Restoration of Arm Mobility with Power-Assist Exoskeletons for Young Men with Duchenne Muscular Dystrophy

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Opportunity and Significance

Duchenne Muscular Dystrophy (DMD) is the most common form of muscular dystrophy, affecting over one in 5,000 boys [1]. Typically, by twelve years of age, muscle mass is reduced to a point where the individuals require power wheelchairs for mobility, and participation in activities of daily living (ADL), such as self feeding and grooming, become significantly more challenging [2]. In this phase of a larger study, we demonstrate the initial impact of an admittance-controlled, hybrid, power-assisted robotic exoskeleton on upper limb mobility.

Technical Objectives

1. Integrate admittance-controlled, power-assist technology into an existing passive mechanical exoskeleton
2. Characterize and refine the performance and behavior of the fundamental admittance control variables when applied to a hybrid exoskeleton system
3. Evaluate the impact of the enhanced hybrid system, by comparing passive mechanical-assisted to power-assisted range of motion (ROM)

Related Work and State of Practice

This study is based on previous research conducted at New Jersey Institute of Technology by Dr. Corrigan and Dr. Foulds, in which they demonstrated the ability of admittance control to successfully augment upper limb mobility in individuals with DMD [3].

Technical Approach and Accomplishments - Manufacturing

- Utilizing 3D printing technology we were able to fabricate a motor frame, gears, and sensor housing assembly, all compatible with the existing passive exoskeleton **(Figure 1)**.

Figure 1:
Hybrid Exoskeleton Arm system with Power Assist and Load compensator

- An admittance control system, developed by RUR, was evaluated and iteratively improved for safety and efficacy, prior to field testing by a research team member with DMD
- The device was then installed on our collaborating partner's Permobil F5 power wheelchair and connected to a local WiFi to enable remote software downloads.

Technical Approach and Accomplishments – Prototype Deployment

- To accommodate COVID-19 related concerns, training, software testing, and evaluation were conducted virtually.
- Based on user feedback, values for the array of control variables that define the admittance control were iteratively refined until considered to be satisfactory by our consultant-participant.
- ROM measurements were captured on digital camera at uniform distances and angles and then measured using a ruler that was held in the frame during the test **(Figure 2)**.
- To ensure ROM data was representative of system performance, all exercises were conducted with the torso upright, centered, and motionless.
- Data is based on "best-effort" controlled motions, with peak displacement and force activities sustained for 3 seconds.

Results and Discussion

- A Comparison of Vertical ROM between the passive and power assisted arms is illustrated in Figure 2 and detailed in Table 1. Of note, the ROM with the power-assisted arm exceed the passive arm assist by 265.8% **(Table 1)**.
- The minimum system activation force required to operate this system (F_R) is 0.22N**(Table 2)**, approximately equivalent to the weight of 4 U.S. Quarters.
- Using the system, the team member was capable of generating upward forces in excess of 21x F_R and downward forces in excess of 9x F_R **(Table 2)**. The output force of the system was greatly magnified compared to the activation force.
- **A full demonstration video, filmed and edited by Zachary and Raegan Smith may be viewed from the PPMD Conference On-Demand Library under the Resources & Tools category, title: Restoration Of Arm Mobility With Power-Assist Exoskeletons**

Figure 2: Vertical ROM of Power Assist Hybrid system (Left) and Passive Assist (Right)

	Max Displacement (cm)	Min Displacement (cm)	Total Vertical ROM (cm)
Power Assist	42.545	-21.59	64.14
Passive Support	13.335	-10.795	24.13
Percent Improvement	319%	119%	265.81%

Table 1: Maximum and minimum displacement of power assist and passive support devices when used by participant with advanced DMD

	F_{MAX} (N)	F_R (N)	$(F_{MAX}/F_R)*100$
Upward	4.8	0.22	2181.8%
Downward	-2.14	-0.22	927.3%

Table 2: Maximum force generated by participant compared to minimum activation force required to activate the Admittance Controlled Hybrid Exoskeleton system.

- During the test and evaluation of this system, our participant was able to hold his arms at any level within the mechanical limits of the structure with little perceived effort.
- Based on the outcome of this trial, it has become apparent that absent the mechanical limitations of the exoskeleton, the vertical ROM would likely have been significantly increased.
- While beyond the scope of this project, over its course it became necessary to develop additional technology which compensates for any additional handheld loads which are picked up after the system has calibrated for the mass of the user's arm. The resulting load compensating wrist support was able to effectively render most objects "weightless".

Next Steps for Development and Test

- In subsequent phases, the study will be expanded to include additional subjects.
- Vertical Range of Motion will be optimized across a DMD population with inhomogeneous arm strength.
- 3-dimensional motion tracking will be added to the system to map ROM and further our understanding of how enhanced assistance against gravity impacts variety and overall participation in ADLs

Commercialization Plan & Partners

- This study was funded by Parent Project Muscular Dystrophy under a global program to advance development in the area of assistive robotics in direct service of the DMD community.
- To ensure our research translates into real world tools, Talem Technologies LLC has partnered with Really Useful Robotics LLC (RUR)
- Design of the mechanical delivery component of this system was conducted in tandem with RUR during development of the control system.
- At the conclusion of this study, the resulting power assist device will have been thoroughly field tested and is anticipated to be a commercially viable design brought to market through Talem Technologies.

References

1. Crisafulli, S., et al., *Global epidemiology of Duchenne muscular dystrophy: an updated systematic review and meta-analysis.* Orphanet J Rare Dis, 2020. **15**(1): p. 141.
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3. Corrigan, M.C. and R.A. Foulds, *Evaluation of admittance control as an alternative to passive arm supports to increase upper extremity function for individuals with Duchenne muscular dystrophy.* Muscle Nerve, 2020. **61**(6): p. 692-701.

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