

Quantitative Tissue Measurements in Transoral Robotic Surgery

D. Stoyanov¹, P. Pratt², E. Edwards, G.-Z. Yang², A. Arora³, A. Darzi^{2,3}, N. Tolley³

¹Center for Medical Image Computing, University College London, ²Hamlyn Centre for Robotic Surgery, Imperial College London, ³St. Mary's Hospital, Imperial College Healthcare NHS Trust
danail.stoyanov@ucl.ac.uk;{p.pratt, eddie.edwards, a.arora, a.darzi, g.z.yang, n.tolley}@imperial.ac.uk

INTRODUCTION

Transoral robotic surgery (TORS) represents a new treatment paradigm for patients with obstructive sleep apnea (OSA). TORS overcomes the limitations of suboptimal access associated with the conventional transoral approach particularly when the tongue base (BOT) is involved. Preliminary results suggest higher cure rates compared with both conventional transoral and external surgical techniques yet with significantly less morbidity [1]. Flexible thulium laser fibres are typically used during TORS for bloodless tissue resection and vaporization to de-bulk tissue volume. However, it is not possible to measure the volume of tissue reduction *in vivo*. The surgeon uses subjective evaluation to qualitatively estimate the desired tissue volume which needs to be removed. The extent of tongue base reduction required can significantly impact on surgical success and patient morbidity including pain, dysphagia and aspiration.

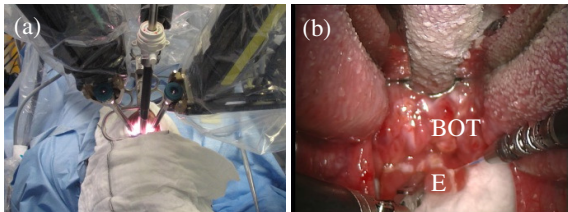


Fig. 1 (a) TORS set up in the operating room (b) the intra-operative view following insertion of a Boyle Davis mouth gag demonstrating the epiglottis (E) and bulky tongue base (BOT) prior to performing tongue base reduction.

A means of computing the volume removed during surgery is therefore desirable and optical 3D reconstructions of the intra-operative stereoscopic laparoscope images represent a potential solution (Figure 1b). Optical computation of 3D tissue shape and motion using stereo-laparoscope images has been shown to be a practical approach towards making *in vivo* metrical measurements at the surgical site [2,3]. Optical methods only rely on images from the laparoscope and do not require additional equipment to be introduced into the theatre or the patient. Such methods rely on the parallax between stereoscopic images to compute the distance between the camera and the tissue. For scenes where the variation in depth is large and there are multiple occlusions techniques that do not make explicit use of tissue surface models are more suitable. The robustness of parallax methods is dictated by the presence of prominent surface texture and, in practice, they are susceptible to view dependent highlights and

structural discontinuities between the tissue and surgical instruments.

In this paper, we report a method for recovering 3D tissue shape at the surgical site at the start of ablation and at the end. These measurements are used to estimate the volume change caused by laser de-bulking at the BOT. Preliminary results on *in vivo* TORS video show that the approach is practical and can potentially be transferred to clinical practice.

MATERIALS AND METHODS

To compute the 3D surface shape of the region of interest at the BOT we assume that the stereo-laparoscope is calibrated such that the intrinsic and extrinsic camera parameters are known. For each incoming stereoscopic image pair at time t the images are rectified to remove lens distortions and to align the epipolar geometry by using the known geometric calibration parameters of the cameras [4]. From the rectified images the disparity $d(x, y, t)$ at an image pixel in the left image $\mathbf{m}_l^t = [x, y]^T$ which provides the correspondence to the projection in the right image $\mathbf{m}_r^t = [x + d(x, y, t), y]^T$ is calculated by using an implementation of the algorithm in [2]. This is based on a growing scheme from an initial set of seed points that are matched across the stereoscopic view using any sparse matching algorithm. The search space is restricted to 1D by rectification and a symmetry constraint is added to ensure left-right disparity map consistency. Any feature point detection and feature matching strategy can be used to generate seed points for the growing method. We use the Shi and Tomasi features [5] as they can be computed efficiently and have been previously shown to work well for short-term tracking in MIS images with a stereoscopic Lucas-Kanade tracking method. More complex strategies can be adapted to work within the framework at the cost of additional computational demands. When the set of all computed matches stop growing the quasi dense reconstruction is complete.

By recovering the 3D shape of the tissue surface at the BOT before de-bulking, during and after the laser has been used, we can compute the change in shape and hence the volume of tissue removed. However, it is common for the camera position and orientation to change during the procedure in order to optimise the surgical field-of-view. Computing this change in camera pose is required in order to register the recovered tissue shape for comparison. This can be achieved using

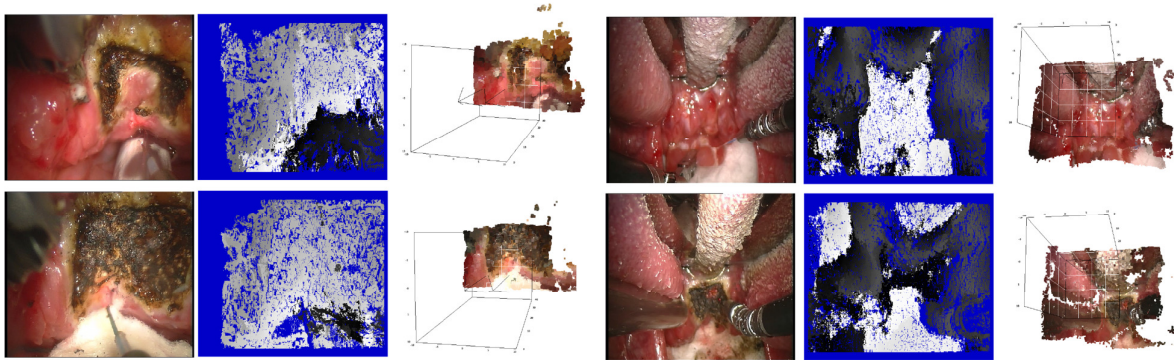


Fig. 2 Two examples of 3D reconstruction of the surgical site for measurement of the ablated volume during BOT reduction. The top row shows images at the start of the laser ablation and the bottom row shows images and at the end of the operation. Exemplar views of the surgical site are shown along with the corresponding disparity map and a 3D rendering of the recovered surface. Note the difference between the position of the scope at the start and end of each procedure as well as the variability across procedures where the working volume can be up to three times larger as shown in the images on the right.

techniques such as SLAM [6] or Structure-from-Motion (SfM) but the problem is ill posed as the surgical site is not rigid [7]. We therefore use a manual technique for this pilot study where the alignment is done by the user with the laparoscopic images shown in Figure 2 and we assume the tissue surface is fronto parallel to the orientation of the camera. The surface comparison is then done on the 2D aligned disparity images as shown in Figure 2.

RESULTS

In order to achieve real-time performance, the proposed reconstruction method was implemented using C++ and currently can operate at approximately 10 frames per second, however, with further optimization it is feasible to achieve more computationally efficient performance using hierarchical solutions and multithreading. Manual registration of the 2D images for calculating the surface difference volume is currently performed offline but an interface can easily be implemented for the operating room while we strive towards an automated solution.

Example results of surface reconstructions before and after ablation are shown in Figure 2 for two TORS cases. We calculated the volume of removed tissue in for case one to be approximately 412mm^3 and for case two 273mm^3 . These measurements are difficult to validate as there is no ground truth available for *in vivo* data. It is likely that source of error due to the assumption of a fronto-parallel scene and due to tissue deformation influence the calculation. Nevertheless these initial results indicate that with the proposed method we can make metric measurements of the change of tissue volume before and after ablation. Additionally, we are also able to measure the surface area of the ablation site, which in the case shown in the left of Figure 2 was 210mm^2 and for the one shown on the right 140mm^2 .

It is easy to observe that there is a large variation in the viewing orientation of the surgical site in the two cases. The reconstruction in one case is of a surface located approximately 50mm from the camera which is

an appropriate set up for optical reconstruction. In the second case however the surface of interest is over 150mm away from the camera and in this case the 5mm stereo baseline of the surgical scope imposes inherent limitations to reconstruction accuracy. In addition, it is easy to observe the variation in viewing orientation between the start of tissue reduction and the final scene.

DISCUSSION

In this study, we have proposed a method for computing the volume of tissue removed using laser ablation during TORS. The method is based on computational stereo using the stereoscopic laparoscope images to compute metric 3D measurements at the surgical site. Preliminary results indicate that the proposed method is promising but further work is required to enhance its robustness and allow for automatic camera adjustment between the start of the procedure and the final ablation. The results of this study provide a platform for ongoing studies which include computationally optimising the method using GPU hardware for intra-operative incorporation to provide real-time feedback for the surgeon.

REFERENCES

- [1] Arora A, Cunningham A, Chawdhary G et al. Clinical applications of Telerobotic ENT-Head and neck surgery. *Int J Surg*. 9: 277-84, 2011
- [2] Stoyanov D *et al*, "Real-time Stereo Reconstruction in Robotic Assisted Minimally Invasive Surgery," in *MICCAI*, 275-282, 2010
- [3] Rohl S *et al*, "Real-Time Surface Reconstruction from Stereo Endoscopic Images for Intraoperative Registration," in *SPIE Medical Imaging*, 2011
- [4] R. Hartley and A. Zisserman, *Multiple View Geometry in Computer Vision*: Cambridge Press, 2000
- [5] Shi J *et al*, "Good features to track," in *IEEE CVPR*, 593-600, 1994
- [6] Moutney P *et al*, "Motion Compensated SLAM for Image Guided Surgery," in *MICCAI*, 496-504, 2011
- [7] Collins T *et al*, "Towards Live Monocular 3D Laparoscopy using Shading and Specularity Information," in *IPCAI*, 2012