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An efficient multiple sclerosis segmentation and detection system using neural networks☆

Mohammad H. Alshayeji[a,*], Mohammad A. Al-Rousan[b], Hanem Ellethy[a], Sa'ed Abed[a]

[a] Computer Engineering Department, College Engineering and Petroleum, Kuwait University, P.O. Box 5969, Safat 13060, Kuwait
[b] Network Engineering & Security Department, College of Computer and Information Technology, Jordan University of Science and Technology, P.O. Box 3030, Irbid 2210, Jordan

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ABSTRACT

In this work, an efficient multiple sclerosis (MS) segmentation technique is proposed to simplify pre-processing steps and diminish processing time using heterogeneous single-channel magnetic resonance imaging (MRI). A spatial-filtering image mapping, histogram reference image, and histogram matching techniques are effectively applied to possess a local threshold per image using the global threshold algorithm. Feature extraction is performed using mathematical and morphological operations, and a multilayer feed-forward neural network (MLFFNN) is used identify multiple sclerosis' tissues. Fluid-attenuated inversion recovery (FLAIR) series are used to integrate a faster system while maintaining reliability and accuracy. A sagittal (SAG) FLAIR-based system is proposed for the first time in MS detection systems, which reduces the number of utilized images, and decreases the processing time by nearly one-third. Our detection system provided a significant recognition rate of up to 98.5%. Moreover, a relatively high dice coefficient (DC) value (0.71 ± 0.18) was observed upon testing new images.

1. Introduction

Multiple sclerosis (MS) is considered one of the most common primary neurological disorders in young adults [1]. Magnetic resonance imaging (MRI) of the brain and spine shows areas of demyelination (lesions or plaques) and provides a series of images that aid in the visual detection of MS lesions [2]. Although expert manual annotations of lesions are feasible in practice, inter-observer variability in the interpretation of MRI can be problematic in many cases. Visual evaluation is also difficult due to several limitations, such as low resolution resulting from physical limitations [3]. An automated, intelligent system of MS lesion detection and quantification could be beneficial in the clinical assessment of many MRI images. Manual analysis is time-consuming and expensive due to the necessary labor and expertise [4]. Therefore, artificial intelligence (AI) and image processing techniques have gained popularity in medical research due to their ability to reduce human intervention for large-scale clinical studies [5]. The objective of the present work is to develop a neural network-based decision system capable of rapidly analyzing MS lesions with a high degree of accuracy. Therefore, we introduce an efficient segmentation mechanism based on simple image processing filters and algorithms without the need to remove the skull and cerebrospinal fluid (CSF) from the processed images, and without separating gray matters (GM) and white matter (WM). Moreover, this paper introduces a novel, simple, and more rapid MS detection and classification system based on the Sagittal (SAG) Fluid-attenuated inversion recovery (SAGFLAIR) series in which a small number of MRI images are used. To the

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* Corresponding author.
E-mail address: m.alshayeji@ku.edu.kw (M.H. Alshayeji).

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Fig. 1. Processing phases utilized in the proposed system.

best of our knowledge, this is the first work proposing the use of SAG series for the detection of MS lesions.

To date, there are no specific symptoms, physical findings or laboratory tests that can be used alone to diagnose MS. Young adults are most commonly affected by MS who also suffer from additional disabilities because of the disease [2]. MS diagnosis depends on various strategies to determine whether an individual meets the established criteria and to preclude other conceivable reasons for the number of manifestations an individual encounter. While many strategies can be utilized, MRI represents the most powerful tool for MS diagnosis due to its ability to detect central nervous system demyelination. Further, MRI can also be utilized for the recognition of a second neurological condition in which an individual has no additional symptoms and, through this approach, affirms the determination of MS as efficiently and rapidly as possible [1].

MRI images are scanned using various devices and are influenced by the inherent parameters of each machine, which affect the result of MS detection and diagnosis. It has been demonstrated that changes in MRI acquisition parameters using the same scanning system, such as pulse sequences, magnetic field strength, spatial resolution, coil technology, and dose of contrast media considerably influence the detection of focal MS pathology [2]. Therefore, using a robust automated system can provide compatible results, while also controlling the time required for diagnosis. Additionally, image processing techniques could differentiate the diversity of intensity better than human eyes as well as deal with several types of image noise. The application of image processing [5] and AI [3] in the medical field are at the forefront of computer engineering research [6].

In this paper, a novel system for MS detection is proposed based on the three main phases presented in Fig. 1. First, the image processing phase [1,5] is applied to single-channel MRI images to obtain a set of tissues that include MS and artifact (AF) by applying spatial-filtering image mapping, histogram image reference, and a histogram matching approach. Second, the processed images are investigated to extract features [7] of MS lesions using mathematical and morphological operations. Third, the extracted features are classified following sufficient training using a multilayer, feed-forward neural network (MLFFNN) [8].

The contributions of this research include:

- Designing, developing, and implementing an intelligent system that aids in classifying and detecting MS using a single-channel MRI as an auxiliary tool. This system functions by integrating the power of image processing and neural network fields on datasets that include heterogeneous images collected from different local hospitals and expert neurologists.
- Introducing an efficient segmentation algorithm that yields significant results and increases system speed over other similar systems. Spatial-filtering image mapping is used to avoid skull and CSF elimination as well as GM and WM separation, as most existing work requires. As a result, the segmentation process is more rapid. This novel segmentation technique uses histogram reference image and histogram-matching approaches to conserve processing time, accelerate the application results, and generalize the system for application to any 2D MRI image regardless of its scan source. Moreover, the system provides a high recognition rate and achieves high dice coefficient (DC) values when compared to similar existing work.
- Introducing a novel MS detection and classification system based on SAGFLAIR series, which reduces the number of utilized images, and decreases the processing time by nearly one-third. This approach makes the system faster than an AXIAL FLAIR (AXFLAIR)-based system while maintaining robust performance and providing a comparably high recognition rate.

This paper is structured as follows: Section 2 represents the related work. Section 3 discusses the proposed system and its stages in detail. An evaluation of the proposed system is presented and elaborated on in Section 4. Finally, the conclusion is presented in Section 5, complete with recommendations for the future.

2. Related work

Many published works have addressed MS segmentation and classification as a useful tool in the medical field via various methods and techniques based on image processing, machine learning approaches or a combination.

Automated MS segmentation has been proposed in various papers [1,3,9–12], and it can be classified into two categories depending on the approach used for MS lesion detection. Thus, García-Lorenzo et al. [13] categorizes MS segmentation techniques into supervised and data-driven (or unsupervised). Specifically, a system that is first trained using a sample of disease features is categorized as a supervised technique [10]. The result of this technique depends on the dataset, how it is segmented, and how it utilizes the MRI protocol, as presented in [14]. Conversely, a system that automatically extracts necessary features from MRI images is classified as a data-driven technique, as presented in [15].

Canny edges and Minkowski–Bouligand dimension were used [9] to segment MRI images and extract features. The synthetic minority oversampling technique and fractal dimension for detecting MS were implemented with the integration of a single hidden layer neural network (SHLNN) as a classifier and then optimized with three steps to achieve the expected performance.