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Fall preventive gait trajectory planning of a lower limb rehabilitation exoskeleton based on capture point theory

Key words: Lower extremity exoskeleton; Capture point; Gait phase; Balance of human-machine system

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Motivation

- For patients with hemiplegia or paraplegia, early rehabilitation training is an important factor for their successful recovery. Lower limb exoskeletons have great potential in improving walking rehabilitation training, because they can guide the patients through repetitive, stable, and quantifiable movements, and provide various training modes and scenarios.
- The balance of a lower limb rehabilitation exoskeleton is of great significance to ensure the safety of patients. In the field of lower limb rehabilitation exoskeletons, extensive research on the balance problem has been conducted.

Main idea

- The instantaneous capture point is obtained by modeling the human-exoskeleton system and using the capture point theory. By comparing the stability region with instantaneous capture points of different gait phases, the balancing characteristics of different gait phases and changes to the equilibrium state in the gait process are analyzed.
- Based on a model of the human-exoskeleton system and the condition of balance of different phases, a trajectory correction strategy is proposed for the instability of the human-exoskeleton system caused by forward leaning of the wearer’s upper body.

Stability problem under different gait phases

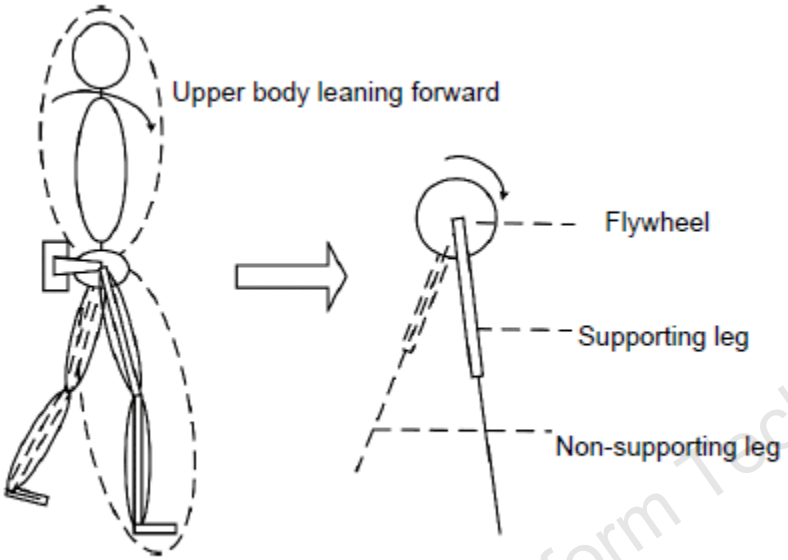

Fig. 1 Simplified model of the human-exoskeleton system

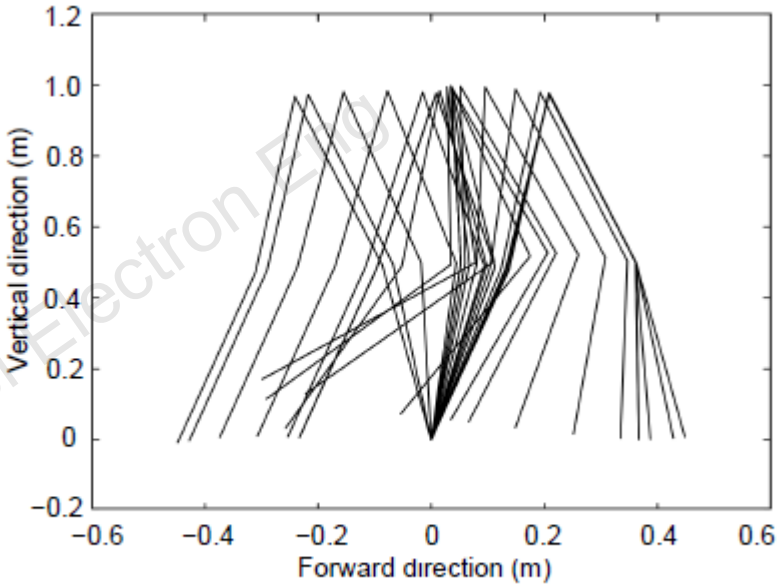

Fig. 4 Bar diagram of a single-step gait

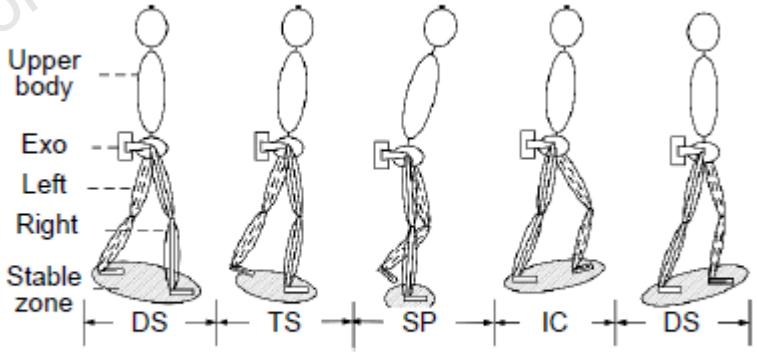

Fig. 3 Stability state changes as gait phase changes

Major results

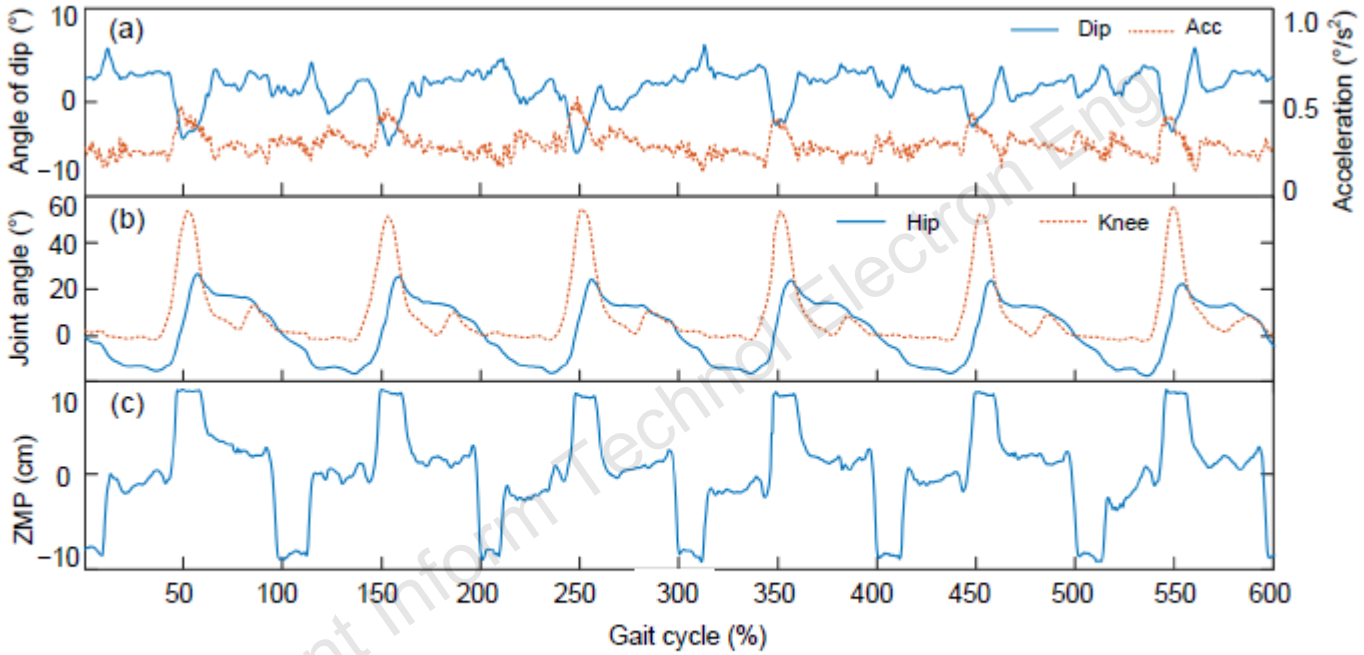

Fig. 11 Modified trajectory gait parameters of the human-exoskeleton system: (a) leaning angle, acceleration of the upper body; (b) trajectory of the unilateral hip and knee joint; (c) ZMP trajectory

The relative changes to the leaning angle of the upper body and acceleration are reduced by the corrected trajectory compared with the reference trajectory.
The range of change for the ZMP is the same as that in Fig. 10, but the transfer process of the ZMP is significantly shorter than that of the former one.
After overbalance of the upper body, the change rates of the joint trajectory and dip acceleration are limited in a small range.

Conclusions

- The dynamics of the human-exoskeleton system has been analyzed, and the rehabilitation gait has been modified based on the CP theory and gait characteristics.
- In the process of gait transfer, the unstable problem caused by upper body tilt has been solved.
- By comparing the difference between the revised and reference trajectories, the motion parameters showed different tendencies. The transfer time of the ZMP has been reduced and the change of the dip angle can be dealt with in a short period. This showed that the revised trajectory has better balance ability than the reference trajectory.