Cascade control methods of a simple nonlinear limb model

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I. Introduction

Motivation and aim: Even the simplest limb model exhibits strongly nonlinear dynamic behavior that calls for applying the results of nonlinear systems and control theory. The control of musculoskeletal structures has considerable importance in the field of human locomotion control, designing and controlling muscle prothesis and artificial limbs. Last but not least the techniques of FES (functional electrical stimulation) - of patients with some kind of paralysis - can be improved with appropriate control methods.

Application of nonlinear control for biomechanical systems has appeared in the literature several times in the past decades. A study proposed by Levine and Zajac [7] has shown, that in the case of the pedaling problem, the control to achieve maximal acceleration for a simple skeletal system is bang-bang. The article of Kaplan [6] provides an optimal control method for muscle activity in the case of the pedalling problem using non-derivative quasi-Newton methods and numerical gradient methods. A further research of acceptable controllers (incl. input-output linearization) for the cycling problem was proposed by Abbot in the degree thesis [1]. Except some articles, the most of the solutions are based on linearization of the model, or on optimization methods with significant need of computing power. In general the usage of nonlinear control engineering methods is not prevalent in literature in this field, and also the applied solutions can be refined with new methods (utilize the cascade properties of such systems). Second, the proof of stability in the case of nonlinear system and control theory is always a challenge for systems with complex state-space models. In this case the system described has a quite complex dynamics, but we can avoid some of these difficulties by applying feedback linearization ([4] or [5]), and by using the backstepping method.

II. Materials and Methods

A. The simple nonlinear limb model:

A nonlinear input-affine state-space model has been developed for a simple one-joint system with a flexor and an extensor muscle (see Fig. 1) which is suitable for nonlinear systems analysis and control. The model takes the nonlinear properties of the force-length relation and the force-contraction velocity relation into account, similar to the one described in [2].

Exerted forces depend linearly on the activation state of muscles, following the principles in [11], [10] and [8]. In this case we used a simplifed version of the model described in [2], and do not take the tendon dynamics into account, as described in [3]. The inputs of the model are the normalized activation signal of muscles, the output is the joint angle, and the number of state variables is 4.

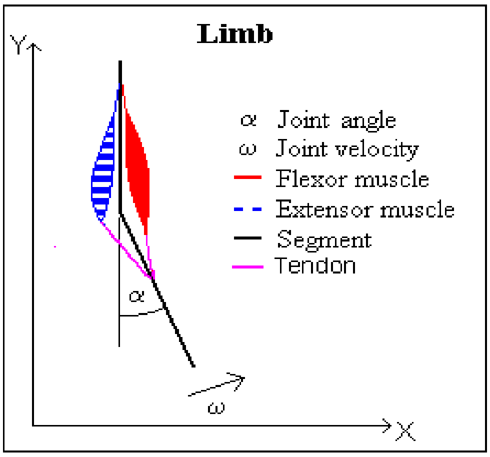

Fig. 1. The system

B. Structure and signal flow of the model

As it can be seen in Fig. 2, the dynamics of the muscle activation do not depend on the dynamics of the limb. So, the muscle activation states can be defined as inputs to the dynamics of the segments.

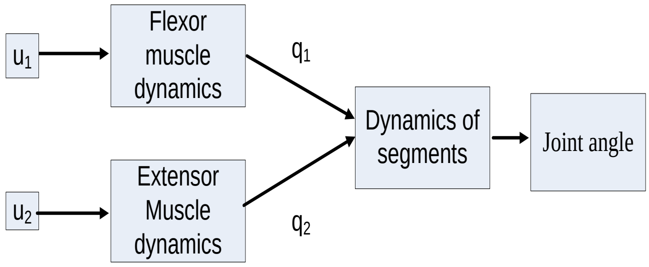

Fig. 2. The cascade structurte of the system

C. Cascade control

In the designed control methods we utilize the cascade structure of the model and apply, for example the backstepping technique described e. g. by van der Schaft in [9]. In some important cases the feedback properties are examined. The controller structure is extended to the task of trajectory following. Simulations are performed to test the theoretical basis for control design - in the trajectory following case, a sinusoid trajectory should be followed. Several cascade controllers are compared in the case of this two tasks.

III. RESULTS

Simulations were performed to test the theoretical basis for control design - in the case of the trajectory following task, a sinusoid trajectory is followed successfully.

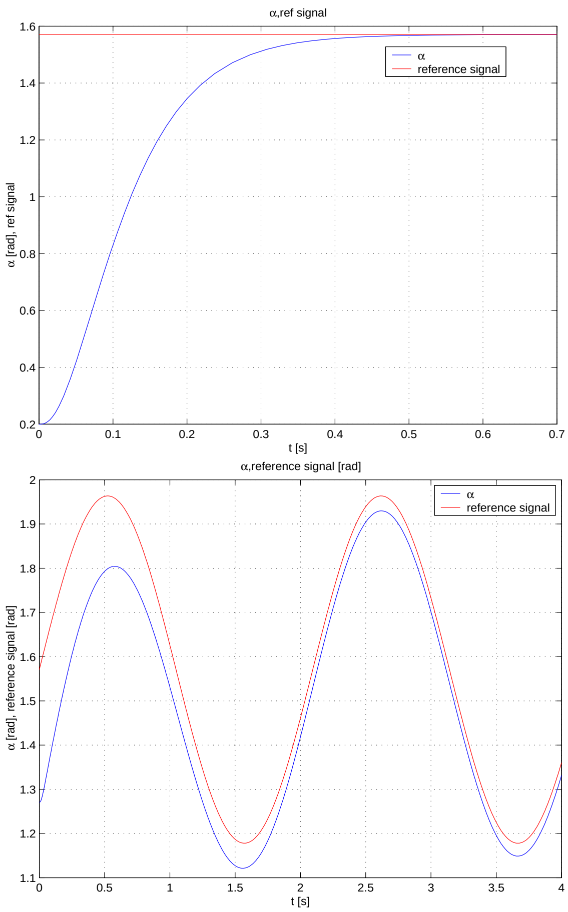

Fig. 3. Output: Joint angle at regulation and trajectory following at backstepping based control

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