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Software Digital Lock-in Amplifier in the application of fNIRS System

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Abstract. Lock-in amplifier is particularly important in the fNIRS-based system, because the lock-in amplifier can recover the low-level signals buried in significant amounts of noise. But the price of lock-in amplifier is very expensive. This paper presented a software method for designing digital lock-in amplifier. Compared with analogue lock-in amplifier, results show that software lock-in amplifier is feasible for experimental research and can replace the expensive analogue lock-in amplifier.

Introduction

Functional near-infrared spectroscopy (fNIRS) is a non-invasive technique that can be used to measure functional activity of the cerebral cortex[1]. This system uses frequency modulated lasers at two different wavelengths light in the range of human tissue optical window are shed onto the cortex through the surface of the scalp[2]. After being scattered from the brain tissue and absorbed by oxyhemoglobin (HbO) and deoxyhemoglobin (Hb) in the cortex[3], the light intensity carrying cortex activation information is detected by Avalanche Photo Diode (APD) . Then lock-in amplifiers are used to extract desired signals buried in noise. According to the different spectral absorption property of HbO and Hb[4], the modified Beer-Lambert Law is used to calculate the concentration changes of HbO, Hb[5].

fNIRS system can be used in research fileds such as brain cognitive, disease diagnosis, as well as Brain Computer Interface (BCI) research[6,7]. Compared with equipment used for brain function imaging such as functional Magnetic Resonance Imaging (fMRI), Position-Emission Tomography (PET), fNIRS-based system has the incomparable advantage of price. But lock-in amplifier is very expensive in this system, especially in the multichannel system. So we used a software method to design a digital lock-in amplifier to replace analogue lock-in amplifier. Then we calculated the concentration changes of HbO and Hb caused by volunteers performing arithmetic task, compared with real analogue lock-in amplifier, results show that our design is suitable for our experimental research. This paper also presented the relative deviation between software calculated lock-in and the real lock-in.

Experiment

The experiment in our study is that volunteers perform arithmetic task. Two different wavelengths light are 695nm and 830nm, with frequency 1000Hz and 2000Hz, from two lasers modulated by TTL level. Scattered light from brain tissue is received by fiber bundle, then through APD, light intensity is converted to electrical signal. And lock-in amplifiers extract the useful signals buried in the noise. We acquired the data with NI data acquisition card (USB6229) , 16 bits resolutions, with sampling frequency 10KHz. The fNIRS system schematic is shown in Fig. 1.

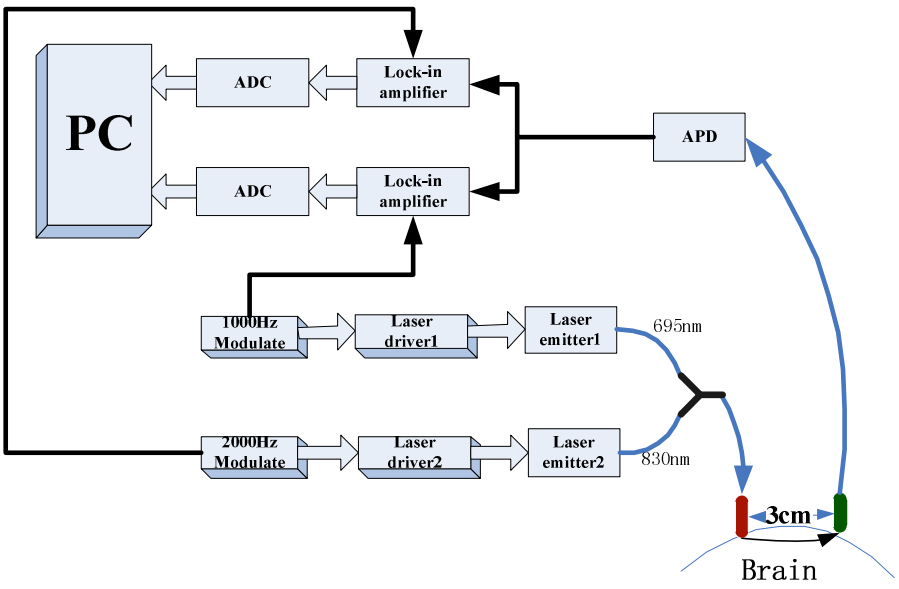

Fig. 1 fNIRS system schematic

Digital lock-in principle

We assume a signal with frequency f, and is digitized at a sampling rate f_s :

$$S(k) = A\sin(2\pi \frac{f}{f_s}k) + B\cos(2\pi \frac{f}{f_s}k) . \qquad k = 0,1,2,.....N-1 . \tag{1}$$

where N is the number of samples. This is multiplied by in-phase and quadrature reference signals, which are digitized at the same sampling rate f_s :

$$R_1(k) = \sin(2\pi \frac{f}{f_s}k) . \tag{2}$$

$$R_2(k) = \cos(2\pi \frac{f}{f_s}k) . \tag{3}$$

where the reference amplitudes are set to one, and phase set to zero. After multiplication the mixers are

$$X_{out}(k) = S(k)R_1(k) = \frac{1}{2}A\{1-\cos(4\pi \frac{f}{f_s}k)\} + \frac{1}{2}B\sin(4\pi \frac{f}{f_s}k) . \tag{4}$$

$$Y_{out}(k) = S(k)R_2(k) = \frac{1}{2}A\sin(4\pi \frac{f}{f_s}k) + \frac{1}{2}B\{1+\cos(4\pi \frac{f}{f_s}k)\} . \tag{5}$$

According to the integral orthogonality principle :

$$\frac{2}{N}\sum_{k=0}^{N-1}\sin(\frac{2i\pi}{N}k)\sin(\frac{2j\pi}{N}k) = 0 . \qquad i \neq j$$

$$\frac{2}{N}\sum_{k=0}^{N-1}\cos(\frac{2i\pi}{N}k)\cos(\frac{2j\pi}{N}k) = 0 . \qquad i \neq j$$

$$\frac{2}{N}\sum_{k=0}^{N-1}\sin(\frac{2i\pi}{N}k)\cos(\frac{2j\pi}{N}k)=0 \ . \qquad any \ \ i,j \tag{6}$$

where i and j are integers. Applying this orthogonality principle to Eq.4 and Eq.5 give $X_{out}=A$, $Y_{out}=B$, then signal amplitude is obtained $S=\sqrt{A^2+B^2}$.

Software Implementation methods

Output data from APD is very weak, so we amplify 1000 multiples. Among the integral orthogonality principle, the number of samples must meet $N=p(f_s/f)$. where p is integer. In our experiment fs = 10 KHz, f = 1000 Hz and 2000 Hz, so we use length N = 1000 every time. In order to maintain the result continuity, we use L = 900 as overlapping data in the next calculation.

Lock-in amplifier in this system is used to extract light intensity signals carrying some information about the cortex activation. So in Eq. 1, A and B are periodic variations not constants. The components of A and B are mainly heartbeat signal, breath signal and brain tissue oxygen change signal caused by arithmetic task. When we perform digital lock-in amplifier with software we actually averaged the amplitude of length N signal. We analyze one channel X_{out} using Eq.4 :

$$X_{out}=\frac{2}{N}\sum_{k=0}^{N-1}S(k)R_1(k)=\frac{2}{N}\sum_{k=0}^{N-1}\{\frac{1}{2}A(n)\{1-\cos(4\pi\frac{f}{f_s}k)+\frac{1}{2}B(n)\sin(4\pi\frac{f}{f_s}k)\} \ . \tag{7}$$

where $A(n)$ and $B(n)$ are variable not constants. Assume that $m=f_s/f$ is the sampling number of one cycle. $p=N/m$ is the number of cycles, then

$$\begin{aligned}X_{out}=&\frac{1}{N}\sum_{k=0}^{m-1}\{A_1\{1-\cos(4\pi\frac{f}{f_s}\mathrm{k})\}+B_1\sin(4\pi\frac{f}{f_s}\mathrm{k})\}\\&+\sum_{k=m}^{2m-1}\{A_2\{1-\cos(4\pi\frac{f}{f_s}\mathrm{k})\}+B_2\sin(4\pi\frac{f}{f_s}\mathrm{k})\}+\cdots\\&+\sum_{k=N-m}^{N-1}\{A_p\{1-\cos(4\pi\frac{f}{f_s}\mathrm{k})\}+B_p\sin(4\pi\frac{f}{f_s}\mathrm{k})\}) \ .\end{aligned} \tag{8}$$

Applying Eq.6 integral orthogonality principle to Eq. 8, X_{out} can be obtained :

$$X_{out}=\frac{m(A_1+A_2+\cdots+A_p)}{N} \tag{9}$$

where $A_1,A_2,\ldots,\mathrm{A}_p$ are signal amplitudes of every cycle, if $A_1=A_2=\cdots=A_p=A$, then $X_{out}=A$. Because the components carried by A are all low frequencys , the amplitude averaged with this method don't have much influence to this system.

Results

In our experiment we used a software method to design a digital lock-in amplifier, we compared results with real analogue lock-in amplifier (LIA-MV-150-S) . Fig. 2 shows the comparison of 1000Hz lock-in data. Fig. 3 shows the comparison of 2000Hz lock-in data. From the two figures, we can see that calculated results by software digital lock-in amplifier are similar with analogue lock-in amplifier.

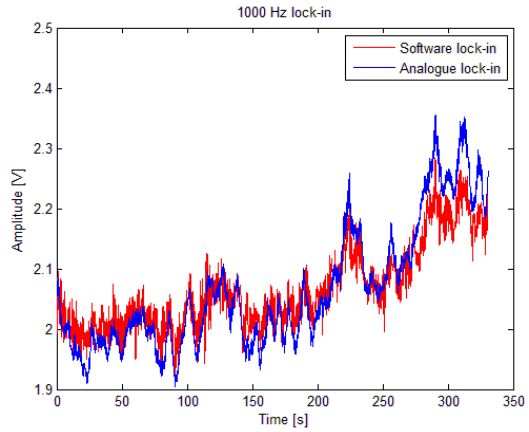

Fig. 2 Comparion of 1000 Hz lock-in

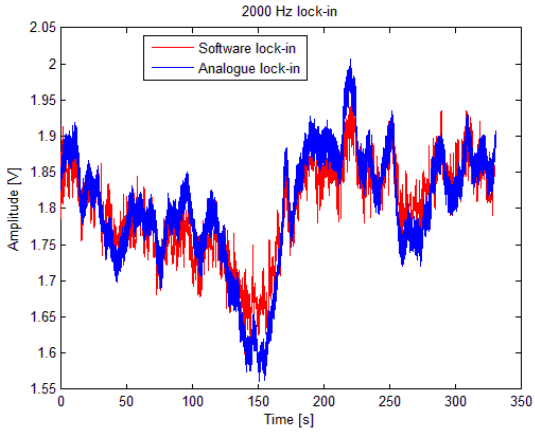

Fig.3 Comparion of 2000 Hz lock-in

This is not filtered, containing heartbeat noise signal, if we denosie it and using the modified Beer-Lambert Law[8], we can calculate the concentration changes of Hb and HbO. The modified Beer-Lambert Law is :

$$\Delta C = \begin{pmatrix} \Delta c_{Hb} \\ \Delta c_{HbO} \end{pmatrix} = \begin{pmatrix} \varepsilon_{\lambda_1,Hb} & \varepsilon_{\lambda_1,HbO} \\ \varepsilon_{\lambda_2,Hb} & \varepsilon_{\lambda_2,HbO} \end{pmatrix}^{-1} \begin{pmatrix} \dfrac{\log \frac{I_{\lambda_1}(t_1)}{I_{\lambda_1}(t_2)}}{DPF_{\lambda_1} d} \\ \dfrac{\log \frac{I_{\lambda_2}(t_1)}{I_{\lambda_2}(t_2)}}{DPF_{\lambda_2} d} \end{pmatrix}. \tag{10}$$

where Δc_{Hb} and Δc_{HbO} are relative concentration changes of Hb and HbO, λ_1, λ_2 are light wavelengths. ε is light extinction coefficient, I is light intensity exciting the tissue, d is the distance between emitter and detector, DPF is the differential path length factor. Fig. 4 shows the comparison of Hb concentration change and Fig. 5 shows the comparison of HbO concentration change. From these figures, we can see that Hb and HbO concentration changes calculated by software lock-in and analogue lock-in are nearly the same, they reflect the changing condition of brain oxygen during arithmetic task.

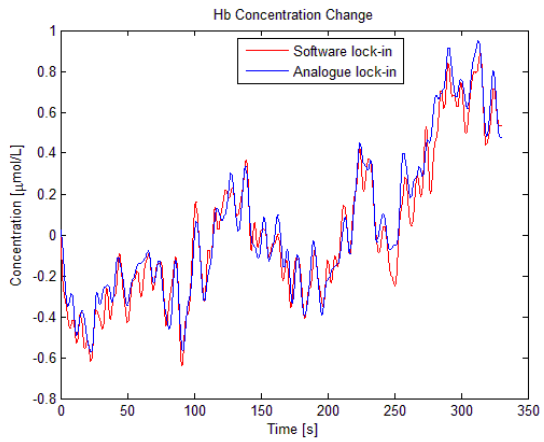

Fig. 4 Comparison of Hb concentration change

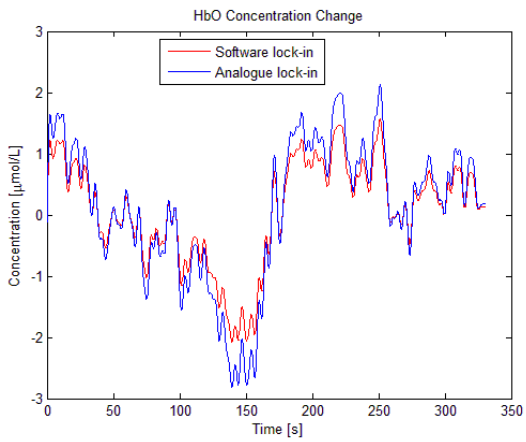

Fig.5 Comparison of HbO concentration change

Software lock-in deviation

In our experiment, two volunteers participated in this test. Every volunteer performed three task tests , and there is an interval time for rest between two tasks. During the third task tests, because fiber bundle moved, we excluded the lock-in data. Deviation between software lock-in and analogue lock-in is shown in Table 1.

The deviation is calculated with

$$dev = mean(\frac{|S_d(i) - S_a(i)|}{S_a(i)} \times 100\%) \quad . \qquad i = 1,2,\ldots \quad . \qquad (11)$$

where S_d refers the value of software digital lock-in, S_a refers the value of analogue lock-in, i refers the time point.

Table 1 Deviation between software lock-in and analogue lock-in

Task Number	subject 1		subject 2	
	1000 Hz	2000 Hz	1000 Hz	2000 Hz
1	1.72%	2.75%	3.47%	3.20%
2	2.45%	2.44%	1.60%	1.70%

Conclusions

This paper presented a software method to design digital lock-in amplifier in the application of fNIRS-based system, compared with real analogue lock-in amplifier, results show that this software lock-in can replace the analogue lock–in for our experimental research, and reduce the expensive instrument cost.

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References

[1] Boas D A, Gaudette T, Strangman G, et al. The accuracy of near infrared spectroscopy and imaging during focal changes in cerebral hemodynamics[J]. Neuroimage, 2001, 13(1): 76-90.

[2] Jöbsis F F. Noninvasive, infrared monitoring of cerebral and myocardial oxygen sufficiency and circulatory parameters[J]. Science (New York, NY), 1977, 198(4323): 1264.

[3] Stepnoski R A, LaPorta A, Raccuia-Behling F, et al. Noninvasive detection of changes in membrane potential in cultured neurons by light scattering[J]. Proceedings of the National Academy of Sciences, 1991, 88(21): 9382-9386.

[4] Okada E, Firbank M, Schweiger M, et al. Theoretical and experimental investigation of near-infrared light propagation in a model of the adult head[J]. Applied optics, 1997, 36(1): 21-31.

[5] Fuster J, Guiou M, Ardestani A, et al. Near-infrared spectroscopy (NIRS) in cognitive neuroscience of the primate brain[J]. Neuroimage, 2005, 26(1): 215-220.

[6] Suto T, Fukuda M, Ito M, et al. Multichannel near-infrared spectroscopy in depression and schizophrenia: cognitive brain activation study[J]. Biological Psychiatry, 2004, 55(5): 501-511.

[7] Huang Z, McWilliams A, Lui H, et al. Near-infrared Raman spectroscopy for optical diagnosis of lung cancer[J]. International journal of cancer, 2003, 107(6): 1047-1052.

[8] Boas D A, Gaudette T, Strangman G, et al. The accuracy of near infrared spectroscopy and imaging during focal changes in cerebral hemodynamics[J]. Neuroimage, 2001, 13(1): 76-90.

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