ANALYSIS OF TURNING ANGLE IN SCOPE OF BRAIN TISSUE SEGMENTATION WITH CUSUM FILTER

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Abstract. *CUSUM filter usage is applicable to provide brain tissue segmentation on DSC perfusion MR images. Such segmentation process operates with deviations between the observed and expected intensities of image points, which are accumulated at time of moving on some trajectory. In order to obtain accurate segmentation results, motion trajectory should be created by the iterative change of movement direction inside the background region in order to reach brain region, and vice versa after boundary crossing. Turning angle value is one of parameters that are used as basic ones to producing a motion trajectory. This study provides analysis of turning angle in scope of its influence on the results of brain tissue segmentation with CUSUM filter on DSC perfusion MR images.*

Keywords: perfusion; magnetic resonance imaging; brain segmentation; region of interest; cumulative sums.

PURPOSE

Brain tissues segmentation is an important step in the process of analyzing the data of dynamic susceptibility contrast (DSC) perfusion magnetic resonance (MR) imaging [1]. The segmentation outcome is so-called perfusion region of interest (ROI). Wrong perfusion ROI placement effects on perfusion parameters assessment results and presence of artifacts on perfusion maps [2, 3].

As was shown in [4] CUSUM filter can be successfully used for brain tissue segmentation on DSC perfusion MR images of a human head with abnormal brain anatomy.

Originally, CUSUM filter [5] is a statistical control that utilizes cumulative sums to detect a moment of time when monitored process undergoes a change. Schematic presentation can be found in Figure 1.

Applying CUSUM filter for image segmentation purpose results in an iterative process of boundary points detection. Found boundary separates image on two regions. Each point of this boundary is an output of decision function, which determines whether the point belongs to the image foreground or to the background. In order to be able to provide segmentation of DSC perfusion MR brain images, filtering of accumulated image points by CUSUM decision function was adopted

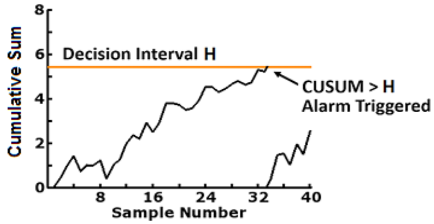


Figure 1: One-sided CUSUM filter that detects changes only in positive direction (the value of cumulative sum is compared with a threshold value H on each step of the algorithm; alarm signal is triggered when the threshold is exceeded).

[4, 6]. The cumulative sum for two-sided CUSUM filter is recursively defined as follows:

$$\begin{cases} S_i^+ = \max(0, S_{i-1}^+ + I_i - \mu_1) \\ S_i^- = \min(0, S_{i-1}^- + I_i - \mu_1) \end{cases}$$

where I_i – image intensity at point *i*; μ_1 – mean value of the previous observations of image point intensities in current region; S^+ and S^- – cumulative sums for upper-sided and lower-sided CUSUM filter respectively. Decision function determines image points as boundary points at steps when $S^+ > \mu_0 - \mu_1$ for upper-sided CUSUM filter (at time of moving from background into foreground region) and $S^- > -(\mu_0 - \mu_1)$ for lower-sided CUSUM filter (at time of moving from foreground into background region); μ_0 – target mean, i.e. mean value of the previous observations of image point intensities in the target region.

As decision function of CUSUM filtering should be applied to iteratively accumulated points at time of moving on a path along the boundary from one region to another, creation of motion trajectory is an important part of algorithm able to achieve an accurate segmentation results.

Overall, the algorithm for creation of motion trajectory should begin with some point that definitely belongs to the target boundary. It guarantees the uniformity of algorithms steps for further boundary search. Basic rules for producing a motion trajectory (iterative change of movement direction in one region in order to reach another one, and vice versa) can operate with only three parameters: turning direction value, turning angle value, and step size [7].

The purpose of this study is to analyze the influence of turning angle on the behavior of motion trajectory base on the assessment of the results of brain tissue segmentation with CUSUM filter on DSC perfusion MR images.

MATERIALS AND METHODS

Every new point (x_k, y_k) of motion trajectory is detected as follows:

$$\begin{cases} x_k = x_{k-1} + V \cdot \cos\theta_{k-1}; \\ y_k = y_{k-1} + V \cdot \sin\theta_{k-1}, \end{cases}$$

where V – distance between two neighboring points on motion trajectory, θ_{k-1} – turning angle. The turning angle value θ_k is iteratively defined as follows:

$$\theta_k = \theta_{k-1} + \theta_k^{step},$$

where θ_k^{step} – angle change value at each step *k* of motion trajectory creation.

To analyze the influence of turning angle on the behavior of motion trajectory in scope of brain tissue segmentation with CUSUM filter 6 clinical DSC perfu-

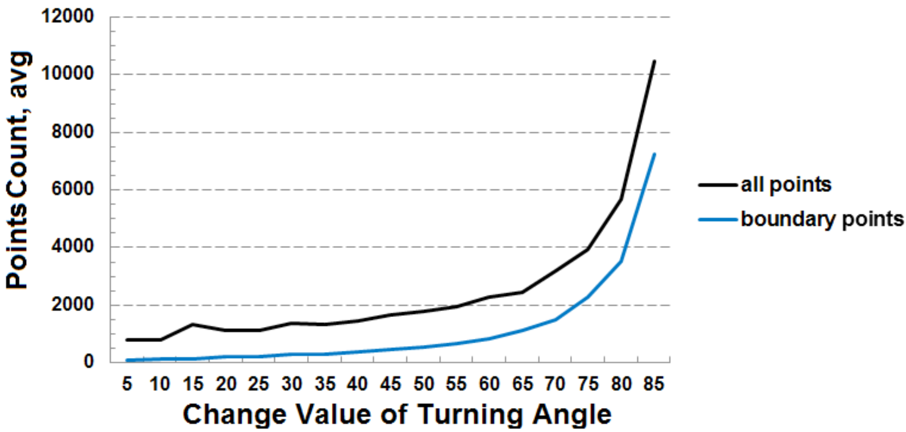


Figure 2: Dependence of the all processed points and found as boundary points on the change value of turning angle.

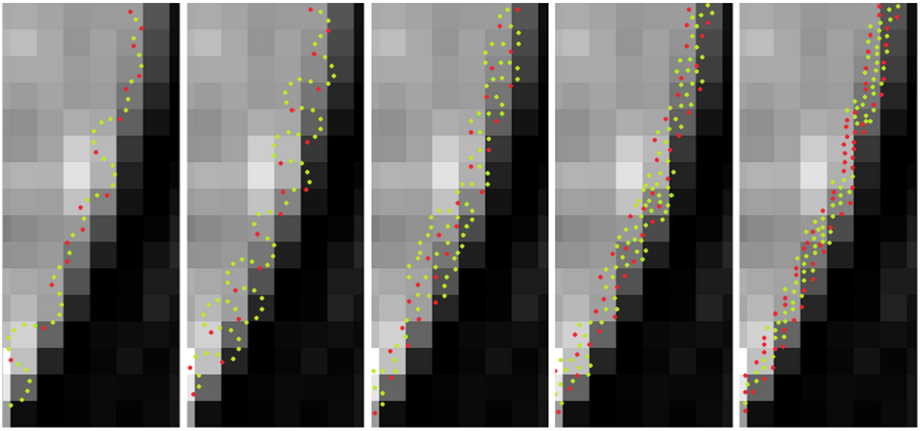
sion MR datasets were used: each MR dataset consisted of 17 slices with 40 dynamic images per slice, image size was 128 x 128 pixels, voxel resolution was 1.8 x 1.8 x 5 mm^3, all images were collected in 12-bit DICOM format.

In order to obtain different movement patterns, image processing software program was in-house developed: implementation in C# language; open-source EvilDICOM (http://rexcardan.github.io/Evil-DICOM/) usage for loading medical images; no preprocessing steps for noise reduction and motion correction; no dependency on image resolution. For each space position of scanned volume segmentation process is performed on the 4^{th} time-point image, on which signal intensity is reached a steady state

In order to analyze the influence of turning angle on the behavior of motion trajectory, the angle values θ^{step} were changed by 5° increment in range of [5°,85°] for each analyzed case. It should be mentioned that as boundary crossing from one image region to another, the sigh of angle θ^{step} was changed on opposite and double value of this angle was used to provide fast changing of movement direction. Step size was defined as a half of the minimal side length of the image pixel spacing. No additional rules were applied for motion trajectory creation to guarantee constant influence of turning direction value and step size parameters.

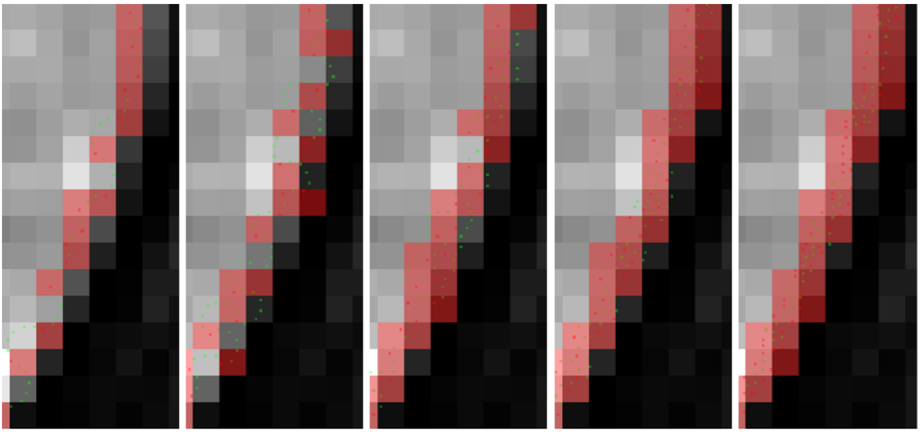
RESULTS

In order to provide optimal trajectory, the change value of turning angle should be selected to detect the maximum number of boundary points, and at the same time to minimize the number of analyzed points. For this reason each case of change value of turning angle was analyzed on two levels. First, the segmentation algorithm should provide boundary from minimal amount of required points.



$\theta^{step}=25°$ $\theta^{step}=35°$ $\theta^{step}=45°$ $\theta^{step}=55°$ $\theta^{step}=65°$

Figure 3: Points of motion trajectory produced by CUSUM filter (the same zoomed-in sample of DSC perfusion MR image of brain; boundary points are marked with red.



$\theta^{step}=25°$ $\theta^{step}=35°$ $\theta^{step}=45°$ $\theta^{step}=55°$ $\theta^{step}=65°$

Figure 4: Boundary constructed from points that were produced by CUSUM filter (the same zoomed-in sample of DSC perfusion MR image of brain; pixels with boundary points are marked with red).

Second, each image pixel, which has found boundary point(s), should have at least one 8-connected neighbor. Such con-strain guarantees that provided boundary will have no gaps.

Regarding the amount of points processed by algorithm, increasing of change value of turning angle leads to increasing of points obtaining by algorithm. It can be explained by the fact that motion trajectory defined according to the mentioned above rules produces sinusoidal-like path. The degree of dependence can be explored in Figure 2.

Although small change values of turning values produce fewer trajectory points, it is not always possible to get boundary without gaps for such cases. Based on the analyzed data, boundaries without gaps were constructed for all cases starting from change value 45 up to 85 degrees. 4-connected pixels in the boundary were observed for all cases starting from value 55 up to 85 degrees.

Segmentation results of DSC perfusion MR image of brain with usage of CUSUM filter according to representative cases are shown in Figure 3 and Figure 4, where five zoomed-in samples of the same region show dependency between change value of turning angle and gaps in boundary constructed from points that were produced by CUSUM filter.

CONCLUSION

Analysis of turning angle was done in scope of its influence on the behavior of motion trajectory. Base on the assessment of the results of brain tissue segmentation with CUSUM filter on DSC perfusion MR images it was shown that optimal change value for turning angle is 45 degrees.

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