A Customized Biplanar Exoskeleton Control Framework for Individuals with Dropfoot

Xiaochen Zhang [1], Susanne Palmcrantz [2] and Elena M. Gutierrez-Farewik [1,3]

[1] KTH MoveAbility, KTH Royal Institute of Technology, Stockholm, Sweden
[2] Department of Clinical Sciences, Danderyd Hospital, Karolinska Institutet, Stockholm, Sweden
[3] Department of Women's and Children's Health, Karolinska Institutet, Stockholm, Sweden
Email: xiaocz@kth.se

Summary

This study presents a customized exoskeleton control framework designed to optimize assistance for individuals with dropfoot. The approach combines objective metrics from multi-objective human-in-the-loop (HIL) optimization, focusing on improving foot kinematics and step length symmetry, with subjective feedback from user preferences. Five chronic stroke participants with dropfoot gait patterns tested the framework using a previously developed ankle exoskeleton. The study demonstrated that the multi-objective HIL optimization improved gait qualities and produced a set of optimal solutions; the preference-based selection of optimal assistive profiles led to the final individualized solutions. This work paves a new way for the development of personalized exoskeleton assistance, especially for individuals with gait impairments.

Introduction

Individualized exoskeleton assistance, such as HIL optimization, has been explored to identify ideal exoskeleton assistive profiles and maximize user benefits, with promising results in reducing metabolic costs and improving walking speed [1]. However, these efforts predominantly targeted non-disabled individuals; to date, few studies have attempted to improve assistance for people with neurological injuries, despite the greater need for individualization in this population due to its heterogeneity [2]. Additionally, while objective metrics are commonly used to guide optimization, subjective factors such as user satisfaction are often overlooked. The purpose of this study, therefore, is to develop an exoskeleton control customization framework aimed at obtaining the optimal assistive profile for people post-stroke, one that considers both objective metrics and user preference.

Methods

We proposed a customized exoskeleton assistance individualization framework that combines objective metrics and subjective feedback. The multi-objective HIL protocol was used for the objective metrics optimization, focusing on improving segment kinematics and enhancing overall performance, while the score-based preference identification framework addressed the subjective assessments. Based on our previously developed ankle exoskeleton, five participants with chronic stroke and dropfoot gait patterns tested the feasibility of the proposed framework in the Promobilia MoveAbility Lab.

3D motion was measured (Vicon) with a standard marker set (CGM 2.4). Participants walked in the laboratory at their preferred speeds in four sessions: 1) NoExo session: walking with normal shoes with no orthoses; 2) Familiarization session: walking with the exoskeleton with different assistive profiles to adapt the device; 3) HIL session: with the powered exoskeleton and HIL optimization to seek optimal assistive profiles that achieve two goals: minimal foot kinematics deviation and minimal step length asymmetry. Each participant tested 3 HIL generations, each consisting of 10 profiles. All participants reported their preferences on a 0-10 scale for each assistive profile, specifically "How much has the assistance made you walk easier?"; 4) Preference session: a few of the most highly assessed assistance profiles were repeated.

Results and Discussion

The Pareto front comprising optimal assistive solutions was sorted for each participant (Fig. 1). Compared to the NoExo condition, the tested assistance profiles improved both foot segment kinematics and step length symmetry, increasingly with each generation, supporting the effectiveness of multi-objective HIL optimization for individuals post-stroke. Instead of identifying a single optimal profile, the balanced nature of multiple Pareto front solutions does not prioritize among the "best" profiles, as each profile in the Pareto front is better in one objective than in the other. Subjective scores of the profiles on the Pareto front varied among participants. Some objectively optimal solutions were subjectively rated as high, but some as low, indicating the importance of incorporating subjective experience when determining individualized solutions. Following this principle, the highest-rated Pareto front solution should be selected as the optimal assistive profile for each participant.

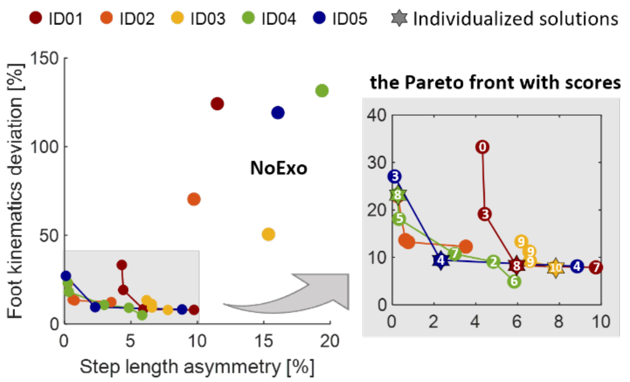

Figure 1. The customized assistance solution based on multi-objective HIL optimization and user preference.

Conclusion

In this study, we proposed a framework for individualized biplanar exoskeleton assistance for persons with dropfoot gait after a stroke. The exoskeleton and individualized assistive profiles achieved the objective goals to improve gait quality, which to some extent agreed with the participants' subjective assessment. This enables us to further pursue many follow-up questions pertaining to the complex relationship between objective performance improvements and subjective experience.

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Reference

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