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An automatic aneurysm extraction algorithm in fused brain digital subtraction angiography images

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ABSTRACT

Brain aneurysm is one of the most life-threatening events, which is associated with a high rate of mortality and disability. There are many factors, which specify the best treatment option for each particular patient. In this paper, an automatic computer-aided extraction algorithm for brain aneurysm, from fused digital subtraction angiography (DSA) images is proposed. In this algorithm, firstly, to remove vessel structure, morphological operations based on multi-directional structure elements and nonlinear diffusion filtering are used. Then, by applying circular Hough transform and region growing algorithms, the aneurysm extraction procedure is performed. In this step, to overcome to poor edge gradient of aneurysm, we define a labeled diffused image which specifies the region growing conditions. Finally, by using morphological operators, the aneurysm extraction performance of our algorithm is improved. In addition, the radius of extracted aneurysm is defined and reported as a geometric feature. The experimental results indicate that our proposed algorithm obtains accuracy rate of 77.5% for the aneurysm extraction on 30 abnormal cases.

1. Introduction

Due to weakness or injury in the wall of artery, an abnormal bulge will be appeared which is named aneurysm. In some cases, the aneurysm rupture can lead to catastrophic complications such as hemorrhagic stroke [1,2]. Cigarette smoking, high blood pressure, severe head injury and family history can have important role to increase a person's risk for having a brain aneurysm. Double vision, numbness and heavy headache can be some symptoms for the aneurysm problem. The three major types of intracranial aneurysms are saccular, fusiform and dissecting. A saccular aneurysm is the most common type of aneurysm which causes subarachnoid hemorrhage [3]. Computerized tomography angiogram (CTA), magnetic resonance angiogram (MRA) and X-ray angiography are the most recent operations which can be used to visually observe the aneurysm in detail [4]. Note that if the brain aneurysm ruptures, it will lead to serious medical problems. However, many aneurysms do not rupture and some unruptured aneurysms do not require treatment. Open surgical clipping and endovascular coiling are two main treatment options for patients who need to be treated [3]. Moreover, there are some factors which affect the way

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of treatment such as age, family history, shape, size and location of the aneurysm [3].

Nowadays, automatic computational geometric feature extraction for evaluating the risk of rupture and treatment plan is essential. Especially, when the large numbers of data sets are used and manual process of these data is very time consuming. To address this issue, based on the aneurysm characteristics such as shape, size and energy, image processing algorithms are applied to detect the aneurysm and then calculate its geometric features. The shape features such as circularity measure [5–7] and sphericity measure [8,9] and also the energy [5–7] and size of the aneurysm [9] are applied to detect the aneurysm.

One of the main problems of presented algorithms for the aneurysm extraction is extracting the aneurysm from the parent vessels. Due to a variety of the medical imaging system modalities, the various studies for the aneurysm extraction from different modalities of the medical imaging systems such as the angiography of retinal fundus images [5,6], the CTA [8] and the MRA [8,9] images of cerebral and the cerebral angiography images [10–12] have been performed. To extract the aneurysm from these images, different image processing techniques have been applied. Hough transform [13] is one of the applicable image processing techniques that have specialized in detection of geometrical shapes in binary images. To detect the aneurysm by Hough transform [6,7], usually a preprocessing stage as vessel structure removal [7] is performed. For example, Abdelazeem [7] removed the vessel structure by applying directional filters. In these algorithms, usually many aneurysm candidates with various sizes are detected by Hough transform and therefore, removal of the false positive candidates is a vital problem.

One spatial filtering along with a post-processing algorithm is a common scenario in the aneurysm detection algorithms [5,8,11]. For example, match filtering [14], and then global thresholding [5], multi-scale sphere-enhancing filter and then modified k-means clustering [8], morphological filtering and edge extraction based on Sobel operator [10], global binary thresholding and average filtering [11] are applied to detect a set of the aneurysm candidates. In these algorithms, different criteria such as the size, shape and energy of the candidate regions are used to determine the aneurysm regions from non-aneurysm regions.

The vessel segmentation and then process on the vessel pattern based on geometrical features also have been used to detect the aneurysm [9]. In this algorithm, firstly, the grayscale thresholding and region growing algorithms were used for the vessel segmentation. Secondly, the aneurysm was enhanced by applying gradient concentrate filter. Then, based on the size, sphericity and the mean value of gradient concentrate image, false positive candidates were removed. The main challenge of this algorithm is the parameter tuning of the region growing algorithm to obtain the vessel pattern properly.

As previously mentioned, the mentioned algorithms attempted to isolate the aneurysm from the vessel structure and similar tissues. Therefore, we conclude that the vessel structure removal is a fundamental preprocessing which its performance has great effect on result of the aneurysm extraction algorithm. Especially, when shape similarity between the aneurysm and vessel overlaps or cross sections of the vessels is seen. However, the vessel structure removal is always accompanied with removing non-vessel structures, which can be the aneurysm in some cases. Thus, there is a tradeoff between performance of the vessel structure removal and aneurysm extraction algorithms.

Note that although medical imaging system breakthroughs are dramatically promoting, in the developing countries, some novel techniques are not affordable and accessible for the medical treatment and diagnosis. For instance, in case of our study, in compared to the MAR and CTA as two cutting-edge techniques, 2-D angiography operation is more accessible and cost-effective in the developing countries. Thus, as one valuable clinical application, implementing an automatic method to extract the brain aneurysm from the 2-D DSA images can be very helpful in public-health application. In this paper, to deal with the lack of medical facilities in the developing country, an automatic and systematic aneurysm extraction algorithm from the 2-D angiography images is proposed. In other words, the detection of aneurysm location in the image and also extraction of the aneurysm geometric features are considered as the main aim of this paper. In this algorithm, the morphological characteristic and size of the aneurysm are considered as two main criteria. In addition, to overcome to the poor edge gradient problem, a labeled diffused image is introduced which the extraction procedure is carried out based on a new definition of the pixel values. To handle the aneurysm detection problems such as different shapes and sizes of the aneurysm in different views of the 2-D angiography images with various contrasts and edge gradients, we design our proposed algorithm in three steps consisting of preprocessing, aneurysm extraction and post-processing.

2. Materials and methods

Fig. 1 shows the block diagram of our proposed automatic brain aneurysm extraction algorithm. Our algorithm is presented in three main steps. The first step is removing the vessel structure based on the morphological operators with the multi-directional structure elements and nonlinear diffusion filtering. In the second step, Hough transform and the region growing algorithm are used to extract the aneurysm candidates. In the last step, the morphological operator is used as a post-processing procedure to improve the aneurysm extraction results. Finally, the radius of each aneurysm is calculated which will help physician to choose the best treatment option. In the following, these steps are described in details.

2.1. *DSA image fusion algorithm*

Our proposed automatic brain aneurysm extraction algorithm is applied on the DSA fused image. For this purpose, we use a state-of-the-art algorithm [15] that lately has been introduced to fuse a sequence of the DSA images. This automatic fuzzy-based fusion algorithm can be summarized in two main steps [15]. In the preprocessing section, at first, registration operation was performed. Then, to find valuable frames in the fusion procedure, the variance and average values of the subtracted frames were used in a frame selection scenario. Next, background estimation and elimination were done.