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DEVELOPMENT AND ANALYSIS OF A DUAL-USE EXOSKELETON FOR REDUCING ENERGY EXPENDITURE DURING WALKING

João Medina [1], Sérgio B. Gonçalves [1], Jorge Martins [1], Luís Quinto [1,2] and Miguel Tavares da Silva [1]

[1] *IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Portugal, {joaomedina, sergio.goncalves, jorgemartins, miguelsilva}@tecnico.ulisboa.pt*

[2] *CINAMIL, Academia Militar, Portugal, luis.quinto@academiamilitar.pt*

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1 INTRODUCTION

As part of the Elite II project, this work focuses on the development and optimization of a quasi-passive ankle exoskeleton aimed at reducing metabolic energy during walking. The proposed solution prioritizes compactness, lightweight, and energy efficiency, making it suitable for both civil and military applications. Key features to develop include a robust structural system capable of withstanding the operational loads associated with military tasks, along with a compact actuation system incorporating a torsional spring and a control unit equipped with sensors to monitor movement and identify phases of the gait cycle.

2 DEVELOPMENT OF THE EXOSKELETON

In the early stages of the Elite II project, a novel quasi-passive actuation system featuring a ramp roller clutch and a solenoid to control and engage a torsional spring was patented, aimed at supporting human movement by reducing the metabolic cost [1, 2]. Subsequent developments included the design of a rigid foot-ankle interface, as well as a more efficient clutch for better torque transmission [1, 3, 4]. Further advancements focused on improving user adaptability, incorporating sliding mechanisms and snap-fit joints for better human-exoskeleton interaction and easier assembly and maintenance. The current state of the exoskeleton is shown in Figure 1.

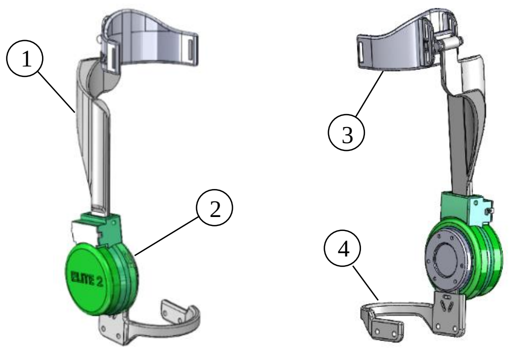

Figure 1 – Left ankle exoskeleton's front and back view

Table 1 – Exoskeleton's main components

	Description
1	Leg link
2	Clutch and electronics housing
3	Tibial interface
4	Foot interface

The group's initial efforts to conceive, design and refine a functional exoskeleton that met the project requirements have delivered significant results and validated the original concept. This meant the project had successfully reached a Technology Readiness Level (TRL) 2, laying the groundwork for further advancements. Although the innovative clutch idea was a fitting solution for the device, the project still had some structural constraints that were limiting its use. Through product development technologies and structural analysis, the goal was to advance the project to a TRL3 by computationally optimizing components and materials, as well as assessing the reliability of the entire structure, and later to a TRL4, where laboratory testing should be carried out. Therefore, structural analysis methodologies, Finite Element Method (FEM) and Computer Assisted Design (CAD) were employed to enhance the previously developed concept, aiming for a reinforced 3D-printed exoskeleton that withstands the required operational loads in both military and civil operations and performs under varying conditions with high wear and fatigue resistance, while being adaptable to different users.

3 RESULTS AND DISCUSSION

Some of the features were redesigned or replaced since they were not easily produced through additive manufacturing, were fragile when used intensively, or were difficult to install/uninstall by the user. The snap-fit joints previously used (Figure 2) were replaced by non-continuous threads for a higher wear resistance and robustness. The exoskeleton's foot interface (Figure 3) was also redesigned to provide a simpler solution that does not require direct screwing to the user's shoe. The parts were dimensioned to sustain stresses considering they were manufactured using additive technologies and with a safety factor that satisfied the project's requirements. The compactness and overall weight of the mechanism were also considered.

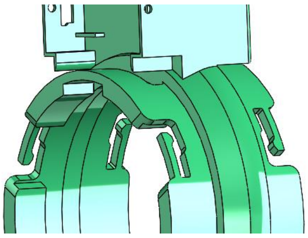

Figure 2 - Snap-fit joints initially used

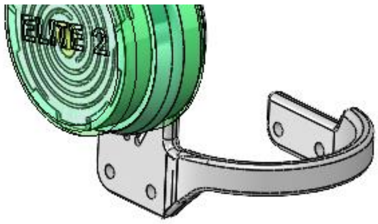

Figure 3 – Previous foot interface

Using the previous work done in this project as a starting point, FEM analysis and CAD software were used to successfully reiterate the initial prototype into a more robust, solid and reliable exoskeleton, taking it from a TRL2 into TRL4 where future work will involve the production of the developed concept and subsequent laboratory testing with volunteers from the Portuguese Army. This device will hopefully be of great assistance not only in military environments but also for personnel from sectors involving manual labor, or people with mobility limitations.

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