# STUDY OF THE INVERSE DYNAMICS OPTIMAL CONTROL TECHNIQUE IN CYCLING

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## INTRODUCTION

In recent developments, the authors have shown the possibility of considerable decreases of computational time, if a hybrid technique optimal control technique is applied [1,2] to find muscle activation patterns in musculoskeletal systems. The so-called Inverse Dynamics Optimal Control (IDOC) method breaks the classical Forward Dynamics Optimal Control Problem (OCP) in two steps:

a) Finding the joint torque curves through the Inverse Dynamics analysis of a real or simulated system;
b) Formulate an OCP that minimizes a cost function comprising a muscle-activation related expression augmented with an error function part between the moments calculated by inverse dynamics and the actual moment generated by muscles. Only muscle dynamics is considered in the OCP dynamic constraints, removing Multi-Body System (MBS) differential equations of the OCP formulation. These equations greatly increase the numerical cost of the OCP, as discussed in [3] for posture.

In this paper, the IDOC method was applied to cycling. The low numerical cost associated with the IDOC method should contribute to improve clinical applicability of mathematical modeling and optimal control, in the prescription of custom rehabilitation programs.

## METHODS

Initially, a MBS of human pedaling was formulated. The crank, ankle, knee and hip torques in both sides were calculated for a subject performing a constant angular velocity cycling movement. The multi-body system is a 2-D, eight bars and three degrees of freedom linkage with two closed loops. Each bar represents crank, stationary bar, thigh, shank and ankle for right and left sides (Figure 1). The model dimensional and inertial parameters, as well as the measured pedal forces, were taken from [4,5].

The IDOC problem was formulated considering ten lower-limb muscles (*gluteus medius,* hamstrings, *biceps femoris* short head, *gluteus maximus*, ilipsoas, *rectus femoris, vasti, gastrocnemius, soleus, tibialis anterior*). A Hill-type muscle contraction dynamics was used. The dependence of the muscle moment arms with joint angles was taken from [6]. The OCP was formulated and solved in the framework of the Consistent Approximations Theory, using the RIOTS toolbox for Matlab [7].

## RESULTS AND DISCUSSION

The torque curves obtained by the MBS inverse dynamics analysis has shown a good agreement with data published by other authors [8]. In addition, the joint torque curves formed by the sum of the individual muscle contributions, after the IDOC solution, were very similar to the inverse dynamics outputs. A series of numerical tests was carried out to find the most suited cost function that should lead to a reasonable matching between the calculated and EMG muscle activation patterns. This exploration is still in progress. However, feasible solutions were found for some muscles, compared to EMG and OCP data presented by [9]. Namely, *soleus, gastrocnemius*, hamstrings and *rectus femoris* has shown similar shapes. Other muscles, however, showed a good agreement with [9] in the maximum activation amplitudes, but with some phase distortion. Other classes of constraints, like endpoint equality and inequality constraints are currently being explored. The computational time used to perform the IDOC solution in one cycle of pedaling at 60 rpm was around 3-4 hours using a 450 MHz Pentium III processor. The results suggest that the method may a suitable alternative to low-cost optimal control analysis of cycling.

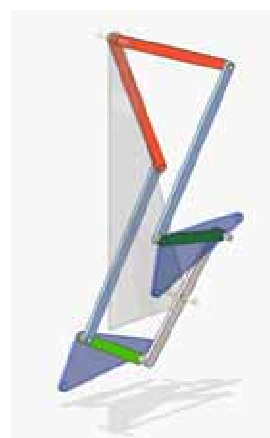

**Figure 1:** Geometry of the cycling model

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