Hybrid Tissue Surface Hyperspectral Imaging and Shape Recovery

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I. INTRODUCTION

Intra-operative information useful in surgical guidance can be provided by tissue surface shape and reflectance spectra. In this work a system enabling hyperspectral tissue imaging (HSI) and shape reconstruction system using structured light (SL) was proposed. This system can switch between the HSI and the SL modes. HSI is capable of reflectance spectra measurement at different locations in an image, so it has the potential in distinguishing tissues which are hard to discriminate under white light, which makes it useful clinically [1, 2]. SL is an active stereo technique consisting of a camera and a projector, which enables object surface reconstruction. Due to its non-reliance on the tissue surface texture information [3], it has demonstrated potential to be useful in textureless tissue surface shape recovery.

The key component of this system is a fibre bundle at whose two ends the fibres are arranged in a linear array, and a randomly-arranged circular bundle, respectively. In HSI mode the standard endoscope illumination is used and the reflected white light enters the bundle at the randomized end and is emitted by the linear array end for capture by an HSI camera. For SL, a supercontinuum laser is dispersed by a prism and then coupled into the linear array end and emitted at the randomized end to form a pattern of randomly coloured distribution of spots. By pattern decoding and calibration the tissue surface can be reconstructed [4, 5]. Switching between these two modes allows collection of white light, hyperspectral reflectance and 3D surface image data. Using the known mapping between the proximal and distal ends of the fibre bundle enables the spectral information of different areas to be linked to their associated 3D surface point. The real-time software platform of this system was built using a GPU. Validation of this system using phantom objects (colour checker card) and ex vivo tissue (rat abdomen, post mortem) has been demonstrated.

II. MATERIALS AND METHODS

The system was extended from a previous work [6]. The central part of the system is a custom optical fibre assembly (Fibertech Optica, Inc., Canada). As a 2.5m long incoherent bundle consisting of 171 50µm core fibres, its fibres are arranged in a linear array in the proximal end and randomly in the distal end (Fig. 1). A GRIN lens (GRINtech GmbH, Germany) with 20mm working distance is attached distally for collimation. The outer diameter of the probe (the distal end with a GRIN lens) is 2.8mm. During the SL mode, the flipper position is set to 0°, and a 4W supercontinuum laser dispersed by a prism is coupled into the linear array end of the bundle (Fig. 1 (a)). Laser rays with different light wavelength is emitted out of the probe, projected onto the object surface, and the image is captured by a CCD (Prosilica GX1050C; Allied Vision Technologies, Inc., USA) mounted on a laparoscope (Karl Storz GmbH, Germany).

Figure 1: Hybrid HSI and SL imaging. Top: In SL mode a multi-coloured laser spot pattern is incident on the tissue and used to triangulate surface shape. Bottom: In HSI mode the fibre bundle collects reflected white light, which is imaged, via a flipper mirror, onto the slit of a hyperspectral sensor. Adapted from [7].

By switching on the white light source and setting the flip position to 90°, the system is turned into the HSI mode, a white light source (Xenon 300; Karl Storz GmbH, Germany) is used for illumination. The reflected light is delivered through the bundle and re-directed by a mirror mounted on a motorised flipper (MFF101; Thorlabs Ltd., UK), then demagnified by 250/50mm focal lens combination, captured by the slit of a HSI camera (Nanos-Hyperspec; Headwall Photonics, Inc., USA) (Fig. 1 (b)).
For shape recovery under SL mode, an algorithm based on fully convolutional networks (FCN) [8] has been employed to detect the spots in endoscopic images, followed by feature matching using a customised feature descriptor. Then together with calibration the tissue surface can be reconstructed.

In the HSI image the spectrum of each fibre was normalised using a white reference target (Spectralon; Labsphere, Inc., USA) to correct for wavelength-dependent transmission characteristics. The estimation of relative haemoglobin concentration was described previously [2].

III. RESULTS

This system has been validated using phantom, and ex vivo experiments.

SL images need to be captured before the HSI mode to locate the spot regions. In the HSI mode the hyperspectral signal from different regions are collected to form reflectance spectra, compared with the gold standard measured by a spectrometer (USB4000HR; Ocean Optics, Inc., USA). The correct spectrum is returned from each fibre, with a mean error of ~ 10% from the gold standard [7]. A three color cylinder was adopted to further demonstrate the HSI imaging part intuitively. The result showed that both the shape and color of the cylinder surface can be recovered using our system (Fig. 2).

The absorbance spectra from different locations on the surface of a post mortem murine abdomen were calculated using the measured reflectance spectra, followed by tissue oxygen saturation (StO₂) extraction with the algorithm described in a previous work [2]. The estimated StO₂ for different locations on the murine abdomen is shown in Fig. 3 (a). The absorbance spectrum from one of the locations is displayed in Fig. 3 (b). For StO₂ estimation, spectra which couldn’t fit the model well ($r^2 < 0.8$) were rejected. As expected from the post mortem organ surface, the estimated average StO₂ is low (14 ± 10%).

This work shows the accuracy of spectra measurement using our system. The main difference between ex vivo and in vivo experiments is the magnitude of StO₂, which does not affect the spectra measurement accuracy. Moreover, since the signal can be captured in one exposure (~ 100ms), spectral artefacts caused by breathing/peristalsis-related movement during in vivo experiments can be minimized.

IV. CONCLUSIONS

A rapid probe-based system has been developed in this work for depth sensing and HSI. The dimension and flexibility of this probe enables its integration with standard endoscopic to assess the gastrointestinal tract and abdomen, for the purpose of measurement of StO₂, tissue recognition, and provision of augmented reality (AR) for surgical navigation together with pre-operative information. The future work will focus on the system optimisation, including the portability improvement and software enhancement, as well as in vivo/ex vivo experiments for further validation.

ACKNOWLEDGMENTS

This work is funded by ERC 242991 and an Imperial College Confidence in Concept award. Jianyu Lin is supported by IGHI scholarship. Neil Clancy is supported by Imperial College Junior Research Fellowship. Danail Stoyanov is funded by EPSRC and the EU-Horizon2020.

REFERENCE