Review of simple SSVEP evaluation FFT based algorithms

Stanislav Stančík, Radoslav Vargic
Faculty of Electrical Engineering and Information Technology STU in Bratislava
radoslav.vargic@stuba.sk

Abstract – **One of promising BCI based system is SSVEP (Steady-State Visual Evoked Potential). There is variety of methods to feature extract and classify information from obtained EEG signal. This paper presents several methods where FFT and PSD based methods were used. The results show that simple FFT algorithms can achieve very high accuracy without need to use more complex classification methods**.

Keywords – **BCI; SSVEP; FFT; PSD**

I. Introduction

Brain-Computer Interface (BCI) has a great potential in variety of technological uses, as in medical, educational, entertainment or device control areas. One of promising BCI systems is SSVEP (Steady State Visual Evoked Potential) due to its inexpensive and small size equipment required for use. This method is based on brain activity, specifically electroencephalography (EEG) signal. In noninvasive applications, signal is recorded or measured by electrodes placed on back of the head where visual cortex is located. This provides option such as to control devices only due to flickering frequency stimulation which is useful especially in medicine as speller for paralyzed patients (method P300) [1].

In BCI in general the signal is pre-processed, features are extracted of him and classified afterwards. There is number of ways to execute mentioned steps, varying from simple to more complex [2, 3, 4, 5].

This paper introduces several FFT and PSD based methods with minimal preprocessing and several simple evaluation algorithms. For comparison, another study [6] from 2016 is used, where evaluation method based on simple FFT is used.

II. Data aquisition

For testing and comparison purposes, free available AVI SSVEP dataset of EEG signal [7] is used. Here, four healthy subjects were exposed to flickering targets of various frequencies to trigger SSVEP responses. Specifically 6, 6.5, 7, 7.5, 8.2, 9.3 and 10 Hz. Each stimulus lasted 30 seconds and at least three recording for each frequency on each subject were carried out. Data were recorded using three electrodes (Oz, Fpz, Pz). The signal electrode is placed at Oz while reference is at Fz and ground at Fpz using the standard 10-20 system for electrode placement. The only processing applied on the data is an analog notch filter at the mains frequency (50 Hz). Sampling frequency was 512 Hz.

As a second dataset (SS SSVEP), for accuracy testing, EEG signal by exposition to very same frequencies was recorded. Again, four healthy subjects were exposed to stimulus. Each stimulus lasted 15 seconds and three recording were carried out for each frequency. Two signal electrodes were placed at Oz and O2, while ground and reference electrodes were placed at ear globes. Data were recorded using OpenBCI Ganglion board HW and BrainBay, third party software. The 50 Hz filter within software was applied. Sampling frequency used was 200Hz.

After evaluation, second electrode (O2) was not considered as results were degraded by it consistently varying from 5% to 20% for different frequencies.

III. Feature extraction and classification

In this section the evaluation methods are described.

Most common feature extraction method in SSVEP is realized by performing FFT of a signal. Fast Fourier transform computes DFT of a sequence, therefore converts signal from time to frequency domain. Response of recorded EEG signal of visually evoked frequency ought to have highest peak in frequency domain diagram after applying FFT.

All evaluation methods were applied to full length samples. First harmonics "1.h" is considered in most of methods. Extension of some methods is considering second harmonics "2.h" (peak, prominence and PSD methods) as measurement also.

Another extension for each method is exponentiation "^2" (second squaring) of spectral values. Using second square roots of values was also considered but decreased accuracy in every case, therefore is not presented.

Several methods based on FFT were developed to measure accuracy of frequency classification. FFT methods are based on Matlab function 'max', which finds maximum peak and afterwards, its position on y - axis is found/calculated, providing exact frequency. First, the range of frequency classes were set as stated in Table 1.

First harmonics frequencies are also considered in most methods, therefore base frequency doubles and range remains the same (6 Hz; 11.75 – 12.25 etc.). Same goes for second harmonics.

TABLE I. FREQUENCY RANGE

Base frequency	*Range*
6 Hz	5.75 - 6.25 Hz
6.5 Hz	6.25 - 6.75 Hz
7 Hz	6.75 – 7.25 Hz
7.5 Hz	7.25 – 7.85 Hz
8.2 Hz	7.85 - 8.75 Hz
9.3 Hz	8.75 - 9.65 Hz
10 Hz	9.65 - 10.35 Hz

A. Max

1) 'Max A'

First method excludes all maximum frequencies out of range 5.75 – 10.35 Hz. If peak is found outside this range, it is replaced by 0 value, and another peak is being found until it can be classified within borders.

2) 'Max A / 1.h'

In this method, if highest found peak belongs to evoked frequency or its first harmonics, it is considered as right outcome.

3) 'Max A + 1.h (+ 2.h)'

This method finds max peak in every considered range and sums spectral value of base frequency and its first harmonics (or also second). Group with maximal value is found afterwards.

B. PSD

Based on FFT, another often used feature extraction method is calculation of Power Spectrum Density. In this case, range of all frequencies are adjusted to have the same length, which is +-0.25 for each (8.2; 7.95 – 8.45, 10; 9.75- 10.25 etc.). PSD in this case is considered as sum of FFT values within given range.

1) 'PSD A'

First PSD method finds band with the highest PSD value.

2) 'PSD A / 1.h (/2.h)'

In this method, highest PSD sum value belonging to band of evoked frequency or its first harmonics is considered as successful outcome.

3) 'PSD A + 1.h (+ 2.h)'

Band values of base frequency and its first and second harmonics are summed and group with highest value is taken as correct outcome.

C. Aditional methods

Two additional methods were tested. One of them was based on giving points to peak in every range. Second method was based on Matlab function findpeaks, which considered signal as mountain where each peak has its prominence [8] that can be considered as gain against ground, smaller or parent peaks.

1) 'Prominence A'

Highest prominence in base frequency range was found, similarly to 'Max' method.

2) 'Prominence A / 1.h'

Highest prominence within base and harmonics range was found. If base frequency or its harmonics prominence was the highest one, it was considered as winner.

3) 'Prominence A + 1.h + 2.h'

Highest prominence in each range was found and prominences from base and harmonics (first and additionally second) were summed. Groups were then compared and group with highest value was found.

4) 'Teams'

In each range, base and first harmonics frequency, largest peak was found and given maximum points that were 14 in this case. Smaller peak obtained 13 points and so on, therefore the smallest one obtained only one point. Team consisting of base and harmonics had its points summed and afterwards team with highest score was found.

IV. EVALUATION OF RESULTS

Each dataset contained target frequency information that was used for evaluation. Samples were compared to target frequency, and all right-classified samples were divided by total number of measured samples giving accuracy percentage. Therefore, methods using STFT consist of bigger number of results. For better legend understanding, if method using second harmonics has same results as method using only first harmonics, second harmonics indication is placed in parenthesis "(+2.h)". Same goes for "(+)" and "(/)" and exponentiation "(^2)" methods/extensions.

A. AVI SSVEP DATASET

All methods were developed, tested and applied on AVI SSVEP DATASET with varying results on different subjects.

1) Method 'Max'

Methods are compared with results ("comp") from [6] as FFT peak value was also used as decisive factor in Fig. 1. In this case, exponentiation and second harmonics had no effect on decision accuracy.

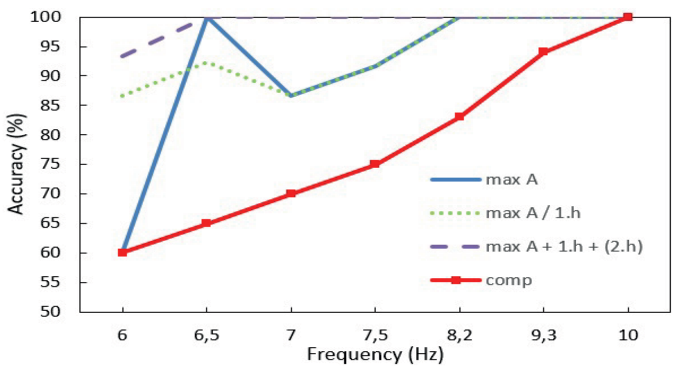

Figure 1. Comparison for group of 'Max' methods

2) Method 'Prominence'

Using second harmonics for decision making based on prominence proved to slightly improve results as shown in Fig. 2. Also, exponentiation of FFT improved results for methods 'Prominence A' and 'Prominence A/1.h' with one case of accuracy decrease for one frequency for the latter method.

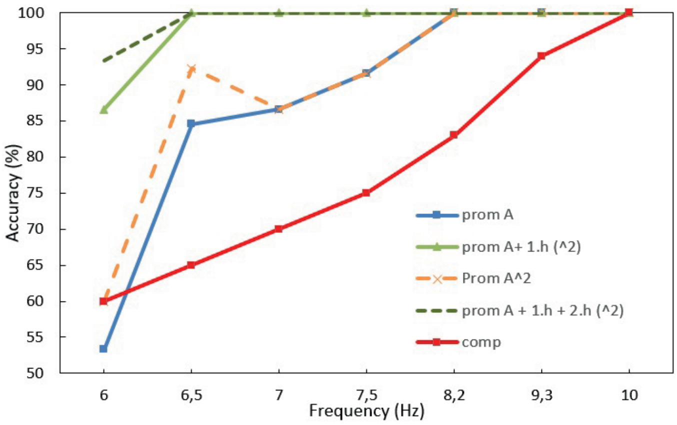

Figure 2. Comparison for first group of 'Prominence' methods

3) Method 'PSD'

Using second harmonics had no effect on method 'PSD A/1.h' as shown on Fig. 3 but had slightly improving effect on method 'PSD A + 1.h' as seen in Fig. 4. In this case, exponentiation of values had positive effect in case of 'PSD A' and 'PSD A + 1.h (and also + 2.h)' visible in both figures.

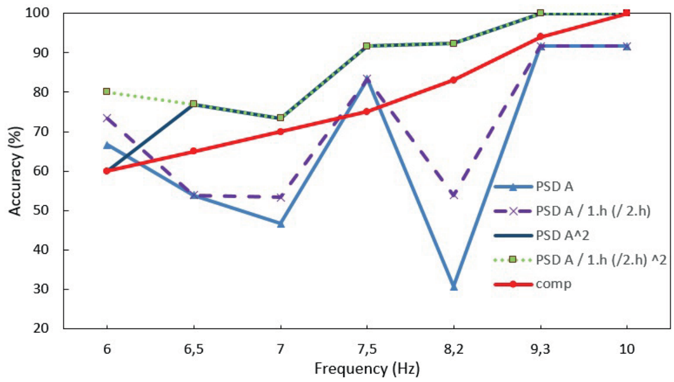

Figure 3. Comparison for first group of 'PSD' methods

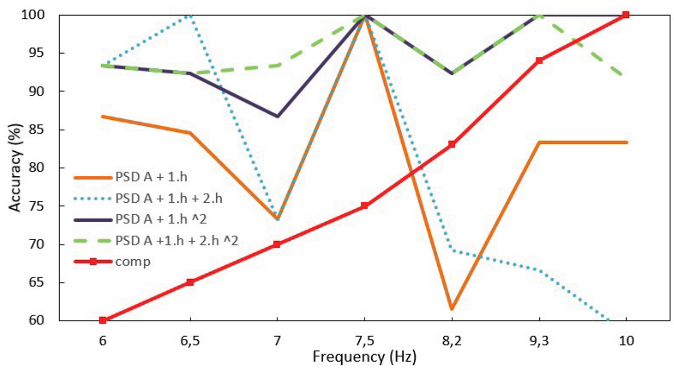

Figure 4. Comparison for second group of 'PSD' methods

4) Method 'Teams'

Last method had also good results varying above 90% for each frequency. Exponentiation of FFT values had no effect.

In Fig. 5, comparison of methods of each type with best results is shown, including last method 'Teams'.

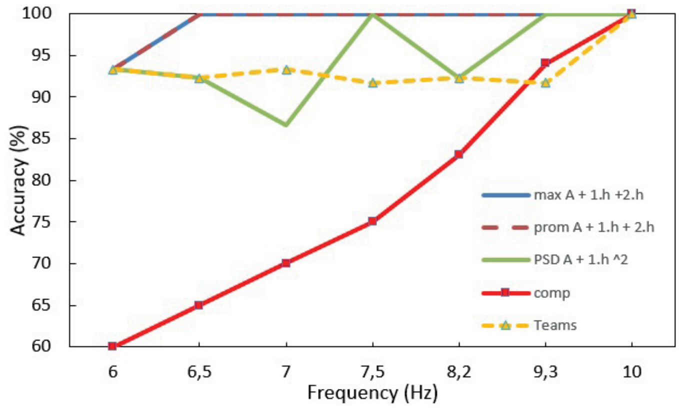

Figure 5. Comparison for best methods of each type

B. SS SSVEP DATASET

Same methods were applied on SS SSVEP dataset. Results of 'Max', 'Prominence' and 'PSD' methods are shown on Fig. 6, 7 and 8. Applying exponentiation had slightly positive effect on 'PSD A' and 'PSD A + 1.h + 2.h' methods only as shown on Fig. 8.

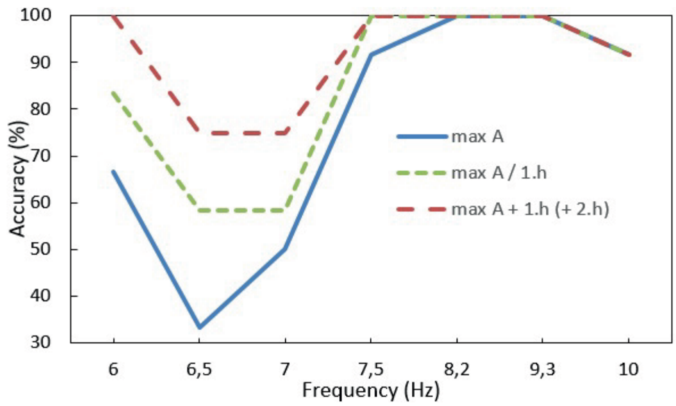

Figure 6. Results of 'Max' methods.

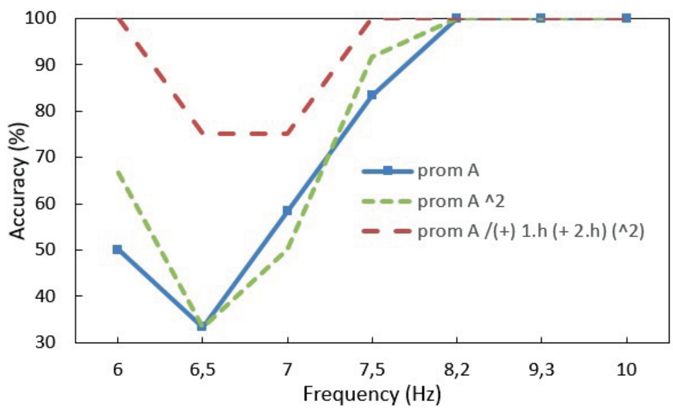

Figure 7. Comparison for 'Prominence' methods

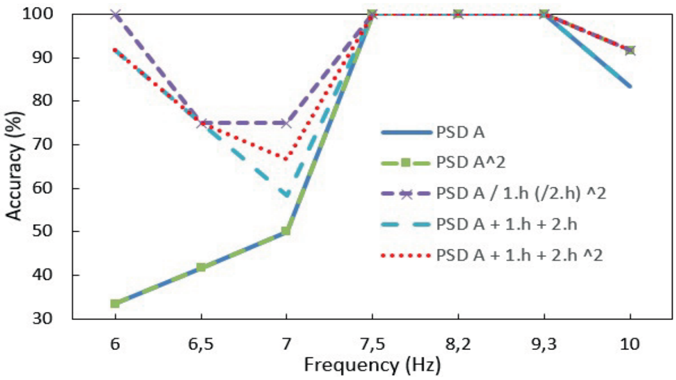

Figure 8. Comparison for 'PSD' methods

Comparison for best methods applied on SS SSVEP DATASET is shown on Fig. 9.

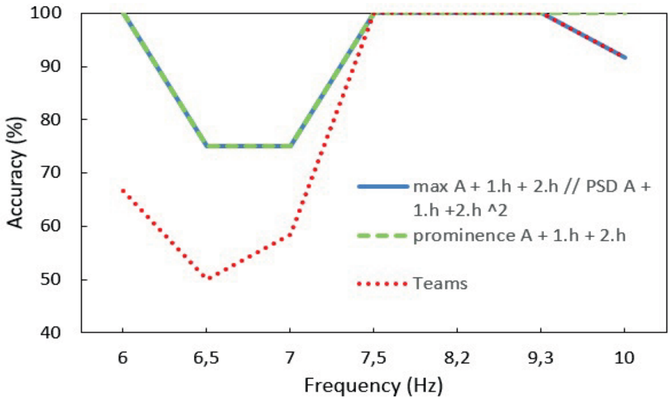

Figure 9. Comparison for best method of each type

C. Both dataset comparison

Best methods of each type were compared on both datasets and results are shown on Fig. 10. For comparable length, only first 15 seconds from each AVI SSVEP sample was used. Overall mean accuracy was 94,14% for AVI dataset and 91,27% for SS dataset, concluding that AVI dataset was slightly better for 15 seconds length time window.

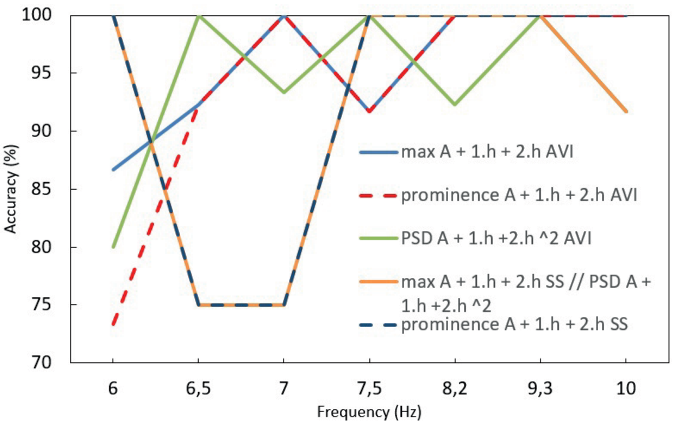

Figure 10. Comparison for best method of each type on each dataset

Lastly, two best evaluation methods were chosen and compared on both datasets in Fig. 11. In this case, spectral values were evaluated using STFT of various length and 1 second shift. Length of this windows is 1, 3, 5, 15 and 30 (only for AVI SSVEP) seconds as shown on X-axis.

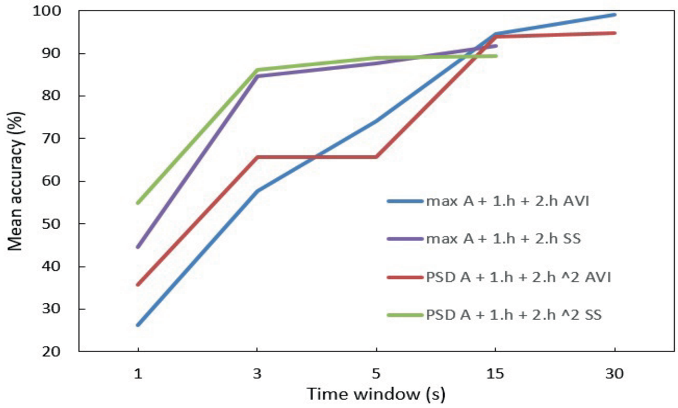

Figure 11. Comparison for two best methods on each dataset

V. CONCLUSION

This paper presented a review of several FFT based methods used to detect and classify evoked frequency based on SSVEP. For this purpose, another dataset was recorded. The results show that high accuracy can be obtained only by performing basic FFT and simple evaluation methods, in comparison with more complex algorithms where other processing and classification steps are used. Also, multiple algorithms provided better results than those of compared study [6]. Based on last comparison graph for both datasets and various time windows, best evaluation method was 'PSD A + 1.h + 2.h ^2' and better accuracy results were achieved on SS dataset.

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REFERENCES

[1] A. Haider, R. Fazel-Rezai, Application of P300 event-related potential in brain-computer interface. 2017

[2] Z. Lin, Ch. Zhang, W. Wu, X. Gao, Frequency recognition based on canonical correlation analysis for SSVEP-based BCIs. IEEE Transaction on Biomedical Engineering, vol 53, June 2007.

[3] B. Guragain, A. Haider, R. Fazel-Rezai, "Hybrid brain-computer interface systems: Approaches, features and trends," in Evolving BCI therapy, IntechOpen. October 2018.

[4] T. Raduntz, J. Scouten, O. Hochmuth, B. Meffert, EEG artifact elimination by extraction of ICA-component features using image processing algorithms, February 2015

[5] E. Parvinnia, M. Sabeti, M. Zolghadri Jahromi, R. Boostani, Classification of EEG signals using adaptive weighted distance nearest neighbor algorithm, King Saud University, January 2013

[6] S. Sheykhivand, T. Yousefi Rezaii, A. Naderi Saatlo, N. Romooz. Comparsion between different methods of feature extracion in BCI systems based on SSVEP. In *Int. J. Undustrial Mathematics*, volume 9, 2017.

[7] AVI SSVEP DATASET, Avilable at: http://www.setzner.com/avi-ssvep-dataset/

[8] Prominence, Avilable at: https://www.mathworks.com/help/signal/ug/prominence.html