Total Energy Shaping for Task-Invariant Control of Lower-Limb Exoskeletons

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Technology description

We present a total energy shaping control methodology for the development of portable lower-limb assistive exoskeletons and orthotic devices that help reduce the human' s effort and augment natural motion. Current robotic exoskeletons restrict joint motion to pre-defined position trajectories during gait rehabilitation; such methods aim to replicate normative joint kinematics but do not reinforce the patient' s natural gait. Although some trajectory-free controllers have been proposed for amplifying human motion, these assume that the user has the ability to fully produce joint kinematics - which is not the case for patients with weakened limbs. Thus, there remains a clinical need to provide new class of powered orthotics & control systems that could be used to rehabilitate and/or assist patients with weakened limbs – often caused by stroke and other neurological injuries.
Herein, we describe a solution that provide trajectory-free torque assistance with total energy shaping to achieve task-invariant control of lower-limb exoskeletons. Building on prior work that uses potential energy shaping for virtual body-weight support (BWS), this control strategy also shapes the kinetic energy of the body - augmenting human gaits in both the direction of walking and the direction of gravity. Total energy shaping alters kinetic goals, such as energy, to provide a flexible learning environment throughout gait training – allowing a greater range of torque assistance that may be adjusted as patients undergo rehabilitation. Compared with virtual BWS alone, the presented exoskeletal control strategy further augments step length and step linear velocity – helping patients to accelerate/decelerate during gait training. Furthermore, this strategy enables the creation of mobile exoskeletons for use outside of a clinic, as both short-term rehabilitative and long-term assistive devices.
Technical Summary:
By shaping the fully-actuated part of the body' s mass matrix, we satisfy the matching condition for different contact phases and obtain trajectory-free control laws for total energy shaping. Simulations of a human-like biped demonstrate reduced metabolic cost and speed regulation in addition to BWS, indicating the potential clinical value of this control approach. The control strategy has also been successfully demonstrated in a new class of powered exoskeletons – which incorporate backdrivability, task-invariant control, and modular joint configurations (to address patient-specific needs).
Value Proposition:

The established trajectory-free, task-invariant, torque control methodology augments the human body’s energy, rather than restricting joint motion to pre-defined position trajectories, to amplify voluntary motion for users with weakened limbs. This control methodology fully leverages the potential of backdrivable actuator technology to improve rehabilitation options for patients living with a limited ability to produce joint kinematics.

Lv, Ge, and Robert D. Gregg. “Towards Total Energy Shaping Control of Lower-Limb Exoskeletons.” 2017 American Control Conference (ACC), 26 May 2017, doi:10.23919/acc.2017.7963706.

Lv, Ge, et al. “On the Design and Control of Highly Backdrivable Lower-Limb Exoskeletons.” IEEE Control Systems Magazine, Dec. 2018, doi:10.1109/MCS.2018.2866605.

Related Link:Device Implementation - Up and Go Demonstration (YouTube - Link)

Application area

Gait rehabilitation and assistance systems

Motorized orthotic devices and exoskeletons

Advantages

Extended Battery Life– Leverages backdrivable actuation to regenerate power from negative work being done on the exoskeleton

Natural Gait Reinforcement– Trajectory-free control, augmented swinging knee motion, and active energy injection into the user's gait allows for more natural locomotion

Customizable– Amount of BWS and inertia compensation can be adjusted to fit patient’s needs and progress, enabling patient-specific therapies for rehabilitation

Versatile– Enables portable rehabilitative orthotic devices for use both in and outside of the clinic

Ease of Use– Significantly less labor-intensive for clinicians and physical therapists; backdrivability promotes participation & comfort for patients with some control of their legs

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