Report Newsletter

December 2013

www.STIFF-FLOP.eu

EUROPEAN COMMISSION
European Research Area

SEVENTH FRAMEWORK PROGRAMME

STIFF-FLOP Workshop 2013, Siegen

Figure 1: The STIFF-FLOP team in the laboratory at the University of Siegen

All project partners were invited to the STIFF-FLOP workshop organised by the University of Siegen (USIEGEN). The workshop was held 21th - 25th October 2013 in Siegen, Germany. The opportunity of meeting all project partners was used to arrange a scientific and technical management meeting. In parallel initial benchmarking experiments were prepared.

Figure 2: Surgeons in talks with engineers

Therefore all partners contributed by presenting the current work progress as well as by putting the parts developed by different partners together in order to prepare further collaborative tests.

Special guests Yoav Mintz and Paolo Pietro Bianchi, who are also part of the EAES Task force, attended the workshop and assisted the team with feedback from surgeons' point of view.

In an invited e-session Bernardo Magnani talked about Product Development Strategies to support the team in the development of a STIFF-FLOP product that can be introduced to the market.

Figure 3: Visit to the ZESS laboratory at the University of Siegen

Contents:

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One of 5 cool robots funded by the EC presented at Robot Safari[EU] at the Science Museum London

During the EU Robotics Week, KCL and SSSA presented STIFF-FLOP during Robot Safari[EU] at the London Science Museum exploring the fascinating world of biomimetic robots. Visitors trekked through the unnatural habitats of biomimetic robots, interacting with creatures that swim, flap, and crawl, in a unique safari experience.

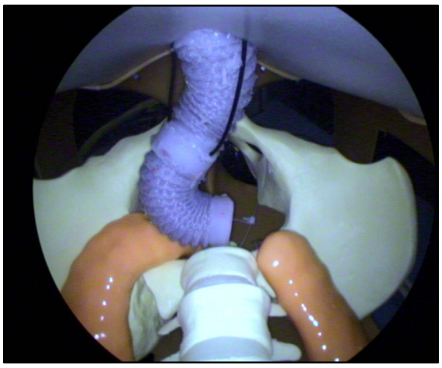

Figure 4: STIFF-FLOP arm entering the abdominal model built by FRK

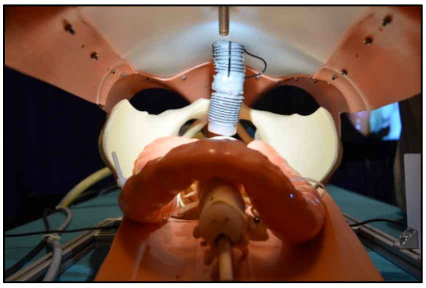

Figure 5: STIFF-FLOP arm entering the abdominal model built by FRK

KCL and SSSA exhibited the STIFF-FLOP project which aims to create a robotic arm based on an octopus tentacle. Its soft and even stiffness-controllable structure will allow surgeons to manoeuvre it gently around organs during keyhole surgery. This means it will be capable of reaching areas inside a patient's body that could not be reached previously. The new prototype of the STIFF-FLOP arm (shown in Figures 4 to 6) had not been on display previously. The demonstration was supported by SCHUNK who kindly provided their Powerball LWA.

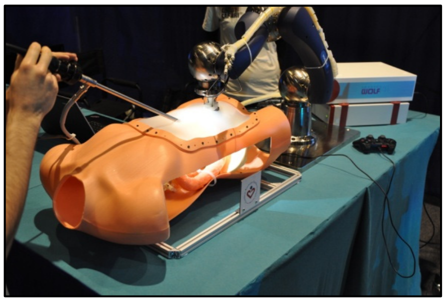

Figure 6: STIFF-FLOP arm attached to end

The BBC interview with Prof. Althoefer can be seen on http://www.youtube.com/watch?v=Xqi_XjewqtQ.

Development of a multi-module STIFF-FLOP manipulator

Scuola Superiore Sant'Anna (SSSA) worked on the development of a multi-module STIFF-FLOP manipulator. Figure 7 shows the general principle behind the manipulator.

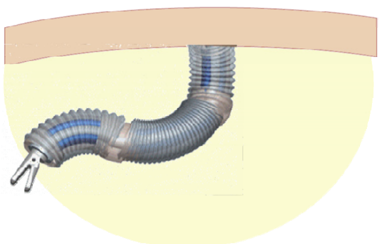

Figure 7: Design of the envisaged STIFF-FLOP manipulator.

The main focus of the research is the development of a manipulator composed of two interconnected modules, mainly addressing the problem on how to bring the actuation to the distal module and how to integrate both the granular jamming based stiffening system and the multiple sensor systems developed by King's College London (KCL). Force/tactile and bending sensors have been integrated in collaborations with KCL and partners are working on fusion and control using these sensors. Different prototypes of 2-module manipulators were fabricated and tested. In Figure 8, the 2-module manipulator is shown inside an abdominal phantom.

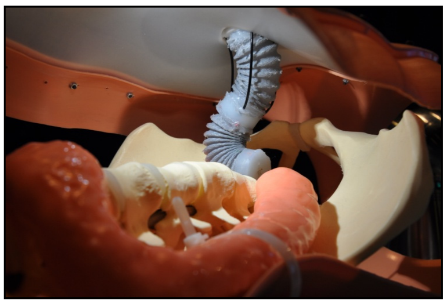

Figure 8: The 2-module STIFF-FLOP manipulator inside the phantom developed by FRK

UoS progress on the braiding sheet for soft robot

The University of Surrey (UoS) successfully validated the finite element model (FEA) of the silicone core of the actuator's kinematic behaviour using data from the robot arm.

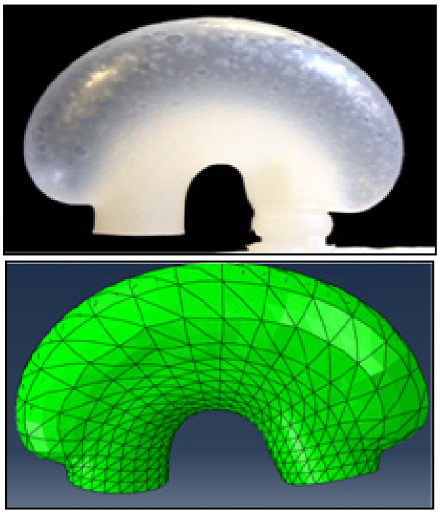

Figure 9: The silicone core of the STIFF-FLOP actuator under 0.65bar pressure and the corresponding, simulated behaviour.

The bending angle was monitored using a magnetic position sensor placed on the tip of the tube and the bending angle extrapolated in terms of the applied input pressure. The simulated bending angle for the same actuating pressure is plotted with the experimental results showing close agreement with regards to the shape of the pneumatic actuator and the obtained bending angle, Figures 9 and 10.

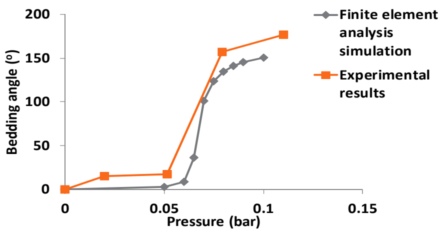

Figure 10: Validation of the FEA model by comparing the simulated bending angle with the experimental bending angle.

The behaviour of the crimped braided sleeve is highly non-linear raising the need for a proper understanding of the mechanical properties and physical behaviour. The orthotropic behaviour of a braided tube such as the one used in the polyester crimped braid for the STIFF-FLOP arm is modelled in finite element analysis software and the mechanical crimping process used to achieve the accordion-like shape of the bellows is simulated (Figure 11), allowing to optimise the fit of the mechanical properties of the braid which is very difficult to assess using conventional mechanical characterisation tools.

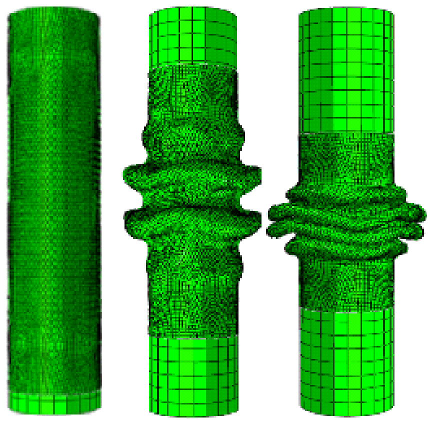

Figure 11: Simulation of the crimping process using Finite Element Analysis software

Control of the sensorised two segment arm

UoS successfully demonstrated the control of the sensorised two-segment robot arm in ROS using the new RoNex board developed by SHADOW (Figure 12).

The optical fibre based bending sensor was calibrated using the Vicon tracking system (see Figure 13) and the data from the Vicon system was used to improve the performance of the optic fibre sensors.

Figure 12: The two segment arm in action

As can be seen from the data presented in Figure 14, the bending angle sensed by the fibre optic sensors is accurate for deflection in a small range of the bending angle. Work to improve the sensor to operate accurately in a wider range is under progress.

Currently, the implementation of the remote control using FRK's 3D haptics and high level control using iterative linear quadratic Gaussian algorithm is under progress. A first remote control experiment between

FRK (Master side) and UoS (Slave side) was successfully conducted.

FRK was able to send commands to the STIFF-FLOP arm located at UoS via their delta robot input device. Communications were achieved using ROS operating via the internet.

Figure 13: Calibration of the bending sensor

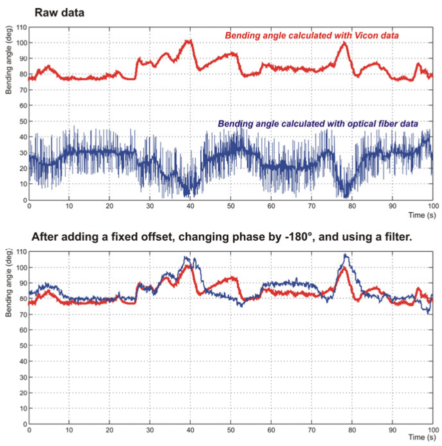

Figure 14: Comparison of the measurements of the bending angle

Incremental learning of skills

In order to improve the learning capabilities of the system and to allow the robot to work under different unexpected situations, the learnt skills can be refined, by taking inspiration from the way humans incrementally refine newly learnt capabilities by trial and error. In this case, expert demonstrations are used to initialize an exploration strategy, where slightly different behaviours (policies) are tested and evaluated towards a better execution of the skill. The improvement of the policy is obtained by using a Reinforcement Learning strategy, consisting in maximizing a predefined reward function, which takes into account the goals that should be achieved along the task. Within the scope of the project, the desired reward functions will be learnt from demonstrations with previously developed techniques (see Newsletter June 2013).

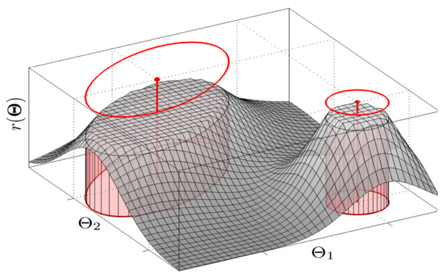

Figure 15: Reward value of two different policies in the parameter space. In this case, two policies are learnt: one has a higher reward, while the second is sub-optimal, but is fulfilled by a greater range of the parameters. The first is more precise in fulfilling the task and the second is more robust to perturbations. The choice between the two depends on the circumstances encountered along the task.

The final result is an optimal policy used by the robot to successfully complete the task. The high flexibility of the robot and the complexity of the environment suggest that there may be usually more than one way to perform the same task. For instance, a final position could be reached by using many different configurations of the robot or many different trajectories can be used to achieve the same goal. Therefore exploration strategies are needed that are able to cope with many different policies at the same time.

The concurrent learning of multiple policies allows the robot to adapt to new circumstances. If one of the options becomes unavailable, as for the sudden introduction of an obstacle, the robot can easily switch

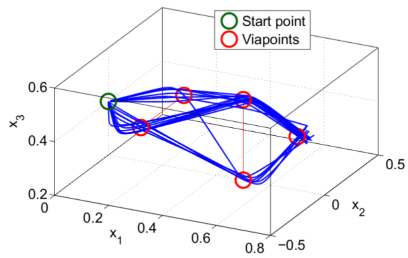

Figure 16: Multiple Policy Learning experiments: the DIPOLE algorithm was able to determine all available options of the task. The blue lines represent the discovered trajectories.

to an alternative policy without having to learn a new one.

Moreover, the robot could be able to exploit the policy that best adapts to the current circumstances. Figure 15 shows a possible scenario where two different policies are learnt simultaneously[1].

Within this context, a new algorithm called DIPOLE[2] was developed by IIT to simultaneously explore and learn multiple policies to solve a given task. The algorithm was tested on a multi-option task using a rigid WAM arm robot: the aim was to pass through a set of predefined targets at given times, with multiple possible options accessible at each time (Figure 16). The algorithm was able to successfully determine all the available strategies.

[1]Calinon et al. Robotics and Autonomous Systems 61:4 369-379 (2013)

[2]Bruno et al. Proceedings of the AAAI Conference on Artificial Intelligence (2013)

Towards position-based control

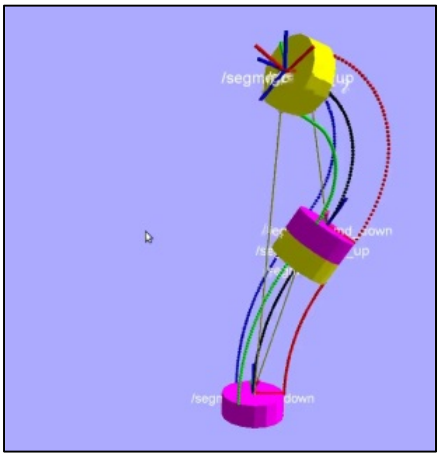

Figure 17: Simulated STIFF-FLOP robot arm

A joint integration work of IIT, Shadow and Tecnalia permitted to implement a first version of robot tip position controller in the STIFF-FLOP architecture. An inverse kinematic framework enables us to deduce the needed modules configuration from a targeted tip location, employing the constant curvature assumption. The desired configuration for each module can then be transmitted to each module controller, in charge of computing the appropriate combinations of pressures in the chambers. This implementation has been validated in simulation, as illustrated in the Figure 18.

The desired tip location can be provided by any control device following the STIFF-FLOP communication policy, and has been currently demonstrated with a regular joystick and the Omega 7 haptic device. The next step is to test whether this inverse kinematics approach also works with the real system. The advantage of the modular STIFF-FLOP architecture is that the current implementation could be easily tested on the real system - as soon as a module pressure controller and a module tip position estimator are provided, independent of the internal mechanisms used for these two components.

Figure 18: Omega 7 haptic device controlling simulated STIFF-FLOP arm

First benchmarking experiments of the STIFF-FLOP arm

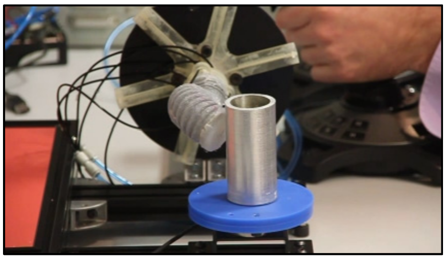

Figure 19: The STIFF-FLOP arm mounted on the benchmarking platform

King's College and Tecnalia conducted the first benchmarking experiments of the STIFF-FLOP arm concept, to analyse the behaviour of the system when interacting with its environment. As illustrated in Figure 19 the tested system was composed of an arm including two flexible structures, mounted onto a vertical support. By controlling the pressures in the chambers of the arm's modules, the tip of the arm gets into contact with an obstacle, and the magnitude of the contact forces is measured. Experiments were performed by augmenting the pressure in one (bending) or all chambers (elongation) of the module. Similar experiments were performed controlling the pressure in both modules at the same time. We also conducted experiments using a real organ (veal kidney). Considering that the arm is still at an early integration phase, the measurements obtained are likely to be improved upon once the system gets fully equipped, in particular, when integrating a position controller and a controllable stiffness mechanism. In the future, the same platform could also be used to compare the interaction forces measured by the arm sensor with the reading from the benchmarking platform. Such kind of experiments will permit to determine the quality of integration of the STIFF-FLOP arm components.

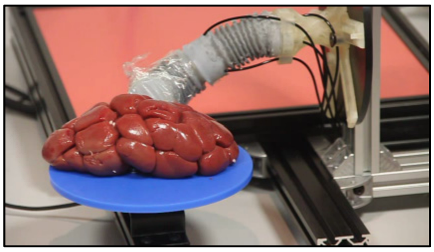

Figure 20: The STIFF-FLOP arm performing benchmarking experiments

Education – the important way to clinical application

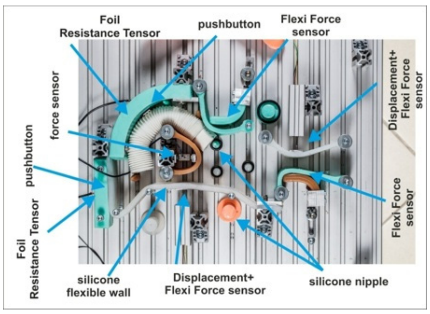

Figure 21: ENT test rig with flexible module inserted

The mission of the Foundation of Cardiac Surgery Development (FRK) is to introduce modern techniques and technologies for heart diseases treatment into clinical practice. It is also an educational centre; numerous conferences, meetings, presentations to exchange experiences of modern techniques and technologies used in surgery are held. Annual conferences "Medical Robots" and "Surgical Workshops", organised at FRK, are attended by many enthusiasts of modern surgery.

During the workshop's exercises it is possible to learn about the advancements in surgical instruments, from classic tools via laparoscopic instruments to highly advanced robotic surgical systems. We hope that soon robots and half-automatic surgical tools constructed by the team of FRK with the input from STIFF-FLOP will be used in clinics and hospitals, helping surgeons and their patients. In the past 10 years, about 1500 young enthusiasts who were interested in surgery visited the surgical workshop. For them, we prepare innovative research and training stations. We use our experience achieved by preparing testing stations for the STIFF-FLOP robot, see Figures 21 to 24.

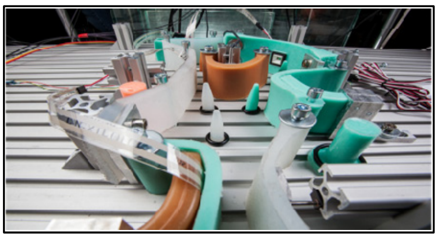

Figure 22: The example of deployment of basic elastic elements and sensors

The systems allows for the implementation of specific tests to verify the robot's manoeuvrability.

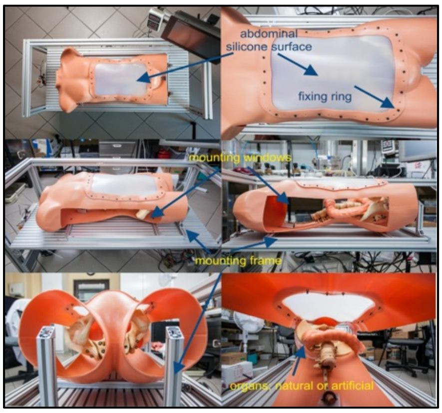

Figure 23: Anatomical model

Our next step for an anatomic test rig will be to develop a realistic 3D model of the human lower gastro-intestinal tract and of entire human abdomen to be used in conjunction with new STIFF-FLOP arm prototypes, with all technical characteristics as desired, in a 1:1 scale.

The operational area will enable us to install flexible elements to simulate abdominal organs, and will contain sensors, including force, tactile and displacement sensors. Each element can be easily adapted to the need of the benchmarking testing that is part of the STIFF-FLOP project.

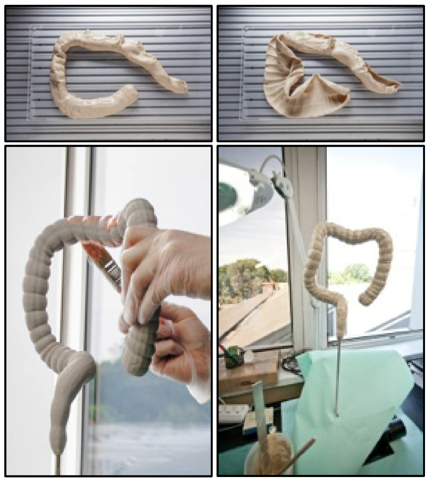

Figure 24: 3D model of Lower Gastrointestinal tract and Abdomen

The Shadow robot company released RoNeX

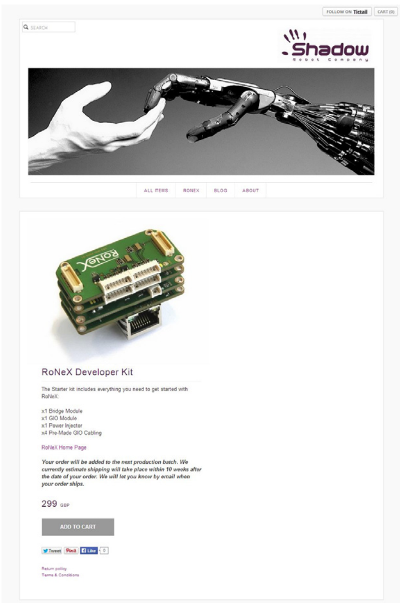

Figure 25: RoNex available in the online shop of the Shadow Robot Company

Shadow Robot Company has now commercialised the integration platform hardware developed in STIFF-FLOP. The commercial name for the system is RoNeX; it is now being manufactured and RoNeX modules are available for purchase on the Shadow Robot Company online shop (www.shadowrobot.tictail.com).
The RoNeX modules currently available are:

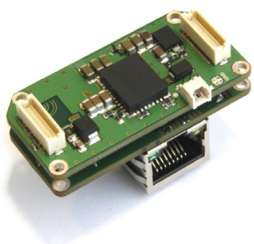

Figure 26: RoNex bridge

Bridge (In) Module:

- Connects Stack to Host PC
- Supports up to 5 Modules
- 12 to 50V DC power input
- 100Mbps data rate

General I/O Module:

- 12 General purpose digital I/O channels
- 12 Analogue sampling channels (12bits, 1kHz)
- PWM on all 12 digital channels

Figure 27: RoNex GIO

Further RoNeX modules are planned for development for the STIFF FLOP project.

14th World Congress Paris, June 25-28, 2014

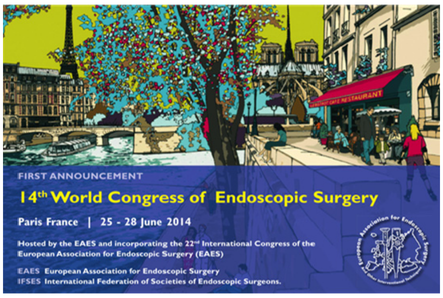

Figure 28: 14th world congress of endoscopic surgery

The 14th World Congress of Endoscopic Surgery will be held in Paris, June 25-28, 2014 under the auspices of the European Association for Endoscopic Surgery (EAES), the International Federation of Societies of Endoscopic Surgeons (IFSES) and in conjunction with several other societies, including the SFCE (Société Française de Chirurgie Endoscopique, SAGES (Society of American Gastrointestinal and Endoscopic Surgeons), the Endoscopic and Laparoscopic Surgeons of Asia (ELSA), Asia Pacific Hernia Society, International Society for Laparoscopic Colorectal Surgery (ISLCRS), Federación Latino Americana de Cirugia (FELAC), and Asociacion Latinoamericano de Cirugia Endoscopica (ALACE).

In this world congress STIFF-FLOP will be introduced to the consortium.

Joint Workshop on New Technologies for Computer/Robot Assisted Surgery, Verona, Italy, September 11-13, 2013

This workshop was supported by STIFF-FLOP and a number of EU projects focussing on the development of surgical robotic systems. The presentations gave a clear view on the status and recent trends of assistive surgical robotic technologies and aimed to propose concrete measures to achieve a critical mass in research and innovation in this field. In fact, regardless of its popularity, the share of European technology used in clinical practice remains disproportionally small, with limited signs of improvement on the horizon. The workshop continued the discussion started at ERF in Lyon and at ICRA in Karlsruhe and attempted to identify the steps necessary to stimulate cooperation among the projects in robotic surgery and the best approach to take advantage of the new funding opportunities in Horizon2020.

Figure 29: Organisers of the workshop

Publications and Press

Selected press releases and interviews:

Science Museum – Robot Safari[EU]:
http://www.sciencemuseum.org.uk/visitmuseum/Plan_your_visit/events/festivals/robot_safari.aspx
http://www.youtube.com/watch?v=HaQmTLRknW0#t=0

EU Robotics Week:
http://www.eu-robotics.net/eurobotics-week/events-2013/robot-safari-eu-3.html

European Commission – MEMO:
http://europa.eu/rapid/press-release_MEMO-13-11047_en.htm

BBC News:
http://www.youtube.com/watch?v=AIBS3MA2H-I

BBC World Service – Robots and us:
http://www.bbc.co.uk/iplayer/episode/p01m366d/In_the_Balance_Robots_and_Us/

On November 12, 2013 a poster presented by Guy Levy at the most important neuroscience meeting at San Diego (the Society for Neuroscience (SfN) with over 30,000 participants) was chosen out of more than 15000 abstracts by the journal Nature to be reported at Nature News online section of the Journal. Below is a short version of the abstract and the links to Nature News and various 'spin over' links that reported the HUJI findings. A paper describing these results is being prepared now for publication.

Citation of the SFN abstract:
G. Levy and B. Hochner. Coordination of flexible arms in the crawling behavior of the octopus. Program No. 169.12.2013 Neuroscience Meeting Planner. San Diego, CA: Society for Neuroscience, 2013. Online.

Article in Nature News:
http://www.nature.com/news/worm-like-movements-propel-octopus-ballet-1.14180

Podcast in Nature News:
http://www.nature.com/multimedia/podcast/neuropod/neuropod-2013-11-29.mp3
At 15:06 to 17:10

Report in the Hebrew University web-site:
http://support.huji.ac.il/HeaderMenu/news-events/press/press_octopus_movement_guy_levy/

Report in Scientific American:
http://www.scientificamerican.com/article.cfm?id=octopuses-propelled-by-worm-like-movement

Report in Ocean Society:
http://www.oceans-society.org/beyond-blue/news/science/octopus-can-execute-complex-movement-through-lacking-in-central-coordination/

Report in Science ORF (Austria)
http://science.orf.at/stories/1728632/

Report about the program that was broadcasted in the radio channel of Science ORF (Austria)
http://oe1.orf.at/programm/355132

Conference contributions:

Event:	**25th International Conference of the Society for Medical Innovation and Technology, Baden-Baden, Germany**
Title:	Surgical Snake-like Robots
Date:	5-7 September 2013

Event:	**Keynote Speech at Leeds Oncological Engineering Conference, Leeds, UK**
Title:	Stiffness controllability: A new paradigm for MIS robots
Date:	15-16 September 2013

Event:	**Richard Tiptaft Visiting Professorships, Guy's Hospital, London, UK**
Title:	On stiffness-controllable robots for minimally invasive surgery
Date:	11-12 July 2013

Event:	**Design of Medical Devices Conference, TU Delft, The Netherlands**
Title:	Soft robotics: A new approach for minimally invasive surgery
Date:	7-9 October 2013

Event:	**Invited talk at Waseda University Professor Atsuo Takanishi and Massimiliano Zecca**
Title:	Soft Robotics: A new approach for MIS
Date:	12 November 2013

Event:	**Research presentation at Ritsumeikan University, Kyoto, Japan, Professor Shinichi Hirai, Soft Robotics Laboratory**
Title:	Tactile sensing and stiffness-controllable robots
Date:	11 November 2013

Event:	**International Workshop on Soft Robotics and Morphological Computation Centro Stefano Franscini (CSF), Monte Verità, Ascona, Switzerland**
Title:	Preliminary mechanical design of a soft manipulator for minimally invasive surgery, *M. Cianchetti, T. Ranzani, G. Gerboni, C. Laschi, A. Menciassi*
Date:	14-19 July 2013

Event:	**the 3rd Joint Workshop on New Technologies for Computer/Robot Assisted Surgery Verona, Italy**
Title:	A modular soft manipulator with variable stiffness, *T. Ranzani, M. Cianchetti, G. Gerboni, I. De Falco, G. Petroni, A. Menciassi*
Date:	11-13 September 2013

Event: **IROS2013. Finalist for the best ICROS IROS 2013 Application Paper Award**
Title: STIFF-FLOP Surgical Manipulator: mechanical design and experimental characterization of the single module,
M. Cianchetti, T. Ranzani, G. Gerboni, I. De Falco, C. Laschi, A. Menciassi
Date:

Event: **Biomed Tech**
Title: Development of a Cable Actuated Joint for a Surgical Robotic Flexible Arm,
M. Zimmermann, T. Ranzani, A. Menciassi, B. Kellner
Date: 7 September 2013

Event: **Society for Neuroscience Meeting, San Diego CA**
Title: Coordination of flexible arms in the crawling behavior of the octopus,
G. Levy, B. Hochner
Date: 9-13 December 2013

Event: **Israel Society for Neuroscience, Eilat, Israel**
Title: Octopus crawling involves a unique strategy for arms coordination,
Guy L, Hochner B.
Date: 14-17 December 2013

Event: **Medical Robotics 2013 – Conference Zabrze, Poland**
Title: organised by Zbigniew Nawrat
Date: 13 December 2013

Event: **Fundacja Rozwoju Kardiochirurgii; Politechnika Śląska**
Title: Niestandardowe rozwiązanie problemu informacji zwrotej z pola operacyjnego dla konsoli robota STIFF-FLOP, *Kamil Rohr, Łukasz Mucha, Krzysztof Lis*
Date: 2013

Event: **NII Shonan Meeting on Cognitive Social Robotics: intelligence based on embodied experience and social interaction**
Title: Robot learning by imitation and exploration with probabilistic dynamical systems,
Sylvain Calinon
Date: November 2013

Event: **Workshop "Benchmarking of State-of-the-Art algorithms in Generating Human-Like Robot Reaching Motions", IEEE-RAS Intl Conf. on Humanoid Robots (Humanoids), Atlanta, Georgia, USA**.
Title: A task-parameterized probabilistic model based on dynamical systems, Sylvain Calinon
Date: October 2013

Event: **Workshop "From Safety to Comfort in the Humanoid Coworker and Assistant", IEEE-RAS Intl Conf. on Humanoid Robots (Humanoids), Atlanta, Georgia, USA.**
Title: Robot learning by imitation and exploration with probabilistic dynamical systems,
Sylvain Calinon
Date: October 2013

Event: **115th National Congress Italian Society for Surgery, Torino, Italy**
Title: NOTES, hypothesis and facts, *Alberto Arezzo*
Date: 13-15 October 2013

Event: **COLOPROCTOLOGY UPDATE, Vercelli, Italy**
Title: NOTES & SILS, *Alberto Arezzo*
Date: 9 December 2013

Event: **2013 Gastroenterology UPDATE, Bolzano, Italy**
Title: Notes, *Alberto Arezzo*
Date: 12 December 2013

Publications:

B. Hochner and T. Shomrat, "*The neurophysiological basis of learning and memory in an advanced invertebrate – the octopus*" in: Cephalopods Cognition edit: A-S. Darmaillacq, L. Dickel, J.A. Mather , Cambridge University Press (in press)

B. Hochner and T. Shomrat, "*The Neurophysiological Basis of Learning and Memory in Advanced Invertebrates The Octopus and the Cuttlefish"* in: Invertebrate Learning and Memory (2013), in the series, Handbook of Behavioral Neuroscience (Series Editor: Joe Huston, Düsseldorf, Germany), published by Elsevier/Academic Press. Title: Invertebrate Learning and Memory. Editors: Randolf Menzel and Paul R. Benjamin

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Advisory Groups

A number of advisory groups were set up and colleagues from different scientific backgrounds agreed to be members of these groups and provide advice to the project where required.

Special Interest Group

- Prof. Andreas Melzer, University of Dundee, UK
- Dr. Irion, Dr. Solleder, Dr. Nowatschin, Karl Storz, Germany
- Dr. Shamim Khan, Guy's Hospital London, UK

Peer Review Board

- Prof. Elena De Momi, Politecnico di Milano, Italy and Co-Investigator of EuRoSurge
- Prof K. Schilling, University of Wuerzburg (to be confirmed)

EAES Task Force

- Prof. Alberto Arezzo and Prof. Mario Morino, Digestive, Colorectal, Oncologic and Minimal Invasive Surgery, Department of Surgery, University of Torino, Italy
- Prof. Rajesh Aggarwal, Department of Surgery, Perelman School of Medicine, University of Pennsylvania, USA
- Prof. Yoav Mintz, Director of Center for Innovative Surgery, Hadassah-Hebrew University Medical Center, Jerusalem, Israel
- Prof. Carsten N. Gutt, Department of Surgery, Klinikum Memmingen, Germany
- Prof. Paolo Pietro Bianchi, Unit of Minimally-Invasive Surgery, IEO Istituto Europeo di Oncologia, Milan, Italy

The TASK FORCE for continuous clinical feedback and consultancy was established and the STIFF-FLOP project was presented officially to all members during the 2012 EAES annual meeting (in Brussels, 20-23 June 2012).