Optimization of an exosuit design for elbow and shoulder joints considering comfort and safety

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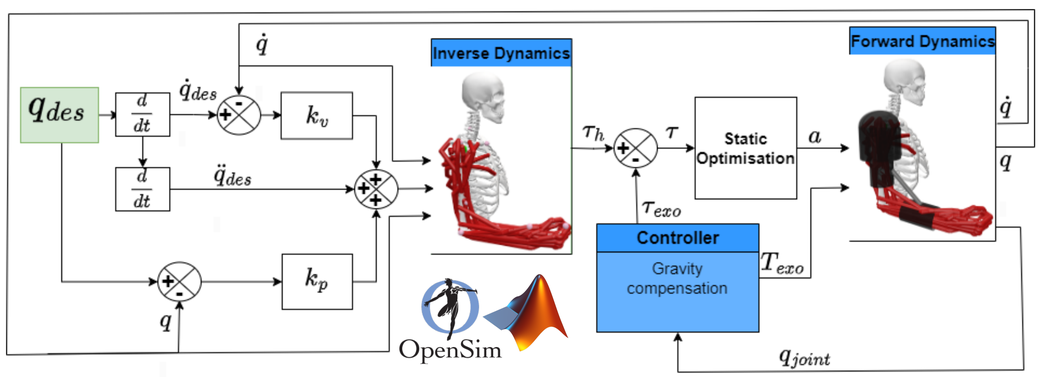
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Introduction

For rehabilitation or assistance applications, a new class of wearable devices called 'exosuits' is developped. Exosuits are lightweight with compliant material, soft actuators and respect biological joints [1]. With cable routing, the design is challenging and safety or confort constraints have to be met. To ensure comfort and safety in the design of wearable robots, a multi-objective optimization method is defined for shoulder and elbow assistance. This optimization method is evaluated with a simulation platform implemented on Matlab integrating biomechanical features from the software OpenSim. Thus, the interaction forces between skin and cuffs and the metabolic cost could be estimated during design phase.

Human in the loop simulation platform

The simulation platform is implemented in MATLAB and incorporates Opensim features and models via the API. The inputs are models, anchor points and a trajectory. The **outputs are metabolic cost, trajectory and the normal and shear forces** applied at cuffs at each time steps.



Comfort and safety conditions

To ensure safety and comfort for the user, conditions are applied on interaction forces between cuff's exosuit and user.

1. No-slip condition

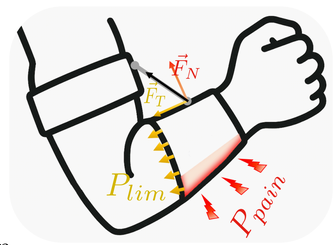
1.a. Coulomb's law

$$\left\|\vec{F_T}\right\| \leq \mu \left\|\vec{F_N}\right\|$$

1.b. With shear forces, **skin damage** at pressure **4kPa** [2].

$$\left\|\vec{F_N}\right\| \leq 2\pi l_{cuff} r_{cuff} P_{lim}$$

$$\Rightarrow \boxed{\left\|\vec{F_T}\right\| \leq \mu(2\pi l_{cuff} r_{cuff} P_{lim})}$$



2. No pain condition

Humans experience discomfort and pain around 25kPa [2].

$$\boxed{\left\|\vec{F_N}\right\| \leq P_{pain} \frac{2\pi l_{cuff} r_{cuff}}{2}}$$

Multiobjective optimization

Trajectory

Comfort and safety constraints

Cost functions

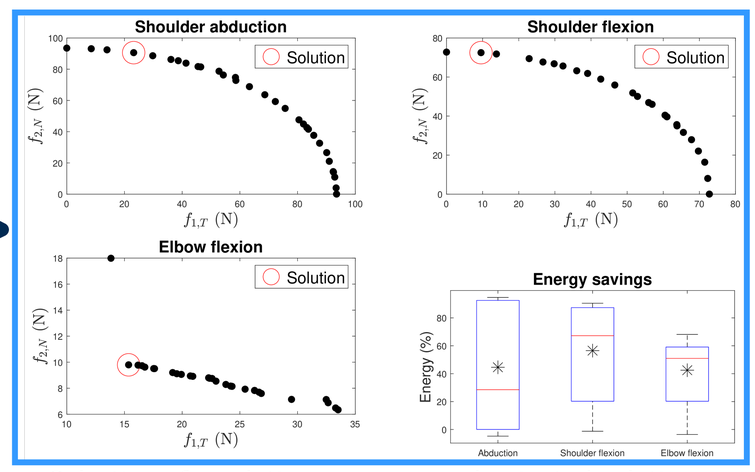
$$\begin{cases} f_{1,T} = \frac{1}{n}\sum_{i=1}^{n} \left\|\vec{F_{T,i}}\right\| \\ f_{2,N} = \frac{1}{n}\sum_{i=1}^{n} \left\|\vec{F_{N,i}}\right\| \end{cases}$$

Geometric constraints

Non-dominated Sorting Genetic Algorithm: NSGA-II

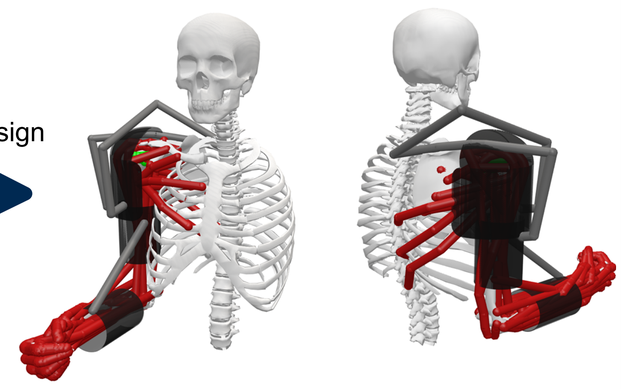
Population: P
Nb of via points: n
Individual: cable via points
$P_i = (p_x^1; p_y^1; p_z^1; ...; p_x^n; p_y^n; p_z^n)$

Pareto front



Selection of a solution among non-dominated solutions

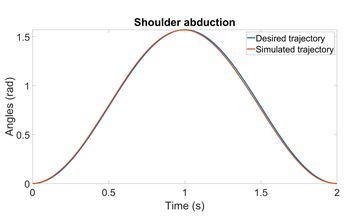
Selected design

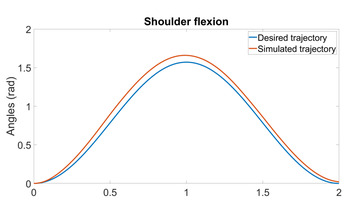


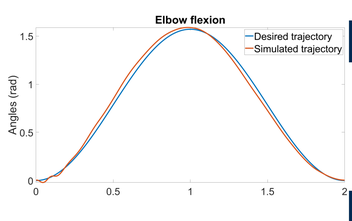
Results: trajectories and energy savings

1 DoF movement

To illustrate the accuracy of the simulator and the performance of the exosuit, three trajectories are computed: shoulder abduction, shoulder flexion and elbow flexion. The results are the simulated angular trajectory and the metabolic cost.

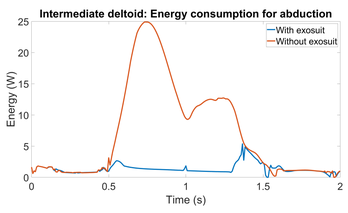


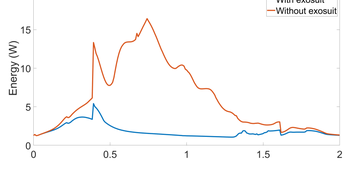


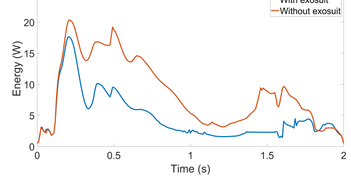


Scan me

Video summary

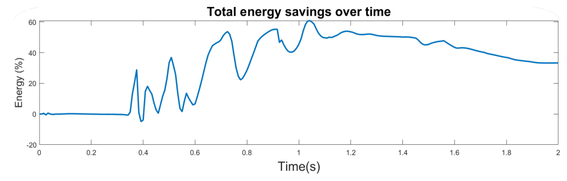


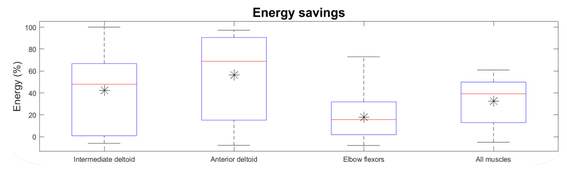


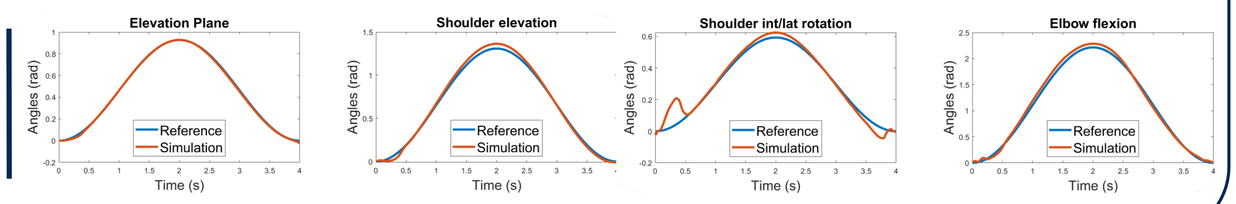


3 DoF movement: drinking task

A drinking task trajectory is computed and the average energy saving is 32%. The muscle the most relieved is the anterior deltoid, with an average saving of 55%.







Conclusion

Implementation of a simulator with user and exosuit in the loop to compute 1DoF and 3DoF movements
Optimization of cable rooting considering confort and safety
Energy saving about 32% for a drinking task

Perspectives

Other models for other limbs could be tested
Add more via points to get smooth cable path
Add passive elements (springs) to the design of the exosuit

References

[1]. Xiloyannis, M., Alicea, R., ..., Masia, L., & Riener, R. (2022). Soft Robotic Suits : State of the Art, Core Technologies,and Open Challenges. IEEE Trans. Robot.
[2]. Tja˘sa Kermavnar, Valerie Power, Adam de Eyto, and Leonard O'Sullivan. Cuff pressure algometry in patients with chronic pain as guidance for circumferential tissue compression for wearable soft exoskeletons: a systematic review. Soft robotics, 5(5):497–511, 2018.