Methodological Article

Isfahan Artificial Intelligence Event 2023: Lesion Segmentation and Localization in Magnetic Resonance Images of Patients with Multiple Sclerosis

Abstract

Background: Multiple sclerosis (MS) is one of the most common reasons of neurological disabilities in young adults. The disease occurs when the immune system attacks the central nervous system and destroys the myelin of nervous cells. This results in appearing several lesions in the magnetic resonance (MR) images of patients. Accurate determination of the amount and the place of lesions can help physicians to determine the severity and progress of the disease. **Method:** Due to the importance of this issue, this challenge has been dedicated to the segmentation and localization of lesions in MR images of patients with MS. The goal was to segment and localize the lesions in the flair MR images of patients as close as possible to the ground truth masks. **Results:** Several teams sent us their results for the segmentation and localization of lesions in MR images. Most of the teams preferred to use deep learning methods. The methods varied from a simple U-net structure to more complicated networks. **Conclusion:** The results show that deep learning methods can be useful for segmentation and localization of lesions in MR images. In this study, we briefly described the dataset and the methods of teams attending the competition.

Keywords: *Lesion detection, magnetic resonance images, multiple sclerosis*

Submitted: 13-Aug-2024 **Revised:** 26-Aug-2024 **Accepted:** 18-Sep-2024 **Published:** 28-Feb-2025

Fariba Davanian[1,2,3], Iman Adibi[2], Mahnoosh Tajmirriahi[4], Maryam Monemian[5], Zahra Zojaji[6], Ahmadreza Montazerolghaem[6], Mohammad Amin Asadinia[7], Seyed Mojtaba Mirghaderi[8], Seyed Amin Naji Esfahani[9], Mohammad Kazemi[7], Mohammad Reza Iravani[10], Kian Shahriari[11], Nesa Sharifi[10], Sadaf Moharreri[10], Farnaz Sedighin[5], Hossein Rabbani[4]

[1]Medical Image and Signal Processing Research Center, Department of Bioimaging, School of Advanced Technologies in Medicine, Isfahan University of Medical Sciences, Isfahan, Iran, [2]Department of Neurology, Neuroscience Research Center, School of Medicine, Isfahan University of Medical Sciences, Isfahan, Iran, [3]Paramedical School, Isfahan University of Medical Sciences, Isfahan, Iran, [4]Medical Image and Signal Processing Research Center, Department of Bioelectrics and Biomedical Engineering, School of Advanced Technologies in Medicine, Isfahan University of Medical Sciences, Isfahan, Iran, [5]Medical Image and Signal Processing Research Center, School of Advanced Technologies in Medicine, Isfahan University of Medical Sciences, Isfahan, Iran, [6]Faculty of Computer Engineering, University of Isfahan, Isfahan, Iran, [7]Department of Electrical Engineering, University of Isfahan, Isfahan, Iran, [8]Department of Electrical and Computer Engineering, Isfahan University of Technology, Isfahan, Iran, [9]Department of Electrical Engineering, K. N. Toosi University of Technology, Tehran, Iran, [10]Department of Biomedical Engineering, Khomeinishahr Branch, Islamic Azad University, Khomeinishahr/Isfahan, Iran, [11]Department of Biomedical Engineering, Islamic Azad University Science and Research Branch, Tehran, Iran

Introduction

Multiple sclerosis (MS) is an autoimmune disease which is the main reason of neural disabilities among young adults.[1-11] The disease arises when the central nervous systems is attacked by the immune system. The main reason of MS is still uncovered; however, it is believed that factors such as genetic records, smoking, or Vitamin D shortage can be effective in disease occurrence.[1,5,9] As a result of this attack, the myelin sheaths of neurons are destroyed, which results in appearing white lesions in the magnetic resonance (MR) images of the brain.[1-8] These lesions can be seen in periventricular, white matter, juxtacortical, and infratentorial parts of the brain. Determining the size and the number of lesions in addition to their places in the brain is of high importance for definitive diagnosis of MS based on the McDonald Criteria.[1,5,8-10]

MR images are the mostly used tools for MS diagnosis. By injecting gadolinium, the place and the size of the lesions can be shown in the MR images.[1-3,5,6,8-10] Segmenting the lesions and localizing them are usually done manually. However, these tasks are difficult and time-consuming, which bring this idea in mind if machine learning methods can be helpful for segmenting and localizing the lesions automatically.

In recent years, artificial intelligence (AI) has been increasingly become attractive in the diagnosis of different diseases. AI can increase the precision, quality, and speed of diagnosis based on different medical images. It can also predict the possible occurrence of diseases, such as different cancers, for a patient. From this point of

Address for correspondence: Dr. Farnaz Sedighin, Medical Image and Signal Processing Research Center, School of Advanced Technologies in Medicine, Isfahan University of Medical Sciences, Isfahan, Iran.
E-mail: f.sedighin@amt.mui.ac.ir

How to cite this article: Davanian F, Adibi I, Tajmirriahi M, Monemian M, Zojaji Z, Montazerolghaem A, *et al.* Isfahan Artificial Intelligence Event 2023: Lesion segmentation and localization in magnetic resonance images of patients with multiple sclerosis. J Med Signals Sens 2025;15:5.

Access this article online

Website: www.jmssjournal.net

DOI: 10.4103/jmss.jmss_55_24

Quick Response Code:

view, AI is now playing a vital role in preventing different diseases and their financial and emotional burdens for the society and also in improving the quality of treatments and patients lives.[12-14]

Considering this reality, AI has also been exploited for MS diagnosis and also detection, segmentation, and localization of MR lesions for MS patients. Using AI can increase the quality of lesion segmentation and localization, which is extremely important for accurate diagnosis of MS disease.[15-23]

A challenge focusing on deriving new AI-based methods for MS lesion segmentation was hosted by the Isfahan National Elites Foundation in IAI2023. The goal of this challenge was to provide novel and effective AI-based methods for segmentation and localization of the lesions in MR images of patients with MS. The challenge was to segment lesions in 3D MR images of patients as close as possible to the ground truth mask images, in addition to localize the lesions and determine if they were in periventricular, white matter, juxtacortical, or infratentorial parts of the brain. In the following sections, complete description of the dataset, evaluation methods, finalist team's methodology, and results are presented.

Dataset description

The dataset consists of FLAIR images of 81 patients captured with MR imaging system (MRI Siemens Avanto scanner system, 1.5 Tesla, Henkestr Erlangen) in Kashani Hospital. The 3D images were in NIFTI format with size 160 × 256 × 236. For each case, a 3D mask image, with the same size of the corresponding MR image, in which the lesions were localized was also available. The images contained lesions in periventricular, white matter, juxtacortical, or infratentorial parts of the brain, where the lesions in different places could be identified by their intensities in the gray scale images. Only few slices of a

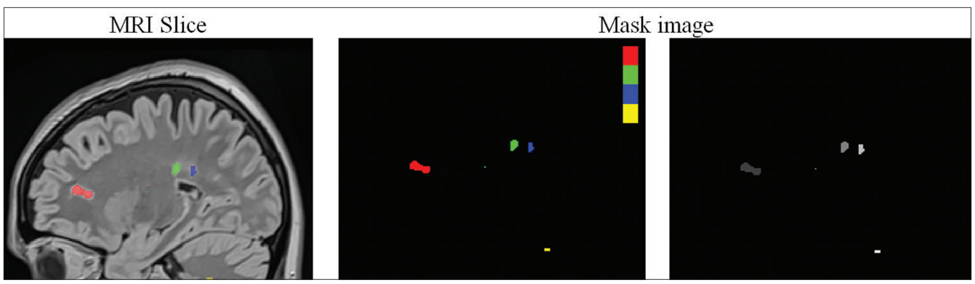

Figure 1: Magnetic resonance imaging slice of a patient containing several lesions in different places of the brain in addition to its corresponding mask slice, in color and gray scale formats, which show the segmented lesions. Lesions in different places of brain have been shown with different intensities or colors, where in the colored image, the red, green, blue, and yellow colors correspond to lesions in periventricular, white matter, juxtacortical, and infratentorial, respectively

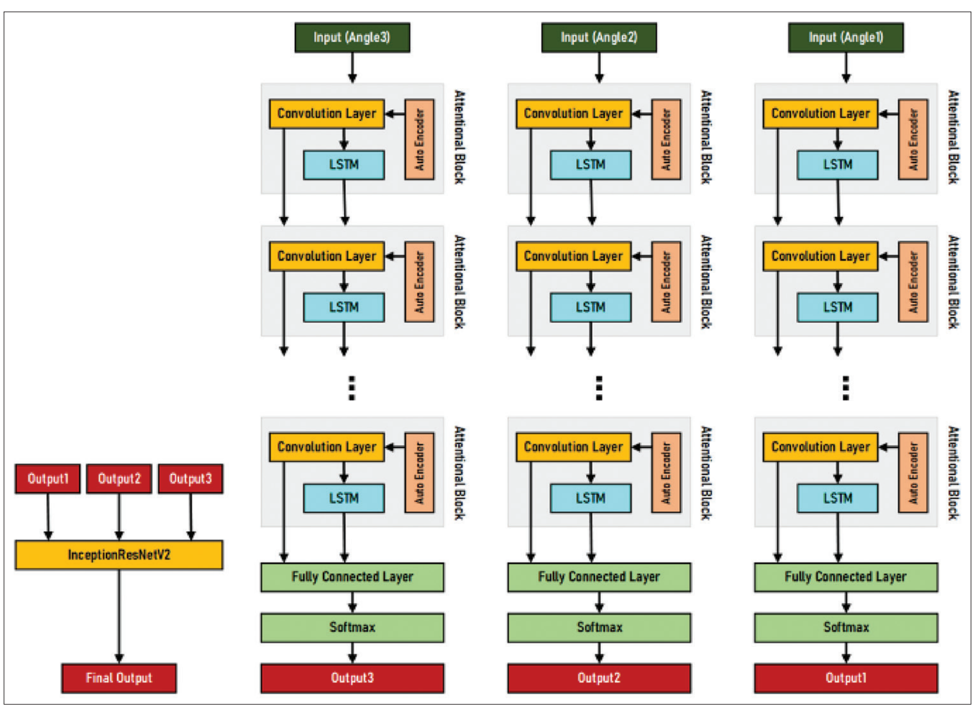

Figure 2: Architecture of the network used by Legends. LSTM: Long short-term memory

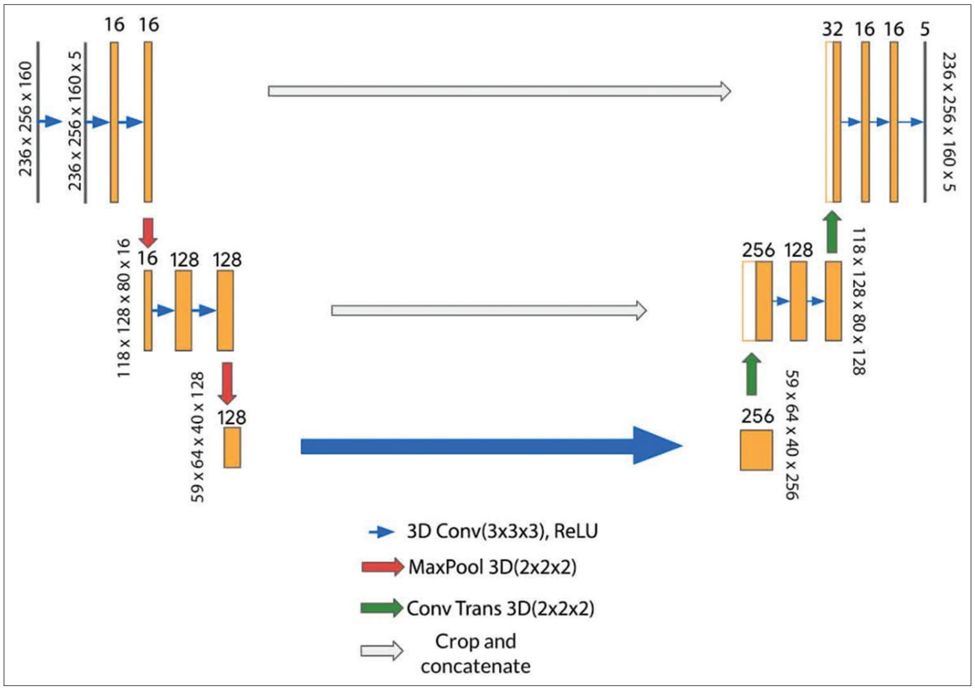

Figure 3: Architecture of the network used by AITech

3D MR image of a patient with MS contained lesions. An example for an MRI slice with several lesions along with its corresponding mask slice (in color and grayscale formats) is illustrated in Figure 1. lesions in different places of the brain were distinguished by different intensities (intensity 1 to intensity 4).

In the training phase, the teams received 50 3D MR images and their respective masks, for training their networks. Then, the first test dataset, including 25 3D MR images without their respective ground truth masks, was given to the teams. The task was to segment different lesions in addition to localize their places in the brain. The received results were comprehensively evaluated and the selected teams were invited as finalists to the last round of the competition, held in Abbasi Hotel. The finalists received the second test dataset containing the remaining 6 3D MR images without their ground truth masks.

Evaluation of the methods

After receiving the first test dataset, the teams had to send their resulting masks for the MR images of the first test dataset in addition to a comprehensive report including their methodology and approach details. The results were evaluated qualitatively and quantitatively. The quality of the methods was evaluated based on the following criteria:

1. The novelty of the method
2. Quality and clarity of the report
3. Rationality of the method and parameter settings
4. Visual performance of lesion segmentation and localization.

The received results were also evaluated quantitatively using the following criteria:

1. Average Dice score, defined as

$$Dice_{score} = \frac{2T_P}{2T_P + F_N + F_P},$$

2. Average sensitivity, defined as

$$Sensitivity = \frac{T_P}{T_P + F_N},$$

3. Average precision, defined as

$$Precision = \frac{T_P}{T_P + F_P},$$

Where

T_p is the number of pixels which contain lesion and have been segmented correctly, F_p is the number of pixels which do not contain lesion and have been segmented incorrectly, and F_N is the number of pixels which contain lesion and have been segmented incorrectly.

Furthermore, the precision in the localization of the lesions was calculated by centroid distance measurement. The mentioned criterion computed the Euclidian distance between the geometric center of the ground truth masks of the lesions and the geometric center of the segmented lesions.

The criteria have been calculated for each of 4 intensities (lesions in periventricular, white matter, juxtacortical or infratentorial parts of the brain). Based on the metrics, the finalists were invited to the second and the last competition phase. The finalists received the second test dataset, including 6 3D MR images without the ground truth masks and derived the results for lesion segmentation and localization. The results were evaluated qualitatively and quantitatively using the mentioned metrics. Based on the evaluations, the winners were ranked as follows:

- First team: Legends
- Second team: AITech.

The details of the methods of the finalists in addition to their results are presented in the following sections.

Description of the Methods

The methods of the finalists were reviewed briefly in the following subsections.

Legends

For the segmentation task, a network consists of five consecutive convolutional layers was exploited. The number of convolutional filters from the first to the fifth layer was 32, 64, 128, 256, and 512, respectively. The input of the network in each stage was an 128 × 128 image. Finally, the output of the network was derived using a soft-max activation function.

For the localization task, long short-term memory (LSTM) networks were used. Therefore, in each layer of the previous network, an LSTM network was added. The number of memory units of the LSTM network in each layer was equal to the half of the convolutional filters which were used in that layer. The structure of the designed network by Legends is illustrated in Figure 2.

AITech

The AITech team exploited a U-net architecture with different contracting and expanding steps and filter sizes for the segmentation and localization of the lesions. The values in the mask images were normalized into (0 1) (instead of 0–4) for handling them with the sigmoid activation function in the last layer of the network. The architecture of the network used by AITech is shown in Figure 3.

Finalist team's results

The results of the finalist for the first and second test datasets are summarized in Tables 1-4. For a more clarification on the results presented in Tables 1-4, the following definitions are used:

1. First test dataset: A dataset including 25 3D MR images without their respective ground truth masks, which received by the teams after the training phase. This dataset was used for selecting the finalists
2. Second test dataset: A dataset including 6 3D MR images without their respective ground truth masks, which received by the finalists in the last round of the competition. This dataset was used for ranking the finalists.

Table 1: Quantitative results of the finalists for the first test dataset

Group	Dice	Sensitivity	Precision
Legends			
Intensity #1	0.51	0.144	0.384
Intensity #2	0.186	0.144	0.384
Intensity #3	0.241	0.199	0.365
Intensity #4	0.207	0.225	0.328
AITech			
Intensity #1	0.468	0.133	0.133
Intensity #2	0.133	0.151	0.146
Intensity #3	0.107	0.082	0.276
Intensity #4	0.000	0.000	0.000

Table 2: Quantitative results of the finalists for the second test dataset

Group	Dice	Sensitivity	Precision
Legends			
Intensity #1	0.526	0.578	0.538
Intensity #2	0.140	0.096	0.357
Intensity #3	0.251	0.197	0.357
Intensity #4	0.167	0.121	0.317
AITech			
Intensity #1	0.482	0.598	0.461
Intensity #2	0.177	0.195	0.202
Intensity #3	0.241	0.210	0.339
Intensity #4	0.000	0.000	0.000

Table 3: Segmented and detected lesions for the second test dataset

Group	Number of ground truth lesions	Number of detected lesions	Number of segmented lesions
Legends			
Intensity #1	77	57	171
Intensity #2	68	27	110
Intensity #3	50	29	160
Intensity #4	18	6	20
AITech			
Intensity #1	77	59	178
Intensity #2	68	29	119
Intensity #3	50	22	72
Intensity #4	18	0	0

In Tables 1 and 2, Dice score, sensitivity, and precision of the two groups for lesion segmentation of the first and second test datasets are presented. In these two Tables, the scores for segmentation of each individual intensity are presented. In Tables 3 and 4, the localization accuracies of the finalists for localizing the lesions with different intensities and for each test image are presented. In Table 3, the number of ground truth lesions with different intensities (for all of 6 test images) in addition to the

Table 4: Average centroid distances of the detected lesions in each image of the second test dataset for different intensities

Group	Image #1	Image #2	Image #3	Image #4	Image #5	Image #6
Legends						
Intensity #1	23.7	36.01	50.52	12.91	46.68	1.44
Intensity #2	73.66	71.67	80.38	50.71	45.16	34.66
Intensity #3	22.50	51.00	1.42	68.05	50.81	34.30
Intensity #4	100	33.87	-	72.54	100	50.41
AITech						
Intensity #1	13.57	32.84	34.02	18.12	37.38	1.00
Intensity #2	60.23	71.76	60.21	54.59	44.83	67.04
Intensity #3	71.64	50.27	3.27	51.37	56.93	50.39
Intensity #4	100	100	-	100	100	100

number of segmented and detected lesions with different intensities for each group are presented. Noted that the detected lesions are the lesions which have been segmented correctly. In Table 4, the average centroid distances for each test image and for different intensities are reported. The results show the precision of each team for the lesion localization. For undetected lesions, the average centroid distance was replaced by 100.

Based on the evaluation results and by considering the visual outputs and the novelty of the methods, the Legends and AITech were ranked as the first and second winners, respectively.

Conclusion and Future Perspective

Effectiveness of AI tools for the detection and prediction of different disease has been proven in different studies. In this challenge, the aim was to use AI methods for segmentation and localization of lesions in MR images of patients with MS. All of the finalist teams preferred to use deep learning methods for these tasks. The networks varied from simple U-nets to a more complicated network proposed by "Legends." As the results show, deep learning methods have the ability for segmentation and localization of the lesions. However, the results show that still there is a significant gap between the acquired results and desired accuracies for a trustable MS lesion segmentation. This issue can be investigated by researchers in future studies.

Financial support and sponsorship

This work was supported by the Isfahan Elite Foundation (IEF), which sponsored the Isfahan Artificial Intelligence Event 2023 (IAI2023). The IEF organized the event and provided financial support for the 10 challenges, including Challenge 6: Lesion Segmentation and Localization in MRI Images of Patients with MS. Several winners received prizes from the IEF.

Conflicts of interest

The authors declare the following potential conflicts of interest:

- ZZ and AM were the organizers of the Isfahan AI (IAI) 2023 competitions on behalf of Isfahan Elite Foundation (IEF), which included 10 challenges.
- FD, IA, MT, MM, FS and HR, served as scientific committee members for Challenge 6: Lesion Segmentation and Localization in MRI Images of Patients with MS. They were responsible for evaluating the methodologies and results of all participant teams.
- MAA, SMM, SANE, MK, MRI, KS, NS, SM are members of the winning teams in this challenge.

None of the organizers and scientific committee members (FD, IA, MT, MM, FS, HR, ZZ and AM) contributed to the development of the methods used by the participating teams. The final decision regarding the winners was made by the policy council members based on the following criteria:

- Technical contribution in developed models by teams,
- The results on initial and final test data of each team,
- The submitted reports and teams' presentations.

The authors have disclosed these relationships to ensure transparency and maintain the integrity of the research.

Acknowledgements

We extend our appreciation to the policy council members, Prof. Behrouz Minaei Bidgoli from Iran University of Science and Technology, Prof. Mohammad Hassan Moradi from Amirkabir University of Technology, Prof. Heshaam Faili from University of Tehran, Prof. Emad Fatemizadeh from Sharif University of Technology, and Prof. Hossein Rabbani from Isfahan University of Medical Sciences, for making the final decisions regarding the winners of all 10 challenges.

Finally, we thank the anonymous reviewers for their valuable feedback and contributions to the improvement of this paper.

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