Towards Surface Electromyography-Ultrasound Imaging-based Human Volitional Effort Prediction for the Assist-as-needed Control of a Cable-Driven Ankle Exoskeleton

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Abstract: Powered ankle exoskeletons are promising devices to improve the walking patterns of people with ankle joint impairments. Current biological signal-based control approaches of powered exoskeletons are limited to surface electromyography (sEMG) to incorporate the human intent of the human muscles. Recently, we showed the advantages of a dual-modal approach that merges ultrasound (US) imaging with sEMG signals to predict ankle joint volitional effort based on offline analysis. However, the use of the dual-modal approach in real-time and in the closed-loop control of rehabilitative devices is yet to be investigated. Therefore, in this work, we propose to include the ankle joint volitional plantarflexion torque predicted via an sEMG-US imaging-driven Hill-type neuromuscular model in the assist-as-needed control of an ankle exoskeleton. A multi-rate observer based on sequential processing is applied to continuously estimate the plantarflexor muscles activation levels by fusing sEMG and US imaging signals. An adaptive impedance controller (AIC) is designed to manipulate the ankle joint impedance to track a pre-defined reference impedance model and make the exoskeleton's behavior more natural. Two neural networks are designed to estimate the overall ankle-exoskeleton system modeling uncertainties and ankle joint volitional effort prediction error. The Lyapunov method-based stability analysis shows the closed-loop system is ultimately uniformly bounded. Experimental studies of three participants with no neurological disabilities walking on a treadmill are conducted to verify the effectiveness of the designed ankle exoskeleton and the AIC approach. Results showed that the AIC approach maintained a relatively accurate trajectory tracking with a root mean square error of 4.76 ± 0.42 ° while provided compliant assistance from the exoskeleton as it responded in real-time to impedance changes. The findings pave a foundation for using multiple-modal biological signals to control rehabilitative or assistive devices.

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