ON CEREBROSPINAL FLUID SEGMENTATION FROM CT BRAIN SCANS USING INTERACTIVE GRAPH CUTS

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Abstract. *Inaccuracy of the manual assessment of brain diseases forces medicine to look for a new solutions. The key factor in the diagnosis of many brain lesions is an accumulation, volume and pressure of the cerebrospinal fluid (CSF) in ventricles and cavities of the brain. In this paper, the problem of segmentation of the CSF is regarded. Specifically, the min-cut/max-flow algorithm is investigated and applied to several CT scans. The results reveals that this approach may provide a basis for further quantitative analysis of brain lesions.*

Keywords: graph cuts, image segmentation, brain, cerebrospinal fluid, hydrocephalus

INTERAKTYWNA SEGMENTACJA PŁYNU MÓZGOWO-RDZENIOWEGO Z OBRAZÓW TOMOGRAFICZNYCH MÓZGU Z WYKORZYSTANIEM TECHNIK GRAFOWYCH

Streszczenie. *Niedoskonałość manualnych metod diagnostycznych w ocenie zmian chorobowych w obszarze mózgu sprawia, że współczesna medycyna poszukuje nowych rozwiązań. Jednym z kluczowych wskaźników postępu choroby jest nagromadzenie, objętość i ciśnienie płynu mózgowo-rdzeniowego (PMR). Artykuł rozważa problem segmentacji PMR z obrazów tomograficznych. Prezentowane podejście bazuje na interaktywnym algorytmie segmentacji opartym na grafach, którego skuteczność daje podstawy do późniejszej, wiarygodnej analizy ilościowej danego schorzenia.*

Słowa kluczowe: graf, segmentacja, mózg, PMR, wodogłowie

Introduction

Medical imaging plays the decisive role in the diagnosis and clinical course of the patient. In today's medicine, the assessment of the brain lesions is always accompanied with the visual comparison of a number of images from radiological examinations. However, high impact of the human factor causes such assessment very tentative. Furthermore, current measurement methods for the quantitative analysis of the lesions are too cumbersome and too-time consuming for everyday clinical routine. Therefore recently, medicine is looking for new solutions [10].

An important factor for the diagnosis of many brain diseases is the accumulation, volume and pressure of the cerebrospinal fluid (CSF). CSF is a colorless fluid flowing inside the ventricles and cavities of the brain. The appearance or abnormal accumulation of the CSF in the ventricles and cavities of the brain may indicate various brain diseases [7]. Figure 1 presents the CT brain scan with CSF area marked with blue outline.

Fig. 1. Exemplary CT brain scan with marked CSF area

Complexity and large variations of anatomical structures of human brain makes a segmentation of the CSF a challenging task for medical image processing. Although, there are many approaches to the CSF segmentation [3÷6], there is still no common solution to this problem.

Previous research [8, 9] performed by the authors concerning the problem of the segmentation of hydrocephalus and CSF area reveals, that the traditional segmentation methods, such as region growing and thresholding approaches are not sufficient. As a result outcomes of the CSF segmentation are often tentative and unreliable. Therefore, current research performed by the authors focuses on the modern image segmentation methods.

Recent approaches to image segmentation indicate the growing popularity of graph based techniques. These methods are used to extract the objects from background by partitioning the graph into subgraphs. The graph-based image representation is partitioned according to a specific criterions designed to classify the nodes (pixels) to object or background areas.

In this paper, a semi-automatic, interactive segmentation algorithm based on min-cut/max-flow approach is presented. Specifically, the influence of incorporating various regional and boundary terms for the segmentation results is investigated.

Presented approach was applied to several representative CT scans of hydrocephalic brains. The obtained results revealed that this algorithm can be successfully applied to both high and low contrast CT images and provide a basis for further quantitative analysis of the hydrocephalus.

1. Interactive graph cuts

Graph G=(V,E) is an abstract data representation consisting of a set V of ventricles (nodes) and a set of E edges connecting the ventricles. Graph based approaches in image processing consider an image as a weighted graph, where pixels are considered as nodes $v_i \in V$ and edges $e_{ij} \in E$ represent the links between neighbouring pixels v_i and v_j. The weight of an edge describes the similarities (or disimilarities) between pixels, calculated with regard to their selected features, e.g. intensities.

Graph based approaches to image segmentation are group of methods which divide a set V of nodes into two disjoint sets representing important regions in the image. The division is performed by removing edges connecting to corresponding subgraphs. Generally, it removes the edges between subsets, thus creates separate subgraphs of graph G.

The algorithm regarded in this paper is based on the min-cut/max-flow segmentation approach proposed by Boykov and Jolly in [1]. It is one of the interactive graph-cut methods, that requires human interaction.

The method considers an image as a weighted and undirected graph G=(V,E), where the nodes $p \in P$ represent pixels, $V=P \cup \{S,T\}$ is a set of nodes and E is a set of edges. Additionally, there are two special nodes: a source (object) terminal S and a sink (background) terminal T. Every pixel has up to four n-links, connecting neighboring pixels, and two t-links: {p, S} and {p, T} that connects these pixels with the terminals. Exemplary graph of a 3x3 image is presented in Figure 2.

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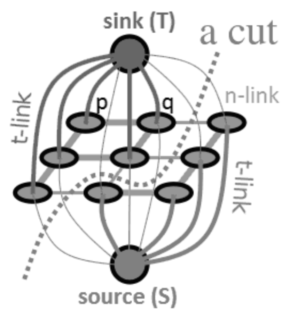

Fig. 2. Exemplary graph of a 3x3 image [8]

Weights assigned to edges define their capacities. Specifically, weights $B_{\{pq\}}$ assigned to n-links represents a boundary term by describing the similarity between neighbouring pixels. Weights R_p(“obj”) and R_p(“bkg”) assigned to t-links represent regional term and define the individual penalties for assigning pixel p to object and background respectively. The suggested edge weighting is given Table 1.
where:

$$K = 1 + \max_{p \in P} \sum_{q:\{p,q\}} B_{\{p,q\}} \tag{1}$$

and O denotes object, B denotes background and λ is a scaling factor indicating the importance of regional term versus boundary term.

Table 1. Weights for n-links and t-links

Edge	Weight	For
$\{p, q\}$	$B_{\{pq\}}$	$\{p, q\} \in N$
$\{p, S\}$	$\lambda \cdot R_p$(“bkg”)	$p \in P,\ p \notin OB$
	K	$p \in O$
	0	$p \in B$
$\{p, T\}$	$\lambda \cdot R_p$(“obj”)	$p \in P,\ p \notin O \cup B$
	0	$p \in obj$
	K	$p \in bkg$

The idea behind the min-cut/max-flow segmentation is that the maximum flow passing from the source to the sink is equal to a minimum cost cut on the graph. Min-cut is then defined by edges which gets saturated when max-flow is sent between the source and the sink. This cut determines the border between the object and background in the image.

2. Algorithm implementation and tuning

For the purpose of this research, a Fiji’s implementation [11] of the min-cut/max-flow algorithm proposed by Boykov and Kolmogorov in [2] was used. The algorithm requires providing and adjust the “foreground bias” and “smoothness” parameters in order to obtain the best possible segmentation results.

The “foreground bias” parameter represents the λ constraint that influences on the regional terms R_p(“obj”) and R_p(“bkg”). The considered algorithm defines this penalties as probability, that the pixels belong to the object or background, respectively. The regional penalties are set in accordance with Equations (2) and (3).

$$R_p(\text{"}obj\text{"}) = -\ln \cdot \Pr(I_p \mid O) - \ln(K) \tag{2}$$

$$R_p(\text{"}bkg\text{"}) = -\ln \cdot (1 - \Pr(I_p \mid B)) - \ln(1 - K) \tag{3}$$

The “smoothness” parameter is used to adjust the penalty for label changes in the segmentation. The higher this value, the less label changes is considered by the algorithm, thus the image gets smoother.

The capacity (weights) $B_{\{pq\}}$ of every *n-link* between the neighboring nodes in the graph is described by the following equation:

$$B_{\{p,q\}} = \exp\left(-\frac{(I_p - I_q)^2}{2\sigma^2}\right)\frac{1}{dist(p,q)} \tag{4}$$

where I_p is intensity of pixel p, σ denotes standard deviation of intensity within the image and $dist(p,q)$ is an Euclidean distance between the pixels in the image.

Additional parameters to adjust the segmentation results in Fiji’s implementation considers the gradient magnitude of the image. Specifically, the “edge image influence” and “edge image decay” parameters can be adjusted. Both parameters have an influence on the edge capacities. In this research, the gradient magnitude was achieved by applying the Sobel operator.

3. Results

In this section, the results of applying the min-cut/max-flow segmentation algorithm to several CT images of hydrocephalic brains are presented and discussed.

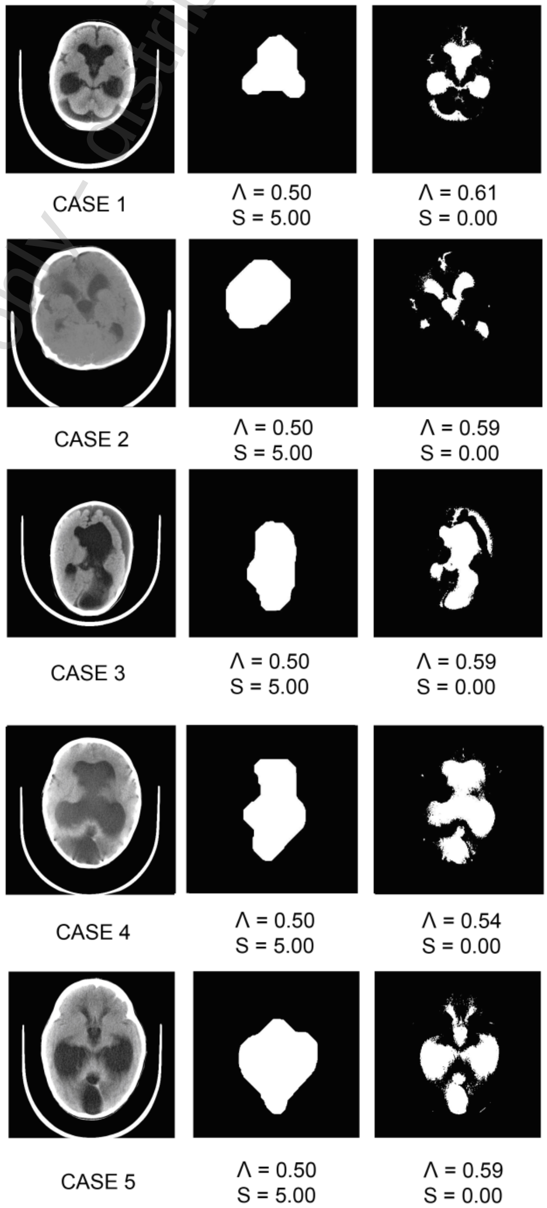

Fig. 3. The exemplary results of min-cut/max-flow segmentations

Figure 3 presents the comparison of the segmentation results for several randomly selected CT images with the adjustments of regional and boundary terms. Specifically, the first column presents the original scan of hydrocephalic brain. Second column presents the output binary image for default method's parameters. Third column presents the subjectively selected best output image.

Figure 4 presents the comparison of the segmentation results for output binary images with the boundary and regional terms adjustments and additional influence of the gradient image parameters. Specifically, the first column presents the original scan of hydrocephalic brain. The second column presents the output binary image for subjectively best R_p("obj") and R_p("bkg") conditions. The third column presents the segmented image with the influence of gradient magnitude information for boundary terms.

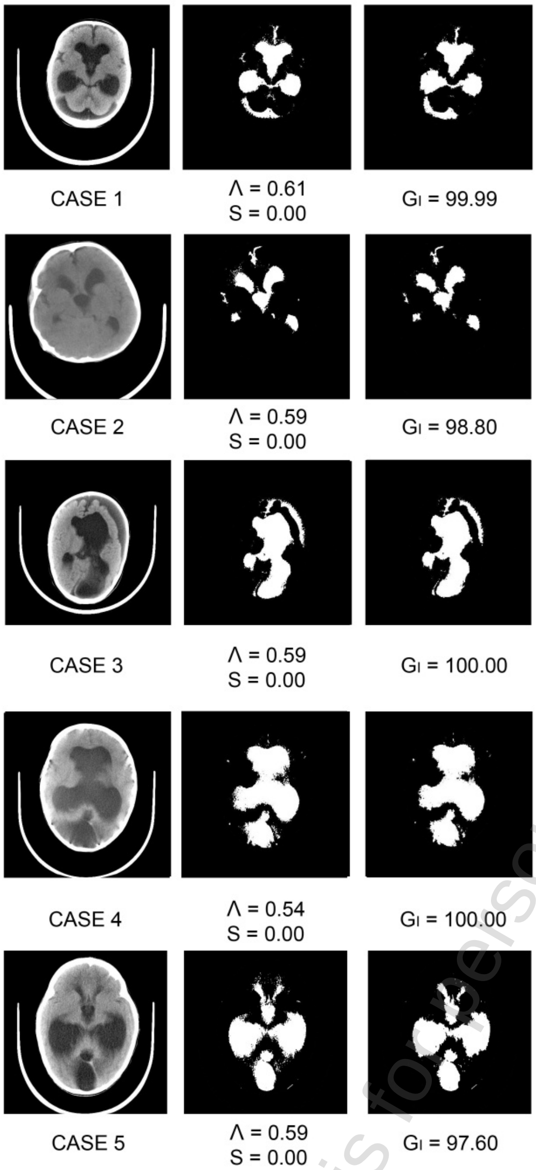

Fig. 4. The influence of gradient magnitude parameters

As can be seen from Fig. 3, the adjustment of the parameters related to the boundary ("foreground bias") and the regional ("smoothness") terms in the image significantly influences the results of image segmentation. In case of hydrocephalic brain scans, it was observed that the optimal value of λ constraint varies at 0.60 and is connected with the very small (or even equal 0.0) smoothness value. The smoothness value of zero corresponds to thresholding the input image.

Fig. 4 shows that the adjusting of the additional parameters related with gradient information does not increase the quality of the segmentation in every considered image.

4. Conclusions

In this paper Fiji's interactive graph cut method based on the min-cut/max-flow segmentation algorithm was investigated. This implementation allows user to adjust several parameters in order to obtain the best possible segmentation results.

Performed tests reveals that the adjustments of the "foreground bias" (related to regional term) and "smoothness" (related to boundary term) parameters significantly influences the results of image segmentation.

On the other hand, additional parameters concerning the gradient magnitude of the image has almost no influence on the segmentation quality in case of the considered class of images.

The obtained segmentation results were positively verified by the specialists from the Department of Neurosurgery of Polish Mother's Memorial Hospital – Research Institute in Lodz. Visual verification of the results confirms that this approach is promising and can be successfully applied in quantitative assessment of hydrocephalus and other brain diseases.

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