Intensity-based Registration of 2D-DSA and 3D-DSA Data Sets for Flow Simulation in Intracranial Aneurysms

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Abstract

We present a method to automatically register 2D cerebral digital subtraction angiography (DSA) images to 3D-DSA volumes. The method can be used for validation of flow simulation results and surgery planning. The algorithm was tested on clinical studies of six patients.

1 Introduction

Blood flow simulations [1] support treatment of intracranial aneurysms and similar defects of the cardiovascular system. Registration of time-dependent 2D-DSA images to rotational DSA (3D-DSA) volumes is necessary for validation of simulation results. For validation purposes, flow information and corresponding spatial information have to be fused. By registering the 2D image and the 3D volume, additional spatial information is incorporated in the 2D image while retaining the flow information.

The goal of the algorithm is to compute a precise registration. The registration should determine translation, rotation and projection parameters, although only the approximate acquisition geometry is known.

2 Method

Our approach aims to find a rigid body registration. The general procedure is to compute maximum intensity projections (MIP) from the 3D-DSA volumes that are as similar as possible to the 2D-DSA images. The projections are then registered to the 2D-DSA images by optimizing the parameters in three steps. Our registration approach is intensity-based and similar to [2].

We use the normalized cross correlation as similarity measure and a regular step gradient descent as optimization algorithm.

Two types of image data are input to the algorithm: A series of 2D-DSA images with n frames that show the blood flow over time and a 3D-DSA volume that shows the blood-filled vessels as a three-dimensional volume at a time. The images of the 2D-DSA data set are integrated to a maximum arterial opacity image (2D-MAX, Fig. 1(a)). This is done by determining the largest intensity value for each pixel for frames 1 to $\frac{n}{2}$. A MIP is computed from a 3D-DSA volume to simulate a 2D-DSA image by conic raycasting (Fig. 1(b)).

We use six extrinsic parameters to determine the registration between the 2D-MAX and projection images: $(\phi, \theta, t_x, t_y, s, \alpha)$. ϕ and θ are the projection parameters that are defined by the position of the virtual camera in spherical coordinates. ϕ corresponds to the primary angle and θ corresponds to the secondary angle of the C-arm system. t_x and t_y are the translation parameters, s and α are the scaling and the in-plane rotation, respectively.

An optimization of ϕ and θ is necessary due to inaccuracies in the acquisition system. The approximate value of ϕ is given by DICOM meta information. As no information about θ is provided, the initial value is estimated to be 0°.

The first step roughly determines t_x and t_y, thus finding a good initialization of the registration. This is done by superimposing the centers of both the 2D-MAX image and the projection image and then performing an optimization algorithm. A special transfer function for MIP creation is used for the purpose of a robust initialization position.

The second step optimizes the parameters ϕ and θ. The exact position, from where the 2D-DSA image is taken, is computed. An exhaustive search is performed in the parameter search space around the estimated projection parameters. The search space is defined by a $10^\circ \times 10^\circ$ grid with a maximal valid deviation of 20° for both projection parame-


(a) (b) (c)

Figure 1: 1(a) A 2D-MAX image produced from a 2D-DSA image, 1(b) A MIP of the 3D-DSA volume, 1(c) The registered image as checkerboard comparison.

ters from the starting position. Step 1 and step 2 are carried out repeatedly to correct translation caused by changing ϕ and θ.

The last step incorporates a fine-tuning where s and α are optimized as well. The search space is strongly restricted as only fine-tuning is necessary.

3 Results

Validating our registration results is difficult because of the lack of known ground truth. We therefore adapted a standard validation method that includes the comparison of reference markers in the acquired image modalities. We manually set markers to salient image features that are visible in both the 2D-MAX image and the projection image. Such image features include bifurcations and aneurysms. To estimate the accuracy, a root mean square (RMS) projection error measured the spatial distance between corresponding markers in the registered images: $e_{RMS} = \sqrt{\frac{\sum_{i=1}^{N}(e_i)^2}{N}}$, where e_i denotes the Euclidian distance and $N = 20$ denotes the number of markers.

The technique was tested on clinical studies of six patients with intracranial aneurysms (example: Fig. 1(c)). The average RMS error was 2.21 mm with a standard deviation of 1.06 mm. Our algorithm had a success rate of 90 %, if the data sets covered the whole cerebral vasculature. This rate is higher than comparable algorithms [3].

4 Conclusion

We demonstrated the ability of our algorithm to produce accurate registrations of 2D-DSA and 3D-DSA data sets. Our registration does not require user interaction. Additional data are incorporated from the 3D-DSA volume to the projection by using an appropriate transfer function to find a robust initialization position. The projection parameters are then determined by optimizing the known approximate parameters given by the acquisition machine.

Our 2D-3D registration algorithm could be applied especially for validating flow simulation results. However, it has also potential in other applications like surgery planning.

Future work incorporates experiments with other similarity measures and an optimization algorithm, which substitutes the exhaustive search in the second step. The algorithm will be extended to cover also the registration of regions of interest.

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