μRALP

Micro-Technologies and Systems for Robot-Assisted Laser Phonomicrosurgery

January 2012 – March 2015

Project Summary

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femto-st SCIENCES & TECHNOLOGIES

Leibniz Universität Hannover

CHRU Besançon centre hospitalier régional universitaire

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March 2015

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 was 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 allowed relocating the laser actuator closer to the surgical site. These technological advancements bring unprecedented levels of accessibility and precision to laser phonomicrosurgeries, while providing a more ergonomic, information-rich, and assistive environment for the surgeon. The results of the project have demonstrated great potential for improved quality, safety, and effectiveness in laser phonomicrosurgery. They will soon enable total tumor removal with minimal damage to healthy tissue. The research efforts herein have generated 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 are paving the way towards new and safer minimally invasive laser microsurgeries, which will lead to a significantly enhanced capacity for cancer treatment in general.

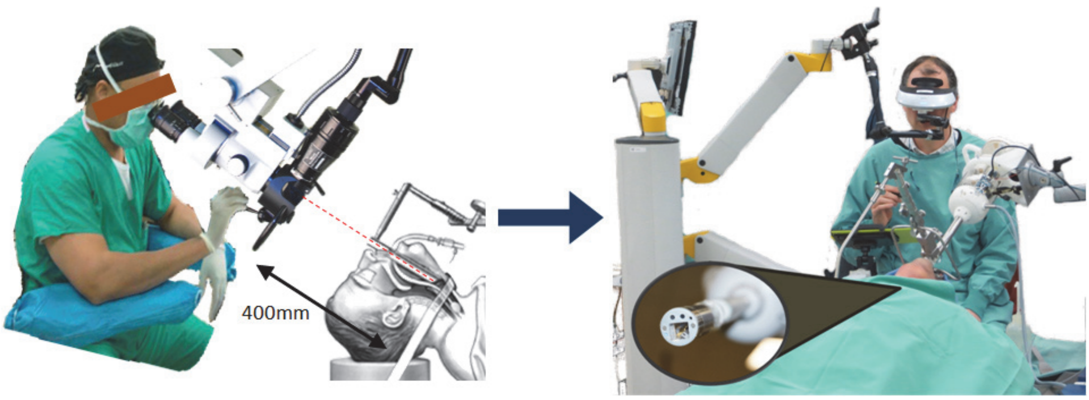

Fig. 1: The µRALP concept: from the gold-standard free-beam laser phonomicrosurgery (left) towards safe and accurate endoscopic micro-robot-assisted laser phonomicrosurgery (right).

2. Consortium

The µRALP project was 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, tremendous activity was recorded on the design, development and evaluation of:

- A hybrid actuated flexible endoscope able to adapt to the curvature of the patient's neck (Fig 2). It features a motorized distal tip deflection system, and integrates the laser beam deflecting micro-robot, the white light illumination system, and the stereo camera system. Further research integrated also a fiber-guided surgical laser and optics for laser refocusing.
- An auto-fluorescence 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, 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 1cm^3 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 features integrated surgeon interfaces for visualization and intuitive laser control, including augmented reality features for surgical planning and safety supervision.
- Cognitive systems for safety supervision based on learned models of laser-tissue interactions,

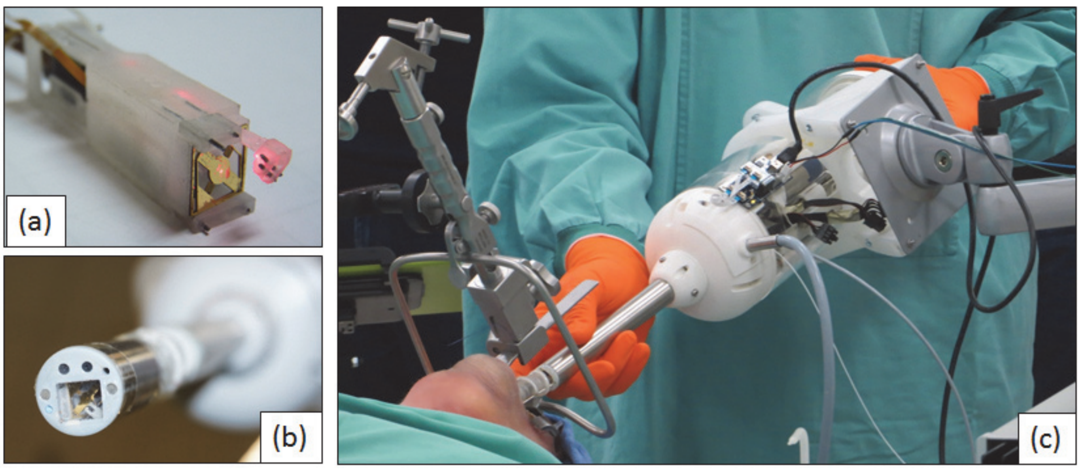

Fig. 2: Final robotics endoscope prototype incorporating: (a) Laser deflecting micro-robot; (b) multifunctional tip and flexible shaft; and (c) hybrid actuation unit.

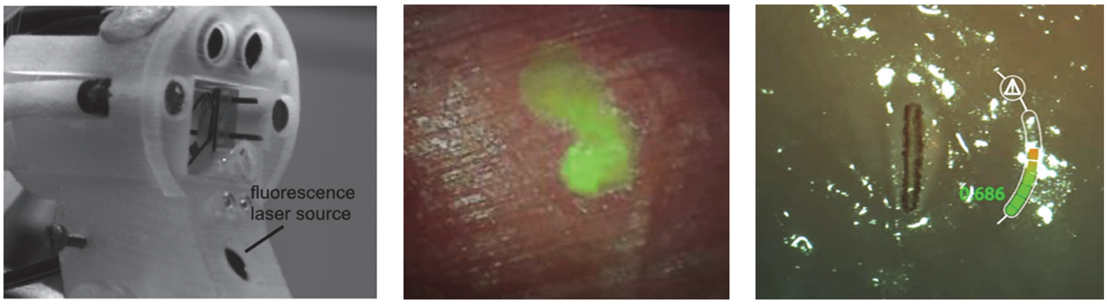

Fig. 3: Hyperspectrum fluorescence imaging system incorporated to the endoscope tip (right) and a sample image captured with the device displayed using augmented reality (center). On the right, assistive system for precise control of laser incision depth based on the cognitive modeling of laser-tissue interactions.

which are able to predict and control the laser incision depth on soft tissue (Fig. 3).

- Tissue depth estimation (3D reconstruction) solutions for enhanced intraoperative surgical planning and visualization, which enable improved laser incision quality and precision through automatic focus adaptation (Fig. 4).
- Visual augmentation and three-dimensional feedback by image overlay, which enables highlighting tumor areas or the registration of the surgical laser workspace.

Intensive collaboration has taken place between the participants since the beginning of the project, allowing the jointly development of the µRALP concepts and prototypes, and their successful integration. Research visits and exchanges between partners have been set as a priority for joint developments, adding to a total of 85 physical meetings at the end of the third project year. These included a total of 9 integration weeks, which brought together all partners and their prototypes for discussions, synchronization and a lot of collaborative work towards the actual integration of all hardware and software systems.

The project achievements were regularly shared with the scientific community and the general public. The consortium has produced 10 journal papers, 33 peer-reviewed conference papers, 43 abstracts, and 3 book chapters. In addition, µRALP has organized 5 technical workshops for the scientific community, and 8 public events dedicated to public dissemination and demonstrations. µRALP project has served as a source of student project topics at various levels (high-school, Masters, PhD). Finally, µRALP Squipabot micro-robot has won the Special Award at MICRONORA 2014, the international industrial fair on microtechnologies.

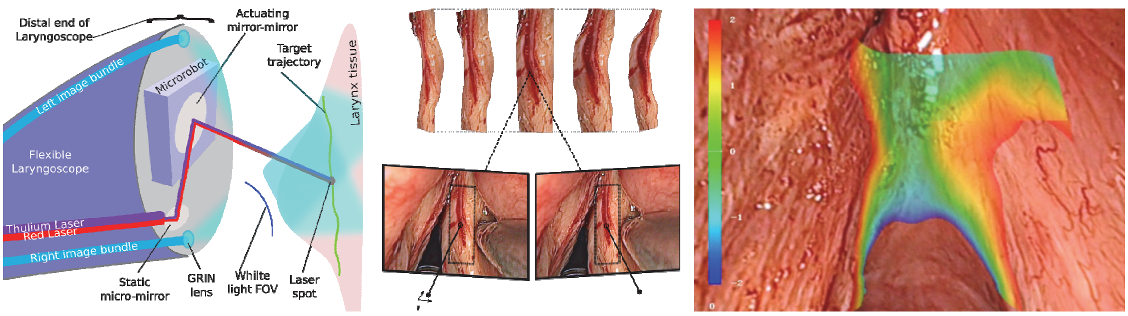

Fig. 4. Schematic view of the stereoscopic high-speed imaging system (left). 3D reconstruction of a vocal fold region observed by a stereo camera (center). Tissue depth estimation augmenting intraoperative surgical visualization to allow proper laser focusing and enable improved laser incision quality.

4. Final results and impact

Significant scientific and technological advances have been achieved in:

Surgeon-Robot Interfaces: Intuitive systems now 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 was created.

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

Medical Robot Design: The project has contributed to creating novel concepts for patient-friendly and surgeon-acceptable medical robots, with increased autonomy for realizing precision tasks.

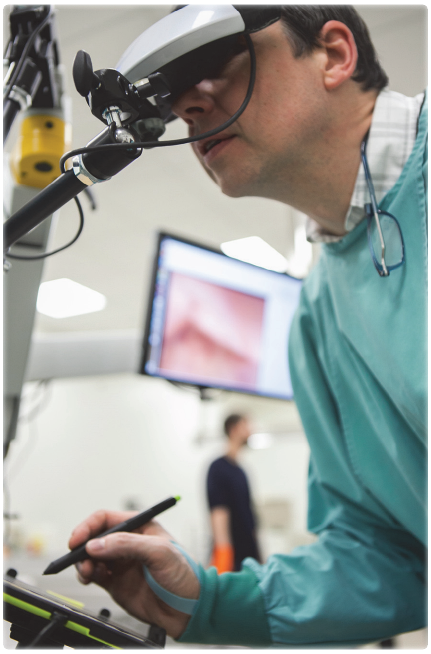

Fig. 5. Teleoperation interface: 3D endoscopic view and intuitive laser control based on a graphics tablet.

Fluorescence-based Cancer Detection: The exploitation of optics and hyperspectral imaging has allowed the creation of an efficient fiber-based system for real-time tumor visualization.

Surgical practice: Laser phonomicrosurgery will benefit from improved access, higher precision and better quality laser ablations. Surgeon fatigue will be reduced, and better patient outcomes are expected.

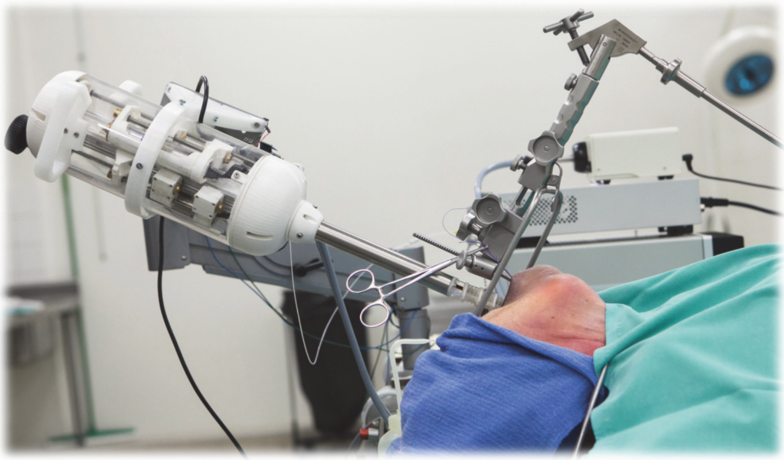

Fig. 6. The µRALP Surgical System was developed and evaluated in realistic operation conditions based on numerous cadaveric studies.

5. Contact information

Leonardo Mattos (Project Coordinator)
Department of Advanced Robotics
Istituto Italiano di Tecnologia (IIT)
Via Morego 30, 16163 Genoa, Italy
Tel: +39.010.71781.409
E-mail: leonardo.mattos@iit.it

Department of Advanced Robotics
Istituto Italiano di Tecnologia
Genova, Italy

AS2M Dept. and
Dept. Optics P. M. Duffieux
FEMTO-ST Institute
Besançon, France

Institute of Mechatronic Systems
Leibniz Universität Hannover
Hannover, Germany

Dept. Otorhinolaryngology and
Clinical Investigation Centre
University Hospital of Besançon
Besançon, France

Dept. Otorhinolaryngology
Università degli Studi di Genova
Genova, Italy

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