Vessel-based non-linear registration of MR/CT images for monitoring of a patient

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Abstract: *Registration of the brains of two different patients is impossible because of variability of the blood vessels. But two brain scans of a single patient made by short time interval can be compared on the base of vascular trees. Main result of this communication is in presentation of a method for such registration. Computer assisted monitoring of a human brain can be an important aid to diagnostics or operability decisions. A brain monitoring can provide precise estimation of changing of a tumor territory, reveal a new lesion in the brain, and so on.*

Keywords**:** brain registration, vascular tree, radial basis functions.

1. INTRODUCTION

We propose a method for registration of the brain tissues on the base of matching the blood vessels. Registration of two brain images is the determination of geometric transformation aligning structures of the brain. Monitoring anatomic changing of the internal structures is an important application of registration. A series of volume images of a patient under examination are acquired in some time intervals. Blood vessels with injecting of contrast coloring solution into vascular system (angiogram) are distinctly displayed on the scans. Either computer tomography (CT) or magnetic resonance imaging (MRI) may be applied in combination with such injection.

There exist dozen algorithms of registration, nevertheless, each of them takes into account specific characters of images and there does not exist an universal method of registration of brain images. This presentation is focused on matching of scans for monitoring changing in anatomical structures of a brain of single patient. For warping brain images we have explored an angiogram of the arteries or vein.

Several authors have already investigated the usage of a blood tree for matching purposes. Nakajima et al. [1] exploited cortical blood vessels for registration of video images of the surgical operation with preoperative MR images for correcting a transformation. Porter [2] linearly warped MRI of a liver and prostate against color Doppler ultrasound volumes on the base of vessels segmentation. Aylward et al. [3, 4] segmented vessels and introduced a metric for rigid registration based on this segmentation for aligning CT images of a liver and a brain. A global rigid registration was followed by piece-wise linear registration of branches in the vessel tree. A method to register MR and B-mode ultrasound images of the liver based on vasculature was presented by Penney [5]. The rigid warping used ultrasound images to establish the correspondence between the MR volume and the patient on the operating table. Lange et al. [6] presented a method to register scans and Doppler ultrasound images of the liver using blood vessels; their technique exploits the B-splines. Reinertsen [7, 8] proposed the registration algorithm using retrospective patient data presenting the anatomical structures in addition to deformations in different parts of the brain. A non-rigid registration method based on the segmentation of the portal veins was developed in [9]. Mathematically it is the combination of an iterative closest point approach and B-spline transformation.

2. METHOD

2.1. *General description of the method*. First of all, we register two brain volumes of a single person, acquired in short time interval. For successful application we need the assumption that in this interval the vasculature holds the same position in the volume relative to the surrounding anatomical structures.

On first stage the contrasted blood vessels (the arteries or veins) are segmented within the region of interest. It means the centerlines of distinct vessels are extracted from the scans. Landmark warping is exploited in proposed method; therefore, the branching points of vessels are selected as matching landmarks. A graph model of a vascular system is designed from one of the scans. It is suitable to use a scan with better resolution. On the second stage a similar graph model is constructed for another scan on the base of the first graph model. Then the anatomical corresponding points of branching of vessels are determined. The third stage consists of a warping procedure. A mathematical method for registration may be selected from various papers on landmark warping. We use radial basis functions that provide exact matching of landmarks along with good interpolation of intermediate tissues. On necessity, precise correction of transformed image can be implemented by any interpolation algorithm (three-linear interpolation, splines, and so on).

2.2. *Blood vessel segmentation*. Usually angiography is applied either to arteries or to veins. Simultaneous angiography to both ones is a rare exceptional case. The names of blood vessels are organized as a forest (in contrast to blood vessel system that forms a directed graph). The largest vessels are the roots of trees, this is the level 0, smaller ones that originate from them form nodes of the level 1, and so on. The arteries and veins generate two different forests that are connected by the capillary vessels. For example, the largest Cerebellar veins are: Superior vein of vermis, Inferior vein of vermis, Superior veins of cerebellar hemisphere, Inferior

veins of cerebellar hemisphere, Precentral cerebellar vein, Petrosal vein. Each of enumerated veins collects blood from several smaller nameless veins, and these smaller veins collect the blood from capillaries. Usually a tree of this vascular forest contains vessels on three – four levels.

Segmentation of vessels starts from the arteries or veins of level 0. Contrasting color of the blood is clearly distinct from surrounding tissues, especially for thick vessels at level 0. The largest vessel on the slices may be selected as an initial element segmenting the vasculature. Starting from this fragment we try to trace the vessel with its branching. Geometrically an evident way of vessel segmentation is to draw its centerline. Segmentation results in a graph model of the vessel system. Branch points of a vessel give nodes of the graph. A segment of a vessel lying between two adjacent branch points is an edge of a graph. Length of the segment may be considered as a weight of the edge. A branch of a vessel of level 0 is a vessel of the level 1, a branch of a vessel of level 1 is a vessel of the level 2, and so on. A process of segmentation may be interactive, for scans with high resolution it may be automatic. In our experiments a number of nodes were approximately equal to a number of edges (the graph has almost a tree structure) and were about 120.

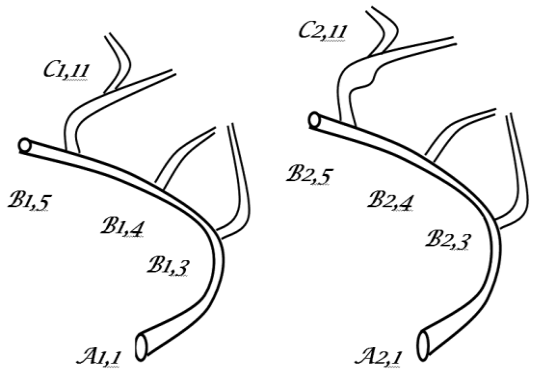

Fig.1 - Fragments of segmented angiograms. Right fragment contains an aneurism at edge [B2,5; C2,11].

2.3. *Construction of matching landmarks*. On the previous stage a graph model of the blood vessels was designed, let it be undirected graph G_1 probably containing a few cycles. It was constructed for an image with better resolution. A similar model is designed for another image; let it be a graph. The graph G_2 is designed on the base of graph G_1. According our assumption (vasculature of the patient is invariable) graphs G_1 and G_2 are isomorphic. Similar nodes of graphs, as show on Figure 1, are matching landmarks for warping algorithm. Analytically they are presented by their coordinates on the images under registration.

2.4. *A procedure of registration*. On the final stage an algorithm that transforms one image onto another is selected from available warping procedures. The thin plate method is our choice for image warping. Radial basis functions are an alternative name of the algorithm; usually researchers refer to a paper [10] as an initial publication, in fact, there exist earlier articles. Specifying coefficients of the function of transformation, one have to solve a simultaneous linear equation, it is the most difficulty of thin plate splines algorithm. 120 landmarks and several stabilizing points it gives a linear system of an order approximately 130. Even modified Gauss method is fast and rather precise for nonsingular system of such order. Besides, the radial basis functions provide good interpolation of space lying between landmarks.

3. RESULTS

Our method was applied for registration of volumes of different modalities, MRA and SW acquired by 4 months' interval. Figures 2 and 3 shows sugittal slices reconstructed from initial axial MRA and SW scans respectively.

Both arteries and veins were registered for the patient. Superior sugittal sinus was selected for segmenting as an initial element. Figures 4 and 5 illustrate 3D volumes with blood vessel tries reconstructed from MRA and SW scans.

Vessel patterns such as branching points and high curvature points were identified in first dataset. They were then used to recognize corresponding landmarks in second dataset.

4. CONCLUSION

Recent advances in medical imaging techniques significantly improve the situation in a noninvasive examination of brain anatomy and physiology. For diagnostic purposes, a brain of a patient may be subject to examination repeatedly for comparing the quantitative and qualitative changing in brain tissues and vasculature.

We present a method for matching a series of computer tomography and/or magnetic resonance angiograms acquired from a single patient. Our method transforms blood vessel system of one image onto another; the transformation is continuous and along with the vasculature transforms surrounding structures. Displacements of volumes enable a practitioner to measure changing of the brain structures.

A vascular system is contrast on the scans of high resolution; it may be identified automatically. Otherwise, interactive procedure should be applied.

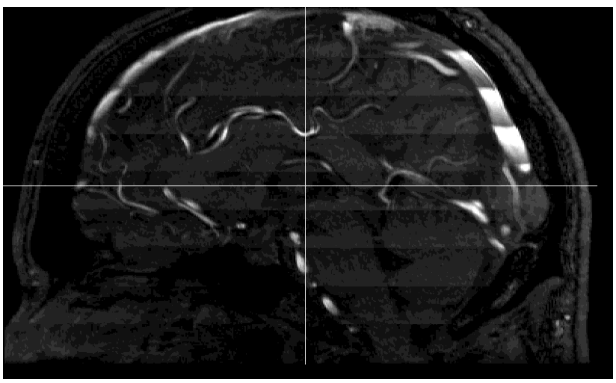

Fig.2 – A sugittal slice of MRA image.

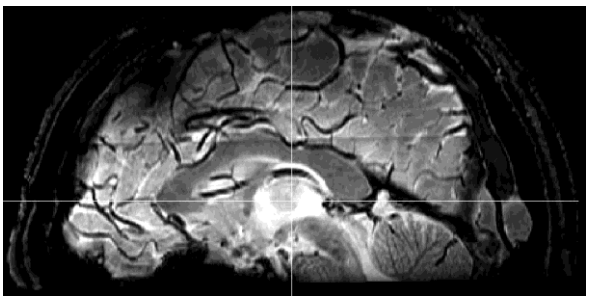

Fig.3 – Corresponding sugittal slice of SW modality scans.

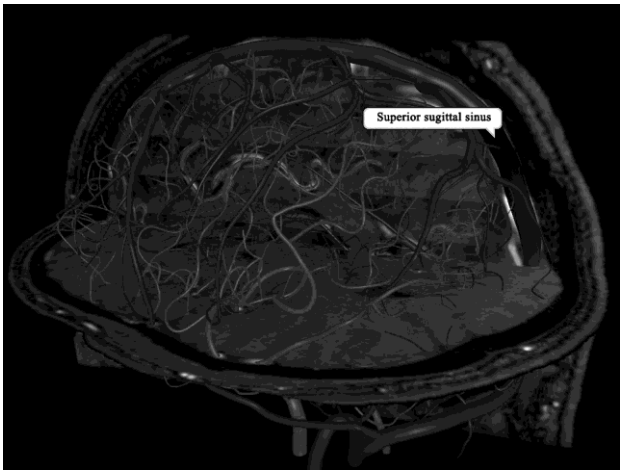

Fig.4 – 3D volume reconstructed from MRA modality scans.

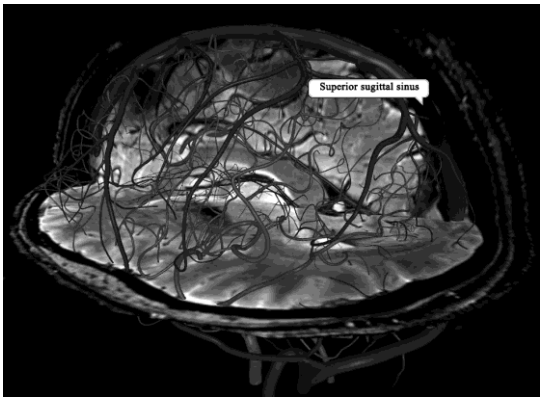

Fig.5 – Corresponding sugittal slice of SW modality scanning.

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