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A control strategy based on intelligent algorithm (PSO) to perform electrical stimulation systems

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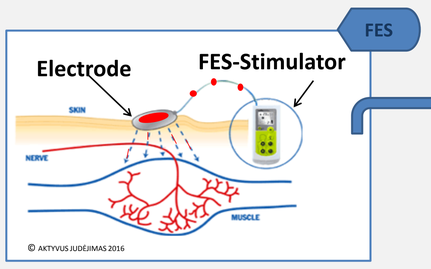
INTRODUCTION

Functional electrical stimulation (FES) is of a great interest in the medical and sportive domains. Improving the efficiency of Functional Electrical Stimulation (FES) systems present an interesting task in industrial FES systems applications [3].

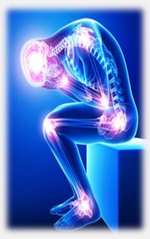
Functional Electrical Stimulation (FES) ✓



Applications:

muscle strengthening

mobility of paralyzed individuals



Treatment of the pain

Rehabilitation (standing)

The protocols used in these applications are limited by:

- The rapid appearing of the muscle fatigue;
- The imprecise generated movements.

To obtain improved performances from FES applications, it is interesting to adjust automatically the stimulation parameters using control strategies and using optimized protocols based on predictive muscle response models [4].

Aims

- ❖ The main goal of this study is to control the muscle force by adjusting the stimulation pulse amplitude of FES Stimulator using the PSO-based PID controller.
- ❖ The intelligent tuning PID Controller is based on a predictive muscle force model which is also identified using the same intelligent algorithm (PSO).

METHODS

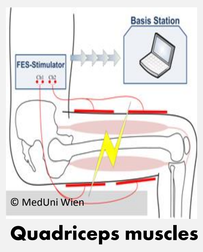
In this study, we control the muscle force by adjusting the stimulation pulse amplitude of FES Stimulator using the PSO-based PID controller. The PSO algorithm is firstly introduced to identify the optimal parameters of the nonlinear force model using experimental data. Then, the Off-line PSO-Based PID controller design is applied to the identified model in order to control the muscle force.

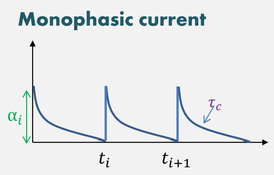
Force model

The muscle force model is a set of two nonlinear differential equations [1]:

$$\begin{cases} \dfrac{dC_N}{dt} = \dfrac{1}{\tau_c}\displaystyle\sum_{i=1}^{n} R_i \exp\left(-\dfrac{t-t_i}{\tau_c}\right) - \dfrac{C_N}{\tau_c} \\ \dfrac{dF}{dt} = A\dfrac{C_N}{K_m + C_N} - \dfrac{F}{\tau_1 + \tau_2 \dfrac{C_N}{K_m + C_N}} \end{cases}$$

$$\textbf{with } R_i = 1 + (R_0 - 1)\exp\left(-\frac{t_i - t_{i-1}}{\tau_c}\right) \quad i > 1$$





The four force model parameters (A, τ_1, τ_2, K_m) are identified by fitting the model to the force data using the following objective function:

$$G = \frac{1}{N}\sum_{k=1}^{N}\left(F_p(k; A, \tau_1, \tau_2, K_m) - F_m(k)\right)^2$$

Control design

- **PID controller design:**

$$u_{PID}(t) = K_p e(k) + K_i \sum_{j=1}^{k} e(j) + K_d(e(k) - e(k-1))$$

- **Particle Swarm Optimization algorithm(PSO):**

PSO technique has been developed by Kennedy and Eberhart in 1995 [2]. It is a population-based approach for optimization problem. At each algorithm iteration:

$$\begin{cases} v_i^{t+1} = wv_i^t + c_1 r_1 (Pbest_i^t - \chi_i^t) + c_2 r_2 (Gbest_i^t - \chi_i^t) \\ \chi_{i+1}^t = \chi_i^t + v_i^{t+1} \end{cases}$$

- **Pulse amplitude computing:**

$$U_n(t) = \frac{1}{\tau_c}\sum_{i=1}^{n} \alpha_i R_i \exp\left(-\frac{t-t_i}{\tau_c}\right)$$

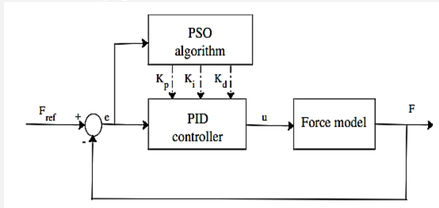


Fig. 1. PID controller tuning based on PSO algorithm for muscular force control

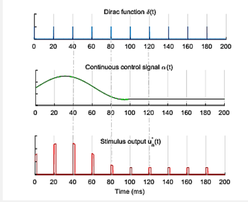


Fig. 2. Schematic representation of the pulse amplitude computing on the muscle force control by FES

RESULTS

Experimental setup

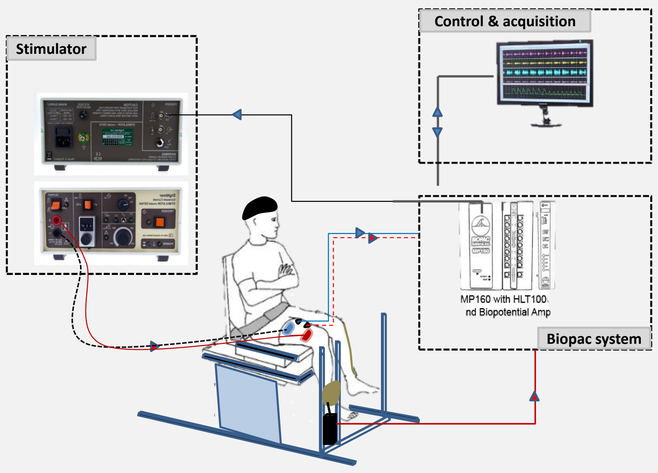


Fig. 3. Schematic representation of experimental arrangement for data collection.

TABLE I
OPTIMAL GAINS TUNING OF THE PSO BASED PID CONTROLLER

K_p	K_i	K_d
0.0935	0.0012	0.1511

TABLE II
IDENTIFIED PARAMETERS FORCE MODEL

A	τ_1	τ_2	K_m
$1.755N/ms$	$68.32ms$	$102.2ms$	0.5631

- For the test subject, the pulse amplitude was fixed to 50 mA and the pulse width was maintained at 500 µs.
- The quadriceps muscle group is stimulated by a pair of surface electrodes connected to the DS7AH Digitimer stimulator (Digitimer Ltd, Welwyn Garden City, Hertfordshire. AL7 3BE. England).
- Under stimulation session, mechanical measurements were recorded using an isometric ergometer comprising machine typically used for strength training (Multi-form, la Roque d'Anthéron, France) connected to one strain gauge (STC 250 kg, sensitivity: 2.9997 mV/V, Celtron Technologies Inc., Santa Clara, CA, USA).
- During the experimentation, data were digitized and stored for analyses using the Biopac MP150 A/D converter and AcqKnowledge v4.2 software.

Muscle force control

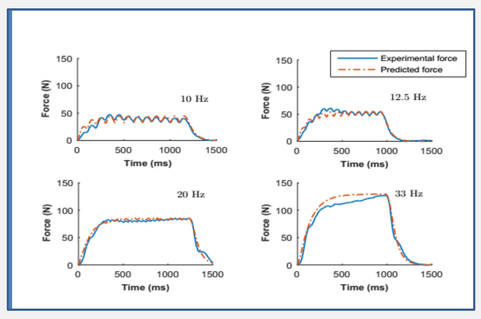


Fig. 4 proved the ability of the estimated model to predict force response for a wide range of frequencies (10Hz, 12.5Hz, 20Hz and 33Hz).

It should be noted that the identified parameters are depending of the standardized pulse's magnitude, the muscle properties of the test subject, the size and the placement of the stimulation pads.

Fig. 4. Examples of predicted force for different frequencies stimulation train when the model is parameterized by the CFT80-CFT30 protocol data for a typical subject.

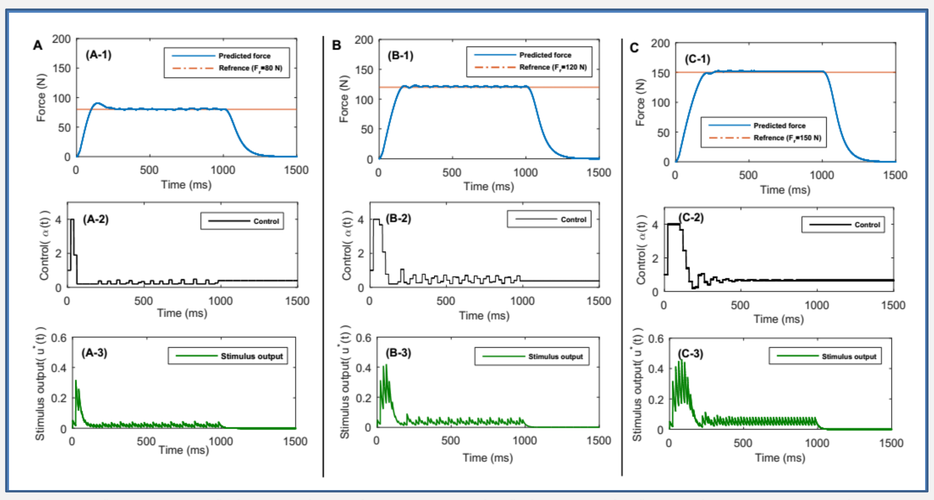


Fig. 5. The performance of the PID based PSO control of the muscle force during 1s stimulation session for three desired forces (A: Fref= 80N, B: Fref= 120N, C: Fref= 150N) using the modified pulse train MCFT30. **(A,B,C)-1:** illustrate the developed force to track the desired force, **(A,B,C)-2:** illustrate the computed pulse amplitude and **(A,B,C)-3:** illustrate the corresponding stimulus output applied to the quadriceps muscle.

CONCLUSION & PERSPECTIVES

In this work, a new controlling strategy PID based on PSO algorithm was designed in order to control the muscle force during stimulation sessions. This developed method is used to compute automatically the stimulus pulse amplitude for each pulse applied to the muscle. Also, using experimental data, the PSO algorithm was explored to identify and to provide a reliable mathematical model that can fit perfectly the muscle response and, as a result, improved the control system.

As perspectives, it will be interesting to validate these numerical results for muscle force control in experimental tests.

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