LENAR: a non-anthropomorphic powered orthosis for gait rehabilitation and assistance

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***Abstract*— A novel treadmill-based wearable robot for the assistance of knee flexion/extension motion was developed. Its non-anthropomorphic structure provides better robustness to misalignments, simpler wearing procedure and dynamic advantages.**

I. Opening design space to non-anthropomorphism

Powered wearable orthoses typically have an anthropomorphic kinematic structure. In such designs, misalignments may arise from the mismatch with human joint axes of rotation, causing spurious reaction forces on the articulations, shear forces on the skin and overall discomfort. The relaxation of the anthropomorphism constraint introduces robustness against misalignments and tremendously enlarges the search space for type-synthesis. Indeed, inertial properties and mass distribution can be conveniently optimized in order to maximize transparency during 'patient-in-charge' mode.

II. LENAR design

The design of the LENAR (Lower-Extremity Non-Anthropomorphic Robot) is based on: *a)* a systematic search of all configurations with a desired mobility to provide mechanical support to two human joints [1, 2]; *b)* a selection of a candidate design solution; *c)* an optimization process to improve ergonomics and minimize actuation requirements [3]. Moreover, the prototype exhibits reduced mechanical impedance by resorting to: *d)* compliant torsion elements in the actuated joints (Series Elastic Actuators, SEAs) [4]; *e)* high efficiency gearmotors; *f)* smart distribution of the inertia of the actuation apparatus; *g)* lightweight design of robotic links. Compared to an equivalent Anthropomorphic Design (AD), it was possible to improve both ergonomics and intrinsic dynamics reflected on the user during the swing phase.

III. Advantages

The analysis of the average LENAR inertia showed a 29% increase of the maximum principal value compared to the case of free walking (robot not worn). Such increase is significantly smaller than the one that would be obtained with an AD including the same actuators (48%). This result supports the choice of a non-anthropomorphic design, considered that overground walking is a dynamical process dominated by inertia. Another important feature of the LENAR consists in the location in proximal districts (close to the torso) of the main swinging masses. Indeed, despite the high torque and power of the SEAs (2 per leg, peak torque of 60 Nm and rated power 300 W), the LENAR is easily backdriveable even when unpowered, with backdriving torques in the order of 11-23% of those delivered by human joints during free walking. This result was also confirmed by reduced alterations in EMG activity of five muscles compared to the free walking condition. Moreover, interaction tests, performed with LENAR link lengths set at different values from the nominal ones, demonstrated no significant alterations to the EMG activity and to torque and angle profiles.

Figure 1. Overview of the LENAR.

IV. Conclusions

The structure of the LENAR assures dynamic advantages in terms of low reflected inertia and high-backdrivability, a feature which is important both in rehabilitation and assistance applications. Moreover, the non-anthropomorphic structure simplifies wearing procedure, since the robot joints must not be aligned to human joints.

References

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