Simulation of Tremor Propagation in the Upper Limb

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Introduction: Essential tremor (ET) is the most common movement disorder [1] and is estimated to affect between 1 and 12 million people in the US [2]. ET is characterized by a rhythmic tremor in the upper limbs while maintaining a posture or performing a movement [3], making activities of daily living, such as eating, clothing, writing, etc., difficult or impossible. Our long-term goal is to develop effective wearable tremor-suppressing devices. To reach this goal, we must first understand how tremor propagates from its mechanical origin (muscle) to the hand, where it matters most. A recent simulation study investigated how tremor propagates from joint torque to joint displacement [4]. The purpose of the current work is to characterize the extent to which tremor in different muscles or muscle groups contributes to tremor at the hand.

Materials and Methods: To study the effect of muscle activity on hand tremor, we follow this approach:
1. *Create a model of upper-limb dynamics*. We have modeled the major 7 degrees of freedom (DOF) from the shoulder to the wrist, actuated by 14 major muscles. Our focus is on tremor in postures where displacements are small, so we can maintain model tractability by linearizing about the postures.
2. *Characterize the effect of input parameters (location and frequency of tremorous muscle activity) on output parameters (amplitude, frequency, and phase shift of tremor)*.
3. *Characterize the effect of model parameters (inertia, damping, and stiffness) on output parameters.*
4. *Characterize the effect of reflex feedback parameters (gains and delay) on output parameters*.

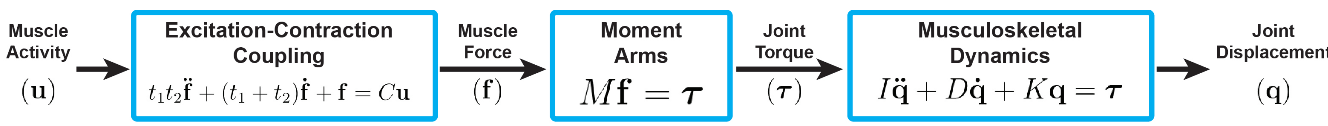

Figure 1. Model of upper-limb neuromusculoskeletal dynamics. The musculoskeletal dynamics (right) were used in the recent study of tremor propagation; the current work uses the full model.

Results and Discussion: Our full model (Figure 1) begins with input **u**, a 14-element vector of neural input to each of the 14 muscles (either a simulated train of impulses or measured EMG). To calculate muscle force, **f** (a 14-element vector of force produced by each muscle), time constants t_1, t_2, and C (a gain between **u** and **f**), have been determined from literature [5]. The 14-by-7 matrix of moment arms, M, was determined from OpenSim using a dynamic model of the upper arm [6]. $\boldsymbol{\tau}$, a 7-element vector of torque acting on each DOF, is the input to the final system, which uses I, D, and K (7-by-7 impedance matrices representing inertia, damping, and stiffness) to calculate **q**, the 7-element vector of displacement in each DOF. Impedance matrices were estimated from literature values [7, 8].

Conclusions: We plan to use our results to determine the mechanical origin of observed tremor kinematics. If our method is feasible for simulated inputs and outputs (impulse trains and resulting kinematics), we will repeat this step to determine if it is feasible for real data (EMG and kinematics from ET patients). The resulting principles will guide the future development of optimal tremor suppression strategies.

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