Chapter 1

Introduction

1.1 Introduction

Medical images are used to locate the abnormalities in human organs. There are various medical imaging modalities available to image human organs. Few of them are x-ray, ultrasound, computed tomography (CT), magnetic resonance imaging (MRI), functional magnetic resonance imaging (fMRI), positron emission tomography (PET) and single photon emission computed tomography (SPECT). Each of them has its own advantages. MRI is non-destructive, non-ionizing and non-invasive imaging modality. MRI helps to know the structure of soft tissues and gives high resolution spatial images of the organs. So MRI is an important and harmless imaging tool to study human organs.

Imaging the human head using MRI is an important procedure to study the brain related diseases and deformities. After imaging the head, one needs to process the image to get the structural and pathological conditions of tissues in the head. The complete image of a human head is obtained using MRI in a series of 20-120 images in 2-Dimension (2D). These images are used to construct a 3 dimensional (3-D) view of the head. Each of the 2D images is called as a slice. A collection of 2D slices is called as volume. The radiologists analyze all the images and send report to the neurological consultant [1].

The MRI is taken in three orientations, axial (bottom to top), sagittal (side to side) and coronal (back to front). There are three types of MRI, T1 weighted (T1-W), T2 weighted (T2-W) and proton density (PD).
1.2 Need for Brain Portion Extraction

Segmenting the brain from the 2D slices is one of the important processes a radiologist do. Segmentation of brain portion from a slice is required for many other subsequent processes such as registration, compression, brain volume estimation, abnormality detection, tumor detection, tissue classification etc. Segmentating the brain portion manually is time consuming, unreliable and operator biased. Moreover it may lead to misdiagnose. So a radiologist needs some computer assistance to analyze the image [1]. Human Head consists of brain, skull, scalp, CSF, eyes, neck, ear, fat, nose etc., and therefore MRI of head is complex. To get the brain portion alone, the non-brain portions are to be removed. Removal of non-brain regions is called as brain extraction or skull stripping or brain portion segmentation [2].

1.2.1 Image Registration

Registration is a process of aligning two or more images in the same spatial coordinates. Images taken for an organ from different modalities like CT, MRI, fMRI, SPECT or PET, differ in their visualization in the same plane. Two or more images are to be aligned to a common co-ordinate position for better image visualization. Such process is known as registration. Functional MRI images, PET and high resolution MR images are used in image registration. MRI contains brain and non-brain tissues, fMRI contain brain tissues and very less non-brain tissues and both are merged in PET images. If we remove the non-brain tissues on MR images then accuracy and robustness of registration process can be increased. This registration process is used to detect growth rate of the tumor with previously taken image [2] [3].

1.2.2 Tissue Classification

Tissue classification is another process which partitions the brain portion into gray matter (GM), white matter (WM) and cerebrospinal fluid (CSF). These tissues are identified by using signal intensities. But problem arises when their
intensities match with other non-brain tissues such as eye, skull, neck, dura, nose and scalp. This problem may be solved by using few preprocessing methods. One among them is separation of brain from non-brain tissues and then makes the classification. Tissue classification is used to detect abnormality in brain, brain volume measurement and cortical labeling [2] [4] [5].

1.2.3 Telemedicine

In India, the available doctors, pathologist and neurologists are not sufficient to meet the healthcare demands of our population. So telemedicine and tele-radiology plays vital role to overcome this problem to certain extent. For tele-radiologist, sending the raw MRI head scans via smart-phone will take more time. So, compression is needed to reduce storage space and transmission time. Compressing the raw MRI using lossless method will be one solution to reduce the transmission time. Still better solution will be removing the background non-brain tissues and compressing the brain portion alone. For that, brain extraction is essential [6].

1.3 Review of Brain Extraction Methods

Several brain extraction methods are reported in the literature. They are classified into semi-automatic and fully automatic methods. Further, they are also classified, based on the techniques used, into region based method [7], edge based methods or hybrid methods, intensity based, morphological operations based and deformable methods [8]. Intensity based methods are more sensitive to intensity bias and morphological operation based methods need more parameters to execute the algorithm. Deformable model needs brain template to execute. Intensity based methods and morphological operation based methods have less time complexity than the deformable models.

Atkins and Mackiewich [2] proposed a brain extraction method. This method initially separates the head and non-head region using an intensity threshold and morphological operations. An isotropic diffusion is applied on the
input image to reduce the noise and diminish the non-brain region. Then they used active contour model to find fine brain mask. This method has some limitations. It is not working well with abnormal subjects and is more time consuming. It does not work on sagittal T1-W data [9].

Brain Extraction Tool (BET) [4] initially computes two threshold values based on histogram and generates a binary image using the threshold values. An expandable sphere is created on the binary image by using Center of Gravity (COG). The sphere is expanded with the help of a smoothing and local threshold value and finally the brain is extracted.

Park and Lee’s method [7] is based on 2-dimensional (2-D) region growing, named as skull stripping based on region growing (SSRG). After eliminating the background, morphological erosion operation is performed. Then, two seed points are selected from the eroded image. Region growing operation is performed using these seed points, to segment the brain.

Brain Surface Extractor (BSE) [10] method makes use of edge detection and morphological operations. This method starts with a preprocessing using anisotropic diffusion. The Marr-Hildreth [11] technique is used for edge detection followed by morphological operations to extract the brain surface. BSE need several parameters to start the algorithm. They are diffusion constant, diffusion iteration and edge constant. This method is based on edge detection. Edge detection fails on low contrast images. So BSE did not work well with low contrast images [12].

Brain Extraction Meta Algorithm (BEMA) [13] first makes registration of the given input MRI volumes. It makes use of BET [4], BSE [10], 3DIntracranial [14] and MRI watershed [8] algorithms to segment the brain portion and combine all the results to generate the brain mask. It produces better results but it takes more time to extract the brain.
3DIntracranial [14] method makes use of histogram, probability density function and threshold value to classify the input image into brain and non-brain voxels. This method needs nine parameters to compute the threshold value. More number of parameters makes inconsistency on results when estimation or initialization is not done properly [4].

Mikheev et al [15] proposed a method based on Bridge Burner algorithm to extract brain from T1-W images. This method is based on thresholding, connectivity, surface detection and operator constrained growth to reach brain boundary.

Model-based Level Sets (MLS) [16] is a deformable model to extract brain. This method computes threshold value using histogram and generates a brain mask. A zero level curve is created from the center of brain mask and moved it towards boundary of brain using level sets. They used adjacent slices to fix the curve on brain boundary, so it increases the processing time. Moreover, this method needs initial values for two parameters, volume of cerebrospinal fluid and inter-slice spacing. This method works only with normal brain volumes and fails for abnormal volumes.

Multispectral Adaptive Region Growing Algorithm (MARGA) [17] is a modified form of 2D region growing method [7]. This method is designed to extract brain from T1-w and T2-w images. This method addresses the problems faced in 2D-region growing method.

Simplex Mesh and Histogram Analysis Skull Stripping (SMHASS) method [18] is one of the recent brain extraction methods. This method is based on deformable model using simplex mesh. Before applying deformable model, preprocessing is performed. In preprocessing, a rough brain is obtained. On the rough brain, simplex mesh is applied with additional information gathered from histogram analysis to extract fine brain portion. This method gives better results but it consumes more time.
Brain Extraction Method (BEM-T1W) reported in [19] is for T1-W images. This method utilized Ridler-Calvard algorithm for computing the threshold value to eliminate background, run length scheme for region labeling and morphological erosion and dilation operations to extract the brain portion. This method did not work well when brain appears in two or more regions. To overcome this problem they extended their 2 dimension version to 3D. The extended version works well where BEM-T1W failed.

Brain Extraction Method (BEM–T2W) reported in [20] is for T2-W images. The input image is filtered with a low-pass filter, and then they applied diffusion process. From the diffused image, a threshold value is computed using Ridler-Calvard algorithm. A binary image is obtained using the threshold value. Morphological erosion operation is performed to remove the weak connections between brain and non-brain tissues. Then connected component analysis is performed to select the brain area.

Watershed based method is reported in [21] for brain extraction. This method is based on the white matter connectivity. This method has segmented more non-brain tissues and is sensitive to noise [22].

Hybrid Watershed Algorithm (HWA) [23] is a combination of two concepts, watershed and deformable surface models, to extract the brain portion. This method did not work well on image with noise, and artifacts [24]. This method is very slow due to its techniques.

A comparative study of four brain extraction methods is reported in [24]. In this work four popular methods BET, BSE, HWA and 3DIntracranial are taken for the study. The comparison is performed in terms of bias correction, slice positions and data sets on brain extraction. Varieties of T1-W sagittal images with different kinds of diseased images are tested. All the methods failed to extract the brain portion from abnormal MRI of human head scans. Their performance is affected by noise present in the images. HWA is more sensitive than others.
Graph cut based method [25] is a three step process to extract the brain portion. In the first step, the background pixels are eliminated using a threshold value and the second step removes the weakly connected portions using graph cut theory. In the final step, a post processing is done to fill the holes on ventricles.

Jiang et al [26] proposed an automatic brain extraction method, hybrid level set based active contour neighborhood model, to extract brain tissue from T1-W MRI. They used Graph Cut Based Active Contour (GCBAC) [27] method to detect initial contours after the preprocessing with BET [4]. GCBAC failed to detect accurate brain boundaries in few regions. To overcome this problem, they developed Active Contour Neighborhood (ACN) method to detect accurate brain boundary.

Ortiz et al [28] reported an unsupervised brain segmentation method. In this method, they extracted the brain portion from volume images using 3D statistical approach. The statistical approach is based on vector quantization and fuzzy clustering. The statistical features are extracted from the image in two different orders by using moving overlapping cube in the 3D volume. The extracted statistical features are modeled using self-organizing map.

Ortiz et al [29] proposed an unsupervised method for brain segmentation. This method has five steps to segment the brain. In the first step, noise is removed. In the second step, they computed few statistical features of the image and are classified into first and second order images and stored it in a vector space. In the third step, they used genetic algorithm to reduce features and store them in a vector space. Then, Self Organizing Map (SOM) is trained using the reduced vector space and compute the Best Matching Unit (BMU). In the fourth step, they used Entropy Gradient (EG) based clustering for grouping the classified vectors. Finally, the segmentation is performed using SOM labeling.

Moreno et al [30] reported a method for classification of brain tissues. The method is an extended version of Chan and Vese two phase energy minimization
formula [31] to multi-phase global energy minimizer and the modified version is implemented to segment the brain tissues.

Kalaiselvi and Somasundaram [32] proposed a method for brain tissue segmentation from MRI based on Fuzzy C-Means (FCM). In this work, they have used the knowledge of intensity characteristics of brain regions in MRI to initialize the centroid. This reduced the processing time. The final values obtained as centroid are compared with the existing FCM method, which initialized the centroid randomly.

Wang et al [33] proposed a brain extraction method based on statistical population specific probability maps. This method employs brain atlas and deformable approach to extract the brain. This method gives better results both for normal and abnormal brain volumes.

Beare et al [34] proposed Marker Based Watershed Scalper (MBWSS) for brain extraction. This method involves watershed transform from markers and large kernel filters. Watershed Transform Marker (WTM) differs from traditional watershed algorithm, here they used regional minimum as marker to segment rough brain portion. Morphological erosion and dilation are used to extract the brain.

Alansary et al [35] proposed a frame work for brain extraction. The framework consists of three steps to extract accurate brain portion. In the first step, they performed preprocessing such as bias correction and edge enhancement to preserve edges. In the second step, they used BET [4] for initial brain extraction. Finally, they removed remaining non-brain tissues using two classification algorithms, Linear Combination of Discrete Gaussians (LCDG) and two level Markov-Gibbs Random Field (MGRF).

Somasundaram et al [36] proposed a brain extraction method based on region growing. In this paper, they used multi-seeded region growing as key technique to segment the brain portion. Brain extraction was done in two stages.
In the stage-1, a rough brain portion is extracted from middle slice of the MRI volume. In stage-2 the fine brain is obtained from rough brain using multi-seeded region growing technique.

Somasundaram et al [37] proposed another two stage brain extraction method. This method extracts the rough brain mask and created a landmark circle in mask in the stage-1. Using the rough brain mask and landmark circle, they extract the fine brain portion from the given volume of MRI in stage-2. They used combination of contour, erosion, dilation and connected component analysis to extract the brain.

Somasundaram et al [38] proposed a brain extraction method based on histogram analysis. Using Otsu's method, they computed a threshold value to eliminate the background pixels. The K-means method is used to remove non-brain tissues. Finally they used histogram analysis for fine brain segmentation.

A new brain extraction method Improved Brain Extraction Tool (IMBET) is proposed in [39]. This method used BET [4] for preprocessing and the output of BET is taken as input to this method. After performing erosion, dilation, connected component analysis, image diffusion and watershed algorithm the fine brain portion is extracted.

Doshi et al [40] proposed a brain extraction method called Multi-Atlas skull stripping (MASS) method. For brain extraction, they create a framework. The framework consisted of three steps, template selection, registration, and label fusion. Then they perform weighted voting (WV) to extract fine brain portion.

Ray et al [41] proposed a simple skull stripping algorithm. This method starts with noise removal using mean filter and binarize the image using a threshold value. After this operation few morphological operations such as opening and closing are performed to remove non-brain tissues. Finally connected component analysis is performed to extract the brain portion.
1.4 Motivation

Each of the method mentioned in the previous section has their own merits and demerits. Few methods worked for specific type of images, few worked well for certain conditions, few of them are time consuming, and few methods have no consistency to segment the brain portions. To address few of these problems we have proposed six automatic skull stripping methods to extract brain from MRI of human head scans.

All the proposed methods are intensity and structure based approaches and work for T1-W MR images of human head scans. All the proposed methods used anatomical facts to extract the brain portions.

1.5 Organization of Thesis

The remaining part of the thesis is organized as follows.

In chapter 2, brain anatomy and basics of MRI are explained. In addition, properties of MR images in relation to the physical tissue properties are explained.

In chapter 3, basics of digital images, basic image processing methods that are used in this thesis are presented. The details of medical image formats are given. The details of materials used in our experiments are given. The performance evaluation parameters, Dice coefficient, Jaccard similarity index and other parameters are given.

In chapter 4, the first automatic brain extraction method based on fuzzy logic and bridge building algorithm is explained. First we compute a threshold value and use it to generate a binary image. We develop a Fuzzy Engine to find the edge pixel on a given binary image. The Fuzzy Engine labels the edge pixels in the binary image. Using the Bridge Building Algorithm (BBA) scalp portion is removed from the labeled image. In BBA, a pair of labeled edge pixels is
connected, only if they are in a straight line in any direction (left, right, top and bottom) and are within a specific distance. Those pairs which satisfy BBA are removed. Then a set operation is performed between the binary image and the resulting image to extract brain portion. Weak connections between brain and non-brain tissues are then removed by erosion. Region identification is performed to select the largest portion from isolated regions, based on the anatomical fact that brain is the largest portion in the head region. We then perform dilation to recover the pixels lost in the previous operations. Dilated image is used as brain mask. Using this mask, the brain portion is extracted from the input image. Application of our method on standard real T1-W data sets shows that the proposed method worked better than the popular methods BET and BSE.

In chapter 5, the second brain extraction method is presented. In this method, we employ Helmholtz Free Energy (HFE), a thermodynamic concept, to remove background pixels. After removing background pixels, simple image enhancement is used to recover pixel intensity. Using another threshold value, a binary image is generated. Still few brain tissues are connected with non-brain tissues. Morphological erosion operation is performed on the binary image to remove such connections. Then all the regions on the image are isolated. We then perform region labeling. From the labeled regions, we chose largest connected region as rough brain. Dilation operation is then performed to produce fine brain mask. The performance of the proposed method is evaluated by applying it on 38 volumes of MRI head scans taken from IBSR, in terms of Dice and Jaccard similarity index.

In chapter 6, the third brain extraction method is given. In this method, we proposed a novel method to extract the brain portion using Bond Number (BN), used for fluid dynamics. Bond Number concept is implemented to detect edges in the MRI of head scans. After detecting the edges, we generate a binary image using a threshold value. The binary image consist different kinds of edge points. We need macro edges, and so we implement Block Truncation Coding (BTC) to
remove micro edges from the binary image. From the input image, we detect the head contours to create head mask. The detected macro edges are subtracted from the head mask. In the resultant image, few non-brain and brain tissues are connected and they are removed using morphological erosion operation. The resulting image had several isolated regions. A connected component analysis (CCA) is performed on the eroded image. Largest Connected Component (LCC) is taken as the rough brain. Dilation operation is performed on the rough brain region to recover the eroded brain tissues. The resulting dilated image is used as brain mask. Finally, brain portion is extracted using the brain mask.

In chapter 7, we present our fourth method. In this method, we first compute a threshold value and use it to remove the background pixels in the MRI. The intensity values of the remaining foreground pixels are left as such. The resulting image consists of gray matter, white matter, cerebellum, scalp, neck region and CSF. Few non-brain tissues with lower intensities connecting brain and non-brain tissues, still present in the image. Top-hat operation is performed to suppress the lower intensity pixels. After the suppression of low intensity pixels, still non-brain tissues are found connected to the brain tissues. Such narrow links are broken by using Neck breaking operations. Another threshold value is then computed and the image is binarized. CCA and LCC are performed on the binary image, to find the largest region. The largest area is then dilated to get the brain mask. Using the brain mask, the brain portion is extracted. Experiments were conducted by applying our proposed method on 48 volumes of data set taken from IBSR and computed similarity measures J and D. Our results are computed with that of the existing methods BET and BSE.

In chapter 8, we present our fifth brain extraction method. This method is based on grayscale transformation. Ridler-Calvard algorithm is used to compute a threshold value. Using the threshold value, background pixels are removed. After eliminating the background pixels, few non-brain tissues with very low intensity are still found in the resulting image. These pixels are removed using intensity transformation. Then we binarize the image using an intensity threshold.
The binary image contained several isolated regions. We identify each isolated regions using region labeling and find the largest region among them. Largest region is the rough brain portion. To recover the pixels lost due to erosion and binarization, morphological dilation operation is performed to get a binary mask. Using the brain mask the brain portion is extracted. The proposed method is evaluated by applying it on 48 volumes of MRI of human head scans and results are compared with that of the existing popular methods BET and BSE.

In chapter 9, we present our sixth brain extraction method. In this method, we make use of Meijster's Distance Transformation (MDT) to remove scalp. The Ridler-Calvard algorithm is used to compute a threshold value and binarize the image. We use the modified Meijster's distance transformation (MMDT) to remove scalp region. Another threshold value is computed to binarize the image. The binary image has several isolated regions. We perform region labeling and identify each region. The largest region is taken as rough brain. Morphological dilation operation is applied on the rough brain to recover the pixels lost due to binarization and create a brain mask. Using the brain mask, the brain portion is extracted. In MRI of human head scans, few slices in the front and back portion of head have brain in small regions. These brain regions are lost on those slices during region labeling. This problem is solved by using 3D approach for those slices. Application of our method on standard real T1-W data sets shows that the proposed method worked better than the popular methods BET and BSE.

In chapter 10, summary of conclusions are given. Scope for future enhancement is outlined.