RESEARCH OF FAST INITIAL RESPONSE FEATURE FOR BRAIN SEGMENTATION ON MR IMAGES WITH CUSUM FILTER

Alkhimova S.M.
Associate Professor of the Department of Biomedical Cybernetics, PhD
National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"

Diumin O.D.
Student of the 4th course
National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"

Abstract. *Perfusion region of interest for the brain can be detected effectively on DSC perfusion MR images with CUSUM filter. This detection is based on the filtering of brain boundary points among accumulated ones at the time of moving on some trajectory. The filtering of points is provided by the CUSUM decision function. Applying of fast initial response feature for CUSUM filtering scheme gives a more rapid response to the out-of-control situation, and, as a result, provides more accurate segmentation results achieved through reduced processing time. This study aimed to analyze the impact of fast initial response feature on the results of brain segmentation on DSC perfusion MR images with CUSUM filter.*

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

PURPOSE

Nowadays, dynamic susceptibility contrast (DSC) perfusion magnetic resonance (MR) imaging actively used in the diagnostic and management of cerebrovascular and oncological diseases [1, 2]. In this technique the first pass of a contrast bolus through examined brain tissue is tracked by a dynamic series of T2-weighted or T2*-weighted MR images. Each voxel of such images represents tissue signal attenuated by a susceptibility-induced signal loss that is proportional to the amount of contrast agent in the microvasculature. Signal intensity-time curves generated from single-voxel or voxels region are used to calculate various perfusion parameters (rCBV, rCBF, MTT etc.) and to create color maps of regional perfusion.

Poor detection of perfusion region of interest (ROI) leads to numerous artifacts on produced color maps and can cause wrong quantitative assessment of perfusion parameters [3, 4]. The general applicability of CUSUM filter in the scope of brain segmentation on DSC perfusion MR images was shown in previous studies [5, 6]. However, a fast initial response (FIR) feature for CUSUM filter can permit more rapid response to the out-of-control situation [7], as a result this feature for CUSUM filter applicable for brain segmentation on DSC perfusion MR images can decrease processing time. On the other hand, as the number of analyzed points on motion trajectory should be minimized, utilization of the FIR feature can minimize cases with loops inside one region, e.g., when motion trajectory makes a full circle inside one region without returning to the boundary. Removing such loops can positively impact segmentation results through the detection of more smoothed boundaries of the brain.

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 segmentation with CUSUM filter on DSC perfusion MR images.

Therefore, the aim of this study is an analysis of the impact of fast initial response feature on the results of brain segmentation on DSC perfusion MR images with CUSUM filter.

MATERIALS AND METHODS

In terms of statistics, the CUSUM filter is used to detect a change-point [8]. The change-point of a process disturbance is considered to be found when the value of the cumulative sum exceeds the decision interval. At the time of continuous monitoring of the process cumulative sum value is reset to zero after change-point detection and the search process of new change-points continues.

Usage of CUSUM filter for image segmentation is an iterative process of point detection that belong to the ROI boundaries. In the case of brain segmentation, boundary detected with CUSUM filter separates image on Ω_1 and Ω_2 regions, which correspond to brain region and background (non-brain tissues and air pixels) region, respectively. Points for filtering are iteratively accumulated at the time of moving on a trajectory along the boundary between these two regions. At the time of image points accumulation CUSUM decision function filters them for belonging to change-points. As a point is filtered as a change point, it is considered that a moment of crossing from one image region into another has arrived and this point is marked as a boundary point.

The cumulative sum for two-sided CUSUM filter that adopted to detect brain boundaries on DSC perfusion MR images [4] is defined as follows:

$$\begin{cases} S_i^+ = \max(0, S_{i-1}^+ + I_i - \mu_2) \\ S_i^- = \min(0, S_{i-1}^- + I_i - \mu_1) \end{cases}$$

where I_i – image intensity at a point *i*; μ_1 and μ_2 – mean value of the previous observations of image point intensities in brain region and background region, respectively; S^+ and S^- – cumulative sums for upper-sided CUSUM filter (moving from background into the brain) and lower-sided CUSUM filter (moving from the brain into background region), respectively. Decision function determines image points as boundary points at steps when $S^+ > \mu_1 - \mu_2$ for upper-sided CUSUM filter and $S^- > -(\mu_1 - \mu_2)$ for lower-sided CUSUM filter.

In the case of applying of FIR feature for the CUSUM filter, the cumulative sum value is not reset to zero after change-point detection. Instead, the cumulative sum value is set to something other than zero (called a “head start”) [7]. In this

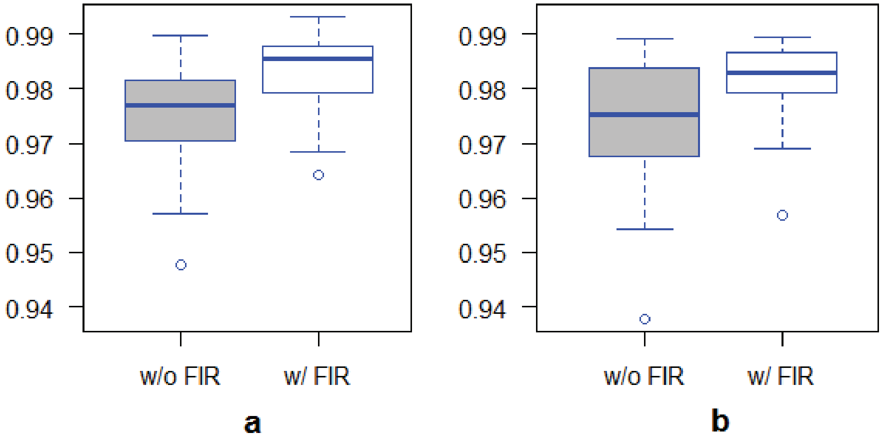

Figure 1: Box-and-whisker plot of Dice similarity indices: **a** – CUSUM statistics based on points previously obtained in the region; **b** – CUSUM statistics based on points obtained in the region from previous steps of algorithm excluding points from the current search process.

study “head start” value was set as a half of the cumulative sum value that was obtained in the region from the previous step of the algorithm.

CUSUM filtering scheme is designed to use the past information along with the current information that makes it very sensitive to shifts in the process parameters [9]. Taking into account that the CUSUM filter adopted to detect brain boundaries uses mean as process parameter [6], analysis of the FIR feature impact was done for two cases. In the first case, mean for CUSUM statistics was estimated from n previous points obtained in the region: Ω_1 region for S^- statistics and Ω_2 region for S^+ statistics. In the second case, mean estimation was done only from points obtained in the region from previous steps of algorithm excluding points obtained during the current search process. In the current study, the value of n was set equal to 45.

To estimate the quality of brain segmentation on DSC perfusion MR images through the applying FIR feature for the adopted CUSUM filter, DSC head MR datasets from 3 patients with cerebrovascular disease were used. 17 slices with 40 dynamic images for each slice were acquired from each patient on a 3.0 T scanner (Achieva, Philips Healthcare, Best, the Netherlands); images were collected in 12-bit DICOM (Digital Imaging and Communication in Medicine) format. Imaging parameters of MR scanning were: RT = 1500 ms, ET = 30 ms, FA = 90°, FoV = 23 x 23 cm, image matrix = 256 x 256, slice thickness = 5 mm, and gap = 1 mm.

The results of brain segmentation with CUSUM filter were compared with a reference standard that is perfusion ROI manually marked by an experienced radiologist and confirmed by a second one. Dice similarity index was used as a valida-

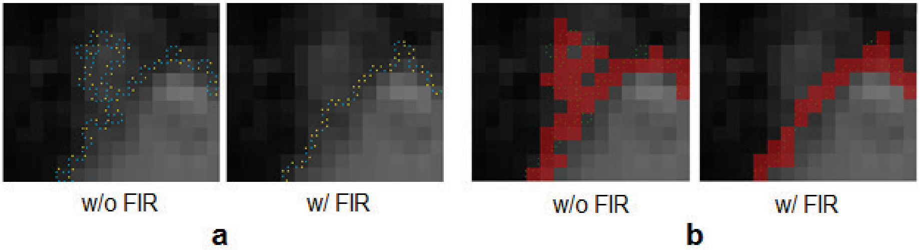

Figure 2: Impact of FIR feature on the results of brain boundary detection with CUSUM filter: **a** – motion trajectory produced by CUSUM filter; **b** – brain boundary constructed from points that were produced with CUSUM filter.

tion metric to assess the spatial overlap accuracy of segmented brain ROI and reference standard.

RESULTS

In the first analyzed case, average Dice similarity indices were 0.9739 and 0.9827 for results obtained with and without applying the FIR feature for CUSUM filter, respectively. In the second analyzed case, average Dice similarity indices were 0.9736 and 0.9807 for results obtained with and without applying the FIR feature for CUSUM filter, respectively. Box-and-whisker plot of Dice similarity indices across all analyzed images is given in Figure 1.

Results of brain segmentation on DSC perfusion MR image with the usage of CUSUM filter according to representative cases are shown in Figure 2, where zoomed-in samples of the same region show the impact of FIR feature on the brain boundary detection.

The total number of processed points was decreased by 27.01% and by 21.18% for the first analyzed case and the second analyzed case, respectively. At the same time, the total number of boundary points was increased by 44.49% and by 66.41% for the first analyzed case and the second analyzed case, respectively.

The average processing time per image decreased after applying the FIR feature for the CUSUM filter from 32.2ms to 25.6ms for the first analyzed case and from 31.8ms to 26.2ms for the second analyzed case, respectively (Intel Core i5-460M 2.53 GHz, single-threaded).

CONCLUSION

Analysis of the FIR feature was done in the scope of its impact on the results of brain segmentation with CUSUM filter on DSC perfusion MR images. Applying "head start" as a half of the cumulative sum value obtained in the region from the previous step of the CUSUM filtering algorithm provides more rapid response to the out-of-control situation, and as a result, decreases processing time and minimizes cases with loops inside one region

REFERENCES:

1. Lanzman, B., Heit, J. J. Advanced MRI measures of cerebral perfusion and their clinical applications // Topics in Magnetic Resonance Imaging. – 2017. – V. 26, N. 2. – P.83-90.

2. Welker, K., Boxerman, J., Kalnin, A., Kaufmann, T., Shiroishi, M., Wintermark, M. ASFNR recommendations for clinical performance of MR dynamic susceptibility contrast perfusion imaging of the brain // American Journal of Neuroradiology. – 2015. – V. 36, N. 6. – E41-E51.
3. Alkhimova, S. M., Sliusar, S. V. Analysis of effectiveness of thresholding in perfusion ROI detection on T2-weighted MR images with abnormal brain anatomy // KPI Science News. – 2019. – V. 126, N. 4. – P.35-43.
4. Alkhimova, S. M. Impact of perfusion ROI detection to the quality of CBV perfusion map // Technology Audit and Production Reserves. – 2019. – V. 5, N. 2 (49). – P.4-7.
5. Alkhimova, S. M. CUSUM Filter for Brain Segmentation on DSC Perfusion MR Head Scans with Abnormal Brain Anatomy // 3rd International Conference on Frontiers of Image Processing (ICFIP 2019). – Florence, Italy, March 16-18, 2019. – P008.
6. Alkhimova, S. M., Krenevych, A. P. Brain Tissues Segmentation on MR Perfusion Images Using CUSUM Filter for Boundary Pixels // International Journal of Computing. – 2019. – V. 18, N 2. – P. 127-134.
7. Lucas, J. M., Crosier, R. B. Fast Initial Response for CUSUM Quality-Control Schemes: Give Your CUSUM A Head Start // Technometrics. – 1982. – V. 24, N. 3. – P.199-205.
8. Page, E. S. A test for a change in a parameter occurring at an unknown point // Biometrika. – 1955. – V. 42, N. 4. – P. 523-527.
9. Nazir, H. Z., Riaz, M., Does, R. J., Abbas, N. Robust CUSUM control charting // Quality Engineering. – 2013. – V. 25, N. 3. – P.211-224.