Optimizing Design and Control of Lower Limb Exoskeletons for Paraplegic Patients

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Abstract: Exoskeletons are orthoses that cover big parts of the human body and are also sometimes referred to as robotic suits or wearable robots. The first exoskeletons became available around 2005 and were destined to enhance human motion capabilities by amplifying the muscle forces. The goal was to make healthy people walk faster or further and to carry larger loads, with applications e.g. in the military sector or for nurses in hospitals. Latest developments have allowed to generate enough energy on board to produce exoskeleton movement without any or just little muscular support. This makes exoskeletons also very interesting for medical applications, e.g. to allow patients with serious paralysis who would otherwise be bound to wheelchairs to walk again.

The design and control of exoskeletons are very challenging tasks. In the design process, the structure of the exoskeleton has to be designed such that it is not too heavy, but still able to safely carry the dynamic loads occurring during the targeted type of motions, such as walking on different terrains.Actuators have to be correctly chosen to produces the required loads for moving the combined human-robot system. The control task is challenging, because the motions are highly dynamic and because of the coupled human-robot system. With respect to stand-alone autonomous robots, it has the advantage of the availability of human intelligence in the system and of human reflexes in at least a part of the body. But the exoskeleton, must exhibit a sufficient robustness to also cope with unforeseen control inputs and perturbations from the human user.

In the context of a HEIKA project with the KIT, we have developed a tool, ExoOpt, that supports the design process of an exoskeleton and allows to determine required control inputs for a motion. We have established a model of a lower limb exoskeleton and combined this with a full 3D model of the human body using anthropometric data. Human motion capture recording of walking on level ground and different values of slope walking (up and down) have to used to perform a least squares optimal control fitting of the model to the recorded motion. This has been repeated for different choices of human and exoskeleton mass. The resulting model trajectories and control give a large number of insights into the mechanical requirements for the device and the particular motion. Among others, we get information of required torques to move the overall systems, the loads (stress) in the joints, the required joint velocities which all are very helpful insights for a designer.

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