Cable-Driven Parallel Robot Assisted Confocal Imaging of the Larynx

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Abstract: LaryngoTORS, a transoral laryngeal surgery robot, can manipulate instruments accurately. Confocal imaging has potentials in laryngeal cancer diagnosis but suffer from high scanning requirement. This work studies using LaryngoTORS to assist confocal imaging of larynx.
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1. Introduction

The LaryngoTORS robotic system is a novel cable-driven parallel robot (CDPR) designed for transoral laser laryngeal surgery. The CDPR mechanism can manipulate the tip of a laser fibre like a string puppet, achieving line scans of high accuracy and repeatability [1]. The robotic system is not limited to therapy but has the potential for fibre or probe-based optical scanning. Confocal endomicroscopy is a minimally invasive optical technique that enables *in vivo* confocal imaging of tissue structures [2], providing an effective means of eliminating signals from out-of-focus light and allowing fluorescence imaging of tissue surface at a cellular-level resolution [3]. Recent researches show that confocal endomicroscopy can detect the squamous cell carcinomas successfully, including in the diagnosis of laryngeal cancer [4]. However, one challenge is the relatively small field of view (240 µm to 600 µm, Cellvizio, Mauna Kea, France) [5], which can be expanded via mosaicking to stitch adjacent frames and create a large imaging area. But video mosaicking needs to maintain optimal probe pose and tissue-contact while performing slow and precisely controlled scanning motions [6]. Thus, this study explores the possibility of using LaryngoTORS to manipulate the end tip of a confocal endomicroscopy fiber bundle to perform a large area scanning on a simulated vocal cord. In addition, the similar technology can be used in other applications. This can allow better images during scanning microscopy data by using the actuation information to assist the mosaicking process, or better localisation of probe-based spectroscopy data on the tissue.

2. Materials and Method

The LaryngoTORS robot is shown in Fig. 1(a)-(c), consisting of a hollow cylinder scaffold of 22 mm diameter and 28 mm depth. An over-tube located in the scaffold was driven by six bowden cables to realize 5 degrees of freedom motion (3 for translations, and yaw and pitch rotations). The cable-driven over-tube was controlled by a manipulator (Geomagic Touch, 3D Systems, USA). A GastroFlex UHD probe connected to the Cellvizio system from Mauna Kea is inserted into the hollow scaffold and into the over-tube (Fig. 1(b)&(c)). The probe had 30,000 fibre bundle imaging elements and a micro-objective lens, providing a FOV of 240 µm and a resolution of approximately 1.2 µm. Porcine fat tissue was placed in front of the robot to simulate part of vocal folds (Fig. 1(d)) and a USB camera was mounted in the centre of the scaffold to provide visualization.

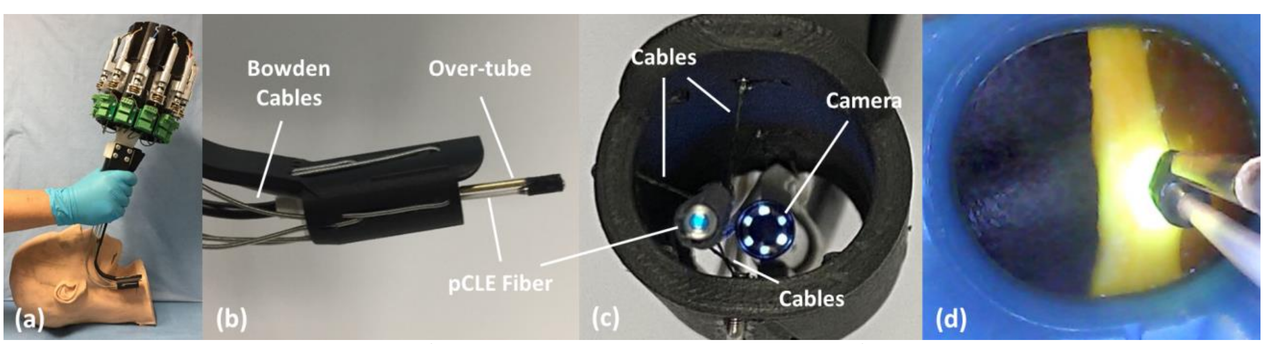

Fig. 1 Experimental set-up: (a) The prototype of LarygoTORS robotic system [1]. (b) Side view of the robot. The GastroFlex UHD probe was attached at the end of the over-tube. (c) Front view of the robot with the probe showing the over-tube connected with cables and the USB camera for visualization. (d) View from the camera showing the porcine tissue attached to the front of the robot.

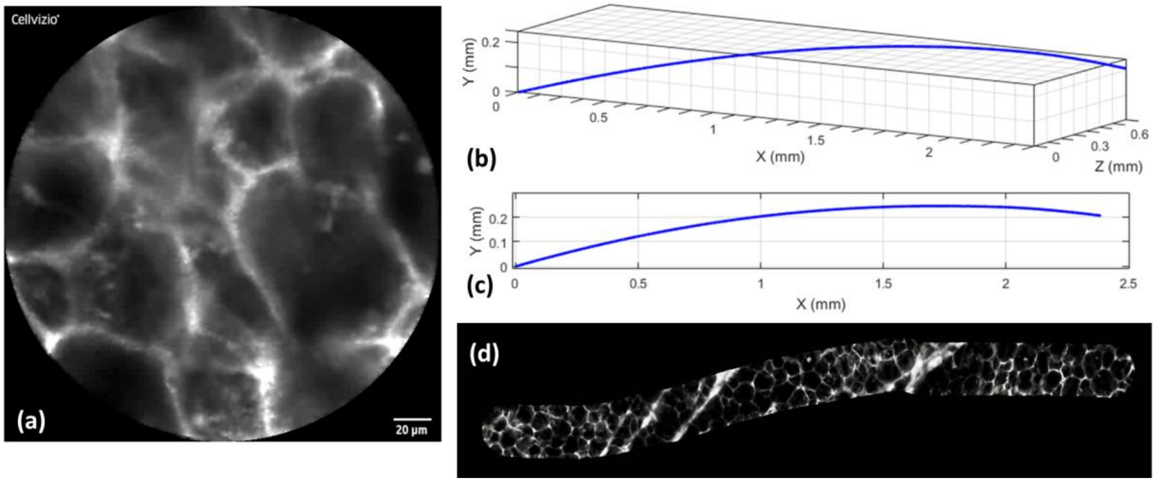

Fig. 2 (a) Confocal imaging of porcine fat tissue using GastroFlex UHD probe with a Cellvizio system. (b) & (c) Illustration of robot trajectory pattern for confocal scanning in 3D and 2D respectively. (d) Mosaic image of robot-controlled confocal scanning on the perirenal fat tissue.

3. Results

In the experiments, porcine fat tissue was stained with 0.1% fluorescein solution for 1 minute and then washed with saline before scanning. A representative imaging result is shown in Fig. 2(a), clearly showing adipocytes in the fat tissue. The scanning path was manually defined by control points, including a start point, an endpoint, and roughly equidistant points between these. In this experiment, 4 control points were used, and a scan path was generated via spline interpolation which the robot follows autonomously. Fig. 2(b)&(c) show the generated scan path in 3D and 2D respectively. As shown in Fig. 2(d), an ultra-long mosaic image was formed from the scanning results, which benefits from robot-controlled smooth motion scanning with sub-millimetre accuracy. The mosaic image also fits well with the robot scanning trajectory pattern as shown in Fig. 2(b)&(c).

4. Discussion

Cable-driven parallel robot LaryngoTORS has the ability to perform accurate scanning. In this study, the LarynoTORS robot was used to manipulate the fibre bundle probe of the Cellvizio confocal endomicroscopy system to explore large area scanning on a simulated vocal cord. Experimental results demonstrate that large area mosaic images can be formed from scanning results in porcine fat tissue. The robot trajectory can be used to aid the mosaicking reconstruction process. A limitation of the current design is that the inner diameter of the over-tube is only 1.2 mm, which is smaller than the GastroFlex UHD probe. A slimmer probe which can be accommodated in the over-tube will be used for further tests. In addition, the robotic system can be used in other fiber or probe-based applications, such as diffuse or fluorescence spectroscopy and intraoperative optical coherence tomography. This information can also be registered and aligned with white light or narrowband images acquired by the robot-mounted imaging system to augment the standard surgical view.

5. Acknowledgment

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6. References

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