Cooperation of mono- and bi-articular muscles: human lower limb

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Key words: *muscle system, lower limb, mono-articular muscles, bi-articular muscles, Pareto-optimum problem*

1. Introduction

A key role in understanding of limb dynamics and kinematics, human gait and its modelling, plays a problem of muscle activity and its cooperation [1] and is often considered [2, 3]. In this paper, a description of mono- and bi-articular muscles cooperation of lower limb is presented. The Pareto-optimum problem is derived and considered in the case of movement performed in a sagittal plane of the body. Lack of solution, what implicates in lack of movement repeatability is shown. Experimental verification of descripted problem is also presented and discussed.

2. Pareto-optimum problem

2.1. *Considered mathematical problem*

Following Pareto-optimum problem is derived and considered:

$$\{\sigma_i\},\ \sigma_i = \frac{F_i}{S_{i\ anat}}, \tag{1}$$

where σ_i is the i-th muscle tension, F_i –force generated by i-th muscle and S_i – anatomical cross-section of the i-th muscle. $\boldsymbol{J}$ stays for following objective function:

$$J : \mathbb{R}_+^{r+m+s+o} \Longrightarrow \mathbb{R}_+^1, \tag{2}$$

$$J(\sigma_1, \ldots, \sigma_n) = \left(\sum_{i=1}^{r} \sigma_i,\ \sum_{i=r+1}^{r+m} \sigma_i,\ \sum_{i=r+m+1}^{r+m+s} \sigma_i,\ \sum_{i=r+m+s}^{l} \sigma_i \right),\ l = r+m+s+o \tag{3}$$

Where: m, r – number of mono-articular flexors muscles of tight and shank, respectively, n – two joint flexors, o, s – one joint extensors of tight and shank, respectively, p – two joint extensors muscles. It is shown that presented problem is indeterminate (infinitely many solutions exist). Some of them have to be excluded by physiological restrictions or by adding additional criterions.

2.2. *Practical verification*

Presented problem was verified inter alia by motion capture system. Exemplary obtained results are presented in Figure 1. Moreover, other methods of verification were used.

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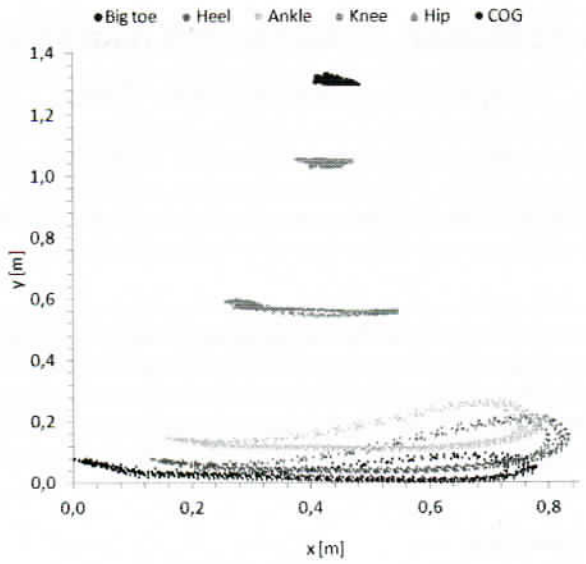

Fig. 1. Repeatability of steps during treadmill gait obtained from video analysis: displacements of toe, heel, ankle, knee, hip and center of gravity (COG); x – anterrio-posterior axis, y – longitudinal axis of the body.

An inconsistency of consecutive cycles are seen; small but distinguishable differences in each cycle can be observed, like difference in stride length, hip and knee vertical and horizontal displacement. Also accelerations and velocities were calculated and reveal the same problem. In this case, an experiment were performed on a treadmill, but it can be assumed, that a free gait is even more complicated and inconsistent. [4]

Acknowledgments: The work has been supported by the National Science Centre of Poland under the grant OPUS 9 No. 2015/17/B/ST8/01700 for years 2016-2018.

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