Reconstruction of Eye Movements Signal using Inductive Model Detecting Saccades

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Abstract. *This article describes a method for reconstruction of eye movement signals interfered with saccades and post-determination of inherent frequencies in the signal. For healthy patients, a signal of their eye movements should contain the same frequencies as movements generated by special rotating chair. To determine frequencies in eye movements, saccades have to be removed first. This is not an easy task, because saccades can have various shapes. To detect saccades, we use inductive models trained on various saccadic eye movement signals. To remove saccades and to reconstruct the eye movement signal we wrote special script replacing saccades with estimated trend of signal based on the output of the inductive model. When the reconstructed signal is transformed to the frequency domain, it is easy to decide, whether the eye movements signal contains the same frequencies as the original signal of the rotating chair.*

Keywords

Inductive modeling, biological signals, saccades,
eye movements, frequency analysis.

1 Introduction

Balance disorders of patients can be detected by means of special examination on a rotating chair. In Motol Hospital, Prague, new examination procedure is being prepared. The movement of the rotating chair is superposed from more frequencies. Patients head is fixed to the chair and during rotation the patient is watching a static light point on the wall. During the examination, both signal of eye movements and driving signal of rotating chair are recorded.

Eye movement signals contain correction movements, so called “saccades”, bringing the observed target back to the visual field of the patient (see Figure 1.1.). The aim is to find out, if eye movements of patient contain the same frequencies as the driving signal of rotating chair – in other words, if the patient is able to track the stimulus (light point).

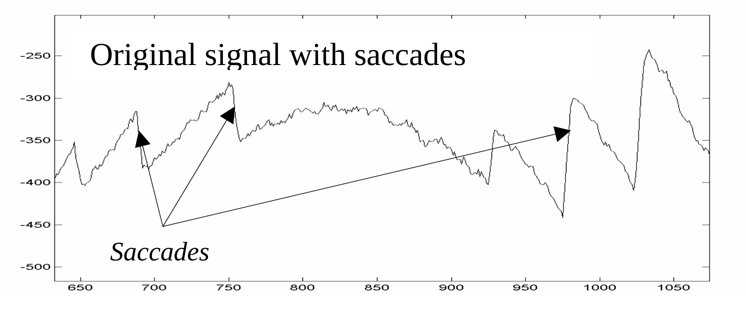

Fig. 1.1. Example of eye movement signal with saccades. The center part of this picture is without saccades, while parts on left and right side contain saccades.

The analytic tool used in Motol Hospital to evaluate eye movement signals simply transforms measured signals to the frequency domain. The problem is that saccades disturb the frequency spectrum of eye movements' signal; therefore it is necessary to filter them out.

The goal of our research is to develop a tool that will automatically remove disturbances (saccades) from the eye movement signal. The tool has to be robust enough to handle data from patients with balance disorders and signal with several stimulation frequencies interfered.

2 Process of reconstruction

The eye movement signal is reconstructed in three steps: training data synthesis, identification of saccades and the reconstruction (removing the disturbances, filling out estimated values).

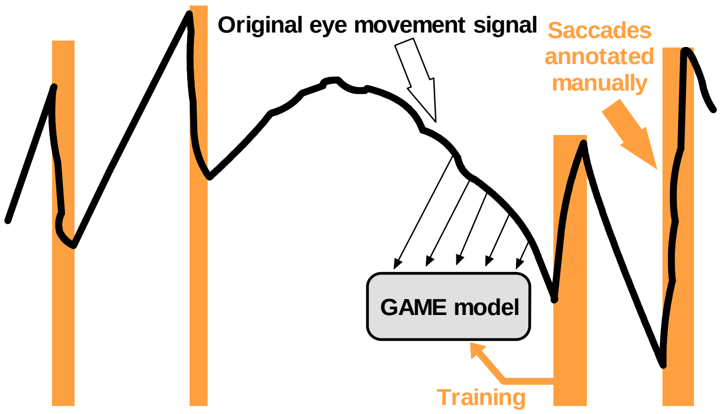

Fig. 2.1. Saccades are manually annotated and the original eye movement signal together with the annotation is used to prepare the training set for GAME method.

The first step is to prepare the training data. The key task is to annotate the saccades in the eye movement signal. For this we purpose are using a program which allows us to manually annotate the saccades in signal and save this information as a target signal for training. We prepare training data set consisting of several samples of eye movement signal as input variables and presence of saccade as the output.

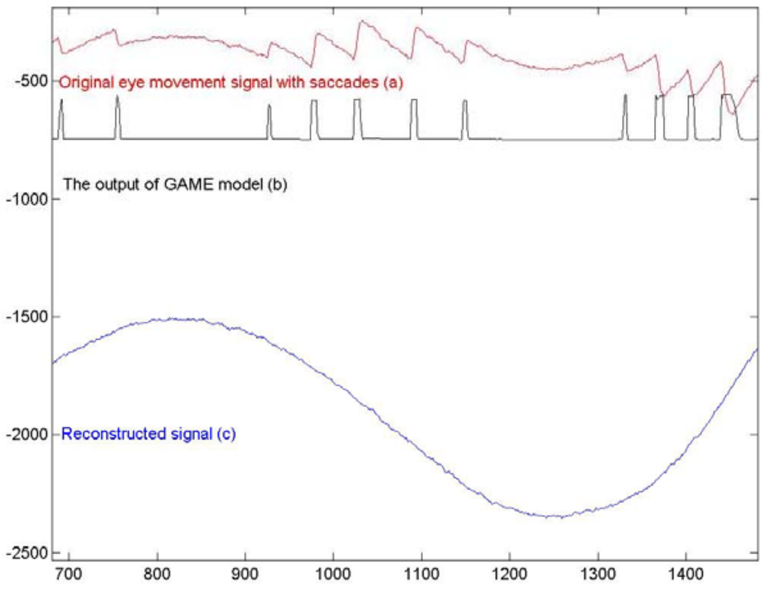

Fig. 2.2. The original signal (a), the output of GAME model (b) and reconstructed signal (c).

In the second step the data set is used to generate inductive models using the GAME method [2]. Generated GAME model in fact acts as an automatic annotator of saccades.

In the third step we reconstruct the signal using a script, which have two inputs (original eye movements signal and GAME model saccade estimation) and one output, the reconstructed signal. The method of reconstruction is based on information about signal character in the neighborhood of saccades. When saccade is estimated, the original signal is replaced with linear approximation of trends in the beginning and the end of saccade. The original eye movement signal with saccades (a), the output of the GAME model (b) and the reconstructed signal (c) are displayed on the Figure 2.2.

The first stage – removing the saccades from the eye movement signal was successful. The reconstructed signal still contains some disturbances – in our case high frequency noise.

To remove this noise, we can use a filter. When the signal is filtered out, it can be transformed into frequency domain to check, if it contains stimulation frequencies. These operations are described bellow.

3 Frequency analysis of original and reconstructed signals

For the filtering operation we choose the smoothing filter Sawitzky-Golay [3] because it can be parameterized to avoid deforming signal in low frequencies. The result of the smoothing is very good (see Figure 3.1). The high frequency disturbances were completely removed from the signal.

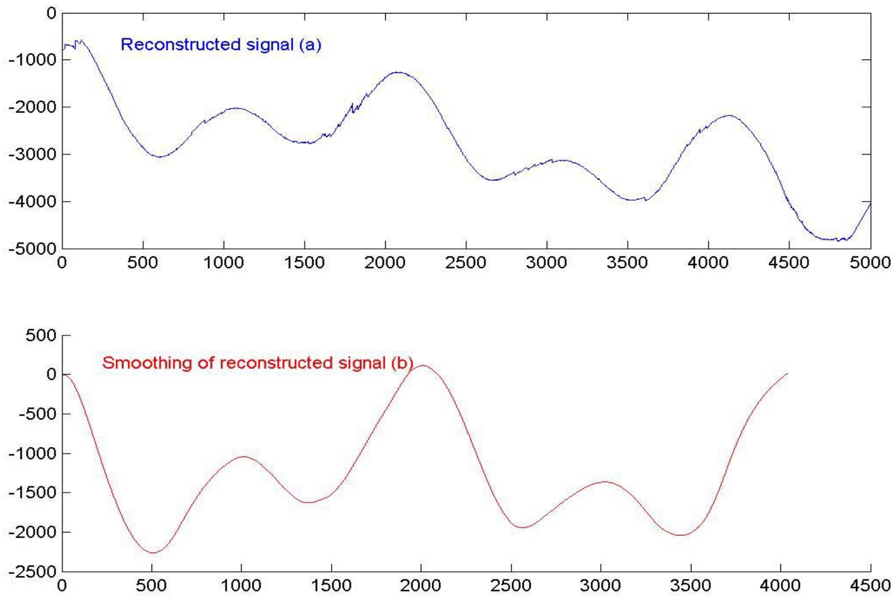

Fig. 3.1. Reconstructed signal (a) and smoothed reconstructed signal (b).

After the filtering, the signal can be transformed into the frequency domain to check out if it contains the frequencies of the stimulation (rotation of the chair).

Eye movements of healthy subjects should contain all frequencies used for the stimulation. The Figure 3.2 shows the original and the reconstructed signals in the frequency domain.

At first we were unable to locate any frequencies in the reconstructed signal, later we have truncated the signal to the length of the period and the FFT [4] revealed peaks in the reconstructed signal.

The Figure 3.2 also demonstrates that the location of the stimulation frequencies would be impossible without the reconstruction of the eye movement signal.

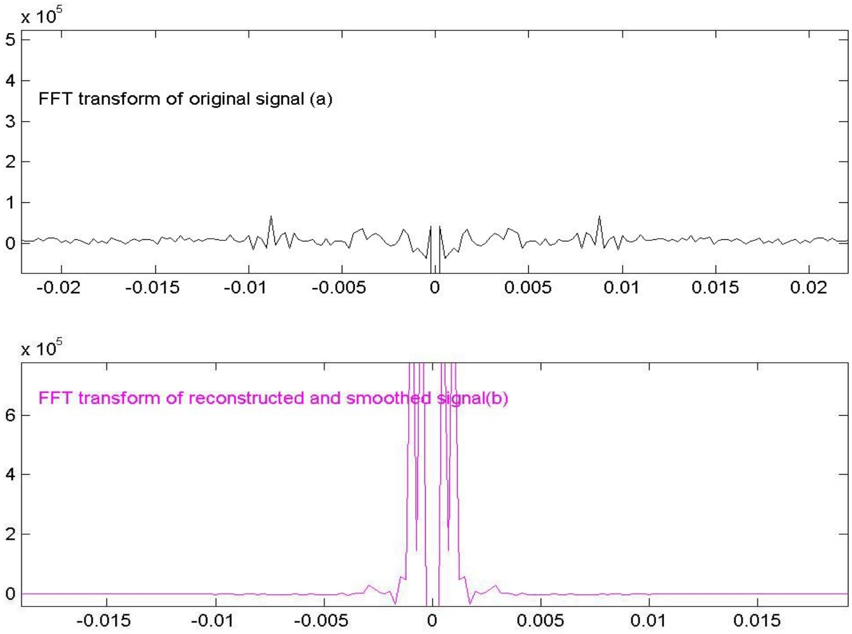

Fig. 3.2. FFT transform of original (a) and reconstructed signal (b).

When you look at the Figure 3.2, you can observe two peaks in the FFT of the reconstructed signal (in fact four peaks because of FFT symmetry). In the frequency domain of the original eye movements' signal no peaks are apparent.

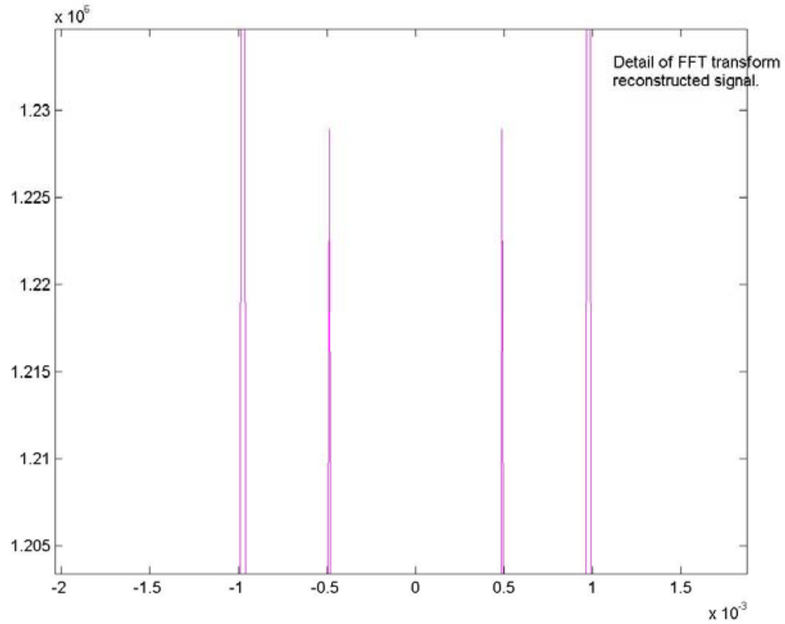

Fig. 3.3. Frequencies of the rotating chair can be found in the reconstructed signal.

The data are taken from the examination where a patient was sitting on the chair rotating at combined frequencies 0.1 and 0.05 Hz. These frequencies can be found also on the Figure 3.3, where the relevant part of the previous figure is displayed in detail.

The stimulation frequencies 0.1 and 0.05 Hz were successfully located in the eye movement signal that was treated by techniques described above.

4 Conclusion

In this paper we presented successful medical application of the inductive modeling. We trained the GAME inductive model to detect saccades in the eye movements' signal. Subsequently we used this model to filter out saccades and reconstructed signals. In reconstructed signals as against to the original ones, we are able to detect frequencies of the rotating chair. This allows experts to recognize abnormal eye movements of patients with balance disorders.

5 Acknowledgements

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