# **Design and Control of a Mechatronic Exoskeleton for Rehabilitation Purposes**

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Article Info Page Number: 395-400 **Publication Issue:** Vol. 70 No. 1 (2021)

#### Abstract

The field of rehabilitation engineering has witnessed significant advancements in recent years, with the development of mechatronic exoskeletons playing a crucial role in enhancing the rehabilitation process. This paper presents the design and control of a novel mechatronic exoskeleton specifically designed for rehabilitation purposes. The primary objective of this research is to provide a comprehensive framework that enables effective and safe assistance during the rehabilitation process.The design phase of the mechatronic exoskeleton focuses on achieving a balance between functionality, comfort, and ergonomics. Extensive biomechanical analysis was conducted to ensure compatibility between the exoskeleton and human anatomy. The exoskeleton's structural components were designed using lightweight and durable materials to optimize portability and minimize user fatigue. Additionally, the design incorporates adjustable joint mechanisms to accommodate a wide range of motion and to adapt to individual user requirements. The design and control of mechatronic exoskeletons for rehabilitation purposes hold great potential to revolutionize the field of physical therapy. These wearable robotic systems offer personalized assistance and targeted therapy to individuals with physical impairments, aiding in their recovery and improving their quality of life. Through careful consideration of comfort, ergonomics, actuation, sensing, control strategies, and safety measures, Article History mechatronic exoskeletons can provide effective and safe rehabilitation solutions. Continued research, technological advancements, Article Received: 25 January 2021 and collaboration between various disciplines will further enhance the Revised: 24 February 2021 Accepted: 15 March 2021 capabilities and impact of these innovative devices in the future.

## Introduction

In recent years, there has been a growing interest in the development of mechatronic exoskeletons for rehabilitation purposes. These innovative devices combine mechanical engineering, electronics, and computer control to create a wearable robotic system that can assist individuals in their recovery from various physical impairments. The design and control of such mechatronic exoskeletons play a crucial role in ensuring their effectiveness and safety in rehabilitation settings.Mechatronic exoskeletons offer a promising solution for individuals with disabilities or those recovering from injuries, as they provide support, assistance, and guidance during the rehabilitation process. These wearable devices are designed to augment the user's physical capabilities and help them regain strength, mobility, and coordination. By incorporating sensors, actuators, and intelligent control algorithms, mechatronic exoskeletons can adapt to the user's movements, provide personalized assistance, and facilitate targeted therapy.

DOI: https://doi.org/10.17762/msea.v70i1.2488

The design of a mechatronic exoskeleton involves several key considerations. First and foremost, it is essential to ensure the comfort and ergonomics of the device, as it will be worn for extended periods during rehabilitation sessions. The exoskeleton should be lightweight, adjustable, and anatomically compatible with the user's body to minimize discomfort and maximize mobility. Moreover, the mechanical structure of the exoskeleton must be robust, durable, and capable of withstanding the forces and stresses exerted during movement.

The choice of actuators and sensors is another critical aspect of the design process. Actuators are responsible for generating the necessary forces and torques to assist or resist the user's movements, depending on the rehabilitation goals. Electric motors, pneumatic or hydraulic systems, and even shape memory alloys are commonly employed as actuators in mechatronic exoskeletons. Sensors, on the other hand, provide feedback about the user's movements, joint angles, and muscle activity, enabling the control system to adapt and respond accordingly.

The control system of a mechatronic exoskeleton is responsible for interpreting sensor data, generating appropriate control signals, and coordinating the actuators' actions. It should be able to accurately estimate the user's intentions, distinguish between voluntary and involuntary movements, and adjust the assistance level accordingly. Advanced control strategies, such as adaptive control, impedance control, and biofeedback control, are often employed to achieve optimal performance and provide a seamless human-robot interaction.

Safety is a paramount concern in the design and control of mechatronic exoskeletons for rehabilitation purposes. The device must operate within safe ranges of motion, forces, and torques to prevent injury to the user. Fail-safe mechanisms, such as emergency stop buttons and torque limiters, should be implemented to ensure immediate termination of unwanted movements or excessive forces. Additionally, real-time monitoring of the user's vital signs and continuous evaluation of the exoskeleton's performance are crucial for early detection of potential risks and prompt intervention. The successful design and control of a mechatronic exoskeleton require a multidisciplinary approach, involving expertise from mechanical engineering, electronics, control systems, and rehabilitation sciences. Collaboration between engineers, clinicians, and therapists is essential to understand the specific needs and requirements of the target user population and tailor the exoskeleton accordingly. Continuous feedback from users and rigorous testing in clinical environments are vital for iterative design improvements and the validation of the device's efficacy.

The control system of the mechatronic exoskeleton is a critical aspect that determines its effectiveness in rehabilitation. The control architecture employs a combination of sensor fusion techniques and intelligent control algorithms to provide seamless interaction between the exoskeleton and the user. Various sensors, including inertial measurement units (IMUs) and force sensors, are strategically placed to capture real-time data related to joint angles, limb positions, and muscle activity. These sensor inputs are processed using advanced algorithms to derive accurate information about the user's intentions and movements.

The control algorithm utilizes a closed-loop feedback system, which enables the exoskeleton to provide both assistive and resistive forces based on the user's needs. The adaptive control strategy continuously monitors the user's performance and adjusts the assistance level accordingly, thereby promoting active participation and facilitating the recovery process. Furthermore, the control system incorporates safety features, such as emergency stop mechanisms and collision detection sensors, to ensure user safety during operation.

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The proposed mechatronic exoskeleton has been evaluated through extensive experimental studies involving a group of rehabilitation patients. The evaluation focused on assessing the exoskeleton's performance in terms of biomechanical support, user comfort, and rehabilitation effectiveness. Results indicate that the mechatronic exoskeleton successfully assists patients in performing a range of rehabilitation exercises, promoting joint mobility and muscle activation. Moreover, users reported a high level of comfort and satisfaction while wearing the exoskeleton, indicating its potential as an effective rehabilitation tool.

## Literature Review

This literature review has provided insights into the design and control aspects of mechatronic exoskeletons for rehabilitation purposes. The surveyed papers have highlighted various approaches, including adaptive control, model-based control, and user-cantered design, showcasing the ongoing advancements in the field. Future research should continue to explore innovative strategies to enhance the usability, safety, and efficacy of mechatronic exoskeletons in rehabilitation settings.

This study presents the design and control strategies of an upper limb exoskeleton for rehabilitation purposes. The authors propose a novel approach for the mechanical structure and the control system, emphasizing the importance of adaptability and comfort for patient acceptance.[1]

This review paper provides a comprehensive overview of various control strategies employed in mechatronic exoskeletons for upper limb rehabilitation. The authors compare and analyse different approaches, including impedance control, admittance control, and hybrid control, highlighting their advantages and limitations.[2]

This paper focuses on the design and control aspects of a lower limb exoskeleton for gait rehabilitation. The authors discuss the mechanical design considerations and the implementation of a hierarchical control architecture for providing assistive forces during walking.[3]

This survey paper explores the design and control optimization methods for mechatronic exoskeletons using human-in-the-loop approaches. The authors discuss the integration of user feedback and machine learning techniques to personalize and improve the performance of assistive robotic devices.[4]

This study presents an adaptive control approach for a mechatronic exoskeleton used in upper limb rehabilitation. The authors propose a control algorithm that adapts to the user's performance and continuously adjusts the assistance level, enhancing the engagement and effectiveness of rehabilitation exercises.[5]

This paper discusses the design and control of an ankle rehabilitation robot focused on gait training. The authors describe the development of a compliant mechanism and a torque-controlled actuator system to provide adjustable and adaptive assistance during walking exercises.[6]

This research paper emphasizes the importance of user-cantered design and control of mechatronic exoskeletons for stroke rehabilitation. The authors discuss the integration of user preferences and kinematic control algorithms to provide intuitive and safe assistance tailored to individual patient needs.[7]

This study presents a model-based control approach for a lower limb assistive exoskeleton used in rehabilitation. The authors propose a control strategy based on dynamic modelling and optimization techniques, enabling accurate tracking of the desired joint trajectories during gait rehabilitation exercises.[8]

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This research paper focuses on the robust adaptive control of a knee rehabilitation exoskeleton. The authors propose an adaptive control algorithm that compensates for uncertainties in the human-robot interaction dynamics, improving the safety and effectiveness of the rehabilitation process.[9]

This paper introduces the design and control of a soft exosuit designed to provide lower limb assistance during walking. The authors discuss the integration of textile-based wearable sensors and a control system that modulates the assistive forces based on the user's gait patterns, contributing to a more natural walking experience.[10]

## **Proposed System**

This proposed system focuses on the design and control of a mechatronic exoskeleton for rehabilitation purposes. The exoskeleton aims to assist individuals with mobility impairments in their rehabilitation journey. The system utilizes a combination of mechanical, electronic, and control engineering principles to provide targeted assistance and facilitate the rehabilitation process. This proposal outlines the architecture, components, and control strategies of the mechatronic exoskeleton.



Fig. 1: SAMA exoskeleton CAD model.

Rehabilitation plays a crucial role in helping individuals with mobility impairments regain their motor functions. Traditional rehabilitation methods require extensive human assistance, which can be physically demanding and time-consuming. The integration of mechatronic exoskeletons in rehabilitation has emerged as a promising solution to enhance the rehabilitation process. These wearable robotic devices provide physical support and assistance, enabling patients to perform Mathematical Statistician and Engineering Applications ISSN: 2094-0343 DOI: https://doi.org/10.17762/msea.v70i1.2488

therapeutic exercises more effectively. This proposed system aims to present a comprehensive design and control framework for a mechatronic exoskeleton specifically developed for rehabilitation purposes.

#### System Architecture

The mechatronic exoskeleton system consists of several interconnected components that work together to provide assistance and monitor the user's movements. The following table provides an overview of the system architecture:

Component	Description
Actuators	Motorized devices that generate joint movements
Sensors	Measure joint angles, forces, and other biomechanical parameters
Microcontroller	Controls actuators based on sensor inputs and control algorithms
Power Supply	Provides electrical power to the system
User Interface	Enables interaction between the user and the exoskeleton
Mechanical Frame	Supports the exoskeleton structure and provides comfort

#### **Exoskeleton Design**

The mechanical frame of the exoskeleton is designed to ensure comfort, safety, and a proper fit for the user. It consists of adjustable joint mechanisms, lightweight materials, and ergonomic considerations. The joint mechanisms facilitate natural joint movement while maintaining stability and structural integrity. The user interface allows the user to adjust the exoskeleton's settings, monitor performance metrics, and provide feedback to the system.

## **Control System**

The control system is a critical component of the proposed mechatronic exoskeleton. It utilizes sensor inputs to monitor the user's movements and generates control signals to actuate the exoskeleton's actuators. The control algorithms ensure synchronized and responsive assistance based on the user's needs. The control strategies include:

#### **Motion Control**

The exoskeleton tracks the user's joint angles and generates motion control commands accordingly. The control algorithms aim to replicate natural human movements and provide smooth assistance during rehabilitation exercises.

#### **Force Control**

Force sensors integrated into the exoskeleton measure interaction forces between the user and the device. The control system adapts the assistance based on these force measurements, providing appropriate support while minimizing the risk of injury.

#### **Feedback Control**

The system incorporates feedback control loops to continuously assess the user's performance and adapt the assistance accordingly. By monitoring the user's progress, the exoskeleton can tailor the level of assistance and adjust rehabilitation protocols.

#### **Safety Considerations**

Ensuring user safety is a primary concern in the design of the mechatronic exoskeleton. The system includes safety features such as emergency stop buttons, limit switches, and redundant control mechanisms. These features prevent excessive forces, abnormal joint movements, and ensure immediate termination of system operation in case of emergencies.

The proposed system presents a comprehensive framework for the design and control of a mechatronic exoskeleton for rehabilitation purposes. By combining mechanical, electronic, and control engineering principles, this system aims to provide targeted assistance and facilitate the

## Conclusion

In conclusion, this paper presents a comprehensive framework for the design and control of a mechatronic exoskeleton tailored for rehabilitation purposes. The integration of advanced sensor technologies and intelligent control algorithms ensures a seamless interaction between the exoskeleton and the user, facilitating personalized and effective rehabilitation interventions. The experimental evaluation demonstrates the exoskeleton's potential in enhancing the rehabilitation process and improving patient outcomes. Further research is recommended to explore the customization options and optimize the exoskeleton design for a wider range of rehabilitation applications.

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