Newsletter

July 2015 **www.stiff-flop.eu**

EUROPEAN COMMISSION
European Research Area

SEVENTH FRAMEWORK PROGRAMME

2015 Review Meeting: A great success

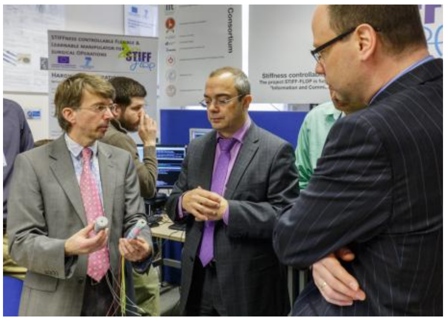

Figure 1: Prof Kaspar Althoefer demonstrates the STIFF-FLOP arm to the EC.

STIFF-FLOP held their year-3 review meeting at King's College London on 17 March 2015, for the first time with new Project Officer, Michel Brochard taking over from Christoph Klein. The three project evaluators continued to offer their expertise and helped to lead this project to success:

Professor Peter Brett
Brunel University, UK

Dr Ulrich Seibold
German Aerospace Center, GER

Professor Jaydev Desai
University of Maryland, USA

The event was part of a block review meeting with three other leading EU-funded research projects µRALP, CASCADE and ReMeDi.

The STIFF-FLOP consortium successfully showed their enhancements that had evolved during the past year including a new soft robotic manipulator with integrated stiffening and embedded force/torque sensors. The two-segment manipulator was mounted on a SCHUNK lightweight arm (LWA) and successfully operated inside a phantom model. Along with a new forward kinematics model, the STIFF-FLOP team demonstrated how learning algorithms can benefit surgeons during surgical interventions.

The project is now in the final year and all partners are currently preparing the cadaver tests to be conducted in Dundee in October and also the final review meeting which will be held again at King's College London.

Figure 2: The two-segment STIFF-FLOP arm with integrated sensors and stiffening mechanism mounted on a SCHUNK LWA, as presented to the Evaluators.

Issues:

For further information about STIFF-FLOP, please contact

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The 2015 Innovative Surgical Robotics Forum

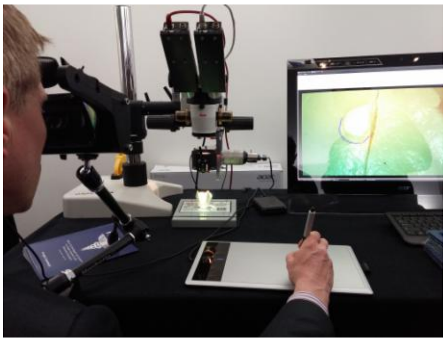

Figure 3: One of the four EU FP7 projects presented at the 2015 Innovative Surgical Robotics Forum: The µRALP system

At the block review meetings of the four EU FP7 projects STIFF-FLOP, µRALP, ReMeDi and CASCADE, pioneering cutting-edge techniques in the field of surgical and assistive robotics were demonstrated. The 2015 Innovative Surgical Robotics Forum was part of this series of review meetings, organised by King's College London in collaboration with the Knowledge Transfer Network UK (RAS SIG). Distinguished speakers talked about clinical needs and how to commercialise medical technology. This event brought together people from the medical field, engineers and researchers with entrepreneurial spirit.

The four projects were exhibiting their latest achievements. Details about the event, the list of speakers and media coverage can be found on the website of King's CoRe: http://surgical-robotics-2015.kings-core.com.

Figure 4: Prof Zbigniew Nawrat and Dr Ulrich Seibold (one of the Evaluators) discussing

Announcement of the STIFF-FLOP Autumn School in November 2015

The STIFF-FLOP consortium is planning an autumn school for young researchers in November. This meeting will be held jointly with the EAES EURO-NOTES workshop which will be in Torino later this year. This event will give a unique opportunity to learn about the evolution of the STIFF-FLOP project and future research developments from invited speakers and members of the STIFF-FLOP team.

More details about the STIFF-FLOP autumn school will be soon published on the project's website www.stiff-flop.

Figure 5: Current STIFF-FLOP manipulator operating inside a 2:2 scale phantom environment of the abdominal area.

Keynote talk at the "The Future of Robotics in Surgery"

Professor Kaspar Althoefer was invited to present the latest achievements of the STIFF-FLOP project at the event "The future of robotics in surgery" jointly organised by the Royal Society of Medicine and HTC Robotics Section on 5 February 2015.

In recent years, surgical techniques have evolved rapidly. The introduction of minimally invasive surgery (MIS) and robotically-assisted MIS have resulted in faster recovery rates for patients, with reduced post-operative pain and minimal scarring.

This one-off meeting aimed at bringing together academic and commercial experts in disruptive engineering solutions to review the latest surgical robotic research and identify where future innovation in this field can benefit patients.

Stiffness controllability for external disturbances

The University of Surrey (UoS) is working towards designing, prototyping and testing a new stiffness control and disturbance rejection system for continuum soft surgical manipulators. The study on performance characteristics of a single module of the soft hyper-redundant STIFF-FLOP manipulator led to the development of a new theory to formulate the dynamic stiffness matrix, which is useful for real-time stiffness control. Constraining the manipulator end effector, UoS were able to capture the forces acting on the tip employing a 3-axis force sensor whilst applying small changes in chambers' pressure.

Different sets of operating conditions result in deriving multiple dynamic stiffness matrices based on the region of operation. Experiments were conducted to derive an empirical description of the characteristics of the manipulator capturing the varying stiffness effects of the actuated arm and consequently realise feedback control response in real-time.

The current system shows high stability when applying a disturbance force of up to 2.5 N with an improved displacement of about 85% compared to the system without stiffness control. The results are promising as it will help to execute accurate procedures with greater flexibility.

Improvement of the robustness of the STIFF-FLOP ROS system map

With all the work that has been done since the beginning of the STIFF FLOP project, priority has been given to enhance the robustness of all the code that has been developed. At the beginning of the project, Shadow set up a number of tools to control the quality of the code. The Shadow robot company investigated how to improve those tools and ensure that all partners have a good set of generic tools for checking ROS code quality.

Shadow sees this as an interesting push for the ROS community in general since apart from ensuring a high code quality, it also makes it easy for users to see the quality level of the code.

Shadow is currently providing multiple level of testing:

- simple build,
- unit tests,
- code coverage,
- static code style checks.

In the near future, the STIFF-FLOP system map will also benefit from:

- integration tests,
- hardware tests,
- automatic nightly builds for easy deployment.

These achievements will be presented during ROSCon 2015 in Hamburg (3-4 October 2015).

Surgeons testing STIFF-FLOP at Guy's Hospital, King's College London

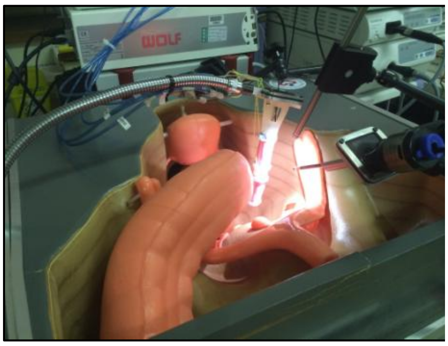

Figure 6: A two-segment STIFF-FLOP manipulator inside the 2:1 scale phantom environment created by FRK.

The STIFF-FLOP team organised tests with the current technology available, consisting of a 2 modules prototype, connected to a rigid arm fixed by a handle and inserted into a sensorised 3D test rig platform prepared by FRK. 17 novice surgeons and students and 8 experienced surgeons from Guy's Hospital were asked to perform Spatial Motion Tests. In this test, the volunteers were had to move the STIFF-FLOP manipulator between defined locations inside the phantom avoiding any contacts with organs and model walls. The volunteers had a maximum of 3 minutes to complete this task. After the performance of the test with the use of the STIFF-FLOP arm the volunteers repeated the same sequence with a conventional laparoscopic forceps.

Finally, the volunteer repeated the same sequence again with the STIFF-FLOP manipulator, in order to verify any learnability of the robotic technique. To analyse the test results, two factors were collected: total time to complete the task, and total number of contacts between the manipulator (any part of the manipulator) and the organs or model walls. We also asked the testers to answer the questionnaire. Initial results will be presented at the 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society in Milan in August 2015.

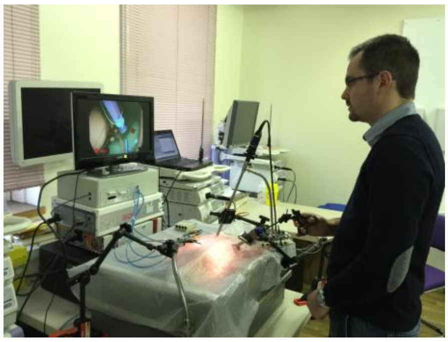

Figure 7: Experimental tests at Guy's Hospital using the STIFF-FLOP system and a laparoscopic tool.

Double chamber approach for enhanced actuation capabilities

A STIFF-FLOP manipulator is composed of several modules or segments. One target of the consortium is to connect and control up to three modules in series, each connected to the previous one via a KCL force/torque sensor. Along with wires of the sensors and a tool at the tip, pipes supplying each chamber with pressurised air have to be fed to each segment in an integrated way. An inner free chamber is created that serves as a guidance channel for tubes and wires. Hence, the diameter of the actuation chambers is reduced in order to generate this free space. Reducing the diameter of the actuation chambers leads to a decreased actuation cross-section area, and hence, reduced actuation capabilities. Additionally, the manipulator behaviour deteriorates when the pressure is raised above a certain value causing the actuation chamber to fold instead of the module to bend. To improve this behaviour, a double actuation chamber construction has been designed and tested (Figure 8). Doubled chambers allow reducing the size of the actuator in radial direction and preserve its capabilities at the same time. The chambers are connected at the tip of the module, so that no additional pressure cables are required.

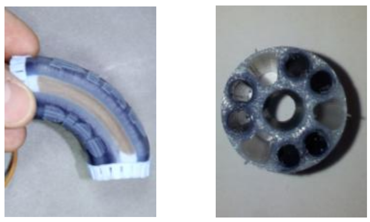

Figure 8: The new improved double channel design makes it possible to reduce the size of the actuator in radial direction

Visual detection of the STIFF-FLOP arm

The objective for the vision system is to provide position information of the STIFF-FLOP arm and to fuse the processed data with the information from other sensors.

The challenging aim USiegen faces with the vision system is to detect the STIFF-FLOP arm which can change its shape by bending and elongating. The position and orientation of the entire manipulator will also vary during an operation. Due to the flexibility of the STIFF-FLOP arm, occlusions might occur so that the robot is only partially visible and the vision algorithm must be capable to compensate for these cases.

The aim of the USiegen team is to implement a method that is automatically trained and capable of providing the STIFF-FLOP arm detection with a high performance. Having thoroughly reviewed robust vision algorithms, the implementation of a method based on Support Vector Machines (SVMs) was selected.

SVMs describe a texture based pattern recognition method which is well capable to classify different objects. The basic idea for this method is that not the entire image is analysed as a whole but it is split into smaller sub-images which are processed and classified whether they contain the STIFF-FLOP arm or the background.

Initially, the method is trained using known objects which are already classified. In our case, they are classified as “STIFF-FLOP arm” and “Background”. Afterwards the trained data is used for a fast detection in a real-time application which is integrated in ROS. For the training some sample files are selected which show the STIFF-FLOP arm.

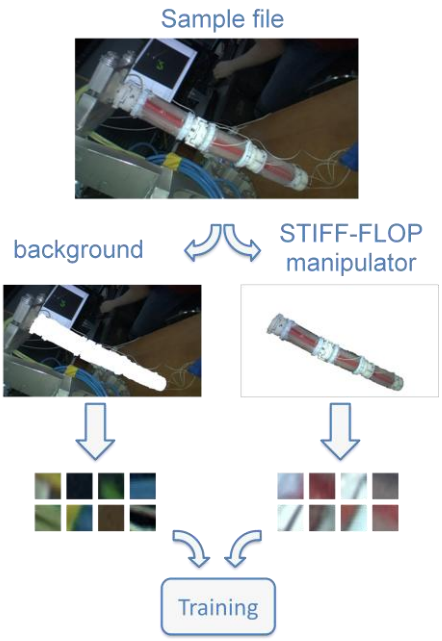

Figure 9: Training procedure for the SVM method

In these images, the STIFF-FLOP arm is separated from the background as illustrated in the Figure 9.

The STIFF-FLOP arm as well as the background are split up into small sub-images and fed into the training procedure which divides those sub-images by a hyper plane in a vector space. This data is saved and used for the real-time tracking.

During the real-time tracking of the STIFF-FLOP arm, the image is split up into small sub-images again which are classified by the trained hyper plane whether they contain the STIFF-FLOP arm or the background.

The connected sub-images containing the STIFF-FLOP arm are selected to calculate the centre line of the arm. The diameter of the STIFF-FLOP arm is calculated perpendicular to the centre line (see Figure 10).

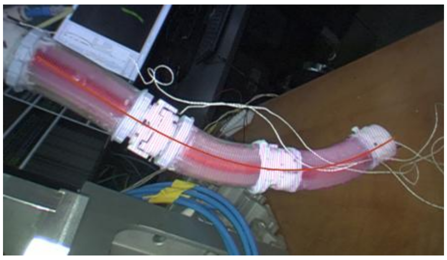

Figure 10: The STIFF-FLOP arm with the detected centreline (red) and diameter (purple)

The centre line delivers the horizontal and vertical position of the STIFF-FLOP arm in the coordinate system of the camera. The distance to the camera is estimated by analysing the diameter of the arm.

The resulting position of the STIFF-FLOP arm in the coordinate system of the camera is published in ROS.

Learning autonomous behaviours from demonstrations

One of the challenges arising when using a flexible robot for surgical procedures comes from the need of controlling the redundant degrees of freedom of the manipulator. In fact, the surgeon is interested in controlling the end-effector of the robot to reach the intervention area and perform the surgical task; the flexibility of the robot should not be an additional task for the user, but only a means to bring the instruments mounted on the end-effector to the desired location.

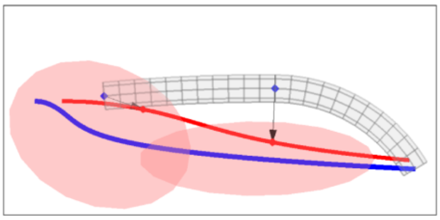

Figure 11: The algorithm that is used to control the body of the robot. The red ellipses represent the model of the variability of the end-effector during the task, the blue line is the average trajectory, the red line represents the minimum curvature compromise.

Within this framework, IIT developed a positional controller for the body of the flexible robot that is able to learn the correct behaviour for the body of the flexible manipulator from the movements made by the end-effector that is directly controlled by the surgeon.

The algorithm is based on a statistical model of the movements performed by the surgeon that is incrementally generated as the surgical task is carried on. This statistical model is aimed at keeping track of the possible variability of the movements of the surgeon inside the abdomen.

The only additional requirement for the doctor before starting the surgical task is to explore as much as possible the available space inside the abdominal area. The controller is then implemented by projecting the desired displacement commands in the null space of the robot, in order not to interfere with the commands that the surgeon is giving to the end-effector. The resulting displacement of the body is generated by exploiting the allowed variability to keep the robot close to a minimum curvature shape. This allows a better manipulability of the end effector together with a greater distance from the hardware limits of the structure.

The algorithm was tested in simulation and was able to smoothly drive the robot inside a simulated constrained environment.

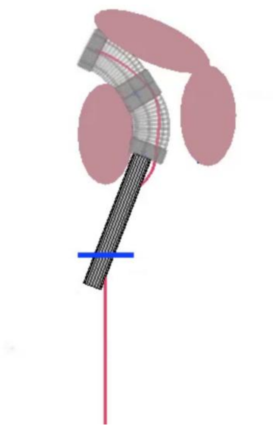

Figure 12: The STIFF-FLOP robot body is controlled to enter inside a constrained environment.

6 DOF inverse physics-based inverse kinematics

The inverse kinematics algorithm described in the previous newsletter has been improved to enable the tip of the manipulator not only to reach the goal position, but also to control its orientation.

Figure 13 shows the manipulator behaviour while the desired position is changing and the orientation is fixed. The right figure illustrates the change of the orientation of the tip while the position is fixed.

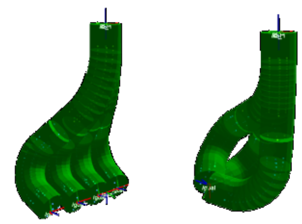

Figure 13: Change of the position, orientation fixed

HUJI's progress in the STIFF-FLOP project

This year, the HUJI team has completed three major and very important studies.

In one [Richter *et al.*, 2015], we reveal a new aspect of flexibility of the motor control system of the octopus by showing how arm movements are modulated under (specific) new and unfamiliar constraints. Octopuses that were limited in reaching to targets with only one arm through a hole in a transparent wall revealed quick adaptation to the novel situation by using alternative, suitable motor programs instead of the conventional one used in the normal, unconstrained environment.

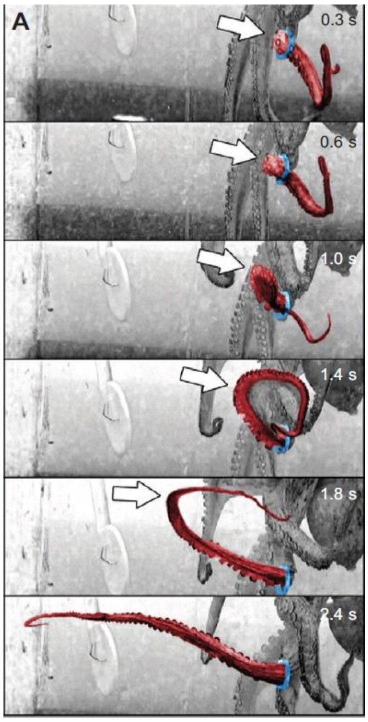

Figure 14: Picture sequence of a typical straight reaching and fetching movement of an octopus arm in a constrained situation.

In the next study [Levy *et al.*, 2015], we show the unique strategies

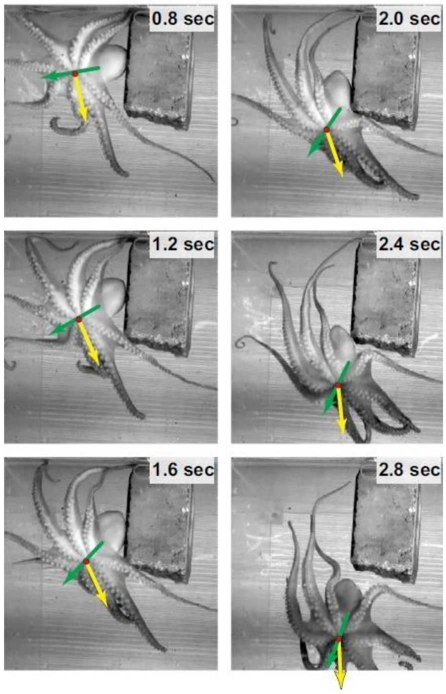

Figure 15: Six time frames from crawling sequences. Green arrows mark body directions; yellow arrows give the crawling direction.

which are used by the octopus to coordinate its arms in the crawling behavior. The extreme hyper redundancy of its body prevents the octopus from using common strategies for arm coordination. Instead, unique and brilliantly simplified control strategies emerged, in an embodied fashion during evolution, in the body and nervous system of the octopus and in the interactions between them. The unique strategy exploits the radial symmetry of the arms around the body to enable crawling in any direction relative to the facing direction while independently controlling the facing direction relative to the ground, and by using instantaneous decisions to coordinate the arms rather than by basing arm coordination on the output of central pattern generators.

In the third study [Hanassy *et al.*, 2015], we give an elaborated description of the reaching movement of the octopus arm, that is complementary to our findings from 19 years ago [Gutfreund *et al.*, 1996]. We show that arm elongation is an essential component in the reaching movement, and the flexibility of the motor program in reaching is based also on the dynamic combination between bend-propagation and arm-elongation.

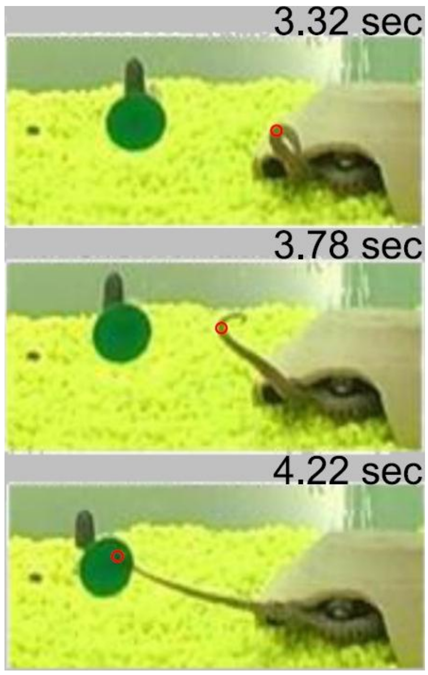

Figure 16: The octopus fetching movement.

Publications:

Matthias Mende, Erwin Gerz, Hubert Roth, **"Evaluierung eines magnetischen Tracking Systems für den Einsatz in einem neuartigen minimal-invasiven chirurgischen Robotersystem",** IEEE Workshop 2015 Medizinische Messtechnik, Vortragsreihe an der Hochschule Ruhr West, Mülheim an der Ruhr, Germany, 17.04.2015

Erwin Gerz, Matthias Mende, Hubert Roth, **" Optische Detektion und Positionsbestimmung eines neuartigen flexiblen minimal-invasiven chirurgischen Robotersystems",** IEEE Workshop 2015 Medizinische Messtechnik, Vortragsreihe an der Hochschule Ruhr West, Mülheim an der Ruhr, Germany, 17.04.2015

J. Fraś, J. Czarnowski, M. Maciaś, J. Główka, M. Cianchetti, Member, IEEE, A. Menciassi, Member, IEEE , **"New STIFF-FLOP module construction idea for improved actuation and sensing",** ICRA 2015

S. Hanassy, A. Botvinnik, T. Flash, and B. Hochner, **"Stereotypical reaching movements of the octopus involve both bend propagation and arm elongation."** Bioinspiration & biomimetics 10, 035001 (2015).

Guy Levy, Tamar Flash, and Binyamin Hochner, **"Arm Coordination in Octopus Crawling Involves Unique Motor Control Strategies."** Current Biology 25, 1195 (2015).

Jonas N Richter, Binyamin Hochner, and Michael J Kuba, **"Octopus arm movements under constrained conditions: adaptation, modification and plasticity of motor primitives."** The Journal of experimental biology 218, 1069 (2015).

Danilo Bruno, Sylvain Calinon, and Darwin G. Caldwell, **"Learning the stiffness of a continuous soft manipulator from multiple demonstrations"** ICIRA 2015, The 8th International Conference on Intelligent Robotics and Applications, 24-27.08.2015, (submitted 12th June 2015)

Angela Faragasso, Agostino Stilli , Joao Bimbo,Helge Wurdemann and KasparAlthoefer, **"Visual Sensing Mechanism for Real Time Stiffness Computation in Endoscopic Surgery"**, Robotics: Science and System Conference Workshop, July 2015.

Angela Faragasso, Agostino Stilli, Joao Bimbo, Helge Arne Wurdemann, Kaspar Althoefer, **"Multi-axis Stiffness Sensing Device for Medical Palpation**", International Conference on Intelligent Robots and Systems, IROS 2015.

Helge A. Wurdemann, Agostino Stilli, and Kaspar Althoefer, **"Lecture Notes in Computer Science: An antagonistic actuation technique for simultaneous stiffness and position control"** ICIRA 2015, The 8th International Conference on Intelligent Robotics and Applications, 2015.

Helge A Wurdemann, Sina Sareh, Ali Shafti, Yohan Noh, Angela Faragasso, Hongbin Liu, Kaspar Althoefer, **"Embedded electro-conductive yarn for shape sensing of soft robotic manipulators"** EMBC 2015, International Conference of the IEEE Engineering in Medicine and Biology Society, 2015.

Shan Luo, Wenxuan Mou, Kaspar Althoefer, and Hongbin Liu, **“Novel Tactile-SIFT Descriptor for Object Shape Recognition”** IEEE Sensors Journal, in press, 2015.

Shan Luo, Wenxuan Mou, K. Althoefer, and H. Liu, **“Localising the Object Contact through Matching Tactile Features with Visual Map”**, Proceedings of the IEEE International Conference on Robotics and Automation (ICRA), Seattle, U.S.A, May 2015.

Sina Sareh, Yohan Noh, Tommaso Ranzani, Helge Arne Wurdemann, Hongbin Liu, Kaspar Althoefer, **“A 7.5mm Steiner chain fiber-optic system for multi-segment flex sensing”** International Conference on Intelligent Robots and Systems, IROS 2015.

Ali Shafti, Federica Andorno, Nicola Marchese, Simone Arolfo, Abdullatif Aydin, Oussama Elhage, Yohan Noh, Helge A. Wurdemann, Alberto Arezzo, Prokar Dasgupta and Kaspar Althoefer, **“Comfort and Learnability Assessment of a New Soft Robotic Manipulator for Minimally Invasive Surgery”** EMBC 2015, International Conference of the IEEE Engineering in Medicine and Biology Society, 2015.

S.M. Hadi Sadati , Yohan Noh, S. Elnaz Naghibi, Althoefer Kaspar, and Thrishantha Nanayakkara, **"Stiffness Control of Soft Robotic Manipulator for Minimally Invasive Surgery (MIS) Using Scale Jamming*"** ICIRA 2015, The 8th International Conference on Intelligent Robotics and Applications, 24-27.08.2015, (submitted 12th June 2015)

Alexander Jupp, Thomas Manwell, Kaspar Althoefer, and Hongbin Liu, **"Surface Classification for Crawling Peristaltic Worm Robot"** ICIRA 2015, The 8th International Conference on Intelligent Robotics and Applications, 24-27.08.2015, (submitted 12th June 2015)

Patents in progress:

- Patent about manipulator with multiplied actuation chambers
- Patent about enhanced soft manipulator manufacturing technology
- Patent about manipulator with reinforced chambers by single thread. (pending)
- Patent about manipulator with reinforced chambers manufacturing technology. (pending)

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
- Dr. David Noonan, New York, USA

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. The STIFF-FLOP project was presented officially to all members during the 2012 EAES annual meeting (in Brussels, 20-23 June 2012).