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Deformable Registration of Prone and Supine Colons for CT Colonography

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***Abstract*— CT colonography (CTC) is a non-invasive technique for detecting colorectal polyps and colon cancer. Through the addition of the prone scanning with the original supine scanning, the possibility of detecting the polyps is increased. The registration process for this application requires the comparison between the prone and supine colons for diagnosis. A level-set representation of the object boundary using a distance map is presented in this paper as an input to demons registration algorithm for supine and prone CT colonography image data. After first aligning the colon volumes based on the patient's anus position, distances inside and outside the objects' boundary are computed. The level-set from the distance map allows the demons algorithm to decide the moving direction for the initial demons' force between the two colons. We present a result with a 3 dimensional volume of a patient's colon. The results suggest that our method has excellent registration performance with high confidence even with considerable deformation of the colon lumen in 3 dimensional case.**

I. Introduction

Colorectal cancer is the second leading cause of cancer deaths in the United States. There are approximately 130,000 new cases of colorectal cancer and 60,000 deaths from it each year in the United States [1]. Most colon cancers are malignantly transformed from polyps (extra growths from the surface of a mucous membrane). The risk of developing colon cancer can be reduced by early detection and removal of colorectal polyps via screening [2]. CT colonography (CTC) or Virtual colonoscopy (VC) is a minimally invasive technique for examining the whole colon to detect colorectal polyps and colon cancer. CT colonography is minimally invasive, cost-effective, and free of risks and side effects such as perforation and infection of the colon, compared to conventional optical colonoscopy. CT colonography is a patient friendly procedure because it is convenient for patients [3]. Therefore, CT colonography is a very useful tool for screening and surgical planning.

One of the challenging problems against the practical use in clinical situations is the complexity of the human colon. Its deformation by peristalsis and the diverse shapes of polyps make it difficult to distinguish polyps from other non-threatening entities in the colon [4]. The presence of liquid stool also increases the difficulty of examining the colon lumen for detection of polyps. The additional prone scanning with the original supine scanning increases the possibility of detecting the polyps [5]. Remaining stool may conceal the lower parts of the interior colon when the patients are in the prone or supine positions for CT scanning. Thus, the comparison of the prone and supine examination results are required. Automatic registration techniques are required for the comparison between the prone and supine colons for diagnosis. This is a deformable non-rigid registration process because there are many factors leading to severe deformation of colon shape between the supine scanning and the prone scanning. First is remaining stool in the colon. This generates the flat air-fluid level depending on the posture of the patient. Another factor for extreme deformation of colon shape is an inadequate colonic distention. High contrast gas/tissue interfaces results when the insufflating gas for distention, such as CO2, fills the lumen. Thus the insufficient colonic distention may lead to severe topological deformations of the colon such as collapsed segments of the colon in the reconstructed image. On the other hand, the overdistention of the colon can make the thin haustral folds invisible, which also obstruct the registration. As the last factors, the normal colonic movement owing to peristalsis, and the shape changes of colon caused by patient's weight when patient is prone are another main reasons of severe deformation.

Acar *et. al* [6] and P. Li *et. al* [7] register the supine and prone colons using the relative colon wall positions to the colon centerlines. The premise for this approach is that a stretching, shrinking and deformation of a colon from changing the position of a patient for supine and prone CT colonography can be modeled by piecewise linear mapping functions. The authors make piecewise linear functions from the assumption that the beginning and the ending points of the prone and supine CT data correspond to the same anatomical points, and the morphological similarities exist between the local extrema of the 3D prone and supine CT data along the medial axis colonic path. However, there may be more factors in the change of the colon's shape that cannot be described by simple linear stretching and shrinking with changes in the patient position.

In this paper, a level-set representation of the object boundary using a distance map is presented as an input to demons registration algorithm for supine and prone image data. After preprocessing including flipping and initial alignment of the colon volumes, the level-set inside and outside the objects' boundary are computed using a distance map. The supine and prone colon volumes represented by the level-set are used as inputs of demons registration algorithm. From this level-set representation, the demons algorithm can register the 3D volumes with high accuracy even though the two objects are very separated and less overlapped. The experimental result with a 3D volume of a patient's colon is presented.

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II. Methods

A. Demons algorithm

Thirion [8] suggested an image-matching algorithm using a diffusion process. Using the demons concept from Maxwell's demons algorithm in thermodynamics, Thirion considered the non-rigid image matching process as a diffusion process. The theory behind this algorithm is that the object boundary can change its shape depending on the position of the demons within the image domain. The demons' forces, which deform the object shape, are generated to reduce the disparity between the source and the target images. As Thirion indicated in his paper, this algorithm cannot be applied when the two objects do not initially overlap. If the extent of overlap between the source and the target is small, the result of this demons' algorithm does not converge.

B. Overlap ratio

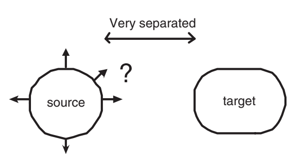
In the demons algorithm, the extent of overlap between the source and the target can be one of critical factors which affect the image registration results. Therefore, we define the overlap ratio to describe the extent of overlap between the two images as follows.

$$\textit{Overlap Ratio(OR)} = \frac{\textit{Intersection of two objects}}{\textit{Area of smaller object}} \times 100$$

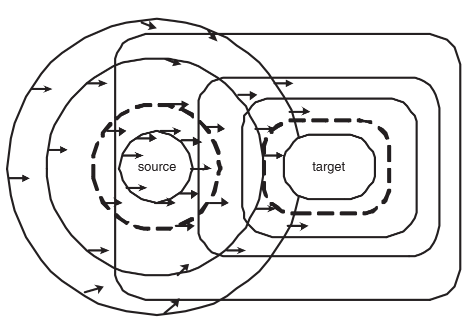
Since there is no standard criterion to evaluate the 3D non-rigid registration result, we used this OR as an approximate criterion to estimate the extent of the correctness for the non-rigid registration result.

C. Generation of the level set

When registering between supine and prone colons, it is common that only very limited parts of colons are overlapped with small OR. In order to cope with the non-overlapped case or the very low OR case, we generate the level-set representation of the object boundary using a distance map. Distances inside the object boundary are denoted by negative values, and the distances outside the boundary are denoted by positive values. As Figure 1 shows, this level-set representation allows the demons algorithm to decide the moving direction for the initial demons' force even though each of the two objects is very separated. Since the segmented colon volume is described with binary values (the outside is 0 and the inside is 1), the intensity difference between the two objects cannot be accounted for. Thus, the level-set representation of these objects allows the corresponding image region to be maintained as the difference of intensities found in the original demons algorithm implemented in Thirion's paper [8].



(a) Very separated objects



(b) The effect of the expanded surfaces of objects

Fig. 1. The influence of level sets of very separated objects on Demons' force. (a) Demons' force cannot be decided because of the non-overlapped separation between source and target. (b) Initial direction of Demons' force can be decided by the expanded surfaces of the source and target.

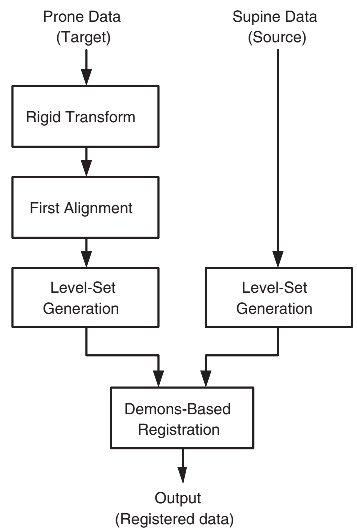


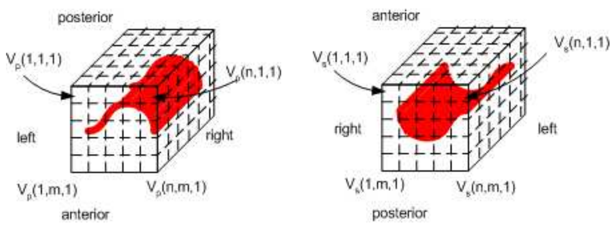
Fig. 2. Block diagram for the suggested method

D. Method details

Figure 2 shows the block diagram of the suggested method in this paper. This method preprocesses either the source or target data. It can be noted that the prone data is preprocessed arbitrarily before level set generation, while the supine data does not need preprocessing.

1) Rigid Transformation : The voxel order CT-scanned at the patient's prone posture does not conform to the voxel order CT-scanned at the patient's supine posture as shown in Figure 3. Therefore, either the supine or prone colon data should be flipped before the registration processing.

2) First alignment : Initial alignment between these two colon data is required because the detailed relative position of the patient in the CT scanner may be different. The location of the patient's anus was chosen as a fiducial point for the alignment of the colon volumes because the relative position of patient's anus is a unique point in relation to the colon, which is less influenced by the change in a patient's posture. While the overlap ratios (OR) before the first alignment are less than 18%, the overlap ratios after first alignment are



(a) (b)

Fig. 3. CT-scanned data with different order at prone and supine posture. (a) prone data, (b) supine data

more than 40%. As mentioned earlier, the extent of overlap between the source and the target can be one of critical factors which affect the image registration results. Therefore, this first alignment plays an important role in the registration accuracy by increasing the overlap ratio between the source and target colons.

3) Implementation of level-set : In order to make use of the implementation within the National Library of Medicine Insight Segmentation and Registration Toolkit [9] (ITK), the level-set scaling was adopted in both the level-sets of supine and prone colons as shown in Figure 4. Although the minimum values inside the volumes for the supine and prone colon are different, the same positive value was added to both the inside levels to synchronize the original object boundaries for supine and prone colons. After the registration process is finished, the added value should be used to get the boundary surface for the deformed object instead of the zero level set.

4) Demons-based registration : The multi-resolution pyramid procedure was adopted for efficiency. Four layers were utilized from the coarsest to the finest layer to search the deformation field in this large 3D data set. Iteration numbers for each layer were set to be 500, 700, 800 and 550 from the finest layer to the coarsest layer respectively.

E. Implementation details

As mentioned above, ITK was used to implement our method. This open-source software system was used to

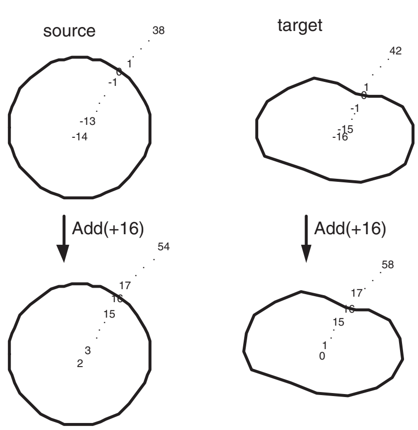
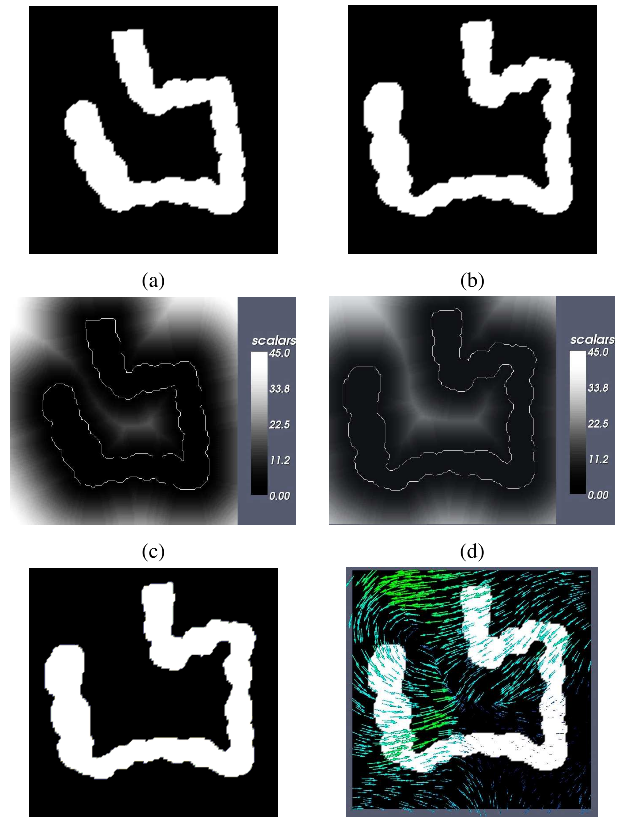


Fig. 4. Level-set scaling with the positive deepest value.



(a) (b) (c) (d) (e) (f)

Fig. 5. 2D example for demons' registration with level set representation. (a) Source Image, (b) Target Image, (c) Level set for source image, (d) Level set for target image, (e) Registered image and (f) Deformation field

support the image segmentation and registration in 2D and 3D data. The Visualization Toolkit [10] (VTK) format was used to store the image data, and ParaView [11] was used to analyze and view the image data.

III. RESULTS

Figure 5 shows the image data after each step in the 2D registration process between the two synthetic images using the suggested method. Since it is difficult to show the 3D level-set images for the source and the target, we offer the 2D level-set images for the source and the target in Figure 5(c) and (d). Figure 6 displays the registration results for 3D volumes using the suggested method between the supine and the prone colons segmented from a patient's CT data. As one can see in Figure 6(c), the reconstructed colon looks similar to the original colon with an exception to two artifacts highlighted in Figure 6(f). The main reason for these differences is that some parts of the source volume were merged during the downsampling of the source volume in an effort to reduce the computational burden (From 512x512x340 to 256x256x170). Figure 7 shows the variation of the OR in each step. From the suggested method, we can obtain an OR of up to 95%.

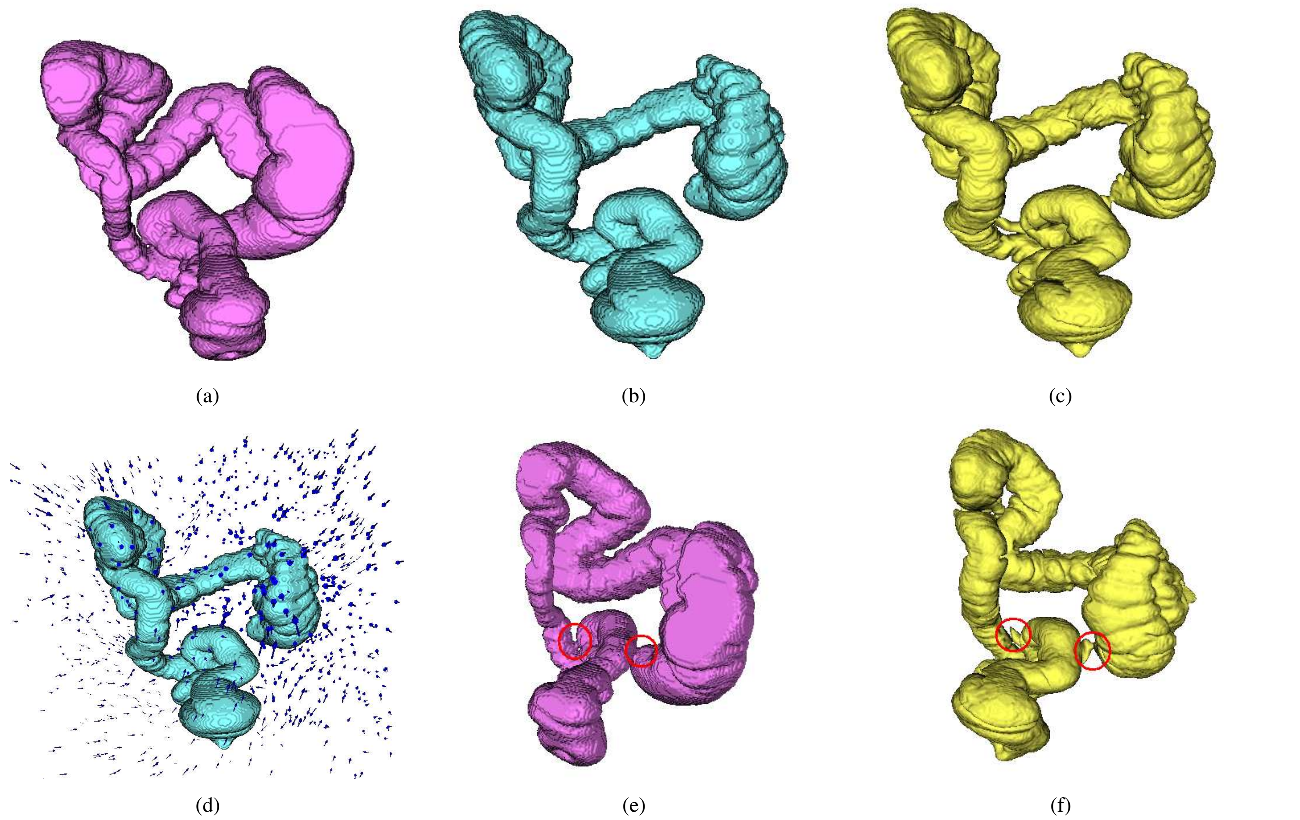


Fig. 6. 3D example for demons' registration with level set representation. (a) Source supine colon, (b) Target prone colon, (c) Registered colon, (d) Deformation field, (e) Merged regions of source and (f) Error region corresponding the merged region

IV. Conclusion and Discussion

The results of the suggested method were accurate for the 3D volume of a patient's colon. This method computes and compares all virtual levels outside and inside the object as expanded surfaces. Therefore, this method requires intense computational power. The quality of the segmentation from the raw CT data before the registration procedure is important in the performance of this method as it is with other registration methods. As mentioned above, we used subsampled source and target volumes because of the large original volumes. This subsampling may cause a deterioration in the quality of the segmentation. The memory size required for dealing with a full sized volume is as follows.

2 level set representations (float size):	(512x512x340) x2 x4
Temporary reconstructed volume (float size):	(512x512x340) x4
Deformation field (x, y, z, float size):	(512x512x340) x3 x4
Total:	2.14 GBytes

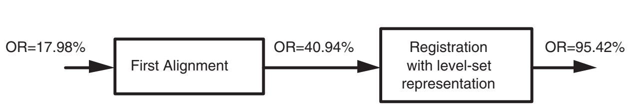


Fig. 7. The variation of overlap ratio (OR) in each step.

In future works, we plan to reduce the required memory size for this method, and investigate 3D registration with topological differences between the two objects.

References

[1] S. Parker, T. Tong, S. Bolden and P. Wingo, "Cancer statistics 1997", *Cancer Journal for Clinicians*, vol. 47, pp.5-27, 1997.

[2] C. L. Wyatt, Y. Ge and D. J. Vining, "Automatic segmentation of the colon for virtual colonoscopy", *Computerized Medical Imaging and Graphics*, vol 24, pp.1-9, 2000.

[3] M. Wan, Z. Liang, Q. Ke, L. Hong, I. Bitter and A. Kaufman, "Automatic Centerline Extraction for Virtual Colonoscopy", *IEEE Trans. Medical Imaging*, vol. 21, no. 12, December, 2002.

[4] R. M. Summers, "Challenges for computer-aided diagnosis for CT colonography", *Abdominal Imaging*, vol. 27, pp.268-274, 2002.

[5] J.G. Fletcher , C.D. Johnson , T.J. Welch , *et al*., "Optimization of CT colonography technique: prospective trial in 180 patients", *Radiology*, vol. 216, pp.704-711, 2000.

[6] B. Acar, S. Napel, D.S. Paik, P. Li, J.Yee, R.B. Jeffrey and C.F. Beaulieu, "Medial Axis Registration of Supine and Prone CT Colonography Data". 2001 Proceedings of the 23rd Annual EMBS International Conference, pp.2433-2436, 2001.

[7] P. Li, S. Napel,B. Acar, D.S. Paik, R.B. Jeffrey Jr.and C.F. Beaulieu, "Registration of central paths and colonic polyps between supine and prone scans in computed tomography colonography: Pilot study" *MED PHYS*, 31 (10): 2912-2923 OCT 2004.

[8] J. P. Thirion, "Image matching as a diffusion process: an analogy with Maxwell's demons" *Medical Image Analysis*, vol. 2, no. 3, pp. 243-260, 1998.

[9] National Library of Medicine Insight Segmentation and Registration Toolkit (ITK) http://www.itk.org/index.htm

[10] Visualization Toolkit (VTK) http://www.vtk.org

[11] ParaView: Parallel Visualization Application http://www.paraview.org/HTML/Index.html