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Technical Section

A hybrid pixel-based classification method for blood vessel segmentation and aneurysm detection on CTA

S. Kostopoulos[a,*], D. Glotsos[a], G.C. Kagadis[a], A. Daskalakis[a], P. Spyridonos[a], I. Kalatzis[c], M. Karamessini[b], T. Petsas[b], D. Cavouras[c], G. Nikiforidis[a]

[a]Medical Image Processing and Analysis Group, Laboratory of Medical Physics, School of Medicine, University of Patras, 265 00 Rio, Greece
[b]Department of Radiology, University Hospital of Patras, 265 00 Rio, Greece
[c]Medical Image and Signal Processing Laboratory, Department of Medical Instruments Technology, Technological Institute of Athens, 122 10 Athens, Greece

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Abstract

In the present study, a hybrid semi-supervised pixel-based classification algorithm is proposed for the automatic segmentation of intracranial aneurysms in Computed Tomography Angiography images. The algorithm was designed to discriminate image pixels as belonging to one of the two classes: blood vessel and brain parenchyma. Its accuracy in vessel and aneurysm detection was compared with two other reliable methods that have already been applied in vessel segmentation applications: (a) an advanced and novel thresholding technique, namely the frequency histogram of connected elements (FHCE), and (b) the gradient vector flow snake. The comparison was performed by means of the segmentation matching factor (SMF) that expressed how precise and reproducible was the vessel and aneurysm segmentation result of each method against the manual segmentation of an experienced radiologist, who was considered as the gold standard. Results showed a superior SMF for the hybrid (SMF = 88.4%) and snake (SMF = 87.2%) methods compared to the FHCE (SMF = 68.9%). The major advantage of the proposed hybrid method is that it requires no a priori knowledge of the topology of the vessels and no operator intervention, in contrast to the other methods examined. The hybrid method was efficient enough for use in 3D blood vessel reconstruction.

Keywords: Vessel segmentation; CTA; Hybrid; Snake; FHCE

1. Introduction

An aneurysm is an abnormal bulging outward of an artery. Brain aneurysms (also called intracranial aneurysms (IAs)) are commonly located at the branching points of the major blood vessels at the base of the brain. IAs are usually discovered after they rupture, causing subarachnoid hemorrhage (SAH), i.e. bleeding in the subarachnoid space [1,2]. A recent review [3] indicates a prevalence in the general population of up to 6%.

SAH is a serious condition with high morbidity and mortality. At 75% of the cases, SAHs are due to ruptured IAs, which usually originate from the major blood vessels of the cerebral arterial circle (circle of Willis) or from their branching arteries [4].

Detection of IAs has been traditionally performed using standard digital subtraction angiography (DSA) [5]. Computed Tomography Angiography (CTA) is a new non-invasive imaging modality that has recently started to be recognized as a rapid and accurate alternative to the standard DSA technique for brain aneurysms visualization [6–9].

Brain aneurysm detection is of crucial importance, since it enables the quantification of a variety of crucial parameters (i.e. the width of the neck of the aneurysm, its orientation, and its relation to the parent vessel), that significantly affect treatment planning and surgical intervention [2,6]. Thus, accurate detection and segmentation of brain blood vessels in CT angiograms is of major importance to the radiologists.

*Corresponding author. Tel.: +30 2610 997745; fax: +30 2610 996106.
E-mail address: skostopoulos@upatras.gr (S. Kostopoulos).

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Although numerous studies and reviews have been devoted to the demanding task of vessel segmentation [10–14], from the technical aspect, there is no general technique that may be effectively applied to all modalities [12]. Regarding CTA, most previous studies have used inbuilt CT-software to segment aneurysms [5,8], others have employed commercial software to outline aneurysms [6,9], and few have experimented with own developed software for segmentation [10,13,14]. However, most segmentation techniques require a priori knowledge and/or operator intervention. Snakes (active contours) have been shown to be among the most promising techniques [10,14,15]. Another promising segmentation method is the pixel-based classification, employing supervised or unsupervised classifiers [16–18], that require no a priori information and, to our knowledge, have found no application in vessel segmentation.

In the present study, a hybrid semi-supervised pixel-based segmentation algorithm for the segmentation of aneurysms on CTA is proposed and it is compared against two other novel and reliable techniques that have been previously tested in vessel segmentation applications: an advanced thresholding technique, using connected elements, that has been employed in vessel segmentation on DSA images, and an advanced snake method [19], that has been previously used in aneurysm segmentation on CTA images.

2. Material and methods

Eleven cases of patients with IA were examined. From each case, a Digital Imaging and Communications in Medicine (DICOM) dataset of CTA brain images (Siemens Somaton Plus 4, Siemens AG, Erlangen, Germany) was acquired from the Department of Radiology of the University Hospital of Patras, Greece. Dataset comprised 924 CTA images in total. CTA data slices were interpreted, using a typical window width (150 HU) and window center (100 HU), by an expert radiologist (T.P.). As the basic interest was focused onto the major brain blood vessels, from where the aneurysm originated, a square (256×256) was cropped from the CT images resulting in images with primarily blood vessels and brain parenchyma.

An experienced radiologist (M.K.) delineated manually the aneurysm (and its attached vessel) at each CT image slice twice, within a week's time interval, to investigate intra-observer delineation error. Fig. 1 concerns one case with the aneurysm outlined by the radiologist in 12 out of 24 CT slices that the aneurysm extended.

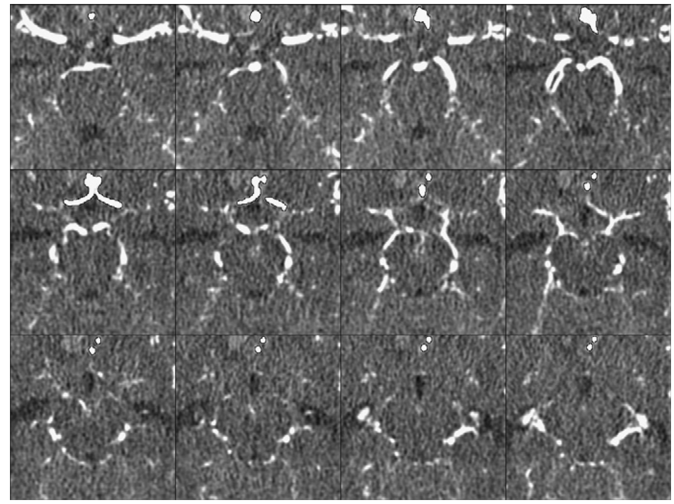

Fig. 1. Radiologist's delineation of aneurysm and attached vessel (anterior communicating artery).

2.1. Hybrid semi-supervised pixel-based classification method

2.1.1. Hybrid classifier design

A pixel-based segmentation algorithm, employing the probabilistic neural network (PNN) classifier [20], was designed to discriminate image pixels as belonging to one of two classes: blood vessel and brain parenchyma. The design of the classifier requires that an adequate number of class patterns (combination of textural features, extracted from 5×5 regions of interest surrounding each pixel) have to be selected from the images. One-third of the images of all cases was randomly chosen and used to design the hybrid classifier (training set) and the remaining images were employed to evaluate the classifier's performance (testing set). From each image of the design set, class patterns were selected from the blood vessel and brain parenchyma regions. In most pixel-based segmentation algorithms [16,17], selection of image samples, to form class patterns, has been performed manually. Such image-sample collection procedures, however, introduce users' subjectivity and suffer from a limitation concerning the maximum number of samples that the physician is prepared to collect. To alleviate this, the selection of image-samples regions was performed automatically using an unsupervised (requires no training) *k-means* clustering methodology, which, combined with the supervised (requires training) pixel-based classification technique, formulated the proposed hybrid algorithm (see Fig. 2).

The *k*-means [21] was designed to take as input patterns the image pixel intensities, while the goal was to divide the patterns into two clusters; one containing the vessels' pixels and the other the parenchyma's pixels.

The algorithm divided the image pixels according to the following procedure:

1. Two pixels were (randomly) selected as the initial clusters' centroids.
2. The rest of the image pixels were distributed to the two clusters, following the minimum Euclidean distance rule from its centroid.
3. New class centroids were calculated.
4. Steps 2 and 3 were repeated until both cluster-centroids stabilized.