FLAG-ERA JTC 2016 Project Seminar

Rome, February 25, 2020

The RoboCom++ Project: Rethinking Robotics for the Robot Companion of the Future

01/03/2017 – 31/10/2020

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FLAG-ERA JTC 2016 Project Seminar

Rome, February 25, 2020

OUTLINE

- ❑ Project at-a-glance
- ❑ Extension of project duration
- ❑ To date project results
- ❑ Working on the final outcome

Project at-a-glance

Project key data

- RoboCom++ is gathering the community and organising the knowledge necessary to **rethink the design principles and fabrication technologies of future robots.**
- RoboCom++ aims at **developing the Robot Companions of the year 2030**, by fostering a deeply multidisciplinary, transnational and federated efforts.

Funded partners (received funding from NRFOs belonging to FLAG-ERA JTC 2016 Call Board of Funders)	**13**
In-Kind partners (participate in the Project activities with own or external resources)	**14**
Months duration	**36 + 8**
Funding	**2.825.012,05 €**

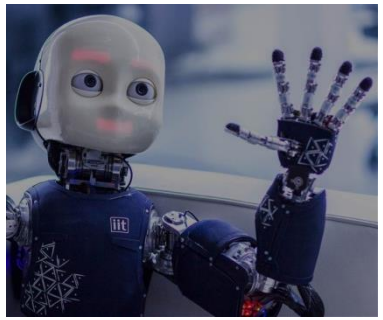
RoboCom++ Consortium

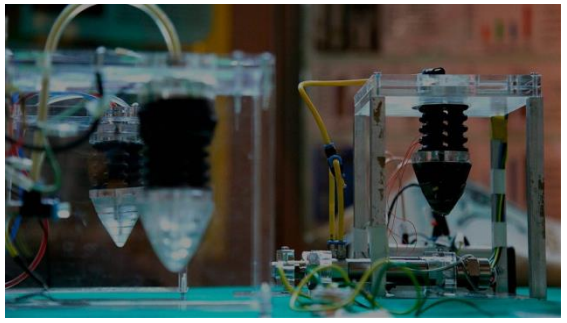
1. Scuola Superiore Sant'Anna (Italy)
2. Université Libre de Bruxelles (Belgium)
3. University of Zagreb (Croatia)
4. Tallinn University of Technology (Estonia)
5. Centre National de la Recherche Scientifique/LAAS (France)
6. Laboratoire National de Métrologie et d'Essais (France)
7. Istituto Italiano di Tecnologia (Italy)
8. Riga Technical University (Latvia)
9. National Institute for R&D in Microtechnologies (Romania)
10. Universitatea Transilvania Brasov (Romania)
11. Ecole Polytechnique Fédérale de Lausanne (Switzerland)
12. Middle East Technical (Turkey)
13. Bilkent University (Turkey)
14. University Carlos III of Madrid (Spain)
15. Weizmann Institute of Science (Israel)
16. Czech Technical University (Czech Republic)
17. Vrije Universiteit Brussel (Belgium)
18. National Technical University of Athens (Greece)
19. Universitat Politecnica de Catalunya (Spain)
20. Cognitive Systems Research Institute (Greece)
21. Technical University of Kosice (Slovakia)
22. University of Plymouth (United Kingdom)
23. University of Twente (The Netherlands)
24. Consorzio Nazionale delle Ricerche (Italy)
25. Universidad de Sevilla (Spain)
26. Imperial College London (United Kingdom)
27. University of the West of England (United Kingdom)

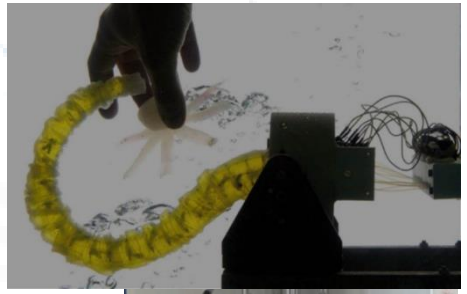
RoboCom++ Vision

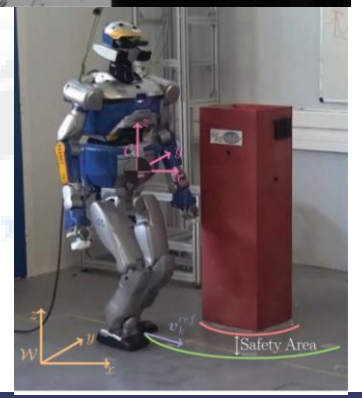
- RoboCom++ is pursuing a radically new design paradigm, grounded in the scientific studies of intelligence in nature. The emerging topics related to the Project include the concepts of **bioinspired control and cognition**, **embodied intelligence**, **morphological computation**, **simplexity**, **developmental approaches**, **human-robot interaction**, **soft robotics** and **smart materials.**
- The robots of the future will effectively negotiate natural environments, better interact with human beings, and provide services and support in a variety of real-world, real-life activities.

The dawn of **Bioinspired**, **Cognitive**, **Connected** and **Collaborative Soft Robot Companions** of the Future

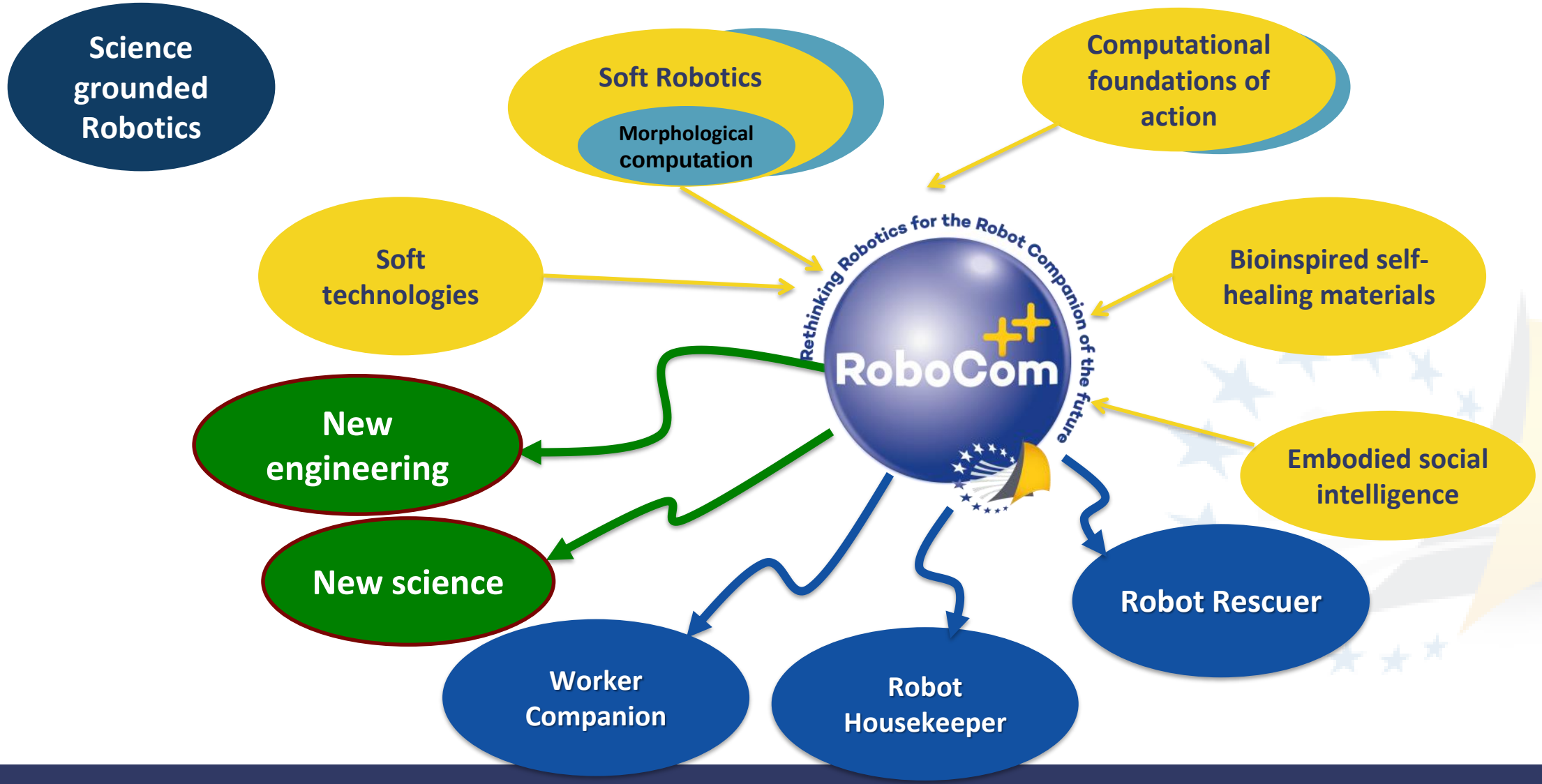








RoboCom++ Unifying vision



RoboCom++ Objectives and Impact

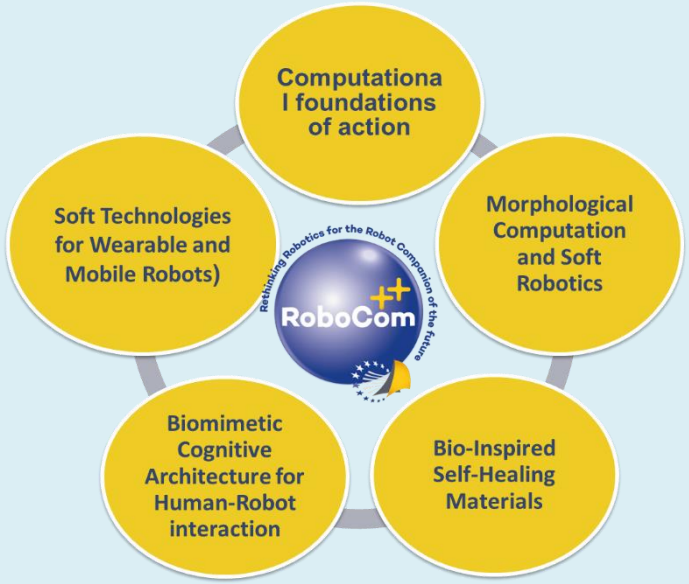
- The main objective of the RoboCom++ proposal is **to lay the foundation for a future global interdisciplinary research programme** (e.g., a FET-Flagship project) **on a new science-based transformative Robotics**, to be launched by the end of the H2020 Programme.
- RoboCom++ aims at gathering the community and organise the knowledge necessary **to rethink the design principles and fabrication technologies of future robots.**
- RoboCom++ aims at **developing the cooperative robots (or Companion Robots) of the year 2030**, by fostering a deeply multidisciplinary, transnational and federated effort.
- RoboCom++ pursues **a radically new design paradigm**, grounded in the scientific studies of **intelligence in nature**. This approach allows achieving complex functionalities in a new bodyware with limited use of computing resources, mass and energy, with the aim of exploiting compliance instead of fighting it.
- The **Companion Robots conceived in RoboCom++ may foster a new wave of economic growth in Europe** by boosting the deployment of ubiquitous robots and web-based robotic services.

RoboCom++ Community is pursuing its ambitious objectives by cooperating along three main lines of action

1. BUILDING THE COMMUNITY

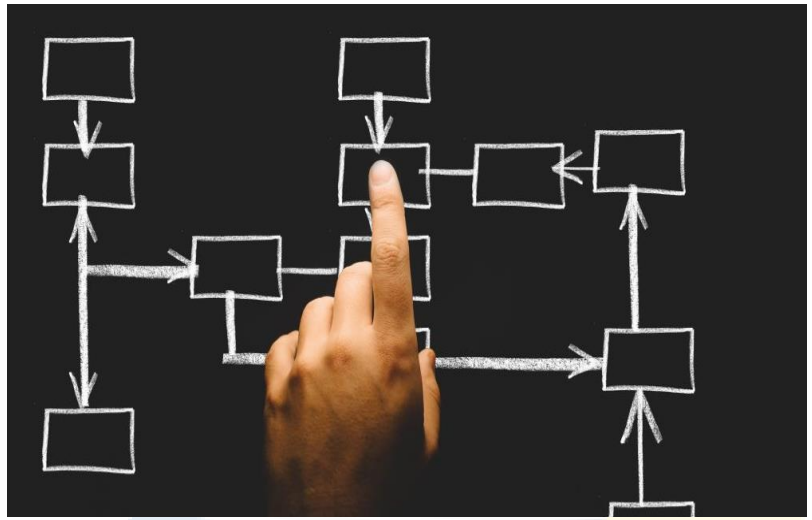
- ✓ **Building an interdisciplinary community** of outstanding, highly motivated and committed experts and organisations.
- ✓ **Involving a wider community of roboticists and non-roboticists** (including material scientists, mathematicians, AI experts, biologists, physicists, neuroscientists, economists, sociologists, philosophers, others).

2. RESEARCH PILOT PROJECTS



- ✓ **Targeting exploratory pilots** with the aim of investigating and assessing new discoveries and technologies relevant to RoboCom++ and that could be developed at a much larger extent.

3. DEFINING S&T ROADMAP



- ✓ **Designing the S&T framework** of the future global research programme **on Robotics** (e.g. a FET-Flagship project)

Extension of project duration

RoboCom++ extension of duration

- With regard to the third line of action (Defining S&T roadmap), the RoboCom++ community contributed to the Preparatory Action of a **FET-Flagship proposal on Robotics**, which was submitted on September 2018. On February 2019, the RoboCom++ Consortium received the notification of **rejection of this proposal**. On May 2019, the entire FET-Flagship Program was cancelled.
- The RoboCom++ Consortium deemed **necessary to rethink the final outcome of the Project** in order to leave a footprint of the same relevance of the rejected proposal. The Consortium decided to focus the Project remaining activities on the preparation of an **Open Access Book** which would need considerable time to be prepared.
- Following this decision, on January 2020 a **request for extension of 8-months** of the project duration was submitted to the FLAG-ERA Coordinator. **The extension has been granted on January 30, 2020.**
- **The new end date of the RoboCom ++ project is October 31, 2020.**

RoboCom++ extension of duration

Along with the extension of duration, the following **changes to the work plan** were approved:

deletion of the deliverables
strictly related to a positive result of the FET-Flagship proposal

- ✗ D4.2 “S&T future FET-Flagship requirements chart”
- ✗ D4.3 “S&T roadmap and plan of future FET-Flagship”
- ✗ D6.3 "General Finance Plan of the future Flagship”

merging into the Open Access Book

- D2.5 “Document on Benchmarking, Challenges and Competitions for Science”
- D7.3 “White paper on policies for Robot Companions”
- D8.3 “Dissemination Plan for the future Flagship on Robotics”
- D8.4 “RoboCom++ final outreach report”
- D9.2 “Final activity and management report”

To date project results

RoboCom++ Work Plan

WP1 - “Creation and consolidation of the RoboCom++ Community”

SSSA

WP2 - “Research reproducibility”

IIT

WP3 - “RoboCom++ research pilot projects”

LAAS

WP4 - “S&T roadmaps” EPFL

WP5 - “Exploitation & Competitiveness Strategy” EPFL

WP6 - “Governing structure of the future Flagship” SSSA

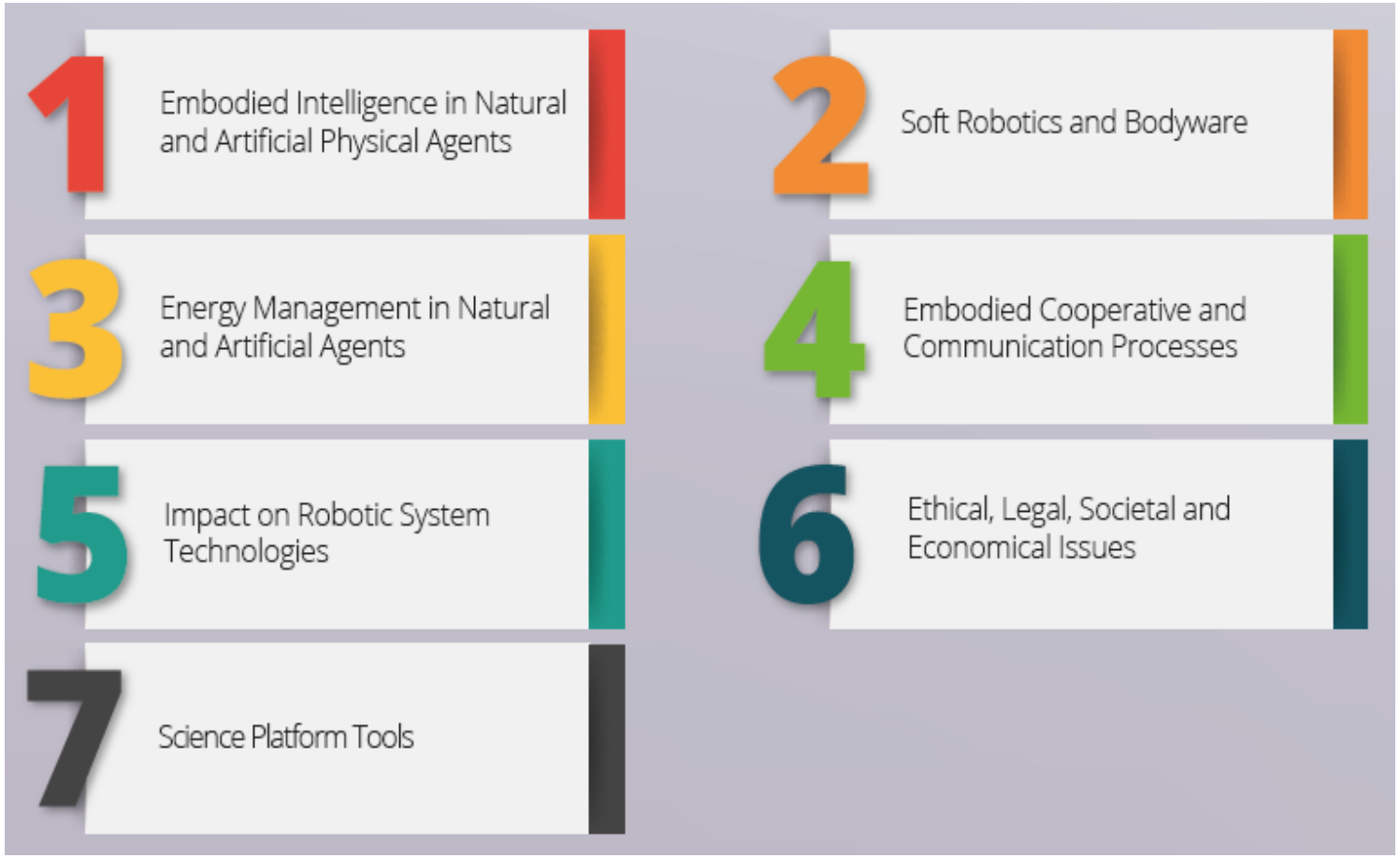
WP7 - “Robots and jobs: economical, ethical, legal and societal challenges for the Robot Companions” SSSA

WP8 - “RoboCom++: Outreach, Communication and Dissemination”

WP9 – “RoboCom++ Coordination and Management”

RoboCom++ Community (WP1)

We have reached n. 47 Community Members Organised in 7 Working Groups (WGs)

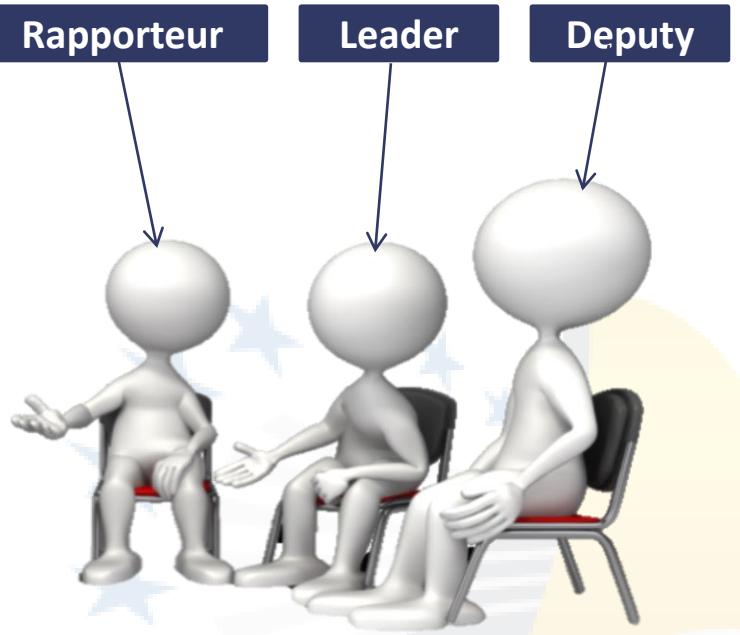


Objectives of the WGs:

- define the **roadmap for a future global interdisciplinary research programme on Robotics**;
- **enlarge the RoboCom++ Community, involving the main research groups** from universities and other organizations representing excellence in science-grounded robotics including experts in biology, neuroscience, material science, energy, social sciences, and in those engineering areas related to the main topics covered by each WG.

RoboCom++ Working Groups

1. Embodied Intelligence in Natural and Artificial Physical Agents
2. Soft Robotics and Bodyware
3. Energy Management in Natural and Artificial Agents
4. Embodied Cooperative and Communication Processes
5. Impact on Robotic System Technologies
6. Ethical, Legal, Societal and Economical Issues
7. Science Platform Tools



Each Working Group is composed by a **WG Board** with 3 members and several **WG Experts** in the respective research topics of the WG

WG1 Embodied Intelligence in Natural and Artificial Physical Agents

RESEARCH TOPICS:

- Modelling of Systems Integrating Rigid and Compliant Sub-Systems and Components
- Control of Systems Integrating Rigid and Compliant Sub-Systems and Components
- Computational Foundations of Action
- Morphological Computation
- Design Principles
- System Biology Vs Robotics Models
- Neurorobotics, Neuroscience and Robotics
- Embodied Social Intelligence
- Bioinspired Perception and Control
- Learning in Physical Agents (Robots, Animals, Plants)
- Collective Behaviour (Robot Networks and Swarms, Bird Flocks, ant Colonies, Facebook Trending, Slime Moulds, Coral)
- Cognitive Architectures For Companion Robots Based on The Needs of The Human
- Human-Like Robot Behaviour
- Remote Brain Concept in Robotics
- AI Agents for Robots

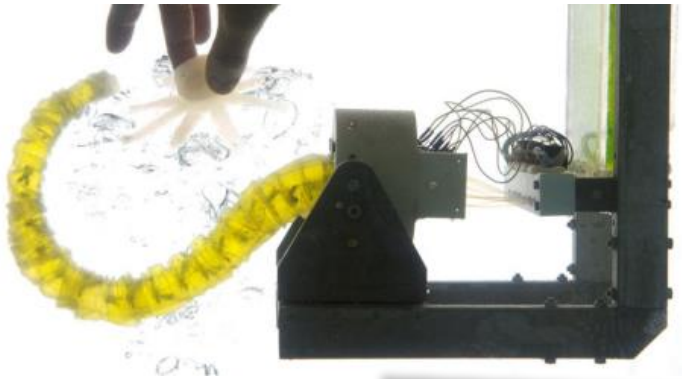
WP1 LEADER: Fabio Bonsignorio, Scuola Superiore Sant'Anna/The BioRobotics Institute, Italy
WG1 DEPUTY: Tamar Flash, Weizmann Institute of Science, Israel
WG1 RAPPORTEUR: Erol Sahin, Middle East Technical University/KOVAN Research Lab, Turkey

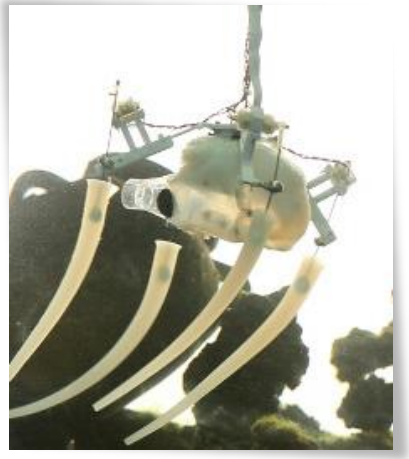
WG2 Soft Robotics and Bodyware

RESEARCH TOPICS:

- Sensors
- Actuators
- Soft Robotics Technologies and structures
- Smart Materials
- Artificial skin
- Control architectures and paradigms for soft robots
- Bioinspired self-healing materials
- Flexible and Stretchable electronics
- Evolutionary Robotics
- Design principles







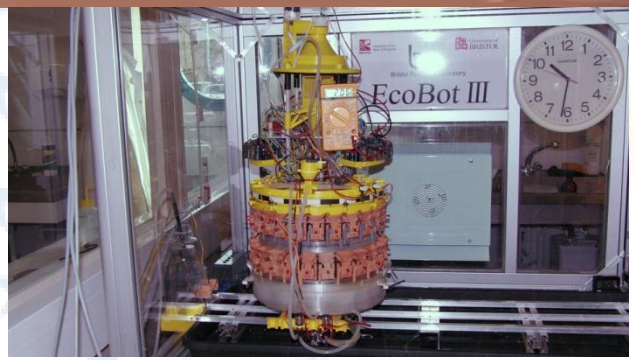
WG2 LEADER: Cecilia Laschi, Scuola Superiore Sant'Anna/The BioRobotics Institute, Italy
WG2 DEPUTY: Maarja Kruusmaa, Tallinn University of Technology, Estonia
WG2 RAPPORTEUR: Bilge Baytekin, Bilkent University/ Department of Chemistry and National Nanotechnology Research Center, Turkey

WG3 Energy Management in Natural and Artificial Agents

RESEARCH TOPICS:

- Harvesting
- Storage
- Metabolism
- Energy in partially actuated dynamic systems
- Energy in systems integrating rigid and compliant sub-systems and components
- Energy in plants
- Energy in animals
- Soft devices for energy harvesting and storage
- Design principles for high efficiency
- Design for disassembling and reusability

"Passive Dynamic Walker" "Ranger"



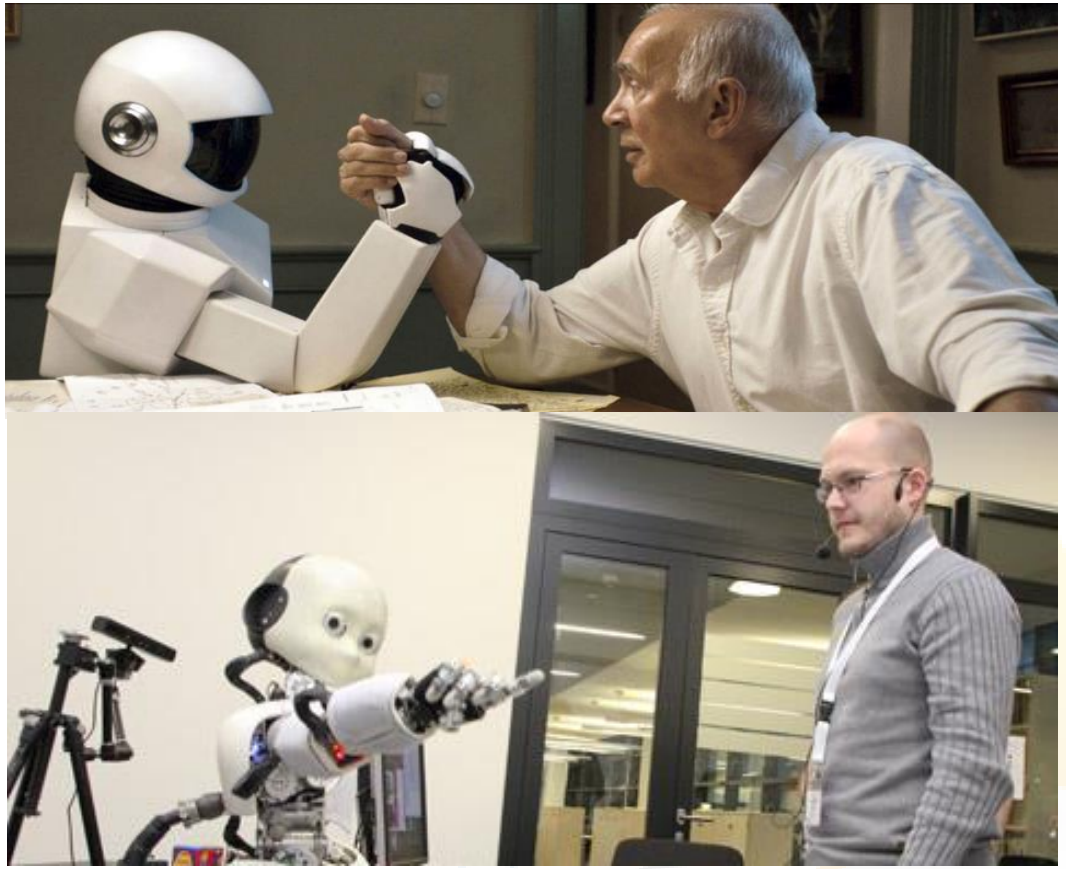
"EcoBot III"

WG3 LEADER: Ioannis Ieropoulos, Bristol BioEnergy Centre/ Bristol Robotics Laboratory (BRL), United Kingdom
WG3 DEPUTY: Stefano Stramigioli, University of Twente (UTW), The Netherlands
WG3 RAPPORTEUR: Carmen Moldovan, National Institute for R&D in Microtechnologies, Romania

WG4 Embodied Cooperative and Communication Processes

RESEARCH TOPICS:

- Communication (language, emotions, gestures)
- Human Robot Interaction
- Human-pet Interaction
- Haptic feedback
- Programming by demonstration
- Safety and dependability
- Shared control
- Social behaviours in the natural and artificial worlds
- Development and Co-Development in Physical Agents
- Collective behaviours



WG4 LEADER: Alberto Sanfeliu, Universitat Politecinca de Catalunya /Institut de Robotica i Informatica Industrial, Spain
WG4 DEPUTY: Giulio Sandini, Istituto Italiano di Tecnologia, Italy
WG4 RAPPORTEUR: Stefano Mazzoleni, Scuola Superiore Sant'Anna/The BioRobotics Institute, Italy

WG5 Impact on Robotic System Technologies

RESEARCH TOPICS:

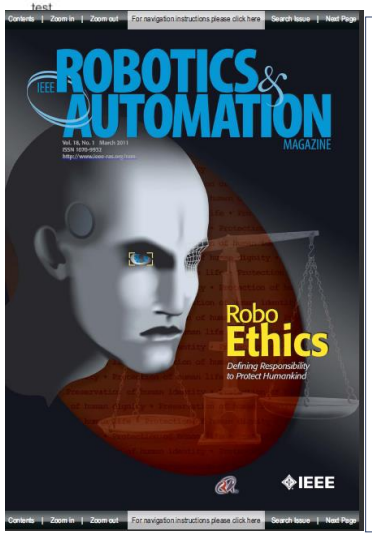
- Wearable Robots/Exoskeletons
- Prosthetics
- Medical Robots
- Assistive (healthcare, elderly, home, transportation) Robots
- Rescue Robots
- Co-worker and Artisan Robots
- Aerial and Flying Robots
- Marine Robots
- Space Robots
- Mobile (legged, wheeled, crawling) Robots
- Humanoid Robots
- Educational and Social Robots
- Cloud Robotics for Industry 5.0

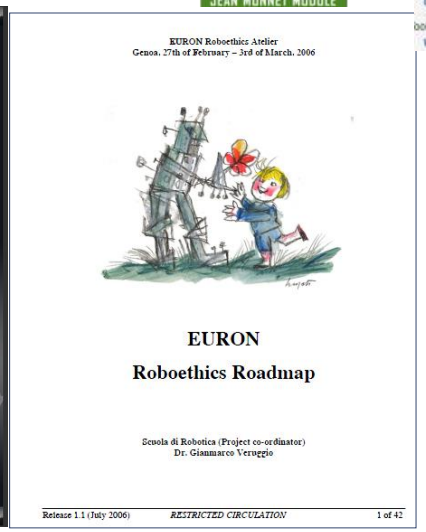
WG5 LEADER: Bram Vanderborght, Vrije Universiteit Brussel, Belgium
WG5 DEPUTY: Massimo Caccia, Consorzio Nazionale delle Ricerche/Istituto di Studi sui Sistemi Intelligenti per l'Automazione, Italy
WG5 RAPPORTEUR: Egons Lavendelis, Riga Technical University/ Dept. Artificial Intelligence and Systems Engineering, Latvia

WG6 Ethical, Legal, Societal and Economic Issues

RESEARCH TOPICS:

- Societal
- Economic
- Ethical
- Legal, Regulation and Insurance issues
- Robots and Jobs
- Equal Opportunities
- Education
- Sustainability



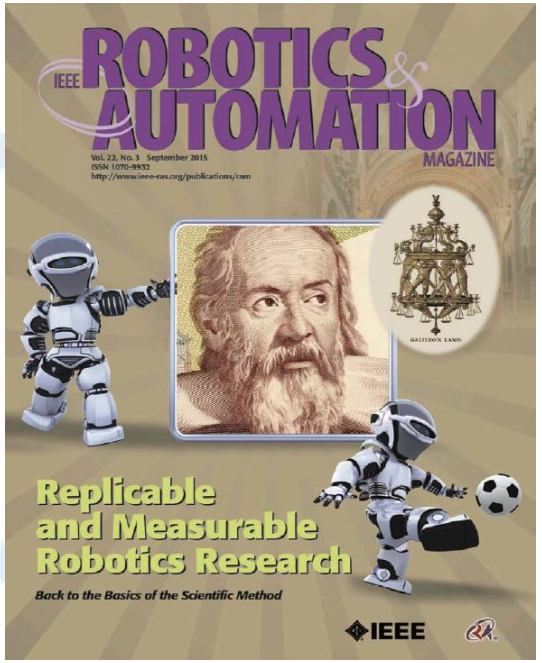


WG6 LEADER: Andrea Bertolini, Scuola Superiore Sant'Anna/ Institute of Law, Politics and Development, Italy
WG6 DEPUTY: Olivier Galibert, Laboratoire National de Métrologie et d'Essais, France
WG6 RAPPORTEUR: Arianna Martinelli, Scuola Superiore Sant'Anna/ Institute of Economics, Italy

WG7 Science Platform Tools

RESEARCH TOPICS:

- Open-Source Development
- Open Science Platforms
- Novel Software Architecture (Neuromorphic, reservoir computing emergent etc.)
- Tools for Reproducibility of Experiments
- Tools for performance assessment



WG7 LEADER: Barbara Mazzolai, Istituto Italiano di Tecnologia (IIT), Italy
WG7 DEPUTY: Giorgio Metta, Istituto Italiano di Tecnologia (IIT), Italy
WG7 RAPPORTEUR: Olivier Galibert, Laboratoire National de Métrologie et d'Essais, France

FET-Flagship proposal “Robotics”

Developing further robot **abilities** would enable robot **application** in our environments, on the humans’ side, to address societal and economical challenges and to promote industry growth.

- Definition of robot abilities

- Launch of calls for ideas
- Selection of one or more ideas
  (based on diverse scientific approaches) to fund

- (Comparative) assessment of results

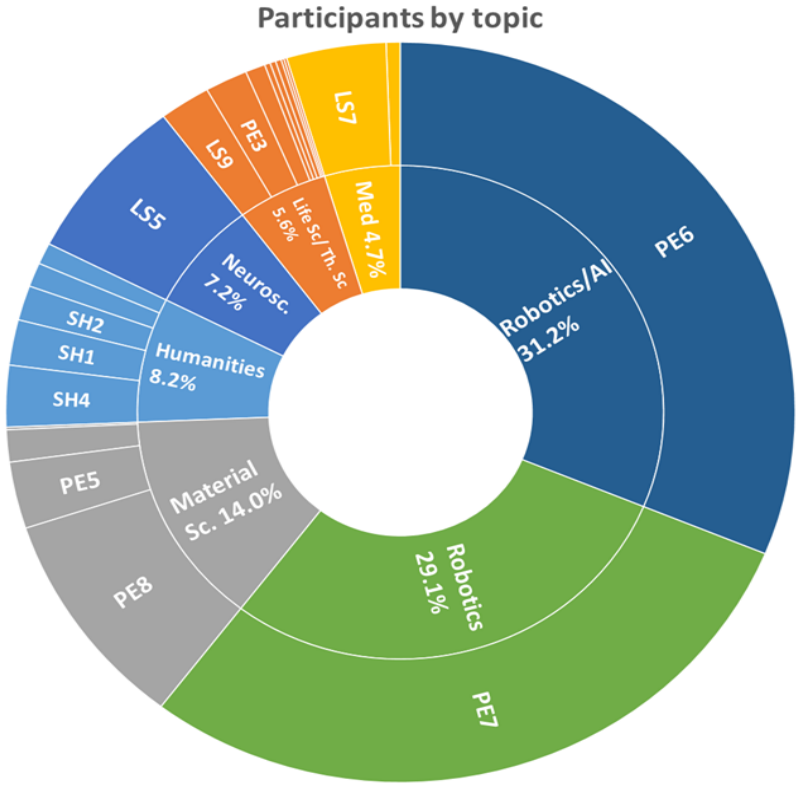
Modular
Scalable in time and budget

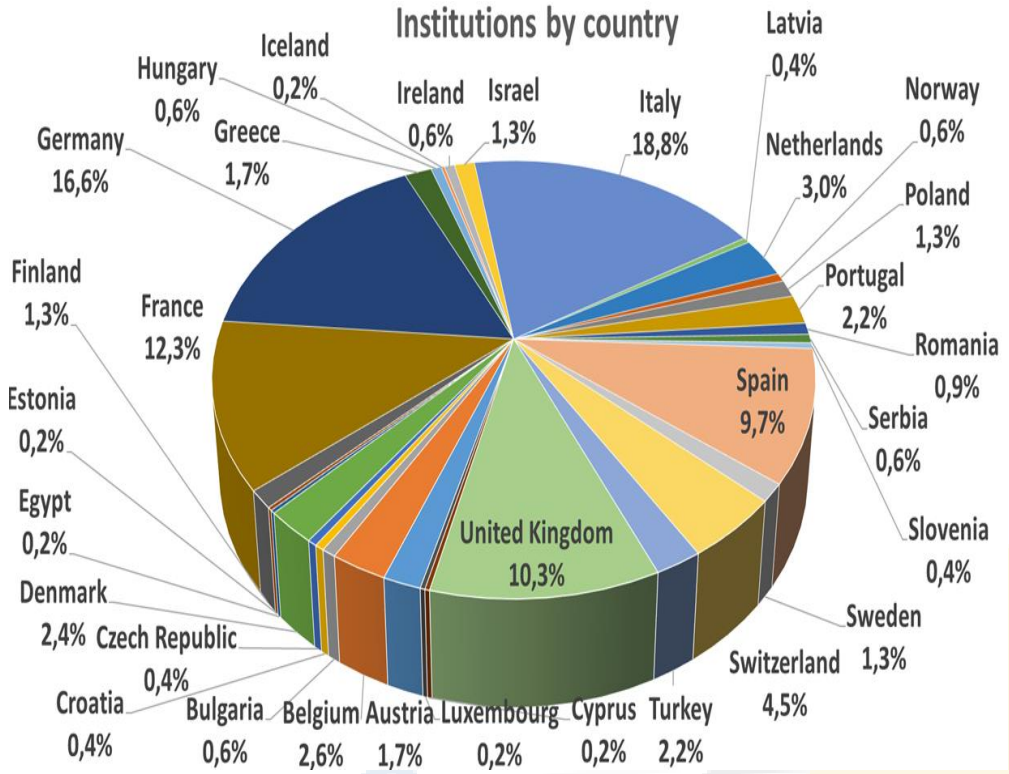
Inclusive
Anyone can participate, if contributing to the objective

Scientific valuable
Different approaches validated scientifically

FET-Flagship proposal “Robotics” Community

With the aim to facilitate scientific integration, beyond multidisciplinarity, a large community has supported the **FET-Flagship Preparatory Action proposal “Robotics”.**





865 participants, 465 institutions, 367 endorsments

An online registration system was set up for participants to join the proposal: https://www.roboticsflagship.eu/participate/.

FET-Flagship proposal “Robotics”

TOPIC : Preparatory Actions for new FET Flagships

Topic identifier:	FETFLAG-01-2018		
Publication date:	27 October 2017		
Types of action:	CSA Coordination and support action		
DeadlineModel:	two-stage	**Deadline:**	20 February 2018 17:00:00
Opening date:	31 October 2017	**2nd stage Deadline:**	18 September 2018 17:00:00

Three main areas:

1. **ICT and Connected Society:**
   Robotics, Interfaces and Artificial Intelligence
1. Health and Life Sciences
2. Energy, Environment and Climate change

RESULTS

Funded proposals:

1. Time machine	**CH**	**15/15**
2. Humane AI	**DE**	**15/15**
3. Energy-X	DK	14/15
4. LifeTime	DE	14/15
5. Sunrise	NL	14/15
6. Restore	DE	12.5/15

Reserve list:

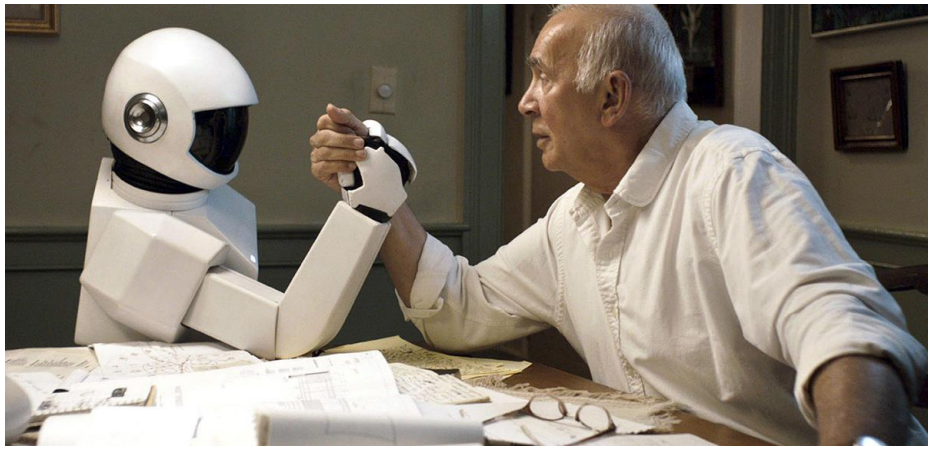
Robotics Flagship	**IT**	**14.5/15**

FET-Flagship proposal “Robotics”

MAIN CONCEPT

ECONOMICS

Ambition of studying **new economic models and public policies**, with machines at work, for taking advantage of robot labour, without threatening society, but rather providing socio-economic benefits.



SOCIAL SCIENCE

Studying **social models for introducing robots in the society of humans**, investigating legal frameworks that can enable the wide application of robots in our environments and studying the ethics of human-robot interaction, of robot integration, of human-robot hybrids, of human augmentation.

RoboCom++ Research reproducibility (WP2)

WP2 aims to provide the RoboCom++ community with the **tools for exchanging and validating results** in accordance with the highest standards of scientific rigour.

More specifically it aims at:

- definition of **research reproducibility requirements,**
- development of **test platforms**,
- definition of rigorous **scientific experimental protocols**,
- definition of a set of **benchmarking best practices**,
- development of **toolboxes**,
- analysis of **fabrication technologies for soft robotics**,
- development of a **standard programming language and middleware**.

RoboCom++ Research reproducibility

- **IEEE RAM** has introduced **a new set of R(eproducible) articles** to start a thread of publication that manages the issues of Reproducible Research in Robotics.

- SSSA has cooperated to the development of the new reproducible research platform (integrating CodeOcean – www.codeocean.com - code sharing infrastructure and simulation tools such as Cyberbotics Webots). A **technical meetings involving top CodeOcean** staff has been held at IROS 2017 in Vancouver.

- A **workshop on 'Reproducible Research in Robotics**: Current Status and Road Ahead' has been held at ICRA 2017 in Singapore.

- Similar activities have been held at **ERF 2017** in Edinburgh, at **ERF 2018** in Tampere and at **ICRA 2018** in Brisbane.

RoboCom++ Research reproducibility

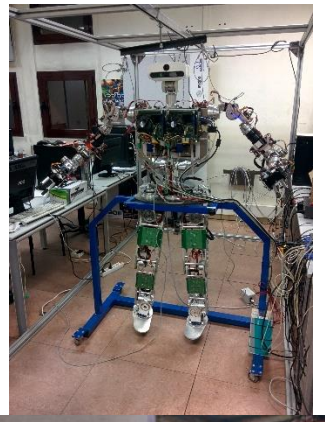
- In collaboration with LNE, LAAS-CNRS has conducted a study that aimed at **benchmarking the HRP-2 humanoid Robot during locomotion**. To this end a campaign of measurement was conducted on the robot in a controlled environment.
- In order to benchmark various motion modalities and algorithms **a set of performance indicators for bipedal locomotion** were computed. The scope of the evaluated motion-generation algorithms is rather large as it spans analytical solutions to numerical optimization approaches able to realize real-time walking or multi-contacts.
- The effect of **temperature variations and vibrations** at different frequencies on the robot walking capabilities was also investigated.

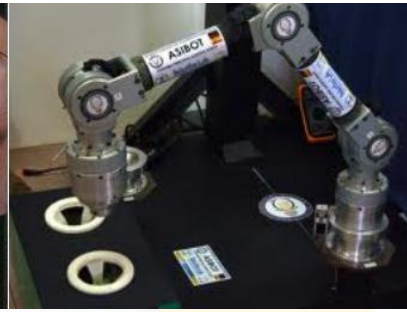
RoboCom++ Research reproducibility

University Carlos III of Madrid (UC3M) has developed **several test platforms**:

- TEO, **a humanoid robot** for locomotion and manipulation activities.
- Maggie, **a social robot** for interaction with the human.
- **An arm exoskeleton** for rehabilitation of upper-limb after stroke.
- ASIBOT, **an assistive robotic arm** for assistance to disabled people.

IIT has devoted a significant effort to the development of the **second version of the R1 robot**, with relevant improvements to the reachable workspace of the robot, and to the shoulder and upper-arm mechanics whose design has been simplified and made easier to construct.



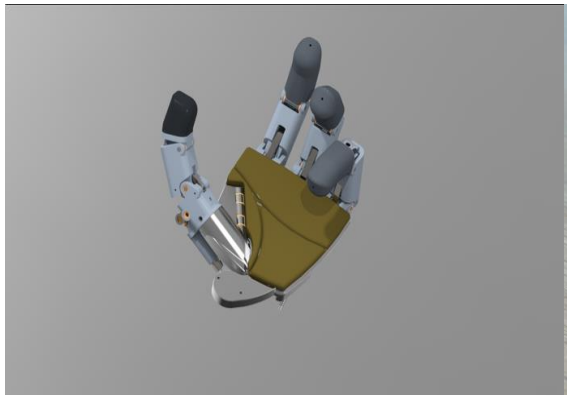


RoboCom++ Research reproducibility

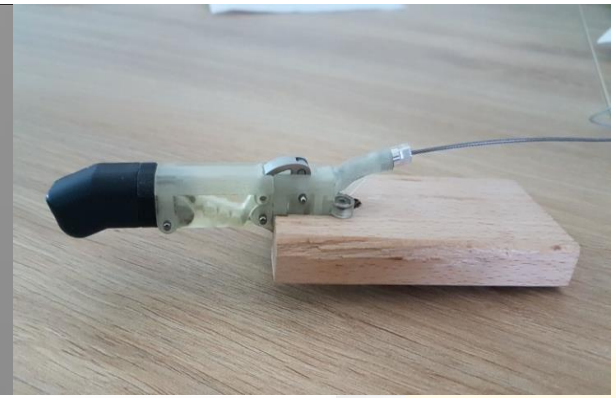
IIT has been working on the **humanoid robot iCub**, which represents nowadays one of the standard platforms for performing robotic research.

In order to enhance the iCub manipulation performances, **the iCub Tech facility has started a new hand design project**. The mechanical design has been simplified by reducing the number of fingers to 4.

At the current stage, the hand project has already moved from conceptual design to detailed design and **a first prototype of the finger has already been built and tested**.



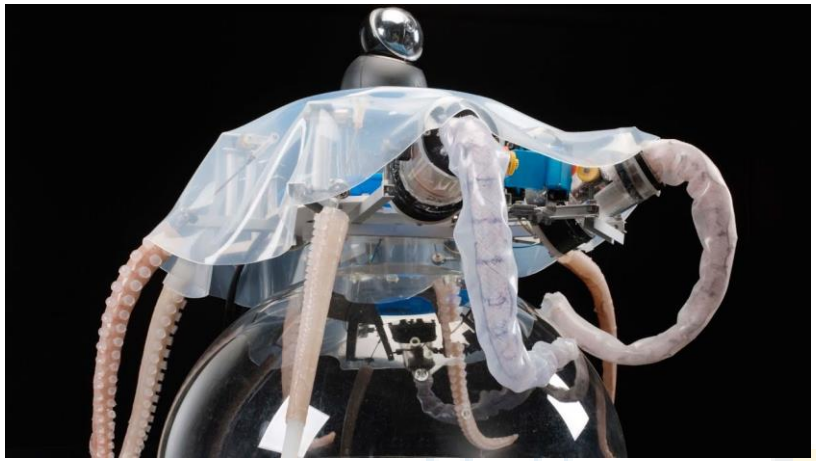
The CAD design of the new hand of the iCub humanoid robot



The prototype of one finger of the designed hand

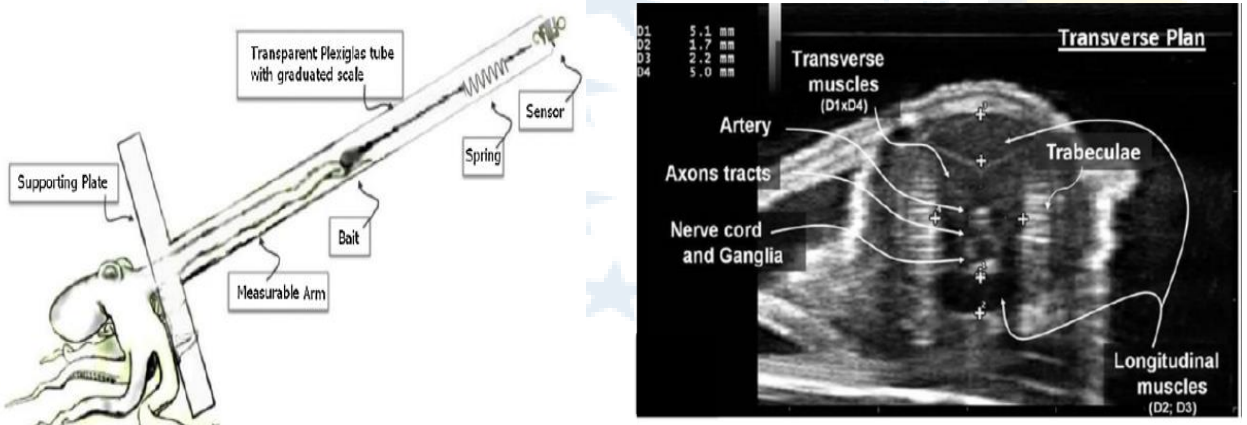
RoboCom++ Research reproducibility

The **pioneer works performed by SSSA and IIT on the octopus arms and suckers** have provided a set of basic **protocols related to the characterization of functional parameters** given a defined problem, such as the characterization of the mobility of an animal swimming and manipulating in water.



Tools to be used for the measurements, specific procedures, and the needed statistics have been also defined, showing a **general model for experimental protocols for soft robot companions.**

Methods for measuring the arms in vivo have been developed to specifically quantify the elongation, shortening, pulling force, stiffening and morphology.



Methods for measuring the arms, biomechanical (up) and morphological (down) characteristics in vivo

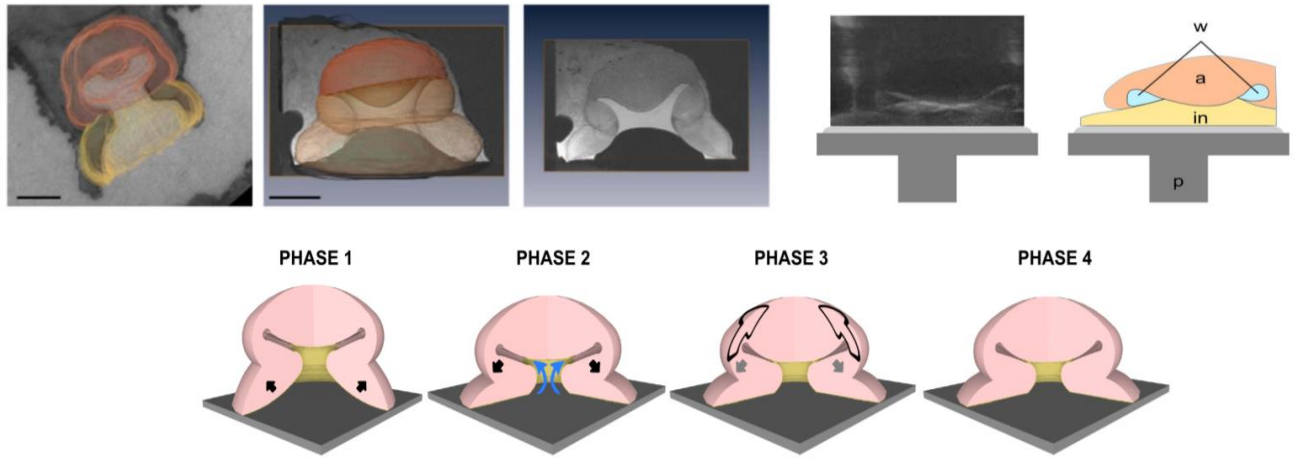
RoboCom++ Research reproducibility

For the arms, the **instruments and experimental protocols were designed to obtain active measurements of the arm**.

The **protocol for measuring the animal**s has been defined together with experts in biology and repeated for animals different in size and gender.

The **analysis of internal structure** was performed with a non-invasive methodology, such as ultrasound imaging, in order to preserve the muscular arrangement in vivo and in the aquatic environment .

Analysis of the octopus suckers morphology and adhesion mechanisms



Mazzolai B., Margheri L., Laschi C. (2020) Quantitative Measurements of Octopus vulgaris Arms for Bioinspired Soft Robotics. In: Bonsignorio F., Messina E., del Pobil A., Hallam J. (eds) Metrics of Sensory Motor Coordination and Integration in Robots and Animals. Cognitive Systems Monographs, vol 36. Springer, Cham

RoboCom++ Research reproducibility

- From September 2017, the IEEE Robotics & Automation Magazine has been **soliciting R-articles**, and a few are already in the pipeline.

- Thanks to **the R-article process in IEEE RAM**, the Robotics Community is now able to make progress towards an environment where **reproducible research is possible** and common.

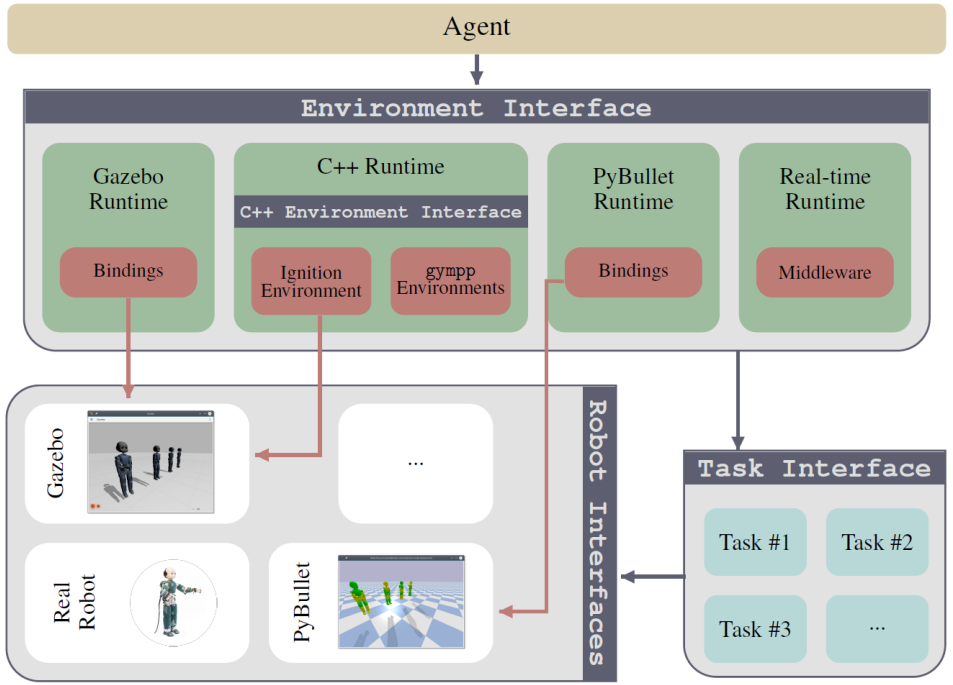
- The **2018 issue (Vol. 25, Issue 3) of the IEEE RAM** highlights the importance and timeliness of this topic. This special issue is composed of replicable experiments, demonstrating the improvements in the state of the art and identifying areas where further work is still needed.

RoboCom++ Research reproducibility

Reproducibility can be improved following two directions:

- Firstly, the entire community would benefit from a **standardized framework** to apply reinforcement learning techniques to simulated robots. We believe that also in the robotics domain, standardized environments would trigger the same virtuous cycle that characterized the past breakthrough in reinforcement learning.

- With the final aim of improving reproducible robotics research, **we have developed Gym-Ignition**, a framework to create reproducible reinforcement learning environments for robotic research. The environments created with Gym-Ignition target both simulated and real-time settings.



RoboCom++ Research reproducibility

Gym-Ignition aims to narrow the gap between reinforcement learning and robotic research. It permits roboticists to create simulated environments using familiar tools like Gazebo, SDF3, and URDF4 files to model both the robot and the scenario.
A Comparison of frameworks that provide robotic environments compatible with Openai Gym:

Software	Reproducible	Multiple Physics Engines	Photorealistic Rendering	Accelerated	Parallel	Real-Time Compatible	Modular	Open Source
OpenAI Robotic Environments				✓	✓		✓	∼
Gym-Gazebo2		✓		✓	✓			✓
openai ros		✓		✓			✓	✓
Bullet3 Environments	✓	✓		✓	✓	✓	∼	✓
Nvidia Isaac Gym	✓	✓	✓	✓	✓	✓		
Unity ML-Agents	✓	✓	✓	✓	✓			∼
Gibson	✓		✓	✓	✓		✓	✓
RaiSim	✓		✓	✓	✓			
PyRoboLearn	✓	✓		✓	✓		✓	✓
Gym-Ignition	✓	✓	∼	✓	✓	✓	✓	✓

Gym-Ignition is the first project that integrates with the new Ignition Robotics suite developed by Open Robotics . We believe that it will progressively take over the current generation of the simulator, providing new features, enhanced performance, and improved user experience.

RoboCom++ Research Pilot Projects (WP3)

CNRS-LAAS is coordinating the work done by partners related to the five targeted exploratory research pilots:

1. **Computational foundations of action (LAAS)**
2. **Evolutionary approaches for soft robots exploiting morphological computation (SSSA)**
3. **Soft technologies for wearable and mobile robots (EPFL)**
4. **Bioinspired stimuli-responsive and self-healing materials (BU-CHEM)**
5. **Embodied social intelligence for human-robot interaction (IIT)**

- Intended to **produce proofs of feasibility, rather than prototypes**.
- **Addressing key problems** that are representative of the “New Robotics” approach promoted by RoboCom++.

Pilot Project #1: Computational Foundations of Action (LAAS, RTU, METU, UC3M)

OBJECTIVE: Explore the «computational foundations of action» by following an interdisciplinary approach, with the aim to make robot companions able to plan and execute daily tasks in and adaptive and robust way.

- LAAS worked on the **analysis of the human movement** and on the **development of a general motion generation framework**. Continues the work on multi-contact to the **design of a quadruped robot** in collaboration with the Max Plank Institute.
- Based on a theory research done, RTU has been developed **a ViaBots model** for ensuring long term adaptivity (also called Viability) in multi-robot systems. RTU is about to validate the proposed model on a physical multi-robot system based assembly line.
- METU investigated **how collaborative robots** (cobot), typically composed of a robotic arm and a gripper carrying out manipulation tasks alongside human coworkers, **can be imbued with HRI capabilities** by applying ideas and principles from character animation.
- UC3M contributed with new improvements on the development of companion and assistant robots. They continued working on the **development of TEO**, a Full-size humanoid robot as a personal robot companion with whole body multi-contact stability.
- USE/GRVC developed computational approaches to increase the efficiency of aerial robots and worked on increasing the embodied Intelligence of current aerial robotic manipulators and on the **development of computational methods for energy efficient flights**.

Pilot Project #2: Evolutionary approaches for soft robots exploiting morphological computation (SSSA, TUT, IIT, UTBV)

OBJECTIVE: Demonstrate that **computational processes inspired by natural evolution can be used to design effective and adaptive robot bodies and brains for complex tasks and environments.**

- Investigation on the **free-form evolution of simulated walking and swimming soft robots** in different environments.

An evolutionary system was put in place by SSSA and IIT to perform experiments that showed how different materials lead to the evolution of different morphologies, behaviours, and energy-performance trade-offs. They found that stiffer robots evolve more sophisticated and effective gaits and morphologies on land, while softer ones tend to perform better in water.

- Investigation on the **combination of evolutionary algorithms and learning**.

A comparative study was done at SSSA between two bio-inspired control architectures for quadruped legged robots, where learning takes place either during the evolutionary search or only after that. Results show better performance metrics for the robotic agent whose locomotion method has been discovered by applying the adaptive module during the evolutionary exploration for the locomotion trajectories.

- Investigation on **learning-based control methods in soft robots**.

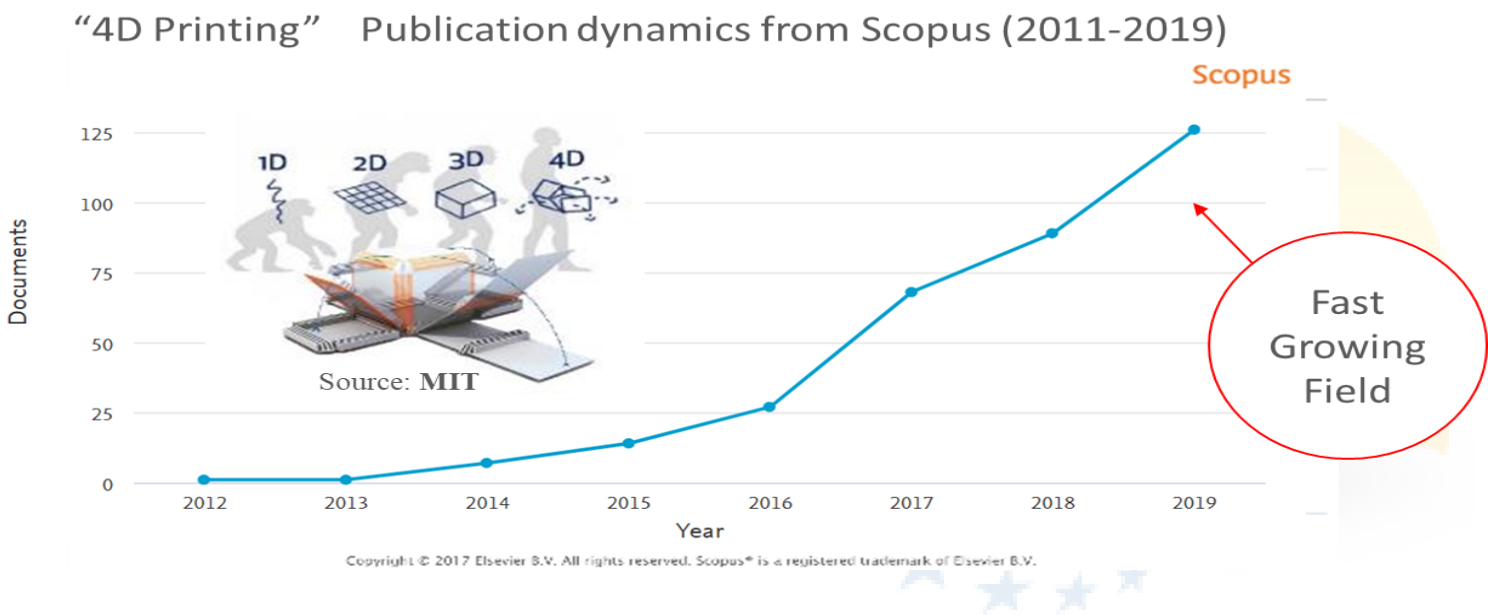
After the implementation at SSSA of several learning-based control systems on existing soft robots, learning showed to be a successful approach in the control of soft robots.

Pilot Project #2: Evolutionary approaches for soft robots exploiting morphological computation (SSSA, TUT, IIT, UTBV)

Based on 3D printing technology of stimulus-responsive materials, **4D printed structures evolve as a function of time and exhibit intelligent behaviour** due to interaction between stimulus and smart materials.

Targets benefit in robotics include: an integrated fabrication of soft artefact, the functionalization of structures, a reduced (optimized) control based on embodied intelligence, the possibility of a high exploitation of the environmental conditions.

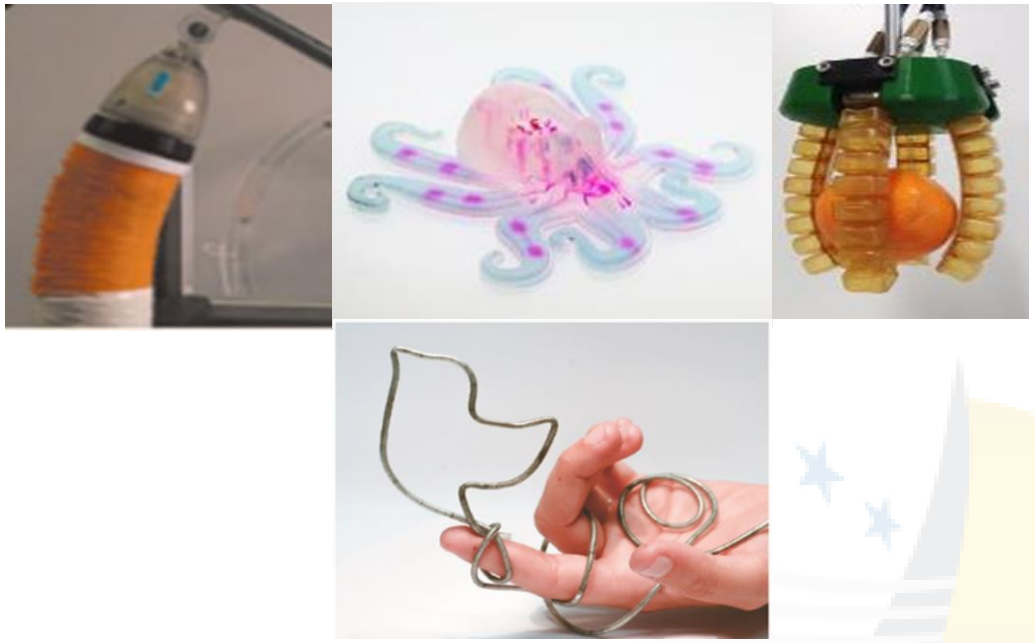
The fourth dimension of printing allows the transformation and the functionality benefits.



Pilot Project #2: Evolutionary approaches for soft robots exploiting morphological computation (SSSA, TUT, IIT, UTBV)

Conformable electronics includes approaches with **ultrathin substrate, ink printable materials, physical or chemical or initiated chemical vapour deposition, dry transfer, water transfer, and tattoo transfer**.

As a point of convergence of the previously described technologies, **hybrid 3D printing represents a new method for producing soft electronics**, combining direct ink writing of conductive & dielectric elastomeric materials with automated pick-and-place components by integrated additive manufacturing.



From left to right to down: self-growing robot based on 3D/4D printing; chemical powered soft robot; soft robot based on self-healing material; liquid metal.

Pilot Project #2: Evolutionary approaches for soft robots exploiting morphological computation (SSSA, TUT, IIT, UTBV)

References

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2. Corucci F., Cheney N., Giorgio-Serchi F., Bongard J., Laschi C. (2018). “Evolving soft locomotion in aquatic and terrestrial environments: effects of material properties and environmental transitions”, Soft robotics 5(4), 475-495.
3. George Thuruthel T., Ansari Y., Falotico E., Laschi C. (2018). “Control Strategies for soft robotic manipulators: a survey”, Soft Robotics 5(2).
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5. Massi E., Vannucci L., Albanese U., Capolei M.C., Vandesompele A., Urbain G., Sabatini A.M., Dambre J., Laschi C., Tolu S., Falotico E. (2019). “Combining evolutionary and adaptive control strategies for quadruped robotic locomotion”, Frontiers in Neurorobotics 13:71.

Pilot Project #3: Soft technologies for wearable and mobile robots (EPFL)

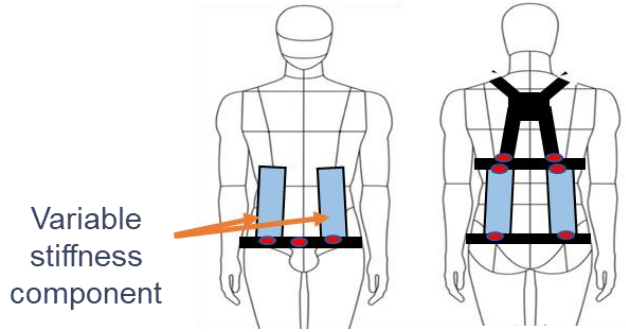
OBJECTIVE: Demonstrate the suitability of soft, compliant technologies in two different ways relevant for the robot companion

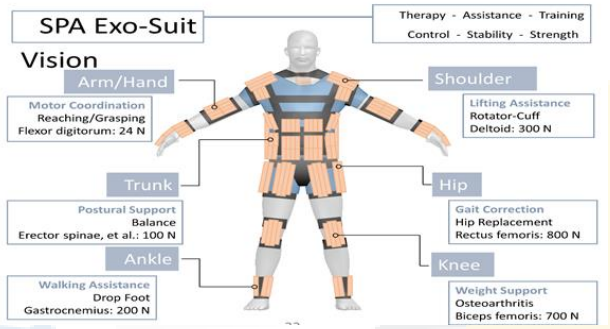
- Working in collaboration, the BioRob (A. R. Wu) and LIS (V. Ramachandran, C. Rognon) labs at EPFL carried out work in **modelling, simulation, and testing of body movement with haptic feedback devices** (FlyJacket, electro-adhesive clutch). For the Flyjacket, we tested different force guidance profiles to reduce error in drone operation, haptic perception of force feedback, and learning with haptic guidance.

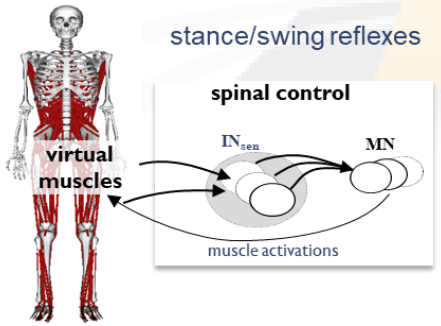
- We co-supervised a semester project on the **development of an upper body model subjected to forces at the torso**.

- To validate this model, we carried out a **human subject experiment to build an empirical dynamical torso model** of user with force feedback.

- Analysis of this data is ongoing.



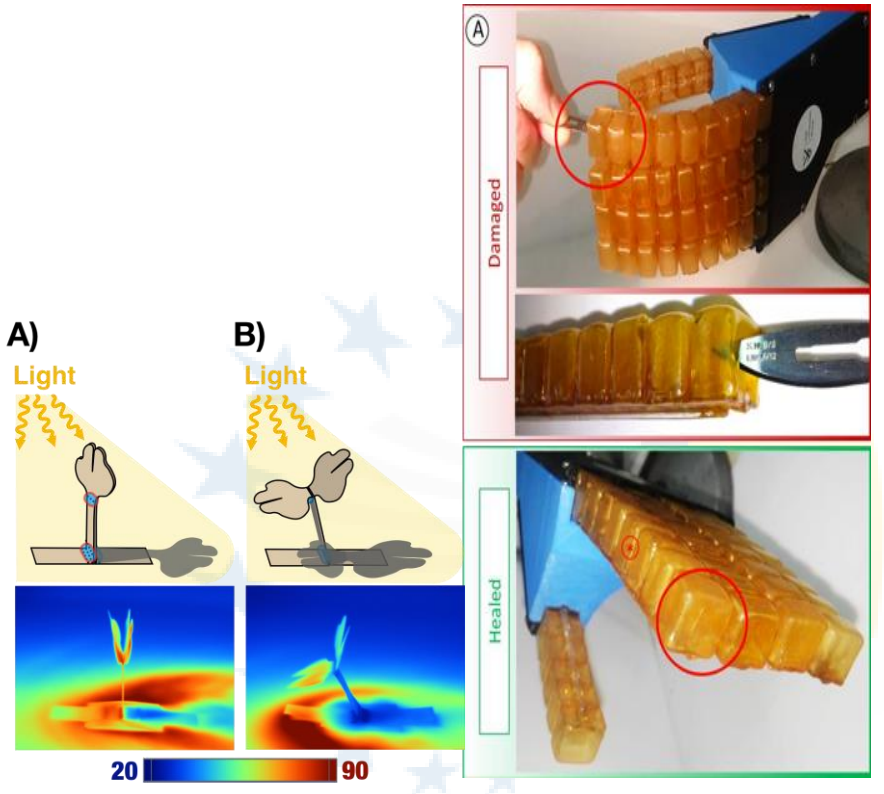




Pilot Project #4: Bioinspired stimuli-responsive and self-healing materials (VUB, BU-CHEM)

OBJECTIVE: Investigate bioinspired materials and methods able to self-heal, for their use in a new generation of robots.

- A major breakthrough is realized by VUB which is inspired by the powerful biological healing function to **repair microscopic and macroscopic damage**.
- Material scientists have managed to incorporate similar properties into synthetic materials to create 'self-healing (SH-) materials' over the past 15 years.
- BUCHEM for the first time realized **functional actuators with self-healing properties** and realized a **self-healing pneumatic artificial muscle**, **soft robotic gripper and soft robotic hand.**
- Moreover, **the material can be fully recycled**.



References

1. Roels, E., Terryn, S., Brancart, J., Van Assche, G., & Vanderborght, B. (2019, April). A Multi-Material Self-Healing Soft Gripper. In 2019 2nd IEEE International Conference on Soft Robotics (RoboSoft) (pp. 316-321). IEEE.

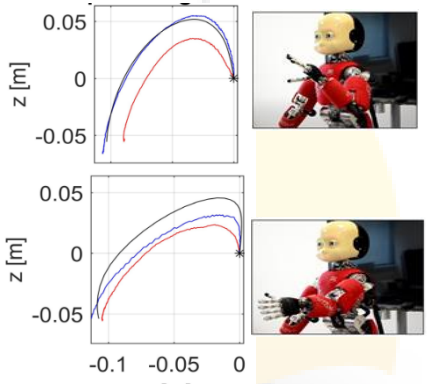
Pilot Project #5: Embodied social intelligence for human-robot interaction (IIT, UNIZG-FER, UPL)

OBJECTIVE: Develop a brain-inspired approach to endow robotic companions with the capability to simulate the perspective of the "other" in order to anticipate the consequences of actions and engage in cooperative behaviors.

We worked to establish the basis of a perceptual system for the iCub that allows it to learn in an autonomous way sensorial regularities of its environment. The proposed architecture will be the basis to endow the iCub robot with a visual context from which it can learn, for example, a sorting or an assembly task.

- **Reciprocal recognition of agency**

We showed that the iCub robot can be recognized as a social partner in the case of a dyadic interaction scenario. An experiment has been designed to test the importance of self-experience in individuals.

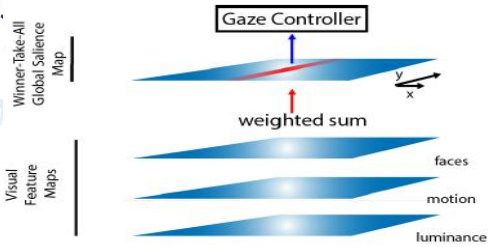


- **Representing others' and the environment**

We developed a cognitive architecture that allows the robot to build an egocentric representation of the world mimicking at the same time the cognitive structure of working memory. The autonomous face localisation and word-object learning achieved is demonstrated with the cognitive architecture.

- **Integrated Cognitive architecture from Robot's Episodic memory**

We identified how a robot could learn a simple task of assembly and sorting and reuse it to infer other actions by leveraging on RL algorithms. We identified the necessary components to perform reinforcement learning, mainly the software (simulation, learning framework) and install it to work with the iCub robot.



RoboCom++ S&T roadmaps (WP4)

- Literature survey has been done, interviews has been conducted, transcribed, analysed and combined with the contributions from the Working Groups, to **define a list of future application scenarios for the robotic technologies analysed**.
- About **20 such scenarios have been defined** as narratives situated at a precise point in time and place, and based on a plausible evolution of current robotic technologies and highlighted a clear societal/economic demand.
- These scenarios can be described in short narratives and accompanied by illustrations; together with the **list of technological and scientific goals** and the list of critical risks (both derived from the interview and the literature survey).
- Through a synergy with another project funded by the Swiss National Foundation, a collaboration was started in January 2019 with the group of Prof. Rafael Lalive at the University of Lausanne (Department of Economics) to **develop a conceptual and methodological framework for assessing the likely impact of future robotics on the job market**.

Exploitation & Competitiveness strategy (WP5)

- EPFL has defined a conceptual and methodological framework to collect **recommendations from the industrial network** as well as **from business promoters**. In particular, a recommendation has emerged to focus on robotics clusters as unit of analysis, and to explore their potential in promoting and supporting an exploitation and competitiveness strategy for innovative robotics.
- The industrial network comprised of robotic companies (suppliers and integrators), cluster managers, and supporting entities are articulating their recommendations as to what are the **key ingredients to make a robotic cluster successful.**
- A subset of **key Robotic abilities from the SPARC Multi-Annual Road** has been matched to their human counterparts and is being assessed (by EPFL-Lis lab members) for their Technology readiness level (TRL); this assessment will allow to establish a correlation between the human skills required by a job, the corresponding robotic abilities, and the level of development of the latter.
- This framework can become a basis to automatically calculate **to what extent a human task can be replaced by a robot.**

Designing, Governing, Structuring and Financing the future FET-Flagship on Robotics (WP6)

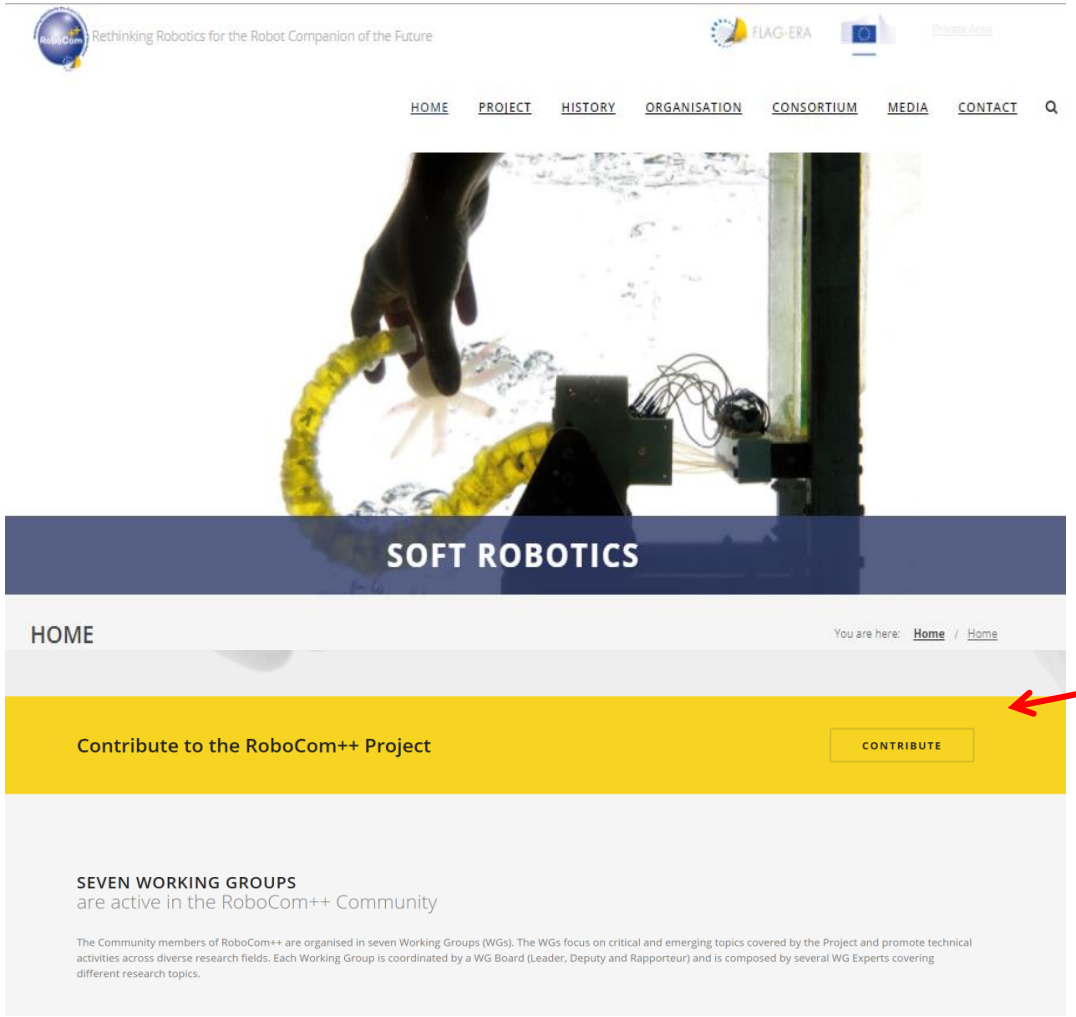
- The FET Flagship proposal obtained **explicit support, through letters of endorsement, from 367 institutions**. Most letters (more than 70%) are from the participants' research institutions and they reflect the nice interdisciplinarity of participants.
- **Institutions favouring technology transfer**, like the German Fraunhofers and other national **innovation centres**, were also supporting the flagship proposal and many companies endorsed the proposal, both as producers or users of robotics, **large companies and SMEs**.
- The proposal obtained the **endorsement of several national public bodies and research agencies**, like the Ministries in charge of research in Germany, Italy, and other European countries, and the Italian Ministry of Industry.

The FET-Flagship proposal was not funded!

Robots and jobs: economical, ethical, legal and societal challenges of the Robot Companions (WP7)

- WG6 (Working Group: Ethical, Legal, Societal and Economic Issues) partners have performed **extensive research** on the topics of liability, technical and ethical standardization, product safety and certification, taking into considerations the existing legal framework at European and national level.
- The framework identified so far has been assessed, taking into account its implementation and its consequences, with the aim of identifying what works and what instead fails to deliver the intended outcome. The **deliverable D7.1** "State of the Art on Societal Impact of Robotics", prepared in close cooperation with the members of WG7, reports a **preliminary analysis of the economic aspects, the ethical issues and the legal and the social implications of the Robot Companions**. The work is ongoing.
- WG6's members organized the following activities:
  - "Europe Regulates Robotics" Workshop within the European Robotic Forum Symposium, Tampere, Finland, March 2018
  - "Europe Regulates Robotics" Conference, Scuola Superiore Sant'Anna, Pisa, Italy, 27-28 September 2018
  - "Propose a regulatory & risk management framework" Workshop within the INBOTS Conference, Pisa, Italy, 19 October 2018
  - Workshop "Alternative approached to liability in robotics" within the European Robotic Forum Symposium, Bucharest, Romania (March 20-22, 2019)

Outreach, Communication and Dissemination (WP8)



RoboCom++ website contains news, the main events of the RoboCom++ project and background information regarding the main results of the project

The dedicated web page used to share information about the working groups topics, activities, news, photos and promotional materials

Outreach, Communication and Dissemination (WP8)

Publications involving a single project partner	
At international level	
Peer-reviewed journals	54
Books or chapters in books	2
Communications (conferences)	21
Other (technical report, student semester project)	4
At national level	
Communications (conferences)	7
Popularisation exhibitions	2

Publications involving several project partners	
At international level	
Peer-reviewed journals	1
Books or chapters in books	2
Communications (conferences)	9
At national level	
Communications (conferences)	7
Other (student semester project)	4
Popularisation exhibitions	1

Valorisation (software, products, spin-offs, etc)	
International patents obtained	1
National patents pending	1
Company creation	4
Other (participation to standardisation committee	1

RoboCom++ Workshop at RO-MAN 2017

RO-MAN2017

Pestana Palace Hotel, Lisbon, Portugal

August 28 to September 1, 2017

26th IEEE International Symposium
on Robot and Human Interactive Communication

The IEEE International Symposium on Robot and Human Interactive Communication, Ro-MAN2017, has been held in Lisbon and the conference theme has been: **Human-Robot Collaboration and Human Assistance for an Improved Quality of Life**.

The objective of the Workshop "**Rethinking Robotics for the Robot Companion of the Future: the RoboCom++ Fet-Flagship-Proof-of-Concept Project"** was to inform general audience about the ambitious aims of the RoboCom++ Project and to start the brainstorming on the objectives and contents of the proposal for a CSA initiative towards a FET Flagship RoboCom++ full proposal.

The event was attended by 50 guests

Paolo Dario

RoboCom++ at ERF 2018: Grand Scientific and Societal Challenges for the Robot Companion of the Future

In particular the objectives of this event were to:

- investigate the concepts of embodied intelligence, morphological computation and simplexity;
- analyse the revolutionary potential of soft robotics;
- explore the development of alternative energy sources;
- investigate the different aspects of embodied cooperative and communication processes;
- investigate how to make Robot Companions “accepted” at any social scale and estimate qualitatively and quantitatively the impact of the pervasive use of Robot Companions on jobs, productivity, sustainability, social welfare and economy.

List of invited speakers:
Paolo Dario, Cecilia Laschi, Barbara Mazzolai, Tamim Asfour, Stefano Stramigioli, Geoff Pegman (R.U. Robotics)

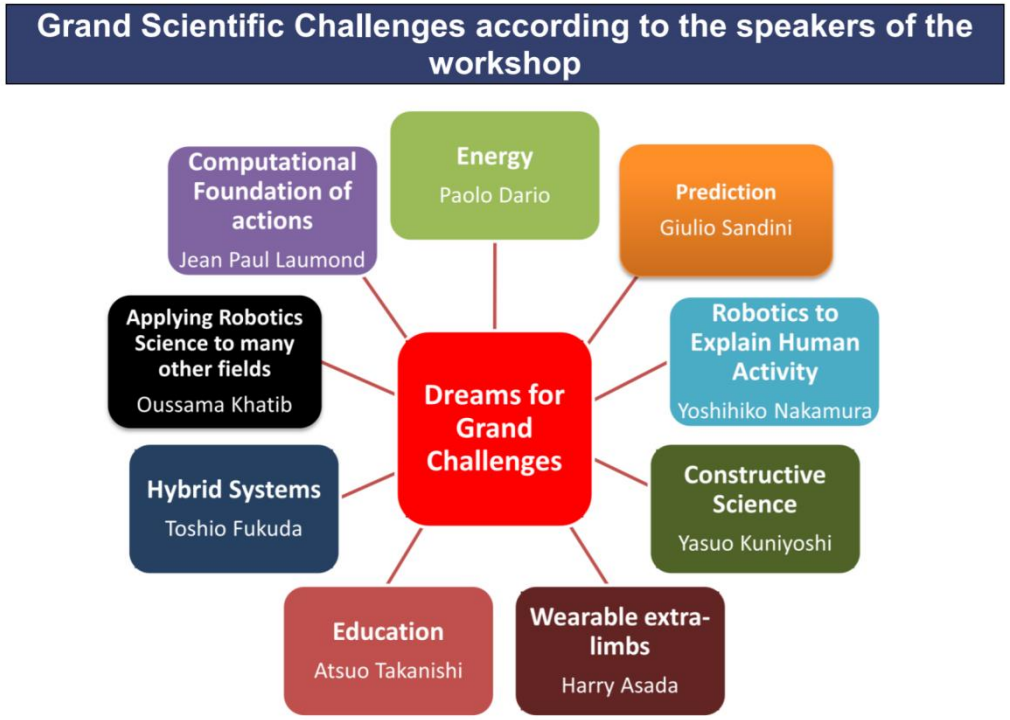
This proposal has obtained the support of the euRobotics Topic Groups on Robot Companions and on Bio-Inspired Robotics

RoboCom++ at ICRA 2018: Workshop on Grand Scientific Challenges for the Robot Companion of the Future

ICRA 2018
21-25 May 2018
Brisbane Convention & Exhibition Centre

List of invited speakers:
Paolo Dario, Oussama Khatib, Jean Paul Laumond, Atsuo Takanishi, Harry Asada, Toshio Fukuda, Anibal de Almeida, Yasuo Kuniyoshi, Yoshihiko Nakamura, Giulio Sandini, Adam Stokes

This proposal has obtained the support of many (eight) IEEE RAS TCs.



RoboCom++ at ICT Conference 2018

ICT 2018 took place in Vienna on 4-6 December 2018. This research and innovation event attracted 4800 visitors and focused on the European Union's priorities in the digital transformation of society and industry. It presented an opportunity for the people involved in this transformation to share their experience and vision of Europe in the digital age.

During this event was hosted, among the Networking Programme, the parallel session **"Science-grounded Robotics: the TERRINet and RoboCom++ European Projects"**

The Networking Session aimed:

- to present research services, access opportunities and the high-level training offered by the TERRINet Robotics Research Infrastructure Network;
- **to grow the visibility of the RoboCom++ Community as a reference point for robotic research and development in Europe and worldwide;**
- **to present the Working Groups of the RoboCom++ Community.**

ROOM 2.44

Science-grounded Robotics: the TERRINet and RoboCom++ European Projects

RoboCom++ at IROS 2018 and at ERF 2019

Picture of the exhibition area that we have booked to promote and disseminate the RoboCom++ Project at the IROS 2018

October, 1- 5, 2018 Madrid, Spain. 2018

Pictures of the exhibition area that we have booked to promote and disseminate the RoboCom++ Project at the ERF 2019

20-22 March 2019, Bucharest, Romania

Plenary Meetings and Activities (WP9)

1. **RoboCom++ Kick-off Meeting** March 6-7, 2017 Pontedera (Italy)
2. **FLAG-ERA JTC 2016 Project Kick-off Seminar** April 28, 2017 Riga (Latvia)
3. **Workshop "Rethinking Robotics For The Robot Companion Of The Future"** @ RO-MAN 2017 August 28, 2017 Lisbon (Portugal)
4. **RoboCom++ Plenary Meeting** October 5-6, 2017 Prague (Czech Republic)
5. **Workshop "Grand Challenges for the Robot Companions of the Future"** @ ERF 2018 March 15, 2018 Tampere (Finland)
6. **FLAG-ERA JTC 2016 RoboCom++ Project Seminar** March 22, 2018 Rome (Italy)
7. **Workshop "Grand Scientific Challenges for the Robot Companion of the Future"** @ ICRA2018 May 18, 2018 Brisbane (Australia)
8. **RoboCom++ Plenary Meeting** March 21, 2019 Bucharest (Romania)
9. **RoboCom++ Plenary WebEx Meeting** December 19, 2019

List of Deliverables

No.	Designation	Nature*	Delivery date	Lead Partner
D1.1	Definition of WGs and planning of meetings and type of reporting required	Report	16/05/2017	SSSA
D1.2	RoboCom++ community website	Website and Report	19/05/2017	SSSA
D8.2	RoboCom++ Website and Dissemination material	Website and dissemination material	19/05/2017	SSSA
D1.3	RoboCom++ Database	Website	19/05/2017	SSSA
D8.1	Strategic Communication & Dissemination Plan	Report	26/06/2017	SSSA
D2.1	Robotics Research Reproducibility requirements document	Article	24/09/2017	SSSA
D1.4	RoboCom++ Plenary Meeting and Report	Report	31/10/2017	SSSA
D7.1	State of the Art on Societal Impact of Robotics	Report	15/11/2017	SSSA
D4.6	Federation of current initiatives	Report	26/03/2018	EPFL
D5.1	Recommendations from Industrial	Report	28/11/2019	EPFL
D5.2	Recommendations from Business	Report	28/11/2019	EPFL

List of Deliverables

No.	Designation	Nature*	Delivery date	Lead Partner
D6.1	Governance structure and legal framework of the future FET-Flagship on Robotics	Report	28/11/2019	SSSA
D6.2	Organisational structure for RTD in the future FET-Flagship on Robotics	Report	28/11/2019	SSSA
D3.2	Cognitive architecture REA IIT	Report	30/01/2020	IIT
D1.3	RoboCom++ White Papers	Report	Finalizing	SSSA
D2.2	Early Prototypes of Experimental Platforms	Report	Finalizing	IIT
D2.3	Prototypes of Experimental Platforms	Report	Finalizing	IIT
D2.4	Document on Experimental protocols for Robot Companions	Report	Finalizing	IIT
D2.5 (ex-D2.6)	Early Prototype of Repository for Dataset, Toolbox and Best practices	Report	Finalizing	IIT
D2.6 (ex-D2.7)	Prototype of Repository for Dataset, Toolbox and Best practices	Report	Finalizing	IIT
D3.1	Development of a generic software environment for motion planning and whole-body motion generation of humanoid robots	Report	Finalizing	CNRS-LAAS

List of Deliverables

No.	Designation	Nature*	Delivery date	Lead Partner
D3.3	Soft technologies for wearable and mobile robots	Report	Finalizing	EPFL
D3.4	Soft robots showing morphological computation	Report	Finalizing	SSSA
D3.5	Report on implementation of responsive and self-healing materials in robotics	Report	Finalizing	BU-CHEM
D3.6	S&T outcomes from feasibility studies	Report	Finalizing	EPFL
D4.1 Ex-D4.3	S&T risk analysis and related contingency plan	Report	Finalizing	EPFL
D4.2 Ex-D4.4	Plan for S&T knowledge accumulation and sharing	Report	Finalizing	EPFL
D5.1	Update “Recommendations from Industrial network”	Report	Finalizing	EPFL
D5.2	Update “Recommendations from Business promoters”	Report	Finalizing	EPFL
D5.3	Update “Competitiveness White Paper”	Report	Finalizing	EPFL
D7.2	Report on Robot Companion Impact	Report	Finalizing	SSSA

List of Milestones

No.	Designation	WP involved	Delivery date	Partners involved
1	First community set-up, in terms of members, database, web tools	WP1	31/05/2017	SSSA; All partners
2	RoboCom++ Strategic Communication & Dissemination Plan, Website and Dissemination material	WP8	26/06/2017	SSSA; All partners
3	First RoboCom++ Plenary Meeting and Report	WP1	06/10/2017	All Partners
3	Early experimental platforms for research reproducibility	WP2	01/10/2018	IIT

Working on the final outcome

Preparation of the Open Acess Book

The **RoboCom++ Open Access Book** will be configured as a final output of the Project aiming:

- ✓ **to boost the global outreach of the RoboCom++ Project** and,
- ✓ **to guide the future generations of robots**,
- ✓ placing **Europe at a forefront position in shaping the robots of the future**.

We are in contact with Springer which we will soon provide with:

- Title of the Book
- A short summary (in 100-120 words) of the book. (Should start with “This book highlights…..”)
- A tentative table of contents
- A tentative submission date for the final manuscript
- Number of pages and figures estimated (please count 500 words per page, without figs and tables)
- A short biography (in 6-8 lines) of each Editor. Also include the full affiliation (postal address) and email address for the Editor(s)

Preparation of the Open Access Book

Tentative Title: Rethinking Robotics for the Robot Companion of the Future

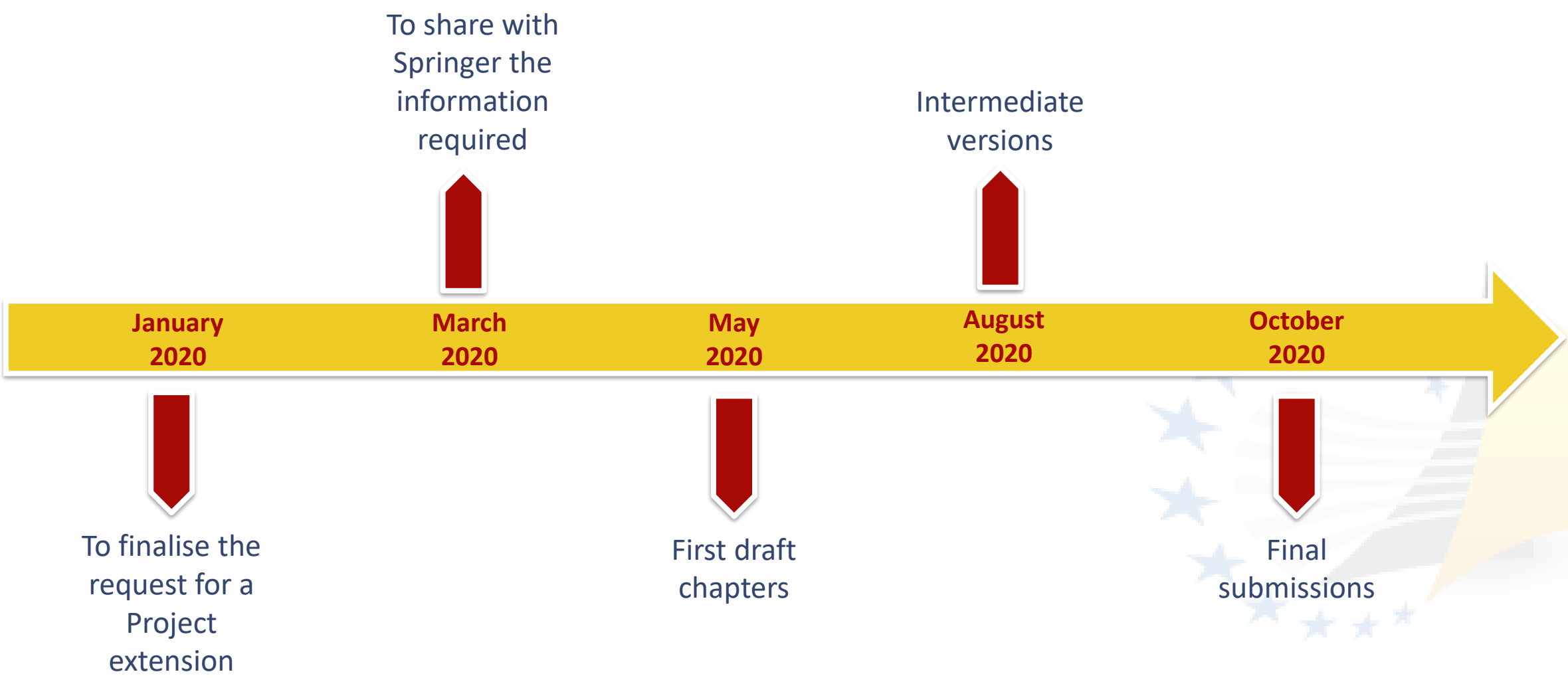
Editorial Board (to be confirmed)

- Paolo Dario SSSA
- Dario Floreano EPFL
- Cecilia Laschi SSSA
- Philippe Soueres LAAS
- Barbara Mazzolai IIT
- Stefano Stramigioli UT
- Egon Lavendelis RTU
- Bilge Baytekin BU-CHEM
- Alberto Sanfeliu UPC

Tentative Table of Contents

1. Introduction
2. Embodied Intelligence in Natural and Artificial Physical Agents
3. Soft Robotics and Bodyware
4. Energy Management in Natural and Artificial Agents
5. Embodied Cooperative Communication Processes
6. Impact on Robotic System Technologies
7. Ethical, Legal, Societal and Economic Issues
8. Science Platform Tools
9. Research Pilot Projects
10. Vision on the future of Robotics

Editorial Timeline



Thank you!

robocomplusplus.eu

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RoboCom++ Consortium