Endomicroscope for Gastrointestinal Cancer Detection: Concept and Preliminary Results

M. T. Chikhaoui [2]***, M. Ourak*** [3]***, Q. Tanguy*** [1]***, P. Struk*** [4]***, K. Rabenorosoa*** [1]***, S. Bargiel*** [1]***, B. Tamadazte*** [1]***, N. Passilly*** [1]***, O. Gaiffe*** [1]***, L. Froehly*** [1]***, C. Gorecki*** [1]***, P. Lutz*** [1] ***and N. Andreff*** [1]

[1] *FEMTO-ST, Univ. Bourg. Franche-Comté/CNRS/ENSMM, 25000 Besançon, France*
[2] *Laboratory for Continuum Robotics, Leibniz Universität Hannover, Hanover, Germany*
[3] *Department of Mechanical Engineering, Division PMA, KU Leuven, Celestijnenlaan 300B, B-3001 Heverlee, Belgium*
[4] *Department of Optoelectronics, Silesian University of Technology, Poland*
Contact: nicolas.andreff@femto-st.fr

This paper presents a novel concept of a smart endomicroscope proposed as demonstrator within Labex ACTION. The recent results on the key components are described in order to state the advance of this project.

1 Introduction

Gastrointestinal cancers are among the most common cancers in the world. Especially, gastric cancer is the third most common cause of cancer-related death in Western countries due to the difficulty to cure it. The main reason is due to the late diagnosis then most patients present with advanced disease. Cancer mortality can be reduced if cases are detected earlier by adequate means and afterwards treated. Early diagnosis can be achieved using image enhancement of esophagogastroduodenoscopy and optical biopsy avoiding punch histological biopsy. The recent advances in optical biopsy, especially for optical coherence tomography (OCT) have demonstrated that OCT images corresponded very closely to the standard histological light microscopic slides [1, 2]. In addition, the miniaturization of the OCT probe has reached some interesting diameter (up to 0.3 mm) [3, 4] in order to consider its integration on millimeter size continuum robots. Concentric tube robots (CTR) for medical applications have been intensively developed during the last decade [5]. The combination of OCT and high dexterous CTR constitutes an interesting approach to improve early diagnosis of gastrointestinal cancers.

The smart endomicroscope demonstrator of the Labex ACTION proposes a breaking approach with cancer diagnosis in the digestive tract. This paper states the recent advances regarding investigations on the smart endomicroscope demonstrator (Section III) after recalling the proposed concept in Section II. Finally, Section IV concludes the paper.

2 Concept

The demonstrator 4[1] of the Labex ACTION aims to develop a concept of smart endomicroscope for early detection of neoplastic lesions in the human stomach tissue, based on the Swept Source Optical Coherence Tomography (SS-OCT) combined with a measurement probe with integrated Mirau micro-interferometer, and mounted on a continuum robot arm. The objective is to achieve in vivo microscopy of stomach tissues and to point out lesions by landmarks with needle knife. Afterwards, the Endoscopic Submucosal Dissection (ESD) known as a mainstay of early gastric cancer treatment may apply to remove lesions. The global view of the concept is presented in Fig. 1 describing two CTR with hybrid actuation inserted through auxiliary channels of an endoscope. The concept aims to introduce

[1] `http://labex-action.fr/en/demo4-smart-endoscope`

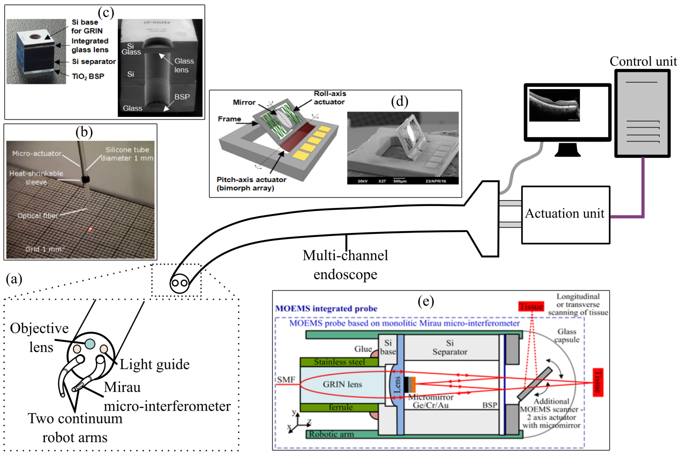

Figure 1: *(a) The proposed concept for the smart endomicroscope, (b) tri-layer PPy actuated tube, (c) prototype of the MEMS scanner, and (d) schematic view of the SS-OCT endomicroscope system with the architecture of MOEMS Mirau probe.*

non-contact and non-invasive in vivo diagnosis with high resolution and reasonable penetration depth with a MOEMS Mirau probe, a 2-axis MEMS micro-scanner (acquisition of real-time 3D images), a CTR augmented with electroactive polymer based-actuators, and visual servoing for automated OCT-probe positioning.

3 Preliminary Results

3.1 Mirau micro-interferometer

The SS-OCT system consists of a pigtailed illumination and detection blocks, connected via a Gradient Index (GRIN) lens collimator to a MOEMS measurement probe (Fig. 1 (e)) ($4 \times 4 \times 20$ mm^3). The key component of the probe is a monolithically integrated Mirau micro-interferometer with glass lens (Φ=1.9mm) and beam-splitting plate (BSP). The design and fabrication of the Mirau components by vertical multi-wafer bonding approach (Fig. 1 (c)), have been presented in [6]. It is designed to provide a fast axial scanning of tissue with A-scan sweep rate of 110 kHz, providing axial and lateral resolutions of 5.2 μm and 10.2 μm, respectively.

3.2 Two-axis MEMS micro-scanner

Design and fabrication of 2-axis electrothermal MEMS micro-scanner (Fig. 1 (dc)) were recently reported in [7]. The scanner is developed to perform the B-scans on the previously reported Mirau micro-interferometer. The performed scans reach large mechanical angles of 32° for the frame and 22° for the in-frame mirror. Three resonant main modes can be observed through the measurements using MEMS analyzer[2], pure pitch of the frame at 205 Hz, a pure roll of the mirror plate at 1.286 kHz, and coupled mode of combined pitch and roll at 1.588 kHz.

[2] MSA-500 from Polytec (Irvine, CA, USA)

3.3 CTR augmented with electroactive polymer based-actuators

CTR is identified as a promising robotic structure, well suited to access confined space. In order to improve their dexterity and workspace, it has shown that introducing a variable curvature on a segment, or on a part or the entire tube which constitutes the robot, is kinematically effective [8]. Therefore, the challenge is to integrate the variable curvature on tubes with diameter less than 2 mm. As detailed below, the proposed approach is based on the use of conducting polymers, especially polypyrrole (PPy). We have shown that its synthesis is reproductible and the obtained actuators are stable enough to consider their integration on millimeter size robots [9]. In addition, tri-layer PPy actuators are able to bend 1 mm tube (Fig. 1 (b)) with approximately 5 mm displacement at the distal tip [10].

3.4 Visual servoing for automated OCT-probe positioning

In order to address repetitive optical biopsies, design of a partitioned vision-guided scheme is proposed. Indeed, this approach uses two image modalities to perform 6 degrees of freedom (DOF) positioning tasks. The development aims to partition the control into the 3 DOF controlled by the white light images provided by a CCD camera. The remaining 3 DOF are controlled by B-scan images acquired with an OCT system. The ground-truth validations were consisted of several SE(3) positioning tasks which were successfully performed. The obtained results have demonstrated the efficiency of the controller in terms of accuracy (some tens of micrometers and few hundred of millidegree in the translation and rotation Cartesian space, respectively), convergence, and repeatability, as shown in [11].

4 Conclusion

In this paper, we summarized the recent results on the smart endomicroscope demonstrator after recalling its concept. Technical and theoretical advances on different components were presented to state the demonstrator achievement. Future work will focus on the integration of these results on the defined configuration of the endomicroscope.

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