Development of a surgical stereo endoscopic image dataset for validating 3D stereo reconstruction algorithms

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INTRODUCTION

In the last decades, endoscopic stereo images have been exploited to retrieve tissue surface information of the surgical site using 3D reconstruction algorithms [1], [2]. The application of such algorithms in Computer Assisted Surgery (CAS) tools for Minimally Invasive Surgery (MIS) requires a robust validation process in order to guarantee reliability and safety. 3D reconstruction algorithms are commonly evaluated comparing their result with respect to a reference Ground Truth (GT) [3]. However, few datasets providing endoscopic images and GT are openly available.

In [4], a stereo-image dataset of a moving heart phantom was generated using the *da Vinci*® surgical system, providing a CT scanner-based GT. In [1], a dataset of stereo-images of ex-vivo animal organs was developed providing a CT scanner-based GT, where different conditions were investigated, such as presence of blood and smoke, and different pose of the endoscope.

Considering the increasing necessity of surgical datasets, the aim of this work is the generation of an Endoscopic Abdominal Stereo (*EndoAbS*) dataset composed of stereo-images with associated GT for 3D stereo-reconstruction algorithm validation. To recreate the surgical scenario, a polyurethane surgical phantom abdomen was built. Images were captured with a stereo-endoscope, while for acquiring the GT a laser scanner (calibrated with respect to the stereo-endoscope) was used. This dataset is openly available on-line[1] for the benefit of the CAS community.

MATERIALS AND METHODS

The generation of the dataset consists in three main steps:

1) Surgical Scenario Development: An abdominal model made of kidneys, liver and spleen phantoms was developed through a molding process, using 3D organ models provided by 3DIRCADB[2]. The 3D negative molds were designed using the software Blender 2.7.4 and 3D printed using the Elite Dimension 3D printer (layer thickness: 0.25 mm). A bi-component

[1]http://nearlab.polimi.it/medical/dataset/, Apr 2016

[2]http://www.ircad.fr/research/3dircadb/, Apr 2016

(a) (b)

Figure 1: On the left liver, spleen and kidneys are shown; on the right the ribcage containing the organs is shown.

polyurethane elastomer (F-105 A/B 5 shore, BJB Enterprise) was combined with a softening agent (SC-22, BJB Enterprise) in order to create the phantoms having approximately the real tissue characteristics.

The organs were also painted to simulate the tissue texture and small superficial vessels. Tubular structures were attached and painted on the surface of the liver and kidneys to represent main vessels, as it is shown in Fig. 1a. In addition, a ribcage-like support was 3D printed (Fig. 1b) to maintain the relative position between the organs.

2) GT generation: The GT was generated using a laser scanner. A camera-laser calibration algorithm was designed to express the GT in the camera reference system, allowing the comparison with the point cloud obtained by a 3D reconstruction algorithm. The camera-laser calibration consisted in computing the rigid transformation $\mathbf{T}_{\mathbf{C_1}}^{\mathbf{L}}$ between the same set of points in the camera reference system $\{\mathbf{C_1}\}$ and in the laser reference system $\{\mathbf{L}\}$ (see Fig. 2); hence, a non-symmetric octagonal calibration plate was designed, which vertices $\mathbf{p}_{vert}$ were used for the calibration process. The 3D vertex coordinates were identified both in $\{\mathbf{C_1}\}$ and in $\{\mathbf{L}\}$ ($\mathbf{p}_{vert}^{\mathbf{C_1}}$ and $\mathbf{p}_{vert}^{\mathbf{L}}$ respectively), and $\mathbf{T}_{\mathbf{C_1}}^{\mathbf{L}}$ was computed solving the equation (1) with the Singular Value Decomposition (SVD) method:

$$\mathbf{p}_{vert}^{\mathbf{C_1}} = \mathbf{T}_{\mathbf{C_1}}^{\mathbf{L}} * \mathbf{p}_{vert}^{\mathbf{L}} \quad (1)$$

For facilitating the comparison between the GT transformed in $\{\mathbf{C_1}\}$ and the 3D reconstructed point cloud, the GT was stored into a 2D map so that, the (u, v) cell of the map contains the 3D coordinates of the point represented in the (u, v) pixel of the left image. In

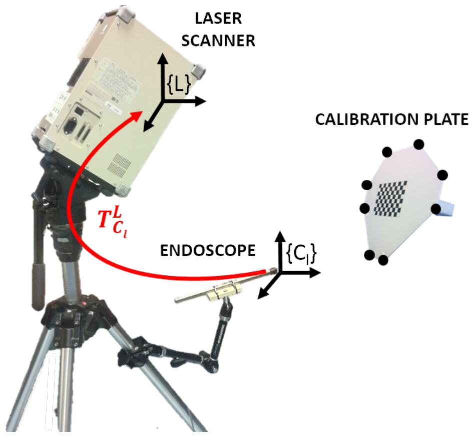

Figure 2: Setup for camera-laser calibration.

order to discard the GT 3D points having the same (u, v) coordinates, but different depth values, the GT point cloud was oversampled and, in each cell, only the point with minimum z was kept.

3) Dataset generation: The laser scanner and the stereo endoscope were positioned in order to have approximately the same point of view, looking towards the surgical scenario. Since a real stereo laparoscope was not available, two Ultra Mini CMOS Color Cameras (MISUMI) with 640×480 pixel resolution were assembled to create a custom-made endoscope with a baseline of 6 mm. In order to simulate laparoscopic lighting conditions, two white LEDs were integrated in the endoscope and the images were captured in a dark room. The GT was measured with the laser scanner VIVID 910, which has a sub-millimeter accuracy (x = ± 0.22 mm, y = ± 0.16 mm, z = ± 0.07 mm).

Thus, the obtained dataset was made of:

- 120 stereo-images of the surgical scenario (PNG format);
- GT point cloud (TXT format);
- Camera calibration parameters (TXT format);

The camera calibration was performed using the Stereo Camera Calibrator Toolbox of Matlab 2015b. In order to allow the validation of a 3D stereo-reconstruction algorithms under different conditions, the images were reproduced introducing: (i) presence of smoke, created immersing dry-ice in hot water; (ii) 3 different light levels, varying the led intensity; (iii) two phantom-endoscope distances ($\approx$ 5 cm and $\approx$ 10 cm).

EVALUATION AND RESULTS

A compressive mechanical test was done on polyurethane samples and a sample of porcine liver to identify the best percentage of the softening agent used to replicate real tissue mechanical properties. Results showed that using 50% in volume of the softening agent a Young's Modulus of 0.97 kPa was reached, similar to the Young's Modulus of the porcine liver (0.95 kPa).

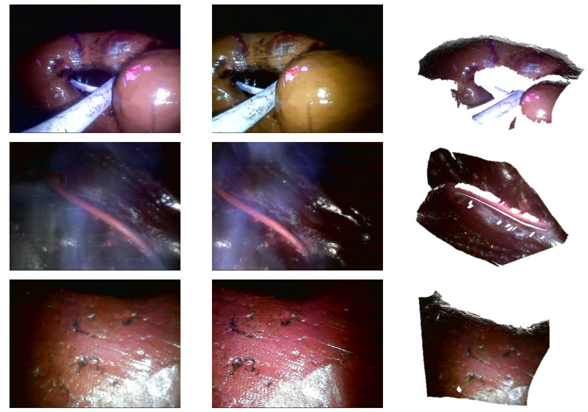

Figure 3: Samples of stereo-images and GT from EndoAbS dataset: left (top-down): kidney at $\approx$ 10 cm distance and 3rd light level, liver at $\approx$ 5 cm with smoke and spleen at $\approx$ 5 cm at 3rd light level; right: the relative GT of each image.

The abdominal phantom organs were qualitatively evaluated comparing the obtained images with respect to real surgical images. Realistic features, such as light specularity, homogeneous texture, vessels and smoke presence were reached as shown in Fig. 3.

Regarding the camera-laser calibration, the calibration error was 0.43 mm (25-75 $perc$: 0.41 mm - 0.43 mm), computed as the median Euclidean distance between a set of points in $\{\mathbf{C_l}\}$ and the same set of points in $\{\mathbf{L}\}$, transformed in $\{\mathbf{C_l}\}$ using the computed $\mathbf{T^L_{C_l}}$.

CONCLUSION AND DISCUSSION

This work presents a stereo endoscopic surgical dataset for the validation of 3D reconstruction algorithms, providing stereo-images of a phantom abdomen with an associated GT and camera calibration parameters.

Future work aims at improving the dataset generating video sequences representing tissue motions and deformations due to the contact with surgical instruments. Since the images generated are noisy due to the intrinsic characteristic of the image sensor, it could be interesting to generate the same dataset with an high quality HD stereo endoscope.

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