Project title: Shared Assistance in Locomotion for Lower-Limb Wearable Robots

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Aim of the project

Wearable robots have not realised their potential impact yet due to unintuitive control interfaces. Extension to more sophisticated tasks will require inferring the user's motor intent.

Virtual environments provide a safe and accessible way to test and evaluate users' responses, but current systems rely on inverse dynamics that can quickly become inaccurate with the occurrence of forces from an external virtual device. Forward simulations, yet unexplored in the domain of shared human-robot assistance for lower-limb assistance, can generate stable walking policies, modelling key aspects of the user's motor control and its relationship with the wearable device.

The proposed project's core aim is to implement and evaluate a deep reinforcement learning based motion controller. In the initial phase, we employ a marker-based opto-electronic motion capture system and surface electromyography. We then use the captured kinematics to develop a control policy that translates high-dimensional features into low-dimensional control. This advancement is pivotal for creating adaptable lower-limb wearable robots tailored for those with mobility impairments.

Project description

Wearable robots can transform the way we aid individuals with mobility impairments. However, they have not yet realised their potential impact. Commercially available wearable robots face challenges, such as user intent detection, as well as issues related to intuitive control interfaces and limited degrees of freedom (DoFs) control [1]. Current intention-based wearable robots rely on neuromuscular interfaces, but the muscle activation that can be decoded is often insufficient (e.g., noisy) for reliable triggering of non-steady-state locomotion (e.g., turning, changing walking speed, starting stair ascension). This limits them to a small number of tasks, and control is often perceived as rigid and unnatural by the user [2]. Strategies are needed to synchronize generated motion with user motor intent towards the extension to more sophisticated tasks and higher levels of assistance. For instance, for leg exoskeletons, the system needs to detect that the user plans to ascend stairs or traverse a slippery walkway, so joint torques can be adjusted to maximize assistance and stability.

The development of new control strategies is hampered by limited access to hardware and participants [3]. Establishing physical environments that ensure validated, reproducible, and safe testing requires complex and specialized equipment. To expedite hardware and controller design iterations, emulation hardware can be used, but it may impose limitations on the range of test environments and locomotion tasks due to the mobility constraints of the emulation platform. In the realm of upper limb device design, virtual environments have proven effective in addressing these issues [4]. However, applying this approach to locomotion tasks introduces challenges. To provide the necessary kinematic and kinetic context for the operation of a simulated lower-limb device, the user's movements must also be simulated. Relying solely on inverse dynamics is insufficient because motion trajectories reconstructed from experiments quickly become inaccurate when virtual forces are introduced. In contrast, unexplored predictive forward simulations can generate stable walking strategies that model essential aspects of the simulated user's motor control. These simulations enable the device to respond to disturbances and leverage assistance in response to modelled gait abnormalities, in the case of individuals with impairments, and adapt with compensatory motions.

Musculoskeletal modelling used to tailor specific interventions to movement disorders, generate reproducible outcomes, and enhance patient care by revealing relationships between baseline conditions and rehabilitation effectiveness [5]. Traditional models like OpenSim [6], based on inverse dynamics, are unable to handle contact-rich dynamics, necessary to simulate human-robot interaction [7]. Open-source RL-driven MuJoCo-based [8] techniques have facilitated interfaces that translate tensors into human movements with contact-rich interactions. The need is boosted by recent strides in human locomotion modelling, demonstrating increased generalizability when incorporating real-world kinematics [9], [10]. However, a biomechanics evaluation of the reliability of a contact-rich model is still lacking. These drawbacks may limit the successful transfer of control policies from simulation to reality.

This project will increase understanding of shared autonomy between the user and the control policy of an active wearable robot, towards both short-term and long-term generalizable non-continuous locomotion tasks.

References

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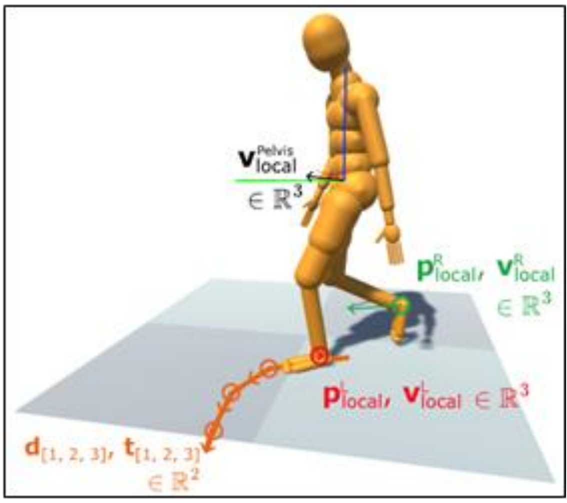

Illustration from Hodossy and Farina 2023, showing the motion system, including the velocity of the pelvis, the position and velocity of the feet (left and right) and the directional and trajectory. The study used MuJoCo to evaluate shared autonomy between human and ankle prothesis, which is significantly different from a unilateral ankle exosuit.

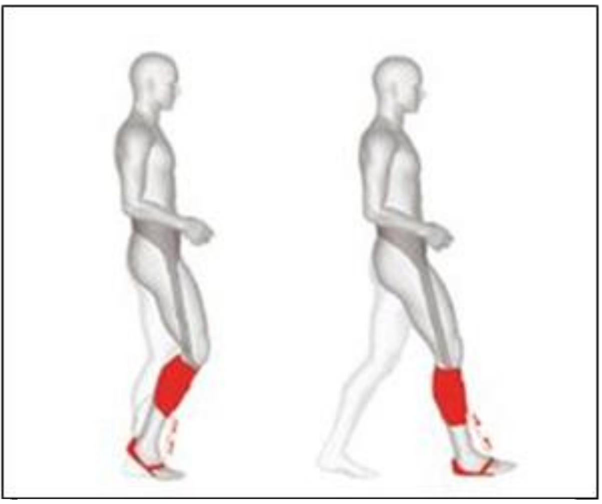

Illustration of an ankle exoskeleton that will be implemented in the simulator.