Reinforcement Learning through Physics-based and Data-driven Approaches for Exoskeleton Control in the Real World

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Wearable robots have demonstrated potential for enhancing mobility, but their control strategies often require extensive human testing or rely on manually crafted control rules [1], [2]. This creates challenges in translating them from clinical to community use. Typically, these robots have complex and custom transition rules that involve a high number of parameters to detect gait events and generate assistive torque. These parameters are adjusted for specific activities and individuals using biomechanical measurements or feedback, which can take hours for each activity. Moreover, while these controllers work well during steady-state walking, they struggle to adapt to changes in walking speed and generate abrupt and discontinuous assistive torque due to their gait event-specific rules. This limits the effectiveness of exoskeletons, especially when used in community settings. Simulating musculoskeletal movements through the use of accurate musculoskeletal model-based approaches shows great potential in addressing challenges faced in developing controllers [3], [4]. However, these approaches have been confined to simulation environments due to the inherent difficulties in modeling the inseparable coupling between humans and robots.

We have developed a novel approach by combining physics-based and data-driven methods. Our approach enables automatic learning of control strategies entirely in simulation, eliminating the need for manual control laws and extensive human testing. Figure 1 shows our physics-informed and data-driven reinforcement learning approach for continuous and automatic control of a portable exoskeleton.

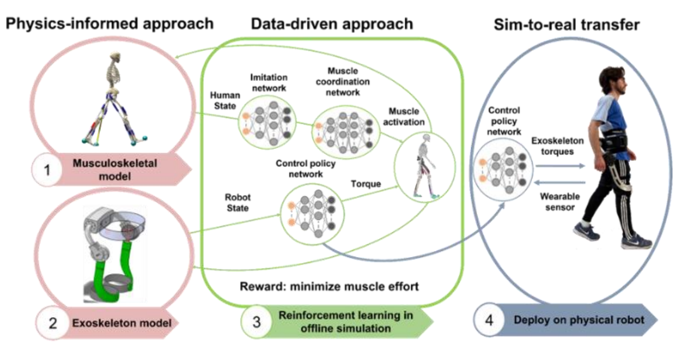

Fig. 1. Our framework combines physics-informed and data-driven reinforcement learning techniques to facilitate continuous and automatic control of a portable exoskeleton, which aims to improve human performance during walking and running activities.

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The muscle response is modeled with the Hill-type model, and human dynamics are modeled with Euler-Lagrangian equations. To generate realistic musculoskeletal responses, we trained a motion imitation network to generate joint torque commands and a muscle coordination network to signal muscle activations. Additionally, we unified the physical model of the exoskeleton with the musculoskeletal model to model realistic human-exoskeleton interaction forces. We utilized Reinforcement Learning to train exoskeleton control networks that work harmoniously with the neural networks that control the musculoskeletal model, allowing for the automatic learning of control strategies in the presence of human-machine interactions. Lastly, we implemented dynamics randomization during training to ensure the seamless deployment of controllers on physical hardware and generalization across varying individual characteristics.

Our controller successfully reduced the metabolic cost of the hip exoskeleton during walking and running by 20.9% and 15.8% respectively across various speeds for a group of eight individuals (5 males and 3 females). Figure 2 shows a significant reduction in the metabolic cost of a test subject during walking and running when compared to with and without exoskeleton conditions.

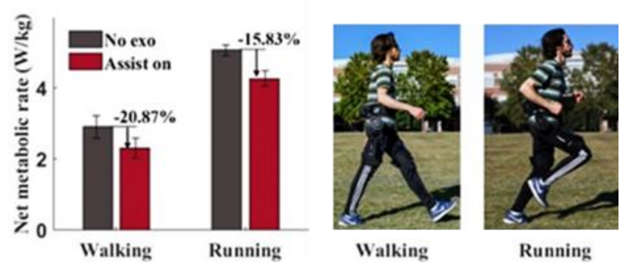

Fig. 2. Significant reduction in metabolic cost of a test subject during walking and running, when compared to with and without exoskeleton conditions.

References

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