A Framework for Deformation Estimation of Elastic Bodies from Monocular Images

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***Abstract*— This paper introduces a method to estimate deformation of elastic bodies using monocular camera images. As this issue is originally an ill-posed problem, sparse constraints are used in the objective function. Using a motion capture system, estimation performance is evaluated by the ground truth deformation of a rubber object. The results show that 12 patterns of elastic deformation by a pull of 10.0mm in average can be estimated with 4.0 mm root mean square error.**

I. Introduction

Understanding the three-dimensional (3D) geometry of organs during treatment is an essential factor for tumor localization and decision-making, and intraoperative image guidance is gaining attention in various field of surgery [1-3]. Because internal vessels and tumors can change during treatment, estimation of organ deformation is a technical challenge. We focus on a marker-less estimation approach without additional measurements such as intraoperative imaging or placement of optical markers.

This paper introduces a method to estimate elastic deformation of organs using monocular camera images. This approach computes local organ deformation with internal structures using a finite element (FE) model. 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.

II. Methods

Since deformation estimation from monocular images is originally an ill-posed problem, we formulate it as a minimization problem of global shape differences between camera images and model images. Elastic deformation can be calculated when an appropriate external force is applied to the FE model. Therefore, we propose the objective function that optimizes force constraints so as to obtain the closest appearance between the two images. Sparse constraints based on the compressive sampling theory [4, 5] are introduced to the function, and the model shape is updated 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.

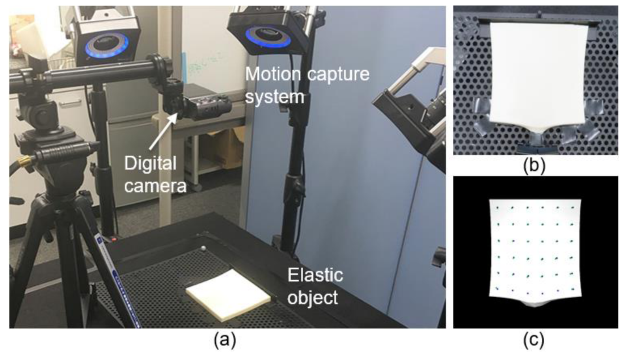

Fig. 1. Evaluation of estimation performance using a synthetic rubber object. (a) Experimental environment for measuring elastic deformation, (b) 2D appearance of a deformed state and (c) estimation results and measured marker positions as ground truth.

III. Experiments and results

We conducted experiments to evaluate estimation performance using a synthetic rubber material with a flat board shape. 36 optical markers that corresponds to the vertices of the FE model were attached to the surface, and the estimation error was quantitatively evaluated by the root mean square error (RMSE) between the 3D position of estimated vertices and that of the markers. 12 patterns of elastic deformation were generated, and the 2D appearance and the positions of optical markers were measured. The results showed that the deformation by a pull of 10.0mm in average could be estimated with 4.0 mm RSME.

References

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