MR-compatible Bio-inspired Soft Manipulator with Stretchable Sensing Sleeve for RMIS*

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In robot-assisted minimally invasive surgery (RMIS), robotic tools enter the body through narrow openings and manipulate soft organs that can move, deform, or change in stiffness. The traditional robotic manipulation concepts that rely on fixed stiffness distributions, such as with the da Vinci Robotic System, have limitations on these laparoscopic and robot-assisted surgical procedures due to restricted access through Trocar ports and lack of haptic feedback. More importantly, difficulties occur due to rigid robot tools operating inside a confined space filled with organs. This can also lead to tissue tears since the surgeon does not have haptic feedback from the strong mechanical power of the rigid robotic arms.

King's College London leads the EU FP7 project called STIFF-FLOP which addresses some of the challenges to do with stiffness control of current RMIS systems. The aim is to develop a soft manipulator with controllable stiffness that is inherently safe for the patient.

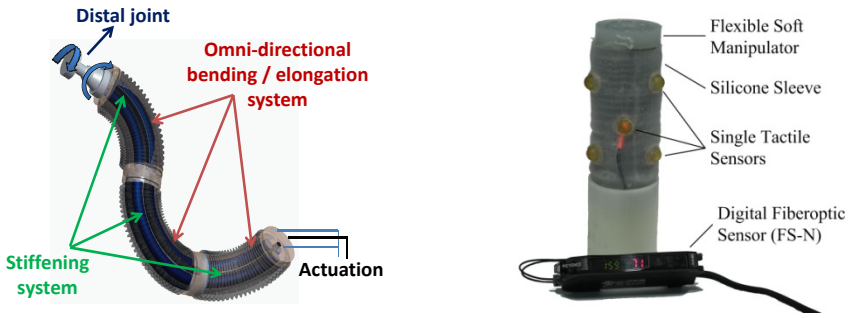

Figure: CAD drawing of the overall architecture of the STIFF-FLOP manipulator (left) and one single soft manipulator module of the stretchable sensor sleeve with multiple tactile sensors (right).

Based on gained knowledge of the octopus biomechanics, Scuola Superiore Sant'Anna (SSSA) produced guidelines for the manipulator design which resulted in the development of a single manipulator segment (module) taken inspiration from the octopus' functionalities relevant for the intended surgical application. Medical specifications were considered in detail for the technological analysis, blending surgical requirements and constraints with biological inspiration. After evaluating several soft actuation technologies, the proposed design consists of a multi-chamber pneumatic actuation system for bending and elongation and a granular jamming based solution for stiffening (see left figure). This coupling allows the generation of the desired movements combined with the possibility of simultaneously tuning the passive stiffness of the structure. Moreover the choice of such soft actuators confer a high degree of squeezability to the device which can be compressed and highly deformed (for example during the insertion procedure) without affecting the manipulator functionalities.

In order for the STIFF-FLOP soft manipulator to reconfigure itself and to control its pose to avoid any damage to organs and to provide haptic feedback to the surgeon, tactile sensors are integrated with the structure of this modern soft flexible laparoscopic tool. An MR-compatible bio-inspired tactile sensor sleeve which takes inspiration from the sensing mechanism in cucumber tendrils has been developed at KCL. In order to acquire tactile signals independent of the soft structure of the actuator during manipulation, retractable hemispherical tactiles were developed based on intensity modulated sensing techniques and distributed along the robot (see right figure). Due to the basic structure of a single tactile sensor, it is miniaturiseable and suitable for MIS. Multiple sensors are connected along the arm by a sleeve of a softer material. The main achievement of the developed sensor system is that each tactile sensor independently functions despite of any elongation or bending of the manipulator.

The STIFF-FLOP robotic arm imitates features of the octopus of being soft, able to elongate and able to control the arm's stiffness. Hence, the arm will reconfigure itself and stiffen by pneumatic actuation to perform compliant force control tasks while facing unexpected situations or bending around organs to reach the surgeon's area of intervention and operate on parts of the body that could not be reached previously. The STIFF-FLOP project will allow pushing the boundaries of current medical robotics technology and will develop an ergonomic RMIS system based on soft manipulation.

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