Analysis and Processing of Brain Signals

Galina S. Panayotova and Georgi P. Dimitrov
University of Library Studies and Information Technologies, Sofia, 1784, Bulgaria
Email: panayotovag@gmail.com

***Abstract*—Brain-computer interface (BCI) allows users to control many external devices through brain signals. These signals can be recorded by brainwave controlled applications, such as EMotiv Epoc +14, however the reliable translation of users brains' information is still a big challenge. It requires the effective interaction between the information produced by user's brain activity and the BCI system, which translates that activity into the digital signals and an appropriate algorithm to translate the brain signals to commands. Brain signal analysis and techniques are widely explored in order to improve the adaptation of the BCI system to the user. This article is focused on the analysis and processing of the received brain signals. Data are obtained within a research which explores the capabilities of Arduino robot management through brain signals from BCI.**

***Index Terms*—sensors, brain-computer interface, processing two signals, big data, data processing, emotive**

I. Introduction

The main goal of this study is focused on the analysis of the signals received from the Brain-computer interface (BCI), and processed by the Arduino robot. It would help for developing mathematical apparatus and algorithms to be used in improving the work of some electrical devices, such as wheelchair and other similar devices needed by people with reduced abilities [1], [2]. Unfortunately, the standard interface, which is distributes with the BCI devices has a limited number of commands. For the purposes of this research our team analyses the signals received from the BCI, which correspond to the minimum required signals for driving a car. We have determined 8 (eight) simplified base commands - START, STOP, LEFT, RIGHT, FORWARD, BACKWARD, FASTER, SLOWER.

The architecture of the proposed system is very simple and depicted in Fig. 1. It comprises of:

- An EEG headset Epoc 14+ or Epoc 5+ insight
- A PC software
- Camera (in this case – RunCam2)

We have a licensed copy of the EMOTIV Cortex SDK software, which provides an access to the raw EEG data. Cortex is an API powerhouse for creating BCI applications and integrating data streams from headsets with a third party software. Built on JSON and Web Sockets, Cortex makes it easy to record data for experiments. Cortex is a wrapper around Software Development Kit (SDK) and houses all the tools required to develop with EMOTIV [3].

Figure 1. Map of the electrodes in Epoc Insight 5 channels.

Signals which are generated from the brain in the form of EEG are sensed by the 5 sensors of EMOTIV Insight device [4]. This device can discern 5 signals (Fig. 2):

- AF3 – Attention
- T7 – Verbal memory
- Q1 – Visual Processing
- T8 – Emotional memory
- AF4 – Judgment

Figure 2. Map of the electrodes in Epoc Insight 5 channels.

Figure 3. Brain Serv – Faster.

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EEG data are picked up by the sensors, which in turn allow the data to be sent through Bluetooth to the computer [5]. The received signals are sent to the database. It is to be mentioned that one application was developed by the Software Laboratory. This application has plenty of properties such as: to record BIG DATA, which is the case with the row data received from BCI, to provide pictures, to provide streaming video clips and other analytical outputs. Fig. 3 and Fig. 4 show BCI images at FASTER and SLOWER.

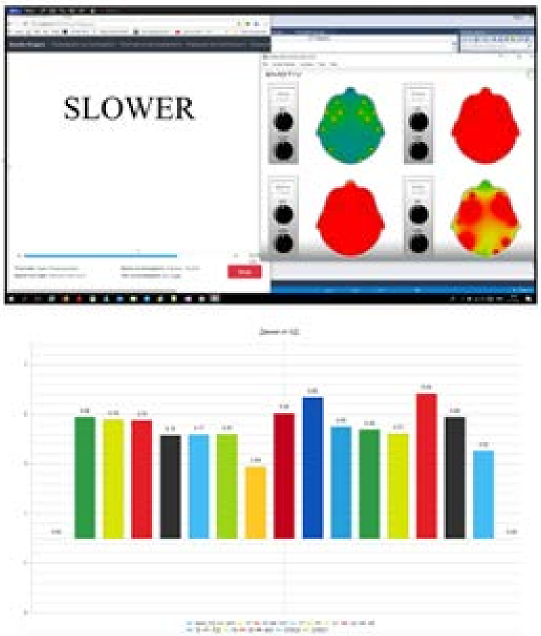

Figure 4. Brain Serv – Slower.

Based on the received data which correspond to the faster and slower signals the **main goal** of the study is to analyse and determine the differences between the Faster and Slower signals and to define the specific peculiarities for each signal individually.

II. Background Theory

Mathematical models process data received from a real physical object [6]. It could be introduced as the following functional system:

$$\Phi_i(X, Y, Z, t) = 0,$$

where X is the vector of input variables,

$$X = (x_1, x_2, \ldots, x_n)^t,$$

Y is the vector of output variables,

$$Y = (y_1, y_2, \ldots, y_n)^t,$$

Z is the vector of external impacts,

$$Z = (z_1, z_2, \ldots, z_n)^t,$$

t is the coordinate of time.

In most cases, the object is determined by a n-dimensional vector of characteristics

$$X = (x_1, x_2, \ldots, x_n)^t,$$

where x_j corresponds to the jth characteristics which we observe. They form a matrix X of type $n \times \rho$ which rows and columns are independent. Then we create the data matrix or study matrix which rows are the observations of the survey characteristics, while the columns present the variables of the study.

The article will use the multivariate scattering analysis (MANOVA). The model allows for classification, regression, data visualization, finding regularities and identifying common characteristics of a group of objects [7].

In statistics, **multivariate analysis of variance** (**MANOVA**) is a procedure for comparing multivariate sample means. As a multivariate procedure, it is used when there are two or more dependent variables, and is typically followed by significance tests involving individual dependent variables separately. It helps to answer:

- Do changes in the independent variable(s) have significant effects on the dependent variables?
- What are the relationships among the dependent variables?
- What are the relationships among the independent variables?

The obtained data are analyzed with Matlab.

III. Research Methodology

The data used are collected by the BCI experiments and later analyzed offline. Real-time data captured by the 5-channel EMotiv Epoc has been also used. In real time the signals received from the Epoc are transferred via Bluetooth into the computer. Each trial is transformed to 129 rows of data into the database. The count of the records is shown on Table I. The data are obtained with SDK tool, provided by Emotiv (github.com/Emotiv/ community-sdk). The collected information for the experiment, the commands, raw data and screen capture are recorded at the same time into the database. Finally, data are exported and processed using MathLab environment [8], [9].

The article analyzes data which correspond and process two signals: Faster and Slower. The data obtained are given in Table I.

TABLE I. Number of Experiments and Row Data

WORD	count of experiments	Count of RAW data
Faster	148	24800
Slower	136	27340

Denote:

- x_1 – AF3 data;
- x_2 – T7 data ;
- x_3 – Q1 data;

- x_4 – T8 data;
- x_5 – AF4 data;

The monitoring system is defined as an ordered 5-dimensional vector

$$x = (x_1, x_2, ..., x_5),$$

where x_j (j = 1, ..., 5) corresponds to the data from the respective channel [10], [11].

IV. Analysis of BCI Signals: Faster and Slower

Fig. 5 shows a graph based on the values collected of the Faster and Slower signals in Matlab environment.

```
>> plot(AF4(:,1))
>> hold on
>> plot(AS4(:,1))
>> AF4F=1
```

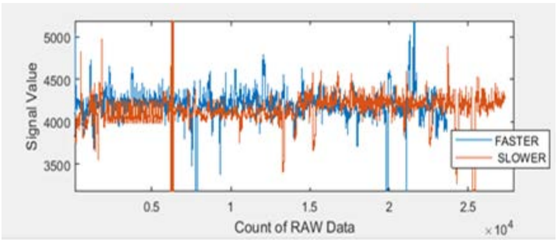

Figure 5. Graph of two signal vales for Faster and Slower.

A. *Exploration of the Correlation Matrix of All Channels*

The evaluation is based on the correlation analysis in the environment of MATLAB [12], [13]. The most familiar measure of the dependence between two quantities is correlation coefficient [14]. The value of the correlation coefficient is taken as a compliance criterion, comparing the raw data.

The correlation matrix of the SLOWER signal for the two channel AF3 and T7 is as follows:

```
>> corrcoef(MAS(:,1),MAS(:,2))
ans =
    1.0000    0.1523
    0.1523    1.0000
```

R12 = 0.1523 < 0.5 and is s statistically insignificant.

In this case, the correlation matrix for each pair of variables is the following type: (Table II and Table III)

TABLE II. Correlation Matrix of SLOWER

AF3	T7	O1	T8	AF4
1	0.1523	0.4581	0.5133	0.6074
	1	0.4723	0.1661	0.0908
		1	0.3011	0.3014
			1	0.4674
				1

Confidence level 95%. n = 27340.

TABLE III. Correlation Matrix of FASTER

AF3	T7	O1	T8	AF4
1	0.1861	0.3060	0.6202	0.6401
	1	0.2774	0.2355	0.1884
		1	0.2159	0.2622
			1	0.4902
				1

Confidence level 95%. n = 24800.

The results show that only R13 and R14 from Table II and R13 and R14 from Table III are higher than 0.5 and they are statistically significant.

B. *Exploring the Correlations between the Corresponding Channels on FASTER and SLOWER*

We calculate the correlation between 1 channel on FASTER and 1 channel on SLOWER.

```
corrcoef(AVG_FASTER(1:200,1),AVG_SLOWER(1:200,1))
ans =
    1.0000    0.1474
    0.1474    1.0000
>>
```

We calculate the correlation between 2 channels on FASTER and 2 channels on SLOWER.

```
corrcoef(AVG_FASTER(1:200,2),AVG_SLOWER(1:200,2))

ans =
    1.0000    0.2061
    0.2061    1.0000
>>
```

Calculate the correlation between 3 channel on FASTER and 3 channels on SLOWER.

```
corrcoef(AVG_FASTER(1:200,3),AVG_SLOWER(1:200,3))

ans =
   NaN   NaN
   NaN   NaN
>>
```

Calculate the correlation between 4 channel on FASTER and 4 channel on SLOWER:

```
corrcoef(AVG_FASTER(1:200,4),AVG_SLOWER(1:200,4))
ans =
    1.0000    0.1613
    0.1613    1.0000
>>
```

Calculate the correlation between 5 channel on FASTER and 5 channel on SLOWER:

```
corrcoef(AVG_FASTER(1:200,5),AVG_SLOWER(1:
200,5))
ans =
   1.0000    0.1522
   0.1522    1.0000
>>
```

The correlation coefficients are lower than 0.21. The latter means that no direct dependencies were found between the data of the respective channels.

V. Conclusion

The aim of this report is to find out how effectively our brain waves can be used in order to generate a command or any action. Studies in the field of brain-computer interface (BCI) have become increasingly important and vast and they surely have led to the creation of a whole new symbiotic relationship between man and machine.

This report is a step for further development of the analysis of brain signals in support of the future improvement of the solutions, limitations and deficiencies.

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Galina S. Panayotova is a Doctor of Mathematics and Professor of Mathematical modeling in the State University of Library Studies and Informational technologies, Sofia, Bulgaria and University "Prof. Dr. As. Zlatarov"- Burgas, Bulgaria. Her Research interests are Mathematical and Computer Modeling, Big Data, Use of information technologies and applications in education. She is the author of more 110 scientific publications, books and textbooks.

Georgi P. Dimitrov is a Doctor od modeling and Simulation process and Professor of Computer Science in the University of Library Studies and Information Technologies, Sofia, Bulgaria and Deputy Dean of the Faculty of Information Systems and Technologies. He currently works in area on Big Data, Web Data Analyst, IoT and etc. He is the author of more 90 scientific publications, books and textbooks.