Recovering Extremely Low Frequency Signal from the Signal-Dependent Noise Background

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Abstract: We developed a signal dependent noise tensor, which can be used to describe the fluctuated geomagnetic field coupled with Extremely Low Frequency (ELF) signals for our further biological signal processing study. In order to isolate the coupled ELF signals from the signal dependent noise, we introduced Quantization (QT) decoding method to discrete the noise and recover the coupled signals from the background. The signal to noise ratio of the coupling ELF can be amplified by QT in the power density spectrum (PDS). [Nature and Science. 2004;2(4) (Supplement): 1-3].

Key words: Extremely Low Frequency (ELF); noise; power density spectrum (PDS); signal

Introduction

The signal dependent noise can be presented as a noise tensor n_{ij} at time t_{ij}, in which index indicates the i th sample at energy level j. The signal can be shown as s_{ij}. Power density spectrum (PDS) analysis for tensor $n_{ij} \oplus s_{ij}$ can be used to identify the coupled signals s_{ij} in n_{ij}. The intrinsic coupling oscillation can be captured by probe and converted to electrical voltages shown in oscilloscope.

Theory and Methods

Set an AC ELF signal s_{ij} as input to the background n_{ij}, the output can be transformed to electrical voltages shown to oscilloscope. By using HP Benchlink, we collect the output data and transform it to Microsoft Excel as text files. Matlab and Fortran programs were performed to analyze the data and get PDS. Figure 1 illustrates the flow chart of the QT process

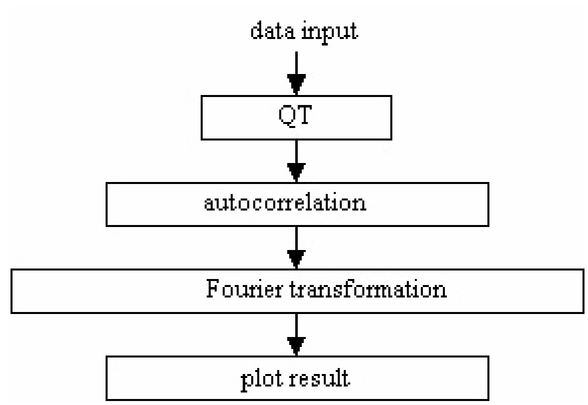

Figure 1. The flow chart of the QT

Consider the data output sequence x_{ij} = s_{ij} □ n_{ij}, where x_{ij} indicate the jth element in ith ensample.

Step 1: Get x_{ij}

Step 2: Set QT value from v_1 to v_6, where

$v_1 > v_2 > \ldots > v_6$ for six QT levels

Step 3: Compute $\overline{x}_{ij}$, the average value of x_{ij}

Step 4: If $x_{ij} > \overline{x}_{ij}$, set $m_h = x_{ij}$,a high threshold value m_h should be defined.

If $x_{ij} < \bar{x}_{ij}$, set $m_l = x_{ij}$, a low threshold value m_l should be defined.

If $x_{ij} > m_h$ set $m_{hh} = x_{ij}$, a second high threshold m_{hh} should be defined.

Step 5: Set $\bar{x}_{ij} = m_{h1}$ if $m < \bar{x}_{ij} < m_h$

$\bar{x}_{ij} = m_{1h}$, if $m_l < \bar{x}_{ij} < m$

$\bar{x}_{ij} = m_{11}$, if $\bar{x}_{ij} < m_1$, where

$m_{hh} > m_h > m_{h1} > m > m_{1h} > m_1 > m_{11}$.

Step 6: If $x_{ij} > m_{hh}$, set $\bar{x}_{ij} = v_1$

If $m_{1h} < x_{ij} < m_{hh}$, set $x_{ij} = v_2$

If $m_{h1} < x_{ij} < m_h$, set $\bar{x}_{ij} = v_3$

If $m < x_{ij} < m_{h1}$, set $x_{ij} = v_4$

If $m_{1h} < x_{ij} < m$, set $x_{ij} = v_5$

If $m_1 < x_{ij} < m_{1h}$, set $x_{ij} = v_6$

It is defined amplitude signal to noise ratio as $ASNR = \frac{A_s}{A_n}$, where A_s is the amplitude of the coupled ELF signal and A_n is the amplitude of the noise. In contrast, $SNR = \frac{P_s}{P_n}$, where P_s is the power of the output ELF signal calculated from PDS and P_n is the power of the noise. Noise can be defined as all unpredictable signals in PDS. Since both ASNR and SNR can be calculated, the plot of ASNR versus SNR produces a function curve showing the correlation between input amplitude and output power. Even through noise may have its own characteristic; we can calibrate the function curve with the help of adjusting trial signal's amplitude to control the power difference by QT analysis. For instance, using a data sequence to simulate a sample function consisting of 2000 elements including a 15 Hz sinusoid signal, $x_{ij}(t) = s_{ij}(t) + k \times n_{ij}(t)$, label index i is from 1 to 2000 for this sequence. The dimension of the noise tensor is 2000 × j. For simplicity, take j = 1, the power spectrum can be simply calculated. Note that the identified ELF signal is supposed being occurred at 15 Hz. The frequency component of power density spectrum of the noise being illustrated will depend upon the characteristic of n_{ij}.

In addition, Figure 1b showed the magnetic fluctuation very near the cell layer on the patch substrate.

Results

The power density spectrum calculation result is illustrated in Table 1. We are not able to identify ELF 15 Hz without QT if its signal to noise ratio (S/N) is lower than 0.015.

Table 1. The power density spectrum calculation result (- : not able to identify ELF 15Hz, however ; +: able to identify ELF 15Hz)

ASNR	15 Hz	QT	S/N Ratio
1.0	+	+	1.5
0.5	+	+	0.37
0.1	-	+	0.015
0.05	-	+	0.004
0.01	-	+	0.0001

Discussion

Our results provide evidence suggesting that QT is able to affect the PDS, which is linked with the energy modulation within the noise and shows the power that the noise could sense. The purpose of this report is to provide a new method to recognize the ELF buried in signal dependent background noise.

Conclusion

The noise sensitivity to the ELF signal has been studied for a years. QT can help to recognize ELF and increase both ASNR and the SNR providing a function curve to characterize the signal dependent noise. By using this function curve, we can find the best estimate signal-to-noise ratio of the coupled ELF. The remaining question is how can we find the best combination of the weights of QT in experiments. Fuzzy and neuronet analysis may help for further noise tensor characteristic studies.

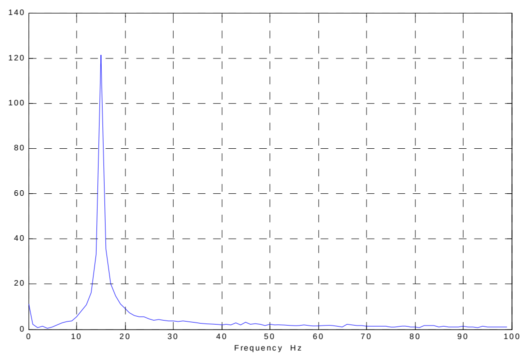

Figure 2. If S/N=1.5, the ELF signal component at 15 hertz is shown

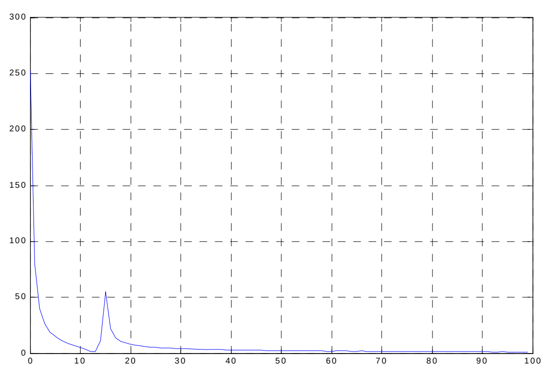

Figure 3. If S/N=0.37, the ELF component signal at 15 hertz still can be shown

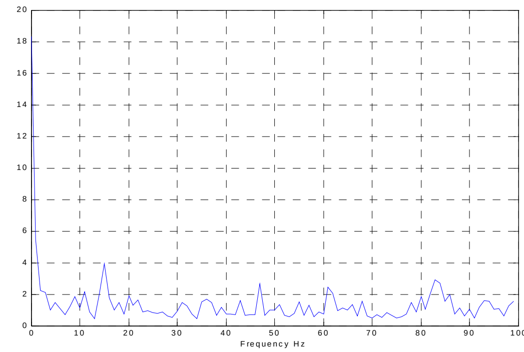

Figure 4. If S/N<0.37, we are not able to identify the ELF signal at 15 hertz

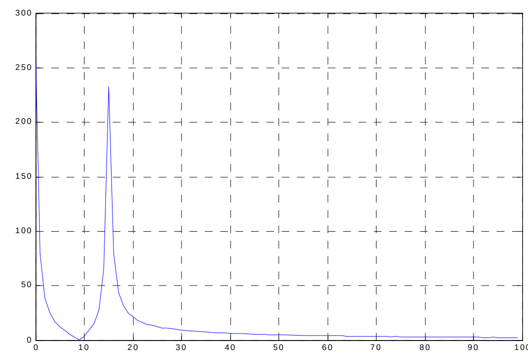

Figure 5. ELF signal at 15 hertz is identified by QT when 0.0001< S/N <0.3

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