WAIST ASSISTIVE WEARABLE POWERED EXOSKELETON FOR ARMED PERSONNEL

BTP MID-TERM REPORT PHASE I

submitted by

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ABSTRACT

Armed Personnel works in a harsh environment, extreme temperatures, and walk on uneven terrains for miles with a heavy backpack. Therefore, it reduces the efficiency of the personnel on the battlefield leading to the loss of several lives. Hence, the armed personnel needs strength to enhance their performance and efficiency by decreasing their effort to walk and carry the heavy loads on uneven terrains. The exoskeleton is a wearable device that enhances the strength and the performance of the operator. Exoskeletons are collaborative, hence they are evolving rapidly in all the fields, medical, military, industrial, and civilian. In this project, we aim to design a lower extremity, a waist-assistive powered exoskeleton for the enhancement of strength and agility of the military personnel carrying heavy payloads.

Keywords: Exoskeleton, Lower Extremity, Payload, Strength, Waist-assistive

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1 INTRODUCTION

An exoskeleton is a rigid, external, and supporting cover of the body used for protection and strength enhancement. It is a wearable device that contains a framework wrapping the user's body. An exoskeleton consists of a frame that plays a similar role as of the bones in a human body. The links are connected using rotary joints that can either be passive or powered. Exoskeletons are mainly classified based on the framework, power, and extremity. The framework can either be rigid or soft. However, in this project, a rigid body framework will be designed because of its versatility.

Exoskeletons are evolving rapidly in all the fields. They are being used in rehabilitation centers to treat paraplegics, in hospitals, in industries to reduce the worker's effort, and in the military. However, the main focus of the project is to design an exoskeleton for military purposes. Armed personnel gets exhausted by carrying heavy loads for miles on uneven terrains, thereby, reducing the efficiency of the main mission. A wearable exoskeleton powers the joints and reduces the load experienced by the pilot. Hence, a powered exoskeleton can help military personnel to enhance strength and performance.

1.1 LITERATURE REVIEW

The very first exoskeleton was built in 1890 by Nicholas Yagn [3]. It was a passive exoskeleton with mechanical elements such as springs, bucklings, and resilient connections to support the weight of the body. The first powered exoskeleton(Hardiman) was designed and fabricated by General Electric in 1971. It was designed to lift 1500 pounds to a height of 6ft [2]. It had 15 DoF on each side with bilateral control and works based on a master-slave system. However, Hardiman had failed because of its complex motion, overcontrol, and safety issues.

There have been a lot of developments in powered exoskeletons after Hardiman. However, none of them have made a significant change in terms of control and flexibility, until the BLEEX exoskeleton by the University of California, Berkeley. BLEEX is a lower extremity exoskeleton with 7 DoF on each side powered by linear hydraulic actuators [4]. Later, many exoskeletons have been developed such as HULC, SuitX, HAL, and so on. Exoskeletons are slowly emerging outside of labs to medical patients, rehabilitation centers, and the military. However, there are many limitations to the exoskeleton in terms of comfort, weight, cost, and complex restricted motion. A lot of research is going on to make the gait motion smooth, to increase the wearer's comfort by replacing rigid links with tendons and soft links, and to reduce the weight of the exoskeleton.

1.2 MOTIVATION BEHIND THE WORK

Exoskeletons are being researched and developed rapidly all over the world, however, the level of research going on for the development of exoskeletons in India is quite low compared to the other countries. Recently, DRDO has taken an initiative to develop and fabricate an exoskeleton for military purposes [1]. Premier Institutions, companies, and industries are researching extensively on the problem statement to develop an exoskeleton. Developing an exoskeleton will increase military power and it is the strongest weapon to the nation's development. Hence, we have chosen the problem statement to research on the existing exoskeletons and design an exoskeleton that could enhance the strength of the personnel.

1.3 OBJECTIVES

The primary objectives of the project are mentioned below:

1. To design a waist assistive lower extremity exoskeleton to enhance the strength of armed personnel
2. Structural Analysis of the framework in FEM
3. To develop a dynamic model for the exoskeleton and simulate it in Gazebo
4. To fabricate and test the designed exoskeleton

1.4 GANTT CHART

Gantt Chart is the timeline of the activities involved in the project. It gives a rough estimation of the time required to finish the project. The Gantt chart 1.4 represents the list of activities along with the sub-activities on the left side, and the timeline is mentioned on the right side.

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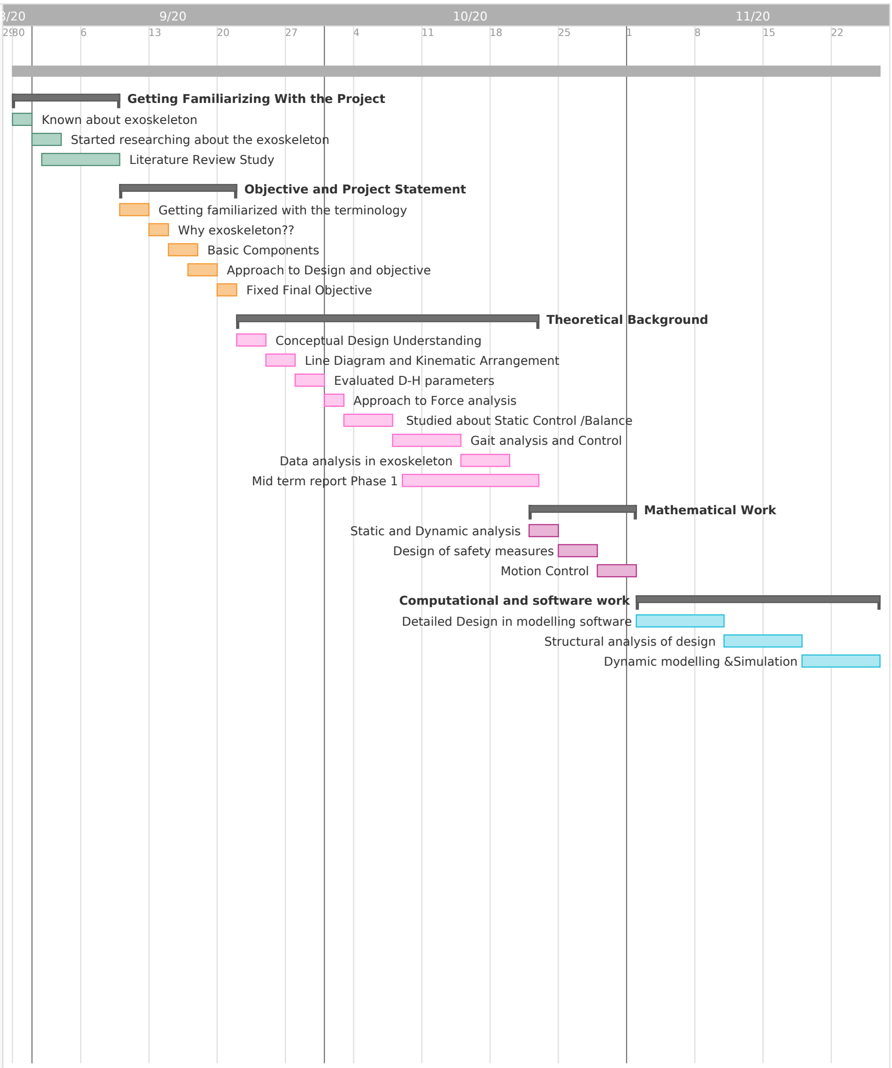
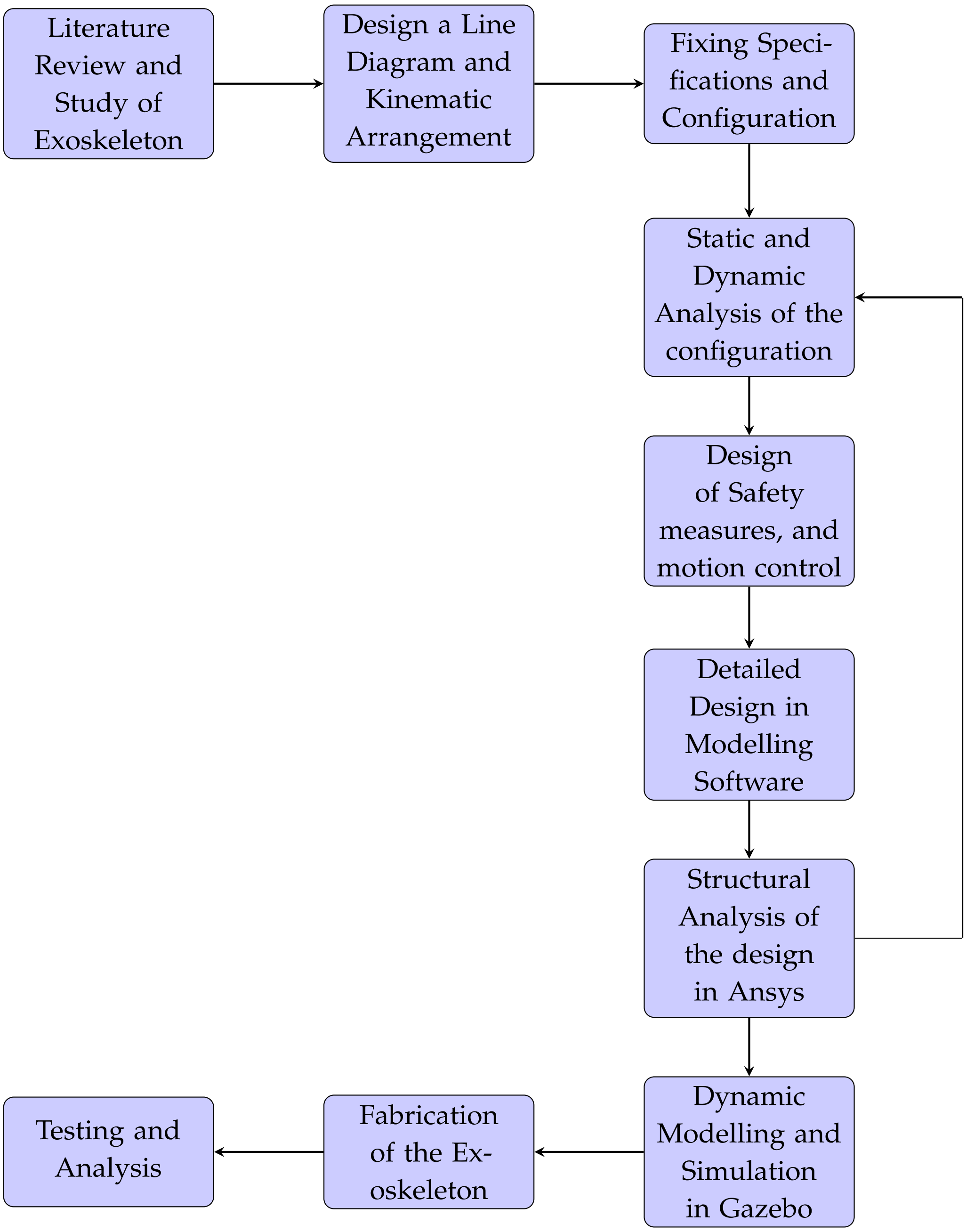
Gantt chart for BTP	start	end	0h	0%
Getting Familiarizing With the Proj...	**30/08/20**	**09/09/20**	**0h**	**0%**
Known about exoskeleton	30/08	31/08	0	0%
Started researching about the exoske...	01/09	03/09	0	0%
Literature Review Study	02/09	09/09	0	0%
Objective and Project Statement	**10/09/20**	**21/09/20**	**0h**	**0%**
Getting familiarized with the termino...	10/09	12/09	0	0%
Why exoskeleton??	13/09	14/09	0	0%
Basic Components	15/09	17/09	0	0%
Approach to Design and objective	17/09	19/09	0	0%
Fixed Final Objective	20/09	21/09	0	0%
Theoretical Background	**22/09/20**	**22/10/20**	**0h**	**0%**
Conceptual Design Understanding	22/09	24/09	0	0%
Line Diagram and Kinematic Arrang...	25/09	27/09	0	0%
Evaluated D-H parameters	28/09	30/09	0	0%
Approach to Force analysis	01/10	02/10	0	0%
Studied about Static Control /Balance...	03/10	07/10	0	0%
Gait analysis and Control	08/10	14/10	0	0%
Data analysis in exoskeleton	15/10	19/10	0	0%
Mid term report Phase 1	09/10	22/10	0	0%
Mathematical Work	**22/10/20**	**01/11/20**	**0h**	**0%**
Static and Dynamic analysis	22/10	24/10	0	0%
Design of safety measures	25/10	28/10	0	0%
Motion Control	29/10	01/11	0	0%
Computational and software work	**02/11/20**	**26/11/20**	**0h**	**0%**
Detailed Design in modelling software	02/11	10/11	0	0%
Structural analysis of design	11/11	18/11	0	0%
Dynamic modelling &Simulation	19/11	26/11	0	0%



1.5 METHODOLOGY

The methodology of the project and the approach to the project is depicted in the flow chart 1.1.

Figure 1.1: Flow Chart for the methodology



2 WORK PROGRESS

Objective :- Designing a waist assistive lower extremity, powered exoskeleton to enhance the strength and agility of the armed personnel.

Specifications :-

1. Payload - 30 kg
2. Degrees of freedom - 13
3. Active Joints - Flexion/extension in Hip, knee, ankle ; Hip abduction/adduction
4. Passive Joints - Hip, ankle Rotation; Ankle abduction/adduction, rotation
5. Actuation - Electric motors

2.1 FRAMEWORK

We considered the framework of the exoskeleton with rigid links. The whole frame arrangement can be considered as an 8-linked kinematic chain. It has seven active joints and is powered with electric motors, whereas the other six joints are passive. To avoid complications, the hip abduction joint is designed to be common to both the legs, which allows the lateral movement of the exoskeleton. For simplified calculations, the exoskeleton is divided into two halves at the hip abduction joint. The base of the exoskeleton is assumed to be at the hip abduction joint.

2.1.1 *Line Diagram of left half of the Frame*

Isometric view of the exoskeleton's left leg simplified view(Line Diagram) is represented in the fig 2.1. The base of exoskeleton is assumed to be at the hip abduction joint center. DH parameters can be calculated from the line diagram of the left leg.

DH parameters for the designed configuration are given by the table 2.1, where θ_k and d_k represents joint angle and joint distance respectively, whereas a_{k-1} and α_{k-1} represents link length and link twist angle respectively. The transformation matrix can be found from the DH parameters. When the position matrix of the end-effector in the non-inertial frame is multiplied with the transformation matrix, the result gives the position of the end-effector w.r.t the base

Table 2.1: DH Parameters for the left leg

θ_k	d_k	a_{k-1}	α_{k-1}
θ_1	0	0	$-\pi/2$
$\theta_2+\pi/2$	$-a_2$	d_2	$\pi/2$
$\theta_3+\pi/2$	0	0	$\pi/2$
θ_4	0	$-d_4$	0
$\theta_5-\pi/2$	0	$-d_5$	0
$\theta_6-\pi/2$	$-d_6$	a_6	$-\pi/2$
θ_7	0	0	$-\pi/2$

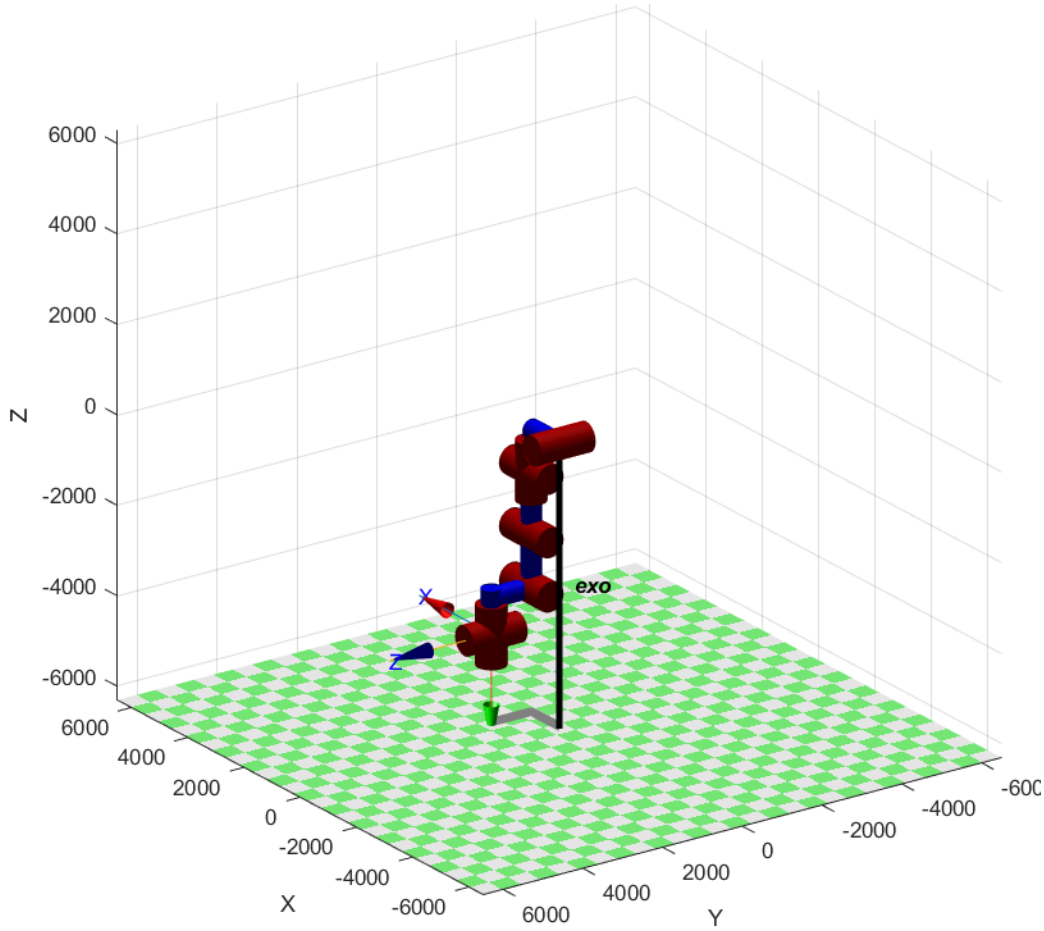


Figure 2.1: Isometric view of the line diagram of the Left leg in MATLAB

2.1.2 *Line Diagram of right half of the Frame*

Isometric view of the exoskeleton's right leg simplified view(Line Diagram) is represented in the fig 2.2. The base of exoskeleton is assumed to be at the hip abduction joint center. DH parameters can be calculated from the line diagram of the right leg.

Table 2.2: DH Parameters for the right leg

θ_k	d_k	a_{k-1}	α_{k-1}
θ_1	0	0	$-\pi/2$
$\theta_2+\pi/2$	$-a_2$	$-d_2$	$\pi/2$
$\theta_3+\pi/2$	0	0	$\pi/2$
θ_4	0	$-d_4$	0
$\theta_5-\pi/2$	0	$-d_5$	0
$\theta_6-\pi/2$	$-d_6$	a_6	$-\pi/2$
θ_7	0	0	$-\pi/2$

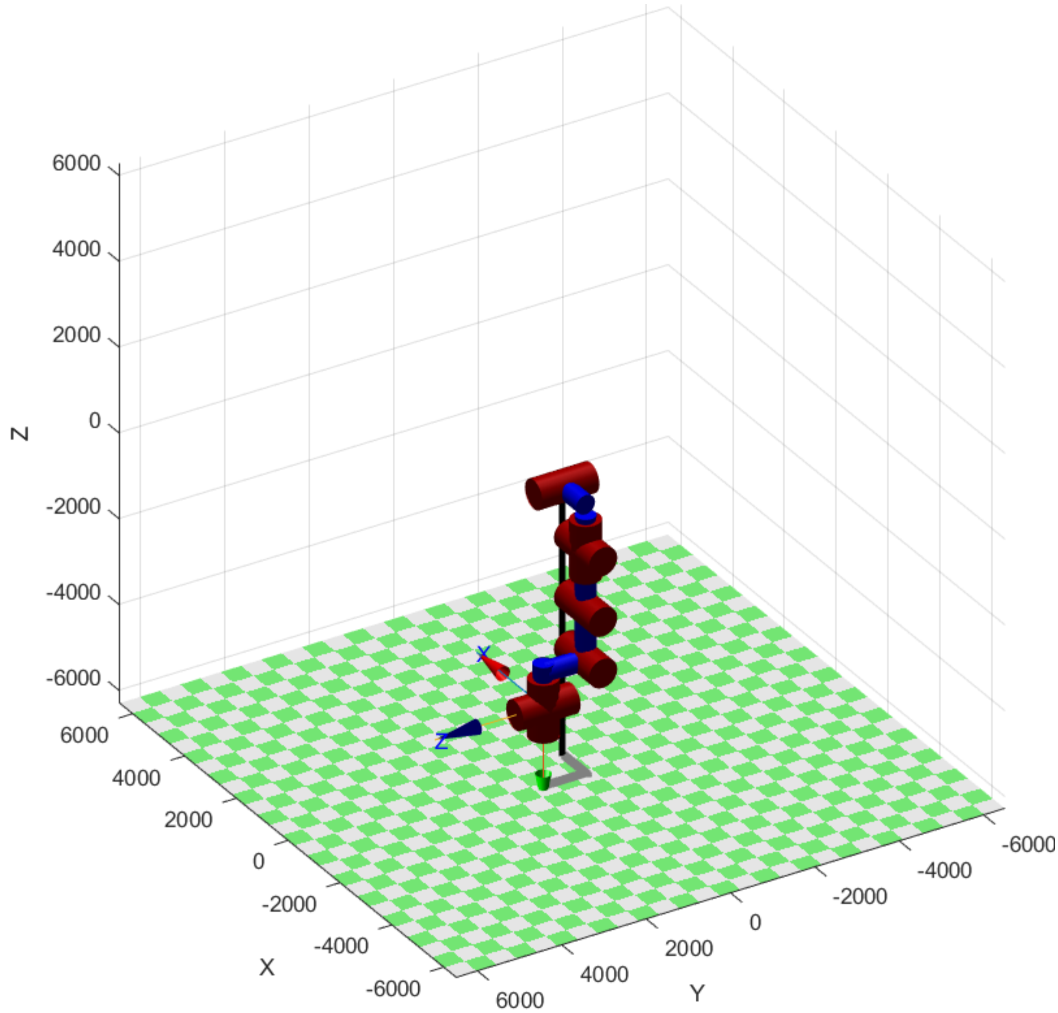


Figure 2.2: Isometric view of the line diagram of the Right leg in MATLAB

DH parameters for the designed configuration are given by the table 2.2, where θ_k and d_k represents joint angle and joint distance respectively, whereas a_{k-1} and

α_{k-1} represents link length and link twist angle respectively. The transformation matrix can be found from the DH parameters. When the position matrix of the end-effector in the non-inertial frame is multiplied with the transformation matrix, the result gives the position of the end-effector w.r.t the base.

2.1.3 *Challenges to the current design*

1. Knee joint assumed in the design can facilitate only flexion/extension. But, the knee joint in the human body facilitates sliding in addition to the flexion/extension. Due to sliding, the anticipated position of the end effector will be different from the actual one. Hence, some mechanisms such as the four-bar mechanism should be facilitated in addition to the rotary joint.
2. The lateral forces in the exoskeleton gait need to be compensated. Hence, the hip abduction joint should be actuated. However, complexities will arise due to the lateral movement provided by the hip joint. Hence, the design should incorporate some mechanism to avoid complexities.

2.2 WORK THAT HAS TO BE DONE

Phase I :-

1. Re-designing the mechanism for the exoskeleton based on the challenges in the current design
2. Static & Dynamic Analysis
3. Motion Control
4. Design of safety measures
5. Detailed Design in modelling software
6. Structural Analysis of the design
7. Dynamic modelling & Simulation

Phase II :-

1. Possible Modifications to the design
2. Material Choice for the frame design
3. Fabrication
4. Testing & Analysis

BIBLIOGRAPHY

[1] *Exoskeleton - Technology Development Fund - DRDO.* URL: https://tdf.drdo.gov.in/funding_details/index/21. (Accessed: 12.10.2020).

[2] Bruce R Fick and John B Makinson. "Final report on Hardiman I prototype for machine augmentation of human strength and endurance." *United States Army Project No. IM62410105072, General Electr. Co., New York, DTIC Accession Number: AD0739735* (1971).

[3] Nicholas Yagn. *Apparatus for facilitating walking, running and jumping*. US Patent 440,684. 1890.

[4] Adam B Zoss, Hami Kazerooni, and Andrew Chu. "Biomechanical design of the Berkeley lower extremity exoskeleton (BLEEX)." *IEEE/ASME Transactions on mechatronics* 11.2 (2006), pp. 128–138.