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Tomasz HACHAJ*

THE UNIFIED ALGORITHM FOR DETECTION OF POTENTIAL LESIONS IN DYNAMIC PERFUSION MAPS CEREBRAL BLOOD FLOW, CEREBRAL BLOOD VOLUME AND TIME TO PEEK

This paper presents an unified algorithm that enables detection of lesions in cerebral blood flow (CBF), cerebral blood volume (CBV) and time to peek (TTP) perfusion maps. The algorithm has one adaptive parameter for each type of perfusion map, the rest of algorithm is common for all kinds of perfusion images. There are two steps of the algorithm: in the first step the algorithm detects symmetry axis of a perfusion map (between left and right hemisphere), in the second stage the level of asymmetry in cerebral blood flow, cerebral blood volume or time to peak is measured by detection of regions with different perfusion in both brain hemispheres. Test of the algorithm were performed on a set of 84 different CBF, CBV and TTP images showing or not cerebral blood flow and volume anomalies. The algorithm presented in this publication has achieved satisfactory results. On 85,7% maps asymmetry regions was properly detected.

1. INTRODUCTION

Dynamic computer tomography (CT) / magnetic resonance (MR) perfusion treatment is a modern and broadly used neuroradiology technique that enables to evaluate total and regional blood flows in time unit. Perfusion Computer Tomography (P-CT) treatment enables recognition of structural changes of ischemia and shows the difference between ischemic and hemorrhagic stroke. In the countries of Western Europe brain stroke is the third – due to its frequency – reason of death (just after heart attack and cancer) and the most frequent cause of death in elderly age [1]. There are various methods of treatment of ischemic and hemorrhagic stroke and there is a short period of time when treatment can be performed, so it is important to early find the cause of illness. The cause of ischemic and hemorrhagic can be found by analysis of brain perfusion maps. Brain perfusion imaging becomes more and more popular in head injuries, epilepsy, brain vascular disease and especially in stroke diagnosing [8].

This paper presents a novel method which enables detection of potential lesions that can be visualized in cerebral blood flow (CBF), cerebral blood volume (CBV) and time to peak (TTP) maps. Despite the fact, that the average values for each of the perfusion parameter has been computed, the diagnosis is based on comparison of relative values of symmetric regions of interest (ROI) of blood perfusion between left and right hemisphere. [8]. There are a few algorithms for detecting lesions on CT images (i.e. [6]) but there are no common methods for analyzing series of dynamic perfusion images like brain perfusion maps. Commercial software for perfusion imaging that is broadly used in hospitals (i.e. Syngo Neuro Perfusion CT by Siemens) doesn't contain a mechanism that enables automatic detection of perfusion anomalies that can be seen on perfusion maps.

The algorithm presented in the following paper is mainly based on mathematical morphology that is commonly used as a reliable tool for image analysis [2]. Mathematical morphology is successfully used not only in medical image analysis but also in materials engineering [3] and in many other fields of science [9]. The algorithm derived by the author has been implemented in Matlab environment. The test set for the algorithm consisted of 28 CBF, 28 CBV and 28 TPP perfusion maps from 8 different patients. Maps were generated with Syngo Neuro Perfusion CT software by Siemens.

2. THEORETICAL BACKGROUND

There are four types of basic perfusion maps: cerebral blood flow perfusion map (CBF), cerebral blood volume (CBV), mean time transit (MTT) and time to peak (TTP). In dynamic perfusion treatment the contrasting material is injected in to the cardiovascular system relatively quickly (impulse injection). CT scanner measures the contrast material that remains in the capillary network creating set of images (about 40 for each treatment, with 1 second delays between scans). As a result the time density curve (TDC, also called time intensity curve TIC) for brain arteries and tissues is obtained. The value of pixels in TTP perfusion map is measured as maximal value of TDC curves. This map does not need any further calculation. In order to generate the rest of dynamic CT perfusion maps the Meier - Zierler model is commonly used [10]. It is possible to use it if the blood flow is constant and contrast enhancement is linearly dependent on contrast concentration. Each pixel of a perfusion map corresponds to the value of perfusion in the given point. Usually a map has a resolution of 512 x 512 pixels.

* Institute of Computer Science and Computer Methods, Pedagogical University ul. Podchorążych 2, 30-084 Kraków,

3. DETECTION OF SYMMETRY AXIS AND REGIONS OF POTENTIAL LESIONS

In order to perform perfusion image analysis it is necessary to find lines that separate left brain hemisphere from right (in the following text it is called "symmetry axis"). In many CT scans the head of the patient is slightly rotated on small angle towards the bed of tomograph (the symmetry axis is not orthogonal towards to OX axis). The symmetry axis of the image is not always the same line that separates the brain hemispheres what makes problem more complicated. In commercial software the symmetry axis is selected manually. It is difficult to propose a certain algorithm for automatic determination of symmetry axis because CT scans are performed in many different planes and because of that any assumption about the outline of the patient brain cannot be stated. Those facts obstruct the structural – based image analysis algorithms (algorithms of that kind often finds good solutions in medical images describing [5]).

The algorithm of symmetry axis derivation proposed by author comes as follow (the symbols used in the following algorithm are presented in Table 1):

a) find the square window in the area of image (ROI) in which pixels corresponding to brain are located.
b) compute number of rows of ROI ($y_{\max} - y_{\min}$), separate the ROI on identical number of horizontal "slices" of the same width as basic ROI (best results very obtained for 20 regions). For each of the regions compute coordinates of the centre of mass.

Centres of mass obtained in the previous step are used for calculation of the symmetry axis of the object (the equation of symmetry axis is simply $y = a \cdot x + b$). The angular coefficient (*a*) and the translation coefficient (*b*) are both estimated with least square method. In order to improve detection of symmetry axis several first and last centres of mass should be omitted (empirically tested, that it should be 3 first and 3 last centres). This is because the irregularity of borders of brain image of perfusion maps. The improvement in the final calculation of symmetry axis can be obtained by performing on each of the "stripes" of image morphological closing with structural semi – circular element with relatively large size (best results was for 25 pixels diameter).

The same algorithm for detection of regions of potential lesions (asymmetries with the sufficient size) was used for processing all kinds of maps. The values of the factors used as the parameters in the algorithm were empirically determined. In order to make analysis of the algorithm easier each image on Fig. 1 and Fig. 2 was collared with colour palette (LUT) [7]. Black color corresponds to smallest values of CBF / CBV / TTP, red colour corresponds to the highest ones. The algorithm has one adaptive parameter T (threshold). The best detection results was obtained for CBF and CBV if T = 60 and for TTP if T = 20.

Table. 1 Notation used in the description of the algorithms (based on notation from [2]).

Notation in algorithm	Description
$A := B$	Assignment A to B.
I	The binary image.
i	Gray - scale image.
a	Asymmetry map (for CBF, CBV or TTP).
Floor	Returns the largest integral value that is not greater than number given.
Fill	„Filling the holes" in the binary image.
Label	Labels all the components in the binary image.
Bin_X	Binarization with bottom threshold X.
$I \Theta E_X$	Erosion with semi – circular structural element with diameter X.
$I \oplus E_X$	Dilation with semi – circular structural element with diameter X.
$I \circ E_X$	Opening with semi – circular structural element with diameter X.
$I \bullet E_X$	Closing with semi – circular structural element with diameter X.
Med_{YxY}	Median filter sized YxY.
$A \cap B$	Logical multiplication of images A and B.
$A \cup B$	Logical intersection of image.
$\bar{I}$	Mirror image of image I towards vertical symmetry axis.

The algorithm goes as follows (compare with Fig. 1):

a) Loading DICOM file with perfusion map.
b) Detection of the symmetry axis with the algorithm that was described above.
c) Reduction of number of gray shades on CBF CBV and TTP map. After this operation the homogenous areas with sharp borders on both sides of perfusion map are obtained. With this operation the median filtering (task (d)) produce homogenous areas with sharp borders between regions with different perfusion; without this operation (or with median filtration with bigger window size) borders between regions with different perfusion are strongly blurred.
$i(x, y) := Floor\left((i(x, y)/15)*15\right)$

d) Median filtration with the window size of 15x15 pixels. The result image lacks some details (the presence of them would make further analysis of image harder because they generate large number of asymmetry regions). If there are too much small asymmetry regions the proper classification turns to be impossible.
$i := Med_{15x15}(i)$

e) Comparison of the left and the right sides of the image. As the result the asymmetry map is obtained. The asymmetry map generation goes as follows:
For each pixel on $i(x,y)$ that belongs to the left part of the image, check if $i(x,y) > 0$ or for the symmetrical pixel towards symmetry axis detected in (b)) $\bar{i}(x,y) > 0$.
   - If $i(x,y) = 0$ and $\bar{i}(x,y) = 0$, the background of the image is found.
   - In the other case one of the following condition is satisfied:
     - If $i(x,y) > 0$ and $\bar{i}(x,y) = 0$ or $i(x,y) = 0$ and $\bar{i}(x,y) > 0$ then one of the pixels belongs to the brain region and the other can belongs to the background (if the symmetry axis was not set properly the region of CBF / CBV / TTP map is asymmetric) or both of pixels belong to the brain region, but in one of the cases CBF / CBV / TTP value is very small.
     - If $i(x,y) > 0$ and $\bar{i}(x,y) > 0$ both regions belong to the brain.
   - Relative asymmetry of regions is computed:
     - If $i(x,y) > \bar{i}(x,y)$

$$a(x,y) := Floor\left(10 \cdot \left(\frac{i(x,y)}{\bar{i}(x,y)}\right)\right)$$

     - In other cases:

$$a(x,y) := Floor\left(10 \cdot \left(\frac{\bar{i}(x,y)}{i(x,y)}\right)\right)$$

If one of the pixels $i(x,y)$ or $\bar{i}(x,y)$ has 0 value the 1 is assigned.

f) Detection of potential asymmetry. The binarization with bottom threshold T is performed (only pixels with value greater than T are present on the result image). T is the adaptation parameter of the algorithm and depends from the type of perfusion map (see above).
$A := Bin_T(a)$

g) The symmetry axis obtained in (b) does not necessarily separate brain into symmetry regions. On the asymmetry map A the border of the brain region can be detected as potential asymmetry. In order to eliminate this effect the binary mask of "potentially biggest brain region" P is created. The mask is the same size as mask A and it is consisted of pixels for which $i(x,y) > 0$ or $\bar{i}(x,y) > 0$. All the "holes" in the interior region of map are removed. The border of the mask is also removed by morphological opening with semi – circular structural element of diameter 5.
$P(x,y) := Bin_1\left(i \cup \bar{i}\right)$
$P := Fill(P)$
$P := P\Theta E_5$

h) Calculation of logical multiplication of the asymmetry mask A and the brain mask P.
$A := A \cap P$

i) Elimination of narrow links between regions. Morphological opening with semi – circular structural element of diameter 3, performs that operation.
$A := A \circ E_3$

j) The last step of the algorithm is the elimination of all small regions. Performing morphological erosion of semi – circular structural element of diameter 10, accomplishes this task. In the resulting image there are only regions that contain some pixels that „survived" the above operation.
$l := Label(A)$
$A' := A\Theta E_{10}$
If $A'(x,y) > 0$ add the whole region with label $l(x,y)$ to the result image A.

k) The asymmetry map A is combined with CBF / CBV / TTP map (from point (b) of this algorithm).

The results of above algorithm is presented step by step in Fig. 1 for TTP map (in case of CBF / CBV maps results are similar). Figure 2 shows four triplets of CBF / CBV / TTP perfusion maps and the same triplets (after processing them by the algorithm) with lesions marked.

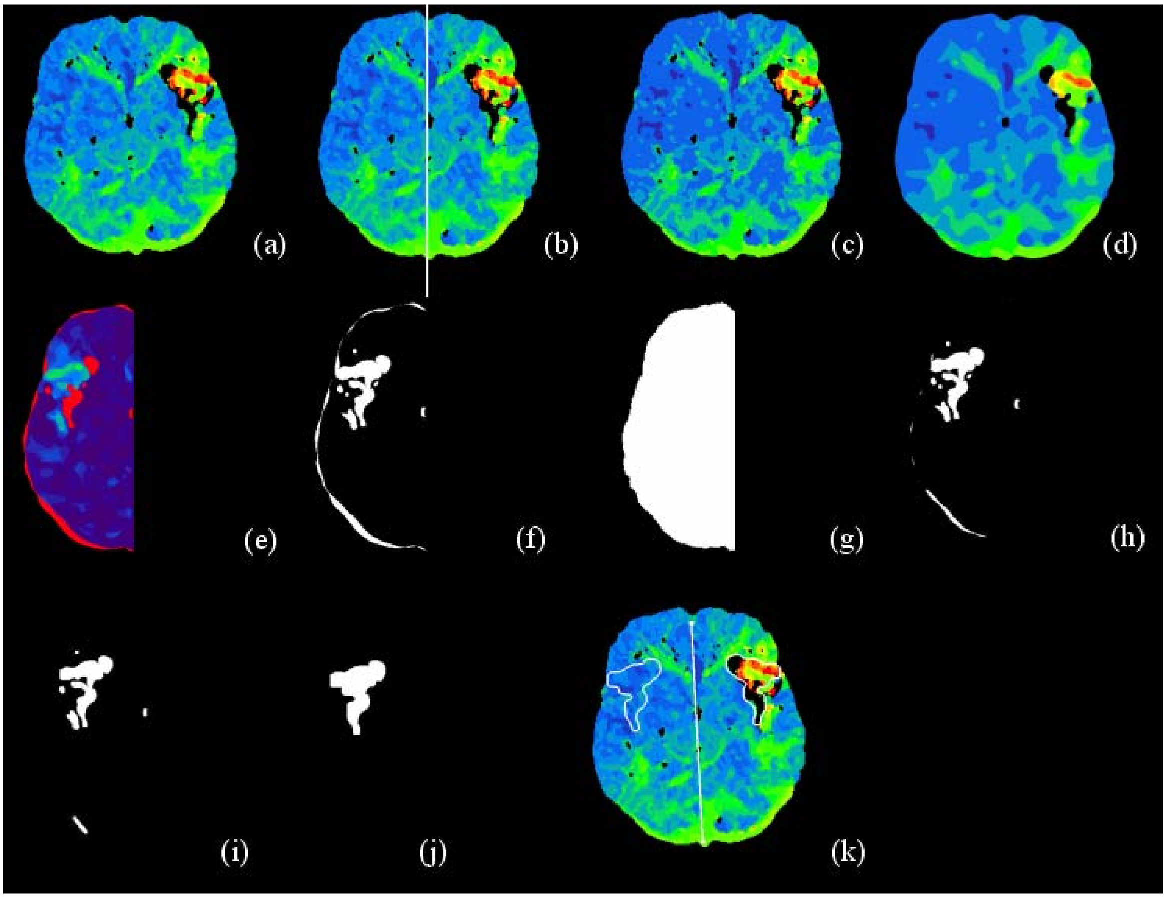

Fig. 1 The steps of asymmetry – detection algorithm of TTP map. Each point represents different task of the algorithm.

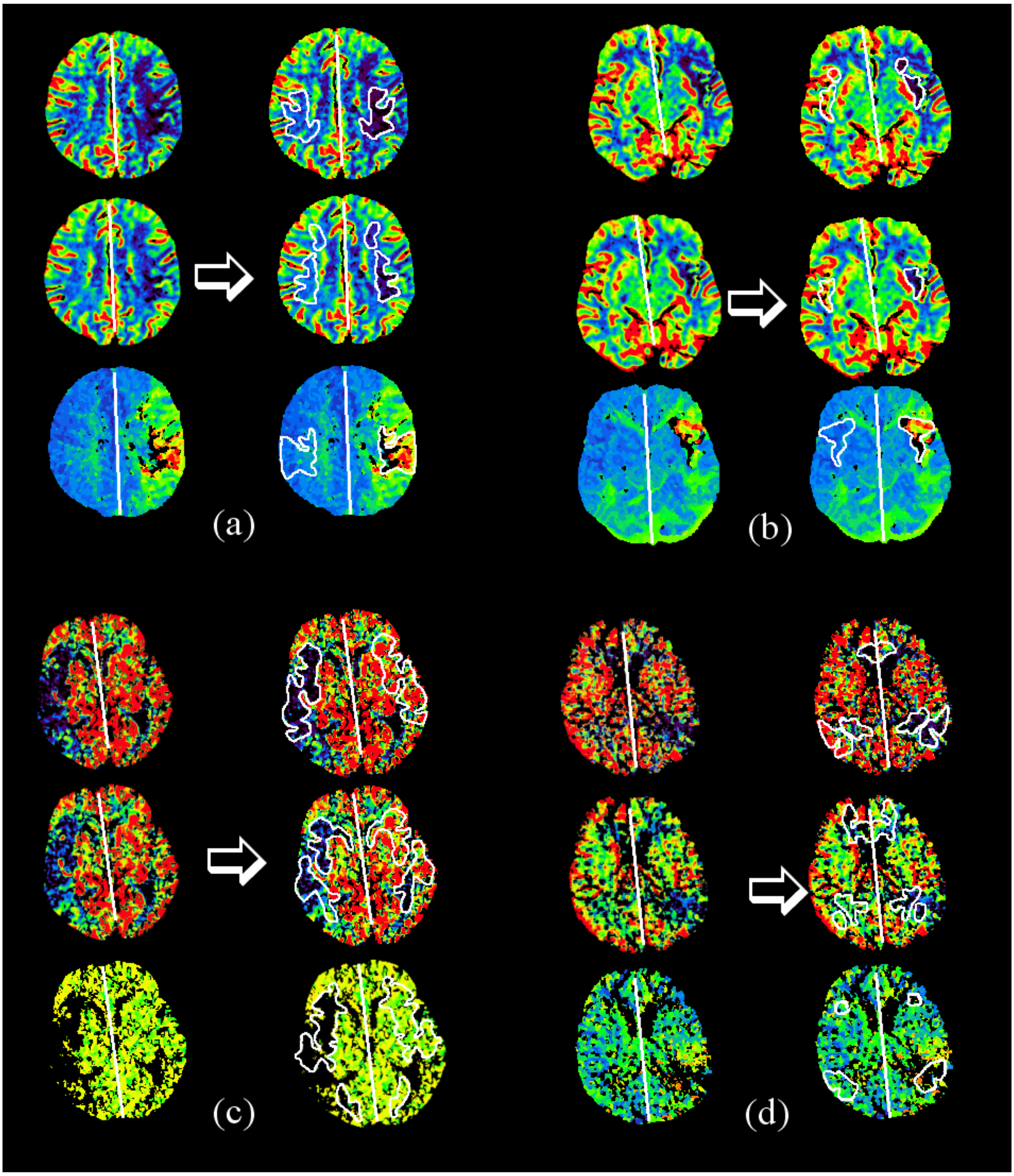

Fig. 2 CBF (top left), CBV (middle left) and TTP (bottom left) perfusion maps. Right from the arrow the same triplet after processing it by the algorithm. Detected borders of potential lesions regions are marked with white line. Description of the images: (a), (b) CBF and CBV is slightly decreased (TPP increased) on the left on the level of the top sides of lateral ventricle frontally and parietally (c) CBF and CBV is decreased (TPP increased) in the region of right middle cerebral artery, brain stroke was diagnosed (d) CBF and CBV is slightly decreased (TPP increased) on the left on the level of the top sides of lateral ventricle frontally, parietally and temporally.

4. RESULTS AND DISCUSSION

The algorithm for detection asymmetry in perfusion maps has been tested on 28 CBF, 28 CBV and 28 TTP perfusion maps from 8 different patients. That test set consisted of 36 cases where abnormal perfusion was diagnosed. The symmetry axis was correctly detected in 42 cases (21 for CBF, 21 for CBV maps - because CBF and corresponding to it CBV map has identical pixels positions - and 20 for TTP maps). In other cases deviation was not larger than 5 degrees from proper symmetry axis. In three cases for CBF maps, four cases for CBV maps and three cases for TPP maps improper symmetry axis causes overestimation of asymmetry regions (Fig. 2 d), the improper region can be seen in the central part of the brain near confluence of the sinuses). The errors of that kind could be caused by insufficient symmetry of the binary mask applied on the brain image. There are two reasons of this: asymmetry of CBF / CBV / TTP perfusion maps (lack or very small perfusion in some regions) or natural brain asymmetry.

The detection of asymmetry was tested on the same set of images. All of the CBF and CBV maps that do not have diagnosed asymmetry were rightly classified (no asymmetry detected). On four TTP maps algorithm has found asymmetries that were not classified as lesions in medical diagnosis. On one of the images of CBF that contained lesions no changes were detected (on the level of the top sides of lateral ventricle in the left hemisphere; in medical documentation lesions was described as fractional). On three CBF and CBV maps small excessive regions of asymmetry were detected that was situated close to automatically detected symmetry axis (for this maps symmetry axis was not rightly detected and it was slightly rotated towards the true axis that separate brain hemispheres). In one case in CBV map algorithm detected to large asymmetry region (it was enlarged by region near automatically detected symmetry axis).

The algorithm presented in this publication has achieved satisfactory results. 85,7% maps was properly diagnosed (85,7% for each kind of map). 75% errors in CBF maps and 100% errors in CBV and TTP maps was caused by over - detection of asymmetry regions. Errors were eliminated in cases when symmetry axis was manually selected. After that 96,4% CBF maps and 100% CBV maps was rightly diagnosed (manual correction of symmetry axis does not eliminate error diagnosis in TTP maps). In order to eliminate that kind of errors new algorithm for symmetry axis detection should be developed. After manual correction of wrong detected axis the error diagnosis for population of all maps that was tested was 6%. Important remark is that the same algorithm with only one adaptive parameter (threshold T) can produce proper asymmetry maps for CBF, CBV and TTP perfusion maps. Further research will be directed on improving the algorithm shown, adapting it to MTT perfusion maps and proposing methods for creation of diagnosis prognoses based on information derived by the detection algorithms (automatic “image understanding” [4]).

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