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SEGMENTATION OF THE HIPPOCAMPUS REGION USING DIFFERENT MACHINE LEARNING TECHNIQUES FOR ALZHEIMER'S DISEASE DIAGNOSIS

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Abstract

Hippocampus region of the brain is one of the first involved regions in Alzheimer's disease (AD) and mild cognitive impairment (MCI), a prodromal stages of AD. Since the change of hippocampal volume is a defined biomarker for Alzheimer's disease, hippocampus segmentation of brain image can be used to assist the diagnosis of Alzheimer's disease. In this paper, the segmentation of the hippocampus region from brain Magnetic Resonance Images (MRI) is per- formed for the diagnosis of Alzheimer's disease with help of different machine learning based image segmentation techniques. The database images are obtained and processed using Histogram Equalization for enhancement. The hippocampus region is located and segmented from the processed brain MRI image using different image segmentation techniques. Then, the segmented image is compared with the ground truth image using image quality parameters. With the help of the parameters, the efficient technique for the segmentation of the hippocampus region, a biomarker for diagnosis of AD.

Keywords: Alzheimer's disease, Hippocampus region, Magnetic Resonance Imaging, Machine learning.

1. INTRODUCTION

Alzheimer's disease is a progressive neurologic disorder that causes the brain to shrink (atrophy) and brain cells to die. Alzheimer's disease is the most common cause of

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dementia, a continuous decline in thinking, behavioral and social skills that affect a person's ability to function independently. Memory loss is the key symptom of Alzheimer's disease. Early signs include difficulty remembering recent events or conversations. As the disease progresses, memory impairments worsen and other symptoms develop. The exact causes of Alzheimer's disease aren't fully understood. But at a basic level, brain proteins fail to function normally, which disrupts the work of brain cells (neurons) and triggers a series of toxic events. Neurons are damaged, lose connections to each other and eventually die. Alzheimer’s disease can be classified into three grades.

The stages are Cognitively Normal (CN), Mild Cognitive Impairment (MCI) – the pro-dromal stage of AD, and the Alzheimer Disease (AD). The classification is important for clinical diagnosis and adequate intervention. The diagnosis of Alzheimer’s disease can be observed from Magnetic Resonance Images (MRI)

Hippocampus is a complex brain structure embedded deep into temporal lobe and has the major role in learning and memory. Humans and other mammals have two hip-pocampi, one in each side of the brain. The hippocampus is part of the limbic system, and plays important roles in the consolidation of information from short-term memory to long-term memory, and in spatial memory that enables navigation. The hip-pocampus is located in the all cortex, with neural projections into the neocortex in hu-mans, as well as primates. The hippocampus, as the medial pallium, is a structure found in all vertebrates. Hippocampus is an extension of temporal part of cerebral cortex. The region can be distinguished externally as a layer of densely packed neurons, which curls into S-shaped structure on the edge of temporal lobe [1]. It is the earliest and most severely affected structure in several neuropsychiatric disorders such as Alzheimer's disease (AD), epilepsy etc. Rates of hippocampal atrophy have been used as both diag- nostic and prognostic marker in clinical trials of AD. It has been seen that patients with minimal cognitive impairment (MCI), have 10-15% of volume loss of hippocampus while those with early AD, this loss is about 15-30%. In those with moderate AD, it may reach to the extent of 50%. Atrophy of hippocampal region in brains is one of the most consistent features of AD and defined as the earliest brain region and is most severely affected. A popular hypothesis called ‘hippocampo-cortical-dissociation’ has proposed that early damage to hippocampus causes a ‘dissociation’ between hippocam- pus and cerebral cortex, leading to failure of registration of information emanating from hippocampus. Some amount of hippocampal atrophy is seen in all patients with AD. A number of neurotransmitter alterations also occur in brains of AD such as noradrener- gic, serotonergic, and glutaminergic regions corresponding to neuron loss in hippocam- pal region.

Kelvin Zhou.S (2016) illustrates the use of machine learning in different medical image applications and analysis that includes object recognition and segmentation [2]. Smis- tad M (2015) describes the different segmentation techniques applied for various med- ical images [3]. The comparison of the techniques is performed based on the accuracy parameters. In this paper, the segmentation of the hippocampus region using different

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machine learning techniques for the identification of AD. Segregation of hippocampus region is a diagnostic biomarker for the recognition of different stages of AD

2. METHODOLOGY

In this paper, segmentation of the hippocampus region from the brain MRI images is performed. The segmented hippocampus region will be analyzed to diagnose the Alzheimer's disease. Different image segmentation techniques like K means segmentation, Support Vector Mechanism segmentation, Random Forest segmentation, Ada- boost segmentation, Markov Random Field segmentation are implemented for the segregation of region of hippocampus. After segmentation, the efficient technique is obtained by comparison of the different technique segmented images using comparison parameters such as Structural Similarity Index (SSIM), Hausdorff distance, Dice coefficient, Peak to Signal Noise Ratio (PSNR). Thus the efficient technique for segmentation of hippocampus region is determined for the diagnosis of hippocampus region.

The MRI brain images are obtained from the ADNI (Alzheimer's Disease Neuro- imaging Initiative) database. The database is formed by various researchers worldwide from different academic and private institutions. The database used in the paper is acquired from a 3-Tesla Magnetic resonance Imaging (MRI). The brain images are avail-able in different forms that includes T1-weighted images (MPRAGE). The database images are processed for the segregation of hippocampus region to analyze the state of Alzheimer's disease (http://adni.loni.usc.edu) [4, 5].

2.1 Pre-processing

The Brain MRI images obtained from the database is processed for the enhancement of the region of hippocampus. In this stage of pre-processing, the speckle noises are removed from the raw brain MRI images using despeckle filter. Median speckle filter is applied for the filtration of speckle noises which a nonlinear filtering techniques [6]. This technique is implemented to remove speckle noises from the finer regions in the slices of MRI which enhances the hippocampus region. Histogram based contrast enhancement, Contrast limited adaptive Histogram equalization is used for enhancement of the small and finer regions in the MRI brain images [7]. Limited adaptive distribution of pixels improves the contrast and intensity of the region of interest. These pre-processing techniques are performed for the effective segmentation of the hippocampus region.

2.2 Image Segmentation

The processed MRI brain images are analyzed and segregation of hippocampus region is performed using different machine learning techniques [8]. Segmentation of the region of interest is necessary for the identification of AD.

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K-means segmentation

K-Means clustering algorithm is an unsupervised algorithm and it is used to segment the interest area from the background. Clustering is a method to divide a set of data into a specific number of groups. One of the most popular method is k-means clustering. It classifies a given set of data into k number of disjoint cluster. K-means algorithm consists of two separate phases. In the first phase it calculates the k centroid and in the second phase it takes each point to the cluster which has nearest centroid from the respective data point. There are different methods to define the distance of the nearest centroid and one of the most used methods is Euclidean distance [9].

$$J = \sum_{\square=1}^{k} \times \sum_{\square=1}^{n} \| x_{\square}^{(j)} - c_{\square} \|^2 \qquad (1)$$

Where J is the objective function, k is the number of clusters, n is the number of cases, x is the case iteration, c is the centroid for cluster j in equation (1).

Adaboost segmentation

Adaboost segmentation is a weak optimization technique that illustrates the regions of interest based on the frequent series rounds of training [10]. The sequence of the training segmentation process integrated with the weighted average defines the region of interest. The implementation of the process of adaboost segmentation is simple and maximizes the edges and margins of the regions [11]. The final segmentation output defined as H(x) is illustrated in the equation (2)

$$H(x) = sign\{\textstyle\sum_{\square=}^{T} \alpha_t h_t(x)\} \qquad (2)$$

Where t represents the training series

Support vector Machine

The SVMs are supervised machine learning techniques that make a non-probabilistic binary classifier by assigning new examples to one class or the other. At the core of kernel SVM is a kernel function that captures the non-linear relationship between the representations of input data and labels in statistical machine learning algorithms. Formally, a kernel function is defined as, Let x be a non-empty set [12]. Then a function $kY: Y * Y \rightarrow R$ is called a kernel function on Y if there exists a Hilbert space $\mathcal{H}_x$ over R, and a map $g: Y \rightarrow \mathcal{H}_x$ such that for all $x1, x2 \in Y$ in equation

(3) We have

$$k_Y(x_1, x_2) = (g(x_1), g(x_2))_{\mathcal{H}_Y}, \qquad (3)$$

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Markov random field segmentation

Markov random field (MRF) segmentation is a conditional probability model, where the probability of a pixel is affected by its neighbouring pixels. MRF is a stochastic process that uses the local features of the image. According to MRF formulation, the target image can be represented as a graph

$$G = \{V, E\} \quad (4)$$

Where V is the vertex set and E is the edge set. A vertex in G represents a pixel in the images and an edge between two vertices indicate that the corresponding pixels are neighbours in equation (4). For each object S in the image, each vertex is assigned with label 1 when it belongs to S, and with label 0 when it does not [11]. Then, the label of a voxel is, finally, determined by a similarity to object S (*i.e.*, probability PS_X) and sim-ilarity to object S of each neighbours.

Random forest segmentation

Random forests or random decision forests are an ensemble learning method that are used to build predictive models by combining decisions from a sequence of base models. Random forest segmentation uses an algorithm which selects a random subset of the features at the process of splitting each candidate to reduce the correlation of the trees in a bagging sample [13]. Given training dataset $X = \{x_1, \cdots, x_n\}$ with labels $Y = \{y_1, \cdots, y_n\}$, bagging repeatedly and randomly samples (K times) the training dataset, and replaces the original training dataset by fitting binary trees to these samples. Let X_k and Y_k be the sampled dataset, where $k = \{1, \cdots, K\}$, and let T_b denote the binary tree trained with respect to X_k and Y_k in equation (5). After training, predictions on the test dataset, $\tilde{x}$, can be made as averaging the predictions from all individual trees:

$$\tilde{y} = \frac{1}{K} \sum_k T_b(\tilde{x}) \quad (5)$$

2.3 Image Quality Parameters

The segmented images form the different image segmentation techniques has been compared with the reference image by few image quality parameters. The parameters used are Structural Similarity Index (SSIM), Dice coefficient, Hausdorff distance, Peak to Signal Noise Ratio (PSNR), Root Mean Square Error (RMSE).

Structural similarity index (SSIM).

SSIM measures the perceptual difference between two similar images. It cannot judge which of the two is better: that must be inferred from knowing which the “original” and which has been subjected to additional is processing such as data compression.

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Dice similarity coefficient.

The Dice similarity coefficient (DSC) was used as a statistical validation metric to evaluate the performance of both the reproducibility of manual segmentations and the spatial overlap accuracy of automated probabilistic fractional segmentation of MRI im-ages. The DSC measures the spatial overlap between two segmentations, A and B target regions, and is defined as

$$DSC(A, B) = 2 (A \cap B) / (A+B) \qquad (6)$$

Where ∩ is the intersection in equation (6).

Hausdorff distance.

The Hausdorff distance (HD) between two point sets is a commonly used dissimilarity measure for comparing point sets and image segmentations [14]. The average Hausdorff distance between two finite point sets X and Y in equation (7) is defined as.

$$d_{AHD}(X,Y) = \left(\frac{1}{X}\sum_{x \in X} \min_{y \in Y} d(x,y) + \frac{1}{Y}\sum_{y \in Y} \min_{x \in X} d(x,y)\right)/2 \qquad (7)$$

Peak to signal noise ratio.

The PSNR block computes the peak signal-to-noise ratio, in decibels, between two im-ages. This ratio is used as a quality measurement between the original and a compressed image PSNR indicates a ratio of the maximum possible value (power) of an indicator with the performance of a distorting noise, which generally impacts its representation quality in equation (8):

$$PSNR = \frac{20 log}{\sqrt{255 MSE}} \qquad (8)$$

Root mean square Error.

RMSE is used to measure the difference between the source image and the segmented image, the smaller the value of RMSE, the better the segmentation performance. Mathematical representation of RMSE in equation (9)

$$RMSE = \sqrt{\frac{\sum_{i=1}^{M}\sum_{j=1}^{N}[M(i,j)-F(i,j)]}{M*N}} \qquad (9)$$

Where M and N are size of the image, i and j are the pixel positions in the image. M (i, j) is the segmented image and F (i, j) is the original image [15]

The comparison of the image quality parameters is performed to analyse the efficient machine learning technique for the segmentation of the hippocampus region.

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3. RESULTS AND DISCUSSION

In this paper, segmentation of the hippocampus region from the 3D brain MRI images using machine learning techniques. The segmented hippocampus region will be analyzed to diagnose Alzheimer's disease. The source image will be pre-processed andenhanced. Then the image segmentation is done using different machine learning image segmentation techniques. Further different image quality parameters are used to compare the segmented image with the ground truth for the determination efficient segmentation technique.

Magnetic Resonance Images of the 3D Alzheimer's disease brain images has been used as input image which was taken from the database called ADNI (Alzheimer's dis-ease Neuroimaging Initiative). Comparing the output segmented image with the Alzheimer's disease hippocampus region annotated is compared with the output image thatefficiently segments the hippocampus region and helps in diagnoses the Alzheimer' disease from brain MRI images. The hippocampus region segmented from the processed images from the coronal view of brain MRI images. Before segmenting the brain MRI images, the images have been pre-processed using median speckle filter. The contrast enhancement is performed using Contrast – limited Adaptive Histogram Equaliation (CLAHE). The pre-processed images are shown below in figure 1.

Fig 1: Images of pre-processed MRI brain images

The different machine learning techniques are applied for the process of segmentation of the hippocampus region from the brain MRI images. The segmented images of the different techniques are shown below in figure 2.

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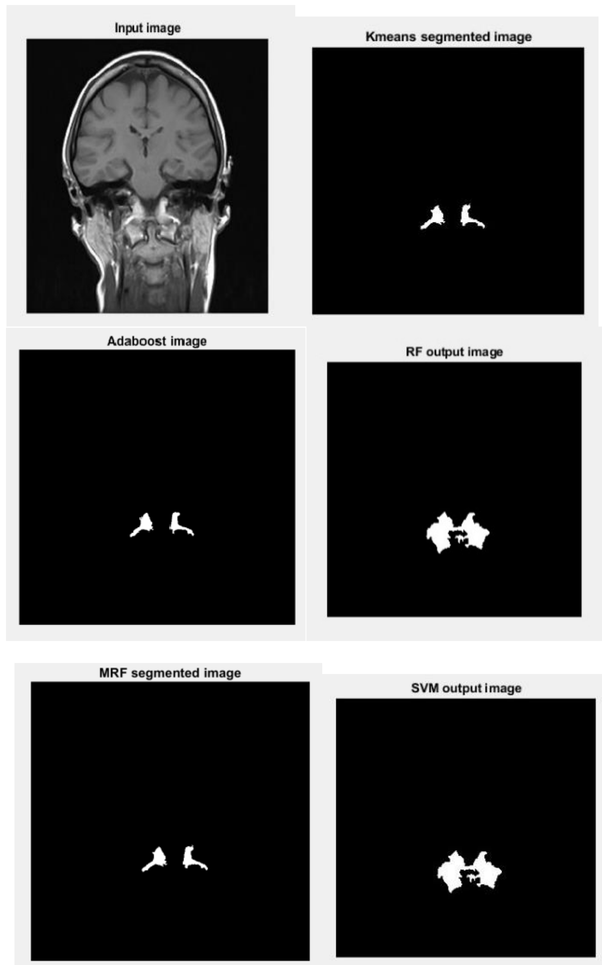

Fig 2: Segmented images of Hippocampus region

The output segmented images have been compared with a ground truth image of an Alzheimer's disease hippocampus region of the brain annotated by a radiologist using image comparison parameters such as Structural Similarity Index (SSIM), Dice coefficient, Hausdorff distance, Peak to Signal Noise Ratio (PSNR) and Root Mean Square Error (RMSE). The similarity values are obtained from the process are shown in the table 1.

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Table 1: Similarity values obtained from the comparison parameters

Parameters	Adaboost	MarkovRandom Field	SupportVector Machine	K means segmentation	Random Forest
SSIM	0.96722	0.96773	0.95083	0.96722	0.95083
Dice Coefficient	0.94266	0.84266	0.47098	0.07597	0.73553
Hausdorffdistance	0.89986	0.72773	0.07300	0.14284	0.59001
PSNR	25.1303	17.0089	14.8036	17.0089	14.8036
RMSE	0.00306	0.01991	0.03308	0.01991	0.03308

The similarity values obtained lies within the normal range, hence the ababoost segmentation method can be used to segment the hippocampus region from the MRI brain images. Comparison of the quality parameters are illustrated as a graphical representation in figure 3.

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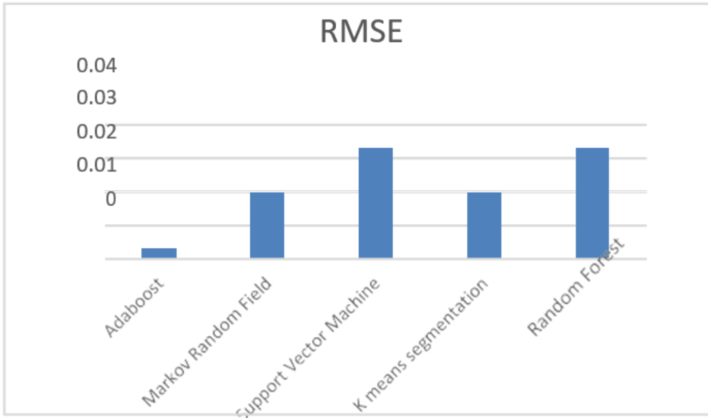

Fig 3: Graphical representation of the image quality parameters of machine learning techniques

Hippocampus region segmentation from the MRI enables the effective identification of Alzheimer's disease (AD) and determine the transitional stages of AD. ER Mulder

(2014) defines the hippocampal volume changes as an assessment measure for the analysis of AD and Mild cognitive impairment by analyzing the MPRAGE MRI brain images [16]. In the paper, database images of MPRAGE are obtained for the segmentation of the hippocampus region using machine learning techniques. Y. Shao (2019) illustrates the hippocampus region segmentation using boundary regression, the basic initialization part of machine learning. The classification-guided boundary regression de-pends on the feature extraction and node splitting of the MRI brain images subjective to the training process. In the training sections, the mapping of the segmented region occurs for the segmentation of the region of interest, hippocampus. Thus the paper de-fines different machine learning techniques for the segmentation of the hippocampus region, in which Adaboost technique defined to be more effective compared to other techniques.

4. CONCLUSION

The detection of Alzheimer's disease can be made efficient with the help of the segmentation of the hippocampus region from brain Magnetic Resonance Imaging using different machine learning based image segmentation techniques [16, 17]. In the proposed system different machine learning image segmentation techniques has been used which include K means image segmentation, Adaboost segmentation, Support vector mechanism segmentation, Markov random field segmentation, Random forest image segmentation. A ground truth image of Alzheimer's disease hippocampus region from Brain MRI images has been used as reference. The MRI brain images are used in the proposed system which is taken from the ADNI (Alzheimer's disease Neuroimaging Initiative) database. Coronal view images of the brain MRI have been used in this system. First, the source image has been pre-processed using median speckle filters and enhanced using Contrast Limited Adaptive Histogram Equalization (CLAHE).

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The hippocampus region is segmented from the brain MRI using the five techniques proposed in this system. Further the segmented images using different segmentation techniques have been compared with ground truth image using the comparison parameters such as Structural Similarity Index (SSIM), Dice coefficient, Hausdorff distance, Peak to Signal Noise Ratio (PSNR) and Root Mean Square Error (RMSE). The comparison parameter values obtained can be used to determine the efficiency of the image segmentation technique which can be further used for the accurate diagnosis of the Alzheimer's disease. The similarity values obtained lies within the normal range, hence the Ada- boost segmentation technique is determined to be more efficient for the segmentation of the hippocampus region for the diagnosis of AD.

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