Year-2 Publishable Summary

March 2014

1. Project objectives

Lasers form an increasingly common tool for precision treatment of pathological conditions on delicate and vital human organs. Laser phonomicrosurgery, which is a suite of complex otolaryngological surgical techniques for the treatment of minute abnormalities in the larynx, is one such example. However, laser aiming control for this procedure relies completely on the dexterity of surgeons, who must operate through a microscope and deal with its associated poor ergonomics, and this can have a strong impact on the quality of the procedures. In addition, the laser beam is directed from a comparatively large range (400mm), resulting in accuracy and consistency problems, and requiring extensive surgeon training. In this multidisciplinary project a redesign of this surgical setup is being pursued to create an advanced augmented micro-surgical system through research and development of real-time cancer tissue imaging, surgeon-machine interfaces, assistive teleoperation, intelligent (cognitive) safety systems, and augmented-reality. Furthermore, research and development of new endoscopic tools and precision micro-robotic end effectors will allow relocating the laser actuator closer to the surgical site. This will result in unprecedented levels of accessibility and precision, while the surgeon will operate in a more ergonomic, information-rich, and assistive environment. The outcomes of the project will be improved quality, safety, and effectiveness in laser phonomicrosurgery, enabling total tumor removal with minimal damage to healthy tissue. The research efforts herein are generating new knowledge in the design and control of medical micro-mechatronic devices; cancer tissue imaging; assistive teleoperation in medicine; physician-robot interfaces; and cognitive systems for surgery. These technological advances will pave the way towards new and safer minimally invasive laser microsurgeries, leading to a significantly enhanced capacity for cancer treatment in general.

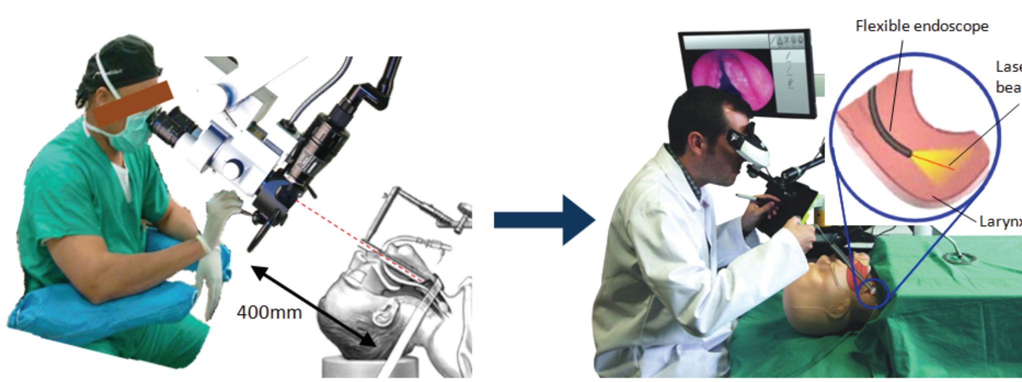

Fig. 1: The µRALP concept: from the gold-standard open-air laser phonomicrosurgery (left) towards safe and accurate endoscopic micro-robot-assisted laser phonomicrosurgery with fluorescence-based cancer detection (right).

2. Consortium

The µRALP project is performed by the following consortium:

Istituto Italiano di Tecnologia (Coordinator), Genova, Italy

Institut FEMTO-ST, Université de Franche-Comté, Besançon, France

Leibniz Universität Hannover, Germany

Università degli Studi di Genova, Italy

Centre Hospitalo-Universitaire, Besançon, France

3. Work performed and achievements

Based on the specification and medical guidelines defined at the beginning of the project, a tremendous activity was recorded on the design, development and evaluation of:

- An actuated laryngoscope with two continuum sections able to adapt to the curvature of the patient's neck (Fig 2). It also features a motorized distal tip deflection system, which is designed to integrate the laser beam deflecting micro-robot, the white light illumination system, and the stereo camera system.
- A hyperspectral cancer imaging system based on an optical fiber bundle, which is already being test on clinical trials involving human tissue excised from diseased larynxes (Fig.3).
- A multi-view high-speed imaging system based on optical fiber bundles, which is being used for the development and testing of new algorithms for precise visual servoing of the laser beam.
- An out-of-plane micromanipulator with parallel kinematics, fitting in a 1cm3 volume and able to scan the vocal fold at a 2cm distance (instead of 400 cm in the current gold-standard system);
- µRALP Surgical Cart, created to integrate the entire surgical system in a compact and ergonomic setup compatible to operating rooms. It already features integrated prototypes of novel surgeon interfaces for visualization and intuitive laser control, including augmented reality features for surgical planning and supervisory safety systems.
- Cognitive systems for safety supervision and control based on learned models of laser-tissue interactions, which are able to predict tissue temperature dynamics and laser incision depth.
- Tissue depth estimation (3D reconstruction) solutions for enhanced intraoperative surgical planning and visualization, which also enable improved laser incision quality and precision through automatic focus adaptation and tissue motion compensation (Fig. 4).

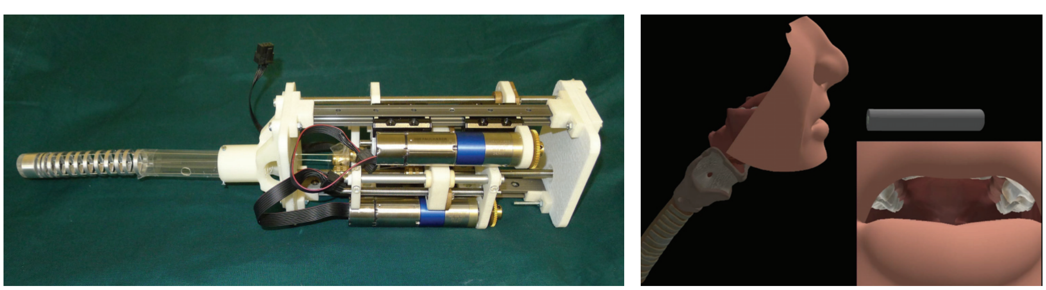

Fig. 2: Proof-of-concept actuated laryngoscope prototype incorporating adaptive shaft and multifunctional deflectable tip (left). Graphical 3D simulator demonstrating the µRALP concept of robot-assisted endoscopic laser phonomicrosurgery (right).

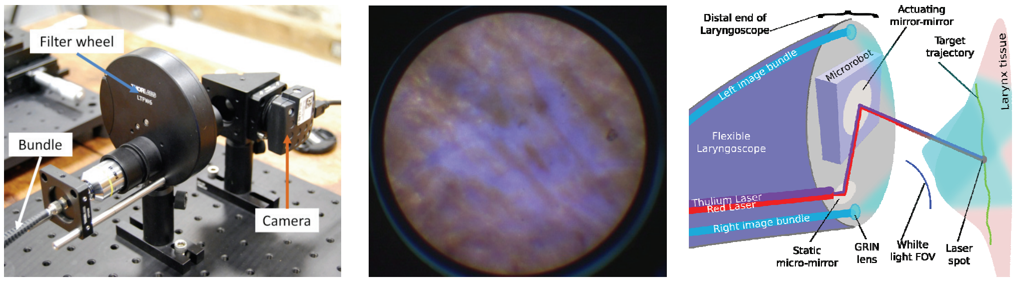

Fig. 3: Hyperspectrum fluorescence imaging prototype (right) and a sample image captured with the device (center). Schematic view of the stereoscopic high-speed imaging system (right).

- A graphical 3D simulator that demonstrates the µRALP concept of robot-assisted endoscopic laser phonomicrosurgery.

Intensive collaboration has been taking place between the participants since the beginning of the project, allowing the jointly development of the µRALP concepts and prototypes, which are already undergoing integration. Research visits and exchanges between partners have been set as a priority for joint developments, adding to a total of 61 physical meetings at the end of the second project year. Two integration weeks were held in Hannover, bringing together all partners and their prototypes for discussions, synchronization and physical systems integration.

The project achievements have been regularly shared with the scientific community and the general public. The consortium has published one journal paper in The Laryngoscope, 24 peer-reviewed conference papers, 37 abstracts, and two book chapters. In addition, µRALP workshops were held at IEEE Biorob 2012 in Rome, and at the RGC-2013 conference in Hannover. The consortium has also contributed to the organization of the CRAS-2013 workshop in Verona with other EU projects involved in robotic surgery. Finally, the µRALP project has served as a source of student project topics at various levels (high-school, Masters, PhD).

A strategic plan for exploitation and dissemination of the results of the project has been drafted.

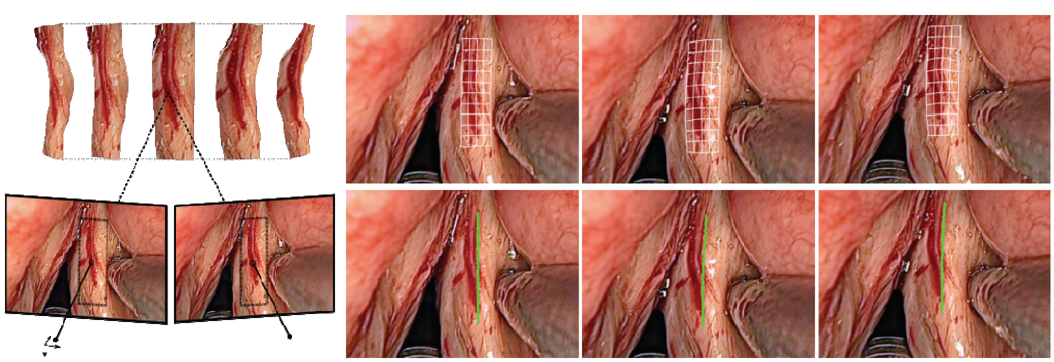

Fig. 4. 3D reconstruction of a vocal fold region observed by a stereo camera (left). Motion tracking of a region of interest for adapting a planned incision on the vocal folds (upper right) where virtual laser path (green) follows the occurring tissue deformation and camera motion (lower right).

4. Expected final results and impact

At the end of the project, significant scientific and technological advances are expected in:

Surgeon-Robot Interfaces: Intuitive systems will provide a more ergonomic and information-rich operating setup for the surgeon, enabling unprecedented levels of precision and safety thanks to transparent robot control, intraoperative planning, and cognitive supervisory systems.

Spatial Micro-Mechanisms: A methodology for designing out-of-plane micro-fabricated mechanisms, with high range of motion and piezoelectric actuation, will be proposed.

Three-dimensional Vision and Control: Novel solutions for 3D reconstruction of the surgical scene will allow significant improvements in surgical robot control, intraoperative planning and in the quality of laser incisions though adaptable laser focusing.

Medical Robot Design: The project will contribute to creating novel concepts for biocompatible, patient-friendly and surgeon-acceptable medical robots, with increased autonomy for realizing more complex tasks.

Fluorescence-based Cancer Detection: Appropriate exploitation of optics will allow for efficient diagnosis and accurate localization of tumors.

Surgical practice: Laser phonomicrosurgery will require less training than currently, with less surgeon fatigue and better patient outcomes.

5. Contact information

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6. Project website

www.microralp.eu