Improving the Design of an Underactuated Hand Exoskeleton with Evolutionary Algorithms

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***Abstract*— We propose to optimize the link lengths of an underactuated hand exoskeleton with thirteen link lengths and one actuator input to achieve maximum force transmission on the finger joints. The first prototype of the device was originally designed with a naive-iterative approach (i.e., brute force); we hypothesize that using a (meta)heuristic optimization method (i.e., Evolutionary Algorithms) will yield better results in less time, allowing us to extend the search space.**

I. INTRODUCTION

Optimization holds a crucial role in designing wearable robotic devices for human interaction – especially for healthcare and physical rehabilitation. While designing such robots, designers must ensure that the forces are transmitted through rigid links to the human body effectively, and users can reach their natural range of motion [1]. Engineers with no background in optimization might design by trial-and-error (i.e., a naive-iterative approach) [2]. However, such approaches are based on brute force, increasing the computation time and causing the search space to be significantly limited.

After an extensive literature search on state-of-the-art optimization methods implemented on active exoskeletons, we observed that the most common methods are the Interior-Point Algorithm [3], Swarm Intelligence [4], and EAs [5]. In this work, we will use Evolutionary Algorithms (EAs) to optimize the link lengths of an underactuated hand exoskeleton to maximize the force transmission on the finger joints to achieve a reasonable range of motion.

II. METHODS

EAs are population-based stochastic methods so that they can explore diverse areas of wide and constrained search space simultaneously. Unlike classical methods, EAs do not require gradient information and can work on complex, multi-modal, and non-differentiable functions.

The conceptual differences between the two optimization methods are highlighted with a complex design problem. Therefore, we chose to use underactuated kinematics for a hand exoskeleton. A wide variety of rigid link lengths are assigned to the algorithms to be fed into the kinematics equation as the two finger joints (MCP and PIP) are rotated in a natural range of motion. The calculated path of motion for each passive joint and link are then observed to ensure the solutions' feasibility. Finally, the force transmission for each joint is calculated using the Jacobian of the system to maximize the force transmission for fingers. In the naive-iterative approach, the link lengths are incremented sequentially with no relationship to the observed output, whereas the EA generates random configurations of link lengths and *evolves* in the search direction by exploiting the properties of the configurations with the best output.

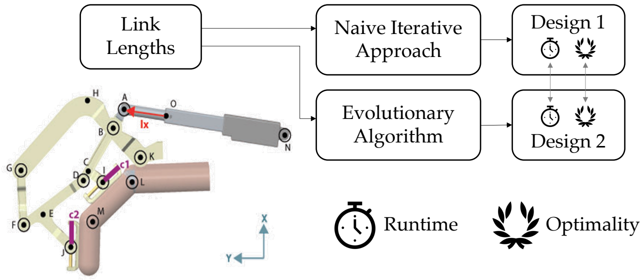

Fig. 1. Schema of the comparison between the two approaches that will be compared in terms of the optimal solution and run time.

III. CONCLUSION & FUTURE WORKS

We hypothesize that EAs can help exoskeleton designers work with complex kinematic chain functions and choose the best link lengths from a wider range of possibilities – compared to a naive-iterative approach. We observed that for a single run on a 16-core 5.4 GHz CPU and 64 RAM machine, the EAs will take up to 2 hours, whereas the naive-iterative approach will take up to 10 hours.

In the future, we will obtain an optimum solution with both algorithms and compare their performance by manufacturing both designs. In addition, we will make use of the efficacy of EAs, by expanding our current optimization problem to multiple objectives (i.e., adjusting for different hand sizes or minimizing some of the current constraints).

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*This work is funded by TUBİTAK 2232-B International Fellowship for Early Stage Researchers Program, number 121C145.

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