Abstract

This doctoral work focuses on bringing brain-computer interface technologies closer to daily life by means of a metrological approach. In particular, applied metrology appears essential because these interfaces enable non-muscular communication through the measurement of brain signals, and even because their components must be characterized to fully understand system operation. Many challenges are associated with daily-life applications, namely non-invasive measurement, wearability, portability, user friendliness, and low cost. Thus, electroencephalography was a key choice for designing the systems. The usage of few acquisition channels was also considered, and proper processing had to be studied to detect the phenomena of interest. Finally, consumer-grade equipment was taken into account in the implementation. Two paradigms were investigated: a reactive interface relying on steady-state visually evoked potentials, and an active paradigm relying on motor imagery.

A metrological characterization of the consumer-grade equipment was first proposed. Characterization results show that a low-cost electroencephalograph can be successfully employed due to its linearity and limited gain error. Also, for the reactive paradigm, the characterization of flickering icons generated by smart glasses demonstrated that the harmonic content of such stimuli can be meaningfully different from the nominal one. This characterization pointed out that their harmonic content should be carefully measured before addressing the brain response to flickering lights, though exploiting commercial smart glasses in the operation of a reactive brain-computer interface is feasible.

Next, a wearable system based on steady-state visually evoked potentials was built by integrating commercial augmented reality glasses with the low-cost electroencephalograph. The power spectral density associated with the evoked potentials was measured to detect the neural phenomena of interest. An experimental campaign conducted with 20 subjects pointed out that mean classification accuracy among

subjects can be as high as 95 % at 10 s stimulation time, but it drops to about 75 % when a 2 s stimulation is considered. Thus, the system can be accurate enough for some industrial and healthcare applications, but further studies are needed to increase the system speed.

Finally, a wearable system based on motor imagery was proposed. A filter bank common spatial pattern algorithm was used for classification. The minimum number of acquisition channels needed for the detection was investigated. Results demonstrated that a single channel is not suitable for the detection of motor imagery, but the number of channels can be as low as three. The exact channels to exploit do depend on the involved tasks and subjects and they can vary from session to session. Nonetheless, the locations of selected channels were compatible with the sensorimotor area reported in the scientific literature. It was then noted that the wearability and portability of such a system could be still achieved, but neurofeedback had to be considered to improve motor imagery detection. The proposed system adopted an extended reality multi-sensory feedback. Results of a further experimental campaign conducted with eight subjects demonstrated that neurofeedback is effective in improving the detection of motor imagery for most subjects. The mean classification accuracy resulted about 70 %, which is an empirical threshold for an acceptable performance of motor imagery brain-computer interfaces.

As a whole the work demonstrated that reactive brain-computer interfaces are close to daily-life applications, though they still deserve an engineering phase, while research and development is needed for an active interface relying on motor imagery, and a deeper study of neurofeedback has been addressed for enhancing the detection of motor-related neurophysiological phenomena.