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Post processing Technique to Detect Active Voxels in fMRI Signals

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Abstract

Universally acceptable data analysis techniques which use all the available, potential information from functional Magnetic Resonance Imaging (fMRI) of the brain are yet to be developed. This is despite the fact that fMRI yields rich temporal and spatial data for each subject scanned. Statistical analysis of fMRI signals corresponding to an auditory data set was performed to determine the contribution of a robust, unknown parameter to the fMRI response. Preprocessing steps were taken in order to remove confounding errors. The Maximum Likelihood Estimation Method was used to determine the unknown parameter contributing to the resulting data. The obtained parameter was used to test the significance of each voxel of the brain by the Wald Test. This process of evaluating the response of each voxel is called the Univariate Analysis, as the analysis is done voxel by voxel.
Keywords - fMRI, Univariate Analysis, Generalised Linear Model, Maximum Likelihood Estimation, Statistical Analysis, Wald Test.

I. INTRODUCTION

(fMRI-Functional Magnetic Resonance Imaging).The fMRI signal is the response of the human brain upon its activation. Since fMRI represents the functional neural activity pertaining to the type of stimulation that it is subjected to, it has generated a lot of interest among researchers in the recent times.fMRI is a non-invasive procedure to study the functional aspects of the brain. This method of study gives insights into the working of an injured or a diseased brain. In functional Magnetic Resonance Imaging, the brain is considered to be split into a large number of voxels (volume element). The objective of fMRI is to assess the activity of each voxel upon activation. fMRI data sets typically consist of individual time series associated with the voxels of the brain. The significance of the response of each individual voxel, to the stimulus is assessed by statistically analysing the associated fMRI time series. In this way, brain activation maps, or statistical parametric maps (SPMs), reflecting brain activity can be constructed.

There are two ways to statistically analyze fMRI data:

- Multivariate Analysis
- Univariate Analysis

A. Multivariate Analysis

Multivariate analysis consists of a set of techniques dedicated to the analysis of data sets with more than one variable. For example, the PCA (Principle Component Analysis), MCA (Multiple

Correspondence Analysis), MDS (Multi Dimensional Scaling) and MLR (Multiple Linear Regression Analysis) are a few such analysis techniques. These techniques are computationally complex and are more recent, which do not present a unified outcome. [1]

B.Univariate Analysis

Univariate analysis performs the exploration of each variable in a data set separately. It examines the range of values, as well as the central tendency of the values. It describes the pattern of the response, here, and an individual voxel's time series to the variable.

Hence In this study, a univariate approach is taken to analyze each independent voxel's activation upon stimulation. The fMRI measurement is modelled using a standard modelling approach called as the "Generalised Linear Model". Here it is considered that each voxel's response is modelled by the Generalised Linear Equation [2]

$$y(t)=X\beta+\varepsilon. \qquad \text{... (1)}$$

THE STATISTICAL ANALYSIS "Generalized Linear Model" is also a common, commercial approach to statistically analyze an fMRI signal. A. Statistical Model The stimulus is an assignment performed by the patient. This assignment is also called as the fMRI paradigm. This paradigm consists of the simple task of listening to binaural beats for a small period of time followed by a resting period.

These binaural beats help the mind to relax, be creative, meditate and do other desirable states of the mind. This paradigm may be said to be designed to study the state of the auditory cortex of the brain when it is aurally stimulated as well as when it is at rest.

An fMRI time series y = (y1; : : : ; yn)T (the superscript T denotes matrix transposition) of equidistant observations can in general be modeled as

$$y(t)=X\beta+\varepsilon, \qquad \text{.....(2)}$$

in which X is an m x n design matrix . It consists of n columns that model signals of interest and nuisance signals such as potential drift. Furthermore, β is an m x 1 vector of unknown regression parameter and ε is an n x 1 vector that represents stochastic noise contributions.

For the computation of the test statistics, the Maximum Likelihood (ML) estimates of the unknown parameters under Wald, Likelihood Ratio and Rao are needed. They are obtained by maximizing the likelihood function with respect to the unknown parameters simultaneously. For this case study only the Wald test statistic was done because the other two methods are much more complex.

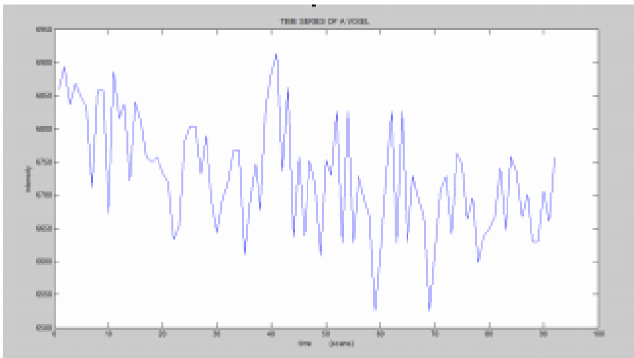

Figure 1. An example time series at a strongly activated voxel from the auditory cortex stimulation experiment.

II. THE FMRI OBJECTIVES

The main objective of fMRI analysis is to determine the active voxels of the brain upon stimulus.

A.SIGNAL PROCESSING

The images were first spatially realigned to correct changes in signal intensity over time. Then the data was spatially normalized to a standard

Talairachspace and resampled to 2mm×2 mm×2 mm voxels. Spatial smoothing was then applied with a 8mm×8 mm×8 mm full-width at half- maximum (FWHM) Gaussian kernel.

The data was arranged as a time series matrix (m×n) , where m is the number of time points and n is the number of the voxels. A discrete cosine transform (DCT) basis set with a cut-off frequency of 1/128 Hz was applied temporally to improve the signal-to-noise ratio. After detrending, the data was temporally smoothed using 1.5s full-width at half maximum of the Gaussian kernel to remove the high frequency noise. The response now consisted of voxel by voxel time series and there were around 1,53,594 voxels after preprocessing . From the time series, a robust value of the unknown parameter β was determined by an estimation method called as the Maximum Likelihood Estimation (MLE). [3]

B.THE MAXIMUM LIKELIHOOD ESTIMATOR

The Maximum Likelihood Estimator is a fundamental to statistical inference. This was used to obtain the estimate of the unknown parameter β, which shall now be denoted as.

D. The Wald Test The Wald Test attempts to incorporate the distance | -Exp( ) | directly into a test of the null hypothesis. Formally the Wald statistic W is the following. [2]

W = (2)

Under null hypothesis, E( ) is the true value of β. From the likelihood theory, it is also known that asymptotically the MLE is unbiased for β. Thus the expression given for W above is a z-score: a statistic minus its mean divided by its standard error. It is assumed that the MLE of β is asymptotically normally distributed. Hence it follows that the Wald test must also have a standard normal distribution. This provides the basis for the Wald's test and the significance of the statistical inference from the test values that were obtained as shown in Figure (2) .

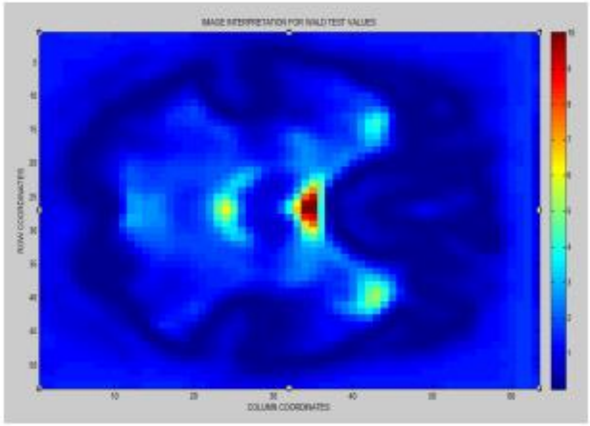

Figure 2. Image interpretation for Wald's test values in a slice. This result correspondes to the Talairach coordinate space giving meaningful coordinates for the centres of activation.

E. The Likelihood Ratio Test The likelihood ratio (LR) test is to likelihood analysis as ANOVA (partial F-tests) is to ordinary linear regression. Likelihood ratio tests are used to compare nested models that are fit using maximum likelihood estimation. Here as special case is considered when there is only a single parameter β and the restricted model specifies a value for this parameter as E( ). The likelihood ratio test is then given as LR = 2[log( )-log(E( ))] (3)

The likelihood ratio test therefore computes the distance between the ML estimator and the true value of the unknown parameter value. This is the Euclidean distance, which is weighted by the curvature of the log-likelihood function at . This forms the basis for the second type of test to determine the activation of voxels upon stimulation. The results thus obtained are shown in figure (3).

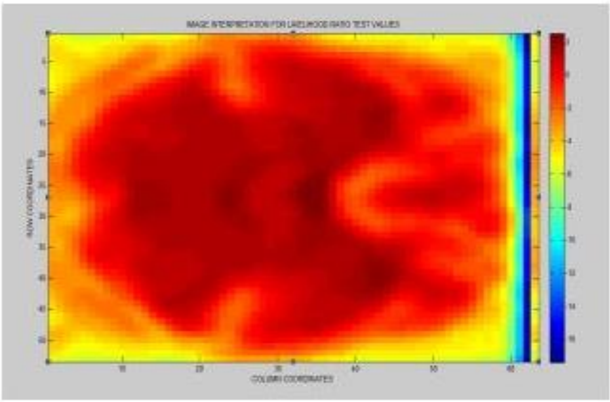

Figure 3. Image interpretation for LR test values in a slice. This result correspondes to the Talairach coordinate space giving meaningful coordinates for the centres of activation.

The data determined by performing Statistical Analysis of fMRI signals using Wald's Test and LR test were used to obtain the image interpretations of the functional activation of voxels as can be seen on a scan slice. The corresponding analysis were done on a lengthy record and hence, when dealing with short records [4], caution must be exercised when performing statistical analysis because in fMRI measurements the, the number of measurements depends on the storage capacity of the scanner and the desired spatial resolution in the brain image.

III. CONCLUSION

The data determined by performing Statistical Analysis of fMRI signals using Wald's Test and LR test were used to obtain the image interpretations of the functional activation of voxels as can be seen on a scan slice. The corresponding analysis were done on a lengthy record and hence, when dealing with short records [4], caution must be exercised when performing statistical analysis because in fMRI measurements the, the number of measurements depends on the storage capacity of the scanner and the desired spatial resolution in the brain image.

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