MODELING AND CONTROL OF HUMAN POSTURAL SWAY

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INTRODUCTION

For quiet standing, the ankle strategy is used for the control of human posture in which the body moves as a rigid mass around the ankle joints. In its simplest form, the body is regarded as a single-link inverted pendulum with movement at the ankle joint controlled by the human postural control system. In patients with neurological impairment, this function might be restored by functional electrical stimulation. A critical part of such a neural prosthesis is the control algorithm. The control techniques used for such dynamic and nonlinear models need to be robust, such that they can perform well in spite of variations in the dynamics and parameters when applied on a real human. Hence, it is the purpose of our study to develop such robust control algorithms for postural control and to evaluate their performance using a computational model of musculoskeletal dynamics.

MODELING AND CONTROL DESIGN

The musculoskeletal dynamics model (Figure 1) consisted of one rigid segment, and three muscles at the ankle joint. Muscles were modeled using nonlinear differential equations from McLean *et al.* [1]. The plant model is complex and nonlinear. Furthermore, there are significant uncertainties in the model, caused by biological variation in human muscle properties. All of these make model-based control designs such as pole-placement, feedback linearization, sliding model control and H_2/H_{inf} difficult to attain. This leaves proportional-integral-derivative controller (PID) as the only common alternative. However, the limitations of PID make its performance unsatisfactory for this application, as shown later.

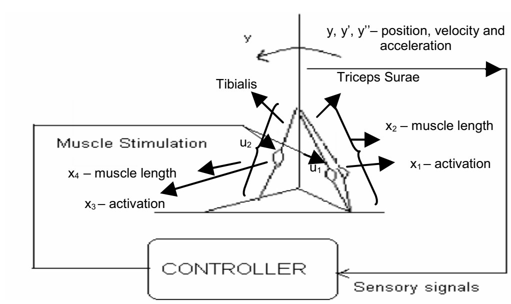

Figure 1: Closed-loop control strategy of the human ankle model

As pointed out by Gao *et al.* [2], problems like this call for a control design framework that is not overly dependent on the mathematical model of the process. In particular, we suggest that the active disturbance rejection control (ADRC) concept fits the nature of this problem well. This is because that the motion problem can be treated as

$$\ddot{y} = f + b \cdot U \qquad (1)$$

where y is the output position and f represents combined effects of internal nonlinear dynamics and external disturbances of the plant, b is a parameter and U is the control signal. In the ADRC framework, a unique state observer is used to estimate the value of 'f' in real time without knowing its mathematical expression. Using this, the control law

$$U = (U_0 - f)/b \qquad (2)$$

reduces the plant to a simple double integral plant, which can be easily controlled. A complete simulation model of the musculoskeletal system and both types of controller was built in Simulink. Desired posture in Figure 2 is 4° from vertical.

RESULTS AND DISCUSSION

The simulation results in Figure 2(a) were obtained at a nominal condition, for which PID and ADRC were tuned. In addition, inertia change and disturbance are added to test the robustness of the controllers as shown in Figures 2(b), 2(c).

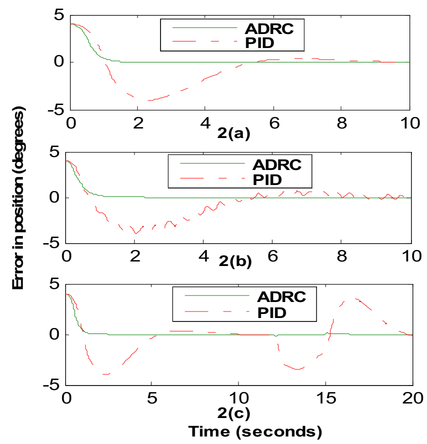

Figure 2: (a) nominal model, (b) with decreased inertia, (c) with a push of 60N-m at t = 12 secs for 3 secs

Based on the simulation results, the response of ADRC appears to be very tolerant to the uncertain and disturbed models. For the nominal condition, results of ADRC show no overshoot, reaching to steady state in less than 2 secs, whereas the control of PID takes 8 secs with a large overshoot. PID results in oscillatory response with decrease inertia by 4 times the nominal value, proving that its performance is sensitive to parameter variations whereas ADRC performance remains consistent. The maximum push that ADRC could withstand is 120N-m but with PID no more than 60N-m could be achieved. Muscle strength was sufficient to recover from a forward lean of 18°. This was attained by ADRC whereas PID could not tolerate more than 7° lean. These initial results show promise that ADRC can be extended to multiple joints for a more complete study of human postural control.

REFERENCES

1. S. G. McLean, *et al.*, "Development and Validation of a 3-D Model to Predict Knee Joint Loading During Dynamic movement", *J Biomech, Nov 2003*
2. Zhiqiang Gao *et al.*, "An Alternative Paradigm for Control System Design", *IEEE Conference on Decision and Control, 2001.*