DEPARTMENT OF COMPUTER SCIENCE
UNIVERSITY OF COPENHAGEN

Accuracy of Deformable Image Registration in Radiotherapy for Liver Cancer

José D. Tascón-Vidarte *jota@di.ku.dk*
Line B. Stick *line.bjerregaard.stick@regionh.dk*
Ivan R. Vogelius *ivan.richter.vogelius@regionh.dk*
Sune Darkner *darkner@di.ku.dk*

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Abstract

The accuracy of deformable image registration is tested with 4DCT images of seven patients. The algorithm used is Symmetric Image Normalization SyN. The images contains gold markers used as ground truth. Registration error are found to be up to 1.6 mm and no statistical difference are found between sequential or referenced registration.

Introduction

Radiotherapy is a treatment where radiation is used to control or kill cancer cells. Uncertainties due to patient motion during radiotherapy can cause underdosing the target and/or overdosing to organs-at-risk [1]. A deformable image registration algorithm corrects patient motion. The algorithm can be applied prior to treatment or intra-treatment.

Despite been widely used, the accuracy of deformable image registration is difficult to test. This difficulty appears due to the lack of ground truth data. As remarked by [2], most of deformable image registration algorithms are only evaluated in lungs and the accuracy in other low contrast organs is unclear. Furthermore, the typical datasets have landmarks manually annotated for lung images. Therefore, we evaluate in this work deformable image registration with a specific dataset for liver with the advantage that contains gold markers as ground truth.

Materials and Methods

Data

The patients are treated with stereotactic body radiation therapy. The data of seven (7) patients are used. For each patient the following images are obtained: 4DCT, 3 MRI in inspiration breath hold, 3 MRI in expiration breath hold. Physicians use the MR images in conjunction with the CT scans to delineate all the organs. The dose plan is then computed by physicists. The registration is tested with 4DCT scans. The image resolution of each image in the 4DCT is 512x512x180 pixels and length per pixel 1x1x2 mm respectively.

The patients are treated with linear accelerators where gold markers are required to align the patient during radiotherapy. The gold markers dimensions are 5 mm in length and 2 mm in diameter. Three gold markers are inserted relatively close to the gross tumor volume (GTV). Figure 1 shows the delineated volumes. The displacement between expiration and inspiration for all the patients is 7.2 $\pm$ 2.4 mm.

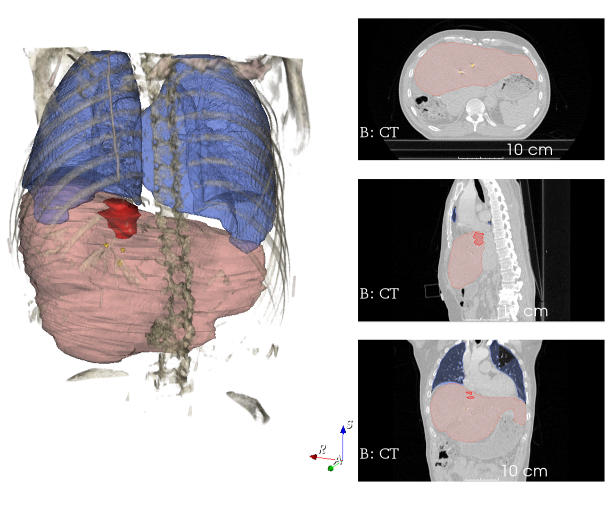


Figure 1: Thorax 3D image with liver(ligth red), gross tumor volume (dark red) and gold markers (yellow)

Algorithm

Avants et al. introduce Symmetric Image Normalization (SyN) algorithm in [3]. SyN algorithm uses Cross Correlation (CC) as similarity metric and the L2 norm of the velocity field as regularization. The transformation or displacement field is then computed by integration. The mathematical setup is formulated as follows.

Cross correlation metric is defined as:

$$CC(I_0, I_1, \varphi(x)) = \frac{\left(\sum_{x\epsilon\Omega_0}^{n} (I_0(x) - \bar{I}_0) \cdot (I_1 \circ \varphi(x) - \bar{I}_1)\right)^2}{\sum_{x\epsilon\Omega_0}^{n} (I_0(x) - \bar{I}_0)^2 \cdot \sum_{x\epsilon\Omega_0}^{n} (I_1 \circ \varphi(x) - \bar{I}_1)^2} \tag{1}$$

The optimization in SyN is described by the energy equation:

$$\arg\min_{\varphi(x)} E = \int_{t=0}^{0.5} \left(\|v_1(x,t)\|_L^2 + \|v_2(x,t)\|_L^2\right) dt + \int_{\Omega} CC(I_0, I_1, \varphi(x)) d\Omega \tag{2}$$

Where:

$\varphi(x) = \phi_1 \circ \phi_2^{-1}(x,t)$ each ϕ_i is subject to:

$\frac{d\phi_i(x,t)}{dt} = v_i(\phi_i(x,t),t) \quad with \quad \phi_i(x,0) = Id$

Registration

In this work, the registration is computed in two ways. The first method uses a single image as reference and the others images are registered to this. The image reference is chosen as the end of expiration, typically phase 5 in the 4DCT. The second method register all the images sequentially. The registration errors are then compared. The process is depicted in Figure 2.

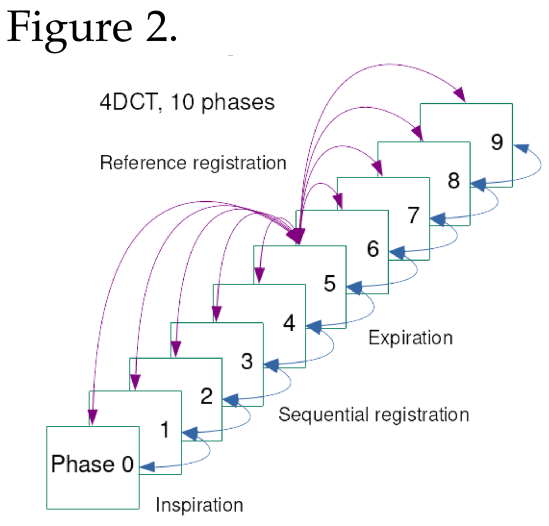


Figure 2: 4DCT scans and registration as referenced or sequential.

Computed Errors

The gold markers are used as the ground truth data to evaluate the accuracy of image registration. Two metrics are used. The first metric is the distance between the ground truth gold markers and the estimated gold markers. The transformation found by registration is applied to the gold markers in a reference phase (of the 4DCT), producing the estimated gold markers.

$$d_{error} = \|x_{m,j} - \varphi_j(x_j) \circ x_{m,ref}\| \tag{3}$$

The second metric is the distance error between the relative motion of the GTV and the relative motion of the gold markers. The GTV position is calculated for every image based on the transformed GTV of the reference image. This is defined as:

$$gtv_{error} = \|(x_{m,j} - x_{m,ref}) - (\varphi_j(x_j) \circ x_{GTV,j} - x_{GTV,ref})\| \tag{4}$$

Results

First, we test the registration algorithm with expiration and inspiration were the maximum displacement occurs. We also compute the distance error per iteration to compare with the metric CC. Figure 3 depict the registration for one patient. We observe that the algorithm converges properly after parametrization.

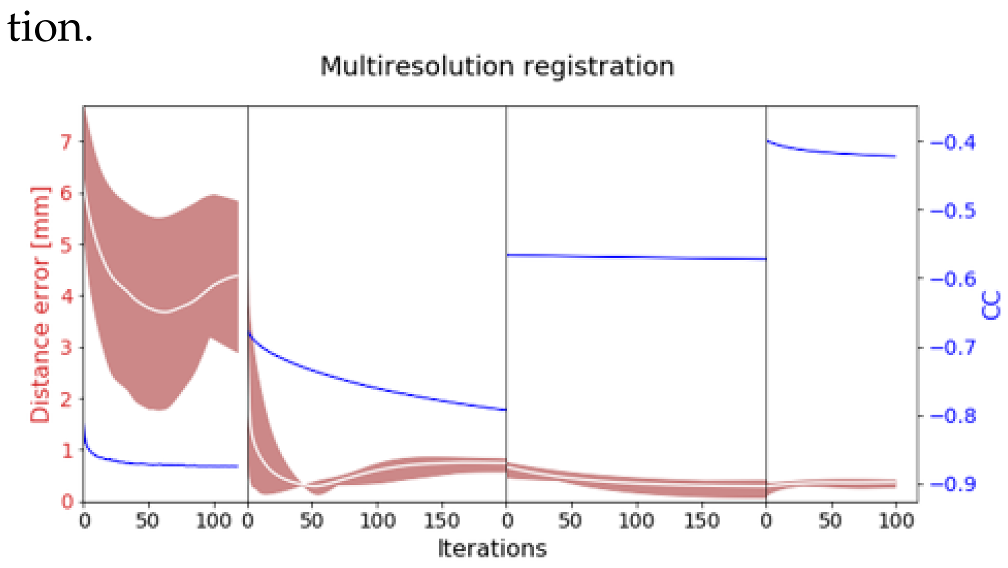
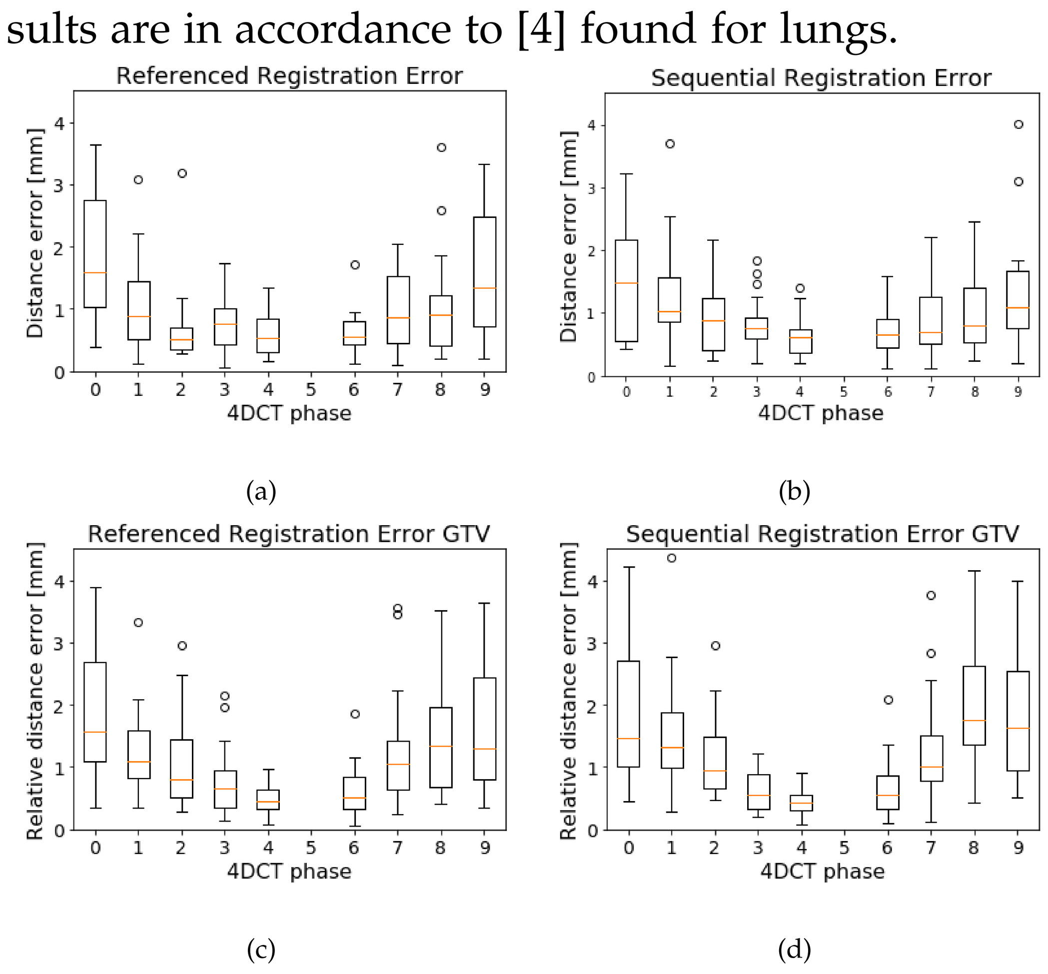


Figure 3: Comparing ground truth distance error with cross-correlation similarity metric in multi-resolution registration.

The registration errors using the transformed gold markers have a maximum average of 1.5 mm and 1.6 mm for the referenced registration and the sequential registration. Also, increased variance is noted for the images further away of the reference phase. However, there are no statistical difference in the registration method. The errors of relative motion between GTV and gold markers have a maximum average 1.5 mm and 1.6 mm. Again, there are no statistical difference between the methods. These results are in accordance to [4] found for lungs.



(a) (b) (c) (d)

Figure 4: Distance errors computed for reference and sequential registration.

Conclusions

We evaluate registration accuracy in liver 4DCT scans. There are no statistical differences between registering the images sequentially or referenced. In the worst case the registration algorithm is accurate up to 1.6 mm average error. This accuracy is adequate for radiotherapy.

Acknowledgements

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References

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