RoboSoft CA
“A Coordination Action for Soft Robotics”

First Community Plenary Meeting
March 31 – April 1, 2014
Scuola Superiore Sant’Anna, Pisa, Italy

Welcome!
Tuscany, Italy

A Country and a region with an extraordinary wealth of artistic and cultural heritage, deep attention to preserving the environment and social relations, excellent climate, good food and a relaxed, friendly atmosphere favoring long and active life (highest life expectancy in the world for males: 80.4 years; second highest for women: 84.9 years)
Tuscany: the Land of Robot(ic)s
The University and Research System in Pisa

Scuola Normale Superiore
Established 1810
150 professors
283 students

University of Pisa
Established in 1343
2,100 professors
50,000+ students

Scuola Superiore Sant’Anna
Established in 1987
100 professors
220 students

CNR
National Research Council
15 Research Institutes
About 1,500 researchers

INFN
National Institute of Nuclear Physics
About 300 researchers
Eminent scientists and statesmen who studied and worked in Pisa

LEONARDO FIBONACCI  
(1170 - 1250)  
Mathematician

GALILEO GALILEI  
(1564 - 1642)  
Scientist, mathematician and philosopher

Giosuè Carducci  
(1835 - 1907)  
Nobel Prize in Literature 1906

ENRICO FERMI  
(1901 - 1954)  
Physicist  
Nobel Prize in Physics 1938

CARLO RUBBIA  
(1934)  
Physicist  
Nobel Prize in Physics 1984

CARLO AZEGLIO CIAMPI  
(1920)  
President of the Italian Republic

ENRICO LETTA (1966)  
Former Prime Minister of Italy
Piazza dei Cavalieri

We are here
Introduction to Soft Robotics and RoboSoft CA

Cecilia Laschi
RoboSoft CA Coordinator

The BioRobotics Institute
Scuola Superiore Sant’Anna

First Community Plenary Meeting
March 31 – April 1, 2014
Scuola Superiore Sant’Anna, Pisa, Italy
Why RoboSoft?

* Soft Robotics is a young emerging area of research and technological development
* Soft Robotics stems from robotics, from one side, and AI, from another side
* Soft Robotics is at the merge of many disciplines and technologies
* Soft Robotics state of the art is increasingly rich, not only with bioinspired solutions, and applications are coming in many fields
* The Soft Robotics community is growing and active, and needs coordination to synergise and consolidate
Soft Robotics: a working definition

Variable impedance actuators and stiffness control
* Highly flexible (hyper-redundant or continuum) robots
* High number of tigid links, multi-axis joints

Use of soft materials in robotics
* Robots made of soft materials that undergo high deformations in interaction
* Soft actuators and soft components
* Control partially embedded in the robot morphology and mechanical properties

Soft Robotics stems from robotics, from one side...

Robotics
From industrial to service robotics
Robots outside factories...

...having to operate in the real world, they need to manage uncertainties and to react to changes in the environment.

Biological systems represent an excellent source of inspiration.

- **Rescue**
- **Underwater**
  - Unstructured environment
  - Perception
  - Reactive behaviour
  - Shared workspace with human beings

- **Space**
Soft Robotics stems from robotics, from one side...

Robotics
From industrial to service robotics

Soft robotics
Bioinspired soft robots


Inchworm-like locomotion, for a flexible endoscope

Examples of state-of-the-art soft robots

Non-biomimetic approaches

Universal robotic gripper based on the jamming of granular material (Corneill University)


Jamming robot (iRobot)

Soft Robotics stems from robotics, from one side, and AI, from another side.
Any cognitive activity arises from the interaction between the body, the brain and the environment (embodiment).

Adaptive behaviour is not just control and computation, but it emerges from the complex and dynamic interaction between the morphology of the body, sensory-motor control, and environment (Embodied Intelligence).

=> A new, soft, bodyware is needed

A biomimetic soft robot with embodied intelligence

Soft robotics is not just a new direction of technological development. The use of soft materials in robotics is going to unhinge its fundamentals.

Soft robotics is going to stand as a novel approach to robotics and artificial intelligence, and it has the potential to produce a new generation of robots, in the support of humans in our natural environments.
Soft Robotics is at the merge of many disciplines and technologies

From biology to robotics

## From biology to robotics

| Biological Specification 

(Octopus vulgaris) | Robotic Solution and Performance |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transverse Muscles</strong></td>
<td></td>
</tr>
<tr>
<td>Design Arrangement</td>
<td></td>
</tr>
<tr>
<td><strong>Mechanical performance</strong></td>
<td>70% of arms mean elongation corresponding to 23% of diameter reduction</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Longitudinal Muscles</strong></td>
<td></td>
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<tr>
<td>Design Arrangement</td>
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<tr>
<td><strong>Mechanical performance</strong></td>
<td></td>
</tr>
<tr>
<td>Max Pulling Force</td>
<td>Mean Pulling Force</td>
</tr>
<tr>
<td>49.8N @ 400mm (m=1600g)</td>
<td>40 N with arm length 400mm (~100g)</td>
</tr>
<tr>
<td>26.8 @ 200mm (m=476g)</td>
<td></td>
</tr>
<tr>
<td>Grasp Point Position</td>
<td>0.75 of total arm length</td>
</tr>
<tr>
<td>Nerve Cord Arrangement</td>
<td></td>
</tr>
<tr>
<td>Design Arrangement</td>
<td>Sinusoidal arrangement at the arm rest length while has a distension during the elongation</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Patent pending</td>
<td></td>
</tr>
</tbody>
</table>

- Input to model for the design of the SMA:
  - NiTi Alloy mechanical properties
  - Wire diameter
  - Average spring diameter
  - Number of coils
  - Heat treatments

- Longitudinal cables
- Sheaths to reduce friction and avoid silicon damages
- Calibration parameters ($t$, $F$)

- End effector position and active arm length

- Wire sinusoidal arrangement
Soft Robotics is at the merge of many disciplines and technologies: **soft actuators**

**Development of the soft actuator for transverse contraction**

1 second of 600 mA direct current and then 50% duty cycle pulse current

6 SMA springs:
- 0.2 mm Flexinol® wire diameter
- \( <D>/d = 6 \) (cycle life parameter)
- Spring internal diameter = 1 mm

Silicone / braided sleeve:
- External diameter = 28mm
- Internal diameter = 20mm
Soft Robotics is at the merge of many disciplines and technologies: **fluido-dynamics**

### Pulsed-jet propulsion in cephalopods

How does a cephalopod swim?  
How do we translate this into a soft robot?

Soft Robotics is at the merge of many disciplines and technologies

Modelling and control

- The cables are embedded inside the body of the soft robot
- They exert a load proportional to the cable tension and to the curvature and it is directed toward the centre of the curvature

Inverse Kinetics: Neural Networks (NN) or Jacobian Method (JM)?

Tip Position

Cable Forces

2-D Space 2 Cables

Defective Model

<table>
<thead>
<tr>
<th>Method (Cost)</th>
<th>Statistic(s) Index</th>
<th>ERR/L [%]</th>
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</thead>
<tbody>
<tr>
<td>JM (351ms)</td>
<td>Mean</td>
<td>1.30</td>
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<tr>
<td></td>
<td>Std</td>
<td>0.55</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>2.62</td>
</tr>
<tr>
<td>NN (0.125ms)</td>
<td>Mean</td>
<td>0.75</td>
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<tr>
<td></td>
<td>Std</td>
<td>0.68</td>
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<td></td>
<td>Max</td>
<td>3.51</td>
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<table>
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<th>Method (Cost)</th>
<th>Statistics Index</th>
<th>ERR/L [%]</th>
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<tbody>
<tr>
<td>JM (351ms)</td>
<td>Mean</td>
<td>0.27</td>
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<tr>
<td></td>
<td>Std</td>
<td>0.03</td>
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<tr>
<td></td>
<td>Max</td>
<td>0.32</td>
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<tr>
<td>NN (0.125ms)</td>
<td>Mean</td>
<td>0.73</td>
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<tr>
<td></td>
<td>Std</td>
<td>0.55</td>
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<tr>
<td></td>
<td>Max</td>
<td>3.1</td>
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</table>


octopus
Soft Robotics is at the merge of many disciplines and technologies

The initial challenge: can we build robots with soft materials?

Soft Robotics applications

Biomedical applications: endoscopy, assistance to elderly and disabled people
Application of OCTOPUS technologies in surgery

http://www.stiff-flop.eu/index.php/home
The STIFF-FLOP robotic manipulator

STIFFness controllable Flexible and Learn-able manipulator for surgical OPerations

Trocar port
Abdominal wall

External sheath (diameter: 32 mm)
Granular jamming stiffening channel (diameter: 8 mm)
Flexible fluidic actuators (chamber radius: 4 mm)

WWW.STIFF-FLOP.EU

The initial challenge: can we build robots with soft materials?

Soft Robotics applications

Biomedical applications: endoscopy, assistance to elderly and disabled people

Realistic simulators of body parts
Realistic larynx simulator

Artificial biomimetic device mimicking the principal functions of a larynx by replicating its main structures and material properties.

Cover: Epithelium and Superficial Lamina Propria
Vocal Ligament: Intermediate and Deep Lamina Propria
Body: Vocal Muscle

Electro- magneto- rheological fluids
Pneumatic actuation
Cable driven actuation system

In collaboration with University of Pisa, Cisanello Hospital, Prof. Ursino
The initial challenge: can we build robots with soft materials?

Soft Robotics applications:
- Marine applications
- Realistic simulators of body parts
- Biomedical applications: endoscopy, assistance to elderly and disabled people
- Marine applications
Soft Robotics for marine applications

PoseiIDrone

* Marine ‘soft’ robot
* Can operate in contact with the sea bottom or the manufactures to explore
* Locomotion and grasping capabilities

Fondazione Livorno, 2012 – 2015
PoseiDRONE: a Soft Robot for a novel generation of Underwater Vehicles
The initial challenge: can we build robots with soft materials?

Soft Robotics applications:

- Biomedical applications: endoscopy, assistance to elderly and disabled people
- Realistic simulators of body parts
- Marine applications
- Manufacturing, Agriculture
- More to come!
Soft Robotics: a growing research field at international level

Figure 2: Total number of papers by year with the words "soft robotics" in title, abstract or keywords. (Source: Scopus)

Papers ("soft robotics" in title, abstract or keywords, source: Scopus)

Papers ("Soft Robotics" in Topics, source: ISI)

Special issue on "Soft Robotics" of Advanced Robotics 26(7), 2012

Special issue on "Soft Robotics" of Actuators
Soft Robotics: a growing research field at international level

Events

* Swiss-Japan Joint Seminar on "Soft Robotics: Morphology, materials, and functionalities", University of Tokyo, June 20-23, 2010
* Special session on “Soft Robotics” at FET11 conference, Budapest, May 4-6, 2011
* Workshop at the IEEE International Conference on Advanced Robotics (ICAR 2011),
* 4 organized session on related topics at IEEE International Conference of Robotics and Automation (ICRA 2012).
* ETH Summer School on “Soft Robotics”, Zurich, Switzerland, 2012 & 2013
* IEEE IROS 2013 Workshop on “Soft Technologies for Wearable Robots”
* IEEE ICRA 2014 Workshop on “Soft and Stiffness-Controllable Robots for Minimally Invasive Surgery”
Soft Robotics: a growing research field at international level

- RAS TC on Soft Robotics
- Co-Chairs: Fumiya Iida, Cecilia Laschi, Akio Ishiguro, Robert Wood

http://www.softrobotics.ethz.ch
A Coordination Action for Soft Robotics is extremely necessary and timely in the current landscape of robotics and biorobotics to endorse the rapid development of this new area at the merge of engineering and science and its community and to exploit the challenging potentiality of the use of soft technologies for the future generation of machines.

A common forum will help soft robotics researchers to combine their efforts, to maximize the opportunities and to materialize the huge potential impact.

On the other hand, leaving the soft robotics community scattered would waste its potential for scientific progress and technological innovation, as the achievements in this field do not find proper publication, presentation and discussion in existing scientific contexts.

RoboSoft will create the missing framework for the soft robotics scientists, regardless of their background disciplines, and will enable the accumulation and sharing of crucial knowledge needed for scientific progress in this field.
This objective also supports Coordination and Support Actions for creating the best conditions within which FET research can flourish and achieve the transformative impacts that it aspires to. These activities may be, for example:

- actions, including networking and dissemination activities, aiming at the emergence of new research communities or collaborations involving a broad diversity of disciplines and actors into FET research;
- actions towards the increased active involvement of high-tech research intensive SMEs in exploratory research directions relevant to future ICT markets;
- actions that stimulate excellence and future leadership of pioneering teams of young researchers along new, exploratory research directions relevant to future ICT;
- actions aiming to strengthen the international dimension of FET.
Expected impact

For CSA actions:

- catalyse 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;
- new, engaged and risk-taking research communities prepared to develop new and non-conventional approaches for addressing future challenges in science and society.
The RoboSoft consortium is structured with a CA Coordinator, an Executive Board, Partners, and an Advisory Board.

- **CA Coordinator**: One representative from ETH and one from UOB.
- **Executive Board**: Chair: CA Coordinator (SSSA), One representative from ETH, One representative from UOB.
- **Partners**: SSSA WP leader, ETH WP leader, UOB WP leader.
- **Advisory Board**: Rolf Pfeifer (Chair), George Jeronimidís.
- **RoboSoft community (members)**: 22 members up to now.

The diagram also includes Stakeholders and other scientific communities.
RoboSoft Working Groups (D2.2)

Control Architectures and Paradigms for Soft Robots, Coord. Helmut Hauser, Univ. of Zurich

Biological Insights, Coord. Barry Trimmer, Tuft Univ., Boston

Smart Materials 
Soft Actuators and Soft Sensors, Coord. Barbara Mazzolai, IIT

Modelling & Control

Soft Materials

Energy Harvesting

Soft Actuators

Stretchable Electronics

Soft Sensors

Energy Harvesting and Stretchable Electronics, Coord. Jamie Paik, EPFL

Biology

Neuroscience

Mathematical Modelling

Fluido/Elasto-Dynamics

Material Science

Dynamic!
To change to better reflect scientific and technological progress and challenges
RoboSoft community (D2.1)

Current list of community members

Total 22: 12 EU + 10 non-EU countries

* 2 Biological Insights
* 5 Control Architectures and Paradigms for Soft Robot
* 10 Smart Materials, Soft Actuators and Soft Sensors
* 4 Stretchable Electronics and Energy Harvesting
## Institutions and key persons’ list

<table>
<thead>
<tr>
<th>#</th>
<th>Institution</th>
<th>Key Person</th>
<th>Tentative Working Group</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hebrew University of Jerusalem</td>
<td>Benny Hochner</td>
<td>Biological insights</td>
<td>Israel</td>
</tr>
<tr>
<td>2</td>
<td>Tufts University</td>
<td>Barry Trimmer</td>
<td>Biological insights</td>
<td>USA</td>
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<tr>
<td>3</td>
<td>MIT</td>
<td>Daniela Rus</td>
<td>Control Architectures and Paradigms for Soft Robots</td>
<td>USA</td>
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<tr>
<td>4</td>
<td>Heron Robots</td>
<td>Fabio Bonsignorio</td>
<td>Control Architectures and Paradigms for Soft Robots</td>
<td>Italy</td>
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<tr>
<td>5</td>
<td>IRCCyN</td>
<td>Frederic Boyer</td>
<td>Control Architectures and Paradigms for Soft Robots</td>
<td>France</td>
</tr>
<tr>
<td>6</td>
<td>UZH - AI Lab</td>
<td>Helmut Hauser</td>
<td>Control Architectures and Paradigms for Soft Robots</td>
<td>Switzerland</td>
</tr>
<tr>
<td>7</td>
<td>University of Tsukuba - Flexible robotics Lab</td>
<td>Hiromi Mochiyama</td>
<td>Control Architectures and Paradigms for Soft Robots</td>
<td>Japan</td>
</tr>
<tr>
<td>8</td>
<td>Edinburgh University</td>
<td>Adam A. Stokes</td>
<td>Smart Materials, Soft Actuators and Soft Sensors</td>
<td>UK</td>
</tr>
<tr>
<td>9</td>
<td>IIT Center for Micro-BioRobotics</td>
<td>Barbara Mazzolai</td>
<td>Smart Materials, Soft Actuators and Soft Sensors</td>
<td>Italy</td>
</tr>
<tr>
<td>10</td>
<td>Tallin University, Centre for Biorobotics</td>
<td>Maarja Kruusmaa</td>
<td>Smart Materials, Soft Actuators and Soft Sensors</td>
<td>Estonia</td>
</tr>
<tr>
<td>11</td>
<td>TU Berlin</td>
<td>Oliver Brock</td>
<td>Smart Materials, Soft Actuators and Soft Sensors</td>
<td>Germany</td>
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<tr>
<td>12</td>
<td>Cornell University</td>
<td>Rob Shepherd</td>
<td>Smart Materials, Soft Actuators and Soft Sensors</td>
<td>USA</td>
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<td>13</td>
<td>Seoul National University</td>
<td>KyuJin Cho</td>
<td>Smart Materials, Soft Actuators and Soft Sensors</td>
<td>South Korea</td>
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<tr>
<td>14</td>
<td>Soft Materials Research Laboratory, UCLA</td>
<td>Qibing Pei</td>
<td>Smart Materials, Soft Actuators and Soft Sensors</td>
<td>USA</td>
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<tr>
<td>15</td>
<td>Osaka University</td>
<td>Koh Hosoda</td>
<td>Smart Materials, Soft Actuators and Soft Sensors</td>
<td>Japan</td>
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<tr>
<td>16</td>
<td>EPFL - Laboratory of Intelligent Systems</td>
<td>Dario Floreano</td>
<td>Smart Materials, Soft Actuators and Soft Sensors</td>
<td>Switzerland</td>
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<tr>
<td>17</td>
<td>Carnegie Mellon University - The Robotics Institute</td>
<td>Yong-Lae Park</td>
<td>Smart Materials, Soft Actuators and Soft Sensors</td>
<td>USA</td>
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<tr>
<td>18</td>
<td>The Chinese University of Hong Kong</td>
<td>Michael Wang</td>
<td>Smart Materials, Soft Actuators and Soft Sensors</td>
<td>China</td>
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<tr>
<td>19</td>
<td>EPFL - Reconfigurable robotics laboratory</td>
<td>Jaimie Paik</td>
<td>Stretchable Electronics and Energy Harvesting</td>
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<td>University of Tokyo</td>
<td>Takao Someya</td>
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<td>Fraunhofer IZM</td>
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<td>Vrije Universiteit Brussel</td>
<td>Francis Berghmans</td>
<td>Stretchable Electronics and Energy Harvesting</td>
<td>Belgium</td>
</tr>
</tbody>
</table>
### Working papers and book series

#### WP 1 Management (0-36)
- **D1.1** Project periodic report
- **D1.2** RoboSoft community Agreements

#### WP 2 Setting up of the RoboSoft Community (0-3)

#### WP 3 Consolidation of the RoboSoft Community (3-36)
- **D2.1** RoboSoft Community report
- **D2.2** RoboSoft Working Groups
- **D2.3** Plans for the fertilization events
- **D3.1** RoboSoft Community Plenary Meeting
- **D3.2** RoboSoft working paper
- **D3.3** RoboSoft Summer School
- **D3.4** Book series on soft robotics

#### WP 4 RoboSoft web portal and online tools (0-36)
- **D4.1** RoboSoft website
- **D4.2** RoboSoft database setup
- **D4.3** RoboSoft online tools

#### WP 5 Dissemination and outreach of soft robotics (0-36)
- **D5.1** RoboSoft dissemination material
- **D5.2** RoboSoft Newsletter
- **D5.3** RoboSoft engagement material
Events: 2 Summer Schools
Plan for fertilization events (D2.3)

Types of events:
- special sessions
- workshops
- exhibitions on soft robotics

All RoboSoft community members, especially Working Group Coordinators, are welcome to propose and carry out fertilization events, with RoboSoft funds.
## Plan for fertilization events (2014-2015) (D2.3)

<table>
<thead>
<tr>
<th>Addressed community</th>
<th>Event name and website</th>
<th>Type of event to propose (presentation, exhibition,…)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials, energy, actuators</td>
<td>EuroEAP 2014 conference</td>
<td>Joint event with ESNAM network</td>
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<tr>
<td>Neuroscience</td>
<td>Neuroscience 2014</td>
<td>Symposia or Minisymposia</td>
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<tr>
<td>Cognitive systems</td>
<td>Genetic and Evolutionary Computation Conference (GECCO)</td>
<td>Oral presentation</td>
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<tr>
<td>Materials science</td>
<td>Spring Conference of the European Materials Research Society (E-MRS)</td>
<td>Oral presentation or exhibition</td>
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<tr>
<td>Modeling</td>
<td>Natural Resource Modeling Conference</td>
<td>Oral presentation</td>
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<tr>
<td>Marine Technology</td>
<td>Oceans</td>
<td>Oral presentation</td>
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<tr>
<td>Natural, social sciences, environment</td>
<td>World Congress on Sustainable Technologies</td>
<td>Oral presentation or exhibition</td>
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Concluding remarks

* RoboSoft is representing an important opportunity for our community to consolidate and grow
* RoboSoft is providing resources for scientific initiatives and for dissemination, to the benefit of the members of the RoboSoft community
* RoboSoft is open to new members and to new initiatives – everyone is invited to be collaborative and proactive

Enjoy the meeting and good work!
Thanks

Soft Robotics Team:
- Paolo Dario
- Matteo Cianchetti
- Davide Zambrano
- Laura Margheri
- Marcello Calisti
- Francesco Giorgio-Serchi
- Maurizio Follador
- Michele Giorelli
- Federico Renda
- Andrea Arienti
- Alessia Licofonte
- Serena Tricarico
- Mariangela Manti
- Vito Cacucciolo
- Francesco Corucci

Research Centre on Marine Robotics, Livorno

- CFD Octo-Prop, Marie Curie
- PoseiDRONE, Fondazione Livorno
- RoboSoft CA, FET-Open
- Smart-e, Marie Curie ITN

www.octopus-project.eu
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<tr>
<th>Time</th>
<th>Session</th>
<th>Room</th>
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<tr>
<td>9.00 – 9.15</td>
<td>Registration</td>
<td>Aula Magna</td>
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<tr>
<td>9.15 – 9.45</td>
<td><strong>RoboSoft welcome and introduction:</strong> <em>Cecilia Laschi</em></td>
<td>Aula Magna</td>
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<tr>
<td></td>
<td>RoboSoft CA Coordinator</td>
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<td></td>
<td>(BioRobotics Institute, Scuola Superiore Sant’Anna)</td>
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<tr>
<td>9.45 – 10.30</td>
<td>Invited talk: <em>Paolo Dario</em></td>
<td>Aula Magna</td>
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<tr>
<td></td>
<td>(BioRobotics Institute, Scuola Superiore Sant’Anna)</td>
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<td></td>
<td>“Soft robotics: new frontiers for BioRobotics and Robot Companions”</td>
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<tr>
<td>10.30 – 11.00</td>
<td>Teasers (I)</td>
<td>Aula Magna</td>
</tr>
<tr>
<td>11.00 – 11.30</td>
<td>Poster Session &amp; Coffee Break</td>
<td>Aula Magna Storica</td>
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<tr>
<td>11.30 – 12.15</td>
<td>Invited talk: <em>Rolf Pfeifer</em></td>
<td>Aula Magna</td>
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<td>(AI Lab, University of Zurich)</td>
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<tr>
<td></td>
<td>“Soft robotics - the next generation of intelligent machines”</td>
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<tr>
<td>12.15– 13.00</td>
<td>Assignment of Working Groups</td>
<td>Aula Magna</td>
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