ABSTRACT

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Deterministic and Stochastic Extremum Seeking (ES) approaches are employed to adapt the gains of a Proportional-Integral-Derivative (PID) control law for functional neuromuscular electrical stimulation (NMES). The proposed scheme are applied to control the position of the arm of healthy volunteers and stroke patients so that coordinated movements of flexion/extension for their elbow can be performed. This approach eliminates the initial tuning tests with patients since the controller parameters are automatically computed in real time. The PID controller parameters are updated by means of a discrete version of multivariable ES in order to minimize a cost function which brings the desired performance requirements. Experimental results with healthy volunteers as well as stroke patients show the usual specifications commonly considered in physiotherapy for functional rehabilitation are eventually satisfied in terms of steady-state error, settling time, and percentage overshoot. Quantitative results show a reduction of $65,50\%$ in terms of the root-mean-square error (RMSE) – from $11,65^\circ$ to $4,02^\circ$ – when comparing the tracking curves of the last cycle to the first cycle in the experiments with all subjects.

Keywords: Neuromuscular electrical stimulation; Functional rehabilitation; Adaptive systems; Extremum seeking; PID control; Trajectory tracking.