Title

A simulation study on deformation estimation of elastic materials using monocular images

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Abstract

1. Purpose

Understanding the three-dimensional (3D) geometry of vascular structures and tumors is an essential factor for surgical safety, and preoperative planning and intraoperative image guidance using computed tomography (CT)/magnetic resonance imaging (MRI) images play important roles. Because internal vessels and tumors can change during treatment, online estimation of organ deformation is a technical challenge [1]. Although hardware-based intraoperative support systems [2] have been widely developed, the increase in setup time and additional burden to medical staff are barriers to clinical use. We focus on recent advances in shape recovery techniques [3][4] without additional measurements and their application to intraoperative image guidance.

This study proposes a method to estimate elastic deformation of organs using monocular camera images during surgery. This approach computes local organ deformation with internal structures using a finite element model reconstructed from preoperative CT data. Unlike the feature-point-based tracking approach, deformation estimation is formulated as a minimization problem of global shape differences between camera images and model images. Since this approach works on monocular images, stereoscopic endoscope or specialized multi-camera systems is not needed. This presentation will discuss the methods and possible application to intraoperative image guidance.

2. Methods

To estimate the 3D elastic deformation that matches the monocular images as much as possible, we introduce an objective function which globally evaluates the difference of appearance in the segmented camera image and the model image (Fig. 1). As an initial setup, we assume the initial shape is obtained from a 3D CT image, and the finite element (FE) model M_0 is generated. M_0 is registered to the camera image using rigid transformation, and color parameters of M_0 are optimized to make the overall visual appearance close to the camera image.

When the organ is deformed, the proposed framework computes the model deformation that minimizes the difference between feature values of the organs contained in the camera image (*I*) and of the rendered image (*J*) of the FE model. Elastic deformation can be calculated when an appropriate external force is applied to the FE model. Therefore, the objective function *f* solves a minimization problem of optimizing

force constraints given to the FE model so as to obtain the closest appearance between the two images. The optimization step updates the force constraints until the difference of appearance is converged. Feature-based, point-to-point tracking approaches often fail to compute local displacement because stable detection of feature points is difficult in low-contrast or textureless materials. The global minimization of visual appearance can overcome this instability and allows stable deformation estimation including internal structures.

3. Results

Simulation experiments were conducted to estimate deformed states of a liver model using a monocular camera image. The initial shape was obtained from a 3D liver CT image and modeled by a tetrahedral mesh. The stiffness parameters are homogeneously set to the model. Several patterns of deformed states were first generated using FEM [5], and used for ground truth deformation. In this experiment, we examined if each deformed state can be reconstructed from its 2D visual appearance. Fig. 2 shows a typical estimation result and the spatial map of local estimation errors. The estimation error was quantitatively evaluated by the root mean square error (RMSE) between the 3D position of estimated vertices and that of the ground truth vertices. The result of the experiments showed that the proposed methods could estimate the local displacement with an average error of 8.6%.

4. Conclusion

We proposed deformation estimation methods of elastic objects using monocular camera images. The simulation experiments showed local displacement can be reconstructed with 4.3 mm error when a part of the organs is deformed 5 cm, which achieves a clinically available level. Our future work includes further improvement of the mathematical framework and animal experiments to investigate actual estimation performance.

Reference

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Figures

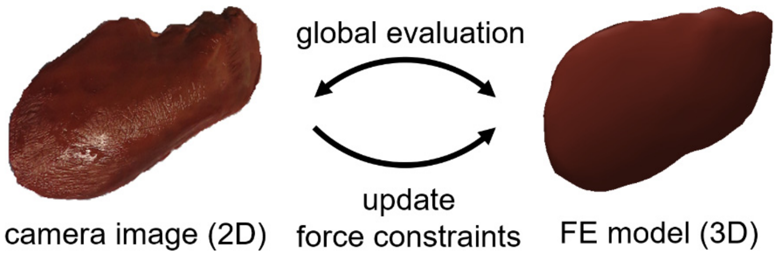

Fig 1. Outline of monocular deformation estimation by minimizing visual appearance of the segmented camera image and the FE model.

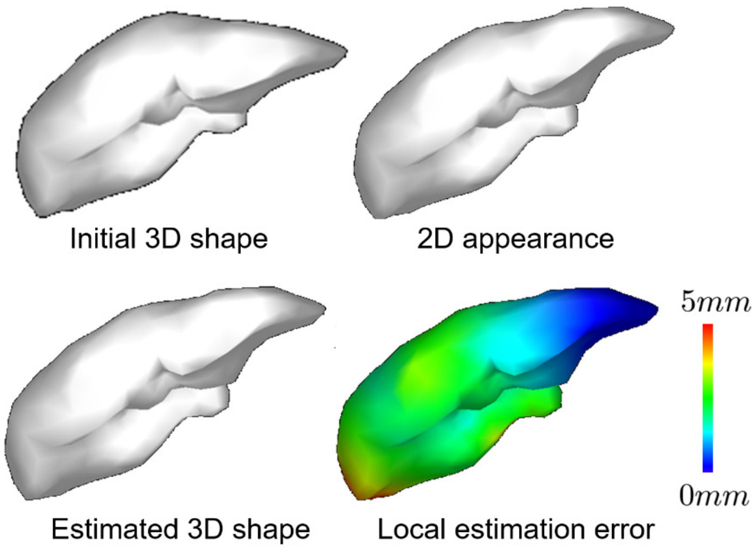

Fig 2. Typical estimation result and the spatial map of local estimation errors obtained from simulation experiments