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3D image texture analysis of simulated and real-world vascular trees

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ABSTRACT

A method is proposed for quantitative description of blood-vessel trees, which can be used for tree classification and/or physical parameters indirect monitoring. The method is based on texture analysis of 3D images of the trees. Several types of trees were defined, with distinct tree parameters (number of terminal branches, blood viscosity, input and output flow). A number of trees were computer-simulated for each type. 3D image was computed for each tree and its texture features were calculated. Best discriminating features were found and applied to 1-NN nearest neighbor classifier. It was demonstrated that (i) tree images can be correctly classified for realistic signal-to-noise ratio, (ii) some texture features are monotonously related to tree parameters, (iii) 2D texture analysis is not sufficient to represent the trees in the discussed sense. Moreover, applicability of texture model to quantitative description of vascularity images was also supported by unsupervised exploratory analysis. Eventually, the experimental confirmation was done, with the use of confocal microscopy images of rat brain vasculature. Several classes of brain tissue were clearly distinguished based on 3D texture numerical parameters, including control and different kinds of tumours – treated with *NG2* proteoglycan to promote angiogenesis-dependent growth of the abnormal tissue. The method, applied to magnetic resonance imaging e.g. real neovasculature or retinal images can be used to support noninvasive medical diagnosis of vascular system diseases.

1. Introduction

Extraction of quantitative information about blood-vessel trees from magnetic resonance images (MRIs), computed tomography (CT) and other imaging modalities can help in medical diagnosis of vascular system diseases. In fact, vessel segmentation algorithms are considered critical components of circulatory blood vessel analysis systems [1].

A vessel tree consists of very large diameter (e.g. 20–30 mm) arteries and veins that split into thinner and thinner vessels and, finally, capillaries whose diameter is in the range of 10 μm. On the other hand, spatial resolution of biomedical images is limited by the data acquisition hardware resources. As for example, in MRI the crucial determinants are strength of magnetic field B_0 and the power of coils and receiver noise [2,3]. As a consequence, the number of image-slice pixels a whole-body scanner produces is at most 1024 × 1024, for a 7T magnet. Then, the smallest element of 3D image will average the tissue properties (expressed by spin density, relaxation times, etc.) in a cube (voxel) of, say, 0.5 mm a side. The voxel size will increase proportionally to the reduction of static

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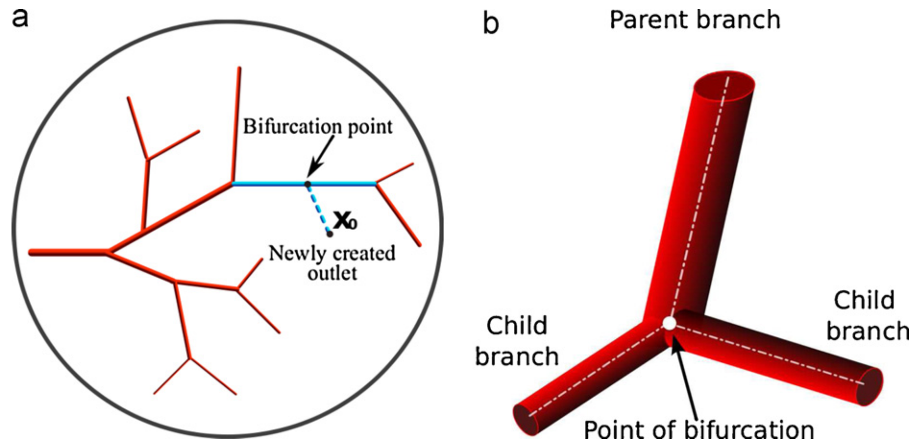

Fig. 1 – Vascular tree scheme: (a) adding a new bifurcation (2D case) and (b) bifurcation – the basic element of the vascular tree.

magnetic field B_0. CT provides slightly better resolution with voxel sizes of e.g. 0.3125 mm × 0.3125 mm × 0.5 mm. In either case, thick vessels can be represented by regions with a substantial number of voxels, which allows relatively accurate evaluation of their geometry, and e.g. blood volume inside them, for diagnostic purposes.

If, however, the vessel diameter becomes comparable with the voxel side, its value can only be roughly estimated. In this diameter range, texture analysis [4] can be considered as a tool that provides the extra diagnostic information [5]. This information can be derived from the existing correlation between image texture parameters and blood vessel tree parameters. Furthermore, thinner branches and capillaries cannot be visualized individually with sub-millimeter voxels. The net effects of their performance can instead be quantified by measuring perfusion. Thus investigation of a whole blood-vessel tree with the use of fixed-resolution imaging techniques requires integration of three approaches of the modeling of the tree. One is geometric (e.g. tubular) model for large-diameter tree elements, second is the texture model for medium diameter range and third can be a lumped (e.g. compartmental) model for blood and nutrients exchange with tissue. This paper deals with the medium-vessel-diameter, i.e. the postulated texture analysis approach.

Texture is the property that reflects a presence of more or less regular patterns in the image [5, Chapter 1]. These patterns originate from spatial arrangement of structural elements of objects visualized in the image. Consider a volume sample from a densely populated tissue region filled with thin blood vessel branches. This region will produce images having large-magnitude components of high spatial frequencies. The texture of such images can be considered rough, or harsh. On the contrary, the spatial frequency spectrum of a region filled with thick veins will contain strong components at the lower range of the spectrum. The texture of their MRI will be perceived smooth – less "busy". The image spectrum can be numerically described by means of wavelet analysis [6] where spatial frequency channels correspond to the scale factor of the transform. Thus, in this simple example, image spectrum carries the information about the diameter and density of blood vessels inside the region of interest. One can predict values of these two parameters by calculating texture features derived from MRI or CT scans measured for a region of interest. On the other hand, too much vessel formation supports a number of diseases, including cancer, inflammatory arthritis, blindness and obesity. Too little vessel formation is linked to stroke, damage to heart muscle after a heart attack and baldness (e.g. [7]). Thus one can expect that quantitative texture analysis has a potential for aiding the diagnosis of diseases that affect blood vessels.

The aim of this paper is to demonstrate that there exist relationships between the physical parameters of blood-vessel trees and numerical texture parameters computed with the use of vascular tree images. It is found that these relationships are stronger for three-dimensional (3D) than for two-dimensional (2D) texture. Computer-simulated blood vessel trees were used in the described study. The tree parameters investigated in this paper are number of output branches, input blood flow, terminal branches flow and blood viscosity. A simple simulator is used to generate images of the trees. Voxel intensity of the simulated image is proportional to the volume of this voxel part which is occupied by a vessel crossing it. The numerical simulation study is followed by experimental confirmation where the 3D confocal microscope images of rat brains are examined. Several classes of analyzed brain tissue were clearly distinguished based on 2D texture numerical parameters.

In Section 2, algorithms and techniques used for vascular tree modeling, imaging simulation and for texture analysis are characterized. Section 3 presents and discusses results of the numerically simulated experiments designed to reveal the links between vessel trees properties and texture parameters of their images.

2. Materials and methods

2.1. *Simulation of vascular tree growth*

In the literature, two approaches to vascularity tree growth simulation are described – one proposed by Bezy-Wendling