AUTOMATED 3D CTA SUBTRACTION OF LOWER LIMBS

Roman Peter
Doctoral Degree Programme (2), FEEC BUT
E-mail: xpeter12@stud.feec.vutbr.cz

Miloš Malínský
Doctoral Degree Programme (2), FEEC BUT
E-mail: xmalin09@stud.feec.vutbr.cz

Supervised by: Jiří Jan
E-mail: jan@feec.vutbr.cz

ABSTRACT

CT subtraction angiography plays a crucial role in diagnostics and medical treatment. The major problem of this method is a movement of patient between but also during pre-contrast and post-contrast image acquisitions. Especially in the area of lower limbs it is very difficult to describe the movement because of the number of bones and different possibilities of soft tissue deformation. Based on these theoretical presumptions a sophisticated methodology based on a combination of rigid and non-rigid registration methods is created.

1. INTRODUCTION

As for reliable classification of peripheral vascular disease in the area of lower limbs, an excellent extraction of blood vessel tree is needed. Thus a sophisticated method that allows removing of other high-density objects from CT angiographic data (CTA) - especially bones - has to be found. Reliable removing of bone is possible only if the bone from the pre-contrast phase and the identical bone from post-contrast phase are in the same spatial position. The process of reliable alignment can be very difficult - especially in places, where blood vessels are connected to high density structures as described in [1]. In real situation there is a lot of possibilities of patient movement between and also during the acquisitions that leads us to use the piece-wise rigid registration combined with minor non-rigid registration in the area of bones and non-rigid registration in the area of soft tissues. Crucial steps for the process of image registration comprise data preprocessing consisting in reliable elimination of unwanted objects, leg segmentation followed by bone segmentation and their mutual mapping.

2. METHODS

This section is divided into three parts. Preprocessing, where the methods of unwanted objects elimination, bones segmentation and mapping are described, registration part and the part of image subtraction and merging. The data used for testing has been provided by CT low dose native mask in calves and on run-offs, Brilliance 40, Philips Healthcare, Netherland, with identical protocols.

2.1. PREPROCESSING

Even if the part of registration process is very important in regard to the quality of final subtraction, the preprocessing provides crucial input data used afterward in the registration process.

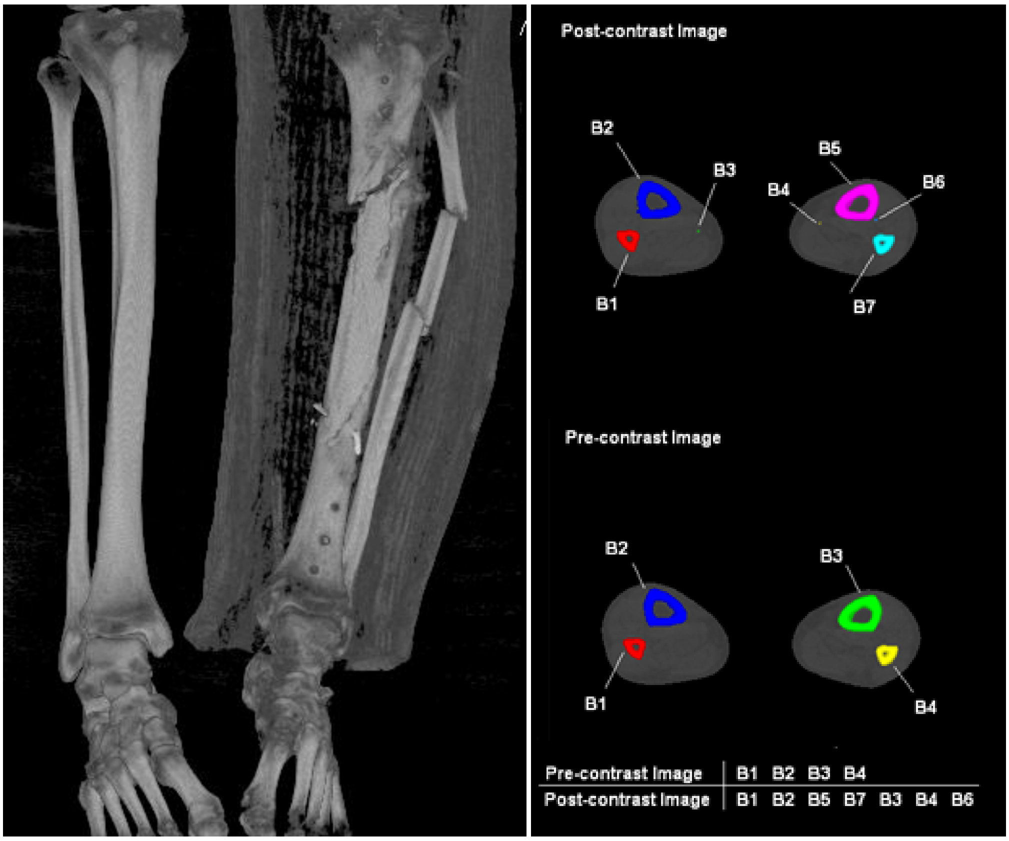

Figure 1: Precontrast acquisition (left), Identification of bones (right)

Artifacts elimination

This section describes the removal process of unwanted objects such as patient desk and artifacts from image reconstruction. The most of reconstruction artifacts is removed by thresholding with the threshold defined by Otsu method [2]. Patient desk and the other unwanted objects are removed by a method based on leg segmentation and higher threshold – clearly determining bones and excluding all other objects.

Identification of corresponding bones

In this section segmentation of bone structures and searching of bone correspondences between pre-contrast and post-contrast phases is described. Bones are segmented by threshold defined by parameters (mean values) of two Gaussian curves derived by approximating of averaged volume histogram [3, 4]. Then for each bone defined in pre-contrast data a corresponding bone in post-contrast data is searched. Based on the size and position of high-density objects, for each bone from pre-contrast phase the most similar bone from post-contrast phase is searched. Based on this presumption and limits, the parameter of reliability for each pre-contrast bone is determined. If the correspondences between both acquisition phases are found, they are marked as reliable, otherwise unreliable.

As for the mentioned reliability, bone-lockers (dilated areas of segmented bones, figure 1) are created either from post-contrast images for reliable bones otherwise from pre-contrast images. In these areas an optimal combination of registration methods (mentioned in 2.2.) is used.

2.2. IMAGE REGISTRATION

Segmented bones represent objects, where a rigid movement is presumed. This is why only shift and rotation transform is used to find the maximal similarity during an optimization process (1).

$$\boldsymbol{\alpha_0} = arg(min_\alpha\, C(F, T_\alpha(M))) \tag{1}$$

, where R is the reference image and F is the to-be-registered (floating) image, which is transformed by $T(\boldsymbol{\alpha})$ to coordinates of the reference image. The registration quality, corresponding to the transform T, is evaluated by the criterion function C. $T(\boldsymbol{\alpha}_0)$ is then the optimally registering transform with respect to the chosen criterion.

For the optimization the CRS algorithm with alternating heuristic combined with cosine similarity function [5, 6] is used. Because of the possible motion also during acquisitions, the rigid registration doesn't guarantee good alignment. This is the reason why the low-level non-rigid post-registration is also needed in the areas of bones.

As for the flexible registration, we use the Demon method (2), which is based on Optical Flow [7, 8].

$$\boldsymbol{u} = \frac{(m-f)\nabla f}{|\nabla f|^2 + \beta^2 (\mathrm{m}-\mathrm{f})^2} + \frac{(m-f)\nabla m}{|\nabla m|^2 + \beta^2 (\mathrm{m}-\mathrm{f})^2} \tag{2}$$

, where $\mathbf{u} = (u_x, u_y, u_z)$ is 3D disparity map estimation, f is the intensity of static image, m is the intensity of rigidly registered floating image and ∇f is the gradient of static image. There are two forces in the equation. The intern (∇f) is based on the edge and the extern force ($m - f$). The term $(\mathrm{m} - \mathrm{f})^2$ which is weighted by β improves the stability of the image registration process.

The Demon algorithm is efficient in sub-pixel but also in pixel registration, which is based on the iteration process. This method is thus useful also as for the soft tissue registration, where the movement might be very complicated.

2.3. SUBTRACTION AND FINAL MERGING

There are two categories of registered volumes obtained as a result of the registration process in 2.2., which determines different subtractions. The final subtraction is defined as follows. Areas defined as bone-lockers are filled by minimal values from both of the mentioned subtractions, while the rest of the volume (leg excepting the bone-lockers) is derived only from the soft tissue registration. Based on experimental results, this approach combining both of mentioned registration methods and subtractions is optimal.

3. RESULTS

Algorithms are implemented in Matlab r2009b. Time of computing is around 1 hour at the workstation supporting parallel processing (8 workers). Our method was tested on set of 30 patients with positive results, evaluated by medical specialist. Our method is able to deal with abnormal cases such as broken leg (Figure 1). Based on the evaluation by medical specialist, our method allows very good visualization of lumen in areas with artery calcifications. As for the qualitative assessment, high-density objects are removed mostly totally even in pedal region [9]. Due to excess movement, only small parts of very distal bones have remained. There are shown also small vessels to diameters below 1 mm on images, which provides a complex view of supplying arterial system.

Figure 2: Final subtracted volume

4. CONCLUSION

Combination of rigid and flexible geometric transform allows us to align complicated mutual motion between both acquisition phases and extract the blood vessel tree reliably. Based on the evaluation by medical specialist, our method might lead to better prognostic and improved treatment especially in diabetic patients. Registered data were visualized on EBW (Extended Brilliance Workspace) Rel 3.5. clinic /Philips NL/ and compared with original implemented method.

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