Non-rigid motion estimation from hierarchical adaptive local affine registrations

Christian Buerger*, Tobias Schaeffter, and Andrew P. King

Division of Imaging Sciences and Biomedical Engineering,
King's College London, St Thomas' Hospital, London
{christian.buerger,tobias.schaeffter,andrew.king}@kcl.ac.uk

Abstract. Non-rigid image registrations have been widely employed in medical imaging to estimate the complex tissue deformations such as those caused by respiratory motion. To reduce the computational burden of non-rigid registration techniques, alternative approaches have been proposed which decompose the non-rigid registration problem into a combination of multiple more simple registration problems, such as locally affine components. For the EMPIRE10 challenge we apply a modified version of a local affine registration algorithm, where all local affine components are embedded in an adaptive hierarchical structure.

Keywords: image registration, non-rigid, local affine, hierarchical structure

1 Introduction

The estimation of non-rigid tissue deformation remains challenging in medical imaging and non-rigid image registration techniques have been proposed to model this kind of deformation (e.g. [7]). However, the computational complexity of non-rigid registration algorithms can sometimes be very high. While some researchers have proposed addressing this issue by implementing their algorithms on an alternative architecture (such as GPU implementations), we focus on simplifying the algorithmic complexity of such algorithms by decomposing the non-rigid registration problem into multiple locally affine components. [5][6] proposed such a registration scheme by embedding locally affine components into a hierarchical registration scheme and demonstrated their technique by registering 2D skeletal muscle images. This work has been extended by Andronach et al. to be applied to 3D registration problems [1][2].

In previous work [3], we have implemented a similar algorithm to [5][6] and [1][2], improving registration performance by including an adaptive scheme in the hierarchical sub-division process. For the EMPIRE 10 challenge, we present a refined version of the algorithm described in [3], modified as described below.

* Corresponding author: Christian Buerger, Division of Imaging Sciences and Biomedical Engineering, 4th Floor Lambeth Wing, The Rayne Institute, St Thomas' Hospital, London SE1 7EH, United Kingdom, phone: +44 (0)20 718 88388, email: christian.buerger@kcl.ac.uk

2 Method

Note that an extensive description of our method has been submitted to a journal paper and is currently under revision. For that reason, the following sections only give a brief description of the basic principles of our algorithm. On full publication of our work, we will update this document with a more complete description.

2.1 Registration

Similar to [5][6][1][2], our registration algorithm is structured in a hierarchical scheme of multiple registration levels L. At the initial registration level $L = 0$ we perform a global affine registration over the complete region of interest Ω. Ω is then subdivided into its child blocks using an adaptive subdivision scheme (see [3]), leading to the next registration level $L = 1$. Affine registrations in all child components are performed and this subdivision-registration process is repeated until a minimum user defined block size is reached.

All registrations do not make use of any of the provided lung segmentations but perform generic whole-field-of-view motion estimations.

2.2 Transformation

We combine the transformations of all local affine components to form an overall smooth transformation at each level. We employ free-form deformations (FFD) based on B-Splines for all registration levels $L > 0$, so that each level is associated with a single free-form deformation, FFD_L.

2.3 Similarity measure

We choose the normalized cross correlation (NCC) as similarity measure during all local affine regsitrations.

2.4 Optimizer

Within each affine registration, a steepest gradient descent optimizer is applied.

2.5 Singularities

Over all 30 registration pairs included in the challenge, our algorithm resulted in between 15 and 20 registration levels, so that the overall deformation for each image pair was described by a combination of 15-20 FFDs. We ensure that each FFD_L at level L is diffeomorphic by limiting the range of each control point to 40% of the current control point spacing [4][8]. Consequently, the combination of multiple FFDs is diffeomorphic. The evaluation of singularities in the EMPIRE10 challenge considers the voxelwise deformation vectors only and does not consider the motion path being estimated during registration. Therefore, we note that although our deformation is deffeomorphic, singularities might appear in the evaluation results.

2.6 Execution times

In order to speed up the execution time of the pairwise registrations, we incorporate a multiresolution approach into the registration process. With respect to an average regsitration level of $L = 15.5$ over all 30 registration pairs, we downsample the images by a factor of 8 for levels 0 to 5, by a factor of 4 for levels 6 to 10 and by a factor of 2 for levels 11 to 14. From level 15 on, the original image resolution was used. With this approach we registered all image pairs with an average execution time of 13.2 min on a workstation with 2 Six-Core processors, Intel Xeon X5670, 2.93GHz, and 96GB Memory.

Acknowledgments. Our work is part of a project for hybrid PET-MR imaging (HyperImage) which is supported by the European Union under the 7th framework program (201651).

References

1. Andronache, A., Cattin, P., Szekely, G.: Adaptive subdivision for hierarchical nonrigid registration of multi-modal images using mutual information. In: Proc. of MICCAI, 2005
2. Andronache, A., von Siebenthal, M., Szkely, G., Cattin, Ph.: Non-rigid Registration of Multi-modal Images using both Mutual Information and Cross-Correlation. Medical Image Analysis, 2008(12):3-15
3. Buerger, C., Schaeffter, T., King, A.P.: Hierarchical adaptive local affine registration for respiratory motion estimation from 3-D MRI. In: Proc. of International Symposium on Biomedical Imaging - ISBI, 2010
4. Choi, Y., Lee, S.: Injectivity Conditions of 2D and 3D Uniform Cubic B-Spline Functions. Graphical Models, 2000(62):411-427
5. Likar, B., Pernus, F.: Registration of serial transverse sections of muscle fibers. Cytometry, 1999(37):93-106
6. Likar, B., Pernus, F.: A hierarchical approach to elastic registration based on mutual information. Image and Vision Computing, 2001(19):33-44
7. Rueckert, D., Sonoda, L.I., Hazes, C., Hill, D.L.G., Leach, M.O., Hawkes, D.J.: Nonrigid registration using free-form deformations: application to breast MR images. IEEE Transactions on Medical Imaging, 1999(18):712-721.
8. Rueckert, D., Aljabar, P., Heckemann, R.A., Hajnal, J.V. , Hammers, A.: Diffeomorphic Registration Using B-Splines. In: Proc. of Medical Image Computing and Computer-Assisted Intervention, 2006