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An Estimation Model of Pupil Size for 'Blink Artifact' and It's Applications

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Abstract. It is well known that the measuring of pupil size is influenced by noises and blinking. This paper describes the development of an estimation model of pupil size for 'blink artifact' which is based on a 3 layered perceptron with back propagation method. The model was trained by pupil responses with artificial blinks. It was found that pupil size during the blink period could be estimated according to the training period. When this model was applied to pupillary changes for subjects viewing TV programs, inappropriate power of frequencies were removed in the frequency analysis for temporal pupillary change. This result provides evidence that this model can remove faults from pupil response measurements.

1. Introduction

It is well known that the pupil of an eye is light sensitive and reacts to light intensity - 'the light reflex'. It has also been found that pupil size changes according to a viewer's emotion and or their workload[1][2]. Therefore pupil size is often used as a measure; as an index of the emotional situation and mental workload[3]. A problem that is often encountered during temporal response observations are 'eye blinks'. The random and frequent nature of 'eye blinks' coupled with the fact that at the time of the blink the eye is covered by the eyelid results in missing pupil size data. It is therefore impossible to obtain an accurate measure of temporal pupillary change. Blink information can also be used as a useful index of emotion[4]. To analyze temporal pupillary change FFT (Fast Fourier Transform) analysis[3] is often used, the problem with this technique is that the 'blink' is an artifact of the situation and compensation is required . Off-line methods have already been developed for the processing of blinks, for example the use of the B-spline method[5] allows for data to be processed automatically.

Alternatively, appropriate filters can be used to suppress noise and artifact for on-line signal detection. Artificial neural networks (ANN) can also be applied as a filter to signal processing[6] and results have shown good performances in most cases. The aim of this study was to develop a noise suppression and compensation method for pupil size during the blink period. It was reasoned that if artifacts could be removed, frequency analysis could be conducted easily on temporal pupillary change.

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In this paper the following topics are addressed: 1) The development of a compensation model for temporal change of pupil size based on the multi-layers perceptron method (MLP). 2) To examine the performance of the developed model on frequency analysis for pupillary change. Additionally, in order to examine the model's performance further experimental data of pupil size was also applied to the evaluation.

2. Modeling

To process the temporal pupillary change based on the ANN model, we used a simple three layer perceptron as a kind of multilayer perceptron (MLP). To reproduce the temporal pupillary change, two vectors were prepared for MLP training[6]. Here the layer number is noted as k ($k = 0, 1, 2$) then input vector and output vector are defined respectively as $Y^{(0)}$ and $\hat{Y}^{(2)}$. The number of units in the layer is noted as N_k. The components of k'th and the components of output vector were displayed as the following:

$$Y^{(0)} = (y_1^{(0)}, \ldots, y_{N_0}^{(0)}), \ldots, Y^{(2)} = (y_1^{(2)}, \ldots, y_{N_2}^{(2)})$$

$$\hat{Y}^{(2)} = (\hat{y}_1^{(2)}, \ldots, \hat{y}_{N_2}^{(2)})$$

A component $y_j^{(0)}$ of input vector corresponds to $\hat{y}_j^{(2)}$ of output vector at the same time. Then the input-output sample set as $\{Y_i^{(0)}, \hat{Y}_i^{(2)}\}$ was given a MLP to simulate the mapping. An estimation value is noted as $y_j^{(2)}$ for the output layer unit. Hence, $y_j^{(2)}$ is given by following the equation:

$$y_j^{(k)} = f_j^{(k)} \left(\sum_{i=1}^{N_{k-1}} w_{ij}^{(k-1)} y_i^{(k-1)} - \theta_j^{(k)} \right)$$

Here $f_j^{(k)}(\cdot)$ is a sigmoidal function and $\theta_j^{(k)}$ is the threshold of the j'th unit in the k'th layer, w_{ij} is the connection weight value between the unit of the two layers. The training was conducted to solve the optimization problem in the following way, which was based on the back propagation method.

$$min \sum_{i=1}^{I} ||Y_i^{(2)} - \hat{Y}_i^{(2)}||^2$$

To develop the model further experimental data of temporal pupillary change was added to the training data. In this paper, simple pupil responses were observed as a light reflex[7]. Light intensity was controlled in square waves (T=4, 3, 2, 1 second) and triangle waves (T=10.7, 5.3, 2.2, 1.1 second). Pupil size was measured from an eye image in 30Hz. The eye image was captured by a small camera which was built into the eye tracker (nac:EMR-7). Pupil size was calculated by an image processor (Hamaphoto:C3160). The size was normalized for each subject, because individual pupil sizes are different. The training data consisted of temporal pupil size without blink in 8 experimental sets. The continuous time series data for the number of input layer units was prepared stepwisely for input data and the subset string of data for the number of output units was prepared to respond to the input data string respectively.

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The total number of training data was 2048 patterns when the number of the input layer units were 15.

Firstly, performance was examined by reproducing pupil size. In order to train the model, the same temporal data was provided to the unit of both input and output layer[8]. The model was trained for 3000 epoch a condition. The number of each layer unit was controlled for model optimization (input layer to 35, hidden layer: 2 to 36, output layer; 1 to 5). The relative error rate for the estimation was evaluated as a mean in five times training, because the initial weights for the connection between units were assigned randomly. As a result 30 units for the input, 8 units for the hidden and 1 unit for the output (this condition displayed as 30-8-1) is the minimum of the average error rate. The difference between the estimation and the training data was lower than 0.002. It seemed that measuring noise was also suppressed. The results suggest that the model had learnt the reproduction procedure. This model was also applied to the experimental data which contained 'blink artifacts', where pupil size in the blink could not be recovered. Figure 1 shows a solid line for the reproduction of the first model when the input data which is displayed in the bold line was given. This failure indicates that the model needs to be trained for recovery estimation for the 'blink artifact'.

Secondly, modified training data which contained pupil size in the blink was prepared. The experimental observation never displayed pupil size during the blink period. The application of the model was to act as an estimation of pupillary size and change. The training data was partially modified according to typical blinking data in the pupillary change[8]. Previous work on blink behavior had provided a measure of duration time, the process of the eye lid closing and so on. The variation and change in pupil size during blinks are a direct response to typical blinking patterns. As a result a pair of pupillary change data with and without 'blink' was created. The blinking pattern was then inserted into the input data instead of the normal data and the output data was reserved. The bold line indicates the partial replaced input data in Figure 1. The center of the figure displays the blink which is the precise point at which pupil size cannot be measured. Therefore, training data gives the model the pattern of the 'blink artifact' and normal pupillary change. A replacement for the input data was randomly inserted, which was based on a blink frequency of once per 3 seconds. The model was trained with the same procedure as the first one. It was found that the 30-12-1 condition was the most optimized for the training data. The output of the model was found to almost overlap the original data (See Figure 1). This result suggests that the model can estimate pupil size during blink periods. This model provides the possibility to view pupillary change without the blink artifact posing a serious problem.

To understand the model processing, the connection weights between two layers were compared respectively. For between input and hidden layers, some units of hidden layers have a strong connection with a few specific units of input layers. For between hidden and output layers, a few units of hidden layers showed a strong connection with the output layer. The output of those specific hidden layer units were observed when a blink artifact was given. An activation of a hidden unit responded to only the blink artifact. Another hidden unit also responded to the edge of blink change. This result indicates that there is a blink detector as a network representation.

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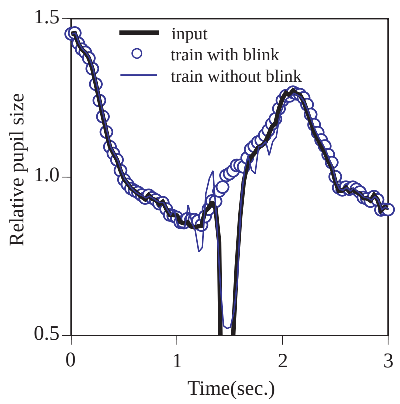

Figure 1: Pupillary change as the output of the model which were trained with and without artificial blink artifact.

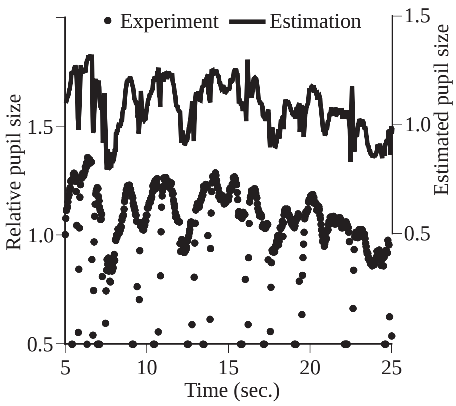

Figure 2: The temporal pupil sizes of the experimental and the estimation model output.

3. Applications

3.1. Compensation Performance

This model was applied to further experimental data which was gathered during an observation of pupil size for subjects viewing TV programs.

In the viewing experiment, three video clips which were pre-edtied for 3 minutes were presented to subjects and pupil size was observed[8]. The video contents were categorized as 1) commercial messages, 2) a program for children and 3) a jet boat image as a quick motion sample. Four subjects participated in this experiment and were paid for their time. During viewing the video clips, the blink appeared frequently, which resulted in a drop in pupil size data (See Figure 2). The estimation model was applied to this observation, the bold line was obtained as output of the model in Figure 2. The blinks in the experimental observation were detected and the pupil sizes were estimated respectively. This model could not however estimate the pupil size in the continuous blinks. It did however reduce the missing value rate for pupil size that was caused by blinks. The models processing of eye blinks managed to reduce the amount of missing pupil data from 20.4% to 1.3%.

As well as eye blinks pupillary change due to screen brightness-'the light reflex' are known to occur. Another MLP which has been developed for the compensation of viewing brightness to extract emotional pupillary change was applied to the data[9]. The performance of the compensation for the brightness was tested by using the analysis of variance measure (ANOVA). To apply the MLP for brightness compensation required a smoothing process. Using this model however pre-processing was not needed. Therefore the performance of the brightness compensation was improved by using the pupil estimation model in the blink. This suggests that the estimation model has a kind of function for the smoothing process.

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3.2. Frequency Analysis

The performance for the frequency analysis on pupillary change was examined. Pupillary change is often analyzed by using the Fourier analysis[3]. The pupilogram has a low pass filter as low as 4Hz because it is a biological signal[10]. Generally it is suggested that most pupil responses are lower than 1.6Hz[10]. Additional pupilograms contain 0.05 – 0.3Hz components which are well known as pupillary noise[10]. As a result pupil responses that are based on emotional or other factors range between 0.3 and 1.6Hz.

Figure 3(a) displays the power spectrum of pupillary change in response to the square wave of light intensity (1Hz). This frequency analysis was conducted with FFT on MATLAB as the DFT (discrete Fourier Transform) of the sequence. There are some spectra lower than 4Hz, it then examined how the pupil responds normally as a low pass filter. This spectrum however contains some noise components because the given stimulus consists of square wave based on a single frequency with some blink artifacts. Figure 3(b) displays the power spectrum which is the processed sequence of pupil response to estimate pupil size in the blink by the compensation model. This figure indicates the reduction of the spectra in higher frequency and it shows the peak spectrum of 1Hz. This suggests that the compensation model suppresses the noise spectra in the frequency analysis.

The frequency analysis was also used on the experimental data, such as that seen in Figure 2. Figure 4 displays the power spectrum with and without the compensation model. For the spectrum without the model processing some noise components are displayed in higher frequency whereas certain noises are removed by using the model processing found in Figure 3. Figure 4(b) shows the frequency for pupil activity. Most spectra appear at a frequency lower than 1Hz. There are however strong power spectra for lower frequencies under 0.3Hz. It suggests that pupillary noise and other lower frequency noise components are observed in the response. Applying the compensation model to pupil response, the frequency components of pupillary change can appear clearly. To extract the emotional component by comparing pupil response spectra between some conditions will be a subject for further study.

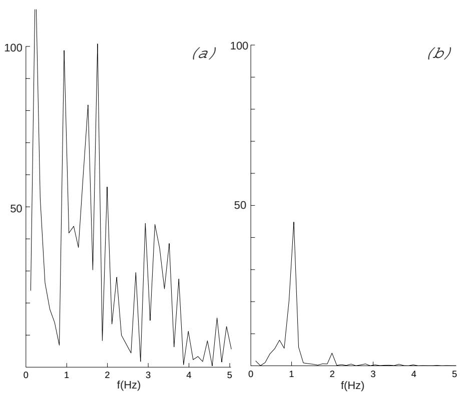

Figure 3: The power spectra for the training data with and without the blink artifact for the pupil size by the frequency analysis.

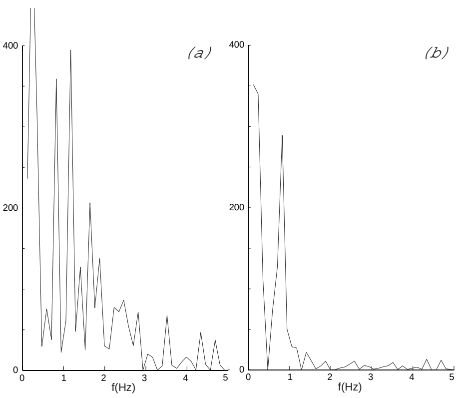

Figure 4: The power spectra for the experimental data and the processed data with the compensation model by the frequency analysis.

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4. Conclusions

This paper describes the compensation model for pupil size in the blink artifact. Firstly, the compensation model for temporal pupil size based on MLP was trained to detect a blink and to estimate pupil size by using blinkless pupillary change and an artificial blink pattern. Secondly, the model was applied to experimental data and its performance was examined. It was found that pupil size could be estimated automatically in most blinks and that the missing rate of pupil size data could also be significantly reduced. The inappropriate power of frequencies were removed in the frequency analysis for temporal pupillary change. This result provides evidence that this model can remove faults from pupil response measurements.

References

[1] Hess E.H., Polt J.M *"Pupil size in relation to mental activity during simple problem solving", Science, Vol.143, pp.1190-1192.* 1964.

[2] Beatty J. *"Task-evoked pupillary responses,processing load, and the structure of processing resources", Phych. Bull., Vol.91, No.2, pp.276-292.* 1982.

[3] Kuhlmann J., Boettcher M. (eds.) *"Pupillography: Principles, Methods and Applications".* W. Zuckschwerdt Verlag, Muenchen, Germany, 1999.

[4] Tada H., Yamada F., Fukuda K.(Ed.) *"Psychological blink (in Japanese)".* Kitaouji shobo, Kyoto, Japan, 1991.

[5] Yoshida H., Yana K., Okuyama F., Tokoro T. *"Respiratory Fluctuations in Pupil Diameter of the Human Eye", IEICE Trans., Vol.J76-D-II, No.3, pp.776-781.* 1993.

[6] Luo F.-L., Unbehauen R. *"Applied Neural Networks for Signal Processing", pp.23-73.* Cambridge University Press, New York, USA, 1997.

[7] Asano S., Yasuike I., Nakayama M., Shimizu Y. *"A Pupil Reaction Model with Neural Network for Brightness Change", IEICE Trans., Vol.J77-A, No.5, pp.794-801.* 1994.

[8] Nakayama M., Shimizu Y. *"An Estimation Model of Pupil Size for Blink Artifact in Viewing TV program", IEICE Trans., Vol.J84-A, No.7, pp.969-977.* 2001.

[9] Asano S., Nakayama M., Shimizu Y. *"A Neural-Network-Based Eye Pupil Reaction Model for Use with Television Programs", Jpn. J. Educ. Technolo. Vol.18, No.2, pp.61-70.* 1995.

[10] Takahashi K., Tsukahara N., Toyama K., Hisada M., Tamura H. *"Neural Networks and Biological Control (in Japanese)".* Asakura shoten, Tokyo, Japan, 1976.