A Preliminary Study on a Statistical Deformation Model of Multiple Organs for Reconstructing Respiratory Displacement

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***Abstract*— This paper describes a preliminary study on constructing a multi-organ statistical deformation model that can reconstruct respiratory displacements, including inter-patient shape differences. Using our method, shape registration can be achieved within 1 mm Hausdorff distance error and the mean respiratory motion of five organs can be represented.**

I. Introduction

A recent study reported that the respiratory motion of tumors can be tracked with satisfactory accuracy using local features [1]. However, it is difficult to track the motion of abdominal cancer because the radiography images are indistinct. Moreover, the displacement and deformation of abdominal organs are not fully understood and have not yet been quantitatively modeled. This paper introduces a preliminary study on constructing a multi-organ statistical deformation model that can reconstruct respiratory displacements, including inter-patient shape differences.

II. Method

Before we construct the statistical deformation model, shape registration must be performed, because a number of the vertices in the surface data $X_i(t)$ (t : time, i : patient id) will not fully correspond with each other. Therefore, we attempt to recreate a patient-specific dataset $Y_i(t)$ that has the same number of vertices and phase structures. We transform the standard model $X_0(t_0)$ to acquire $Y_i(t)$. Each transformation is determined to match $X_i(t)$ and $Y_i(t)$. This transformation algorithm consists of three steps.

STEP 1 Regular Affine Transform

STEP 2 Piecewise Affine Transform

STEP 3 Transform Using Discrete Laplacian [2]

In step 1, we transform $X_0(t_0)$ using an affine transform. The parameters of this affine transform are optimized to decrease the shape error, as defined by the average Hausdorff distance. In step 2, we divide each of the organ models into 27 parts and individually transform each part according to this affine transform. Owing to spatial partitioning, we can achieve effective matching results corresponding to changes in the outer shape. In step 3, local deformations and detailed surface asperity can be represented by modifying $Y_i(t)$ based on a discrete Laplacian [2]. We define the evaluation function using positional and discrete Laplacian constraints, and solve the resulting least-squares equation.

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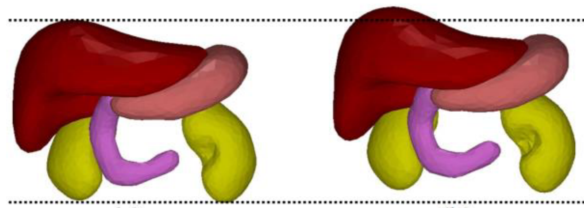

Fig. 1 Mean respiratory motion of multiple organs obtained from registered shape dataset. (a) Maximum inhalation, (b) maximum exhalation.

Table 1. The distance error of the registration results
D_B : mean of bidirectional distance error
D_H : Hausdorff distance error

organ	vertex	D_B [mm]	D_H [mm]
liver	502	0.150	0.676
stomach	402	0.134	0.524
duodenum	352	0.148	0.583
right kidney	452	0.075	0.463
left kidney	452	0.070	0.543

III. Experiments

We reconstructed a dataset for the statistical deformation model. We used data $X_i(t)$ (t = 1…10) from five organs (liver, stomach, duodenum, right and left kidneys) of 11 patients who underwent a 4DCT scan in our hospital. We selected $X_1(0)$ as the standard model, and then acquired all surface models $Y_i(t)$ by transforming $X_1(0)$. Figure 1 shows the mean respiratory motion of multiple organs obtained from the registered shape datasets. Table 1 presents the distance error of the registration results. We confirmed that shape registration could be achieved within 1 mm Hausdorff distance error and that the mean respiratory motion of all five organs could be accurately represented.

References

[1] M. Nakamura, M. Nakao, Y. Matsuo, N. Mukumoto, Y. Iizuka, K. Yokota, T. Mizowaki, and M. Hiraoka, "Application of a feature-based tracking algorithm to KV X-ray fluoroscopic images toward marker-less real-time tumor tracking", Med. Phys., 43(6), p3636, 2016.

[2] A. Saito, M. Nakao, Y. Uranishi and T. Matsuda, "Deformation estimation of elastic bodies using multiple silhouette images for endoscopic image augmentation", IEEE International Symposium on Mixed and Augmented Reality(ISMAR), pp. 170-171, 2015.