A multi-class artificial neural network for vowel speech imagery classification in EEG data

G. De Nunzio [1 2] B. Tafuri [1] A. D. Manca [3] M. Donativi [1 2] R. Cataldo [1 2] M. Grimaldi [3]

[1]Dipartimento di Matematica e Fisica, Univ. del Salento, Italy

[2]Istituto Nazionale di Fisica Nucleare sez. di Lecce, Italy

[3]Dipart. di Studi Umanistici, Centro di Ricerca Interdisciplinare sul Linguaggio (CRIL), Univ. del Salento, Lecce, Italy

This work describes the preliminary results of the development and application of a multiclass Artificial Neural Network (ANN) classifier to be used in the framework of an EEG-based software system for brain-computer interfacing, having the long-term goal of creating an alternative speech tool for people with severe communication handicaps. The classifier aim is to distinguish, in the recorded EEG traces of the subjects, the imagined production of the five Italian vowels, plus a control condition ("no vowel"). The system is currently under test, and proved capable of discriminating the imagined production of vowels with encouraging success rate, though still to be improved.

Sixteen subjects (age 25 ± 3 years) were asked to perform in turn one of six tasks: imagine to produce the /a/ (or /e/, /i/, /o/, /u/) vowel, or remain in a neutral state, without specifically thinking to vowel production. There were six EEG recording blocks, each devoted to one of the five vowels or to the control task, with 180 task repetition each. Each task was triggered by a neutral visual stimulus (alternating white/red crosses on a computer screen, white meaning attention, red meaning task performing). Random times were used for each stimulus presentation, so as to avoid the risk of automatic responses by the subject. The presentation tool was BCI2000. The brain activities of the subjects were recorded (at 250 Hz sampling rate) by an EEG system with 64 active scalp electrodes embedded in an electro cap (actiCAP, Brain Products). The recording software was Brain Vision Recorder. Data processing was performed by MATLAB, EEGLAB being used for preprocessing (down-sampling to 100 Hz; 2 to 30 Hz band-pass filtering; subdivision into labeled epochs).

In these preliminary tests there was no ocular or muscular artifact reduction. The software system was composed of the EEG feature calculation section and the imagined-speech classifier.

In the first software section, EEG epochs were processed by time-frequency analysis in the ambiguity plane [1]. Values of the ambiguity function of the EEG signal $x(t)$:

$$A_x(\tau,\nu)=\int_{\Re} x\left(u+\frac{\tau}{2}\right)x^*\left(u-\frac{\tau}{2}\right)e^{-2\pi i\nu u}\,du$$

in the plane were chosen as features for EEG time series characterization and discrimination. In Figure 1 an example of isolines in the ambiguity plane of a /o/ vowel in imagined production task is shown.

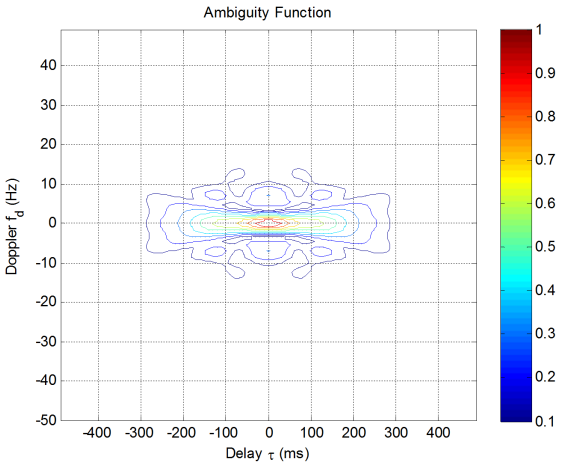

Figure 1. An ambiguity plane for the /o/ vowel.

The multi-class classifier was built according to the Binary Pair Partitioning (BPP) approach [2], in which a n-class classifier is a combination of $\binom{n}{2}$ binary classifiers (15 in this work, see Figure 2). The 100 most discriminant points for each possible couple of classes (e.g. /a/ vs /i/, /a/ vs control, and so on) were identified by

maximizing the Fisher contrast in the Ambiguity planes of the chosen two classes, and formed the feature vector. Each binary classifier was built as a 3-hidden-neuron ANN, which was separately trained and validated by Leave One Out Cross-Validation (LOO-CV), independently for each subject. Classification quality was measured by the ROC (Receiver Operating Characteristics) area under the curve (AUC) of each classifier, and by an overall accuracy figure of merit, i.e. the number of exactly predicted tasks (for each vowel and the control condition) divided by the whole number of validation epochs. Accuracy was about 50% for each wowel, which is not an astonishing result, but must be anyway compared with the theoretical value of guessing a vowel (or the control task) by hazard, which is 1/6. In conclusion, the quality of the system is promising, and the development will continue by testing the effect of artifact reduction, and by the choice of complementary features to be inserted in the feature vector.

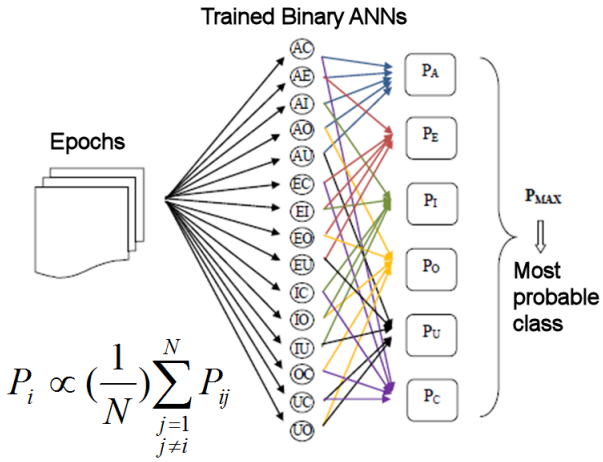

Figure 2. The multiclass ANN-based classifier, according to the Binary-Pair Partitioning approach.

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