Identification of arteries and veins in cerebral angiography fluoroscopic images

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Abstract. In the present study a new method for pixels tagging into arteries and veins classes from temporal cerebral angiography is presented. This need comes from the neurosurgeon who is evaluating the fluoroscopic angiography and the magnetic resonance images from the brain in order to locate the fistula of the patients who suffer from arterio-venous malformation. The method includes the elimination of the background pixels from a previous segmentation and the generation of the time intensity curves for each remaining pixel. The later undergo signal processing in order to extract the characteristic parameters needed for applying the k-means clustering algorithm. Some of the parameters are: the phase and the maximum amplitude extracted from the Fourier transform, the standard deviation and the mean value. The tagged classes are represented into images which then are re-classified by an expert into artery and vein pixels.

1. Introduction
The vascular diseases appear as a result of hemodynamic problems. A medical imaging processing tool which address the problem of hemodynamic information extraction will be valuable in the clinical diagnosis procedure.

After studying the scientific literature is concluded that cerebral blood vessels classification on X-ray angiography is not a very well investigated research topic in comparison to retinal vessels, even if this will help the radiologist in the diagnosis of vascular pathologies.

The proposed method is intended for patients with an arterio-venous malformation, which is not a very common disease, asymptomatic and difficult to be detected. This disease is described as a misconnection of an artery and a vein due to the lack of capillaries then high pressure blood is delivered directly into the veins or venous sinuses which will create the fistula. This can result in a cranial hemorrhage.

The medical staff uses the digital subtraction angiography to visualize the blood vessels. The research goal is to find for these images a method to identify the arteries and veins.

The artery and vein classification was almost solved for retinal angiography [1-2]. For the cerebral approach, a patent [3] provides a visualization of the blood flow evolution into the cerebral vessels’ based on transit time computation. The separation of vessels can be made visually due to the differences in the hemodynamic patterns. This method is not dedicated to vessels separation and it generates only a functional image. In [4] the principal component analysis is used for image classification into four circulation phases.

A prior research [5-6] and the proposed method include a spatio-temporal processing of the dataset. Each pixel is characterized starting from its time intensity curves, which gives the temporal gray level intensities variation. Different types of statistic and signal processing parameters are determined from...
these curves for each pixel and a clustering algorithm, such as the well-known k-means method is used for obtaining the artery and veins classes. In addition to the prior work [5-6], the proposed method introduces the densitometric variables as characteristic parameters, and the comparison of the classification performances will be analyzed in the results section.

2. Materials and Methods

2.1. Data Acquisition

The image dataset for this study is composed of 10 different image series of fluoroscopic X-ray angiography acquired from a neurological clinic in the DICOM format. Each image series contain more than 20 images acquired with a temporal resolution of 3 images/second and with a spatial resolution of 1024x1024 pixels with frontal and lateral projection of the head. The image set is comprised of the early arterial, arterial, parenchymal and venous phases.

The contrast agent is an iodine based solution called Visipaque 320 mgI/mL which is injected into the femoral artery in order to make radiographically visible the vessels. Image quality was optimized in terms of patient dose.

2.2. The Temporal Analysis of Angiography

A temporal signal can be extracted from the fluoroscopic X-ray angiography, by representing the pixel’s value evolution along the image series entitled the time intensity curve (TIC). All these curves have a Gaussian distribution resemblance, except from the background pixels.

After analysing the curves associated with artery or vein pixels, some differences can be observed. The artery TICs have higher pixel values and their peak is located in the first half of the image series (temporal index) in comparison to the vein ones. This confirms the densitometric assumption related to the logarithmic digital subtraction angiography which states that the pixel intensity is directly proportional to the contrast agent density [7].

2.3. The Proposed Algorithm

The algorithm is divided into three main parts:

1. Acquisition and data preparation
   1.a. The acquisition of cerebral X-ray angiography with standard medical procedure.
   1.b. Each temporal image series is logarithmically digitally subtracted with a mask image (the first image of the series acquired before the injection of the contrast agent).
   1.c. The selection of the two images, one which contains only the artery pixels and the other one with the vein pixels.

2. Generating and processing the time intensity curves
   2.a. The generation of the time intensity curve only for the pixels selected into the step 1.c. Some of the pixels will be arteries into the arterial phase and veins into the venous phase. They are eliminated from the study.
   2.b. The filtering and fitting of the temporal curves.

3. The classification procedure
   3.a. Extraction of the characteristic parameters for each curve
   3.b. The k-means clustering algorithm runs for k classes
   3.c. Supervised classification based on visual inspection of the tagged classes
   3.d. Image representation of the artery and vein pixel classes and validation using a ground truth image.

The method is tested for the time intensity curves (TICs) of the vessels pixels in order to provide a more objective validation of the quality of the data clustering into classes.
A one-dimensional signal processing is needed for these temporal curves. A Savitzky Golay filtering [8] and a Gamma variate function fitting is proposed. The Gamma variate function is a complex exponential which contains the wash in and wash out phases of the contrast agent into blood stream [9].

The characteristic parameters of each TIC considered for the classification are:
- After applying the Fast Fourier Transform, the maximum amplitude, its corresponding frequency and phase,
- Densitometric parameters, such as the transit time, the time of bolus arrival and the volume extracted using the equations from [7],
- Statistical parameters, such as the mean and standard deviation.

The output of the k-means algorithm is a vector with indexes of the classes for each pixel which can be represented as an image. A visual inspection is made by radiologists who identify the artery, vein and mixed classes. The probabilistic approach consists of the computation of the Mahalanobis distances between each pixel from the mixed class and the artery class and then for the vein class.

3. Results
Knowing that the algorithm must find at least 2 classes, different simulations were tested with good results for k between 2 and 6.

The tagged pixels for k = 5 classes are represented separately. After visual inspection, two classes appertain to arteries and two classes to veins. Only a single class contained a mixture of artery and vein pixels. For improving the results, the probabilistic approach is considered.

An exemplification of the algorithm is given for one of the image set showing the lateral projection of the head. In the Fig. 1(a) is the ground truth image obtained after the visual inspection of three radiologists. The final representation of the classes after probabilistic approach is represented in Fig. 1 (b). The veins are represented into blue and the arteries into red. Because the fistula is placed at a mal connection between the artery and vein, the central right part contains a group of mixed colors.

![Figure 1](image-url)

**Figure 1.** (a) The ground truth image: arteries-blue and veins-cyan (b) image representation of the classification of pixels into artery (red) and vein (blue) classes

The validation process was made by comparing the classified pixels resulted from the supervised classification with the ground truth for each class, and the results are provided in the Table 1. The success rate is computed as the ratio between the number of successful identification pixels of a class and the total number of pixels of that class.
Table 1. The results of arteries and veins pixels classification

| Classes | Total no. of pixels | Pixels successful identification | Success rate [%] |
|---------|---------------------|---------------------------------|------------------|
| Artery  | 62479               | 61442                           | 98.34            |
| Vein    | 254849              | 180904                          | 70.98            |

The lower successful rate in the vein identification is due to the inclusion of an important part of the fistula (located in the middle - right position) into the artery class in opposition to the grand truth. This region is abnormal because of its high blood flow into veins and therefore can easily be attributed to the artery hemodynamic pattern.

Compared to [5] both success rates are increased and compared to [6] the artery identification is better in opposition to the vein identification. Still in [6] the algorithm is tested only for the centerline pixels, which are accurately tagged and this can explain the better score in the vein identification.

4. Conclusions

A classification of pixels into arteries and veins was performed using a spatio-temporal processing of cerebral angiography using standard clinical procedure.

During the simulations, it was observed that the temporal processing may be useful for computing the transit time, but it can affect the accuracy of the delineation of the arteries and veins classes. When the time series were processed, the vein identification was less accurate in opposition to the arteries.

The drawback of the method is that the accuracy of the background pixels elimination is dependent on the vessel segmentation priorly performed. Nevertheless the algorithm will need images with high spatial and temporal resolution.

Also, the class identification through k-means algorithm is sensitive to random initialization of the centroids. Different classifications results can be obtained after successive simulations. The vein separation was obtained with a smaller success rate, due to their artifacts and it can include some background pixels missed from the vessel segmentation. The fistula is attributed in the ground truth image to the vein class and after the algorithm simulation, it was mostly attributed to the artery class.

The conclusion after the simulation of all data set is that for the frontal projection image set the results are poorer than for the lateral projection, due to many pixels that are artery and vein in different circulation phases. Still, further improvements of the algorithm can be made because it can help the physician to easier detect the vessels abnormalities from the gray scale and noisy angiograms.

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