de Nantes
3. Cacucciolo Vito, The BioRobotics Institute
4. Calisti Marcello, The BioRobotics Institute
5. Cominelli Lorenzo, Centro E. Piaggio
6. Corucci Francesco, The BioRobotics Institute
7. Giorelli Michele, The BioRobotics Institute
8. Hauser Helmut, UZH (*WG Coordinator*)
9. Iida Fumiya, ETH Zurich

10. Laschi Cecilia, The BioRobotics Institute
11. Surya Girinatha Nurzaman, ETH Zurich
12. Mazzei Daniele, Centro E. Piaggio
13. Renda Federico, The BioRobotics Institute

### Energy Storage, Harvesting Soft Devices and Stretchable Electronics Working Group

1. Frediani Gabriele, Queen Mary University of London
2. Giorgio-Serchi Francesco, The BioRobotics Institute
3. Mintchev Stefano, The BioRobotics Institute
4. Ostmann Andreas, Fraunhofer IZM Berlin
5. Paik Jamie, EPFL (*WG Coordinator*)
6. Rossiter Jonathan, University of Bristol
7. Sergi Pier Nicola, The Biorobotics Institute
8. Stokes A. Adam, The University of Edimburgh
9. Tricarico Serena, The BioRobotics Institute

## 10. Annex III: References

– Brown, E., Rodenberg, N., Amend, J., Mozeika, A., Steltz, E., Zakin, M. R., Lipson, H. and Jaeger, H. M. (2010) Universal robotic gripper based on the jamming of granular material, Proceedings of the National Academy of Sciences (PNAS), 107(44), pp.18809-18814.

– Ewoldt, R.H. (2014) Extremely soft: Design with rheologically-complex fluids, Soft Robotics, 1(1) 12-20 (Invited review for inaugural issue).

– Füchslin, R. M., Dzyakanchuk, A., Flumini, D., Hauser, H., Hunt, K. J., Luchsinger, R. H., Reller, B., Scheidegger, S. and Walker, R. (2013) Morphological computation and morphological control: steps toward a formal theory and applications. Artificial Life, 19, 9-34.

– Hauser, H., Ijspeert, A., Füchslin, R., Pfeifer, R. and Maass, W. (2011) Towards a theoretical foundation for morphological computation with compliant bodies, Biological Cybernetics, Springer Berlin / Heidelberg, 105, 355-370.

– Hauser, H., Ijspeert, A., Füchslin, R., Pfeifer, R. and Maass, W. (2012) The role of feedback in morphological computation with compliant bodies, Biological Cybernetics, Springer Berlin / Heidelberg, 106, 595-613.

– Kim, S., Laschi, C., Trimmer, B. (2013) Soft robotics: a bioinspired evolution in robotics. Trends Biotechnol. 31(5):287-94.

– Nurzaman, S.G., Yu, X., Kim, Y., Iida, F. (2014) Guided Self-Organization in a Dynamic Embodied System Based on Attractor Selection Mechanism. Entropy, 16, 2592-2610.

– Pfeifer R. and Bongard J. C. (2007) How the body shapes the way we think: a new view of intelligence, Cambridge, MA: MIT Press.

– Pfeifer, R., Fumiya, I., Lungarella, M. (2014) Cognition from the bottom up: on biological inspiration, body morphology, and soft materials, Trends in Cognitive Sciences, Volume 18, Issue 8, 404 – 413.

– Palleau, E., Morales, D., Dickey, M. D., Velev O. D. Reversible patterning and actuation of hydrogels by electrically assisted ion printing Nature Comm., 4 (2257)

## 11.RoboSoft Consortium and Contacts

### RoboSoft Consortium

Scuola Superiore Sant'Anna, The BioRobotics Institute (Pisa, Italy)
Project coordination and management, organization of the scientific community and initiatives, dissemination and outreach.
Key members: Cecilia Laschi, Paolo Dario, Matteo Cianchetti, Laura Margheri
http://sssa.bioroboticsinstitute.it

Swiss Federal Institute of Technology Zurich (Eidgenössische Technische Hochschule Zürich, Switzerland)
Project web portal and online tools setup and management; support and involvement in coordination action initiatives.
Key members: Fumiya Iida, Surya Girinatha Nurzaman, Luzius Brodbeck
https://www.ethz.ch/en.html

University of Bristol (Bristol, United Kingdom)
Dissemination and engagement activities and contacts with stakeholders; support and involvement in coordination action initiatives.
Key members: Chris Melhuish, Jonathan Rossiter
http://www.bris.ac.uk/

### RoboSoft Contacts

Project Coordinator: Prof. Cecilia Laschi
The BioRobotics Institute, Scuola Superiore Sant'Anna
viale Rinaldo Piaggio 34, 56025 Pontedera (Pisa), Italy
Tel. +39 050 883486, Fax: +39 050 883497, Mobile: +39-348-0718832
Email: cecilia.laschi@sssup.it

RoboSoft Scientific Secretariat and Management
Dr. Laura Margheri
The BioRobotics Institute, Scuola Superiore Sant'Anna
viale Rinaldo Piaggio 34, 56025 Pontedera (Pisa), Italy
Tel. +39 050 883395, Fax: +39 050 883399, Mobile: +39-347-1329605
Email: laura.margheri@sssup.it

**http://www.robosoftca.eu/**