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Power Spectral Density Analysis of Time Series of Pixel of Functional Magnetic Resonance Image for Different Motor Activity

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Functional Magnetic Resonance Imaging (fMRI) is a non invasive modality to detect structure and function of the brain.Brain functions for various activities like motor, sensory, speech and memory process are detected using fMRI modality.Aim:This paper deals with the analysis of power spectrum of pixel time series for different motor activities. The analysis is to relate the power magnitude of the spike in the power spectrum of the fMRI time series with the activity performed.Materials and Methods:ThefMRI data set consists of a sequence of images with respect to time, when the subject performs a definite task in a given block paradigm. The data set consists of four slices each of size 64×64 pixels. The power spectrum is acquired by taking the Fourier transform of the time series. The shape of the power spectrum is often referred to as 1/f or the inverse frequency function. Low frequency noise is removed by applying discrete cosine transform on time series. Data wasoriginally,collected from General Electric Signa 1.5 T MRIsystem for5 malesubjects; 3 subjects:Performed lower limb movement (LL) and 2 subjects: Performed upper limb movement (UL). The power magnitude of the spike is recorded for lower limb and upper limb movement.Results: The spike in the power spectrum at f Hz corresponds to the frequency at which the task is performed. The power magnitude amplitude for lower limb activity is around 14.31 dB and upper limb isaround 4.0 dB.Power spectral density (PSD) of the time series is used for the detection of activitiesoccurring in the brain.

Keywords: fMRI, Time Series, Power Spectrum, Discrete cosine transform.

Neurologists use fMRI, a powerful tool to study the function of the brain. fMRI is a diagnostic method used to study the working of a normal, diseased or injured brain. Risk after neuro surgery or invasive treatment is detected using fMRI. It is an important tool which maps the spatially distributed and temporally dynamic neural activity with high resolution in the space and time domains. The spatio temporal mapping of the brain activity isessential for the investigation of the brain, in terms of functional segregation and coordination[1]. Normal anatomical imaging can provide structural information of the brain. In neurological disorders, the assessment ofonly structural information of the abnormalities present is not sufficient. In such cases, investigating the functional organization of the brain is required[2-8]. The brain coordinates all the different body functions required to perform all life events dynamically. Bodily functions and areas of the brain responsiblefor particularfunctionslike sensory, motor, speech and memory processesare investigated through fMRI studies. An important function of the brain is related to memory which processes and controls past and present information. Human memory processes are divided into three types: Encoding, retention and recalling.Brain regions activated during these memory processes could be investigated through fMRI studies[9-10]. The fMRI technique is used to capture blood oxygenation level dependent (BOLD) contrast. The BOLD signal arises from the interplay of blood flow, blood volume and blood oxygenation in response to changes in neuronal activity. Under an active state the local concentration of oxygenated hemoglobin increases which increases homogeneity of magnetic susceptibility, resulting in an increase in T2*weighted MRI signal[11, 12].

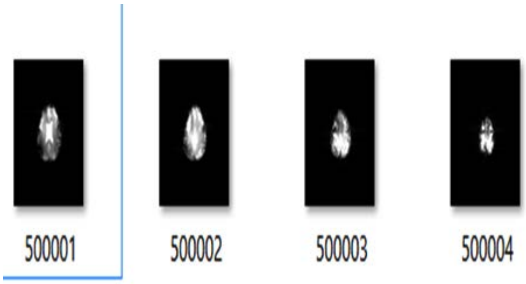

Fig. 1. fMRI images slice 1-4

The most obvious characteristic of noise in BOLD fMRI data is the presence of low frequency drift. This drift is observed in thetime domain and fourier domain. The shape of the power spectrum is often referred to as the 1/f or inverse frequency function[13].The noise appears due to the subject movement or cardiac and respiratory effectswill remain after motion correction[14]. Since low frequency noise is always present in fMRI data, it is important that the frequency of the task does not fall in the range of (0- 0.015 Hz), where the low frequency noise is found[15]. This low frequency noise is removed by using high pass filtering.

MATERIALS AND METHODS

fMRI Data was originally, collected from General Electric Signa 1.5 T MR system (New MRI Center,India). The subjects were made to perform lower limb and upper limb movements. While recording the data set, during ON state the subject was performed limb movements and no activity during OFF state. The period of the stimulus used is 20. The data set was in a DICOM (Digital Image Communication in Medicine) format.

In this fMRI experiment the data set consisted of a sequence of images recorded with respect to time. Echoplanar images (EPI) were recorded while the subject is performed a paticular motor activity[16].The data set consists of four slices

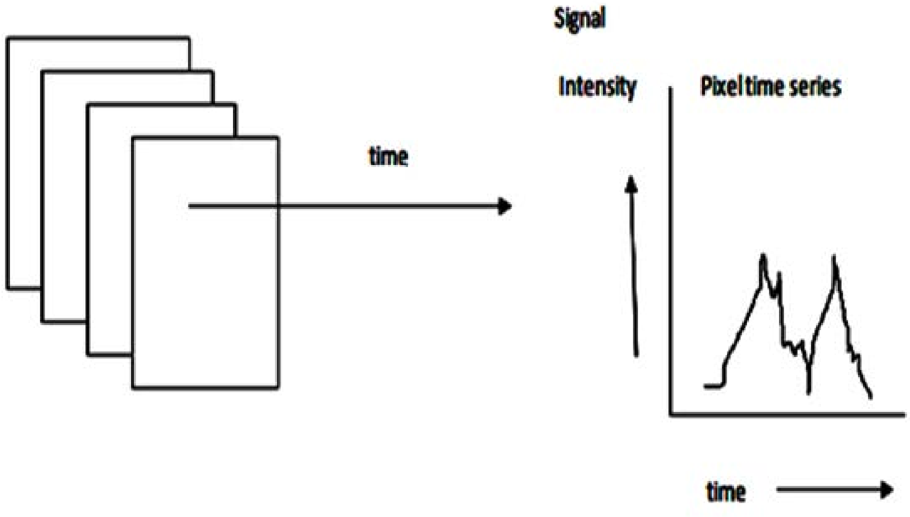

Fig. 2. Sequence of Images Recorded with Respect to Time in fMRI and a Pixel Time Series

each of size 64×64 pixels,cutting through the motor cortex with a repetition time(TR) of 3000msec echo time of 60 msec. EPI images belonging to slice 1,2,3,4 in sequence that were recorded with respect to time are shown in figure 1 [17, 22]. For each motor activity 512 images were recorded.

Time Series

The single image does not give any functional information. In fact the variation of the image intensities are recorded with respect to time. In fMRI, a number of images of the brain are recorded consecutively with respect to time in a single fMRI experiment. Each of the pixels

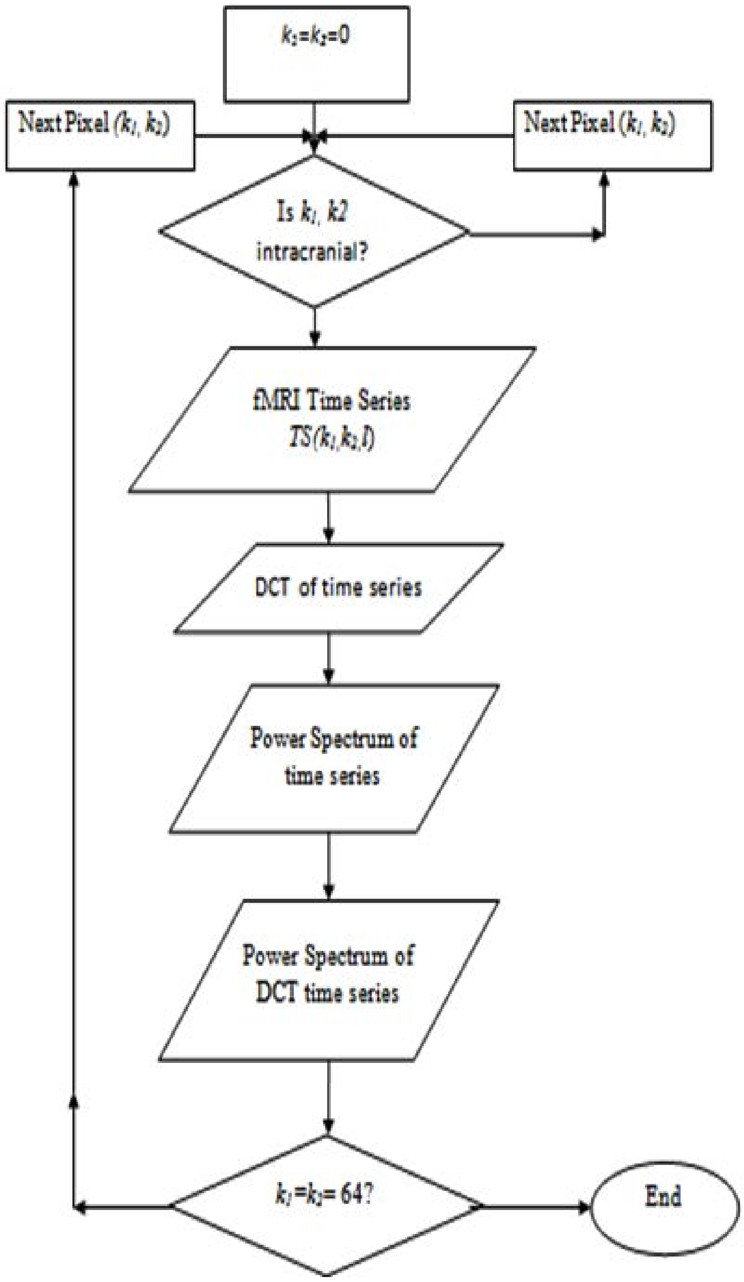

Fig. 3. Flow chart of signal processing

in the image is represented by coordinates (k_1,k_2). The pixel time series corresponds to pixel (k_1,k_2) by TS(k_1,k_2,l), where k_1,k_2 are integers,l being the time index. The noise arises from physical sources(sometimes referred to as scanner drift), from physiological sources, or from residual movement effects. When the subject is performing a task,signal components are added to this noise [17,18]. Figure 2 shows the pixel time series.

The time series of fMRI is represented by

$$TS(k,l) = \pi(TS(k,l), P_T) + \sum_i \pi(TS(k,l), Pp_i) + n(l) \quad ...(1)$$

Where T is the stimulus period, $\pi(TS(k,l), P_T)$ is the projection of time series (TS) onto the T periodic basis elements and Pp is the periodicity subspaces.

Power Spectrum

The Fourier transform reflects the strength (or power) of the signal at each frequency. When the power is plotted across all frequencies, this plot is referred to as a power spectrum. Power spectra are commonly used in fMRI data analysis. They can be useful for characterizing the time course of signals that are estimated using independent components analysis.The power spectrum is acquired by taking the fourier transform of the time series. The X axis of the plot refers to different frequencies whereas the Y axis refers to the power or strength of this frequency. The most obvious characteristic of noise in BOLD fMRI data is the presence of low frequency drift. This low frequency drift in an fMRI time series can be observed in the time domain as well as in the power spectrum in the Fourier domain[19-20].

High pass filtering

The noise components that arise due to previously mentioned sources namely physical physiological and residual movement effects as well as their interaction with the static magnetic field are low frquency noise components. When the subject is performing a task, signal components are added to this noise. Filters are used for removal of noise.The filters used in imaging are designed to pass particular portions (or bands) of the frequency spectrum while removing others. Removing low frequency trends means, to apply a high pass filter. The high pass filtering on time serie is done by using discrete cosine transform (DCT)[11].

Mathematically,

For time points $t = 1,....,N$

The discrete cosine set functions are given below

$$f_r(t) = \sqrt{2/N}\left(\cos(r\pi \tfrac{t}{N})\right) \quad ...(2)$$

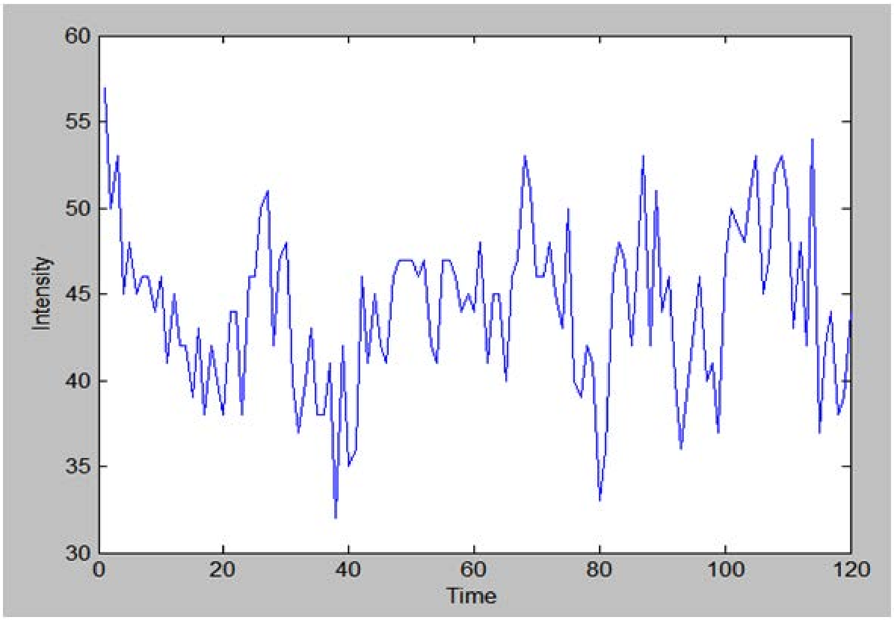

Fig. 4. Original Time Series

The integer index r ranges from 1 to user specified maximum R.

Figure 3 shows the signal processing steps for fMRI data processing the code is implemeted in MATLAB. The analysis is restricted to the intra cranial region only. The intra cranial pixels are separated from the remaining pixels by using a mask. The following steps are incorporated while processing the fMRI data for various subjects.

• Select the pixel time serieswithin the intra cranial

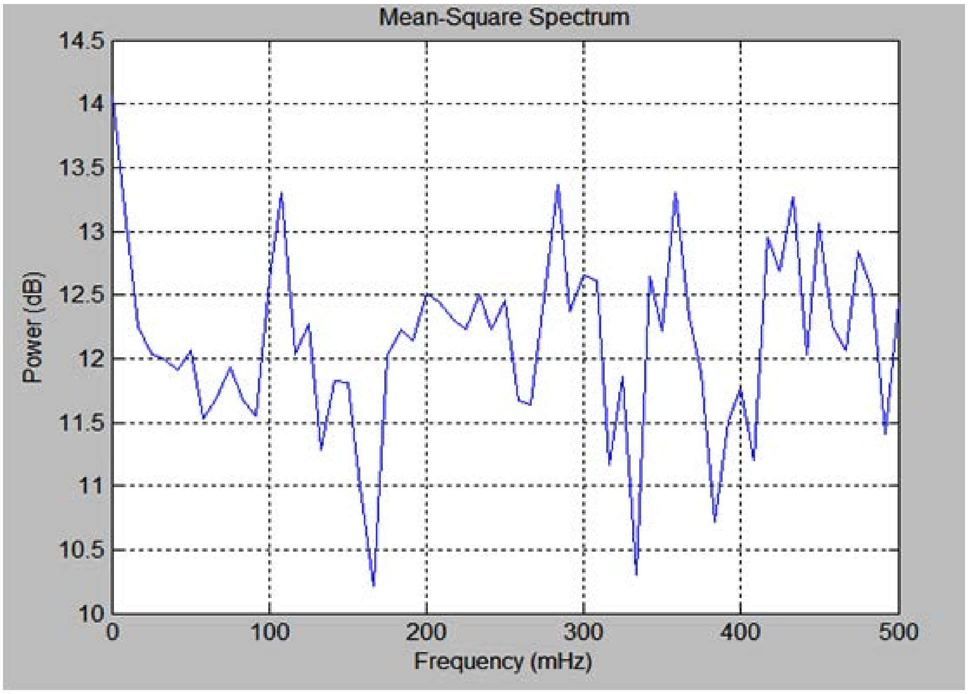

Fig. 5. Power spectrum of DCT time series

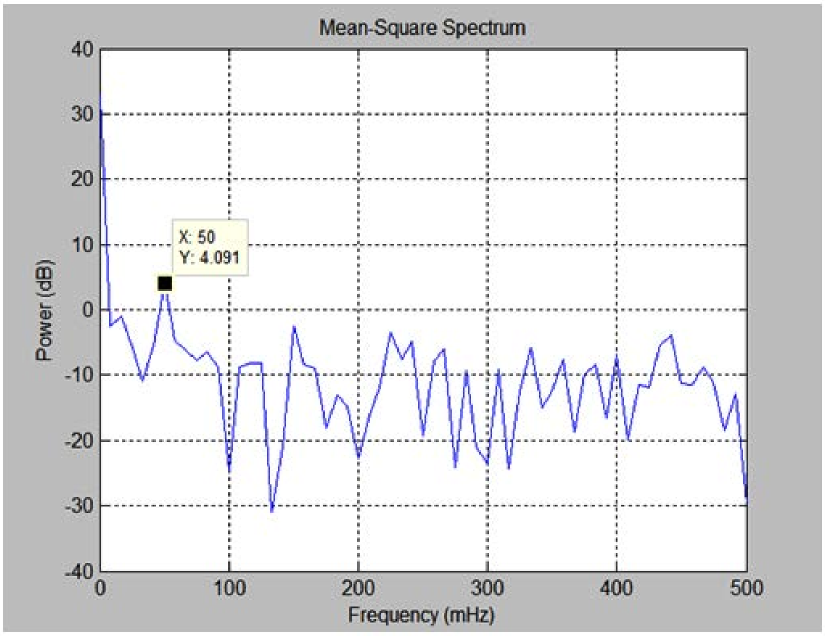

Fig. 6. Power spectrum for UL movement

region.

• Apply DCT on original time series.

• Detect the PSD of DCT time series.

RESULTS

Analysis of fMRI images is implemented for lower limb(LL) and upper limb (UL)movements. Figure 4 shows the original time series as well as low frequency drift. Figure 5 shows the power spectrum of DCT time series. Figure 6 shows the power spectrum for UL movement. Figure 7 shows the power spectrum for LL movement. The spike observed in the power spectrum at f Hz corresponds to the frequency of the task in this experiment. Power amplitude isobserved to bedifferent for

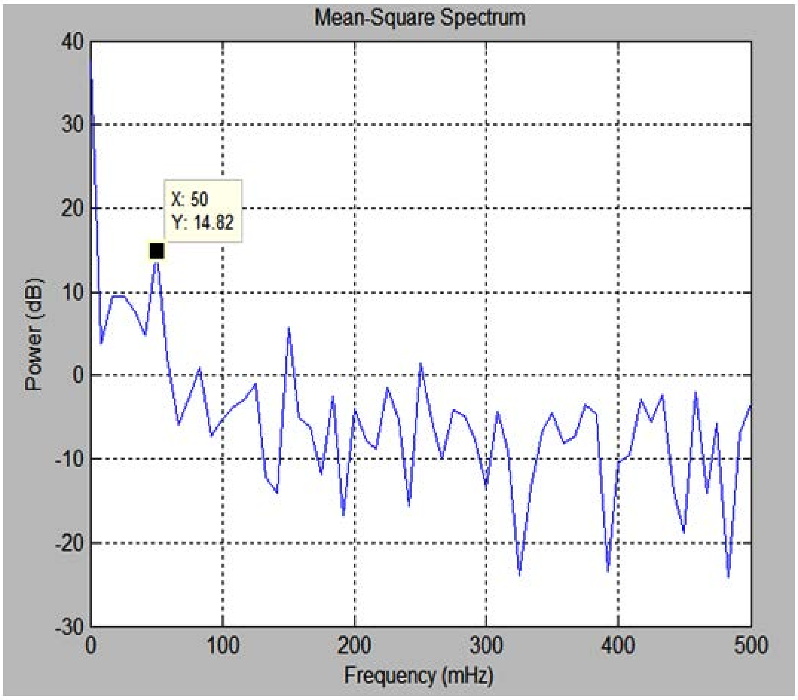

Fig. 7. Power spectrum for LL movement

Table 1. PSD for different activity

Subject	Activity	Power(dB)	Frequency(mHz)	Period (sec)
1	Upper limb movement	3.74	50	20
2	Upper limb movement	4.091	50	20
3	Lower limb movement	14.82	50	20
4	Lower limb movement	14.24	50	20
5	Lower limb movement	13.89	50	20

different activities performed by the subject. Table 1 shows the result of frequency and power for different motor activities performed.

CONCLUSION

Original time series as well as HP filter fit (DCT) timeseries is similar. The power spectrum of the original timeseries exhibited low frequency noise which is removed by using a high pass filter. The power magnitude of the spike is recorded for lower limb as well as upper limb movement. The spike in the power spectrum at fHz corresponds to the frequency of the task. In this experiment the frequency of the task f is 50mHz (once every 20 seconds). The power amplitude for lower limb activity is around 14.31 dB and upper limb is 4.0 dB. The PSD of time series is be used for the detection of activity in the brain. They can be useful for characterizing the time course of signals that are estimated using independent components analysis. Also the detection of activity in brain from fMRI images can be done by applying novel methods like periodicity.Furthermore,brain mapping can be done based on statistical parameters of the fMRI time series for different activities.

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