“systemoverview.png”

Overview of the robotic system. (a) Illustration of the soft fluid-driven robot positioned in the larynx through the oral cavity (left) and aiming at a laryngeal tumor. Intra-op MRI can be introduced to provide the operator with fine monitoring of the laser ablation progress (top right). (b) Overview of the five DoFs endoscopic motion. Pan-and-tilt are provided by both the active bending section and the laser manipulator. The passive bending section facilitates insertion and retraction of the robot by transferring rotation of the hydraulic actuator to linear motion. (c) Side view (top) and below view (bottom) of the soft laser manipulator, which enables omni-directional laser beam steering inside a protective outer shell. (d) Patient-specific dental guard designed for robot anchorage and creating an open-jaw position of the patient.

“lasermanipulatordesign.png”

Design of the soft robotic laser steering system. (a) Laser manipulator integrating three soft chambers with rigid spring reinforcement constraints. An outer shell protects the robot bending and laser steering from external disturbances. The hyper-elastic chambers are 3D-printed from flexible AgilusClear30. The outer shell and SRCs are 3D-printed from VeroClear. (b) The laser lens is housed in the center channel of the laser manipulator and can be steered omni-directionally.

“activebendingsection.png”

Active bending section with length of 24 mm and outer diameter of 9.2 mm, comprising of three soft chambers with individual spring constraints.

“fea.png”

Design optimization of the spring reinforcement constraint. (a) Finite-element-simulated deformation of the laser manipulator at a bending angle of 10°, and stress distributions under three different settings: zero, one and two spring partitions. A single chamber was pressurized to induce bending. (b) Effective bending angle versus applied pressure to the soft chamber, varied from zero to five spring partitions. (c) Maximum von Mises stresses in each model plotted against bending angle.

“lasercollimator.png”

(a) GRIN lens pigtailed with laser fiber. (b) Laser beam profile emitted from three types of fiber ends.

“mechanicalresponse.png”

Mechanical performance test. (a) Angular range of the soft laser manipulator. (b) Bode plot showing the dynamic response of laser lens steering. (c) Robot durability test performed by repeatedly actuating the laser manipulator 2,000 times over 1 hour. (d) Hysteresis test during fluidic inflation and deflation of the soft chambers.

“mechanicalresponse\_bending.png”

Mechanical performance testing for active bending section. (a) Angular range. (b) Following a path on projection plane in numerous cycles. (c) Repeatability of the path following.

“dentalguard.png”

(a) Dental impression with a fast set alginate. (b) Dental plaster molded using the impression body. (c) 3D dental feature obtained from optical scan. (d) Custom-made dental guard with two instrument channels.

“hydraulicmotor.png”

Two-cylinder actuator driven by master-slave hydraulic transmission. Rolling diaphrams are integrated to provide fluid sealing while ensuring minimal sliding friction.

“hydraulicmodeling.png”

Dynamics model of fluid transmission over a pipeline. Input force Fin is employed to push Piston 1, with force Fout applying at the output side. The cross markers “×” below three masses denote the fluid damping.

“tablehydraulic.png”

Nominal values of design parameters in simulation

“tablehydraulicparameter.png”

Physical parameters of the hydraulic transmission system

“simulationhydraulic.png”

Simulation showing the trend of transmission stiffness against: (a) pipe inner diameter; (b) pipe length; and (c) piston diameter. It can be observed that the stiffness profile is significantly affected by the pipe materials: PA 6, PA 66, PTFE and PU.

“hydraulicstepresponse.png”

Step response of a single cylinder transmission, which were measured in two different steps of magnitudes. Experimental and modeled responses are compared. The response time from the signal input is within 40 ms.