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Computation of Brain Asymmetry in 2D MR Brain Images

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Abstract—The automatic computation of brain asymmetry is needed to study structural, volumetric and functional differences between the left and right brain structures to quantify and correct several MR brain deformities. This paper proposed a method to compute brain asymmetric measures such as Asymmetric Volume Index (AVI) and Asymmetric Shape Index (ASI) between the segmented left, and mirrored and registered right brain images. In order to register the right brain with the left brain for shape asymmetric measure, an image registration method based on Fourier-Mellin (FM) transformation is developed as a part of this brain asymmetric analysis.

Index Terms— MRI brain structure, brain asymmetric analysis, MRI brain images, asymmetric volume index, asymmetric shape index

1 Introduction

THE The human brain exhibits an approximately bilateral symmetry across the sagittal plane. A longitudinal fissure separates the human brain into two distinct cerebral hemispheres which divides the brain into two equal parts. However, these two parts are almost never perfectly symmetric even for the normal brains [1][2][3].

Brain morphometric studies often incorporate comparative asymmetric analyses of the left and right hemispheric brain structures. Brain asymmetry is thought to originate from evolutionary, developmental, hereditary, experimental and pathological factors and it has been correlated with asymmetrical behavioral traits such as handedness, auditory perception, motor preferences and sensory acuity [4]. Moreover, brain asymmetry analysis provides methods for computer assisted diagnosis for mental diseases such as schizophrenia [5][6][7]. Several methods have been proposed for brain segmentation [9]-[12], volumetric and structural analysis of brain structures based on interhemisphere asymmetric [13][14][15], asymmetric analysis using voxel-based morphometry [16][17], surface based approaches for asymmetric study[18][19] and asymmetry computation in terms of regional tissue composition [20][21].

In this paper, a new automatic method to compute asymmetric measures such as Asymmetric Volume Index (AVI) and Asymmetric Shape Index (ASI) are calculated between the segmented left and right brain structures. To compute ASI, the mirrored right brain structure is need to be registered with the coordinate space of left brain structure. For this purpose, an image registration method based on Fourier-Mellin Transformation (FMT) [22] is developed. The proposed method was tested with 18 volumes of T1-weighted brain images obtained from Internet Brain Segmentation Repository (IBSR) [23] which includes the delineated brain volumes of all these brain volumes. Computed AVI and ASI values show that the proposed method accurately calculated the asymmetric measures in MR brain images. The remaining part of the paper is organized as follows: In section 2, the methodological details of this proposed method is given. The results and discussion are given in section 3 and the conclusions is given in section 4.

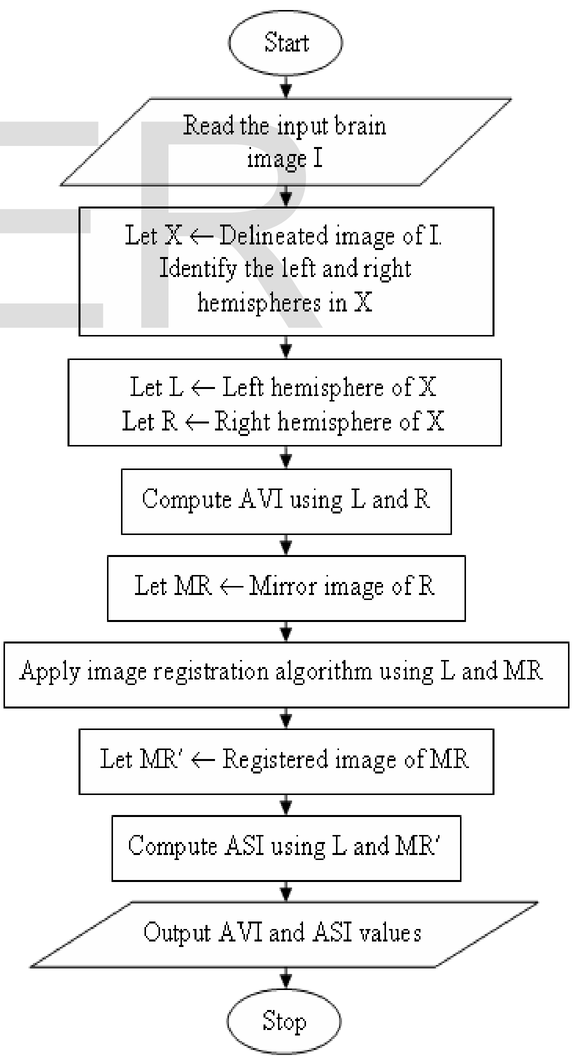

Fig. 1. Flowchart of the proposed method.

2 Methods and Materials

2.1 Brain Asymmetric Analysis

The brain asymmetry analysis is necessary to compute the anatomical and volumetric difference between the left and right brain structures. Even the left and right brain with equal volume may have different shapes. Therefore, a detailed analysis is needed to understand the human brain and its changes for accurate diagnosis of various brain related diseases. The flowchart of the proposed method is depicted in Fig. 1. The proposed method first reads the input brain image I and its corresponding delineated brain image X. In the selected brain images dataset each volume is attached with its delineated image volume containing labeled brain image for all its brain structures. The proposed method reads only the left and right hemispheres in the delineated image and store it as image L and image R respectively. These images are quantitatively analyzed to measure the volumetric difference by calculating AVI [23] measure by applying the following equation.

$$AVI = 2\left(\frac{L-R}{L+R}\right) \quad (1)$$

where, L represents the total pixels in the left brain and R represents the total pixels in the mirrored right brain

Then the quantitative shape difference is measured as per the equation (2).

$$ASI = 1-\left(\frac{2(L \cap R^1)}{|L|+|R^1|}\right) \quad (2)$$

where, L represents the total pixels in the left brain, and R^1 represents total pixels in the mirrored and registered right brain. The deviation of AVI and ASI measures from zero is analyzed and normally it ranges from -1 to +1.

In order to study shape the asymmetric bias, the right brain image R is mirrored to produce the mirrored image MR and then the image MR is registered against the left brain image L. It is necessary to register the image R with the image L, because the mirrored right brain images may not always get aligned with the same coordinate space of left brain as represented in Fig. 2. Therefore, the mirrored right brain image R has to be registered to the coordinate space of the left brain L prior to the computation of ASI.

Image registration is a method to align the reference image in the same geometrical space of base image. Fourier-based methods are the efficient and accurate method to estimate the image transformation such as rotation, scaling and translation for image registration [24]. These methods search for an optimal match for the images as per the information in the frequency domain. This proposed method uses Fourier transformation, log-polar transformation and phase correlation methods.

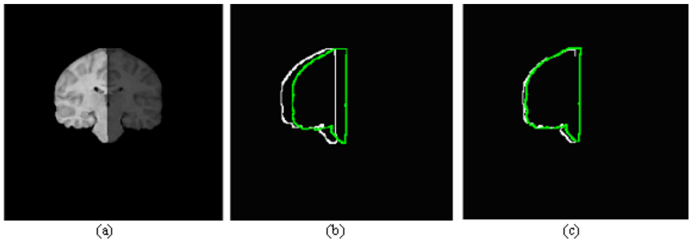

Fig. 2. Shape comparison of left and right brain structures; (a) Segmented left and right brain structure (b) Contours of left (white) and mirrored right brain (green) structures (c) Contours of left (white), and mirrored and registered right brain (green) structures

First the input images are converted into Discrete Fourier Transformation (DFT). The DFT of an image f(x,y) of dimension M×N, where, x=0,1,2,…,M-1 and y=0,1,2,…,N-1 is given by:

$$F\{f(x,y)\}=F(u,v)=\frac{1}{MN}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1} f(x,y)e^{-j2\pi(ux/M+vy/N)} \quad (3)$$

where u=0,1,2,…,M-1, v=0,1,2,…,N-1 and j= $\sqrt{-1}$.

Then, the inverse of DFT is given by:

$$F'\{F(u,v)\}=f(x,y)= \frac{1}{MN}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1} F(u,v)e^{j2\pi(ux/M+vy/N)} \quad (4)$$

Then the Log-Polar Transformation (LPT) is applied on the transformed images. An LPT is a non-linear and non-uniform sampling of the spatial domain. In the log-polar (log r, θ) coordinate system, r denotes radial distance from the center (x_c, y_c) and θ denotes the angle of rotation. Hence, any arbitrary point (x,y) chosen from an image can be expressed in the form of polar coordinates as:

$$r = log_{base}\left(\sqrt{(x-x_c)^2+(y-y_c)^2}\right) \quad (5)$$

$$\phi = tan^{-1}\left(\frac{y-y_c}{x-x_c}\right) \quad (6)$$

Applying a polar coordinate transformation to an image, maps the lines in Cartesian space to the horizontal lines in the polar coordinates. In this method, the logarithmic conversion to obtain the polar coordinates uses base 10. Then it applys DFT on the polar transformed images to compute phase correlation. The Fourier magnitude in polar coordinates differs only by translation. The phase-correlation method is used to find this translation. Phase correlation is a method of image registration and uses Fast Fourier Domain approach to estimate the relative translation between two images. Correlating the magnitude of a FMT, it is possible to obtain an image registration method invariant to translation, rotation and scaling. Then the scale and rotation parameters are derived by calculating the cross-power spectrum. The cross-power spectrum (R) of two images f and f^1 with Fourier transforms F and F^1 is defined as:

$$R = F^1\left\{\frac{F\ F^{1*}}{\left|F\ F^{1*}\right|}\right\} \quad (7)$$

where, F^{1*} is a complex conjugate of F^1, the phase of the cross-power spectrum is equivalent to the phase difference between the images. Then, the rotation Δx and the scale Δy is computed by:

$$(\Delta x,\Delta y) = \arg\max_{(x,y)}\{R\} \quad (8)$$

where, (x,y) is the location of the peak in R. After computing the rotation and scaling parameters, the referenced image is rotated and scaled accordingly to register with the base image. Again it applies DFD on the rotated image and computes the phase correlation to obtain the shift parameters for translation.

The summary of steps involved in the proposed image registration method are described in Alg. 1.

Alg. 1. Image Registration

Input : Base image A and Reference image B.

Output: Registered image B^1.

1. Apply DFT on the input images A and B and shift its zero-frequency component to the center of spectrum and obtain F_A and F_B.
2. Perform LPT to transform F_A and F_B into log-polar space to obtain the image L_A and L_B.
3. Apply DFT on L_A and L_B to get Q_A and Q_B and compute the phase correlation of Q_A and Q_B to obtain r.
4. Find the location (x,y) in r of the peak of the phase correlation.
5. Compute angle of rotation θ = (360/size(r))× y and rotate the image B by -θ to get B_R.
6. Apply DFT on B_R and shift its zero-frequency component to the center of the spectrum to obtain F_{B_R} and compute the phase correlation using F_A and F_{B_R} to get r1.
7. Find the shift parameters (x,y) in r1.
8. Translate the image B_R by the shift parameters (x,y) to produce the registered image B^1.

2.2 Brain Image Datasets Used

Eighteen volumes of T1-weighted images were obtained from the IBSR of the Centre for Morphometric Analysis (CMA) at the Massachusetts General Hospital. Each volume consists of 128 two-dimensional sequential coronal slices with dimensions of 256×256 pixels and the slice thickness is 1.5mm. These MRI scans are acquired from all age groups including juvenile to old age. The IBSR also maintains the manually segmented (ground truth or gold standard) brain mask and delineation of the brain structures performed by trained experts. Several volumes of these dataset had relatively low contrast images.

3 Results and Discussion

This method is applied on all the volumes of the selected dataset and found that the proposed method have accurately computed the asymmetric bias on all the images. To explore the efficiency of this method on asymmetric analysis, a set of sample images and their corresponding left brain, right brain, overlapping the contours of left and mirrored right brains before registration and after registration are shown in Fig. 3.

For the segmented left brain Fig. 3(b), right brain Fig. 3(c) and the outer contours of the left and mirrored right brain images are shown in Fig. 3(d). In Fig. 3(d), there is a considerable variation in the geometrical coordinate space in the left and mirrored right brain contours, they may not be used directly to estimate the ASI. Therefore, the the image registration algorithm presented in Algorithm 1 is used to register the mirrored right brain to the coordinate space of the left brain. The outer contours of the left, and mirrored and registered right brain are shown in Fig. 3(e).

The quantitative asymmetric measures AVI and ASI are calculated for the images of Fig. 3 and are given in Table 1. The values in Table 1 show the volume and shape difference between the left and right brain structures of Fig. 3. It is observed from Table 1 that the computed ASI values after applying the proposed registration on all the selected images of Fig. 3 are lower than the values obtained before registration. For Image-4 of Fig. 3, the computed ASI value before and after registration are same (0.0267). It indicates that for this image the left and mirrored right brain structures are in the same coordinate shape and the proposed registration method does not have changed the coordinate space of the mirrored right brain. It is also evident from the computed ASI value that none of the selected brain images are symmetric yielding ASI as zero even after registering it in the same coordinate space. This confirms the fact that the brain structures are never absolutely symmetric with respect to left and right hemispheres.

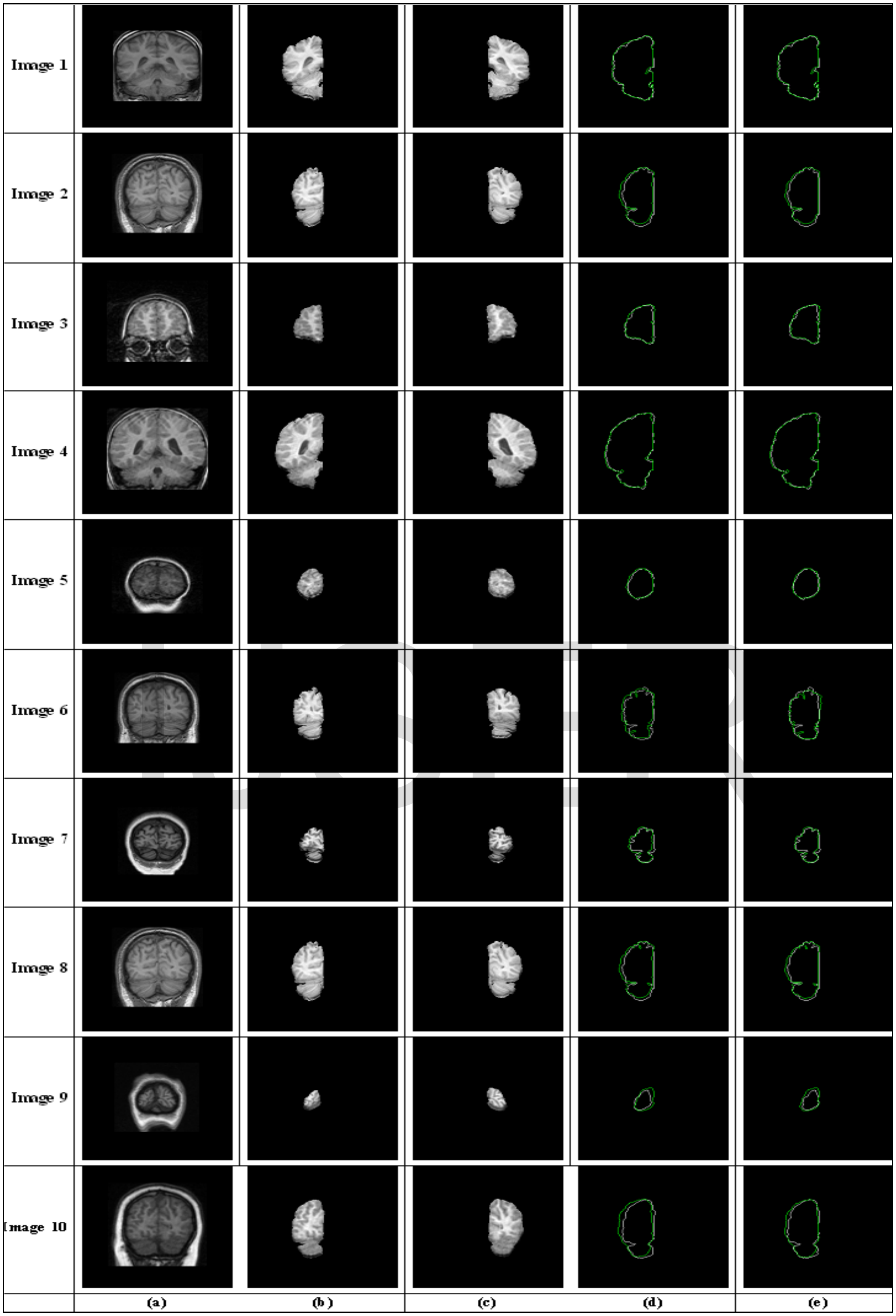

Fig. 3. Process of brain asymmetric analysis; (a) Original image (b) Segmented left brain (c) Segmented right brain (d) Counters of left (white) and mirrored right brain (green) and (e) Contours of left (white), and mirrored and registered right brain (green)

TABLE 1

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COMPUTED ASYMMETRIC MEASURES AVI AND ASI FOR THE OUTPUT IMAGES OF FIG. 3.

Image	AVI	ASI	
		Before Registration	After Registration
Image 1	0.0093	0.0982	0.0319
Image 2	0.0127	0.0940	0.0794
Image 3	0.0064	0.0631	0.0619
Image 4	0.0058	0.0267	0.0267
Image 5	0.0472	0.0599	0.0486
Image 6	0.0516	0.1054	0.0726
Image 7	0.0041	0.1199	0.0983
Image 8	0.0259	0.1173	0.0708
Image 9	0.3136	0.8508	0.2021
Image 10	0.0661	0.1180	0.0710

4 CONCLUSIONS

Brain asymmetric analysis using an image registration method based on FMT is introduced in this paper. Quantitative analysis of brain asymmetry in term of AVI and ASI values were calculated. From the computed asymmetric bias after registering the mirrored right brain by the proposed registration method, it is evident that even in the normal brain the left and right side of the brain are not found to be absolutely symmetric. The computed asymmetric measures revealed the fact that the proposed method presented in this paper facilitates automatic and accurate brain asymmetric analysis for the large volumes of brain images to detect various brain deformatives.

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