Deformation Estimation of Elastic Bodies Using Multiple Silhouette Images for Supporting Endoscopic Surgery

Akira Saito, Megumi Nakao, Yuki Uranishi and Tetsuya Matsuda

***Abstract*— This study proposes a method to estimate elastic deformation using silhouettes obtained from multiple endoscopic images. Our method is able to estimate the local deformation of organs with internal structures using a volumetric mesh model reconstructed from preoperative CT data. The result of the experiments showed that the proposed methods could estimate the deformation with root mean square (RMS) errors of 2.0–6.0 mm.**

I. Introduction

Recently developed surgical navigation systems can display 3D organ shapes generated from preoperative CT data. However, handling intraoperative deformation [1] is still a technical issue for itraoperative image augmentation. Although an optical tracking approach [2] using feature descriptors has been recently investigated for AR-based navigation, the stable acquisition of the features is a problem caused by time-varying illumination in laparoscopic surgery. This study proposes a method to estimate elastic deformation using multiple endoscopic images during surgery.

II. Method

We use silhouette images of organs, (*i.e.* segmentation results of endoscopic images) to estimate the local deformation [3]. Local deformation is represented by displacement of the vertices of the shape model. The next shape of the organ $M(t+1)$ is estimated from the current shape M(t) and the visual hull $H(t+1)$ computed from multiple silhouettes obtained by segmentation of endoscopic images while preserving the shape of $M(t)$ as much as possible. If the elastic body forms a smooth surface, the normal vector at a tangent point of M(t+1) should be similar to the normal vector at the corresponding tangent point of $H(t+1)$. Based on this observation, we first search for each candidates for pairs of tangent point at $H(t+1)$ and $M(t)$, and then evaluate them to select the optimal set using

$$C^* = \underset{C}{\operatorname{argmin}}(|\boldsymbol{v}_s - \boldsymbol{v}_d| + w|\boldsymbol{n}_s - \boldsymbol{n}_d|) \tag{1}$$

where v_d and v_s are candidates of tangent points on $H(t+1)$ and $M(t)$ respectively, n_d and n_s are their respective normal vectors, and w is a weight parameter determined experimentally. Their candidates can be used only when their evaluation values are equal to or less than the threshold E_{th}. We use the relationship C: v_s - v_d as the positional constraints that should be satisfied by the next shape. To achieve shape preservation, we employ a discrete Laplacian as a shape descriptor of the mesh. Finally, the next shape $M(t+1)$ is obtained by minimizing the difference between the discrete Laplacian while preserving the positional constraints.

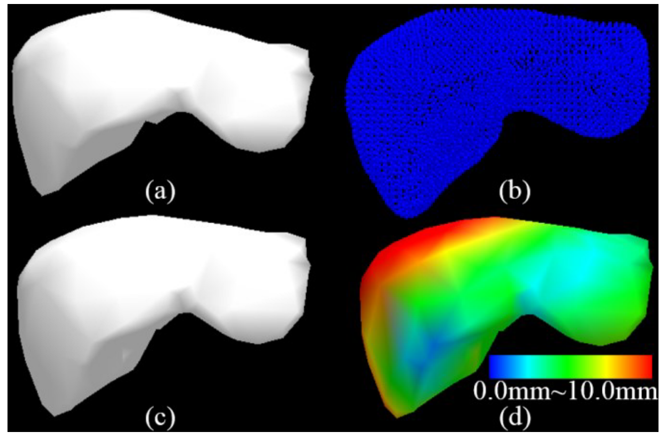

Fig1: Deformation estimation result. (a) initial shape model computed from CT images, (b) visual hull calculated from silhouette images of deformed shape (pulled in 20 mm), (c) estimated shape and (d) local estimation error.

III. Experiments

We conducted simulation experiments to estimate the deformed state $M(1)$ from the initial state $M(0)$ using visual hull $H(1)$ obtained from four camera images of a deformed shape. The initial shape was obtained from liver CT images, and the estimation error was evaluated by the Euclidean distance between the estimated vertices and the ground truth vertices. Fig 1 shows the estimated shape and the estimation error. We confirmed that elastic deformation can be estimated within 2.0–6.0mm root mean square (RMS) error.

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A.Saito, M. Nakao and T. Matsuda are with Graduate School of Informatics, Kyoto University, Kyoto, Japan (e-mail: asaito@sys.i.kyoto-u.ac.jp).

Y. Uranishi is with Cybermedia Center, Osaka University, Osaka, Japan (e-mail: uranishi@ime.cmc.osaka-u.ac.jp)