Outcome of the BCI-competition 2003 on the Graz data set

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Abstract:

The submissions for the BCI competition 2003 to the Graz dataset are evaluated.

Results:

Nine results were submitted from 7 groups. One submission contained only class labels for each trial, no continuous information in magnitude nor in time. For this reason, no time-variation could be obtained.

Table 1: Submitting groups

#	Authors	From
A	GAO Xiaorong, JIA Wenyan, Zhao Xianghua, GAO Shangkai, YANG Fusheng	Tsinghua University, Beijing
B	A.R. Saffari, T. Emami, S. Ashkboos	Sahand University of Technology, Tabriz, Iran
C	Christin Schäfer, Steven Lemm	Fraunhofer FIRST Institut & Universtitätsklinikum Benjamin Franklin, Berlin
D	Jorge del Río Vera,	Spain
E	Thorsten Zander, Guido Dornhege, Benjamin Blankertz	FIRST FhG, Berlin
F	Akash Narayana, Mohan Sadashivaiah, Raveendran Rengaswamy, Shanmukh Katragadda	DaimlerChrysler Research & Technology India Pvt Ltd.
G	Mohan Sadashivaiah, Akash Narayana, Raveendran Rengaswamy, Shanmukh Katragadda	DaimlerChrysler Research & Technology India Pvt Ltd
H	Juma Mbwana, Mark Laubach	Yale University
I	Dan Rissacher	Winooski, VT

Figure 2 shows the time courses of the error rate, the mean and standard deviation for both classes and the mutual information (MI) (as described in [1-2]) for all submitted results. Table 2 summarizes the most prominent results (minimum error, maximum SNR, maximum mutual information, an time T where MI is a maximum).

[1] SNR can be estimated with 1/4*(mean2-mean1).^2./var(noise) [1-2]; but (mean2-mean1).^2./var(noise) was used in the first version. For this reason, the mutual information (MI) had to be re-evaluated and smaller absolut values are obtained.

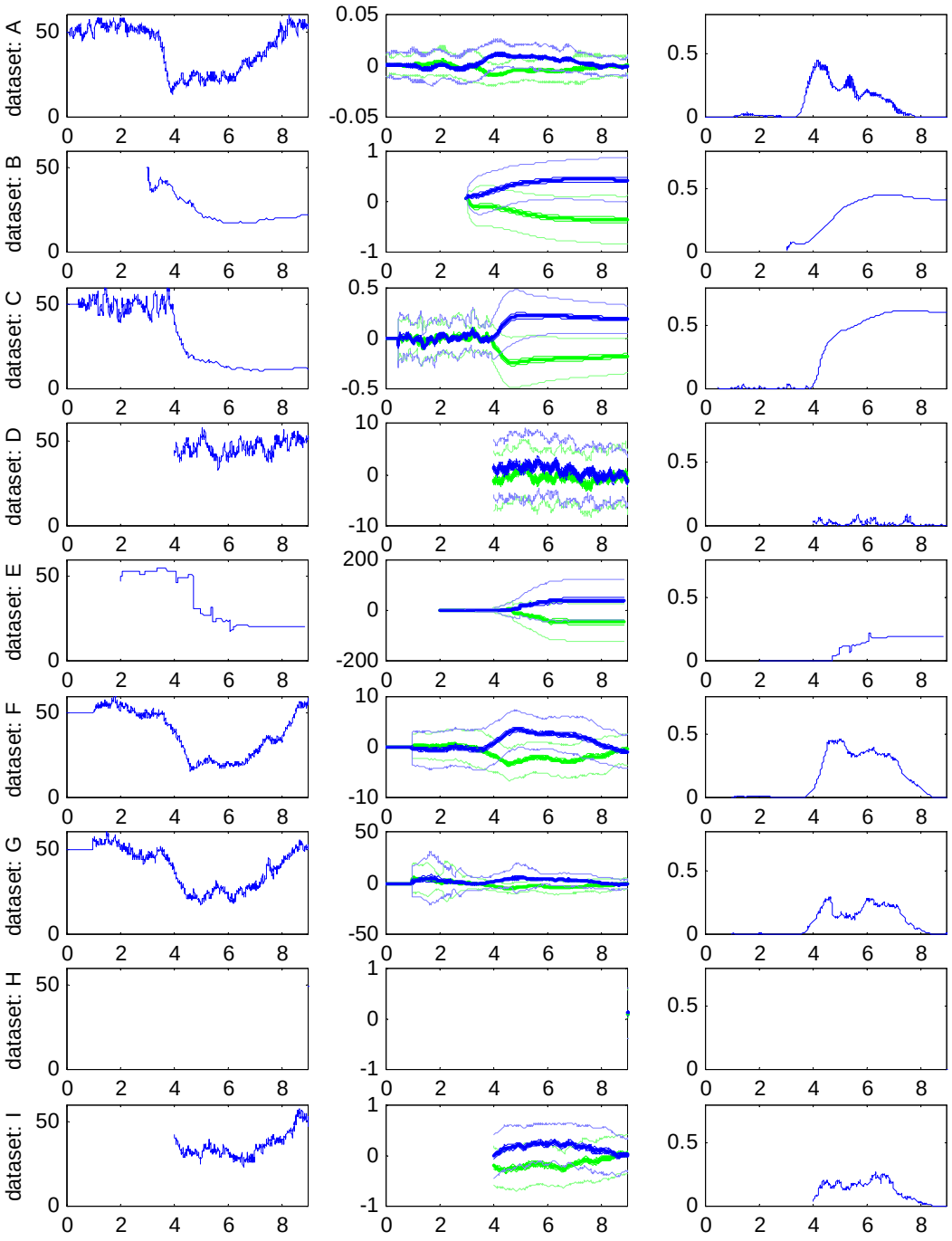

Figure 1: Time courses. The first column shows the time course of the error rate, the second column shows the time course of the mean, standard error and standard deviation for two classes; the third column displays the time course of the mutual information in bits.

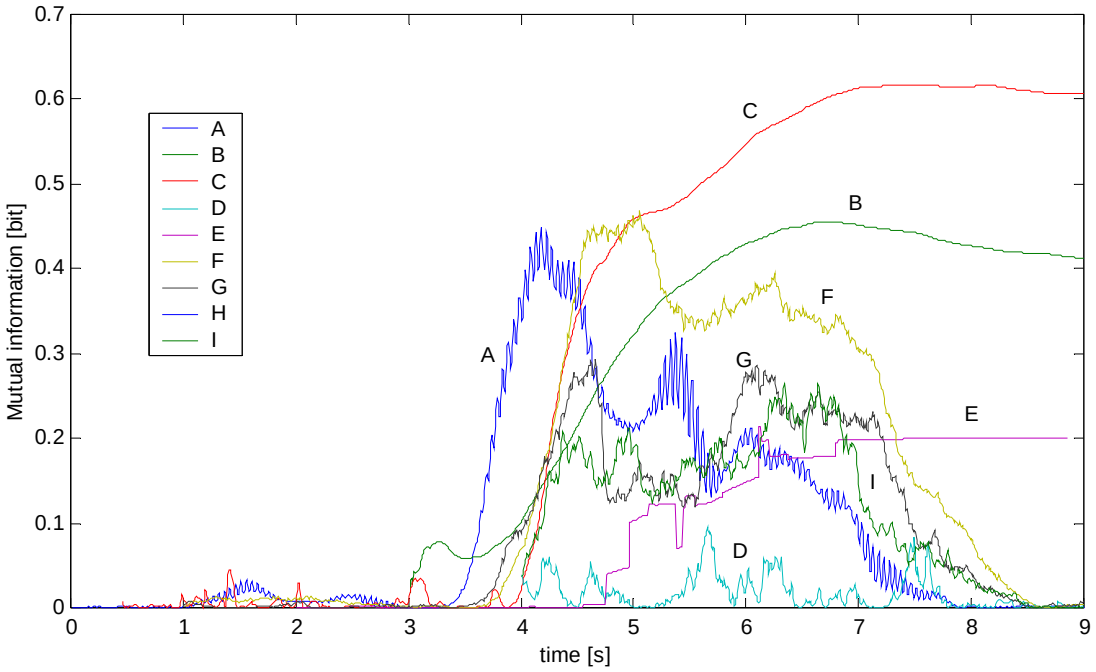

Figure 2: Comparing the time courses of the mutual information.

Table 2: Summary result and ranking

Ranking	group	minimum Error [%]	maximum SNR [1]	**maximum MI [bit]**	classification time T [s]
1	**C**	**10.71**	**1.34**	**0.61**	**7.59**
2	F	15.71	0.90	**0.46**	5.05
3	B	17.14	0.86	**0.45**	6.70
4	A	13.57	0.85	**0.44**	4.18
5	G	17.14	0.50	**0.29**	4.66
6	I	23.57	0.44	**0.26**	6.34
7	E	17.14	0.34	**0.21**	6.13
8	D	32.14	0.14	**0.09**	5.66
9	H	49.29	0.00	**0.00**	9.00

Figure 3 compares the time courses of the mutual information. A shows a steep increase of the MI between t = 3.5 and 4.2 s up to 0.45 bits. B starts even earlier (at t = 3.0 s), but decreases again; then a slow increase up to 0.45 bit is reached at t = 6.7 s. C starts increasing at t = 4.0 s, reaches 0.46 bit at t = 5.0 s and continuous up to 0.61 bit. This is the largest mutual information obtained. D reaches only 0.09 bits at t = 5.66 s. The method E starts of only at t = 5 s, reaching a maximum of 0.21 bits at t = 6.13 s. The method F has a steep increase similar to A 0.5 s later than A and reaches also a maximum of 0.44 bits. Because of the similarity, it can be assumed that A and F use a very similar property of the EEG [the delay might be explained when the different delay times are considered]. G and I reach 0.26 and 0.21 bits at

t = 4.66 s and 6.34 s, respectively. This is also not a bad result, but stays behind the top performer. H did not provide any time information, also the result did not correlate with the true classlabels.

Discussion

It is quite common to use the error rate for comparing different methods. However, the error rate takes into account just the sign of the classifier output but not the magnitude. For this reason, the mutual information is used to compare the different results [1,2].

Also the question must be addressed whether we want take into account the time delay or not. The time-delay does not matter in offline analysis, but if we want to provide online feedback as fast and as accurate as possible, any time delay becomes important. For the former analysis we need to compare just the maximum separability of the data; for the later analysis the steepness of the increase of mutual information is of interest.

When we compare the steepness, we see that methods A, C and F have a similar steepness. Method A is 0.5 s earlier, but this might be caused by a non-causal filter, in real-time processing, we have to add this 0.5 s. Method I has a similar steepness, but does not reach a comparable maximum, G is starts earlier the increase is not as steep. Method B shows an interesting phenomenon; it starts already at t = 3 s, reaches its first peak at t = 3.3s, decreases and starts a slow increase. Due to physiological considerations, the first peak cannot represent deliberately acting because conscious brain activity requires more time. The first peak, probably, reflects a stimulus response. For this reason, only the second and larger peak must be analysed. Here, the methods A, C, F, and for a short period even G, are superior to B. In summary, the methods A, C and F provide the fastest increase in mutual information; also method G should be investigated further, because of its early start.

Since, this is an offline analysis and obviously not all results are based on causal algorithms the time delay of the different methods can not be compared. Hence, the final evaluation criterion is based on the maximum separability. According to this criterion, method C performed best. Christin Schäfer and Steven Lemm submitted the best result with an mutual information of 0.61 bits (error = 10.7 %) (Table 3).

References:

[1] Schlögl A., Neuper C. Pfurtscheller G.
Estimating the mutual information of an EEG-based Brain-Computer-Interface
Biomedizinische Technik 47(1-2): 3-8, 2002

[2] A. Schlögl, C. Keinrath, R. Scherer, G. Pfurtscheller,
Information transfer of an EEG-based Bran-computer interface.
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