A Computational Framework for Muscle-Level Control of Bi-lateral Robotic Ankle Exoskeletons

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Abstract. Recent effort in exoskeleton control resulted in reduction of human metabolic consumption during ground-level walking. In this context, solutions that would enable biomechanical and metabolic benefits across large repertoires of motor tasks would be central in supporting the human in both medical and industrial scenarios. With this idea in mind we created a muscle-driven controller based on electromyography (EMG)-driven musculoskeletal modeling that we interfaced with the robotic bi-lateral Achilles ankle exoskeleton previously developed in our group. Preliminary results on one healthy individual show the possibility of continuously decoding EMG-dependent muscle force and resulting ankle joint moment patterns in real-time across a range of diverse motor tasks. We demonstrate that this information can be used to establish a human-exoskeleton interface with high-resolution at the level of single muscle mechanics.

1 Introduction

Exoskeleton can be a game changer in preventing injury in industry setting and in rehabilitation of paretic patients. Unfortunately, in rehabilitation settings the most advanced gait retainers commercially available (e.g. Lokomat Hocoma, Switzerland) still do not provide consensus on their benefit with respect to classic physiotherapy-based rehabilitation training [1]. In industry settings, heavy working tasks supported by the assistance of an exoskeleton are still not common. Two major unresolved challenges may be identified. The first one, is the robust decoding of the user's intention and the second one is the ability of operating robotic exoskeletons synchronously to human intentions and providing assistance that can vary depending of the wearer's need. To tackle these challenges, we propose the integration of a computational muscle-driven framework for the control of a bi-lateral ankle joint robotic exoskeleton. This concept is based on electromyography (EMG)-driven musculoskeletal modelling. Our proposed method allows continuous joint moment decoding. Furthermore, by giving a percentage of the computed human joint moment to the exoskeleton controller, a variable assistance scheme can be established. In this context, it has been recently shown that the timing of the assistance delivered by an exoskeleton is one of the key element for reducing metabolic consumption [2]. We also recently showed two major

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results. The real-time computation of joint torque using EMG-driven modeling and the possibility to extrapolate the joint moment computation to unknown task (i.e. beyond the calibration task) [3]. In this paper we explain how we interfaced with the bi-lateral Achilles ankle exoskeleton [4] and discuss preliminary results showing that we can compute muscle-level information continuously and synchronously between the user and the exoskeleton.

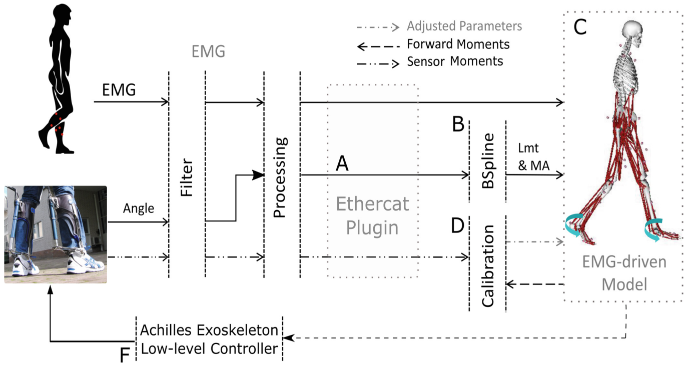

Fig. 1. Schematics representation of the framework and its connection with the Achilles exoskeleton.

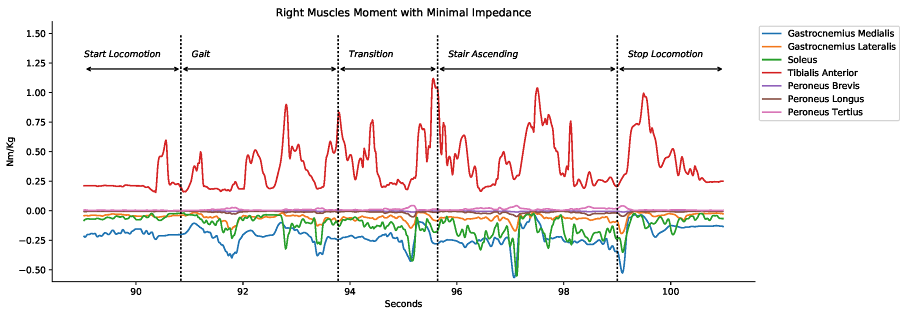

Fig. 2. Right ankle muscles moment for multiple continuous task (gait to stair ascending) with minimal impedance control.

2 Method

We developed a real-time EMG-driven musculoskeletal modeling framework. This framework is building upon a previously developed algorithm in [5] and later enhanced to work in real-time [3]. Our EMG-driven musculoskeletal modelling framework allows the computation of joint moments and intermediate muscle information (muscle force, pennation angle, fiber length) from EMG signals and joint position.

The model includes 14 musculo-tendon unit (MTU) consisting bilaterally of the Gastrocnemius Medialis, Gastrocnemius Lateralis, Soleus, Tibialis Anterior, Peroneus Brevis, Peroneus Longus and Peroneus Tertius. In Fig. 1, we present a schematic representation of the framework and its connection to the Achilles exoskeleton [4]. The Achilles exoskeleton is a bi-articular exoskeleton for the ankles joint. It allows to record ankle position and ankle interaction forces between the user and the exoskeleton. More information can be found in [4]. The inter-communication of the Achilles is based on the real-time network protocol Ethercat.

The main input of our framework are the ankle joint and the experimental EMG signal from 10 muscles bilaterally (all previously cited muscles except Peroneus group). These values are recorded via an Ethercat plugin (Fig. 1A) in real-time and at a frequency of 1000 Hz. This information is transmitted to our framework which will convert the joint position to muscle-tendon length (LMT) and muscle moment arm (MA) for the considered MTU (Fig. 1B). The ankle muscles forces are computed using Hill-type muscle model with the EMG and LMT as an inputs. The resulting forces are projected to the ankle joint using the MA (Fig. 1C). The resulting moment is then send via the Ethercat protocol to the Achilles low-level moment controller (Fig. 1F). To give subject-specific result the muscle model have to be personalized to the user. A calibration procedure is used to determine the user muscle parameter. This calibration procedure consist of an optimization that try to reduce the error between moment computed via our framework and moment recorded by the sensor from the Achilles in isometric condition.

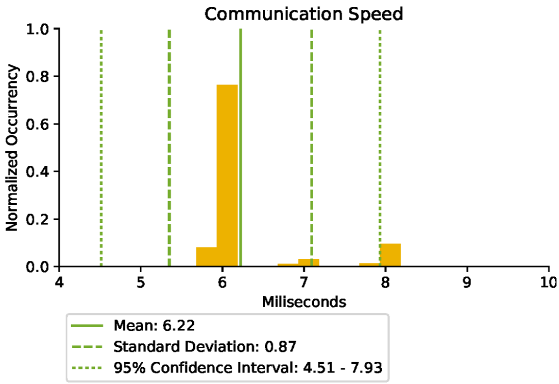

Fig. 3. Timing to send and receive information between the EMG-driven framework and the Achilles low level controller.

3 Result and Discussion

Preliminary experiments were done on one user. After calibration, the user performed over-ground walking followed by stair ascending. Tasks were performed with the robotic exoskeleton being controlled to enable minimal impedance behavior. The real-time computed resulting muscle moment contribution can be visualized in Fig. 2. In Fig. 3, the communication speed to send and receiving information between our framework and the low-level controller of the Achilles can be visualized. These preliminary results were done to first test the possibility for the framework to compute in real-time joint and muscle information including moment and force continuously when interfaced with the Achilles exoskeleton. The second hypothesis is that the computation and communication were fast enough to be under the muscle electromechanical delay (EMD) (between 30–100 ms [6]) as synchronization between the assistance provided by the exoskeleton and the production of force by the user is primordial. Previous result [3] shows that our framework can compute joint moment with a timing <10 ms and here, we show that the communication time was <7 ms which is under the EMD.

4 Conclusion

We show in this abstract that our framework can be interfaced with the robotic Achilles exoskeleton in real-time to compute muscle force and resulting ankle moment continuously. We also show that these outputs are computed under the EMD which is central for allowing synchronization between the user and the Achilles. Future work will test the assistance provided by the framework with different assistance level and asses the quality of outputted moments.

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