EEG
Artifact
Detection

Iván Manuel Benito Núñez

Department of Cybernetics
Czech Technical University in Prague

Prague June 2010

Contents

1 Introduction

This report presents an overview in the area of electroencephalography (EEG) with special emphasis on pattern recognition techniques. In the first steps, basics about the human brain are explained, some important applications of electroencephalography are described and the relevant signals and artifacts are introduced. After the introduction, it is given an explanation of the steps that were followed to implement a program in Matlab that finds the most relevant characteristics of the EEG data which is useful to achieve a good pattern classification. Finally the implementation of a more complex program in C++ is described with the aim of putting in use a pattern recognition methodology in order to find parts of EEG signals affected by artifacts. Artifacts increase the difficulty of analysing EEG in that way that recordings can be unreadable or artifacts can be misinterpreted as pathological activity. Recognition and elimination of artifacts is a complicated task, usually performed by a human expert. Disadvantage of this approach is that elimination of artifacts means discarding possibly a large amount of data, which can greatly decrease the amount of data available for analysis.

The pattern recognition techniques involve the automatic classification of data. These techniques are applied for example in speech recognition, classification of text into several categories, automatic recognition of images of human faces and finding more and more applications each day. By taking an electroencephalogram, the amount of information obtained can be too high in time and space. Some tests, such as those related to sleep, may last longer than 8 hours. Pattern recognition techniques applied to EEG are able to reduce the work to be done by the specialist, allowing them to focus on the most relevant aspects.

At present, there are many studies that have developed highly efficient solutions in the encephalogram data analysis. Besides, each day more complex and efficient techniques appear, it is a branch of research in constant development. This project has not attempted to develop a method of pattern recognition that provides classifications with best results and minimum error rates. However, the main motivation was to know in depth the methodology applied in pattern recognition, acquire skills to work and discover new methods of classification.

2 Brain

The brain is an extremely complex organ of the nervous system rich in neurons with specialized functions and interconnected via long protoplasmic fibres called axons and dendrites. The outermost layer of the brain is the **cerebral cortex**, with 2 to 4 mm thick, contains roughly 15–33 billion neurons and plays a key role in memory, attention, perceptual awareness, thought, language, and consciousness [1].

The transmission of information within the brain is produced by substances called neurotransmitters, substances that are capable of causing nerve impulse transmission. These neurotransmitters are received by the dendrites and are emitted by axons.
The brain uses biochemical energy from cell metabolism as a trigger of neuronal responses.

2.1 Cerebral cortex lobes

A lobe is a part of the cerebral cortex that subdivides the brain depending in its function.

There are four main lobes (Figure 1):

- **Frontal lobes**: The frontal lobes are considered our emotional control centre and home to our personality, controls voluntary movements, the capacity of attention, long-term memory and planning, among other things.
- **Parietal lobes**: They are connected with the processing of nerve impulses related to the senses, such as touch, pain, taste, pressure, and temperature. They also have language functions.
- **Occipital lobes**: The occipital lobe is involved with the brain's ability to recognize objects. It is responsible for our vision.
- **Temporal lobes**: The temporal lobes are involved in the primary organization of sensory input [2]. Individuals with temporal lobes lesions have difficulty placing words or pictures into categories.

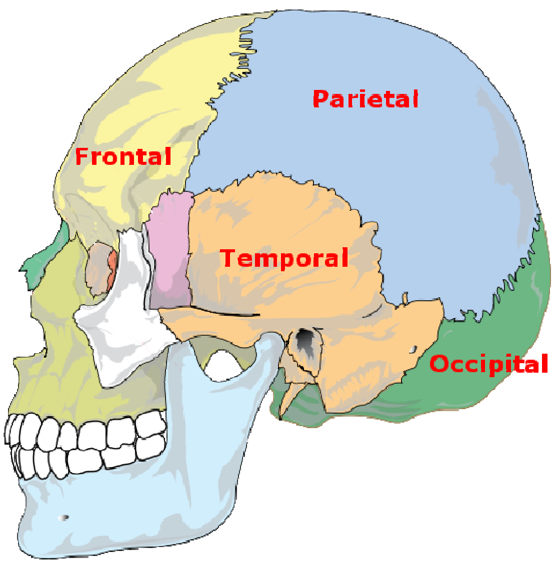


Figure 1: Human skull (brain lobes positions)

3 Electroencephalography

An electroencephalogram (EEG) is a test that measures and records the electrical activity of the brain. The common method to perform the test is placing electrodes along the scalp that will transmit the obtained information to a recorder machine. The amplitude of the EEG is about 100 µV when measured on the scalp, and about 1-2 mV when measured on the surface of the brain. The clinical relevant bandwidth of this signal is from under 1 Hz to about 50 Hz [3].

With this method is possible to determine the activity on a specific location within the brain and to evaluate brain disorders, is the most common reason to diagnose and monitor seizure disorders.

EEGs can also help to identify causes of other problems such as sleep disorders and changes in behaviour. EEGs are sometimes used to evaluate brain activity after a severe head injury or before heart or liver transplantation.

The patient has to be educated to behaviour during the process. Lying on a bed or sit in a chair, he has to be relaxed and maybe he will be ask to close the eyes and be still during the examination. Depending on the test is possible to use a light in some part of the study or to breathe quickly [4].

Levels of arousal, sleeping, relaxing and action, all have a characteristic brainwave pattern.

The activity of the brain is determined in microvolt (µV), and it has to be amplified in a 1.000.000 factor to be showed in a computer screen.

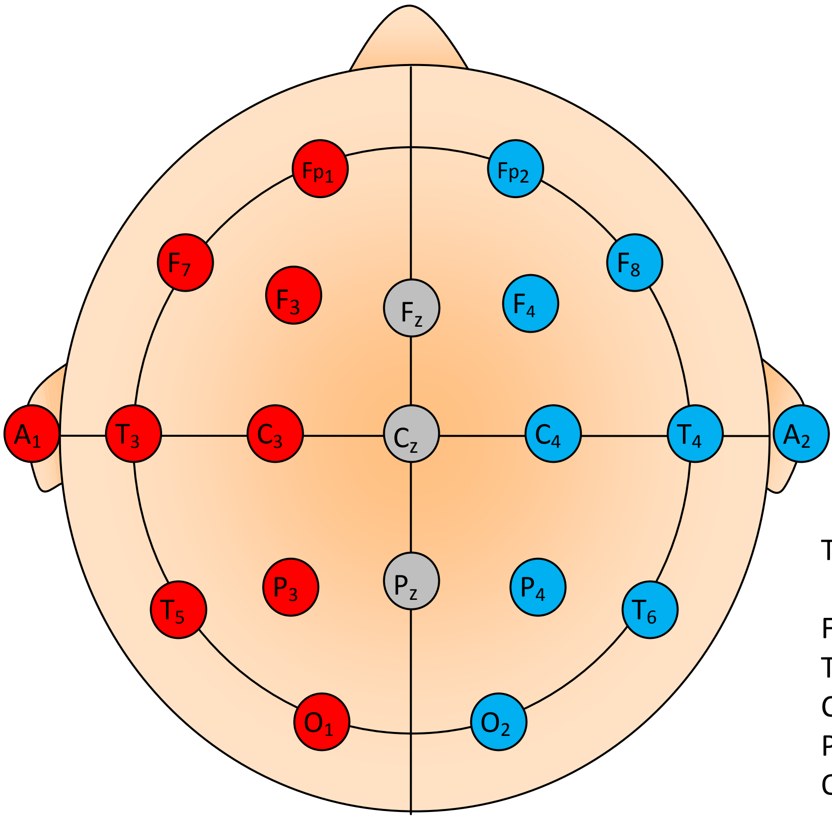
Electrodes

The electrodes are simply small metallic disc devices that provide the conduction of potential electrocortical by wires towards the amplification device and a recording machine. They can be made of gold, silver, tin or copper and are glued to the scalp using a special conductive paste.

To help in the placement of the electrodes there are a special flexible head cover called electrode cap. A disadvantage which has characterized these caps is indicated to be the fact that the electrode positions are fixed, and are not individually adjustable for the requirements peculiar to each individual electrographic analysis and patient [5]. With the right size and requirements of the electrode cap the time of placement and consequently the comfort for the patient are improved.

Placement of electrodes

The placement of the electrodes is commonly standardized to be able to perform an analysis of the given information in any laboratories. The most typical model is called “10-20 International System of Electrode Placement” (**¡Error! No se encuentra el origen de la referencia.**). In this system 21 electrodes are located on the surface of the scalp. The "10" and "20" refer to the fact that the actual distances between adjacent electrodes are either 10% or 20% of the total front-back or right-left distance of the skull . Often the earlobe electrodes called A1 and A2, connected respectively to the left and right earlobes, are used as the reference electrodes.



The letters used are:

F Frontal lobe
T Temporal lobe
C Central lobe
P Parietal lobe
O Occipital lobe

Figure 2. 10-20 International System of Electrode Placement

In addition to the 21 electrodes of the international 10-20 system, intermediate 10% electrode positions are also used. The locations and nomenclature of these electrodes are standardized by the American Electroencephalographic Society. In this recommendation, four electrodes have different names compared to the 10-20 system; these are T7, T8, P7, and P8. These electrodes are drawn grey in the **¡Error! No se encuentra el origen de la referencia.**.

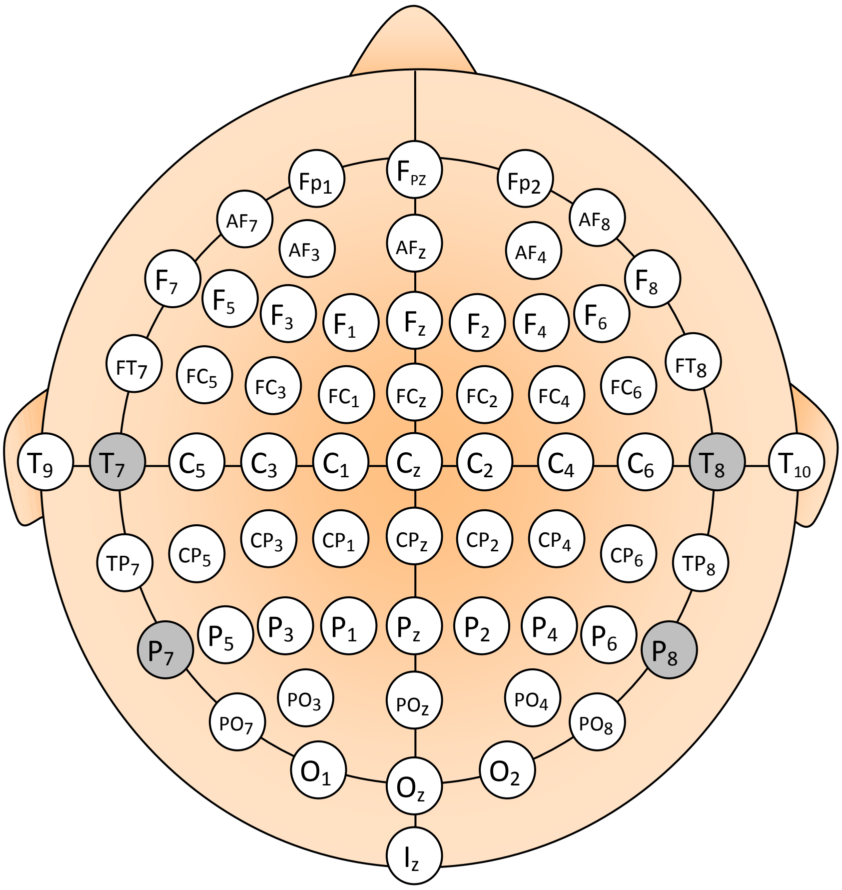


Figure 3. Location and nomenclature of the intermediate 10% electrodes, as standardized by the American Electroencephalographic Society

3.1 Applications

The EEG is indicated in all paroxysmal phenomenons in which the cause is suspected to be of cerebral origin and in all situations of brain dysfunction, especially in symptomatic phase. For example in epilepsy, encephalopathy, coma, diagnosis of brain death, brain tumours and other space-occupying lesions, dementia, degenerative diseases to the nervous system, cerebrovascular disease, head injury, headache, vertigo and psychiatric disorders.

Is the most common and most useful test performed in evaluating patients suspected of epilepsy.

3.1.1 Epilepsy

Epilepsy is a brain disorder that causes people to have recurring seizures. A seizure is usually defined as a sudden alteration of behaviour due to a temporary change in the electrical functioning of the brain, in particular the outside rim of the brain called the cortex [6]. It is usually diagnosed after a person has had at least two seizures that were not caused by some known medical condition like alcohol withdrawal or extremely low blood sugar. An epileptic attack may result in a series of involuntary contractions of the voluntary muscles, abnormal sensations, abnormal behaviours, or some combination of these events.

Epilepsy has many possible causes, including illness, brain injury and abnormal brain development. In many cases, the cause is unknown.

There is no cure for epilepsy, but medicines can control seizures for most people. When medicines are not working well, surgery or implanted devices such as vagus nerve stimulators may help. Special diets can help some children with epilepsy [7].

3.1.2 Sleep

Sleep is a physical and mental resting state in which a person becomes relatively inactive and unaware of the environment. In essence, sleep is a partial detachment from the world, where most external stimuli are blocked from the senses [8].

The brain repeats a cycle along the normal sleep that lasts about 90-120 minutes and is repeated four or five times each night. In this cycle is differentiated by dramatically different forms of brain activity the different stages.

3.1.3 Sleep states

We can divide the normal sleep in two main types, the REM (Rapid eye movement) which involves intense brain self-activation and NREM (non-rapid eye movement) states. NREM sleep is subdivided into 4 substates.
70-80% of the time during a night the brain is in NREM sleep and the other time in REM.

Most dreaming takes place during REM sleep. At least in mammals, a descending muscular atonia is seen in this state, the brain blocks signals to the muscles to remain immobile so dreams will not be acted out.

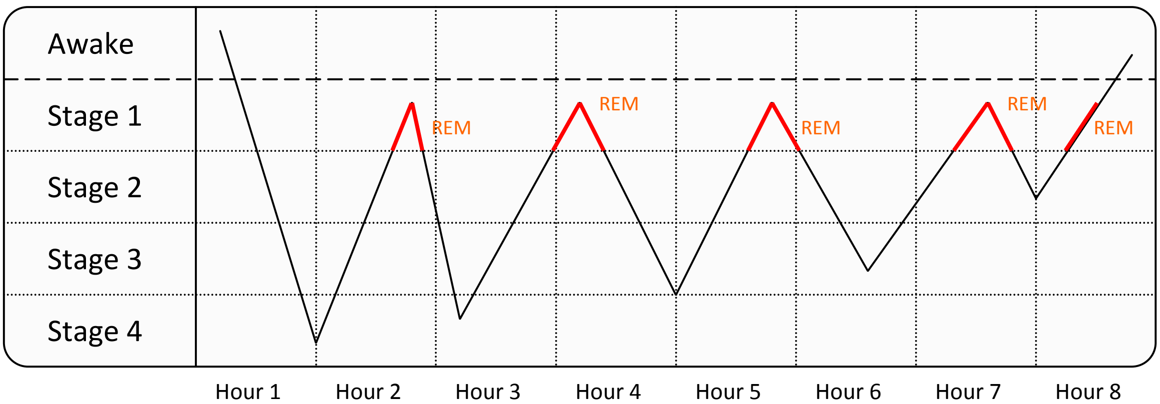


Figure 4. Sleep states of an adult during the night

Table 1 shows some basics discriminations factors about sleep states.

<table>
<tr><th></th><th></th><th colspan="2">EEG characteristic</th><th>Time in this stage</th><th>Eye activity</th></tr>
<tr><td rowspan="4">NREM</td><td>Stage 1</td><td colspan="2">Activity generally in theta range.</td><td>10-12 min.</td><td>Slow eye movements</td></tr>
<tr><td>Stage 2</td><td colspan="2">• Sleep spindles (12-14 hz waveforms) of at least 0.5 seg.
• K-Complexes (a negative wave followed by a positive one)
• Appear delta waveforms.</td><td>40-55% of total sleep time.</td><td rowspan="3">No detected.</td></tr>
<tr><td>Stage 3</td><td rowspan="2">Slow-wave sleep.</td><td>Moderate amount of high-amplitude.</td><td rowspan="2">14-15 % of total sleep time.</td></tr>
<tr><td>Stage 4</td><td>Large amounts of high-amplitude.</td></tr>
<tr><td rowspan="2">REM</td><td>Tonic</td><td colspan="2" rowspan="2">As awake.</td><td rowspan="2">20-25 % of total sleep time.</td><td rowspan="2">Rapid eye movement</td></tr>
<tr><td>Phasic</td></tr>
</table>

Table 1. Basic sleep states information

Table 2 shows that children need more sleep per day in order to develop and function properly: up to 18 hours for newborn babies, with a declining rate as a child ages. A newborn baby spends almost 9 hours a day in REM sleep. By the age of five or so, only slightly over two hours is spent in REM.

	Average Hours of Sleep Per Day
Newborn	18
1 month	15–16
6 months	14–15
1 year	13–14
2 years	13
3 years	12
5-6 years	11
7-8 years	10
9–17 years	9–11
Adults, Including elderly	7–8

Table 2. Hours of sleep by age

3.1.4 Dementia

Dementia is not a specific disease. It is a descriptive term for a collection of symptoms that can be caused by a number of disorders that affect the brain. People with dementia have significantly impaired intellectual functioning that interferes with normal activities and relationships [9]. Dementias are often classified by the region of the brain that is affected. One of the main classifications divides dementias into two main groups: cortical and sub-cortical based on the area of the brain where degeneration occurs [10]. The most important cortical dementia is Alzheimer's disease (AD), which accounts for approximately 50% of the cases. Other known cortical abnormalities are Pick's disease and Creutzfeldt–Jakob diseases (CJD). On the other hand, the most common subcortical diseases are Parkinson's disease, Huntington's disease, lacunar state, normal pressure hydrocephalus, and progressive supranuclear palsy [11].

3.2 Important frequency bands

The classification of EEG waveforms are commonly made according to their frequency, amplitude and shape. The site on the scalp from where the data is recorded is also relevant.

Actually the frequency of brain waves range can be recognize from 0.5 to 500 Hz [12], but not this entire spectrum is going to be considered important in the examination; it is divided in four main groups of frequency ranges that are more clinically relevant (alpha, beta, theta and delta waves).

The most popular way to apply a frequency analysis is on a digital computer using the Fast Fourier Transform algorithm.

3.2.1 Delta

High amplitude brain waves which have a frequency of 3 Hz or less, are normally seen in deep sleep in adults as well as in infants and children.
As they are rarely in awake experience in adults the existence of delta wave can be an indicator of a brain lesion.

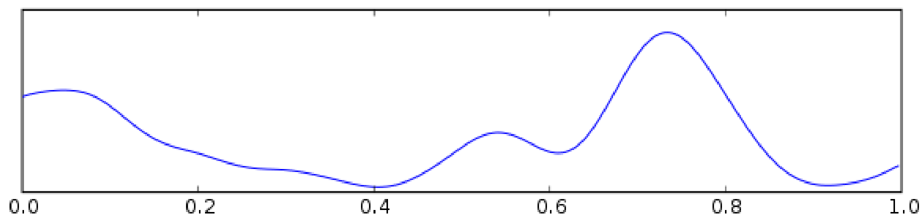


Figure 5. Example of an EEG delta wave, one second sample

3.2.2 Theta

Theta waves lie within the range of 3 and 8 Hz, they are associated with deep sleep and REM state. The theta wave plays an important role in infancy and childhood. Larger contingents of theta wave activity in the waking adult are abnormal and are caused by various pathological problems [11].
Theta waves are generated from the interaction between temporal and frontal lobe.

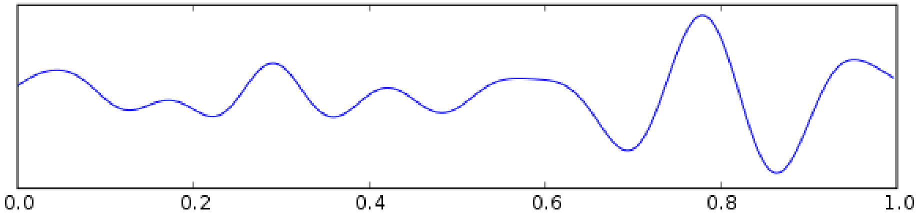


Figure 6. Example of an EEG theta wave

3.2.3 Alfa

For Alfa waves the frequency is in the range of 8 and 12 Hz, they are relationated with relax states. This kind of wave appears in the previous moments to fall asleep. Predominantly they are originated in the occipital lobe during relaxing periods, closing the eyes, but awake. They are attenued when the eyes are open.

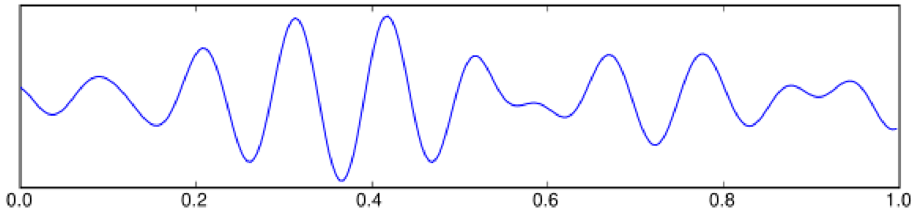


Figure 7. Example of an EEG alfa wave

3.2.4 Beta

For Beta waves the frequency is in the range of 12 and 30 Hz. They are present when the person is awake and with full mental activity. Exaggerated beta activity is found in Parkinson's disease and this links to their motor slowing.

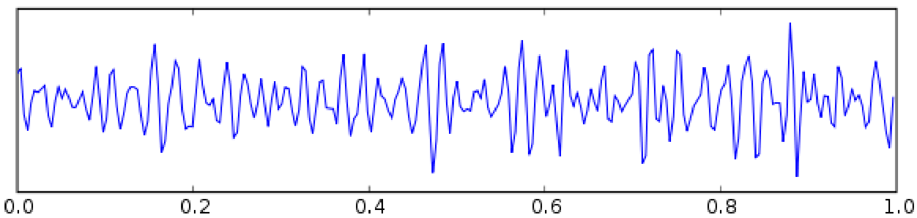


Figure 8. Example of an EEG beta wave

3.3 Artifacts

Signals that are detected by an EEG but not belong to a cerebral origin are called artifacts. They may occur at many points during the recording process. The amplitude of artifacts can be quite large relative to the size of amplitude of the cortical signals of interest. The range of physiological and nonphysiological artifacts is very wide. Types of common artifacts include: power line artifact, eye movement, eye blinking, respiratory artifact, electrode popping, ECG artifact, sweat artifact, loose/broken electrode. In many cases the information that is hidden behind the artifacts are relevant to a proper diagnosis. The artefact detection methods are inadequate if we do not apply after a function to remove them and get back the original wave. Often is in the preprocessing stage were these artefacts are highly mitigated and the information is restored.

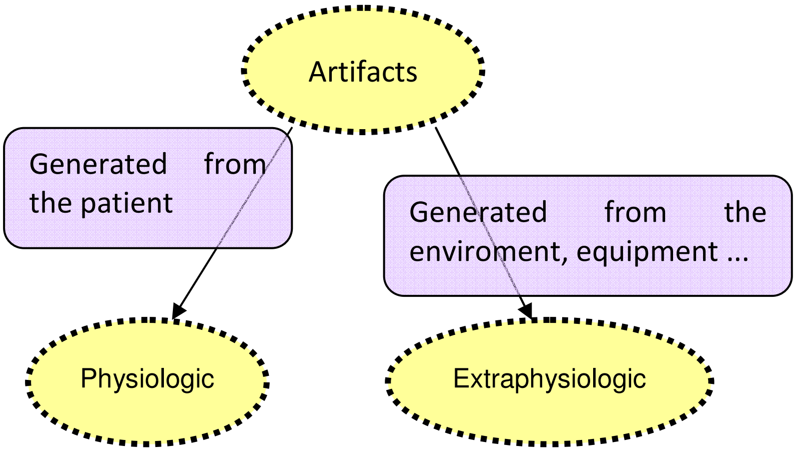


Figure 9. Origin of artifacts

3.3.1 Power line artefact

The source of the most significant noise is acquired from the power line introducing electromagnetic signals of 50 Hz (60Hz). This noise is very much higher than the interested signal, the typical value in the EEG without artifacts is from 10 to 100 microvolts where the power line is from 10 milivolts to 1 volt.

Notch filters with a null frequency of 50 Hz are often necessary to ensure perfect rejection of this strong signal. Several methods are developed to solve it [13].

3.3.2 Muscle artifact

Muscle artifacts are characterized by surges in high frequency activity and are readily identified because of their outlying high values relative to the local background activity. Contamination of the EEG by muscle activity was more frequent towards the end of non-REM sleep episodes when EEG slows wave activity declined. Within and across REM sleep episodes muscle artifacts were evenly distributed [14].

3.3.3 Eye blinks

Blink artifacts are attributed to alterations in conductance arising from contact of the eyelid with the cornea [15].
An eye blink can last from 200 to 400 ms and can have an electrical magnitude more than 10 times that of cortical signals (See page 3). The majority of this signal propagates through the superficial layer of the face and head and decreases rapidly with distance from the eyes.
The next figure shows an example of this artifact, between B3 and B1 tags.

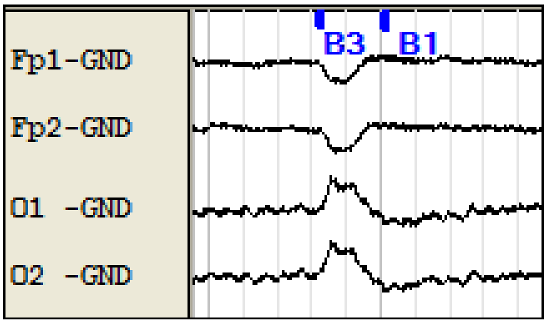


Figure 10. Eye blink artifact detail

3.3.4 Eye movement

Though eye movements may not change the topographical asymmetry of alpha and beta wave, they exert substantial general effects on the whole EEG spectrum [16].
The reflexive eye movements are nearly always present, affect the electrodes of the Frontal region, and is best seen in first two channels Fp1 and Fp2. Eye movement is useful to identify sleep stages.

3.3.5 Sweat artifact

Sweat contains water, minerals, lactate and urea. It can react with the electrodes altering their impedance and producing an unstable baseline.
Over an extensive area of the scalp may result in a saline bridge and gives rise to low amplitude tracings (short circuiting) [17].

4 Signal processing

The term signal includes audio, video, speech, image, communication, geophysical, sonar, radar, medical, musical, and other signals [18].

Processing of EEG signals is a complex process and represents a multilevel procedure composed of several methods. Its main steps are preprocessing, which includes filtering and segmentation, data representation, consisting mainly of feature extraction and dimensionality reduction, and classification.

4.1 Segmentation

The segmentation is the process where the data is divided into smaller pieces. It can be done with a fixed window where the data is split in segments of the same length or using an adaptive segmentation where an algorithm automatically splits the data on sections with analogous characteristics.

4.2 Feature extraction

When the input data to an algorithm is too large to be processed and it is suspected to be notoriously redundant (much data, but not much information) then the input data will be transformed into a reduced representation set of features (also named features vector). Transforming the input data into the set of features is called feature extraction [19].

4.3 Example of signal analysis using Matlab

The following section shows the example analysis of data that is already classified by an expert. Used EEG data were obtained from an individual while sleeping. The goal of this example is to show what features are the most relevant. The graph of these values will be shown along with the chart of the data already classified by the expert. This way, it is possible to see clearly the relationship between extracted features and expert's classification, and to demonstrate that these values are good choice to classification.

The given data is composed of 10 EEG channels, EOG (Electrooculogram), EMG (Electromyogram), ECG (Electrocardiogram), and PNG (Respiration) channels. The classification was made for 30s-length segments and the frequency of acquisition 128 Hz. With this two values is determined that one segment will have 128*30= 3840 samples.

At the first stage, an EEG recording is divided preliminary into equal "elementary" segments. Then, each segment is characterized by a certain set of features. At the third stage, using one of the multivariate statistical procedures, the elementary EEG segments are ascribed to one of a number of classes according to their characteristics.

Figure 11 illustrates the procedure of segmentation and feature extraction on a single channel signal.

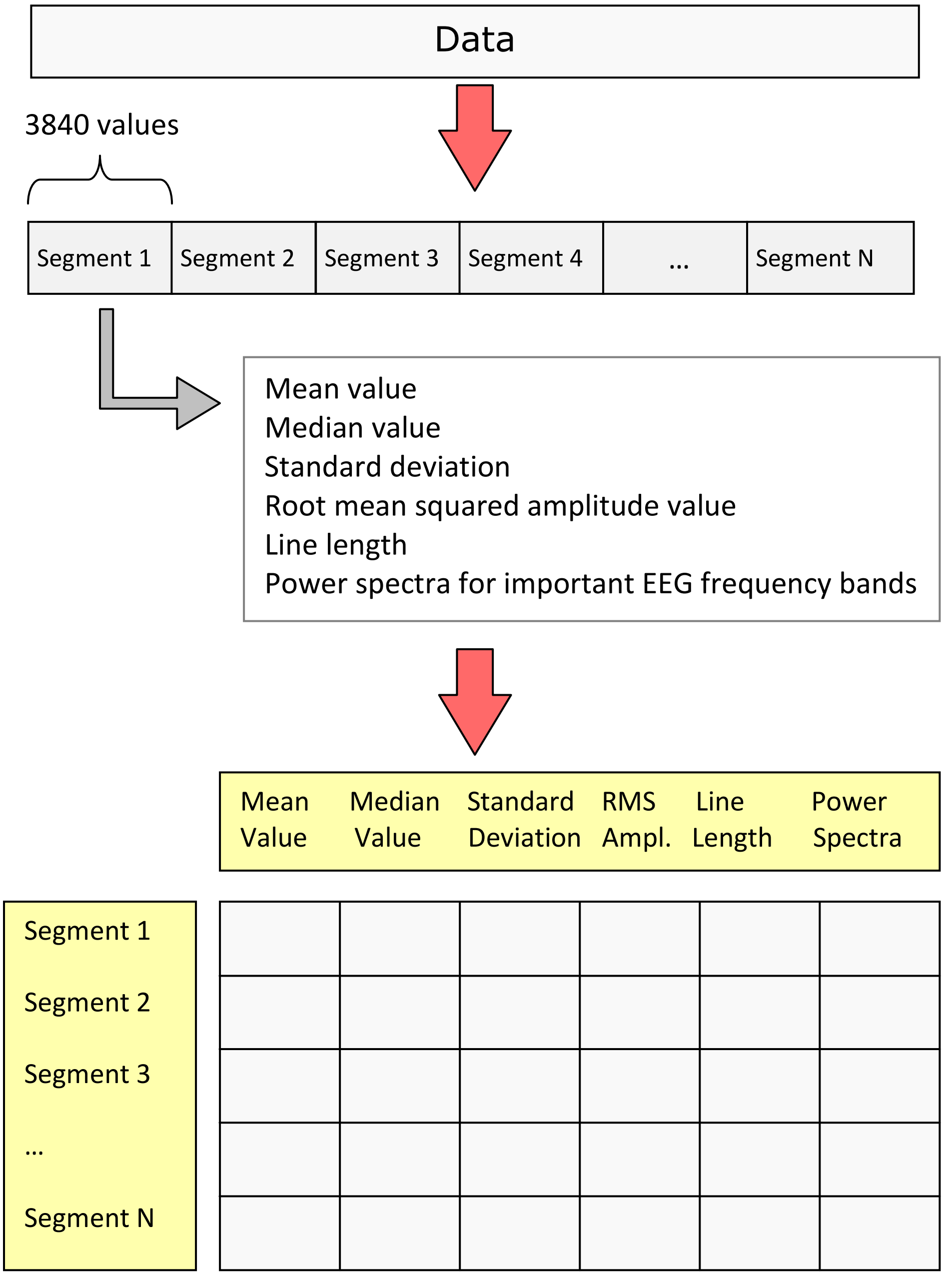


Figure 11. Segmentation and feature extraction

Once we have the matrix with all the parameters calculated we can compute a correlation analysis between these data and the classification given by the expert. Correlation analysis was used to see if the values of two variables are associated. The correlation coefficient is a number between -1 and 1. In general, the correlation expresses the degree that, on an average, two variables change correspondingly. The Figure 12 shows graphically the steps to transform the matrix of features in a matrix of cross-correlation coefficients where each row corresponds to one channel.

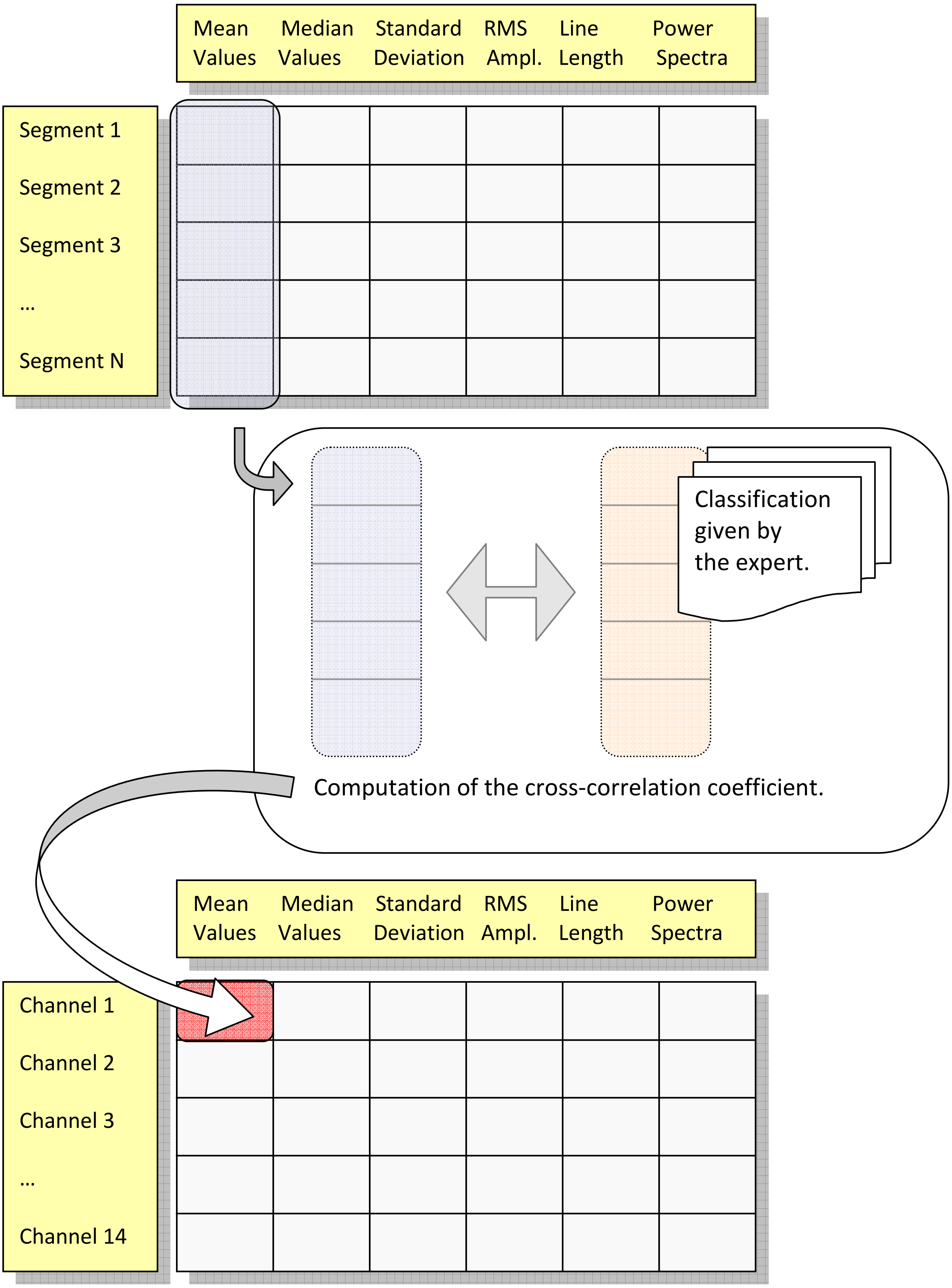


Figure 12. How to get the correlation coefficients matrix

From the obtained final matrix of cross-correlation coefficients we choose the highest five values, the most correlated, and we put them together in a graph with the classified data to see the relationship. The upper plot of Figure 13 is the result of data classification and the lower plot presents values of extracted features. In the Figure 13 it can be noticed that line length feature (line in turquoise colour) produces results in a bigger scale so it is not possible to distinguish the others. Figure 14 is the same plot as Figure 13 but with Line lengh removed.

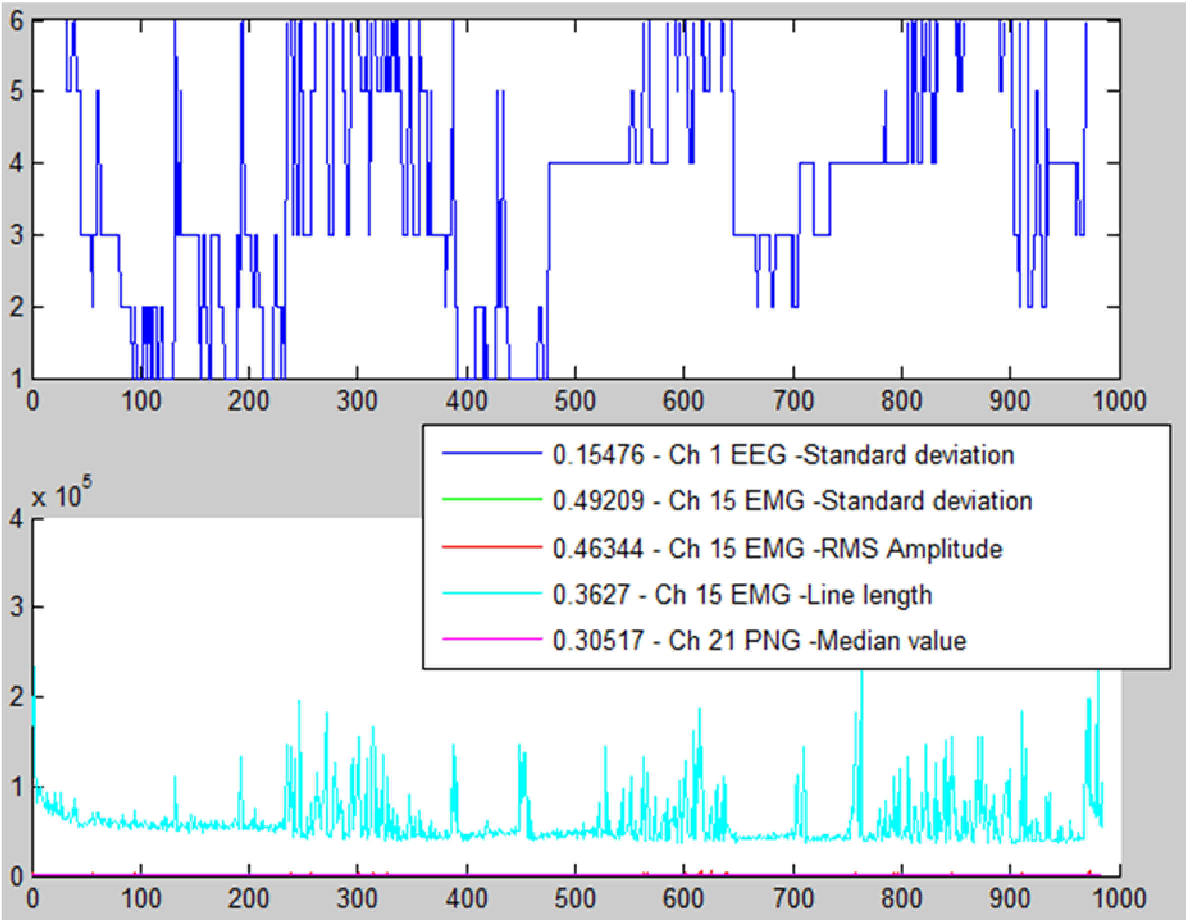


Figure 13. Upper plot shows the result of data classification. The lower plot represents values of extracted features.

The others signal in detail:

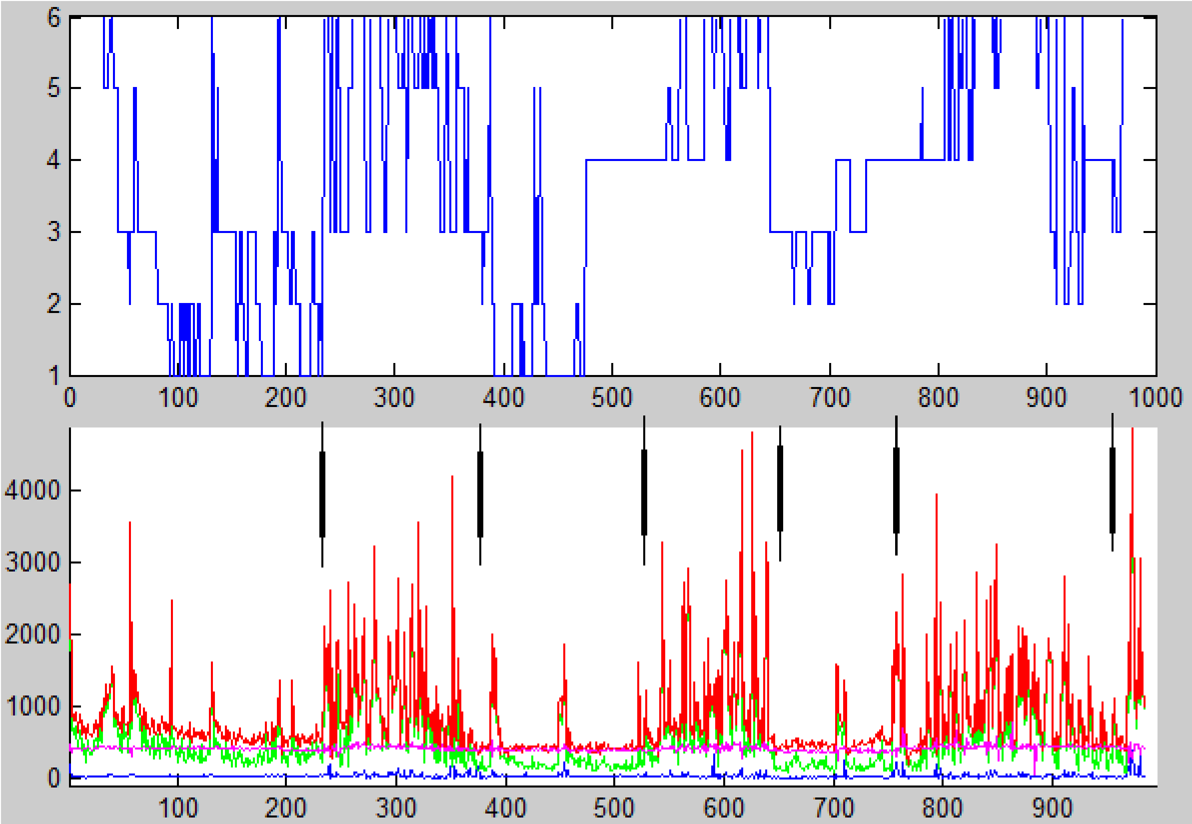


Figure 14. Upper plot shows the result of data classification. The lower plot represents values of extracted features. (Red line correspond to RMS amplitude, green and blue to the standard deviation and pink one the median value)

4.4 Methods for Classification

Any classification method uses a set of features or parameters to characterize each object, where these features should be relevant to the task at hand. The methods are divided in supervised or unsupervised classification. In supervised classification a human expert has to determine into what classes an object may be categorized. It is also provided a set of sample objects with known classes. This set of known objects is called the training set because it is used by the classification programs to learn how to classify objects. There are two phases to constructing a classifier. In the training phase, the training set is used to decide how the parameters ought to be weighted and combined in order to separate the various classes of objects. In the classification phase, the weights determined in the training set are applied to a set of objects that do not have known classes in order to determine what their classes are likely to be [20].

4.4.1 Knn algorithm

How the algorithm works [21] :
First of all we have to select a training data set, a set of data were the data is already classified.
To predict new values that we want to know the class that belongs to, the algorithm looks for the k observations in the training set that are closest to the new value.
The new class will be classified according to the “majority” of the k nearest neighbours.

Using an 'ideal' data set it can be use k=1, meaning that the data is well defined in the space and we just need to pick the nearest neighbor. But in real-world situations, there are always aberrations. To solve this problem is common to select more number of neighbours to reduce any noise.

The project uses for this purpose the ANN library, *“A Library for Approximate Nearest Neighbor Searching”*. The reasons of why is used are because is a c++ library distributed under the terms of the GNU Lesser Public License, it has implemented a number of different data structures and different search strategies and because follows the standard c++ like our program, all of this features makes the library perfect and useful if someone want to experiment and/or adapt the program easily in the future.

5 Artefact detection program in C++

This chapter introduces basics of realized C++ artifact detection program and information needed for its use. Basically, this program works with a special file type which contains the data from EEG, performs the analysis of this data, and writes the result into a new file. The structure of this file comes from EASYS2 software system. In the section 5.3 this format will be explained in more details. Therefore, to view the EEG recordings the software that supports this kind of files is needed. In this project, Wave Finder v1.81 was used. This program was developed for Windows 2000 that supports several formats from EEG machines, and it is used in clinical practice.

In the Figure 15 is presented a screenshot of the Wave Finder program.

Figure 15. Wave finder signals screenshot

5.1 How to use the program

The program can be executed as command-line mode passing arguments or as interactive mode. Each one is used for a specific purpose. With the command-line mode is performed the artifact analysis while the interactive mode is oriented to extract information contained on a file. In this section are explained the options that we have to run the program in both methods.

5.1.1 Command-line mode

Command-line interpreters allow users to issue various commands in a very efficient (and often terse) way. This requires the user to know the names of the commands and their parameters. In this section is explained the basic parameters of this mode.

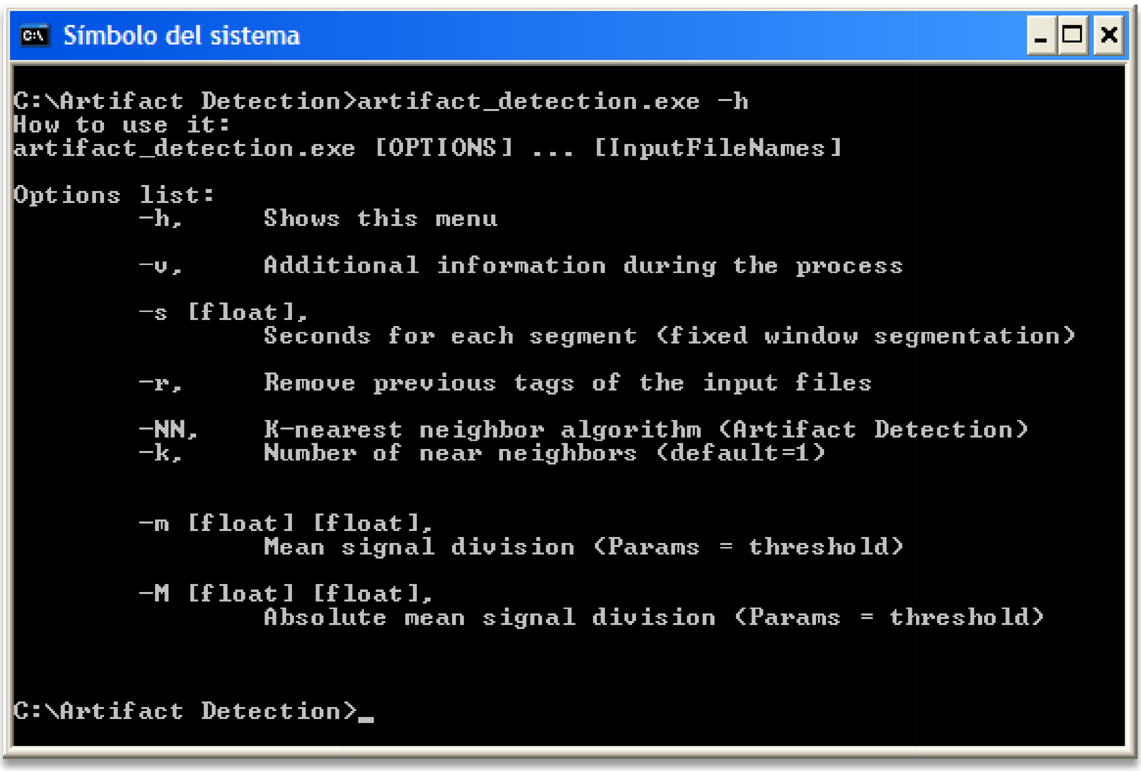


Figure 16. Screenshot of the command-line help menu

<u>Parameters list</u>:

- -v "Additional information during the process", the options enabled and the tag list from the result analysis are printed.
- -s Followed by a float number, set the length in seconds for the fixed window segmentation.
- -r The tags that were in the file are removed before the analysis.
- -NN A near neighbour algorithm analysis will be perform to detect artifacts.
- -k Followed by an integer number, It specify the number of near neighbour that is going to use the near neighbor algorithm.

In a execution you must specify at least the segmentation window. Figure 17 shows as an example the output of a very basic execution.

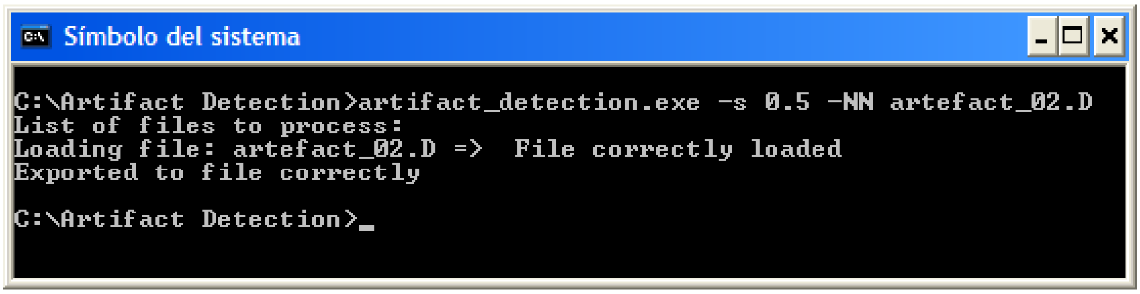


Figure 17. Basic command-line execution

The program informs that the file was correctly loaded and exported. The output name of the file is "out_artefact_02.D", the same name as the input one but with the prefix "out_" added.

5.1.2 Interactive mode

To run the program in interactive mode, open an ms-dos console window and start the utility using the command line without introducing any parameter.

```
artifact_detection.exe
```

The program print a menu as it's showed in the next figure (Figure 18)

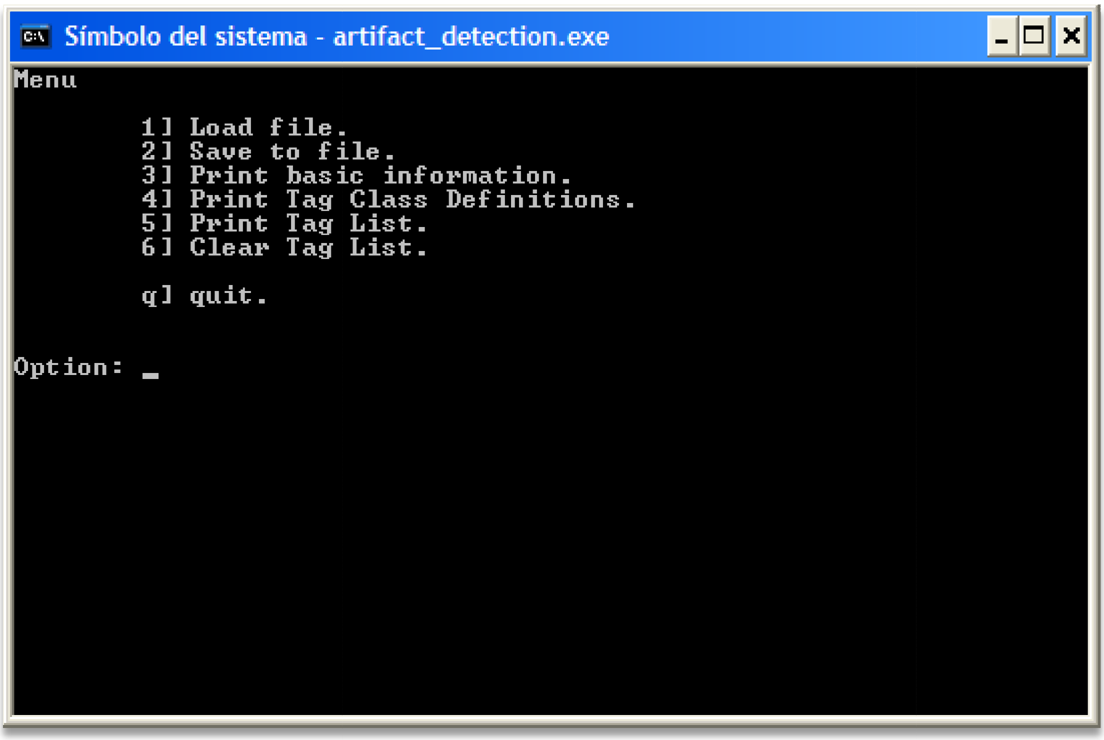


Figure 18. Screenshot of the interactive main menu

The **Option:** prompt shows that the utility is waiting for a command.

The following sections show how to carry out various commands in interactive mode.

To exit, the **q** command is used.

```
Option: q
C:\>
```

The menu options are preceded by a number from 1 to 6. The first thing to do is open a file to work; other options will display an error message if no file is loaded.

Load a file:
You will be ask to enter a file name. If the program can't find or load the file an error message is showed and the main menu will be printed again.

Printing basic information

To display the details of the loaded file introduce the number 3, its output are shown in the Figure 19.

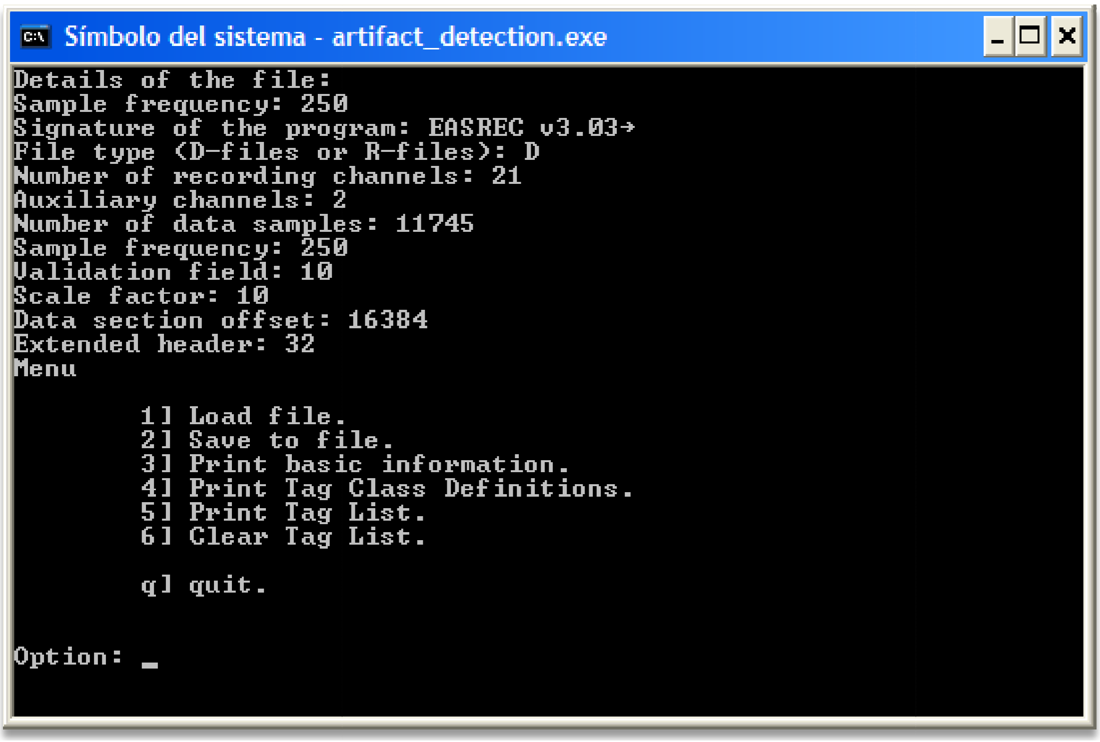


Figure 19. Printing basic information of the file

Options 4-5-6 are about Tags, see the section 5.3.2 to find out more about tags.

5.1.3 Program results

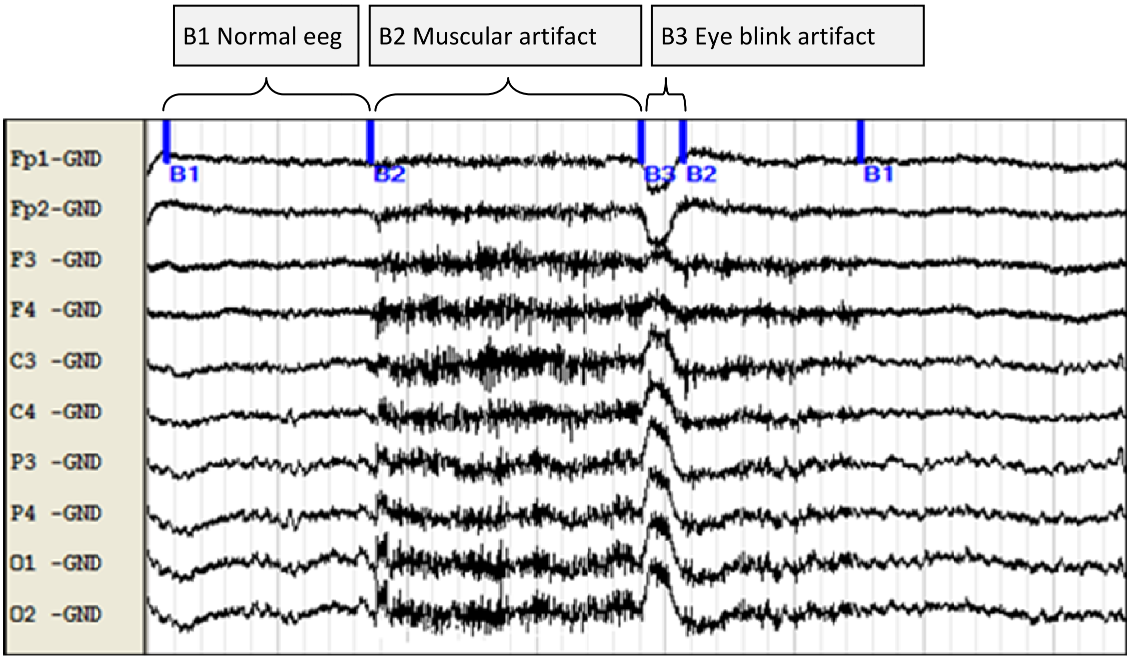


Figure 20. Wave finder screenshot, EEG record with muscular (B2) and eye blink artifacts (B3)

Figure 20. Wave finder screenshot, EEG record with muscular (B2) and eye blink artifacts (B3)Figure 20 shows a section of EEG recording containing the two basic types of artifacts that interest us, muscle artifact and eye blink artifact. The top tags in blue (B1, B2 and B3) defines the type of wave that follows them, they belong respectively to normal waves, muscle artifacts and eye blink artifacts, they are effective until a new tag is found.

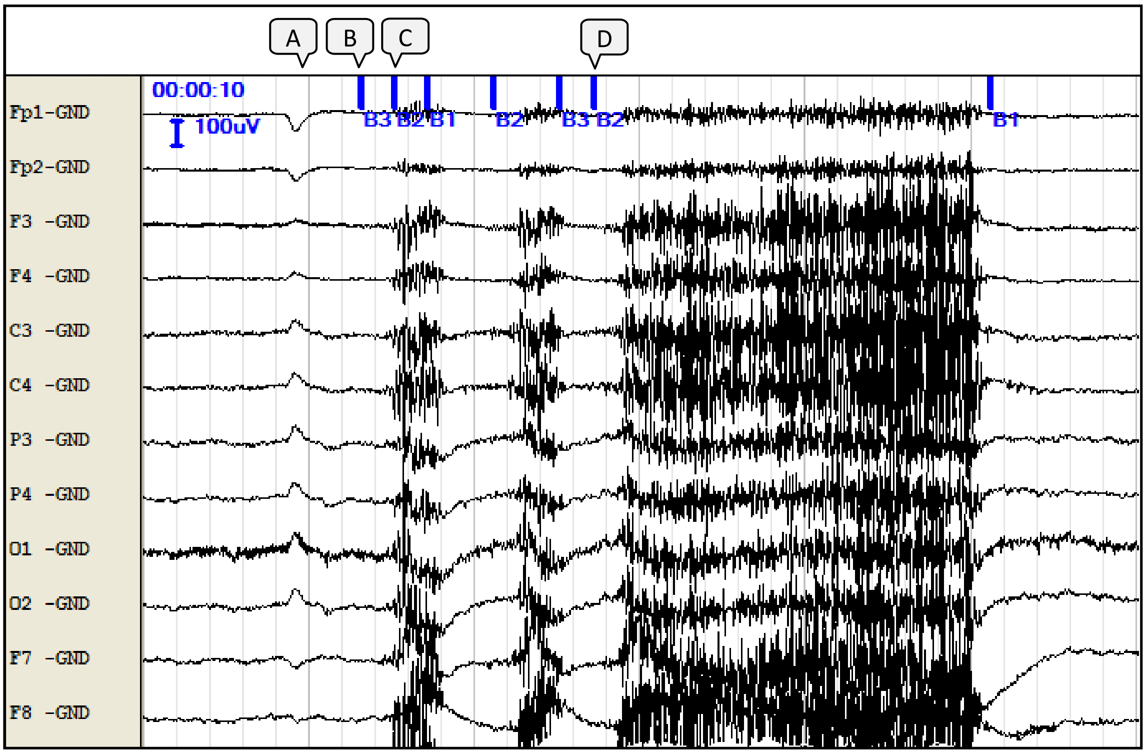


Figure 21. Data classified by our program

The Figure 21 shows a screenshot of another relevant results obtained by our program. We used a segmentation of 0.2 seconds, near neighbour algorithm, and we removed the previous tags of the passed file (in case of their existence).

```
artifact_detection.exe -r -s 0.2 -k 1 -NN artefact_03.D
```

On top of the Figure 21 we added some marks with letters. The following explanation is provided for why these marks are present.

A. Here the program should have placed an artifact tag. The wave at this point can be identified as eye blink.
B. The classification algorithm makes a wrong classification; we can think that the wave belongs to a class in the frontier of normal wave (B1) and muscular artifact (B2), but not eye blink artifact (B3).
C. This tag is correct, but it should be a bit longer.
D. Good classification, muscular artifact detected, after this artifact, normal wave is found.

Some of these problems can be solved if we select different parameters (C) or adding new data to train (A).

5.2 Explaining the implementation

The project was implemented following the C++ standard. The first thing this means is that it will be compiled by most current compilers. The second is the ease for new programmers to join in the project. Programmers can go into any code and look up in the widespread reference manual in case of doubt. The experiences of many projects leads to the conclusion that using coding standards makes the project go smoother.

Classes:

myMath: Some useful functions; Mean, absolute mean, median, variance, standard deviation, root mean square and line length. These functions perform the appropriate calculations on a bounded set of data; all have the same declaration structure. The first parameter 'a' is an array of real numbers. The second and third parameters are respectively the index of the first and last numbers used in the operation, they limit the range of values in a.

```
float mean (float *a,
            unsigned long int start_position,
            unsigned long int finish_position);
```

Electrode class: In this class is stored the data samples of the channel, the name of the electrode (see Figure 2 and Figure 3), the number of samples and the frequency of acquisition among other variables.
The samples acquisitions are stored as a pointer array of float type:

```
float *data;
```

Segmentation class: Segmentation class has functions to calculate the number of samples in each segment, the split points of the segmentation and some additional functions to perform the concatenation of the flags.

TagTable file: Is not declared as a class but it has two struct definitions; the struct TAGDEF (Tag definitions) and the struct TFlag (Tag information)

- TAGDEF: The definition of a tag. It contains an abbreviation name for the tag of 2 characters (actually 3 because the endline character '\n' is included), and a description string (declared as char*).

- TFlag: This struct stores basically the sample position of the tag and the type. This structures has one important thing, it has defined the operators '==' and '<'.

Knn class: Implement the methods of training and classification via the k near neighbour algorithm. Now we are showing the basics of the classification algorithm.

The basic function of search code (classification):

```
kdTree->annkSearch(              // search
         queryPt,                // query point
         k,                      // number of near neighbors
          nnIdx,                    // nearest neighbors (returned)
         dists,                  // distance (returned)
         eps);                   // error bound
```

The library provides the definition of a special data for the points in the space, it is the ANNpoint.

queryPt is of type ANNpoint. ANNpoint is basically an array of floating data points. It is composed by the data obtained from the extraction of characteristics. Therefore the dimensionality of space is given by the number of features used.

k is the number of nearest neighbors.

nnIdx is an array of length k and ANNidx type. It is the result of the query. This array is basically an array of indexes of values in the training data set.

dists is another array that stores the distance of the near neighbour query results.

TEEGData class: Has an array of electrodes, a list of Tflag, a list of TAGDEF and all the information stored in a file from EASYS.

IOFile class: This class has the methods to load and save the data to EASYS files (see section 5.3). The exportation of files has been one of the hardest tasks to solve.

5.3 Structure of data files

The program works with a type of file from the EASYS2 software system. There are two basic file types that are used by this software that are named D-files and R-files. R-files are oriented to represent the result of computational data processing; this type is not used in our program. D-files format files are used for storage of native digitized EEG data, recorded in several channels simultaneously over a certain time period. [22]

We have worked with this file because it is used in the laboratory where this project has been carried out

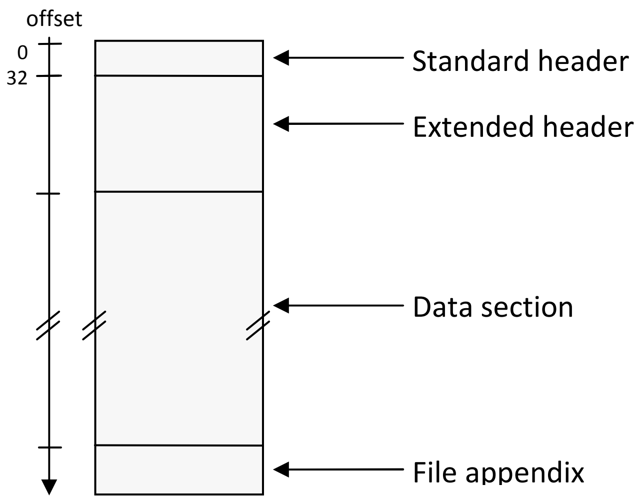


Figure 22. D-File file structure

The standard header file has 11 fields of different types (sizes). Extended header is not with a fixed definition to provide flexibility; therefore it involves a more tedious programming. In some areas of the file appendix is necessary to calculate offsets dynamically. Also, to debug the file resulting by the program is necessary to use a hex editor. A hex editor is a type of computer program that allows a user to manipulate binary (normally non-plain text) computer files.

5.3.1 Standard and Extended header

The standard header has 32 bytes long. It contains the signature of the program that created the data file, the type of the file (D or R), the number of recording channels, the number of auxiliary channels, the sample frequency (in samples per second), the total number of data samples in the data section and the scaling factor used in the data recalibration among others. This data is showed in the Figure 19.

The extended header itself has no fixed structure, compared to the standard header; rather, it is a chain of different records. The order in which records appear in the extended header area is indefinite; the extended header area even needs not to be contiguous.

5.3.2 Tag tables

When a doctor is inspecting the brain waves in a computer program it is useful to have a way to indicate or comment in a specific point the data that is being examined, that is to say, place clinical information. For this purpose there are the event markers or tags.

The information related to tags is normally stored into **file appendix**, following the data area. The Tag Tables area consists of two parts: the Tag List and the Tag Class Definitions area. Offsets and lengths of both tables are stated by the TT record of the extended header. If this record is absent, no tag info is available.

5.4 Adapt/extend the project

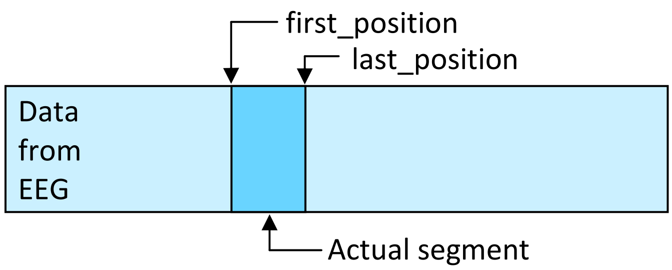
In the KNN algorithm we can make interesting modifications. One is to modify the features that represent the space points. The code is located in the knn.cpp and knn.h files.

ANNkd_tree is a structure provided by the ann library to create a space of training points. The declaration is showed in the next code:

```
kdTree = new ANNkd_tree(          // build search structure
                dataPts,          // the data points
                nPts,             // number of points
                dim);             // dimension of space
```

dataPts is an array of the type defined ANNpoint which is of type ANNcoord*, by default ANNcoord is defined to be of type double.

In dataPts are stored the points of the space. To calculate the position in the space of each point there is a function called getFeatures which receives as arguments the pointer of the EEG data and two more variables that represent the start position and end position of the segment to process.



```
ANNpoint Knn::getFeatures(TEEGData *eeg_data,
                          unsigned int first_position,
                          unsigned int last_position) {

    ANNcoord f_mean = 0,
             f_standard_deviation = 0;


    for(int i=0;i<eeg_data->getNumberOfChannels();i++) {
        f_mean += (ANNcoord) mean(eeg_data->electrodes[i].data,
                                  first_position,
                                  last_position);
        f_standard_deviation += (ANNcoord) standardDeviation(
                                  eeg_data->electrodes[i].data,
                                  first_position,
                                  last_position);
    }

    ANNpoint ann_point = annAllocPt(dim);

    ann_point[0] = f_mean;
    ann_point[1] = f_median;

    return ann_point;
}
```

In the code is showed as an example the calculation of the features that make up a point. It is using two variables to compound it (2-dimension), the mean and standard deviation.

5.5 Project Settings in Windows

In this section is explained how to set-up and configure the project to have the same environment as when it was programmed.

First of all, the C/C++ compiler used is the MinGW version 3.4.5 for windows; MinGW is a port of the GNU Compiler Collection (GCC), and GNU Binutils, for use in the development of native Microsoft Windows applications [23]. It provides a complete Open Source programming tool set.

The IDE (integrated development environment) selected was the **code::blocks** [24] version 8.02, the latest version released is the 10.05 on 30 May of 2010. Code::block is an open source environment with several compiler supports and interface GDB [25], the GNU Project debugger.

The project needs to import the ANN library to use the near neighbour algorithm (see the section 4.4.1 to know more about this algorithm). There are some precompiled versions of the library to use with different compilers but to use the library successfully on Windows using MinGW is necessary to modify the given file ANN.h. This means that we are using our own compiled version of the library in the project. At line 62 you must comment the next code, leave only uncommented the line with the #define DLL_API.

```
//     #ifdef WIN32
//            #ifdef DLL_EXPORTS
//                   #define DLL_API __declspec(dllexport)
//            #else
//                   #define DLL_API __declspec(dllimport)
//            #endif
//     #else
              #define DLL_API
//     #endif
```

In code::blocks is possible to link the library automatically. To do it, go to the build options window, this option is accessible when you click the right mouse button in the project name (management window). Once you open this window, go to the tab 'Linker settings' as shown in Figure 23. Here you have to specify the path to the library.

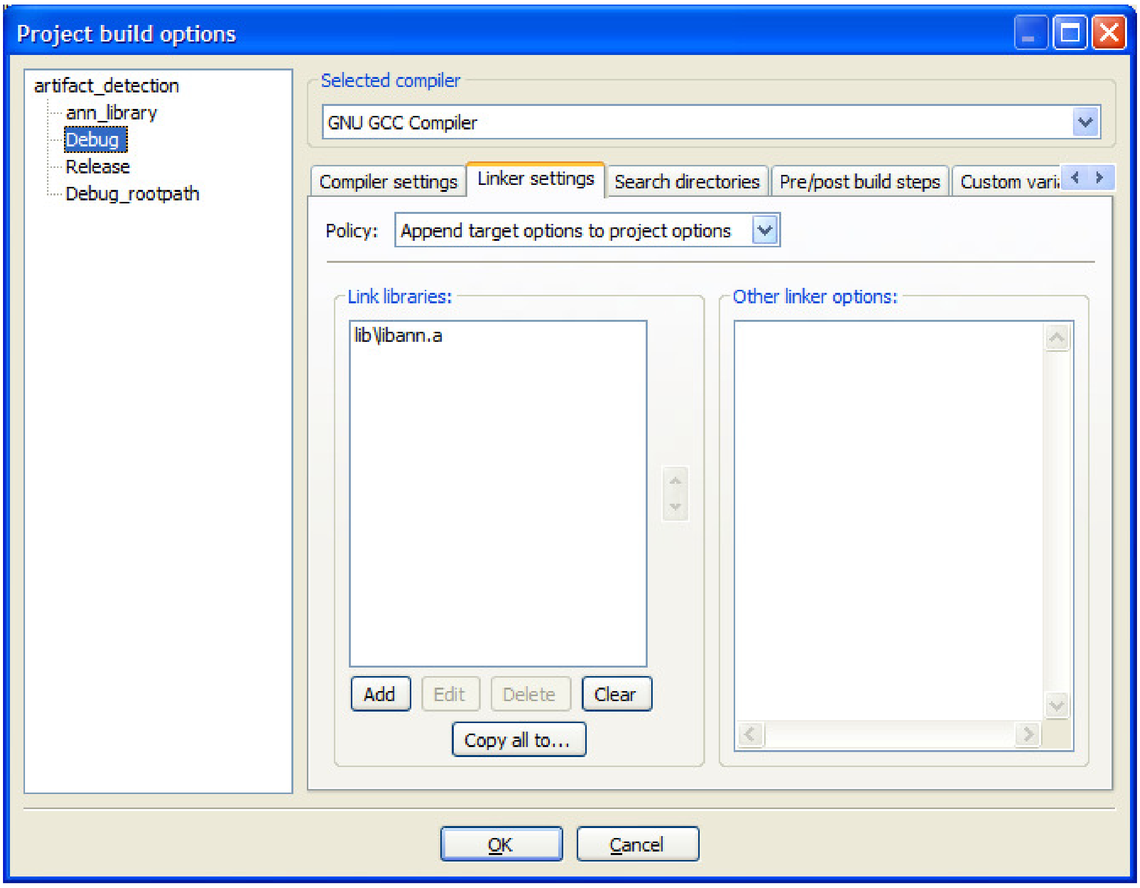


Figure 23. Build options window of code::blocks IDE (ANN relative path location).

After including the library in the project, the compiler needs to know the available functions of the library; the header files define that information. ANN has the ANN.h, ANNperf.h and ANNx.h files.
You must tell to the compiler the location of those files if they are not in the same folder as the executable. In the same window as before, go to the tab 'Search directories' as shown in Figure 24 and located in the sub-tab 'Compiler' select 'Add',

you must select the directory where you want the compiler search the headers to import .

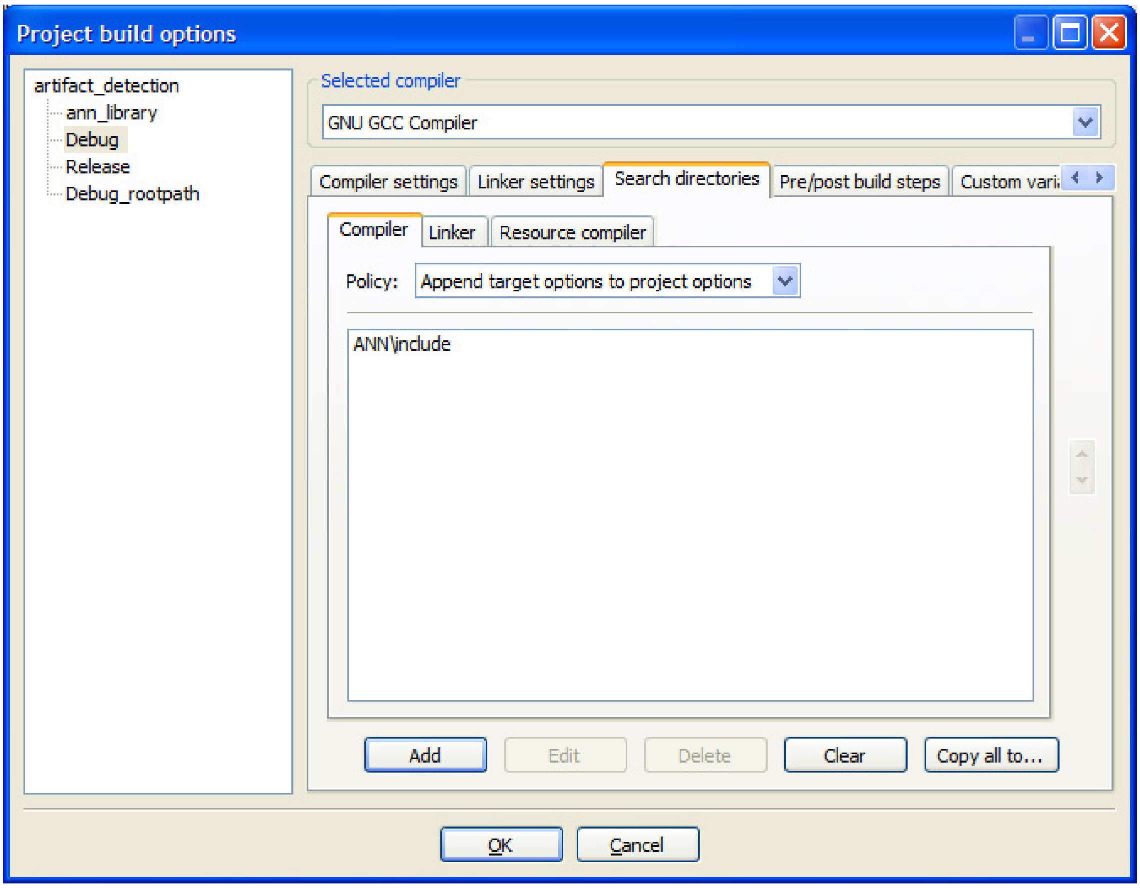


Figure 24. Build options window of code::blocks IDE.

6 Conclusions

In conclusion we have developed skills in working with pattern recognition methods. In our case we worked with information obtained from the brain by an EEG. EEG technology is widely used in cerebral medical diagnostics. An increasing range of researches are growing using this technology. We have worked in a real research environment. The data that we have used could be obtained in any laboratory or hospital.

Our first project was developed in Matlab. The aim has been to focus on some basics of pattern recognition. We worked to apply segmentation and feature extraction to improve a future classification of the data. Matlab allows developing algorithms faster than traditional methods, it has implemented a large number of mathematical functions and it provides instant access to graphics functions specialized. The works shows elemental steps to achieve a classification problem.

Our work in C++ has tried to find solutions to the EEG artifacts. It is a common problem in EEGs. The project developed in C++ can be used as starting point to new projects. It is ideal for future research in this area that will require speed of execution and efficient memory management. In addition, there are many compilers for different platforms using this programming language. For example it is possible to develop such programs for embedded environments.

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