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APPLICATION OF NEURAL NETWORKS AND COLOR INTERPRETATION FOR RAPID ASSESSMENT OF LESION DYNAMICS IN THE BRAIN IN MULTIPLE SCLEROSIS

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Abstract. The article describes a method of using color contrasting in 3D visualization of a multifocal lesion pattern in the brain in patients with multiple sclerosis. Application of the method allows to assess quickly and correctly the dynamics of changes in multifocal patterns based on MRI data obtained at different times. Volumetric reconstruction and color contrasting are carried out in a fully automatic mode and allow to analyze not only the lesion pattern as a whole, but also individual changes in the internal structure of individual foci. This approach reduces the time of the study and at the same time significantly increases the validity and reliability of the study results.

Keywords: multiple sclerosis, convolutional neural networks, 3D reconstruction, multifocal lesion patterns.

Introduction. Currently, magnetic resonance imaging is the main method of visualization of demyelination foci [1]. Over time, the number of foci detected in the patient's brain, their activity, size and localization may change [2]. In multifocal lesions, this becomes a major obstacle to a quick and accurate analysis of the extent of changes that have occurred. The problem is that the radiologist has to analyze the MRI picture in three orthogonal projections. Usually at least 120 (50 + 40 + 30) slices have to be carefully examined and described. On each slice the state of individual fragments of detected pathological foci is highlighted and examined. To assess the picture of the lesion as a whole, it is necessary to mentally put together a volumetric puzzle from many fragments. This not only requires a lot of time and attention, but also determines low accuracy of the result. It is even more difficult to accurately compare two or more MRI scans of a patient performed at different times.

Purpose of the work performed:

- to develop a variant of automatic three-dimensional reconstruction of focal lesions;
- to propose a method for correct comparison of MRI examinations of a patient performed at different times and a quick assessment of the changes that occurred. Not only the general picture of the lesion was analyzed, but also individual changes in the foci noted by the diagnostician.

Methods. An upgraded version of the UNet 3+ architecture [3] was used to segment the foci and to build 3D images. The network architecture was improved [4] by integrating the VGG16 model as a subnet (so-called backbone). In addition, the order of upsampling and convolution operations was reversed (since the standard order requires significantly more video memory) for upstream (using upsampling) full-scale skip connetions.

Correct alignment of 3D patterns was performed using affine transformations. This made it possible to eliminate the dependence on the patient's head orientation during MRI examinations. Advanced mattes mutual information was chosen as a cost function (a function evaluating how accurately the same objects present in the compared images are combined), and Adaptive stochastic gradient descent as an optimizer. The value function used allows combining the series obtained in different modes of MRI investigation.

Relative brightness is used to analyze the intensity of foci, which is calculated as the ratio of average brightness of the foci to average brightness of the background. The entire image is considered the background, except for foci. When the stationary magnetic field of the tomograph is changed, the brightness of the whole image changes: both foci and background. Use of a relative brightness parameter levels out such differences between examinations carried out on MRI machines with different magnetic field strength and, therefore, allows correctly assessing brightness of foci in dynamics.

Visual analysis of changes assumed application of color in two modes: formal and informal. Formal mode was used to identify focal patterns detected on different MRI series. Example in Figure 1.

Informal mode was used to analyze the intensity of the focus. Since there are 256 grayscale in the MRI images, and the eye distinguishes no more than 30 shades, to avoid loss of information, each grayscale level was assigned its own color shade.

Results. Automatic segmentation of foci and subsequent 3D reconstruction allowed not only to quickly obtain a realistic volumetric picture of the lesion and calculate the number of foci, but also to obtain parameters characterizing the focal pattern: the number of foci, the volume of foci, the total volume of the lesion, the localization of each foci (coordinates of their center of mass), the intensity of foci. When analyzing complex multifocal patterns, the average total timeis 52 s. Figure 2 gives an example of combining the patterns shown above (in Figure 1).

Informal color contrasting helps to analyze the nature of the inflammatory process in the volume of an individual focus. An example of visualization of the structure of a separately selected focal inflammation is shown in Figure 3. Each gray level is assigned a color shade: from green (minimum intensity) to red (maximum intensity). According to the change in the size of the lesion and the color distribution within, the effectiveness of the therapy can be monitored.

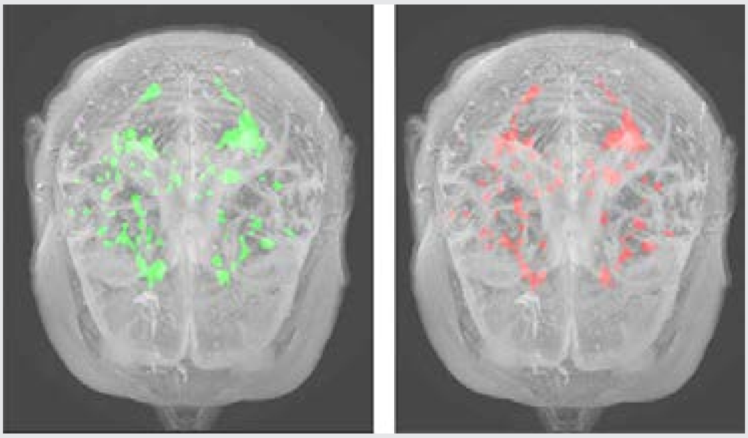

Figure 1 — 3D reconstruction of patient A's lesion patterns. Green color — MRI study of 2019. Red color — MRI study of 2018

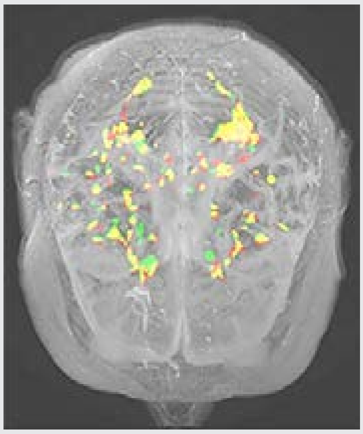

Figure 2 — Overlay of pathological patterns obtained during MRI examinations of patient A in 2018 and 2019. 3D reconstruction, top view. Yellow are areas of overlap (i. e., areas where the lesion persisted). Red color — remyelination area (areas of 2018 not found in the 2019 study). Green color — new areas of inflammation (not found in the 2018 study)

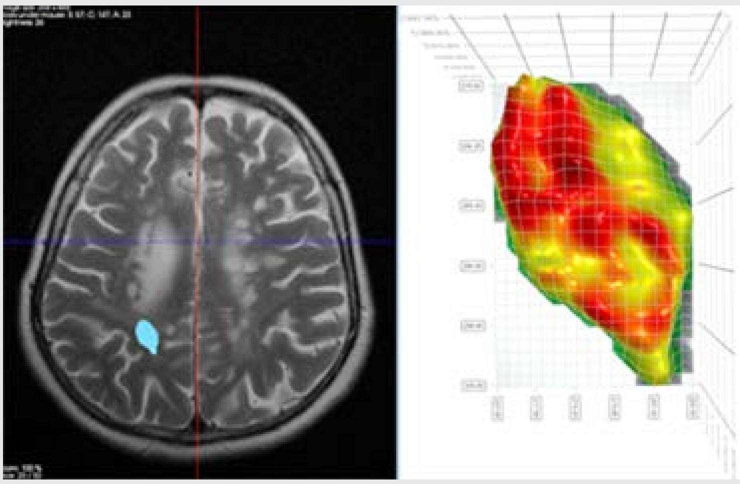

Figure 3 — Color interpretation of the inflammation structure in the volume of demyelination foci according to the MRI study of patient B. The lesion on the axial section is highlighted in blue, on the right — its color 3D reconstruction in enlarged size

Conclusions

1. The proposed method does not depend on diagnostician's perception, largely based on visual perception of individual elements of the lesion. The risk of misdiagnosis increases significantly with the expansion of the lesion volume.

2. The average time to construct and analyze a complex multifocal lesion pattern decreases from 40 minutes with semi-automatic manual delineation to 52 seconds with automatic segmentation.

4. The proposed method allows quantitative assessment of the patient's dynamics regardless of his/her position inside the tomograph during MRI examinations.

5. The proposed method provides the easy way to obtain a complete set of diagnostically valuable and reproducible characteristics with less energy expenditure of the diagnostician and with absolute reproducibility of results.

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Применение нейронных сетей и цветовой интерпретации для быстрой оценки динамики поражения в головном мозге при рассеянном склерозе

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Реферат. В статье описывается метод применения цветового контрастирования при 3D-визуализации картины поражения головного мозга у пациентов с рассеянным склерозом. Метод позволяет проводить быструю, корректную оценку динамики изменений в сложных многоочаговых паттернах, построенных по данным МРТ-исследований, разнесенных во времени. Объемная реконструкция и цветовое контрастирование проводятся в полностью автоматическом режиме и позволяют анализировать не только общую картину поражения, но и индивидуальные изменения во внутренней структуре отдельных очагов. Такой подход на порядок сокращает время исследования и при этом значительно повышает объективность результатов исследования.

Ключевые слова: рассеянный склероз, сверточные нейронные сети, 3D-реконструкция, многоочаговые паттерны поражения.

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