T.C.
SÜLEYMAN DEMİREL UNIVERSITY FACULTY OF ENGINEERING AND NATURAL SCIENCES DEPARTMENT OF MECHANICAL ENGINEERING

Engineering Design I Course Project

Project Title: Combined Hip-Knee Rehabilitation Robot Design

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Class: 1st Education - Section A

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MAK-407 ENGINEERING DESIGN I - PROJECT EVALUATION FORM

Project Title: Combined Hip-Knee Rehabilitation Robot Design

Problem Definition (9 Points)

Need Definition (3):
Engineering/Technical/Product Specifications or Success Criteria (6):

Information Gathering (16 Points)
Literature Review (3)
Market Research/Benchmarking with Similar Products (3)
Article Search (6)
Patent Search (4)

Project Planning (10 Points)

Team Formation and Task Distribution (2)
Work-Time Schedule (Gantt Chart) (3)
Risk Management (Risk Analysis and B Plans) (3)
Meeting Minutes (2)

Concept Generation (25 Points):
Functional Decomposition (5)
Concept/Solution Development for Each Function (20)

Concept Evaluation (15 Points):
Morphological (Form) Table (5)
Determination of Criteria and Weighting (5)
Preliminary Concept Evaluation (PUGH Diagram) and Best Concept Selection (5)

Sustainable Development (10 Points)

Energy Efficiency Improvement (2):How can the device consume less power?
Eco-friendly Production Methods (2): Manufacturing techniques with the least environmental impact.
Responsible Consumption/User Briefing (2): How to educate users about the sustainable use of the device.
Recyclability of Materials (2):Plans for recycling the materials used in production.
Carbon Footprint Reduction (2): Strategies to minimize carbon emissions during the manufacturing process.

SOLIDWORKS Drawings (Final Solid Model) (15 Points)

FORMAT (-10 POINTS Deduction)

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ABBREVIATIONS

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SUMMARY

With the advancement of medical technologies today, the importance of devices aimed at restoring human mobility is steadily increasing. In the lower limbs, the hip and knee joints play a critical role in walking, sitting, standing, and almost every movement of daily life. Damage to these joints due to aging, accidents, surgeries, or various musculoskeletal diseases significantly reduces an individual's quality of life. At this point, rehabilitation exercises are of vital importance both in accelerating the healing process and preventing the progression of the disease.

Within the scope of this project, a combined joint rehabilitation robot will be designed to support the rehabilitation process by operating the hip and knee joints simultaneously. This robot aims to provide patients with controlled and safe exercise opportunities while simultaneously reducing the workload of healthcare personnel. By integrating current technologies into this field, personalized programmable exercise modes, safety systems, and ease-of-use features will be prioritized. In the coming years, with the development of artificial intelligence-supported motion analysis and portable robotic systems, rehabilitation devices are expected to become much more widespread and accessible.

Keywords: Rehabilitation, Hip-Knee Joint Robot, Biomechanics, Health Technologies.

1. INTRODUCTION

1.1 Need

A significant portion of mobility in the human body is provided through joint systems. Within this system, the knee and hip joints are the most frequently used and load-bearing regions in an individual's daily life. Fundamental activities such as walking, running, and climbing stairs are performed directly through the coordination of these joints. However, serious functional losses can occur in these areas due to age-related degenerative diseases, sports injuries, traffic accidents, or post-surgical operations.

These dysfunctions occurring in the hip and knee joints restrict the individual's independent mobility and reduce their quality of life. Failure to manage this process and prolonged inactivity can lead to muscle atrophy, joint stiffness, and secondary health problems. Therefore, early-stage rehabilitation is of critical importance to restore joint function and halt the progression of pathology. In addition to traditional methods, there is a growing need for high-precision systems to increase the efficiency of the rehabilitation process and ensure the accuracy and repeatability of movements. In this context, the lack of technological infrastructures that address the knee and hip—the two fundamental joints of the lower extremity—with a holistic approach and offer intensive and controlled treatment opportunities stands out as a significant need.

1.2. Engineering/Technical/Product Specifications or Success Criteria

1.2.1 Subject

This specification explains the scope and fundamental principles of the Combined Hip-Knee Rehabilitation Robot to be designed. The system to be developed aims to support the treatment process of individuals experiencing mobility restrictions, particularly in the hip and knee joints. In this scope, the robot's technical specifications, safety criteria, durability standards, maintenance and control procedures, ergonomic requirements for the user, and energy efficiency will be taken into consideration.

1.2.2 Conditions of Use

The Combined Hip-Knee Rehabilitation Robot will be used in the physical therapy process following orthopedic disorders, post-accident loss of motion, and surgical operations. The system is suitable for elderly individuals, patients experiencing sports injuries, and people with restricted joint movement. The goal is to restore the functionality of the hip and knee joints through safe and controlled exercises.

1.2.3 Requirements and Features

- The device must be capable of operating both the hip and knee joints simultaneously.
- It should feature customizable exercise programs tailored to the individual user.
- An emergency stop system and overload protection must be included to ensure patient safety.
- It must have an ergonomic design to accommodate patients of various heights and weights.
- The device should be quiet, consume low energy, and be suitable for long-term use.
- It should be easy to set up, portable, and easily operable by healthcare personnel.

1.2.4 Technical Specifications

Table 1: Technical Specifications of the Combined Hip-Knee Rehabilitation Robot

Technical Specifications	Definition
Field of Application	Hip and Knee Rehabilitation
Operating Modes	Walking and Light Exercise
Knee Motion Range	0° – 120°
Hip Motion Range	0° – 90°
Leg Length Range	40 – 65 cm
Motor Type	BLDC (Brushless DC Motor)
Power Supply	Lithium Battery
Control Type	Microcontroller Controlled
User Interface	Keypad Remote Control
Emergency Stop	Available (Yes)
Sensors	Motion and Torque Sensors
Frame Material	Aluminum + Teflon
Device Weight	5 – 7 kg
Dimensions	70x50x40 cm

1.2.5. Packaging and Product Equipment

- When preparing the robot for delivery, an appropriate packaging selection must be made, taking into account the robot's volume and weight.
- To prevent any damage to the product during transportation, the most accurate packaging methods will be implemented.
- To ensure the robot reaches the customer intact, transportation and handling instructions will be clearly indicated on the packaging

1.2.6. Quality, Warranty, and Certification Information

- All components of the designed rehabilitation robot will be selected in compliance with international health and safety standards (ISO, CE, etc.).
- Materials used will be chosen for long-term durability and longevity; the device's performance will be maintained through regular maintenance.
- The system will be covered by a minimum 2-year warranty after production; any malfunctions occurring during the warranty period will be resolved by the manufacturer.
- For user safety, every prototype will undergo a rigorous testing and approval process before being commissioned.
- The product will be certified in accordance with national and international medical device standards.

1.2.7. Safety

Since the Combined Hip-Knee Rehabilitation Robot is a device directly related to human health, safety measures are one of the most critical elements of the design. The system will feature:

- **Emergency Systems:** Equipped with emergency stop buttons and excessive force detection sensors to prevent any harm to the patient.
- **Motion Control:** All movements will occur within controlled speed and torque limits; sudden and uncontrolled movements will not be permitted.

- **Ergonomics & Hygiene:** Parts of the device in contact with the patient will be manufactured from soft, hygienic, and non-allergenic materials.

- **Electrical Safety:** Full electrical safety will be ensured during use, with leakage current protection and high-standard insulation measures implemented.

- **Supervision:** Physiotherapist supervision will be mandatory before operating the system, ensuring the patient is never exposed to risks alone.

- **Maintenance & Self-Check:** Periodic maintenance and tests will be performed regularly, and the device will undergo an automatic safety check before every use.

2. LITERATURE REVIEW

2.1 Introduction

In the literature research report of the **Combined Hip-Knee Rehabilitation Robot** project, information regarding existing rehabilitation devices on the market was gathered, and data to guide our study was collected. Within this scope, commercial products, patents, and scientific articles were analyzed. In the patents section, systems that share similar features with our project or those developed specifically for joint rehabilitation were evaluated. In the scientific articles section, the biomechanical foundations of joint rehabilitation, the methods employed, and the effectiveness of robot-assisted therapy technologies were researched. Additionally, in the technology section, the drive mechanisms, control systems, and sensor technologies used in rehabilitation robots were examined, and their respective advantages and disadvantages were categorized.

2.2 Commercial Products

2.2.1 Hocoma Lokomat

The Lokomat is a robot-assisted gait training device developed by the Switzerland-based company Hocoma and utilized in numerous rehabilitation centers worldwide. Used for lower limb rehabilitation, this system enables individuals with reduced or complete loss of walking ability to take steps again.

2.2.1.1 Main Components of Lokomat:

- Exoskeleton: Connects to and articulates the hip and knee joints.
- Treadmill: Provides a controlled walking surface.
- Body Weight Support System (BWST): Reduces the physical load by carrying a portion of the patient's body weight.
- Feedback Display: Provides visual support and motivation for the patient.
- Adjustable Software: Offers the possibility of operating in passive, assistive, or active modes according to the patient's needs.
- Thanks to Lokomat, individuals can perform hundreds of repetitions in a short period within a safe environment using correct gait patterns.

2.2.1.2 Hocoma Lokomat Technical Specifications

Table 2: Technical Specifications of Hocoma Lokomat Rehabilitation Robot

Feature	Value/Description
Height	239 cm
Width	155 cm
Length	325 cm
Device Weight	1000 kg
Patient Weight Capacity	135 kg
Patient Height Range	150 – 200 cm
Maximum Walking Speed	3,2 km/h

Figure 1: Hocoma Lokomat

2.2.2 HAL – Hybrid Assistive Limb

When a person attempts to move their body, nerve signals are sent from the brain to the muscles via motor neurons, which in turn move the musculoskeletal system. During this process, small bio-signals can be detected on the skin's surface. The HAL suit records these signals through sensors attached to the user's skin. Based on the signals obtained, the power unit articulates the joint, supporting and enhancing the user's movement. The HAL suit features a cyber-control system that includes both a user-activated "voluntary control system" (Cybernic Voluntary Control - CVC) and a "robotic autonomous control system" (Cybernic Autonomous Control - CAC) for automatic movement support.

2.2.2.1 HAL – Hybrid Assistive Limb Technical Specifications

Table 3: Technical Specifications of HAL – Hybrid Assistive Limb Rehabilitation Robot

Feature	Value/Description
Length	430 mm
Width	470 mm
Height	1230 mm
Weight (Double-Leg Model)	14 kg
Weight (Single-Leg Model)	9 kg
Range of Motion (Hip Joint)	Extension 20°, Flexion 120°
Range of Motion (Knee Joint)	Extension 6°, Flexion 120°
Weight Limit	40-100 kg
Operating Time	Approximately 1 hour
Power Suppl	Custom Battery

Figure 2: Hybrid Assistive Limb (HAL)

2.2.3 Hocoma Erigo

Erigo is a robotic device designed to provide early and safe mobilization for patients with severely restricted mobility or those who are bedridden (including wheelchair users).

2.2.3.1 Hocoma Erigo Basic Functions and Features:

- Safe Verticalization: Safely transitions the patient from a lying position to a vertical position based on the tilt table principle.
- Early Functional Mobilization: Performs robot-assisted stepping movements in the lower extremities during verticalization and simulates weight-bearing on the legs.
- Personalization and Control: Through the user interface, the therapist adjusts and adapts all therapy parameters—such as tilt angle, stepping frequency, robotic guidance, and leg loading—specifically for the patient.
- Data Logging and Reporting: Records applied training parameters and generates detailed therapy reports.
- FES Module in ErigoPro: The Functional Electrical Stimulation (FES) module, available in the "Pro" version of the device, stimulates the muscles in synchronization with the robot’s stepping movement.

2.2.3.2 Environment of Use and Supervision

Supervision Requirement: The use of Erigo is mandatory under the supervision of a specially trained physiotherapist or healthcare professional.
Intended Areas of Application: Intensive Care Units (ICU), intermediate and early rehabilitation units, rehabilitation hospitals, and outpatient rehabilitation clinics.
In summary, Erigo is a robotic therapy device designed to safely verticalize patients with severe mobility impairments, aiming for early-stage functional recovery by simultaneously applying robotic stepping and Functional Electrical Stimulation (FES) to the lower extremities.

2.2.3.3 Hocoma Erigo Technical Specifications

Table 4: Technical Specifications of Hocoma Erigo

Feature	Value/Description
Weight	300 kg
Length	227 cm
Width	86 cm
Height	242 cm
Tilt Angle Range	0˚ – 90˚
Weight Capacity	135 kg
Stepping Frequency	8 – 80 steps/min
Max. Leg Load	50 kg
ROM Adjustment	0° – 45° (Symmetric/Asymmetric)
Hip Extension Angle	0° – 10° (Adjustable)
Height Adjustment	56 – 84 cm
Operating Temperature	10˚– 30˚C
Operating Air Pressure	30% – 75% Relative Humidity (RH)
Operating Humidity	700 – 1060 hPa

Figure 3: Hocoma Erigo

2.3 Comparison of Commercial Products

Table 5: Comparison of Commercial Products

Commercial Products / Technical Specifications	Hocoma Lokomat	HAL – Hybrid Assistive Limb	Hocoma Erigo
Weight	1000kg	14 / 9kg	300kg
Length	325cm	430mm	227cm
Height	239cm	1230mm	242cm
Width	155cm	470mm	86cm
Patient Weight Capacity	135kg	40/100kg	135kg
ROM Adjustment	-	-	$0^{\circ} – 45^{\circ}$
Maximum Walking Speed	3.2km/h	-	-

An analysis of the commercial products reveals that the **Hocoma Lokomat**, **HAL**, and **Hocoma Erigo** systems offer specialized solutions tailored to different patient profiles and rehabilitation stages. **Lokomat** stands out in advanced gait rehabilitation due to its high weight capacity and integrated treadmill system. In contrast, the **HAL** system provides active user participation through its lightweight and wearable design. **Erigo** offers a distinct advantage for early mobilization and verticalization, particularly for bedridden patients with severe mobility impairments.

However, these commercial systems possess certain disadvantages, such as being bulky, heavy, and costly, while requiring supervised use within clinical environments. These limitations highlight the necessity for a new generation of rehabilitation robots that are more compact, adjustable, and capable of articulating both hip and knee joints within a single, integrated system.

2.5 Research of Academic Articles Related to Hip-Knee Rehabilitation Robots

2.5.1. Article-1

Article Title: Design and Control of a Hip-Knee Rehabilitation Robot

- **Authors:** F.A.G. Becerra, A.B. Ortega, C.D.G. Beltrán, C.G. Valdivia, R.O.D. Arcega

- **Publication Date:** May 2018

In this study, a novel **parallel robot system** utilizing two **linear slides** along the Z and Y axes was designed for the rehabilitation of hip and knee joints. The robot performs hip flexion movements within a range of **0–120°**. The researchers developed a **kinematic model** based on the position of the slides rather than using angular sensors, thereby making the system simpler and more cost-effective.

For system control, a **Generalized Proportional-Integral (GPI)** controller was implemented, achieving high-precision control using only **position feedback**. Simulation and experimental results demonstrated that the robot tracks the desired motion smoothly and accurately. This study illustrates the effective application of parallel mechanisms in the field of rehabilitation robotics.

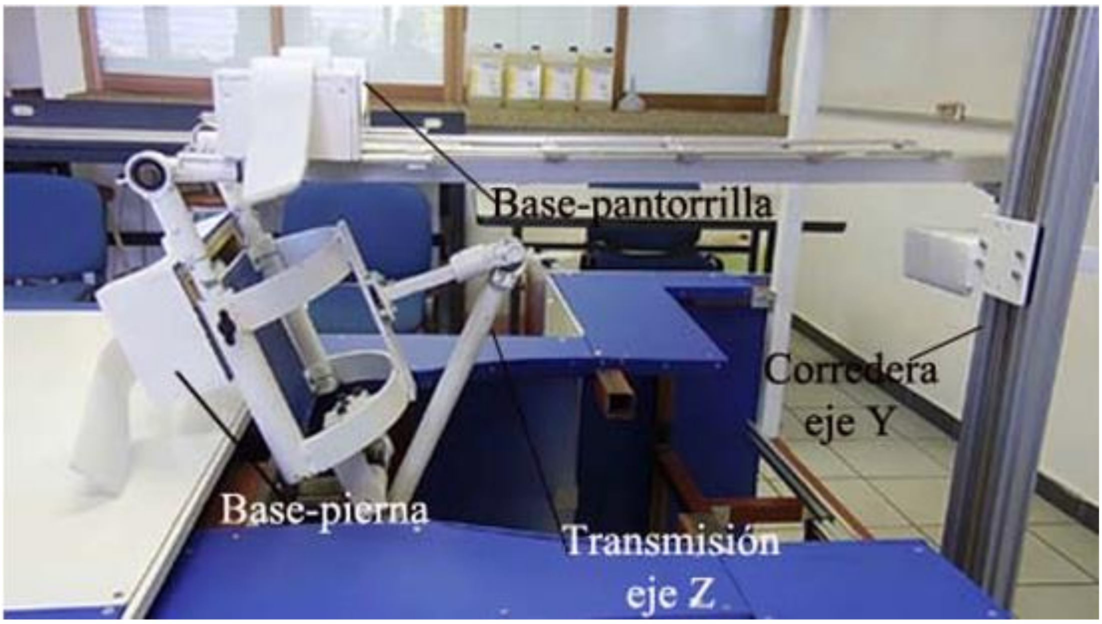


Figure 4: Article-1

2.5.2. Article-2

- **Article Title:** Mechanical Design and Trajectory Planning of a Lower Limb Rehabilitation Robot with Variable Workspace
- **Authors:** Hongbo Wang, Yongfei Feng, Hongnian Yu, Zhenghui Wang, Victor Vladareanu, Yaxin Du
- **Publication Date:** June 2018

In this study, a multi-joint sitting/lying type lower limb rehabilitation robot was designed to accommodate patients of different heights. The most significant feature of this robot is the pioneering use of the **"variable workspace"** concept. This allows the robot to automatically adjust its range of motion based on the patient's physical condition and recovery level.

The design incorporates **torque sensors** for the hip, knee, and ankle joints to achieve high-precision force measurement. Three different **trajectory planning** methods (circular, linear, and free curve) were developed and made applicable according to the specific needs of the patient. In clinical trials involving 60 stroke patients, the robot was proven to be safe and effective.

This research demonstrates the importance of variable workspace and personalized trajectory planning in lower limb rehabilitation robots, while also serving as a reference for future robotic rehabilitation systems.

Figure 5: Article-2

2.5.3 Article-3

- **Article Title:** iLeg – A Lower Limb Rehabilitation Robot: A Proof of Concept

- **Authors:** Feng Zhang, Zeng-Guang Hou, Long Cheng, Weiqun Wang, Yixiong Chen, Jin Hu, Liang Peng, Hongbo Wang

- **Publication Date:** October 2016

In this study, a sitting/lying type robotic system named iLeg, developed for the lower limb rehabilitation of stroke or partially paralyzed patients, is introduced. The robot consists of an adjustable seat and two leg orthoses with three degrees of freedom. Thanks to this structure, hip, knee, and ankle movements are performed in a manner similar to natural human movements. Two different control methods are applied in the system: passive training (PI control) and active training (sEMG-based control). In passive mode, the robot follows predefined movements, while in active mode, the patient directs the movement with the help of muscle signals. In experiments, it has been observed that the system tracks joint movements with an error rate of less than 1%. As a result, the iLeg system has provided an effective neurorehabilitation solution that can be an alternative to rehabilitation cycles by providing both passive and active training.

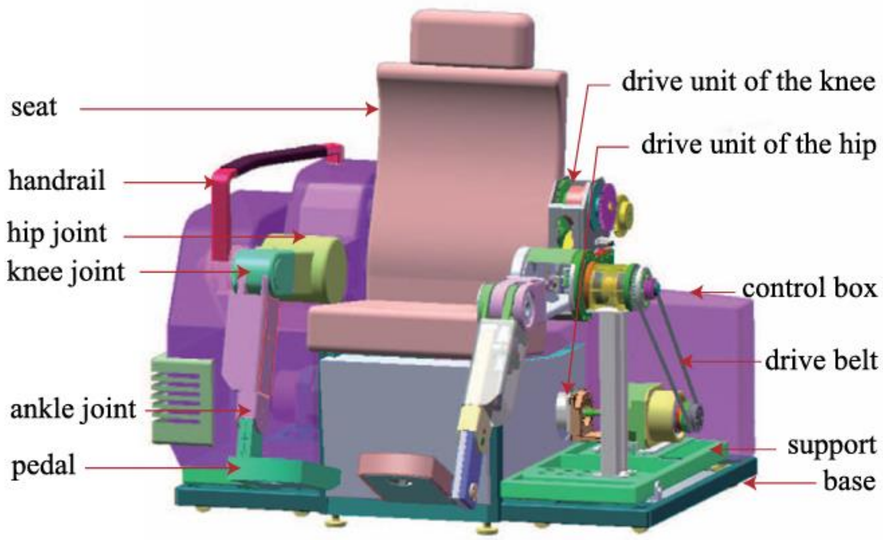


Figure 6: Article-3

2.5.4. Article-4

- **Article Title:** Design and motion control of exoskeleton robot for paralyzed lower limb rehabilitation (Felçli Alt Uzuv Rehabilitasyonu İçin Ekzoskeleton Robotunun Tasarımı ve Hareket Kontrolü)

- **Authors:** Zhiyong Zhu, Lingyan Liu, Wenbin Zhang, Cong Jiang, Xingsong Wang, and Jie Li

- **Publication Date:** February 21, 2024

This article presents the design and motion control of a new lower limb rehabilitation exoskeleton robot system to address the rehabilitation needs of patients experiencing limb movement disorders. The main objective of the study is to develop a multi-scenario robot system and ensure reliable motion control that enables paralyzed patients to perform various daily life movement scenarios such as walking, standing up, sitting, and climbing up and down stairs. Among the methods and techniques used, the mechanical design of the exoskeleton stands out, featuring active joints at the hip and knee, and elastic, under-actuated passive joints at the ankle. It has been confirmed that the designed exoskeleton robot possesses excellent reliability, fast response characteristics, and practicality; furthermore, wearing tests conducted on healthy subjects have verified that the robot can significantly increase mobility and provide effective support to the rehabilitation process.

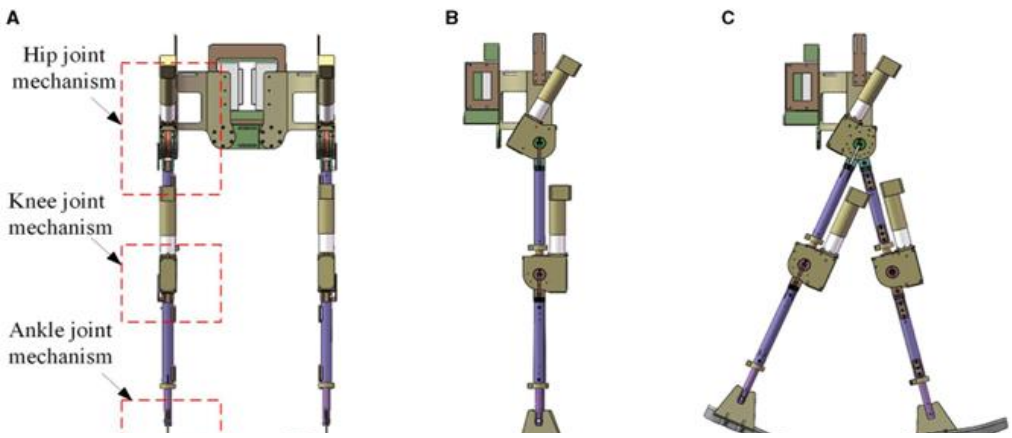


Figure 7: Article-4

2.5.5 Article-5

- **Article Title:** Biomechanical Design of the Berkeley Lower Extremity Exoskeleton (BLEEX) (Berkeley Alt Uzuv Ekzoskeletonu'nun (BLEEX) Biyomekanik Tasarımı)

- **Authors:** Adam B. Zoss, H. Kazerooni, and Andrew Chu

- **Publication Venue:** IEEE/ASME TRANSACTIONS ON MECHATRONICS

- **Publication Date:** Volume 11, Issue 2, April 2006

This article presents the biomechanical design and analysis of the Berkeley Lower Extremity Exoskeleton (BLEEX), developed to address the inability of wheeled vehicles to carry heavy loads over difficult terrain or stairs. BLEEX is the world's first energetically autonomous and field-operable exoskeleton system that can be worn by an operator, guiding leg movement and carrying heavy loads with minimum effort.
The main objective of the study is to explain the anthropomorphic design architecture, choice of degrees of freedom (DOF), hardware structure, and performance metrics of BLEEX. Clinical Gait Analysis (CGA) data were used as the basis for the system design. Each leg has a total of 7 DOF, seven of which are active, and these are driven by high-force capacity hydraulic actuators.
The control system instantaneously shadows the exoskeleton's movements with a special control scheme without taking direct force measurements from the user. Consequently, BLEEX was able to generate its own energy and carry both its own weight and external loads; thus, it has emerged as a practical solution that significantly increases heavy load-carrying capacity in challenging environments.

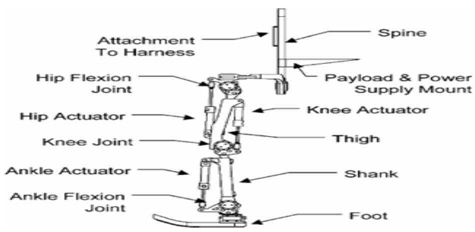


Figure 8: Article-5

2.5.6 Article-6

2.5.6 Article-6

- **Article Title:** Design and Optimization of Lower Limb Rehabilitation Exoskeleton with a Multiaxial Knee Joint (Çok Eksenli Diz Eklemli Alt Uzuv Rehabilitasyon Ekzoskeletonunun Tasarımı ve Optimizasyonu)
- **Authors:** Jiandong Jiang, Peisong Chen, Jiyu Peng, Xin Qiao, Fengle Zhu, and Jiang Zhong
- **Publication Date:** April 14, 2023

This article proposes an anthropomorphic knee exoskeleton featuring a variable instantaneous center of rotation (ICR) to facilitate the rehabilitation of patients experiencing lower limb movement disorders due to conditions such as stroke. The objective of the study is to design a multi-axial mechanism capable of moving along a J-shaped trajectory to reduce movement deviation and increase patient comfort, taking into account the ICR variability caused by the irregular structure of the human knee joint.

To this end, a five-bar mechanism with two degrees of freedom was used, which can adapt to individual differences. Human gait and knee ICR data were measured using an optical 3D motion capture system. Experimental results showed that the movement trajectory of the exoskeleton is remarkably close to human movement. This multi-axial joint provided better bionic compatibility compared to the traditional single-axis design and significantly increased patient comfort during rehabilitation by reducing the human-mechanism interaction force.

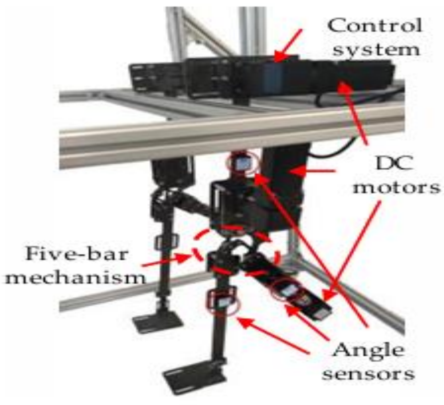


Figure 9: Article-6

2.6 Research of Patents Related to Hip-Knee Rehabilitation Robots

2.6.1. Patent-1

- **Patent Title:** DUAL-PURPOSE HIP AND KNEE JOINT REHABILITATION APPARATUS
- **Patent Publication Number:** US2024082097A1
- **Patent Assignee:** LIN JIN-JHONG

Description: A dual-purpose rehabilitation device for the hip and knee joints; it includes at least one drive unit, a hip joint rehabilitation frame, and a knee joint rehabilitation frame. The user can select and attach either the hip joint rehabilitation frame or the knee joint rehabilitation frame to the drive unit; the drive unit provides a driving force to drive and control the selected frame, applying a dynamic reciprocal (back-and-forth) motion to the user's hip or knee joint. Thus, the aforementioned dual-purpose hip-knee rehabilitation device provides a rehabilitation structure for both the hip and knee joints.

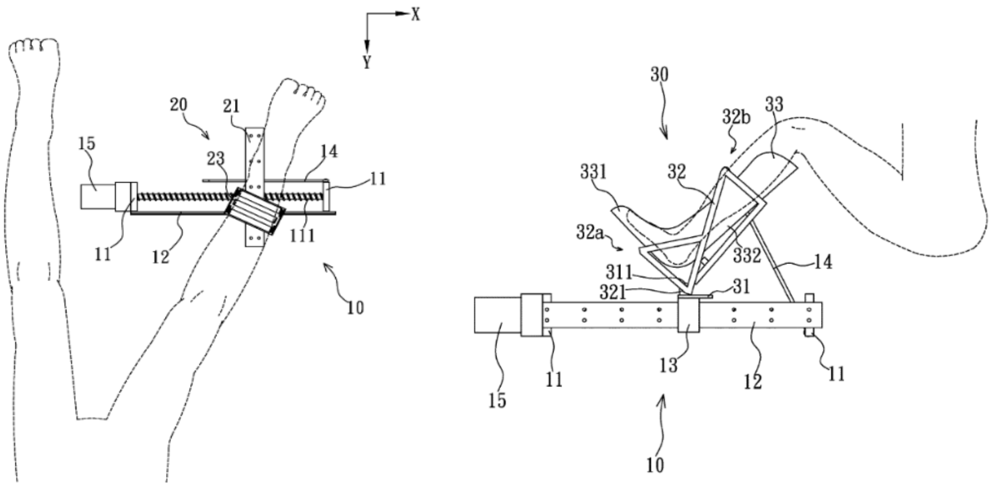


Figure 1 : Patent-1

2.6.2. Patent-2

- **Patent Title:** BEDSIDE LOWER LIMB REHABILITATION TRAINING ROBOT CAPABLE OF MECHANICAL LIMITING
- **Patent Publication Number:** WO2021238501A1
- **Patent Assignee:** GUO LIWEI; LI HENG; LI YAOFENG; XU HONGLIANG; CHU XIANGQIAN; YAN MENG; ZHANG HENG, FU FENGSHENG; HOU YAFEI

Description: A bedside lower limb rehabilitation training robot capable of mechanical limiting; it consists of a fixing frame and a mechanical leg. The mechanical leg includes a thigh module, a calf module, and an ankle module. The thigh module consists of a thigh drive element, a hollow rotary platform, a hip torque sensor, a hip connection disk, and a thigh arm, arranged respectively. The calf module consists of a calf drive element, a knee torque sensor, a knee limiting ring, and a calf arm, arranged respectively. The ankle module consists of an ankle drive element, an ankle connection disk, and an ankle connection plate, arranged respectively. This bedside lower limb rehabilitation robot with a mechanical limiting feature enhances the safety of patients during rehabilitation training.

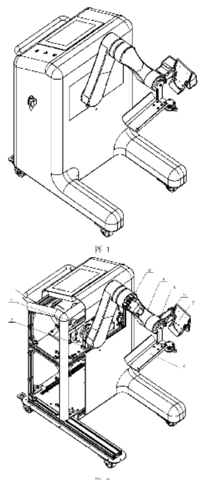


Figure 11: Patent-2 Lower Limb Rehabilitation Robot

2.6.3. Patent-3

- **Patent Title:** Hip-bending and knee-bending rehabilitation training device
- **Patent Publication Number:** CN209048595U
- **Patent Assignee:** GAO LIHONG; JIA RONGJUAN, LI HONGTAO; GAO QIAOYAN

Description: The utility model describes a hip and knee bending rehabilitation training device. The device consists of a vertical column, a controller, an upper limb fixation mechanism, and a lower limb fixation mechanism. The upper limb fixation mechanism includes a chest-back cushion and an upper movement locking assembly. The lower limb fixation mechanism consists of left and right leg movable support devices and a lower movement locking assembly. Each leg support device is composed of a hip joint drive mechanism, an upper swing arm, a knee joint drive mechanism, a lower swing arm, and a footrest. Thus, with the help of these mechanisms, the patient can independently perform hip and knee bending movements and receive multi-functional rehabilitation training.

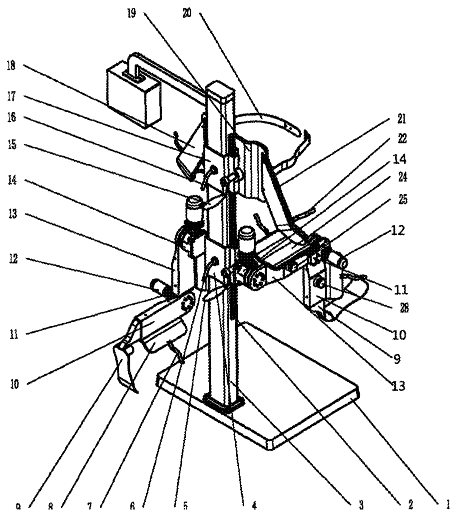


Figure 12: Patent-3 Hip and Knee Training Device

2.6.4. Patent-4

- **Patent Title:** Cerebral palsy comprehensive rehabilitation training assistive tool
- **Patent Publication Number:** CN203662957U
- **Patent Assignee:** LAN ZHI; WANG XITAI, YAN HEPING; ZHANG XIUFENG; MA YAN; LI GUILING

Description: The utility model describes a comprehensive rehabilitation training assistive tool for cerebral palsy patients. The tool consists of a lower chassis, a lower limb exoskeleton device, and a suspension assembly. The lower chassis includes swivel wheels, lower and upper frame bodies, and an exoskeleton tilt adjustment mechanism. The lower limb exoskeleton device provides forward bending, backward extension, abduction/adduction, and rotation movements for the hip joint; flexion/extension movements for the knee; and various dorsiflexion, flexion, and rotation movements for the ankle. The suspension assembly corrects upper body posture by reducing body weight. This tool supports patients in rehabilitating their lower limb joints, correcting abnormal postures, and gradually standing and walking normally.

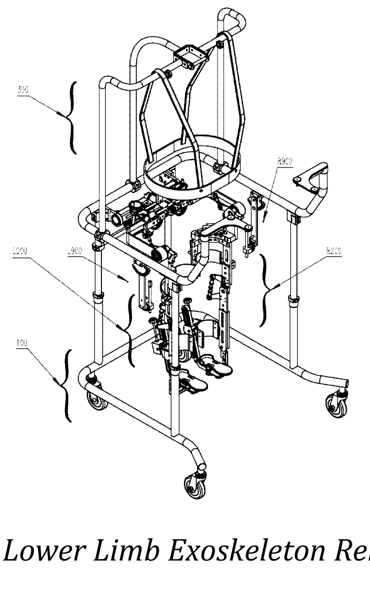


Figure 13: Patent-4 Lower Limb Exoskeleton Rehabilitation System

2.6.5. Patent-5

- **Patent Title:** Adjustable hip and knee joint rehabilitation training device
- **Patent Publication Number:** CN221286819U
- **Patent Assignee:** ZHONG WEN; ZHOU DONGYING, LI FEILONG; LI XIAOXIA; WU ZHUO

Description: The device includes a base plate, a first and a second support plate, a support part, and a goniometer. The second support plate is hinged to both the base plate and the first support plate. The support part carries the first support plate and allows it to be separated from the base plate; thus, the calf part is properly positioned, and by leaning the thigh toward the trunk, only the hip muscles are exercised. In knee flexion exercises, the angle of the first support plate can be adjusted by resting it on different adjustment grooves. The angles of the first and second support plates are measured with a goniometer to increase training efficiency and facilitate data recording of the rehabilitation process.

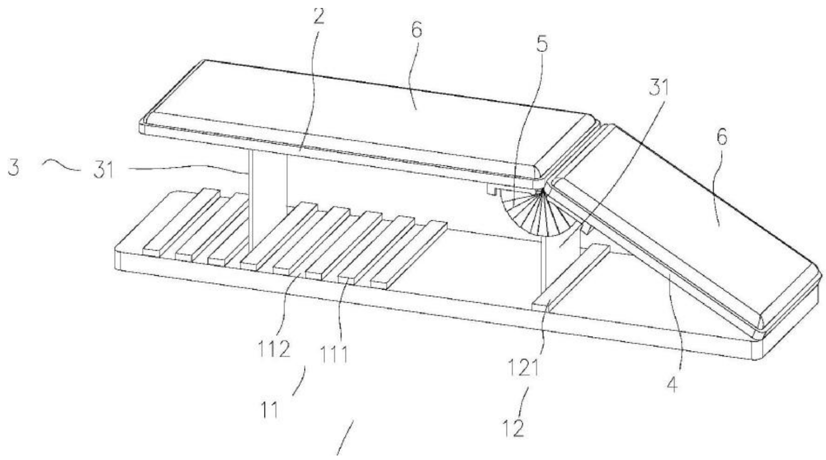


Figure 14: Patent-5 Adjustable Hip-Knee Rehabilitation Device

2.6.6. Patent-6

- **Patent Title:** Hip and knee joint postoperative rehabilitation equipment
- **Patent Publication Number:** CN218392066U
- **Patent Assignee:** NA SOON-CHEON; YANG JIE; ZHAO YONGGANG; WANG NENG; YANG YANWEI; LIU ZHAOXIAN; ZHAO GUANGYU; FAN XUGUO

Description: This equipment includes a base, a connection block placed on the base surface, a connection rod mounted to the connection block, and positioning plates located on both sides of the connection rod and connected to the base. On the base, there is a positioning plate, a movable plate on one side of this plate, sliding strips on both sides of the movable plate, and a first curved block on one side of the plate. The movable plate is connected to the surface of the positioning plate by sliding; the sliding strips on both sides are connected to telescopic rods. One side of each telescopic rod is rotatably connected to a telescopic base. Thanks to this structure, the problem of difficulty in adjusting the length according to user requirements in existing devices has been eliminated.

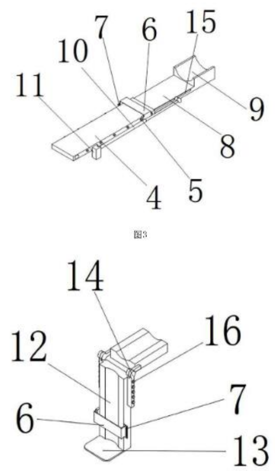


Figure 15: Patent-6 Lower Limb Support and Adjustment Mechanism

2.6.7. Patent-7

- **Patent Title:** Wearable lower limb rehabilitation training system
- **Patent Publication Number:** CN111700778A
- **Patent Assignee:** HE YONGZHENG; WANG GUANGXU; ZHANG YUGANG; SI SHIXIONG

Description: The invention discloses a wearable lower limb rehabilitation training system. The training system consists of a crossbeam, a belt fixed to the crossbeam, a battery box assembly, a controller, a left lower limb system, and a right lower limb system. The left lower limb system includes a thigh frame; the thigh frame houses a thigh mounting plate; a hip joint ball screw is connected to the thigh mounting plate; the nut of the ball screw is fixed to a hip joint sliding block; one end of the hip joint connecting rod is articulated with the hip joint sliding block, while the other end is articulated with a hip joint crank.

The left lower limb system also includes a knee joint assembly located under the thigh frame; the lower end of the knee joint assembly is fixed to a length-adjustable calf mechanism; the lower part of the length-adjustable calf mechanism is rotatably connected to an ankle joint, and a shoe holder is connected under the ankle joint. The thigh frame and calf frame are fixed to tensioning airbag covers. This training system can be used to assist the walking of patients with different types of lower limb dysfunction.

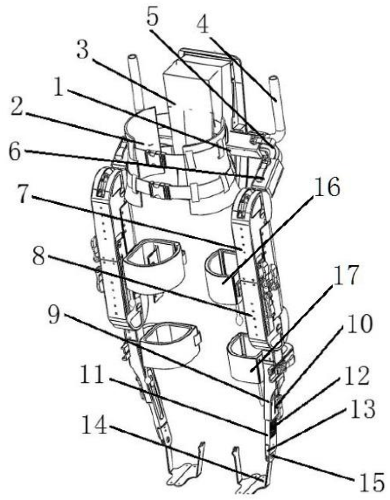


Figure 16: Patent-7 Wearable Rehabilitation Exoskeleton

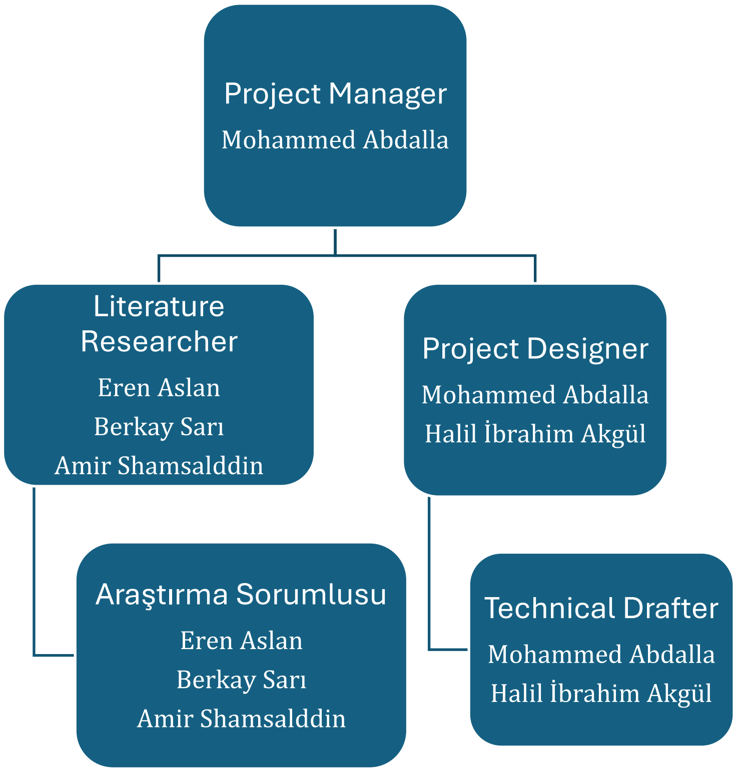
3. Project Planning and Management

This section details the division of labor among the project team and the specified working durations. By defining the responsibilities of each person involved in the project, it is clarified which tasks belong to which team member. Furthermore, a work-time schedule is established, organizing the start and end dates for all activities within the scope of the project. This planning clearly outlines which tasks team members must complete within specific timeframes.

During the risk management process, potential risks that could negatively impact the project are assessed, and precautionary measures against these risks are defined. Additionally, to maintain strong communication within the team, regular meetings are organized and documented with meeting minutes that record the decisions made and the topics discussed.

3.1 Organizational Chart

Table 1: Organizational Chart



3.1.1 Job Descriptions

Job descriptions are documents that explain in detail the responsibilities and tasks to be undertaken by an individual within the scope of a project or organization. These definitions clarify individuals' roles, areas of authority, goals, and the specific areas in which they will actively contribute. By clarifying the responsibilities of both the individual and the team, job descriptions support the organized progress of the project process and the creation of an efficient working environment.

3.1.1.1 Project Manager

The project manager ensures the planned progress of the project process and monitors the work performed. By generating solutions to minor problems encountered during the process, they help ensure the timely completion of the project.

3.1.1.2 Literature Researcher

The literature researcher gathers necessary information by examining academic studies and similar systems related to the project topic. The information obtained is shared with the project team.

3.1.1.3 Project Designer

The project designer creates the mechanical structure and general design of the system. They ensure that the design is functional and aligned with the project's objectives.

3.1.1.4 Research Lead

The research lead researches the technical information needed during the project process. This information is used during the design and implementation phases.

3.1.1.5 Technical Drafter

The technical drafter prepares the technical drawings of the designed parts and the system. They ensure that the drawings are clear and comply with the specific dimensions.

3.2 Work-Time Schedule

Table 2: Work-Time Schedule Table

NO	Yapılan İş	Yapan Kişiler	Başlangıç Tarihi	Bitiş Tarihi	Süre (Gün)	Ekim	Kasım	Aralık	Ocak	Şubat	Mart	Nisan	Mayıs
1	İhtiyaç Tanımı	Tüm Üyeler	04/10/2025	06/10/2025	6								
2	Ürün şartnamesi Araştırılması	Tüm Üyeler	04/10/2025	04/10/2025	1								
2.1	kullanım şartları	A.SH.-E.A	05/10/2025	05/10/2025	1								
2.2	İstek ve Özellikler	E.A.- B.S	05/10/2025	05/10/2025	1								
2.3	Teknik Özellikler	M.A.-H.İ	06/10/2025	06/10/2025	1								
2.4	Kalite - Güvenlik	E.A.- B.S	06/10/2025	06/10/2025	1								
3	Literatür Araştırması		07/10/2025	12/10/2025	6								
3.1	Patent Araştırması	A.SH.	07/10/2025	11/10/2025									
3.2	Makale Araştırması	M.A-B.S.-E.A.	08/10/2025	12/10/2025									
3.3	Piyasa Ürünleri	H.İ.A	08/10/2025	12/10/2025									
4	Proje Planlama		19/10/2025	27/10/2025	9								
4.1	Görev Dağlımı	Tüm Üyeler	19/10/2025	21/10/2025	3								
4.2	İş-Zaman Çizelgesi	M.A.	22/10/2025	22/10/2025	1								
4.3	Risk Yönetimi	Tüm Üyeler	23/10/2025	27/10/2025	5								
5	Kavramsal Tasarım	Tüm Üyeler	09/11/2025	25/12/2025	44								
5.1	Fonksiyonların ayrıştırması	Tüm Üyeler	20/11/2025	27/11/2025	8								
5.1.1	Tahrik Mekanizması	M.A. - H.İ.	28/11/2025	29/11/2025	2								
5.1.2	Hareket İletimi	M.A. - H.İ.	30/11/2025	01/12/2025	2								
5.1.3	Uzunluk Ayarı	M.A. - H.İ.	02/12/2025	02/12/2025	1								
5.1.4	Kalça Bağlama	M.A. - H.İ.	03/12/2025	03/12/2025	1								
5.1.5	Durdurma- Pozisyon Ayarlama	M.A. - H.İ.	04/12/2025	04/12/2025	1								
5.1.6	Diz Bağlama	M.A. - H.İ.	05/12/2025	05/12/2025	1								
5.1.7	Güç Kaynağı	M.A. - H.İ.	06/12/2025	06/12/2025	1								
5.2	Morfolojik Tablo hazırlanması	E.A.- B.S	07/12/2025	07/12/2025	1								
5.3	Kriterlerin Belirlenmesi	Tüm Üyeler	10/12/2025	12/12/2025	3								
5.4	En İyi Konsept Seçimi	Tüm Üyeler	19/12/2025	19/12/2025	1								
5.5	Konseptin SW ile Oluşturması	M.A.- H.İ.	20/12/2025	24/12/2025	5								
6	Detay Tasrımı	Tüm Üyeler	09/02/2026	22/05/2026	90								
7	Şekillendirme Tasarımı	Tüm Üyeler	09/02/2026	22/05/2026	90								

3.3 Risk Management and Contingency Plan (Plan B)

Risk management in the Combined Hip–Knee Rehabilitation Robot project covers the identification, analysis, and control of potential risks that may be encountered during the project process and the use of the device to be developed. The primary goal of risk management is to minimize technical, financial, time planning, and safety risks while increasing opportunities that can contribute to the project. Through this process, design quality is improved, and the safety level is increased by anticipating potential hazards that may occur during the use of the device.

3.3.1 Main Processes

3.3.1.1 Risk Management Planning

In this stage, the scope and method of the risk management studies to be carried out for the rehabilitation robot have been determined. Risks that may arise in areas such as the drive system, fastening mechanism, software, budget, and time planning have been evaluated. In this way, it has been clarified how the risks will be monitored and how the necessary precautions will be taken during the project process.

3.3.1.2 Risk Identification

In this process, potential risks that could affect all stages of the project are identified and each is recorded in detail. The source, impact, and the project stage where each risk might occur are explained in detail.

3.3.1.3 Qualitative Risk Analysis

To perform a qualitative assessment of risks and prioritize their impacts on activity objectives.

3.3.1.4 Quantitative Risk Analysis

Measuring the probability of risk occurrence and their impacts, and estimating their effects on objectives.

3.3.1.5 Risk Response Planning

Developing methods and techniques to enhance opportunities and reduce threats.

3.3.1.6 Risk Monitoring and Control

Monitoring risks, identifying new risks, implementing risk mitigation plans, and evaluating their effectiveness throughout the activity life cycle.

Table 3: Risk Table

Risk	Risk Type	Description
Loss of Personnel	Personal	Personnel leaving the team due to disagreement, illness, or any other reason
Lack of Sufficient Resources	Tools	Lack of information in the literature or commercial product catalogs not being publicly available
Team Member Incompatibility	Personal	Emergence of personal issues, downsizing, or disagreements
Design Delay	Project	Disruptions occurring due to the complexity of the design
Hardware Failure	Technological	Hardware used not being compatible or software being incorrect
Assembly Problems	Project	Dimensional inconsistencies resulting from drawing errors that may occur during design
Budget Insufficiency	Economic	Increase in parts prices due to exchange rate fluctuations during external procurement
Analysis Errors	Project	Caused by the failure to use correct parameters while performing analysis
Size and Weight Risk	Project	Loss of wearability feature due to weight
Mechanical Failure	Technological	Failures arising from regular maintenance or incorrect usage

3.3.2. Risk Probability and Impact

Table 4: Risk Probability and Impact

Risk Probability				
Very High				
High		**8 - 4**	**3 - 10**	**1**
Significant			**2**	**7**
Low			**9**	**5**
Very Low			**6**	
	Insignificant	**Insignificant**	**Insignificant**	**Insignificant**
Risk Probability				

3.3.3. Precautions to be Taken and Plan B

Table 5: Precautions and Plan B

Risk	**Precautions**	**Plan B**
Loss of Personnel	Creating a backup plan for critical positions	Hiring new personnel for a specific period for a fee
Team Member Incompatibility	Defining roles and tasks clearly at the start of the project and holding regular meetings	Resolving the conflict and redistributing roles if necessary
Budget Insufficiency	Making fixed-price agreements with suppliers	Applying to other affordable suppliers
Mechanical Failure	Moving parts of the robot will be maintained regularly, wear indicators will be monitored, and spare parts procurement will be ensured	In case of failure, rapid replacement will be ensured with spare parts, the robot will be stopped, and the failure will be fixed

4. CONCEPTUAL DESIGN

In the design process, valid solutions are created for each concept by determining the functions of the combined hip-knee rehabilitation robot. Subsequently, concepts are developed, and the most logical concept capable of operating at the optimum level is selected from among these options.

4.1 Functional Decomposition

The Combined Hip–Knee Rehabilitation Robot is a system aimed at applying controlled, safe, and repeatable movements to both the hip and knee joints in lower limb rehabilitation. During the design process, the primary tasks that the system must perform are grouped under seven main functions:

- Drive Mechanism Function
- Longitudinal Length Adjustment Function
- Motion Transmission Function
- Leg Attachment Function
- Stop (Safety Stop) Function
- Power Source Function
- Hip Size Adjustment Function

At least two solutions have been developed for each function, the relevant mechanisms have been technically evaluated, and advantage–disadvantage analyses have been conducted.

4.2. Concept and Solution Development for Each Function

In this section, the operating principles of the functions specified in the previous heading will be explained.

4.2.1. Drive Mechanisms

The drive mechanism is the fundamental unit that constitutes the source of mechanical motion generated in the lower limb rehabilitation system. Through this mechanism, the necessary torque and speed profiles for the hip and knee joints are created. Manual, electric motor, hydraulic, or pneumatic drive options offer different levels of performance and control depending on the patient's needs and the intensity of the treatment applied.

4.2.1.1 Brushed DC Motor

Brushed DC motors are electric motors that operate with direct current and ensure the rotation of the rotor through a mechanical commutator-brush system. Due to their simple structure, low cost, and the ease of implementing control circuits, they are widely preferred in prototype and academic studies, such as rehabilitation robots.

Advantages

- Simple structure and low cost: Since the control circuit and mechanical structure are simple, it offers an economical solution for prototype rehabilitation robots.
- Easy speed and torque control: Precise speed adjustment can be achieved using the PWM method, ensuring controlled and safe movement of the hip and knee joints.
- Sufficient torque production at low speeds: When used with a gearhead (reducer), it can easily provide the torque required for rehabilitation movements.

Disadvantages

- Brush and commutator wear: Due to mechanical contact, maintenance needs arise over time, and performance may decrease with long-term use.
- Efficiency and lifespan limitations: Compared to brushless motors, its efficiency and operational lifespan are lower.
- Noise and vibration: Due to the brush structure, it may pose a disadvantage in applications requiring silent and highly precise movement.

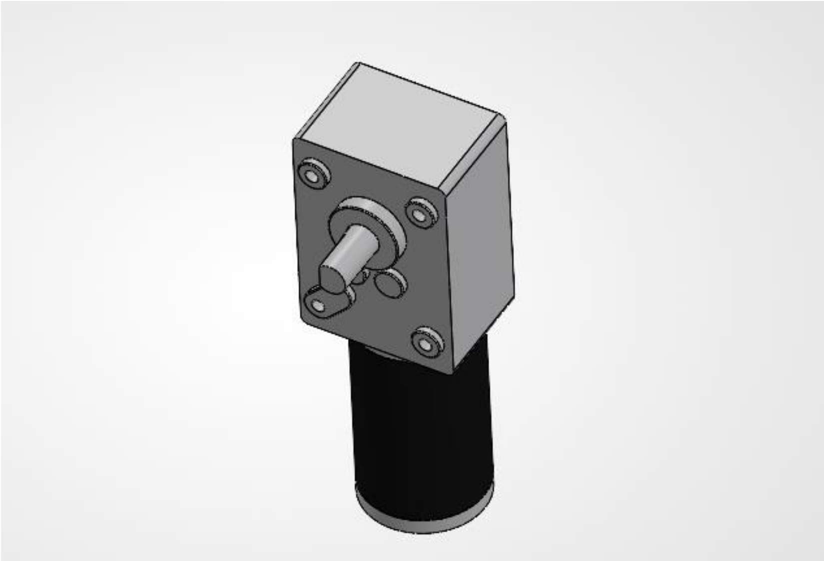


Figure 2: Brushed DC Motor

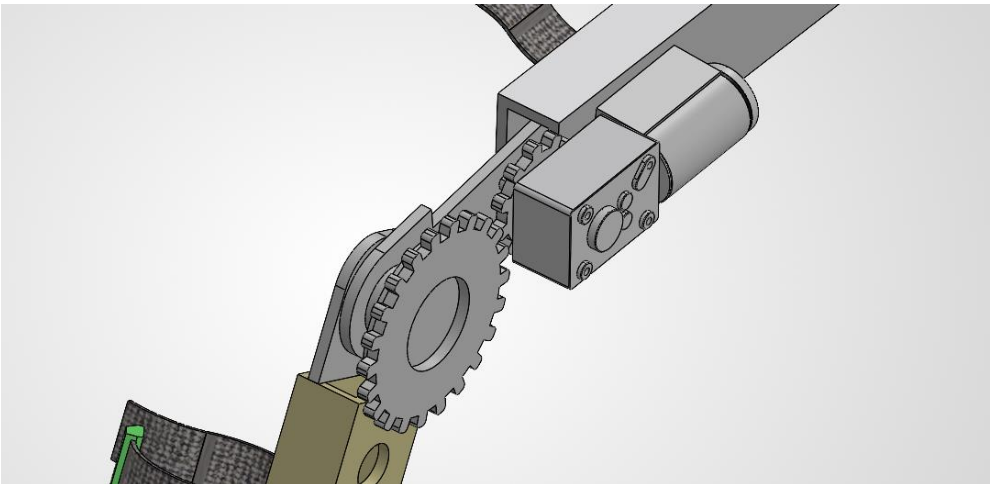


Figure 3: Brushed DC Motor Assembly

4.2.1.2 Brushless DC Motor

Brushless DC motors (BLDC) are motors that convert electrical energy into mechanical energy through the electronic commutation method. Since they do not contain brushes and commutators, mechanical wear is at a minimum level. By controlling the rotor and stator structures with feedback elements such as Hall sensors or encoders, the motor's speed and position can be adjusted with high precision.

Advantages

- High efficiency and long operational life: Since there is no brush wear, maintenance requirements are low, making them suitable for long-term use.
- Quiet and vibration-free operation: Increases patient comfort during rehabilitation and ensures smooth joint movements.
- Precise speed and position control: Joint movements can be performed in a controlled and safe manner using feedback systems.

Disadvantages

- High initial cost: Motor and driver systems are more expensive compared to brushed motors.
- Complexity of the control system: Electronic driver and software requirements make the design more difficult.
- Prolonged prototype development time: Setup, calibration, and testing processes require more time.

Figure 4: Brushless DC Motor (BLDC)

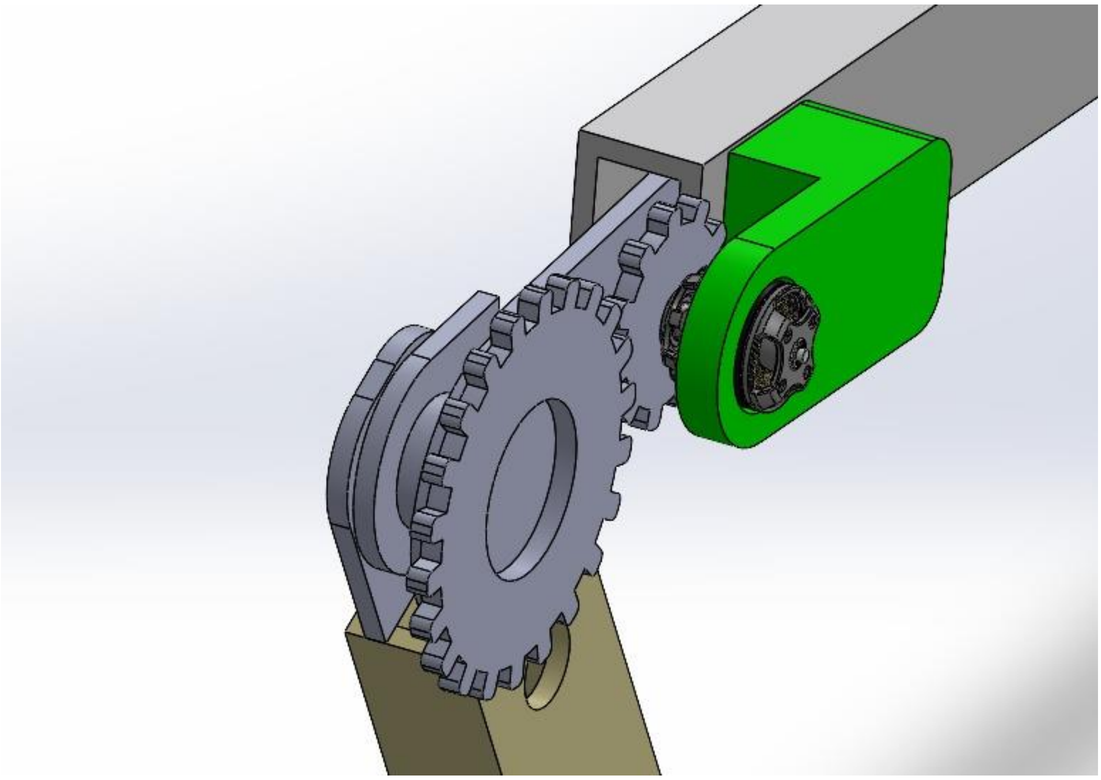


Figure 5: Brushless DC Motor Assembly

4.2.1.3 Pneumatic Drive

Pistons operating with pressurized air are particularly suitable for applications requiring lightweight components and fast motion.

Advantages

- Fast Response and Lightweight: Pneumatic systems have short response times. Additionally, because the actuators are mostly lightweight, they reduce the overall weight of the device. This is advantageous for portable or home-type light robots.
- Clean Working Environment: They are oil-free, so hygiene issues like oil contamination in case of a leak do not occur; this is preferred in medical environments.
- Simple Mechanical Structure and Safety: Since air is compressible, the system naturally shows flexibility under sudden loads. In cases of excessive force application, shock loads can be dampened.

Disadvantages

- Low Maximum Force/Torque: High forces comparable to hydraulic systems or electric motors with gearboxes cannot be produced; they may be insufficient, especially for larger patients requiring high resistance.
- Limited Control Precision: Due to the compressibility of air, precise positioning is difficult in open-loop pneumatic systems; closed-loop servo-pneumatic solutions significantly increase costs.
- Additional Infrastructure Requirement (Compressor/Pressure Line): The necessity of a compressor or a central gas line in portable systems creates operational constraints; compressors also involve noise and maintenance needs.
- Low Energy Efficiency: Energy efficiency during compressor operation is lower than that of motor drivers; energy costs may increase with long-term use.

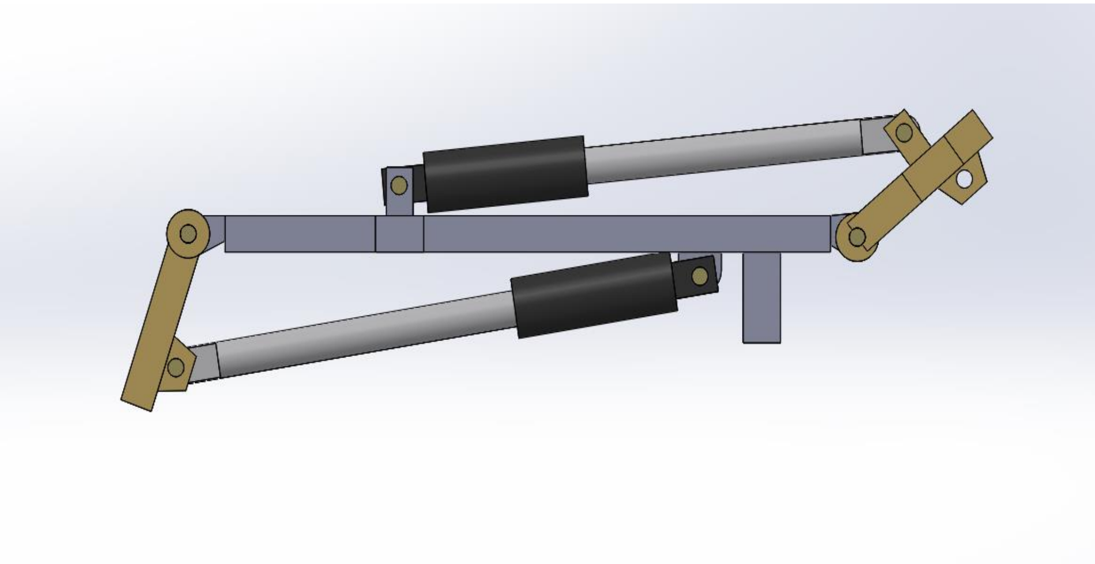


Figure 6: Pneumatic Drive

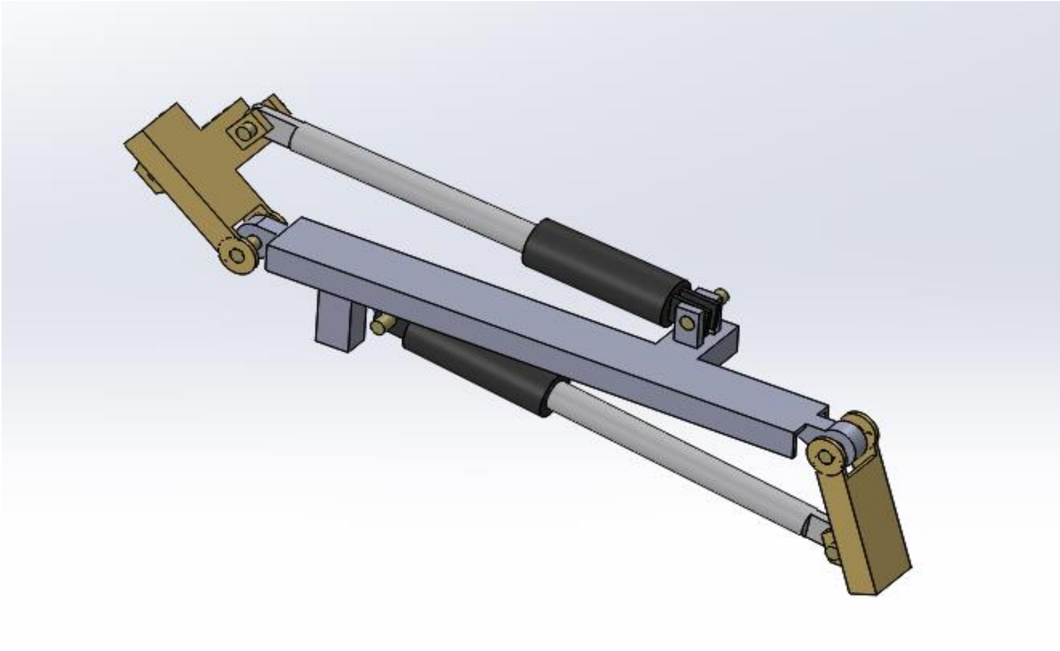


Figure 7: Pneumatic Drive Assembly

4.2.2. Longitudinal Length Adjustment

This function is used to ensure the device **ergonomically adapts** to individuals with different leg lengths.

4.2.2.1 Spring-Loaded Pin Mechanism

Advantages

- Simple and easily mountable: Its mechanical structure is straightforward, requiring no complex calibration or specialized tools for installation.
- Stable and secure adjustment: Once the pin enters the slot/hole, the setting remains locked and will not shift or slip even under significant loads.
- High load-carrying capacity: Since the pins are typically made of hardened metal, they can withstand the high torques and axial forces generated during lower limb rehabilitation.

Disadvantages

- Spring Fatigue: Depending on the quality of the spring used, the mechanism can lose its compression and push-back capability over time. This may prevent the pin from fully seating in the hole or cause it to remain loose, creating a significant safety risk.
- Mechanical Play and Vibration: If there is a gap (clearance) between the pin and the hole due to manufacturing tolerances, a vibration—known as backlash—can occur in the system. Especially in systems requiring precise movement, such as a rehabilitation robot, this play can lead to deviations in the patient's walking trajectory.

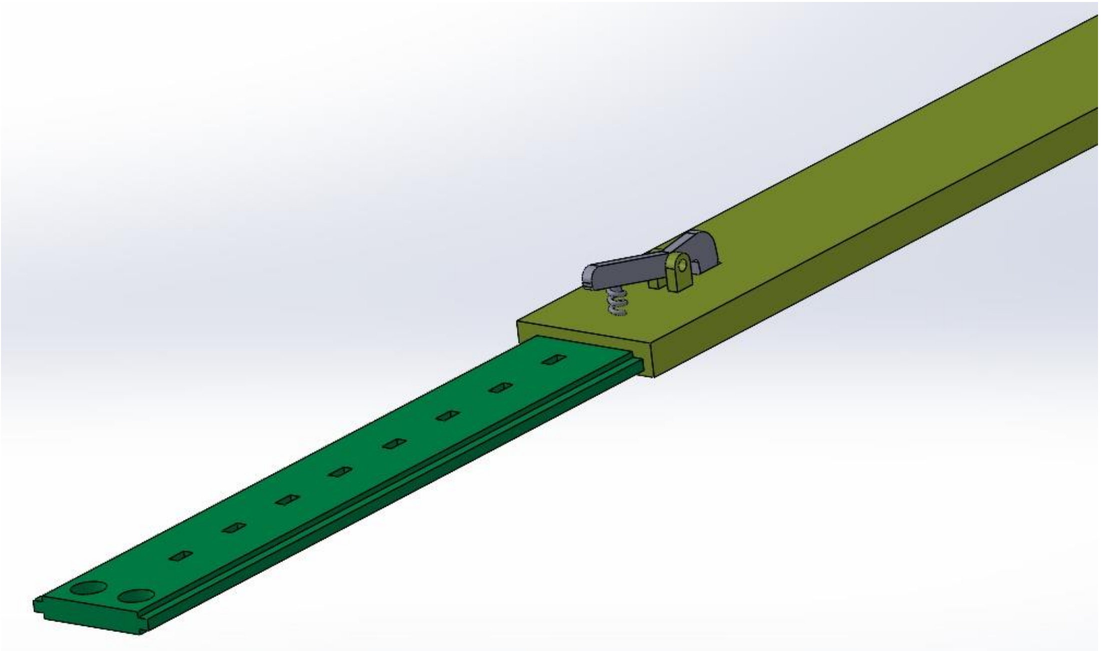


Figure 8: Gear-Adjustable Mechanism

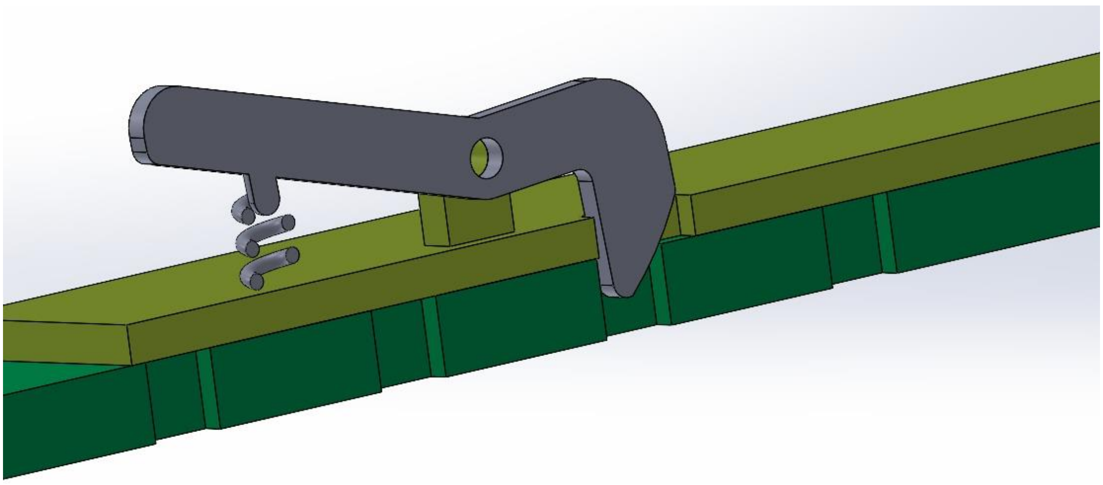


Figure 9: Gear-Adjustable Mechanism Assembly

4.2.2.2 Pin–Hole Fixing

Advantages

- Simplicity and Durability: The hole-column + pin method can safely carry high static and dynamic loads. It is a reliable solution that has been used for many years in sports and fitness equipment, making it ideal for the structural demands of a rehabilitation robot.
- Ease of Service and Economical: Any worn parts (like the pin or the sleeve) can be easily replaced. Both the initial production costs and long-term maintenance expenses are very low.

Disadvantages

- Stepped Adjustment — Lack of Precision: Adjustment is limited by the distance between the holes; fine-tuning for intermediate positions is not possible. This is a significant disadvantage when precise anatomical alignment is required for patient safety and comfort.
- Usability: It requires pulling and re-inserting the pin for every position change. In clinical scenarios where frequent adjustments are needed for different patients, this process can be time-consuming.
- Looseness Due to Wear: Over time, "play" or wobbling may occur at the contact surfaces between the pin and the hole. In such cases, tolerances must be checked and a part replacement plan should be implemented to maintain system stability.

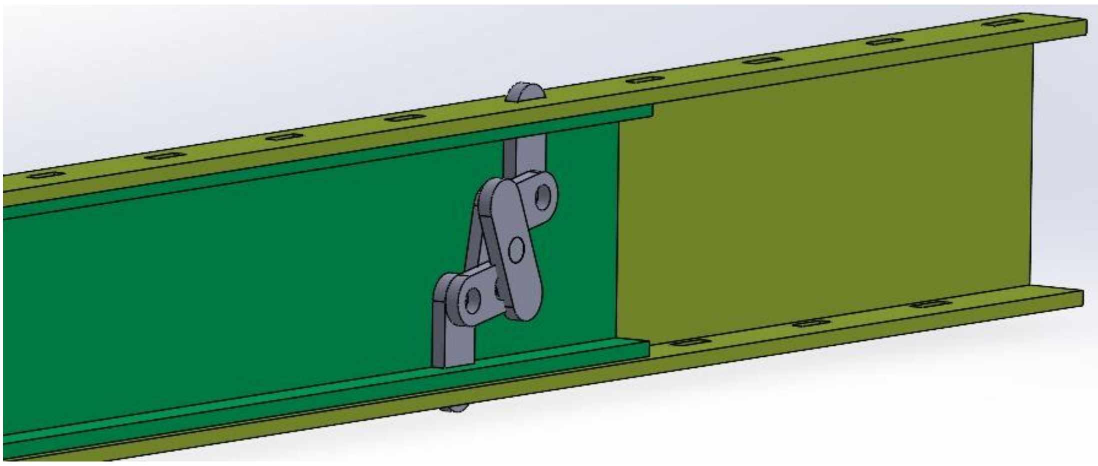


Figure 10: Pin–Hole Fixing

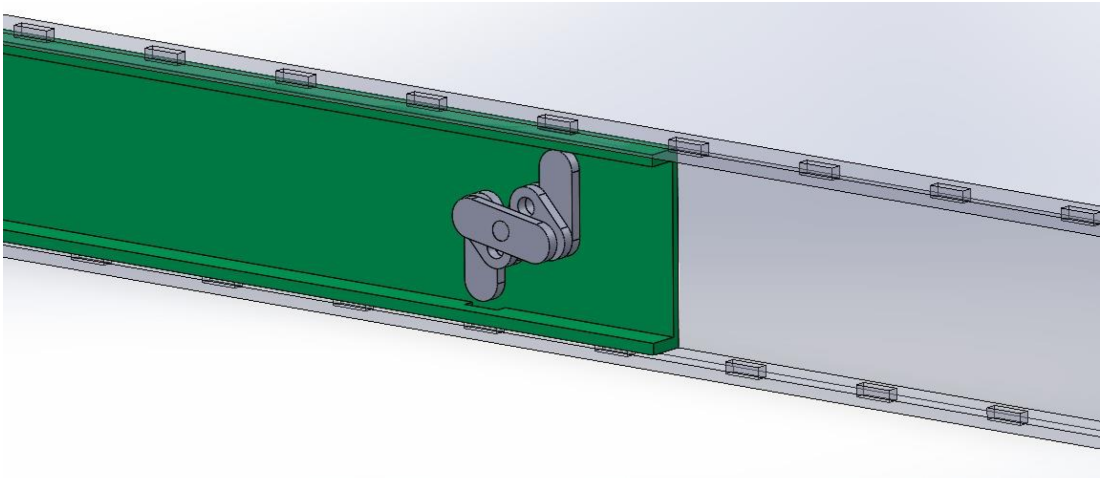


Figure 11: Pin–Hole Fixing Assembly

4.2.3. Motion Transmission Function

This function ensures that the rotary or linear motion generated in the drive unit is transmitted to the joint in the correct form. It is the critical component that determines the accuracy, comfort, and biomechanical compatibility of the movement.

4.2.3.3 Power Transmission via Gears

Advantages

- High Accuracy and Torque Transmission: Gearboxes transmit torque efficiently and are superior in terms of positioning precision and repeatability. This ensures the robot follows the exact therapeutic path without slipping.
- Durability and Stability: Metal gearboxes provide stable performance even under high cycle counts; they are robust enough to be used for years in industrial and medical applications.
- Inherent Braking Features: Certain types of reducers (such as worm gears) exhibit a self-locking tendency. This provides a significant advantage in maintaining a fixed position without drawing extra power from the motors.

Disadvantages

Disadvantages of Power Transmission via Gears

- Wear and Noise: Metal gears can generate noise during long periods of operation, and their contact surfaces naturally wear down over time. Any errors in the gear profile can lead to unwanted vibrations, which may negatively impact the patient's comfort and the robot's sensor accuracy.
- Weight and Volume: Robust gearboxes often result in a non-compact form factor. This added bulk and weight can limit the portability of the rehabilitation device, making it less suitable for home-use or mobile exoskeletons.
- Maintenance Requirements: They require regular lubrication and periodic inspections to ensure smooth operation. If the gears become damaged or misaligned, the repair process can be labor-intensive and technically demanding.

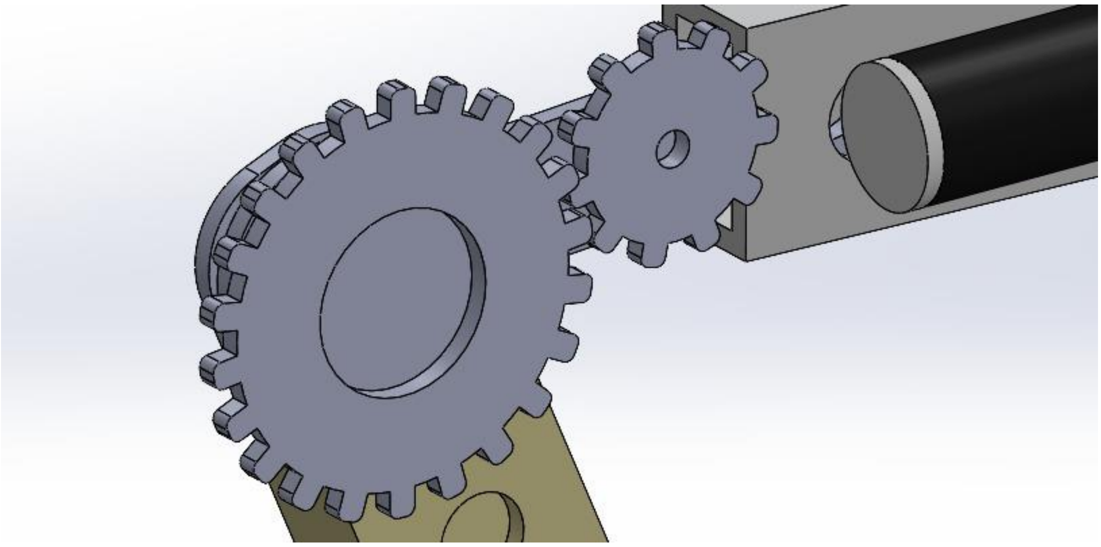


Figure 12: Power Transmission via Gears

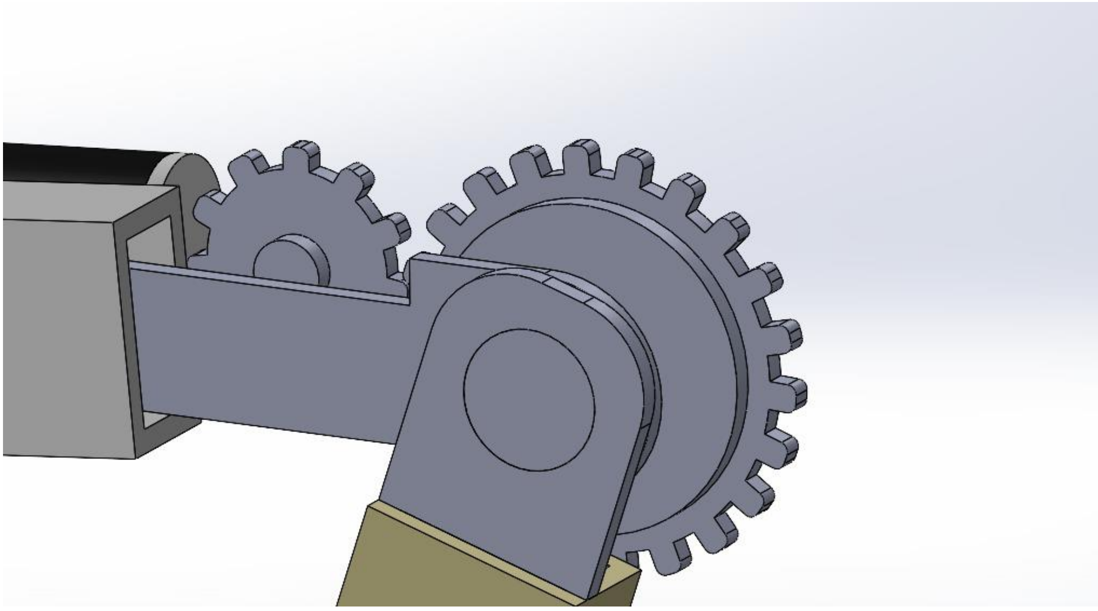


Figure 13: Gear Power Transmission Assembly

4.2.3.4 Power Transmission via Worm Gears

Advantages

- High Torque Transmission: Worm gear systems can transmit high torque at low speeds, making them ideal for the controlled movement of hip and knee joints, which must support a significant portion of the patient's body weight.
- Self-Locking Feature: In many worm gear designs, it is physically difficult for the load to drive the motor (back-driving). This prevents the system from slipping or collapsing under weight if power is lost, providing a critical safety advantage for the patient.
- Quiet and Vibration-Free Operation: Due to the sliding contact of the gear teeth rather than a rolling impact, these systems provide the smooth and comfortable motion required for sensitive rehabilitation therapy.

Disadvantages

- Low Mechanical Efficiency: Due to high internal friction between the screw and the wheel, energy losses are increased. This may cause the motor to consume more power compared to planetary or spur gear systems.
- Risk of Overheating and Wear: During long therapy sessions, the friction generates heat, which can lead to a rise in temperature and surface wear

on the gear teeth. This necessitates the use of specific materials (like bronze wheels) to mitigate damage.

- Precision Alignment Requirement: For the worm gear mechanism to operate smoothly and avoid jamming, the mounting and alignment tolerances must be strictly maintained during the assembly process.
- gerekir.

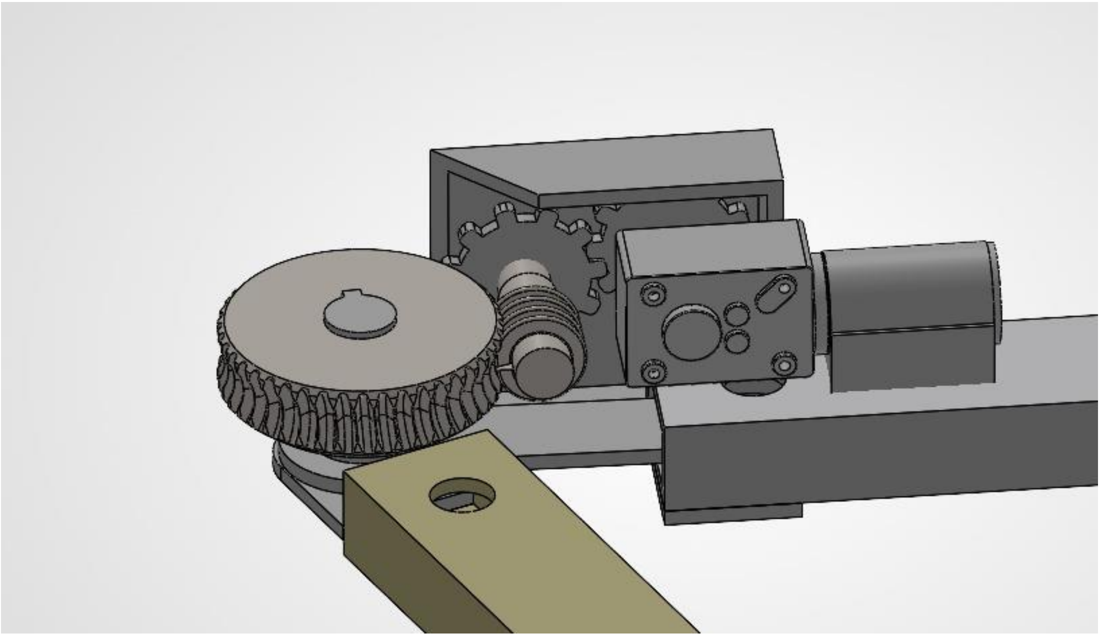


Figure 14: Power Transmission via Worm Gears

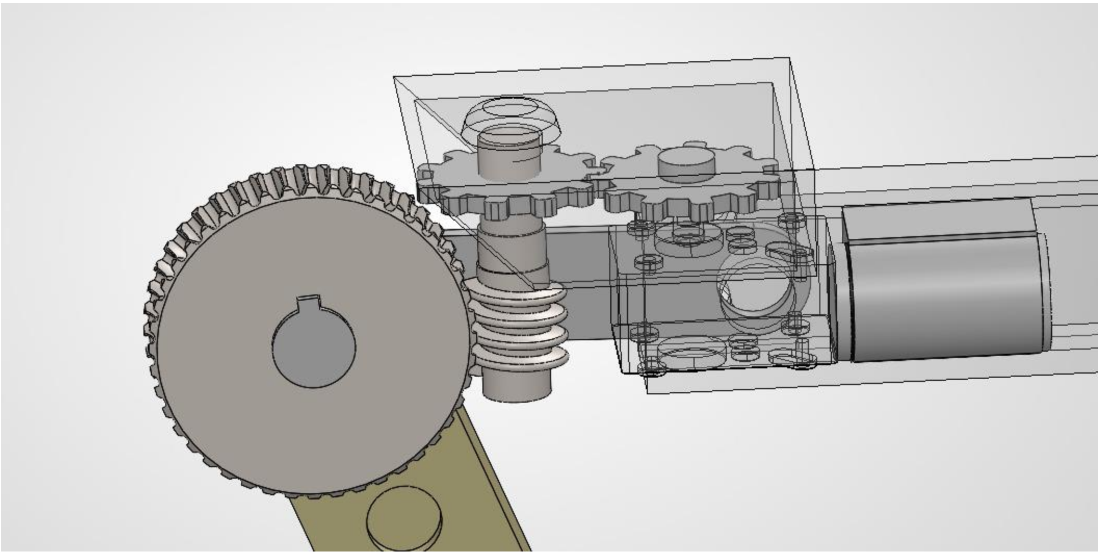


Figure 15: Worm Gear Assembly

4.2.4. Leg Attachment Function

This function ensures that the patient's leg remains stable on the device during movement. Secure attachment prevents unwanted rotations and slippage in the muscles, thereby enhancing the accuracy of the treatment.

4.2.4.1 Buckle Belt Mechanism

Strong belts wrapped around the circumference of the leg are locked with a buckle.

Advantages

- Provides high security: The mechanical locking structure of the buckle withstands high forces.
- Fits all body types: Its adjustable structure allows it to be used by different individuals.
- Durable: It is long-lasting against wear and tear.
- Maintains stability: It prevents the leg from slipping during movement.

Disadvantages

- Time-consuming to apply: Belt tensioning must be adjusted individually for each patient.
- May cause discomfort in some patients: Its rigid structure can create pressure points on the skin.
- Bulky: It occupies a significant amount of space around the leg.

Figure 16: Buckle Belt Mechanism

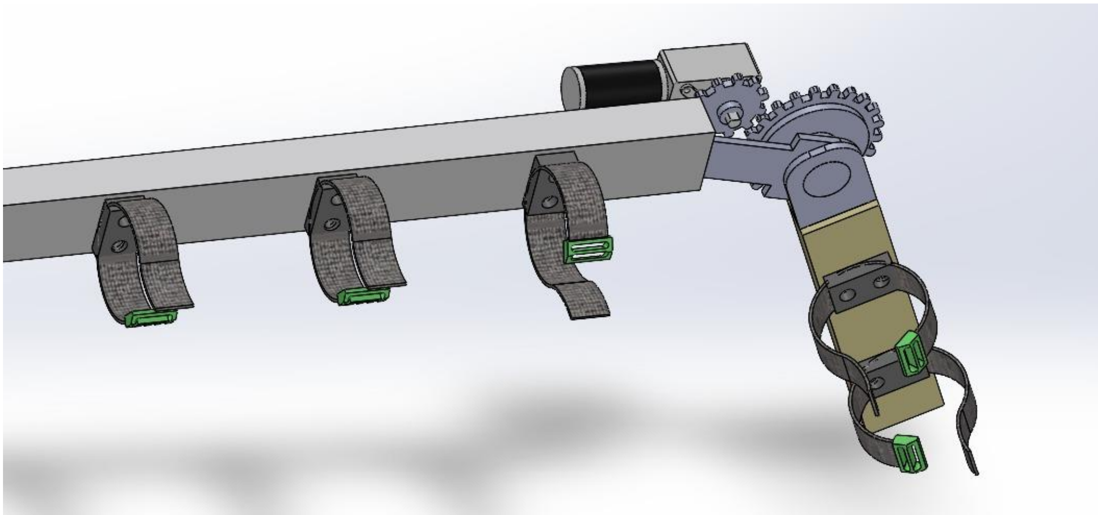


Figure 17: Buckle Belt Mechanism Assembly

4.2.4.2 Velcro (Hook and Loop) Fastening

Soft Velcro surfaces are wrapped around the leg for fastening.

Advantages

- Extremely fast to apply and remove: Practical for intensive clinical use.
- Comfortable: Its soft structure ensures even pressure distribution.
- Economical: Production costs are low and it is easily available.
- Lightweight: It does not cause discomfort to the leg.

Disadvantages

- Adhesion strength decreases over time: Dust and perspiration fill the Velcro surface, reducing its performance.
- Risk of opening under high force: In powerful systems such as hydraulic drives, it may present a security issue.
- Requires frequent cleaning: The surface must be washed often to maintain hygiene.

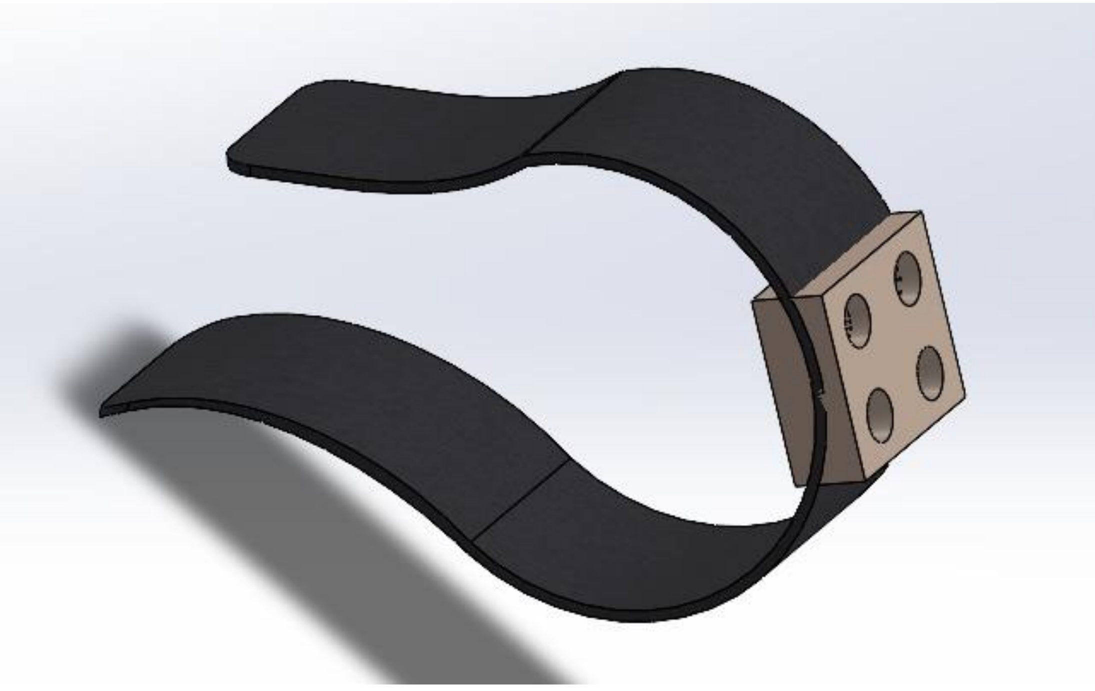


Figure 18: Velcro (Hook and Loop) Fastening

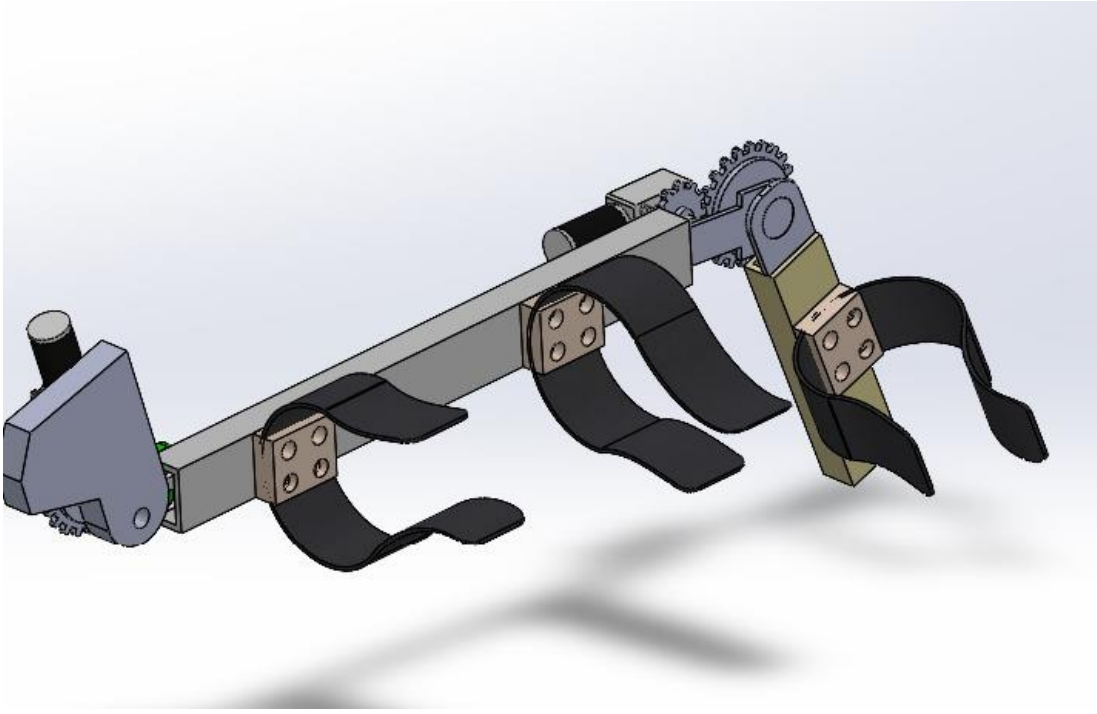


Figure 19: Velcro (Hook and Loop) Fastening Assembly

4.2.5. Stop (Safe Stop) Function

This function ensures the immediate cessation of system movement in the event of a hazardous situation. It is a mandatory safety layer for both user security and the protection of the device.

4.2.5.1 Safety Latch

A manual stopping system that physically disconnects the drive system.

Advantages

- Reacts quickly: Power transmission is interrupted the moment the latch is pulled.
- Independent of electricity: The system can be stopped even if power is cut.
- Provides mechanical security: Provides physical locking in case of excessive strain or force.

Disadvantages

- Requires user intervention: A risk may arise if the patient or therapist does not act quickly.
- Risk of accidental activation: Therapy is interrupted if the latch is pulled by mistake.
- Requires periodic inspection: Regular maintenance checks are necessary to ensure the mechanism functions correctly.

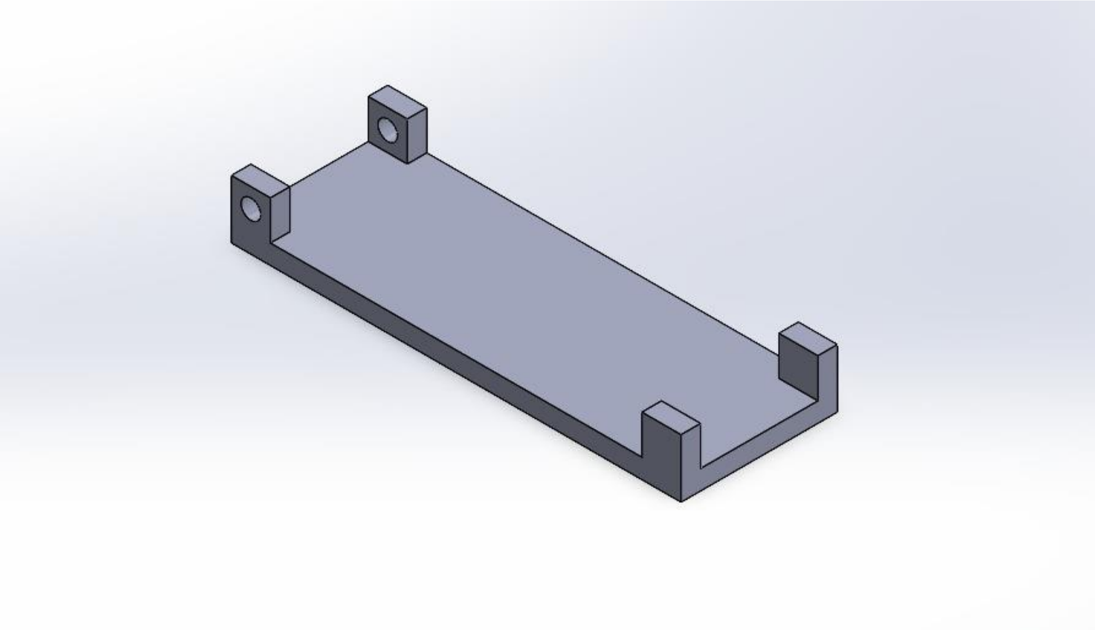


Figure 20: Safety Latch

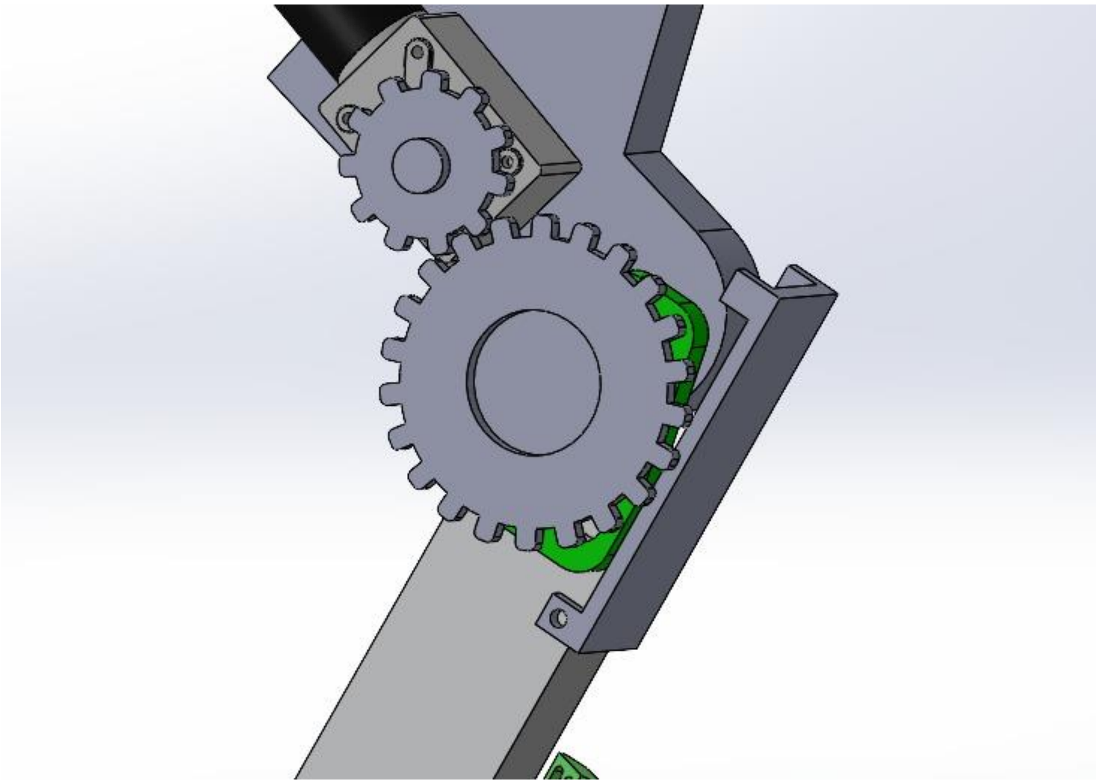


Figure 21: Safety Latch Assembly

4.2.5.2 Electronic Emergency Stop Button

Advantages

- Rapid, Centralized Shutdown: All motor drives can be isolated with a single button; a secure shutdown is performed via the system's control layer. This is the industry standard for rapid intervention in emergencies.
- User-friendly and Visible: E-Stop buttons are designed to be red and easily accessible, allowing for use by both the therapist and the patient.
- Integrated Safety Monitoring: When integrated with the software, the E-Stop socket triggers other safety layers (sensor checks, error logging) simultaneously.

Disadvantages

- Electrical dependency: The fail-safe state of the system depends on the topology of the electronic controllers; the button may become ineffective in the event of a power outage or controller failure.
- Accidental triggering: Inadvertent activation of the E-Stop can lead to interrupted therapy sessions and data loss; therefore, ergonomic and protective design is critical.

- Requirement for redundancy: In electronic safety applications, mechanical backups are generally recommended; system design should incorporate both electronic and mechanical stops.

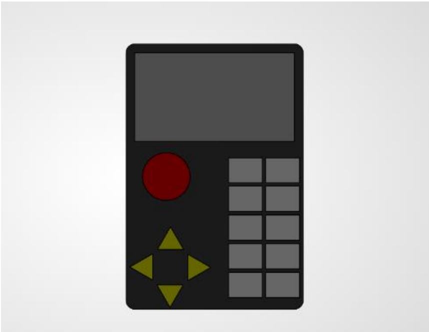


Figure 22: Controller and Electronic Emergency Stop Button

4.2.6. Power Supply Function

The purpose of the power supply function is to provide the necessary electrical energy for the motors and control systems in the rehabilitation robot safely and continuously. It is essential that the power supply has the capacity to meet system requirements and operates stably during sudden load changes. Furthermore, for patient safety, it must be equipped with overcurrent and short-circuit protection.

4.2.6.1 Lithium Battery

It is an independent energy source that powers all electronic and mechanical systems of the robot through high-energy-density rechargeable batteries integrated within the device.

Advantages

- High Portability: It allows the device to be moved freely within a hospital or home environment without being tethered to any cables.
- Uninterrupted Therapy: Even in the event of a power outage, the battery takes over, preventing the sudden interruption of the rehabilitation process and the risk of the patient losing their positioning.

- Electrical Safety: Since it is isolated from the main grid, it minimizes risks arising from leakage currents or high-voltage fluctuations.

Disadvantages

- Limited Operating Time: Depending on the battery capacity, it must be recharged after a certain period; this can disrupt the workflow in busy clinics.
- Cost and Lifespan: High-quality battery packs increase production costs and, over time, lose their charge retention capacity, requiring replacement.
- Weight: The mass of the batteries can increase the total weight of the device, especially in wearable (exoskeleton) designs, affecting user comfort.

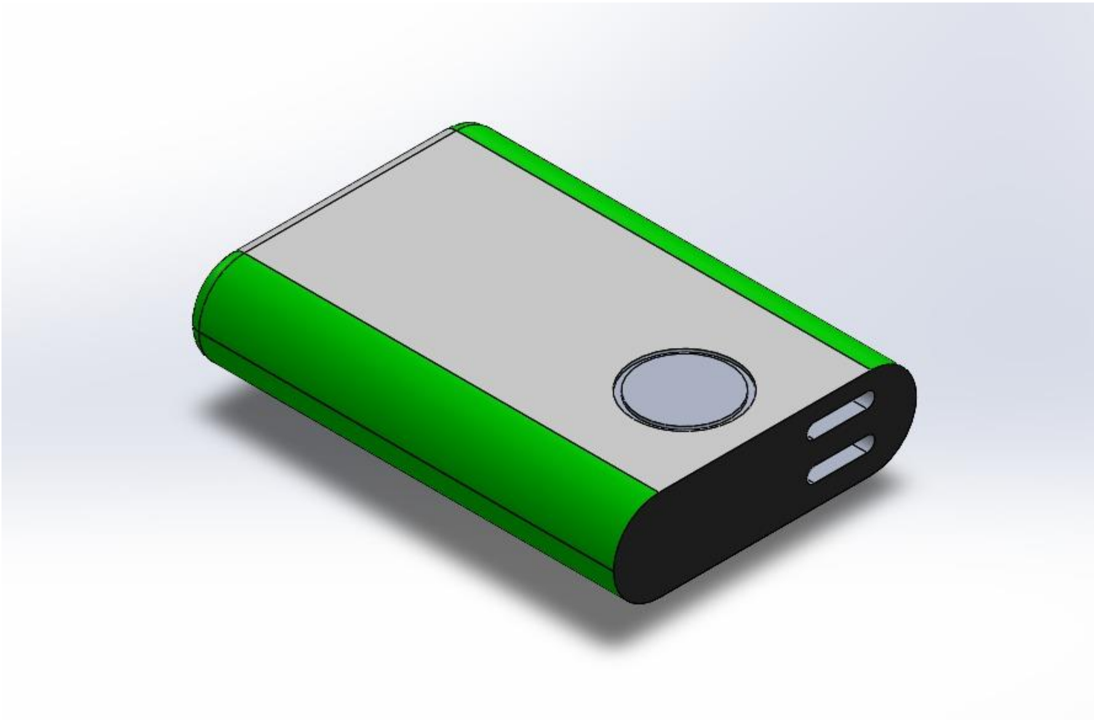


Figure 23: Lithium Battery

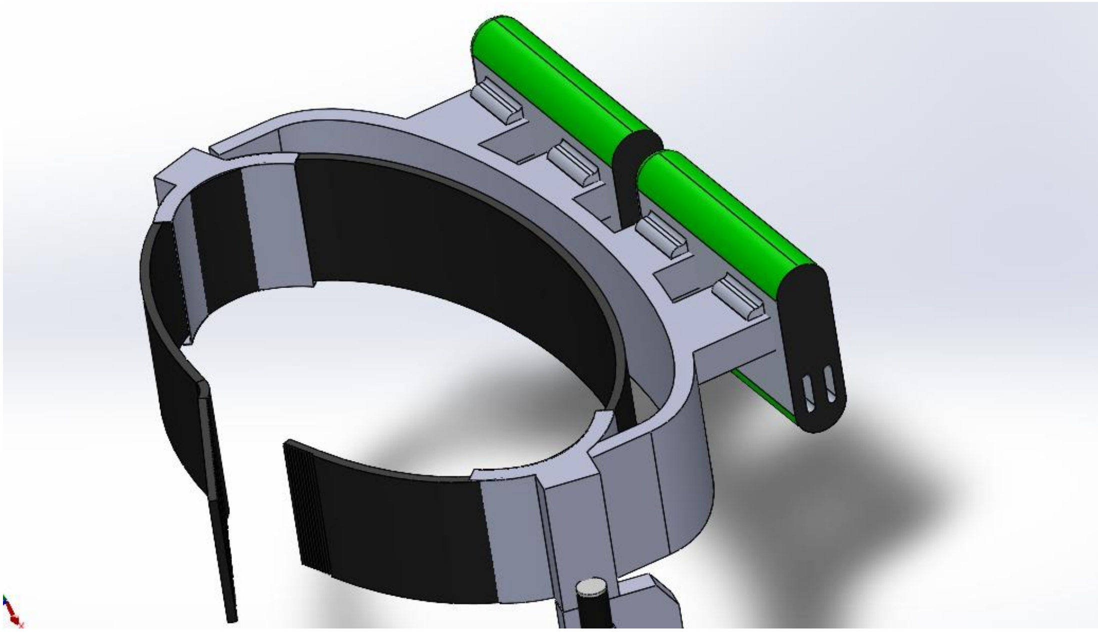


Figure 24: Lithium Battery Assembly

4.2.6.2. Grid-Powered (Mains Supply)

This is the method that provides uninterrupted power by feeding the device directly from the building's electrical line via a power cable and an AC/DC adapter.

Advantages

- Unlimited Operating Time: It allows the device to operate continuously throughout the day without charging concerns, making it ideal for rehabilitation centers with high patient traffic.
- Lighter Design: Since there is no need for heavy battery packs on the device, the total weight of the robot is reduced.
- Low Cost: Because complex battery management systems and expensive lithium cells are not used, the initial investment cost is lower.

Disadvantages

- Limited Mobility: The device must always be near an outlet, and the cables on the floor can pose a tripping or falling risk for both the patient and medical staff.
- Risk of Power Outage: In the event of a sudden power failure, the robot stops; if there is no mechanical locking system, the leg may be left uncontrolled, which jeopardizes patient safety.
- Requirement for Electrical Isolation: Since the device is directly connected to the grid, protection circuits and leakage current measures at medical standards (high-level isolation) are mandatory.

4.2.7 Hip Size Adjustment Function

The hip size adjustment function is designed to ensure the device achieves an ergonomic fit with users of various hip widths. Through this function, the user is correctly aligned within the device, the contact between the leg and the mechanism is optimized, and both comfort and treatment accuracy are enhanced. The adjustment system offers a flexible fit via a spring mechanism and secure stabilization through a belt-based tightening system.

4.2.7.1 Velcro (Cırt Cırtlı) Hip Fastening System

The velcro hip fastening system is preferred in the rehabilitation robot to ensure the user's hip area is secured to the device in a **fast, safe, and comfortable** manner. Thanks to its soft, textile-based structure, it adapts to the user's body and minimizes discomfort that may occur during exercise. Its adjustable nature provides ease of use for patients with different body measurements and saves time in a clinical environment.

Advantages

- Quick Attachment and Removal: Provides practicality in clinical use and shortens preparation time.
- Comfortable: Thanks to its soft structure, it distributes pressure evenly across the hip area, enhancing patient comfort.
- Lightweight and Economical: It does not increase the total weight of the system and is low-cost.

Disadvatages

- Adhesion strength may decrease over time: Dust, sweat, and frequent use can degrade the performance of the velcro.
- Risk of opening under high forces: In applications requiring very high torque, additional safety measures (such as secondary buckles or locking straps) may be required.
- Need for regular cleaning: To maintain hygiene and grip performance, the straps must be cleaned according to clinical protocols.

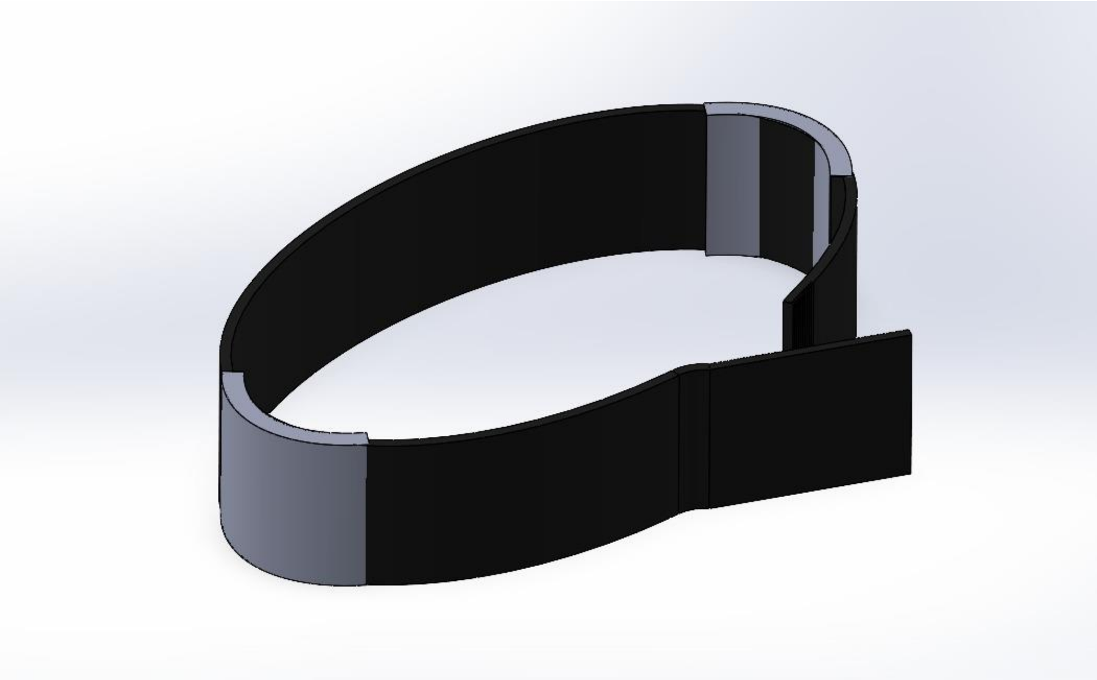


Figure 25: Velcro (Cırt Cırtlı) Hip Fastening System

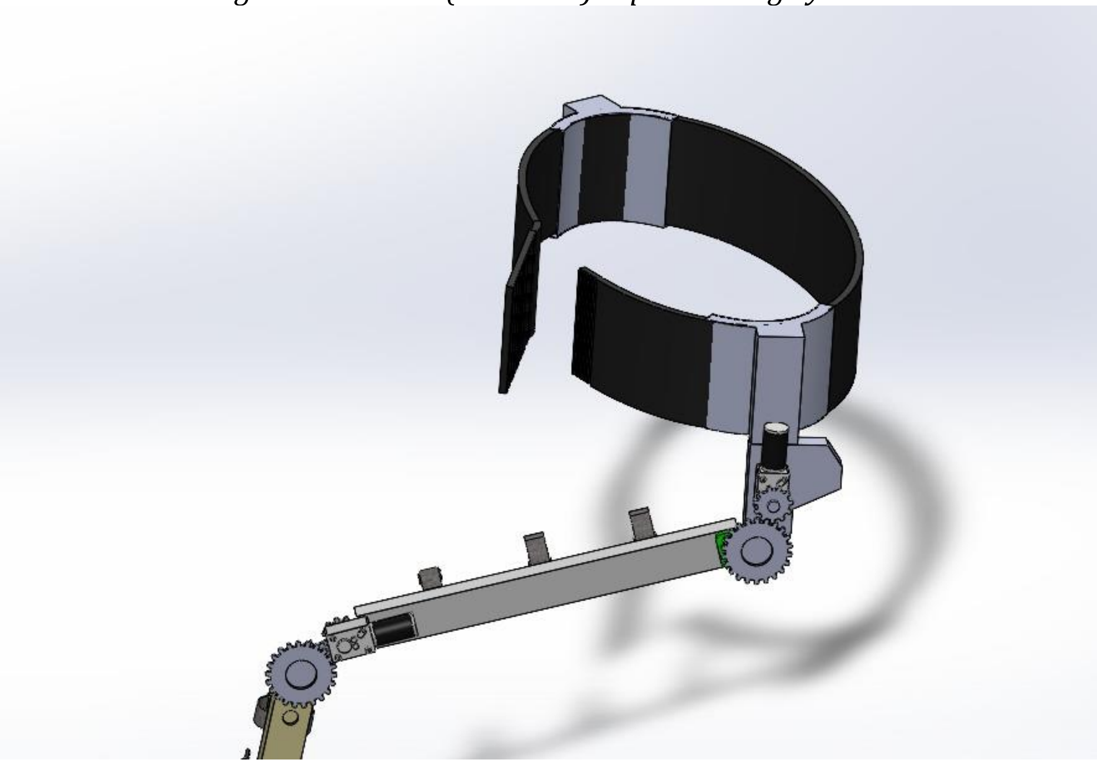


Figure 26: Velcro (Cırt Cırtlı) Hip Fastening System Assembly

4.2.7.2 Belt-Adjustable System

Adjustable belts ensure that the device is tightened specifically for the individual by securely wrapping around the hip area. This system is utilized in rehabilitation applications where stabilization is critical and for patients requiring high levels of security.

Advantages

- Customizable Tightness Adjustment: Allows for personalized compression settings tailored to the individual user's needs.
- Provides High Stabilization: Ensures maximum stability, which is vital during intensive rehabilitation movements.
- Lightweight, Low-Cost, and Replaceable: Does not add significant mass to the system and can be easily replaced if the material wears out.

Disadvantages

- The belt may loosen over time.
- User comfort decreases if overtightened.
- The fabric and buckles are prone to wear and tear.

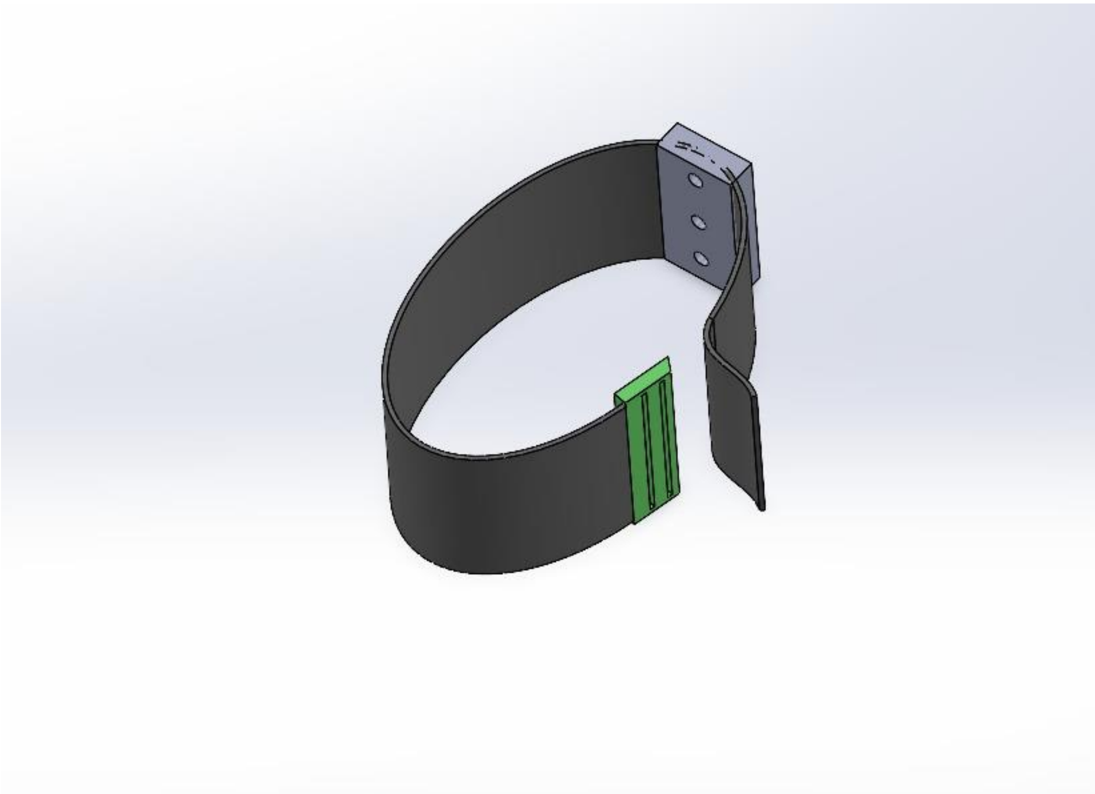


Figure 27: Belt-Adjustable System

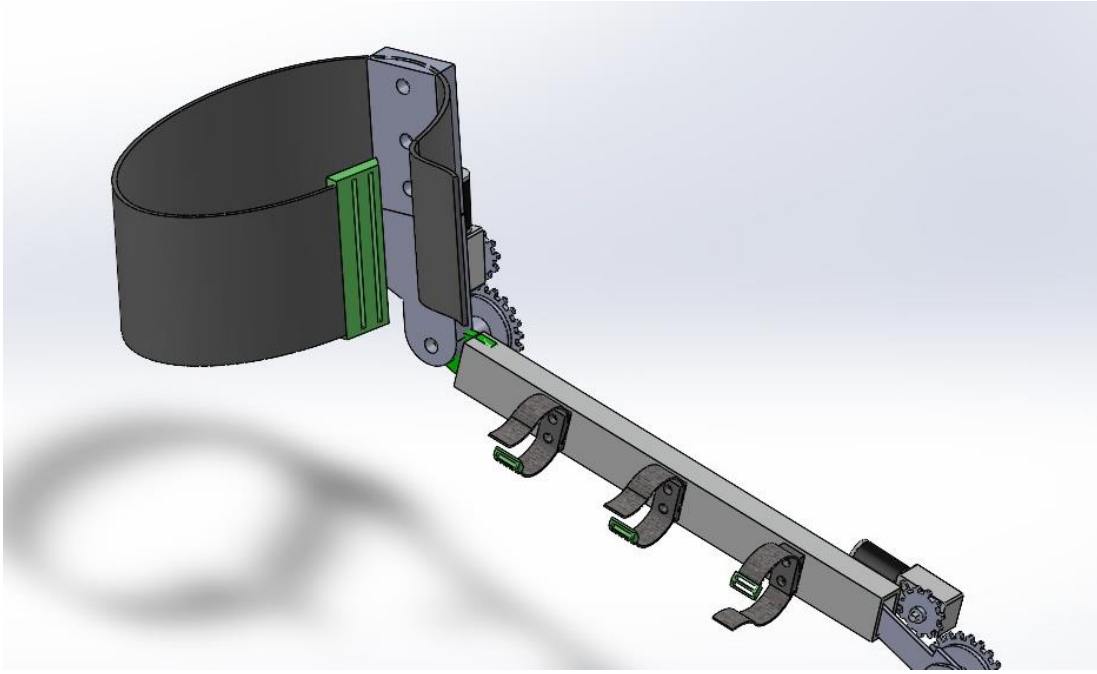


Figure 28: Belt-Adjustable System Assembly

4.3 Morphological Table

4.3.1. Function Names and Order

- **Drive Mechanism Function:**

Brushed DC Motor (S_{11}), rushless DC Motor (S_{12}), Pneumatic Drive (S_{13}).

- **Longitudinal Length Adjustment Function:**

Spring-Loaded Pin Mechanism (S_{21}), Pin-Hole Fixing (S_{22}).

- **Motion Transmission Function:**

Power Transmission with Gears (S_{31}), Power Transmission with Lead Screw (S_{32}).

- **Leg Fastening Function:**

Buckle Belt Mechanism (S_{41}), Velcro (Hook-and-Loop) Fastening (S_{42}),

- **Stopping (Safety Stop) Function:**

Safety Latch (S_{51}), Electronic Emergency Stop Button (S_{52}).

- **Power Source Function:**

Lithium Battery (S_{61}), Grid-Powered (Mains Supply) (S_{62}),

- **Hip Size Adjustment Function**

Velcro Hip Fastening System (S_{71}), Belt-Adjustable System (S_{72}),

Table 6: Morfolojik Table

Solutions / Functions	1	2	3
F1	S_{11}	S_{12}	S_{13}
F2	S_{21}	S_{22}	
F3	S_{31}	S_{32}	
F4	S_{41}	S_{42}	
F5	S_{51}	S_{52}	
F6	S_{61}	S_{62}	
F7	S_{71}	S_{72}	

4.3.2. Concepts

Table 7: *Morphological Table: Selection of Concepts*

Çözümler / Konseptler	1	2	3
F1	S_{11}	S_{12}	S_{13}
F2	S_{21}	S_{22}	
F3	S_{31}	S_{32}	
F4	S_{41}	S_{42}	
F5	S_{51}	S_{52}	
F6	S_{61}	S_{62}	
F7	S_{71}	S_{72}	

Table 8: Selected Concepts Table

Concepts	Selected Concepts
K1	S_{11},S_{21},S_{32},S_{41},S_{51}, S_{61},S_{71}
K2	S_{11},S_{22},S_{31},S_{41},S_{52}, S_{62},S_{71}
K3	S_{12},S_{22},S_{31},S_{42},S_{52}, S_{61},S_{72}
K4	S_{13},S_{21}, S_{42} ,S_{52}, S_{62},S_{72}
K5	S_{12},S_{22},S_{32},S_{42},S_{51}, S_{61},S_{71}

By combining the functions we identified in a logical manner suitable for the system's operation, we have determined 5 concepts. The best concept will be selected among these by considering specific criteria.

4.4. Determination of Evaluation Criteria

4.4.1. Security (Safety Performance)

Safety is the most critical criterion in a rehabilitation robot. Since the patient's leg is physically connected to the device, any excessive force, incorrect angle, rapid movement, or system failure that may occur can directly lead to injury. For this reason, the selected mechanism must:

- Be able to lock itself against excessive load,
- Provide an emergency stop possibility when necessary,
- Not pose a risk of impact or pinching,
- Comply with design principles capable of providing dual-layer security.
- Bu kriter hem tahrik, hem bağlama hem de durdurma fonksiyonları için ağırlığı yüksek belirleyici bir etkendir.

4.4.2 Precision and Repeatability

In rehabilitation processes, it is mandatory for the given angle, speed, and force values to be repeatable for the consistency of the treatment. For this reason, a solution is expected to:

- Be able to provide a specific angle with the same accuracy every time,
- Transmit motion smoothly and without vibration,
- Provide precise control through feedback sensors or mechanical advantages.

4.4.3 Durability and Structural Integrity

The device will operate under load during long-term use. In a rehabilitation robot ;

- Metal fatigue.
- Gear wear.
- Loosening of fastening mechanisms.
- Deformation of latch and lock systems.

Such problems can pose serious safety risks in the long term. Therefore, the selected solution is expected to demonstrate high durability and be capable of being used for years.

4.4.4. Ergonomics and Comfort

The device will be used for long periods by both the patient and the therapist. For this reason:

- Fastening points must not apply excessive pressure to the patient's leg,
- Adjustment mechanisms must be easily accessible,
- Sudden jerks or uncomfortable forces must not occur in the leg during drive operation,
- Adjustment processes must require minimum physical effort for the therapist.

Ergonomics is the decisive criterion for the leg fastening and length adjustment functions.

4.4.5. Manufacturing and Maintenance Cost

In engineering design, cost is always a critical evaluation criterion. However, in medical devices that require high safety, such as rehabilitation robots, cost should be evaluated after the criteria of safety and performance. In the analysis:

- The complexity of the manufacturing process,
- Whether it requires expensive actuators, sensors, or mechanical parts,
- Availability of spare parts,
- Factors such as the necessity for regular maintenance are taken into account.

4.4.6 Adjustability and Adaptability (Adjustability & Adaptability)

The robot will serve patients of different heights, weights, and anatomical structures. Therefore, the selected solutions are expected to:

- Be able to easily adjust the longitudinal length,
- Be able to adapt to different leg shapes,
- Have a wide adjustment range,
- Be capable of rapid modification of length, angle, and connection points.

This criterion is particularly decisive for the length adjustment and fastening functions.

4.4.7. Motion Fluidity and Patient Comfort (Motion Smoothness)

Rehabilitation movements must be vibration-free and smooth. For this reason, it is important that:

- The drive system does not produce sudden accelerations,
- The motion transmission system operates without backlash,
- The crank, belt, or gear systems do not generate vibrations,
- It can mimic natural walking movement on the leg.

This criterion is critically important for the patient's acceptance of the treatment and for the device to be clinically preferred.

4.5 Determination of Weighting Factors Using a Pugh Diagram

Below, the weighting factors for the concepts created for weight factor determination will be identified based on the established evaluation criteria. The calculation of the weighting factors for the selected evaluation criteria has been performed as shown in Table 14.

Table 9: *Comparison of Criteria and Weighting Factors*

Criteria / Reference Criteria	Safety	Control Precision and Repeatability	Durability and Structural Integrity	Ergonomics and User Comfort	Manufacturing and Maintenance Cost	Adjustability and Adaptability	Motion Fluidity and Patient Comfort
Safety	-	0	1	0	0	0	0
Control Precision and Repeatability	1	-	1	1	0	1	1
Durability and Structural Integrity	0	0	-	0	0	0	0
Ergonomics and User Comfort	1	0	1	-	1	1	1
Manufacturing and Maintenance Cost	1	1	1	0	-	1	1
Adjustability and Adaptability	1	0	1	0	0	-	0
Motion Fluidity and Patient Comfort	1	0	1	0	0	1	-
Total	5	1	6	1	1	4	3
Weighting Factor	5/21	1/21	6/21	1/21	1/21	4/21	3/21
Results	0.238	0.048	0.286	0.048	0.048	0.190	0.143

4.6 Selection of the Best Concept

Table 10: Selection of the Best Concept

Criteria	Weighting Factor	K1	K2	K3	K4	K5
Safety	0.238	2	3	5	4	5
Control Precision and Repeatability	0.048	2	4	4	3	3
Durability and Structural Integrity	0.286	2	2	4	3	4
Ergonomics and User Comfort	0.048	5	2	2	4	3
Manufacturing and Maintenance Cost	0.048	3	4	3	4	3
Adjustability and Adaptability	0.190	3	2	4	3	2
Motion Fluidity and Patient Comfort	0.143	4	5	4	3	2
Total	1	**Concepts**				
		0.476 0.096 0.572 0.24 0.144 0.57 0.572	0.714 0.192 0.572 0.096 0.192 0.380 0.715	1.19 0.192 1.142 0.096 0,144 0.760 0.572	0.952 0.144 0.858 0,192 0,192 0.57 0.429	1.19 0.144 1.144 0.144 0.144 0.380 0.286
Total		2.67	2.861	4.096	3.337	3.432

ach selected concept was scored according to the selected criteria. The scores given for each criterion were multiplied by the weighting factor of that criterion. The resulting scores for each criterion were summed to obtain the total score for each concept. The Pugh (selection) diagram is shown in the Table. As a result of the scoring, CONCEPT 3 was selected as the best concept.

5. SUSTAINABLE DEVELOPMENT

5.1 Energy Efficiency Improvement

A BLDC motor is used in the designed system. To further reduce energy consumption, sensors and control boards with low energy consumption can be preferred. Additionally, by using a long-life battery, both energy efficiency can be increased and the device can be ensured to operate uninterrupted for a longer period.

5.2 Manufacturing Method with Minimum Environmental Impact

In the case of using the additive manufacturing method, the damage caused to the environment is less compared to other production methods. Since only the necessary material is used in this method, the amount of waste is reduced. Thus, both material waste is prevented and negative impacts on the environment are reduced.

5.3 User Information for Responsible Consumption

Videos or animations regarding usage can be created so that the product can be used correctly and consciously. These videos will be beneficial both for informing the user and in terms of application. In addition to these, brochures and catalogs can be prepared to convey information on the correct usage and maintenance of the device to the user.

5.4 Recycling of Materials Used

The BLDC motors used in the device can be disassembled and reused. While metal parts can be sent for recycling, plastic parts can likewise be included in the recycling process. Additionally, the belts and hook-and-loop (velcro) parts are structured to be reusable in other products. In this way, the amount of waste is reduced.

5.5 Reduction of Carbon Footprint

Recyclable materials, durable components, and renewable energy usage minimize waste and lower the carbon footprint.

6. SOLIDWORKS Drawings

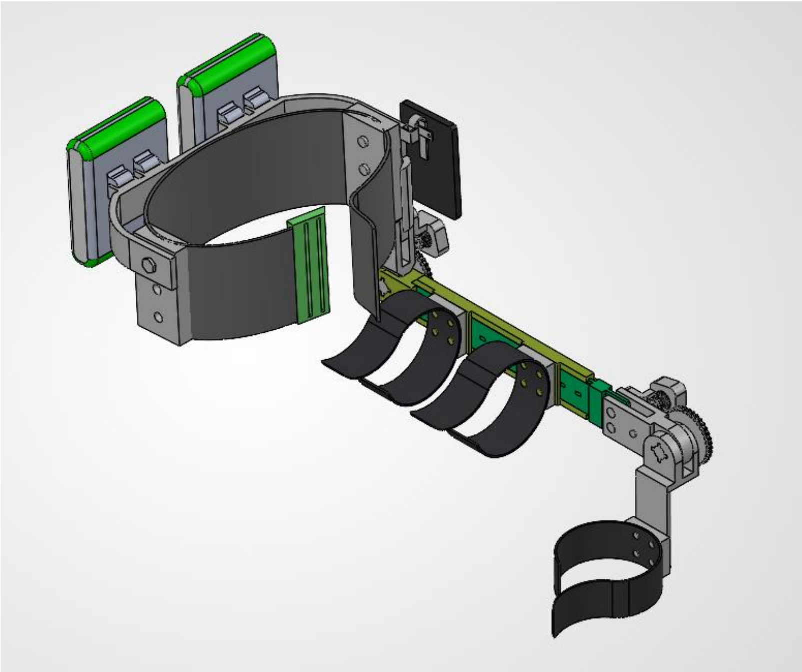


Figure 29: Isometric 1

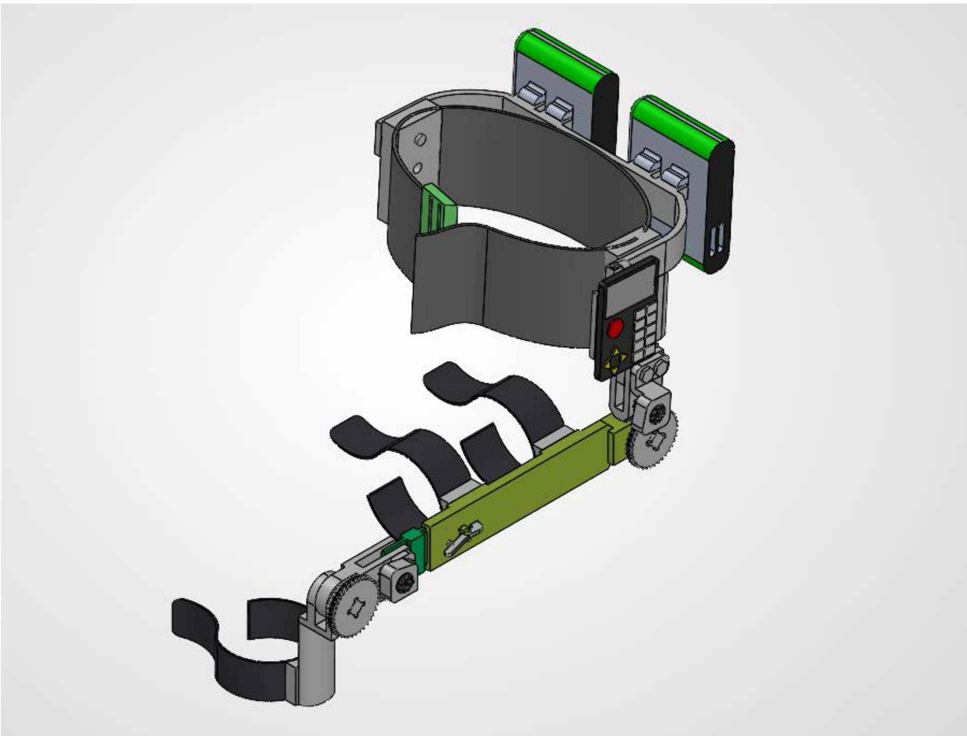


Figure 30: Isometric 2

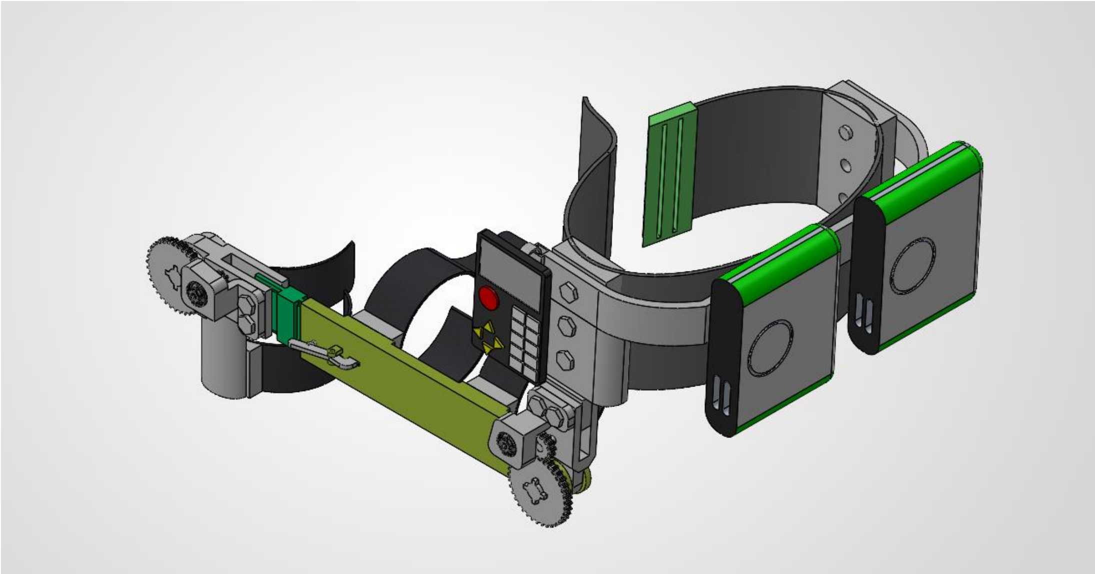


Figure 31: Isometric 3

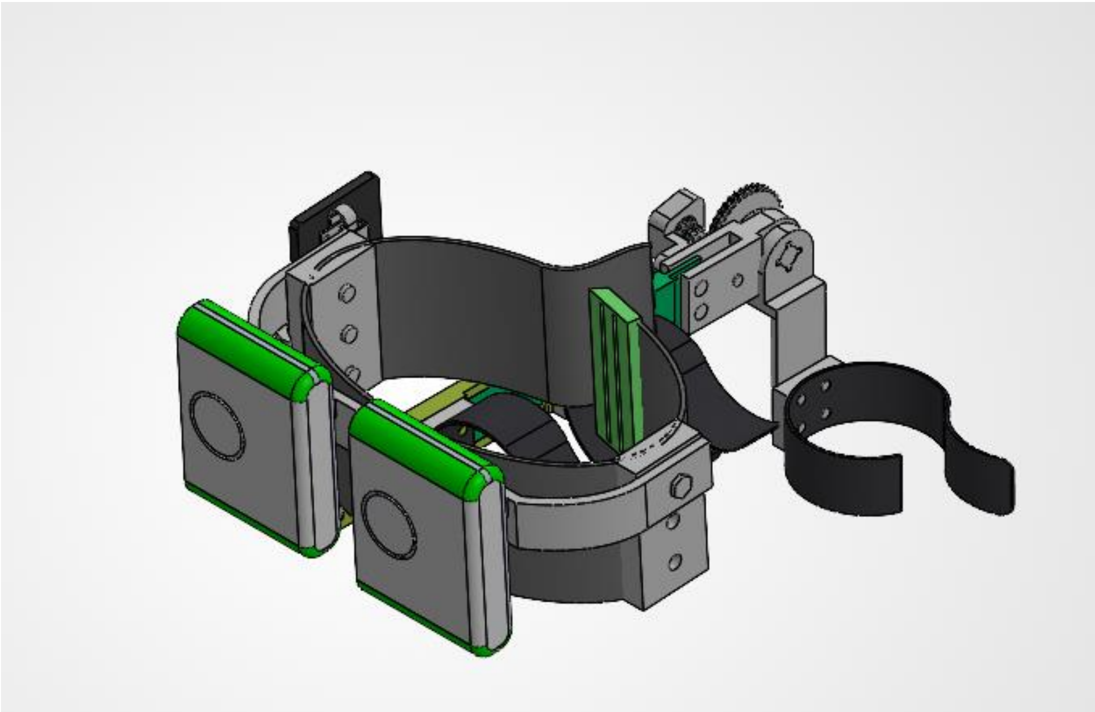


Figure 32: Isometric 4

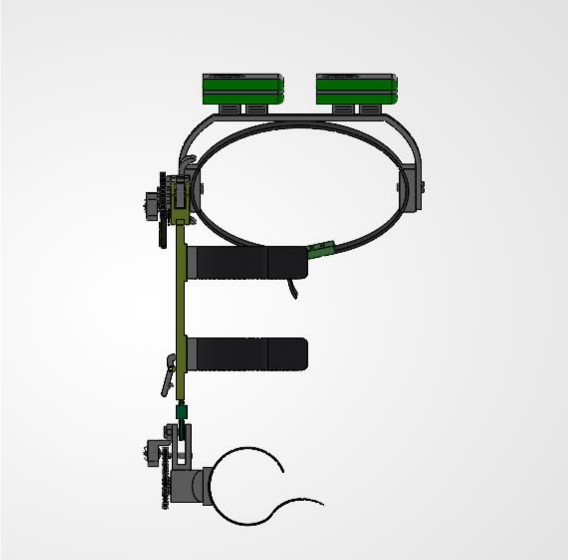


Figure 33: Top View

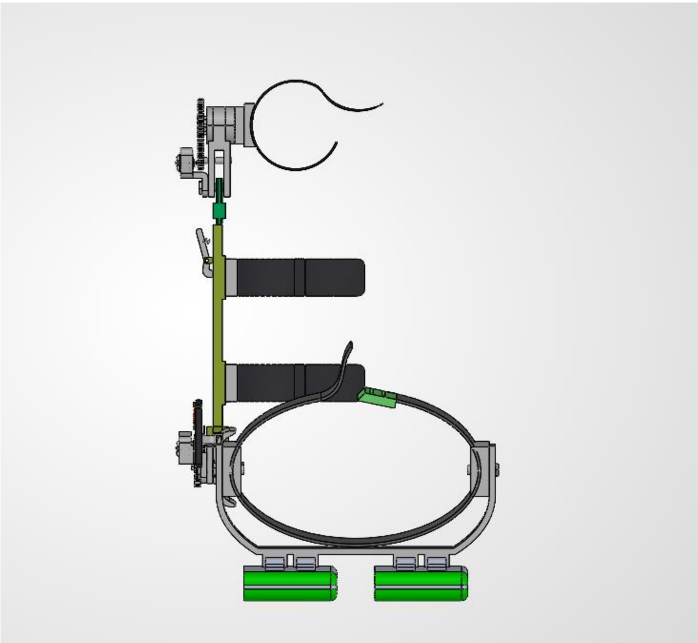


Figure 34: Bottom View

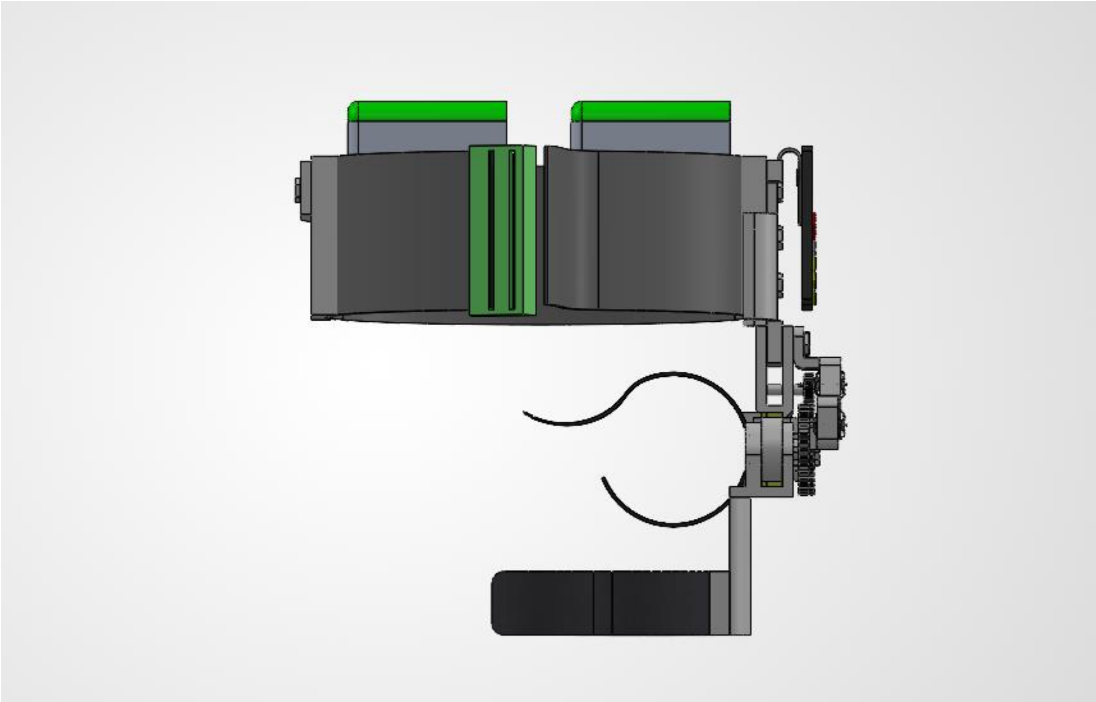


Figure 35: Front View

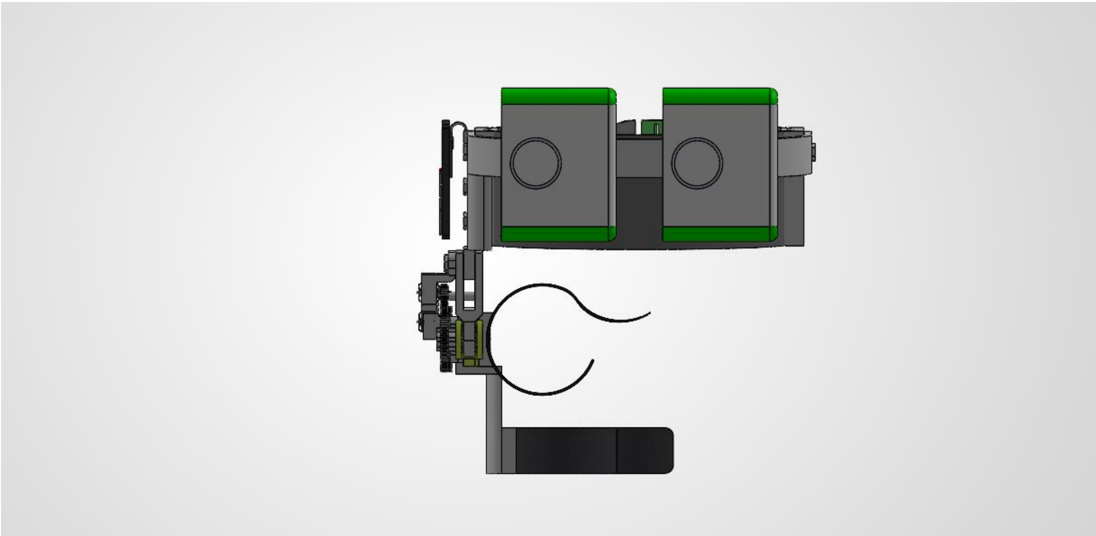


Figure 36: Rear View

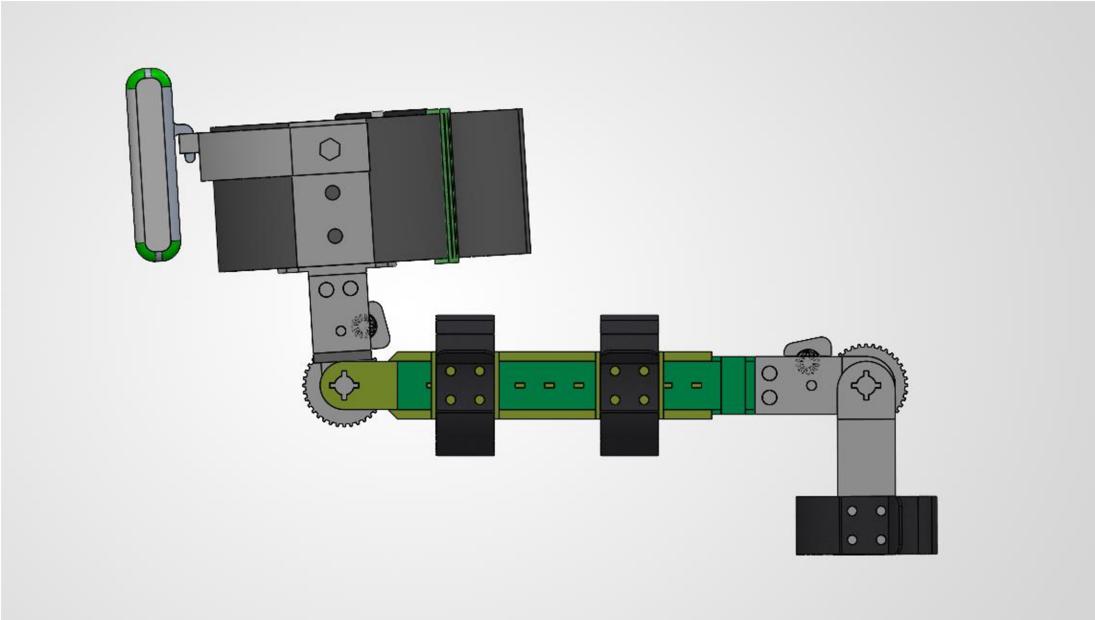


Figure 37: Right Side View

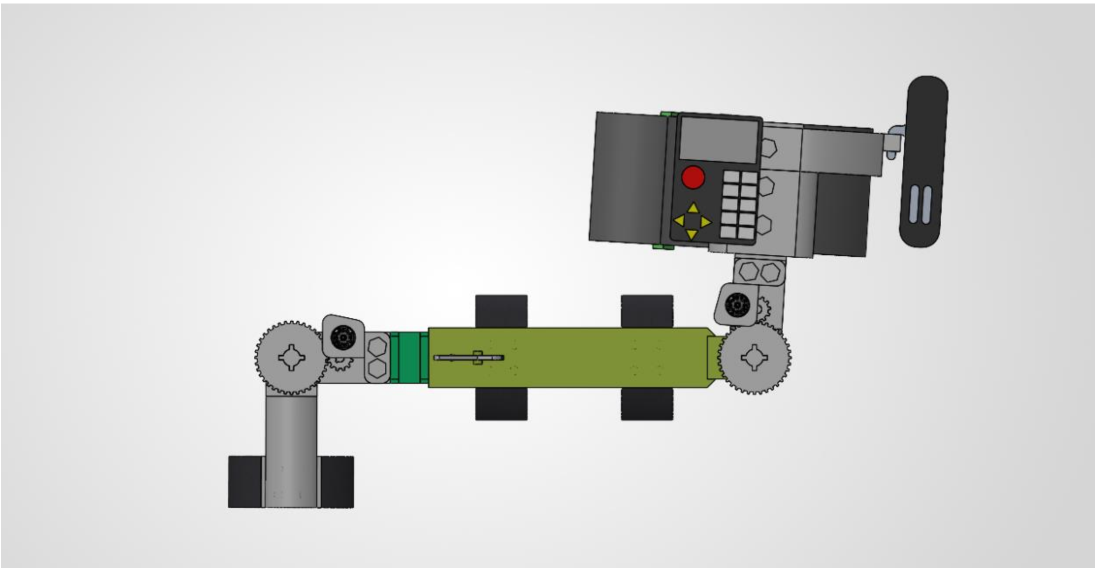
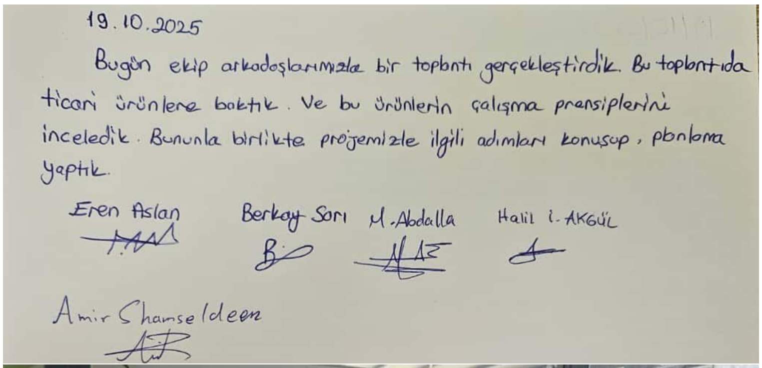


Figure 38: Left Side View

7. Group Meetings

7.1 Meeting-1


19.10.2025

Bugün ekip arkadaşlarımızla bir toplantı gerçekleştirdik. Bu toplantıda ticari ürünlere baktık. Ve bu ürünlerin çalışma prensiplerini inceledik. Bununla birlikte projemizle ilgili adımları konuşup, planlama yaptık.

Eren Aslan

Berkay Sarı

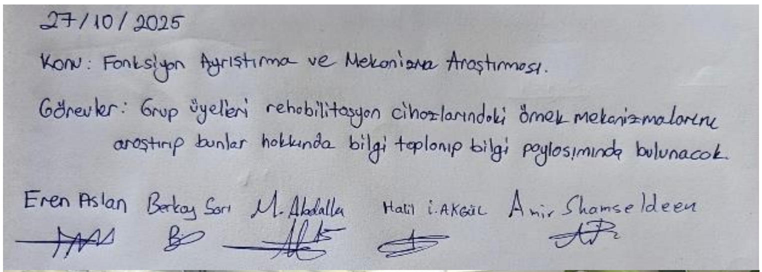
M.Abdalla

Halil İ. AKGÜL

Amir Shamseldeen

Meeting -1

7.2 Meeting -2


27/10/2025

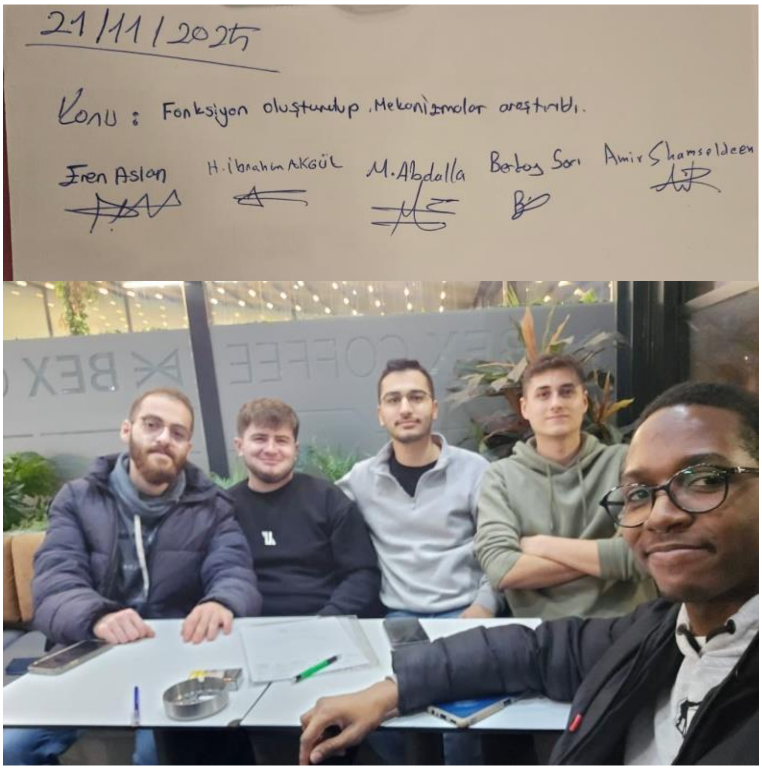
Konu: Fonksiyon Ayrıştırma ve Mekanizma Araştırması.

Görevler: Grup üyeleri rehabilitasyon cihazlarındaki örnek mekanizmalarını araştırıp bunlar hakkında bilgi toplayıp bilgi paylaşımında bulunacak.

Eren Aslan Berkay Sarı M.Abdalla Halil İ.AKGÜL Amir Shamseldeen

Meeting -2

7.3 Meeting -3



Meeting -3

7.4 Meeting -4

Meeting -4

7.5 Meeting -5

Meeting -5

7.6 Meeting -6

Meeting -6

REFERANCES

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- https://www.cyberdyne.eu/en/products/medical-device/hal-limb/
- https://www.hocoma.com/us/solutions/erigo-2/technical-data-sheet/
- https://www.hocoma.com/solutions/erigo/
- https://worldwide.espacenet.com/patent/search?q=pn%3DUS2024082097A1
- https://worldwide.espacenet.com/patent/search?q=pn%3DWO2021238501A1
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