Development of a Real-Time Neural Controller using an EMG-Driven Musculoskeletal Model

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Abstract

Here we present the development of a novel real-time neural controller based on an EMG-driven musculoskeletal model, designed for volitional control of robots and computers. Our controller uniquely enables motion control during both isometric and non-isometric muscle contractions. We address several key challenges in EMG control system design, including accuracy, latency, and robustness. Our approach combines EMG signal processing, neural activation dynamics, and Hill-type muscle modeling to translate neural commands into muscle forces, which can enhance robustness against electrode variability and signal noise. Additionally, we integrate muscle activation dynamics with impedance control, inspired by human motor control system, for smooth and adaptive physical interactions. As a proof of concept, we demonstrate that our system can control a robotic actuator across a range of leg movements, both static and dynamic, and at different operating speeds, achieving high reference tracking performance and state-of-the-art processing time of 2.9 ms, which is important for real-time embedded computing. This research helps lay the groundwork for next-generation neural-machine interfaces that are fast, accurate, and adaptable to diverse users and control applications.

Methods and Results

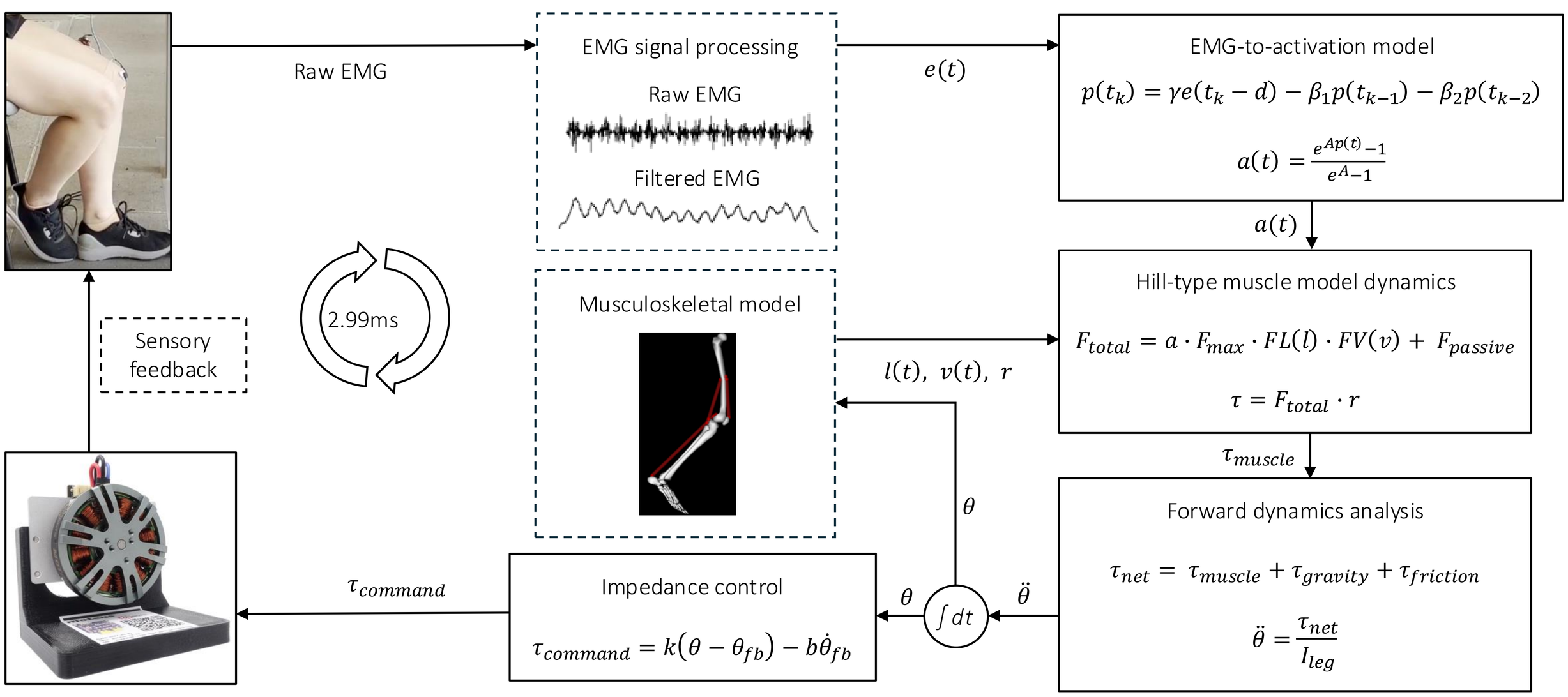


Fig. 1 System diagram of our real-time neural controller using an EMG-driven musculoskeletal model. We process and convert raw EMG signals into neural activations, which drive our muscle and musculoskeletal dynamics models to produce joint torques and movement. We also developed an impedance controller to generate torque commands for our motor actuator, which takes as input the simulated joint kinematics. The control loop is closed by the user receiving visual feedback of the rotating motor.

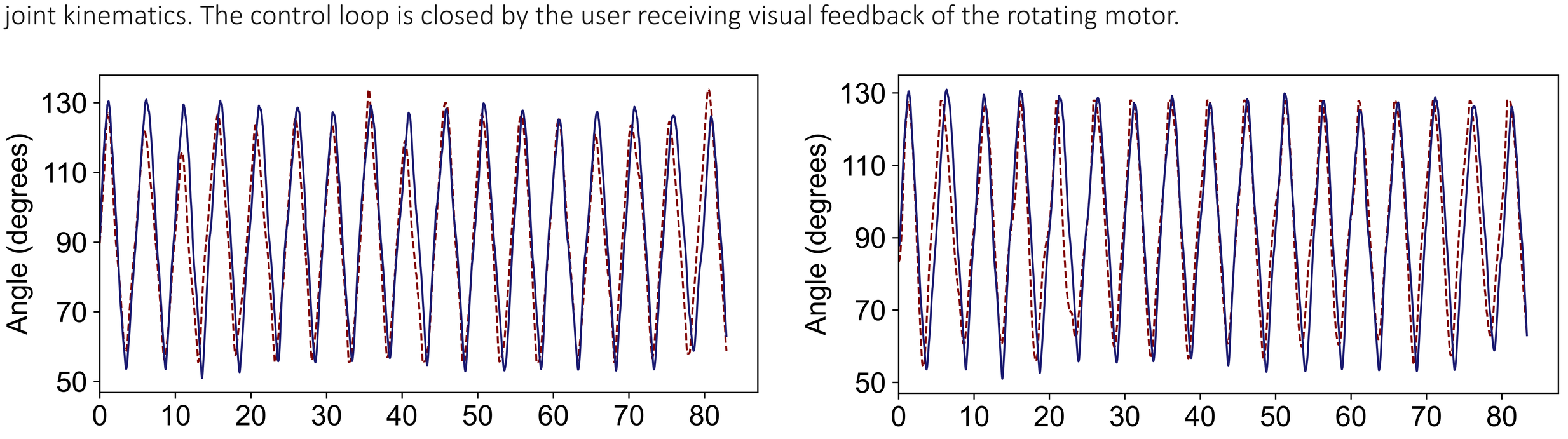


Fig. 2 Trajectory tracking of our EMG neural controller for both isometric (left) and non-isometric (right) sinusoidal movements at 0.2 Hz frequency. The red dashed signals are reference joint angles, and the blue dashed signals are the motor angles of our neural-controlled actuator.