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Literature Review of fMRI Image Processing Techniques

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***Abstract*— Functional Magnetic Resonance imaging is an aid in identifying the brain activated regions by certain stimuli and tasks. It can be used to identify the psychological or other disease states resulting from various neurological impairments and also to make implication on brain connectivity. Several techniques are used for the functional analysis of fMRI neuroimaging data. Here our endeavor is to make a review of various computational methodologies used by fMRI data analysis, which includes various preprocessing methods used for removing noise and enhancing quality in fMRI as well as various statistical methods of fMRI image analysis.**

去噪、增强
图像 质量

***Index Terms*— Functional magnetic resonance imaging, Motion Correction, Statistical parametric mapping, General Linear Model.**

I. Introduction

The human brain which is the centre of the nervous system controls both voluntary and involuntary actions in accordance with the situations. Apart from that the brain controls the sense organs, emotions and also responsible for various movements for the proper functioning of the human body. Any impairment or damage to the brain causes imbalance in the functioning of the body. In order to diagnose and to assess the nature of impairment or damage, the same can be done with fMRI.

Functional Magnetic Resonance Imaging herein referred to as fMRI is an effective tool for analyzing brain functions. The changes in the blood flow and the level of blood oxygenation in the brain which occur pursuant to any neural activity can be assessed by the development of human brain mapping and in that fMRI is used for the electrophysiological assessment of brain processing [1]. It is one of the techniques used by studying the functional analysis of the brain. fMRI is a comparative study of brain functioning images during the specific brain activity state and basal state. The analysis is made by testing the variation in blood flow ie, by subtracting the basal state activity from the specific task activity where there is an increase in the blood flow due to the specific activity [2].The advancement in fMRI helped to detect various factors leading to cognitive behavioral functions, neurodegenerative disorders in its earlier stages[3]. Compared to other imaging Techniques, fMRI is more powerful with relatively good spatial and temporal resolution. Since fMRI is quite efficient in elucidating neural correlates associated with specific brain functions, the technique has got wide acceptance in functional brain mapping both clinically and in research setting.

In an fMRI experiment, magnetic resonance images obtained relating to specific brain functions of a person who is designated with a voluntary, involuntary or cognitive task can be used to detect the functioning of the brain by comparing the patterns of brain activity with the task performance or disease group. On the basis of the level of activation in the brain regions the impairment is identified.

The growth of fMRI during the last years is very rapid and it is widely applied in various fields like neuroscience, psychology, economics and political science [4]. Although much advancement has been made in statistical methods for fMRI analysis, it can be quite challenging to analyze fMRI images. This paper presents a review on various fMRI preprocessing methods and statistical analysis techniques available. The rest of this paper deals with Literature Review in Section 2 and finally, Conclusions are given in Section 3.

II. Literature review

"Making sense of neuroimaging in psychiatry", Malhi GS and Lagopoulos J. According to the authors [1], fMRI is used to study the brain regions based on patterns of brain activity by a specific task performed by a person who is under observation. The peculiarity of fMRI over other methods is that it enables the study of brain function by avoiding the ionizing radiation or the injection of radiopharmaceuticals which are used in various other methodologies.

"Currently Available Neuroimaging Approaches in Alzheimer Disease (AD) Early Diagnosis", Laura Ortiz-Terán, Juan MR Santos,María de las Nieves Cabrera Martín and Tomás Ortiz Alonso. The authors stated that fMRI techniques give the images of various signal intensities which are created at the time of cerebral blood flow while doing the cognitive tasks [2]. fMRI studies shows that there is a lesser activity coordinated in the brain regions in the brain regions of patients with cognitive impairment while they are resting and in activation.

"A review of neuroimaging biomarkers of Alzheimer's disease", Tinu Varghese, R Sheelakumari, Jija S James and PS Mathuranath. The authors stated that [3] the fMRI is based on the principle of comparing the brain images obtained while doing a specific brain activity and in a basal state. The advancement in the field of fMRI from the early periods

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helped to diagnose various cognitive behavioral functions in its earlier stages.

"The Statistical Analysis of fMRI Data", Martin A. Lindquist . According to the author a standard fMRI study can be made by using enormous amounts of noisy data with a complex spatio-temporal correlation structure [4]. To classify fMRI data, various approaches has been made and in that multivariate pattern classification approaches have been successfully applied. By using the said classification, the classifier which is trained to discriminate between various brain states can predict the brain states from the said fMRI data. It is important to show efficiency in preprocessing of the data than the actual method of prediction.

"Overview of Functional Magnetic Resonance Imaging", Gary H. Glover". Here the author says that fMRI analysis compare the differences in signals between the brain states with a probability function by using statistical tests [5]. The statistical test for activation includes a general linear model (GLM), modeled regressor cross-correlation or data-driven models like independent components analysis (ICA).

"Computational Methods for fMRI image Processing and Analysis", *Gabriela Queirós.* In this paper the author used two software for the study of fMRI image analysis, FSL and SPM of Matlab[6]. Statistical analysis of fMRI tests can be done using. FSL and it shows more disadvantages such as imprecise segmentation in the handling of anatomical images. SPM is a dominant calculation tool which enables the partially-automatic tumor segmentation.

"Pre-Processing of BOLD FMRI Data", Mark Jenkinson and Stephen M. Smith. According to the authors, Pre-processing is necessary in fMRI analysis for preparing the raw data taken from the scanner for statistical analysis [7]. Motion correction is a desirable preprocessing method in fMRI experiments, and is often of crucial importance. Motion correction finds a common orientation for all images within a given session and resampling the original data to this reference orientation.

"Longitudinal fMRI analysis: A review of methods", Martha Skup. The author reviews various methods for longitudinal analysis of fMRI including Multiscale Adaptive Regression Modeling (MARM). MARM is proposed for spatial and adaptive analysis of neuroimaging data and it analyzes multivariate imaging data with complex spatial activation patterns [8]. This method relies on building a sphere with a specified radius for each voxel and uses overlapping spheres to capture spatial dependence among different voxels. It can be adapted to analyze more complicated data structures that include a longitudinal time component.

"Improved Optimization for the Robust and Accurate Linear Registration and Motion Correction of Brain Images", Mark Jenkinson, Peter Bannister, Michael Brady and Stephen Smith. According to the authors most methods for registration are based on the mathematical structure of optimizing an intensity-based cost function [9]. They present a novel hybrid global–local optimization method for brain image registration which considerably reduces the likelihood of producing misregistrations due to being trapped by local minima. The consistency test demonstrates the increased robustness of this method and the motion correction experiments shows the accuracy of the registration.

"*Multivoxel Pattern Analysis for fMRI Data: A Review*", AbdelhakMahmoudi, Sylvain Takerkart, Fakhita Regragui,Driss Boussaoud, and Andrea Brovelli. In this paper,[10] the authors stated that General Linear Model approach is used for Statistical Analysis of fMRI images to show the activated brain areas by searching for linear correlations between the fMRI time course and a reference model. The limitation of the GLM model is that the covariance across neighbouring voxels does not give information about the cognitive function under examination. Hence it is replaced by Multivoxel pattern analysis which gathers the information contained in distributed patterns of neural activity to understand the functional task of brain areas and networks.

"Review of methods for functional brain connectivity detection using fMRI", Kaiming Li, Lei Guo, Jingxin Nie, Gang Li, and Tianming Liu. The authors stated that the computational methods for fMRI are alienated into two general categories as model-driven and data-driven methods. Model-driven method includes coherence analysis (CA), cross-correlation analysis, and statistical parameter mapping [11]. The said methods are conventionally simple, direct and also have accurate research goal. In the study of fMRI model based methods are widely used. Even though seed selection is not needed in Data-driven methods, they are ready to detect extensive connectivity network.

"Comparison of data-driven analysis methods for identification of functional connectivity in fMRI", Kim and Yongwook Bryce. According to the author, in the analysis of fMRI for identifying functionally related brain networks, the applications based on data-driven analysis methods, such as independent component analysis (ICA) and clustering are successfully used [12]. The main benefit of data-driven methods is that they can be applied to experimental paradigms when the priori model of brain activity is absent.

"Comparison of two exploratory data analysis methods for fMRI: fuzzy clustering vs. principal component analysis", R. Baumgartner, L. Ryner, W. Richter, R. Summers, M. Jarmasz and R. Somorjai. The authors presented a comparative study on Exploratory data-driven methods in fMRI [13]. In order to examine the MR data acquired under the null condition, with different noise contributions and simulated, varying activation, Fuzzy clustering analysis (FCA) and Principal component analysis (PCA) can be used. PCA transforms the high dimensional input space onto the feature space where the maximal variance is displayed. FCA outperforms PCA when other sources of signal variation such as physiological noise are present, particularly for low contrast to noise ratio (CNR) values.

"Comparison of Data-Driven Analysis Methods for Identification of Functional Connectivity in fMRI", Yongwook Bryce Kim. For identifying functional connectivity in fMRI, the author reviewed data-driven analysis techniques, Gaussian Mixture Model (GMM) and Independent Component Analysis (ICA). Component-wise matching and comparison scheme of

resulting ICA and GMM components are presented using their correlation [14]. On his investigation, he found that GMM outperforms ICA in both synthetic and real data when the pre-specified total number of components in each model was less than 10.

"Advances in Functional and Structural MR Image Analysis and Implementation as FSL Technical Report FMRIB", Stephen M. Smith, Mark Jenkinson and Mark W. Woolrich. For modelling single-session data (FILM), the authors reviewed model based voxelwise General linear model (GLM). He also reviewed the Bayesian method for analyzing multiple sessions/subjects (FLAME)[15]. FEAT is a complete GUI-based tool for model-based FMRI analysis, built around FILM and FLAME, as well as other low-level tools such as FLIRT image registration. In order to carry out temporal model-free exploratory analysis, MELODIC uses independent component analysis.

"Coordinate-Based Meta-Analysis of fMRI Studies with R", Andrea Stocco. Here the application of R to functional neuroimaging is discussed by the author [16]. R can be applied to supplement, expand and innovate the existing approaches eventhough it provides statistical packages and models that are not specific to neuroimaging. It can integrate completely specialized softwares for fMRI data analysis.

"Noise Reduction Techniques in Medical Imaging Data-A Review", Ajay Somkuwar and Shruti Bhargava. In this paper[17], wavelet domain denoising in ultrasound, fMRI, CT, PET and in MRI imaging were demonstrated by the authors. Wavelet based denoising methods is effective to improve Signal to Noise Ratio and to preserve the shape of the activated region in the case of fMRI so that it provides important information for clinical application.

"Predicting Cognitive Decline in Older Adults Through Multi-Voxel Pattern Analysis", Hantk and Nathan. Here the author has done the analysis of fMRI using MultiVoxelPatternAnalysis which examines the functional activation in individuals with increased genetic risk for cognitive decline [18]. The high accuracy of MVPA of fMRI data shows that it may be useful in determining which individuals may be at a higher risk for future cognitive decline, guiding early intervention.

"Review on Analysis and Quantification of Specific Learning Disability (SLD) with fMRI using Image Processing Techniques", Suresh P and K. Bommanna Raja. For the quantification of specific learning disability features, the authors propose to use fMRI using image processing techniques [19].The analysis of features extracted from the pre-processed fMRI images quantifies the classification of Specific Learning Disability, depth of severity, degree of recovery and post doctoral therapy.

"Image analysis of functional magnetic Resonance imaging", Kai-hsiang chuangi, Kou-1viou huang, Ping-eung yips ,Jyh-horng chen and Ming-jang chiu, In this paper, the authors state that data driven tools and methodologies are efficient than the simplified model-dependent analysis methods for fMRI analysis [20]. More accurate activation regions and physiological dynamics can be identified with these new analysis methods, which make further investigation possible and easier.

"Fast Robust Automated Brain Extraction", Stephen M. Smith. According to the author, Brain Extraction Tool (BET) is a new method which uses a deformable model that evolves to fit the brain's surface applying locally adaptive model forces [21]. With this automated method we can segment MR head images into brain and non-brain which is very fast, robust and precise and has been tested on thousands of data sets. Before being applied, BET does not requires preregistration or other pre-processing.

"Shape Preserving Fitting Model for Affective Curves Extraction: An Affective Computing Method on fMRI Dataset ", Fuqian Shi. In this paper, the author proposed a method to acquire critical features from fMRI images [22] which were pre-processed by Fast Fourier Transform (FFT). Time series based Power Spectrum Density (PSD) was calculated by using an improved shape preserving fitting algorithm, and affective curves were acquired afterward. The effectiveness of the proposed methodologies in this paper was calculated by comparing with cubic fitting and 5-th polynomial fitting operations.

"Imaging the default mode network in aging and dementia",Anne Hafkemeijer , Jeroen van der Grond and Serge A.R.B. Rombouts. According to the authors, task-induced decreases in brain activity named deactivations, occur in the default mode network (DMN)[23].The studies shows that from normal aging to cognitive impairment, a decreased DMN functional connectivity and task-induced DMN deactivations are found all along.

"Functional Magnetic Resonance Imaging for Imaging Neural Activity in the Human Brain: The Annual Progress", Shengyong Chen and Xiaoli Li. The authors stated that Statistical methods are used for analyzing neural imaging data and acquire information [24]. In order to prevail over the drawbacks of data-driven ICA while analyzing fMRI images, a compressed sensing-based data-driven sparse GLM is proposed. It enables the estimation of spatially adaptive design matrix and sparse signal components.

"fMRI paradigm designing and post processing tools", Jija S James, PG Rajesh, Anuvitha VS Chandran and Chandrasekharan Kesavadas. The authors propose that in order to determine the activation of voxels in the brain by certain types of stimulus, the statistical analysis test is performed. BrainVoyager software which uses GLM provides options for single subject and multi‑subject statistical analysis [25]. BrainVoyager also supports multivariate approaches like ICA and MVPA.

"Fmri Segmentation Using Echo State Neural Network", D.Suganthi and S.Purushothaman. The authors propose an intelligent segmentation technique for fMRI implementation using an Echostate Neural Network (ESN) [26]. The segmentation of the complicated profile of the fMRI can be made better with the help of the proposed ESN which is an estimation mode with minimum energy. When compared to the Peak signal to noise ratio (PSNR) of the existing back-propagation algorithm (BPA) segmentation method which is

57, the performance of the new segmentation method is found to be better with higher PSNR of 61.

"fMRI Image Analysis using Pixel Neighborhood Segmentation Techniques", Jagdeep KaurÅ and Ruchika Chhabra. The authors proposed a penalized function methodology [27] to correlate the functional activity to the particular brain area and a segmentation algorithm has been developed which provide a good clustering base based on pixel neighborhood. The algorithm is performed over the entire images frames in the MRI video sequence and analysis is made based on area variation.

III. CONCLUSION

Analysis of brain states obtained through functional magnetic resonance imaging (fMRI) poses serious challenges for neuroscientists to uncover various patterns of brain state activity that define independent thought processes. In this paper, we reviewed methods that were developed for preprocessing steps of fMRI which includes registration, smoothing and normalization. For the statistical image analysis, two categories of methods, model-driven methods and data-driven methods can be used. In the study of fMRI, Model-based methods are mostly used due to the reason that it is usually simple and has a direct and precise research goal. Even though a Data-driven method does not require seed selection, they are ready to detect wide-ranging connectivity network. In the statistical analysis section, performances of algorithms differ across different datasets. The beneficiaries of this review paper are the image processing researchers of this emerging area.

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