WearRAcon Europe 2023
European Exoskeleton Conference
October 25-26, 2023

MULTI-OBJECTIVE-BASED HUMAN-IN-THE-LOOP OPTIMIZATION FOR ANKLE EXOSKELETON

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ABSTRACT

Wearable robotics and exoskeletons have become widely used for physical rehabilitation and daily life assistance for people suffering from motor disorders. Human-in-the-loop optimization usually optimizes assistive torque of exoskeletons based on measured individual performance metrics. In this study, a multi-objective optimization method (NSGA-II) was implemented to the Human-in-the-loop optimization, aiming at improving kinematics and reducing muscle activities as well for the people with dropfoot and excessive inversion. One able-bodied subject was tested with a two-DoF ankle joint exoskeleton, where the artificial dropfoot and excessive inversion was imitated. A set of non-dominated solution with four data points were calculated, among which, the maximum EMG reduction during swing phase can reach to 27.8 % compared with exoskeleton off condition with 5.8 % of foot clearance and orientation deviation, whereas one of the rest control profiles can reach the minimal deviation of 1.4 %, with the EMG reduction reduced to 21.0 %. These results suggest that this method could have potential impact on improving the performance of exoskeletons in multiple dimensions, and then provide diverse options for different assistance purposes and individual needs.

Keywords: Exoskeleton, wearable robotics, human-in-the-loop, multi-objective optimization.

1. INTRODUCTION

Exoskeleton technology has demonstrated the potential in enhancing the performance and mobility of individuals with disabilities, where control strategies play important roles in realizing these achievements [1]. By adjusting control parameters based on real-time measurements of human physiological signals, human-in-the-loop (HIL) optimization can provide optimal subject-specific assistance [2][3]. Although the achievements are impressive, most of the studies were focusing on one single objective, such as metabolic cost or muscle activity. However, the altered gait pattern is one important parameter to evaluate the functionality of the device, especially when we assist disabilities, such as people with dropfoot and excessive inversion, so exploring the optimization methods that could take multiple human responses into consideration could introduce a new perspective to improve the exoskeleton performance on individuals. In this study, we developed a multi-objective-based HIL method aiming at seeking for both improving kinematics and reducing muscle activities for people with dropfoot and excessive inversion during walking.

2. MATERIALS AND METHODS

2.1 Non-Dominated Genetic Algorithm II: NSGA-II

Non-dominated Sorting Genetic Algorithm II (NSGA-II) is a multi-objective genetic algorithm, which is an extension and improvement of NSGA. In the structure of NSGA-II, in addition to genetic operators, crossover and mutation, two specialized multi-objective operators, non-dominated sorting and crowding distance, were defined and utilized to create the population of next generation.

In our study, two objectives, the foot clearance and orientation deviation, which measured how the altered foot segment kinematics close to that of normal pattern, specifically for minimal foot clearance height in swing phase and the foot tilting angle at heel strike (eq.1), and the reduction of sEMG of Tibialis Anterior in swing phase (eq.2), were selected to identify the optimal set of control parameters – peak value of motor 1 and the ratio between two motors.

$$\text{Min } Dev_{foot} = \left|\frac{\alpha-\alpha_{ref}}{\alpha_{ref}}\right| + \left|\frac{H-H_{\text{ref}}}{H_{\text{ref}}}\right| \quad (1)$$

$$\text{Max } R_{EMG} = \frac{TA-TA_{ref}}{TA_{ref}} \quad (2)$$

2.2 Experimental design

One able-bodied subject (gender: male, age: 29 years, height: 170 cm, weight: 70 kg) participated in this pilot test. The subject wearing the soft ankle exoskeleton walked on a treadmill at 0.75 m s^{-1}, and a 2-kg weight was put on the lateral side of forefoot to generate a similar gait pattern as dropfoot and excessive inversion. The subject went through four successive generations, each comprising 10 one-min trials with distinct set of control parameters, separated by one minute of rest between trials.

Kinematics and sEMG information were collected and computed based on a Mocap system (Vicon) with reflective markers and sEMG sensors, which were transferred to the controller of exoskeleton in real-time.

3. RESULTS AND DISCUSSION

With the increase in the number of generations, there was a tendency for the data to converge towards the region with minimal deviation and maximum EMG reduction (Figure 1), where the Pareto front, which represents the set of non-dominated solutions (Rank 1), was obtained. Among all the four data points on the pareto front, data point (21.0, 1.4), which has the minimal deviation, shows the potential to assist subjects to gain the kinematics of foot segment that is closer to normal pattern. Data point (27.8, 5.8), on the other hand, reduced the most muscle activities, but the deviation was also the biggest.

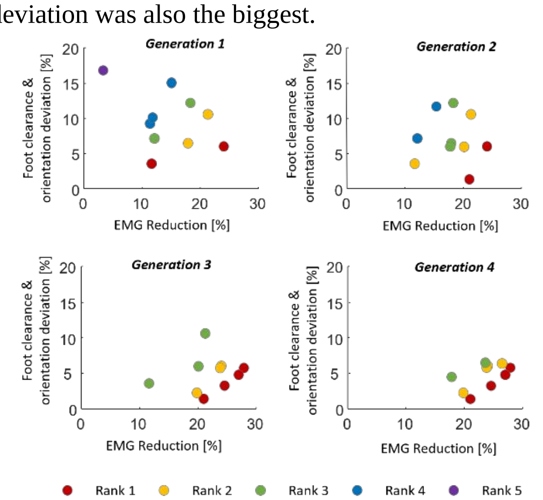

Figure 1: Subject-specific optimal solutions using MSGA-II based HIL optimization across 4 generations.

Based on the method we proposed in this study, the optimal solutions were obtained, which took both improving kinematics and reducing EMG into consideration, and by trading off among them, we can find the set of control parameters which suits for the assistance purpose and individual needs most.

Still there are some limitations. The artificial kinematics of foot segment shown on the subject was not the same as the real patients, and the changing trend of EMG signals should also be tested on them in our future work.

4. CONCLUSION

The purpose of this study was to test the feasibility of the multi-objective HIL optimization aimed at assisting kinematics as well as reducing muscle excitation. Our preliminary results showed that the use of NSGA-II in HIL optimization led to a set of solutions capable of simultaneously improving kinematics and reducing muscle excitation, and exhibited the potential use in motor assistance for individuals with conditions such as dropfoot and excessive inversion.

ACKNOWLEDGEMENTS

We gratefully acknowledge the generous support from the Promobilia Foundation (ref nr 23010), the Swedish Research Council (ref 2018-00750), and Digital Futures (ref KTH-RPROJ-0146472).

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