The µRALP Project: New Technologies and Systems for Robot-Assisted Laser Phonomicrosurgery

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Abstract—**This presentation will summarize the objectives, challenges, activities and targets of the EU project µRALP, which is dedicated to the creation of a new class of robot-assisted surgical system for laser phonomicrosurgeries.**

I. Introduction

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 proposed 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 (Fig. 1). This is expected to allow unprecedented levels of accessibility and precision, while the surgeon will benefit from 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 will generate new knowledge in the design and control of medical micro-mechatronic devices; cancer tissue imaging; assistive teleoperation in surgery; physician-robot interfaces; and cognitive computer vision. 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.

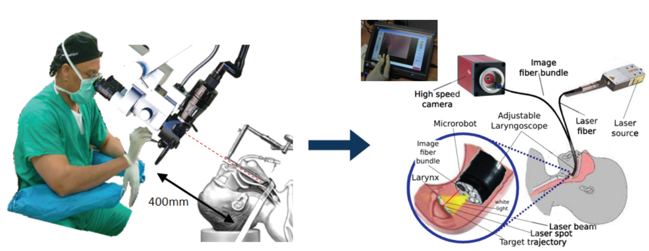

Fig. 1. The µRALP concept: from the gold-standard robot-assisted open-air laser phonomicrosurgery (left) towards safe, accurate and ergonomic endoscopic micro-robot-assisted laser phonomicrosurgery with fluorescence-based cancer detection (right).

II. Project Activities

Initially the project focused at the definition of specifications and guidelines for the final prototype, which was done extensive collaboration with the partner surgeons. This process resulted in a translation of medical needs and constraints to concrete technical specifications, a process that also assisted by the collection and distribution of multimedia data related to laser phonomicrosurgery cases.

Early developments within the project also included the design of experiments and definition of metrics to be used for the evaluation of currently available commercial devices and µRALP prototypes. These have already allowed randomized comparative trials to be performed, generating quantitative and qualitative data related to the precision, usability, and ergonomics of early system prototypes (Fig. 2, left).

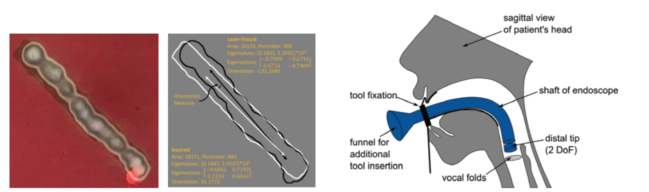

Fig. 2. Representative trial sample and extracted performance metrics (left). Schematic view of the endoscopic system fixed to the patient's mouth utilizing a retractor (right).

Based on the specification and guidelines, the µRALP consortium has been focusing most of its efforts on research, design and development of the constituent new technologies needed to achieved the envisioned robot-assisted system prototype. These include:

- Design of an endoscope body (Fig. 2, right) to bring all the µRALP components (and functionalities) into patient's larynx without stretching his/her neck to painful positions (as it is the case in the current gold-standard practice);
- Design of a hyperspectral optical system to gather fluorescence signal emitted by the cancerous cells, which is compatible with endoscopy (Fig. 3, left);
- Design of 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);
- Design of a multi-view high-speed white-light imaging system, to allow for high-speed recording (and slow-motion

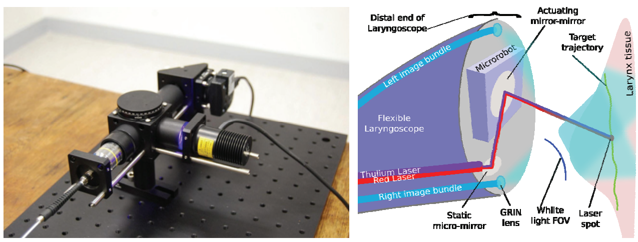

Fig. 3. Optical device for bundle-based fluoroscopy (left). Schematic view of the stereoscopic high-speed imaging system (right).

replay) of the procedure, as well as the real-time tracking and control of the laser motion (Fig. 3, right).

Systems integration has been a concern and a focus of R&D efforts from the beginning of the project. This has been identified as a critical factor for success since different partners are developing different hardware and software parts of the final µRALP system. Furthermore, the criticality of the application requires high safety and robustness. These concerns have lead to the adoption of the Robot Operating System (ROS) as the underlying software structure for inter-process communications and system control. In addition, real-time supervisory hardware is being developed for guaranteeing proper system operation and overall safety.

Interfaces between the surgeon and the µRALP system are also being developed, including a Virtual Scalpel that allows the surgeon to ergonomically define the path to be followed by the laser on the vocal fold (Fig. 4). The use of augmented reality is part of this effort, with the aim of providing relevant and useful information directly on the surgeon's field of view.

Finally, a cognitive supervisory system is being developed to model, supervise and control the laser power in order to avoid carbonization of the tissues and improve surgical quality.

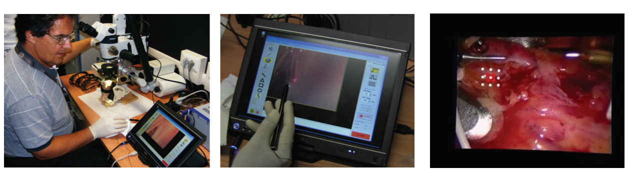

Fig. 4. Early ex-vivo trials of the virtual scalpel system for laser phonomicrosurgery performed at the IIT by a surgeon from UNIGE (left and center). 3D tissue deformation tracking based on SSD and rank transformation of stereo pair (right, image source: Hamlyn Centre, UK).

III. Main Results

Main results achieved by the research consortium during its first project year are summarized in the following list:

- Virtual Scalpel was designed, implemented and tested at a hospital setting. It was found very intuitive and easy to use by surgeons. Comparative trials showed 50% increase in precision with the new system, and the system usability analysis demonstrated an increase in the SUS score from 68% to 84%.
- Augmented reality stereoscopic feedback to the surgeon was developed with superimposition of (simulated) fluorescence data to video images, taking into account tissue deformation.
- An optical bench was designed, assembled and tested which demonstrates the feasibility of observing endoscopically the fluorescence of cancerous cells through an optical fiber bundle.
- A preliminary design of a 3D micro-manipulator with high range of motion and high dynamics was proposed, with innovative technological solutions.
- A novel high-speed vision-based control algorithm (and associated hardware) was derived for the accurate control of the laser spot on the vocal fold, based on an elegant use of multiview geometry.
- The preliminary design of an endoscope to support and position the µRALP technologies in close vicinity to the surgical site has been finalized, implemented and tested in a realistic human mannequin.
- Preliminary trials on ex-vivo swine larynxes were performed to assess the accuracy of preliminary prototypes including the Virtual Scalpel and visual servoing control.

IV. Expected Final Results and Impact

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

- Surgeon-Robot Interfaces: A new and safer surgical setup offering higher usability, ergonomics and allowing better performance will be provided to the surgeon thanks to the use of new interface technologies and cognitive approaches.
- Spatial Micro-Mechanisms: A methodology for designing out-of-plane micro-fabricated mechanisms, with high range of motion and piezoelectric actuation, will be proposed.
- 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.
- Hyperspectral 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 benefits.

Acknowledgement

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Project website: www.microralp.eu