Second Germany-Korea Joint Conf. on Advanced Medical Image Processing,
Darmstadt - Heidelberg - Hamburg, Germany, June 19-24, 1997, pp. 60-63

Landmark-Based Elastic Matching of 3D Medical Images

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Abstract

We describe an approach for 3D image registration based on a set of corresponding anatomical point landmarks and approximating thin-plate splines. This approach is an extension of the original interpolating thin-plate spline approach and has been introduced in [7] to cope with landmark localization errors. The extension is important for practical applications since landmark extraction is always prone to error. Additionally, we are investigating 3D differential operators for semi-automatic localization of anatomical point landmarks.

1 Elastic Image Matching

In neurosurgery and radiotherapy planning it is important to either register images from different modalities, e.g. CT (X-ray Computed Tomography) and MR (Magnetic Resonance) images, or to match images to atlas representations. If only rigid transformations were applied, then the accuracy of the resulting match often is not satisfactory w.r.t. clinical requirements. In general, nonrigid or elastic transformations are required to cope with the variations between the data sets.

This contribution is concerned with elastic matching of medical image data based on a set of corresponding anatomical point landmarks. Previous work on this topic has concentrated on i) selecting the corresponding landmarks manually and on ii) using an interpolating transformation model (e.g., Bookstein [2], Evans et al. [4]). The basic approach draws upon thin-plate splines and is computationally efficient, robust, and general w.r.t. different types of images and atlases. Also, the approach is well-suited for user-interaction which is important in clinical scenaria. However, an interpolation scheme forces the corresponding landmarks to exactly match each other. The underlying assumption is that the landmark positions are known exactly. In real applications, however, the localization of landmarks is always prone to error. This is true for interactive as well as for automatic landmark localization.

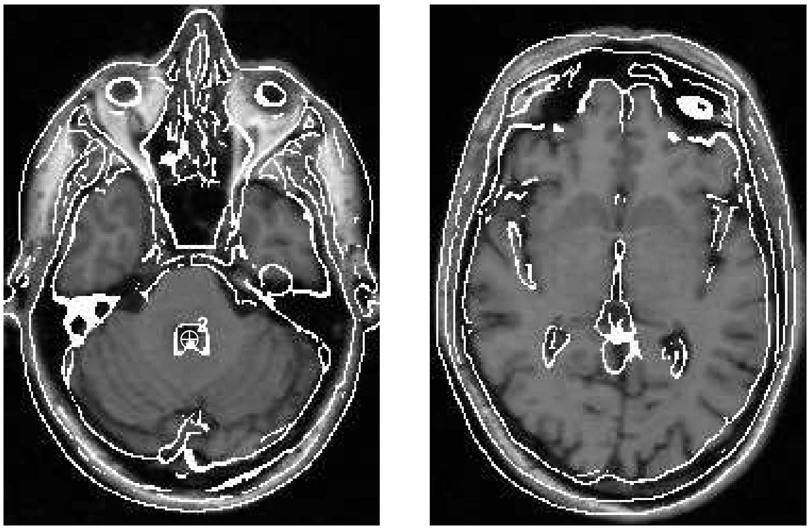

Figure 1: Registration result of two 3D MR datasets of different patients using 'normal' landmarks and 'quasi-landmarks': slice 29 (left) and slice 55 (right).

Therefore, to cope with landmark localization errors, we have extended the original interpolating thin-plate spline approach to an approximation scheme (Rohr et al. [7],[9],[8]). This new approach "approximating thin-plate splines" is based on a minimizing functional analogous to the original interpolating scheme. However, with the new approach the landmarks are not forced to match exactly. Also, it is possible to individually weight the landmarks according to their localization uncertainty and thus to control the influence of the landmarks on the registration result. We have applied this approach to elastic matching of 2D as well as 3D tomographic images of the human brain (see Fig. 1 for an example). It turns out that in general we obtain a more accurate and robust registration result than in the case of interpolation. For a different approach to relax the interpolation condition, see Bookstein [3]. However, this approach has not been related to a minimizing functional. Also, this approach has only been described for the 2D case and has only been applied to synthetic data.

2 Semi-Automatic Landmark Localization

We are also investigating the semi-automatic extraction of anatomical point landmarks using 3D differential operators ([7],[6],[1]). Algorithms for this task are important since manual selection of landmarks is time-consuming and often lacks accuracy (e.g., [4], [5]). As an example, we show in Fig. 2 the application of a 3D 'corner' detector vs. a 2D version

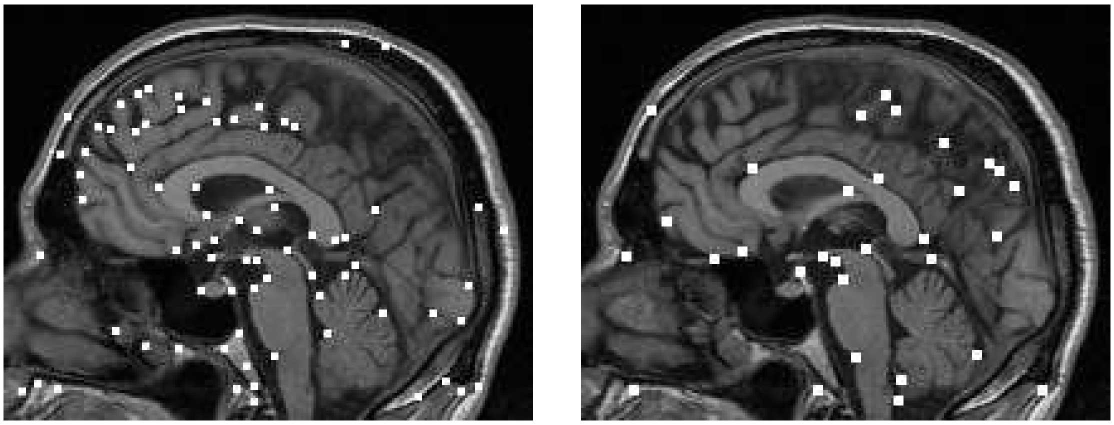

Figure 2: Landmark candidates: Application of a 2D 'corner' detector (left) vs. a 3D extension (right) on a 2D and 3D MR image, resp.

of it. Note, that with the 3D operator there are additional landmarks which have been detected in different slices of the 3D MR image.

Acknowledgement

This work has been supported by Philips Research Hamburg, project IMAGINE (IMage- and Atlas-Guided Interventions in NEurosurgery).

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