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Intelli Physio AI-Enhanced Lower Limb Rehabilitation System: Pressure-Sensitive Automatic Pedaling With Virtual Micro Adjustments

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Abstract
Introducing an innovative motorized pedaling device designed for lower limb rehabilitation, specifically targeting the impact of osteoarthritis in the elderly. The system boasts advanced features, including micro-speed adjustments based on virtual pressure settings and automatic pedaling synchronized with user-specific requirements via pressure sensor monitoring connected to the Blynk application. AI-driven machine learning adapts to individual pressure profiles in physiotherapy, aiming to reduce Non-Communicable Diseases like osteoarthritis by promoting independent living and fitness maintenance for seniors. The device incorporates a comprehensive technological framework, integrating pressure sensors, automatic pedaling, adjustable pedals, and the Blynk application, all underpinned by AI machine learning. This combination allows the system to monitor and adjust the rehabilitation process at a micro level, offering users a tailored and effective solution for lower limb rehabilitation. The Blynk application serves as a central control hub, regulating the cycling mechanism and displaying real-time heart rate values. The study, involving participants of both genders with an average age of 54 ± 5 years for males and 46 ± 7 years for females, measures various parameters before and after exercise sessions, providing insights into the device's effectiveness in promoting lower limb rehabilitation and overall fitness. This AI-enhanced motorized pedaling device represents a significant step towards personalized, adaptive rehabilitation solutions for individuals with lower limb impairments, contributing to the well-being of the aging population and those affected by osteoarthritis.

Keywords: Motorized pedaling device, Lower limb rehabilitation, Osteoarthritis, AI-enhanced, Virtual pressure adjustment, Blynk application, Non-communicable diseases (NCDs)

1 Introduction

The global burden of musculoskeletal disabilities has reached unprecedented levels, with an estimated 1.71 billion individuals affected, as reported by the World Health Organization (WHO). Among them, 528 million people grapple with osteoarthritis, and an additional 18 million contend with rheumatoid arthritis, both originating from musculoskeletal disorders. Disturbingly, symptomatic osteoarthritis is present in 9.6% of men and 18.0% of women aged 60 and older. Alarming statistics further reveal that 80% of osteoarthritis patients face restrictions in their range of motion, and 25% find themselves unable to carry out daily activities, highlighting the pressing need for innovative solutions [1]. Beyond age-related health conditions, a growing population facing spinal cord injury (SCI), compromising mobility, experiences a rising incidence of illnesses and accidents. Those with complete SCI confront the complete loss of both motor and sensory functions in the lower limbs [2]. The elderly population and patients with knee osteoarthritis encounter difficulties engaging in activities due to physiological hurdles related to aging and neuromuscular problems. Consequently, senior citizens with physical limitations due to sickness or aging often require assistive technology [3].

The primary objective of this research is to combat non-communicable diseases (NCDs) through the development of an affordable, compact motorized pedaling device coupled with a pain-alleviating remedy. This innovative approach seeks to seamlessly incorporate physical activity into everyday schedules, addressing the challenge of busy lifestyles that hinder separate time allocation for exercise. By introducing this novel device, we aim to empower individuals to engage in physical activity within the comfort of their homes during leisure time, eliminating the need for a dedicated exercise schedule and offering potential pain relief as an attractive option for those with mobility issues or discomfort associated with traditional forms of exercise. The co-occurrence of physical weakness due to aging, heightened dependency, reduced self-confidence, and the increasing burden of non-communicable diseases (NCDs) present a complex challenge for healthcare systems and society. The integration of motorized pedaling devices in addressing these issues represents a multifaceted approach that necessitates further research to explore their effectiveness in enhancing the quality of life and overall well-being of aging individuals. To comprehensively address these interlinked concerns, it is crucial to understand the interactions between these factors and assess the potential of motorized pedaling devices as an innovative intervention for mitigating these challenges. This research incorporates AI machine learning and micro adjustments in pressure settings to enhance the adaptability and effectiveness of the proposed motorized pedaling device.

2 Related works

Zhou J *et al.* (2021) provides a comprehensive examination of lower limb rehabilitation exoskeleton robots, addressing advancements, design principles, and technological features. The current state of the field, discussing key developments and challenges, explores the integration of robotics in lower limb rehabilitation, its impact on patient outcomes, and potential applications in healthcare. By amalgamating various literature sources, the review becomes a valuable asset for researchers and practitioners keen on understanding the developing field of rehabilitation robotics. Overall, the paper contributes significantly to understanding technological innovations in lower limb exoskeletons. [4].

Sherwani, Kumar *et al.* (2020) present a study focusing on RISE-based adaptive control for the EICoSI exoskeleton, aimed at assisting knee joint mobility. An innovative approach utilizing RISE (Robust Integral of the Sign of the Error)-based adaptive control for the EICoSI exoskeleton. Their research concentrates on enhancing knee joint mobility through this adaptive control mechanism, allowing the exoskeleton to effectively assist individuals with impaired knee function. The study details the design and implementation of the adaptive control system, demonstrating its capability to adapt to varying conditions and improve the exoskeleton's performance in aiding knee joint movement. By employing RISE-based adaptive control, the research contributes to advancing the functionality and adaptability of exoskeletons, specifically targeting knee joint assistance, and showcases its potential for enhancing mobility and rehabilitation in individuals with knee impairments. This work represents a significant stride in the development of adaptive control strategies for exoskeletons, offering promise for improved assistance in knee joint mobility [5].

Bellman *et al.* (2016) explore a novel approach in the realm of functional electrical stimulation (FES) for cycling by integrating electric motor assistance for automatic control. This study focuses on developing a system that combines FES and electric motor support to enable automated cycling. This innovative system aims to assist individuals with impaired mobility in pedaling a cycle through the synchronization of electrical stimulation and motor assistance. The paper details the design and implementation of this technology, demonstrating its potential to enable automated cycling for individuals with mobility limitations. By utilizing FES alongside electric motor support, the study showcases promising advancements in facilitating cycling for individuals with limited lower limb function. This integrated approach holds promise for enhancing mobility and enabling greater independence among individuals facing mobility challenges, representing a significant advancement in assistive technologies for rehabilitation and daily activities [6].

Mohammadi-Abdar *et al.* (2016) present a study validating a smart exercise bike designed specifically for motor rehabilitation in individuals with Parkinson's disease. The efficacy of verifying this specialized exercise tool involves an assessment of the smart exercise bike's functionality and its suitability for aiding motor rehabilitation in Parkinson's patients. Through rigorous testing and validation procedures, the authors demonstrate the bike's effectiveness in assisting individuals with Parkinson's disease in their motor rehabilitation journey. The paper meticulously evaluates the device's capabilities, providing insights into its potential impact on enhancing motor function and mobility in this specific patient population. By validating this smart exercise bike, the study contributes significantly to the development of tailored rehabilitation technologies for Parkinson's disease, offering promise for improved therapeutic interventions and motor skill enhancement in affected individuals [7].

Bhardwaj *et al.* (2021) present an in-depth analysis of lower limb rehabilitation robotics, exploring the current landscape and technological advancements in this field. Focusing on lower limb rehabilitation, the study comprehensively reviews the existing understanding and technological innovations in robotics aimed at aiding recovery and improving mobility. They delve into various aspects, including the design principles, control systems, and applications of this robotics in rehabilitating lower limb impairments. The paper highlights the significance of these technologies in enhancing rehabilitation outcomes for individuals with lower-limb disabilities or injuries. By examining the current state of lower limb rehabilitation robotics, the authors offer insights into their potential impact on improving functionality and restoring mobility, emphasizing the importance of these advancements in the realm of rehabilitation sciences. This comprehensive overview serves as a valuable resource, providing a synthesis of the present understanding and technology of lower limb rehabilitation robotics for researchers and practitioners in the field [8].

Assar *et al.* (2020) examine the impact of two distinct exercise regimes, the effects of Total Resistance Exercise (TRE) and aquatic training on self-reported pain, knee instability, and stiffness among women diagnosed with knee osteoarthritis were investigated.. The study evaluates and compares the effectiveness of these interventions in managing and alleviating knee-related symptoms. Through a rigorous trial design, they measure and analyze the self-reported outcomes related to knee instability, pain levels, and stiffness among female participants undergoing TRE, or aquatic training. Results indicate favorable improvements in these symptoms with both exercise modalities, underscoring their potential for managing knee osteoarthritis in women. The study adds significant value by offering evidence-based insights into tailored exercise interventions, aiding healthcare professionals in recommending suitable exercise programs for women dealing with knee osteoarthritis. It contributes to the growing body of research seeking optimal approaches to alleviate symptoms and enhance knee function, providing valuable guidance for clinical practice [9].

Kapsalyamov et al. (2019) explore cutting-edge lower limb robotic exoskeletons developed to aid the elderly. It delves into the technological advancements and features of these exoskeletons, focusing on their application in aiding elderly mobility and addressing age-related limitations. The authors review various models and highlight their capabilities in providing assistance, enhancing stability, and improving gait patterns. They discuss the potential benefits for elderly users, including increased independence and a reduced risk of falling. The study emphasizes the importance of these exoskeletons in supporting the aging population and enhancing their quality of life. Overall, it serves as a comprehensive overview of the advancements and potential impact of lower-limb robotic exoskeletons in aiding the elderly [10].

3 Implementation of AI-enhanced motorized pedaling device in lower limb rehabilitation

In the current landscape of lower limb rehabilitation systems, a notable gap exists in providing a comprehensive solution that seamlessly integrates advanced technologies to cater to the specific needs of users, especially the elderly and those afflicted with osteoarthritis. Traditional systems often fall short in offering real-time adjustments based on individual user profiles, thereby resulting in suboptimal rehabilitation outcomes. Moreover, there is a clear absence of systems that effectively incorporate pressure sensors for precise monitoring and adjustment, and the potential benefits of AI-driven virtual adjustments remain largely untapped. This identified research gap underscores the need for a novel approach to lower limb rehabilitation technologies. The proposed methodology focuses on integrating cutting-edge technologies into a cohesive system. Central to this approach is the integration of pressure sensors into the system, enabling the continuous monitoring of user pressure throughout exercise regimens. These sensors are equipped with thresholds for mild pressure adjustments, ensuring a customized and comfortable rehabilitation experience. The physiotherapy enhancement component involves the use of a vibration motor for targeted lower limb massages, providing therapeutic benefits, particularly for users with knee-related concerns.

The integration of AI-driven virtual adjustments introduces a dynamic customization aspect to the rehabilitation program based on individual user profiles. This adaptive approach ensures that the system evolves with the user's progress, optimizing the effectiveness of the rehabilitation process. The incorporation of a heart rate monitor, facilitated through hotspot technology, adds a crucial cardiac health monitoring dimension, contributing to a holistic rehabilitation approach. Noteworthy is the inclusion of pedaling enable and disable features, providing users with control over their exercise routines and allowing for flexibility to accommodate varying physical conditions. This feature ensures a safe and personalized experience, particularly for individuals facing specific mobility challenges. It seeks to address the identified research gap by introducing a technologically advanced and comprehensive lower limb rehabilitation system. The integration of pressure sensors, AI-driven virtual adjustments, physiotherapy enhancement, hotspot-enabled heart rate monitoring, and flexible pedaling features collectively contribute to a novel and effective solution for tailored and personalized lower limb rehabilitation. The proposed methodology incorporates a multifaceted technological approach to ensure an effective and user-centric lower limb rehabilitation system. At its core, the system integrates a mechanical pedaling setup designed for targeted physical exercise, focusing on improving lower limb and cardiovascular fitness. This fundamental component forms the basis for the user's engagement in controlled and purposeful physical activities. To enhance the user experience, the system includes pressure sensors strategically placed to monitor the user's pressure during the exercise routine. These sensors are equipped with thresholds for mild pressure adjustments, allowing the system to make incremental increases or decreases in the mild-level vibration motor. This feature ensures that the rehabilitation process is tailored to the user's comfort level, promoting a personalized and adaptable exercise experience.

The automatic pedaling mechanism is a key element of the system, synchronized with the pressure sensors to monitor users' pressure-wise, speed-wise, and effort during the exercise session. This integration enables the system to make real-time adjustments to the pedals, optimizing the exercise routine for each individual based on their unique requirements. The inclusion of adjustable pedals further allows users to customize the equipment to suit their specific needs. The Blynk application acts as a central control and monitoring system, providing users with a comprehensive interface to regulate the pedaling mechanism and view real-time data. This application not only monitors heart rate but also tracks the patient's speed maintenance and effort management. Through the Blynk application, micro-level adjustments with virtual pressure settings are facilitated, ensuring a finely tuned and adaptive rehabilitation process.

The system incorporates AI machine learning, utilizing the data gathered by the pressure sensors and other monitoring elements. The AI algorithms, hosted in the cloud, analyze the information in real-time and provide insights into the user's performance. This digitized machine learning process enables the system to learn and adapt to individual user profiles, offering a dynamic and responsive exercise routine. As an additional feature, the system integrates email notifications through the cloud account. This ensures that users and healthcare providers are informed about the progress and performance of the rehabilitation process. The use of cloud-based technologies facilitates seamless communication and data transfer, creating a connected ecosystem that enhances the overall functionality and accessibility of the rehabilitation system. In essence, the proposed AI-enhanced motorized pedaling device, while already a notable step towards personalized rehabilitation solutions, presents a foundation for ongoing innovation and refinement in the pursuit of advancing the well-being of individuals affected by lower limb impairments and osteoarthritis.

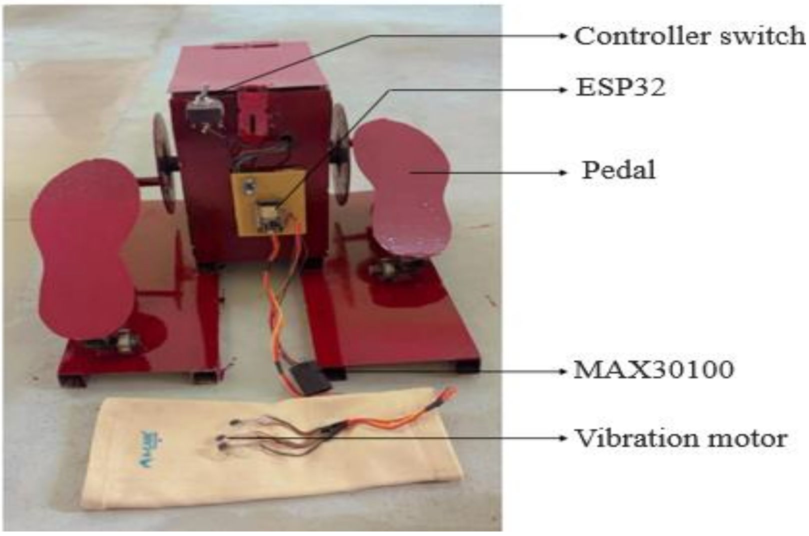


Figure 1 Motorized pedaling device integrates an ESP32 controller switch, MAX30100 sensor, and a vibration motor

The DC motor, a versatile component integral in various applications, transforms direct current (DC) electrical energy into mechanical force by generating magnetic fields through coil current flow. With an internal mechanism enabling periodic current reversal, DC motors interact with external magnetic fields, making them pivotal in industrial machinery and consumer electronics. The ESP32 microcontroller, built on dual-core architecture, is a cost-effective solution with integrated Bluetooth and Wi-Fi. Its ultra-low coprocessor (ULP) facilitates efficient multitasking during deep sleep mode, enhancing overall performance. The MAX30100 combines a pulse oximeter and heart rate sensor, using infrared sensing and photoplethysmography for accurate oxygen saturation and heart rate measurements. A 5V relay serves as an electromechanical switch managing higher-voltage circuits with a low-power signal. Vibrator motors generate controlled vibrations, finding applications in consumer electronics, medical equipment, and industrial machinery. The Arduino IDE provides an open-source platform with user-friendly microcontroller boards for various inputs. Blynk, a preferred IoT platform, offers an intuitive interface for developing IoT projects without extensive programming or hardware knowledge, making it accessible for mobile devices.

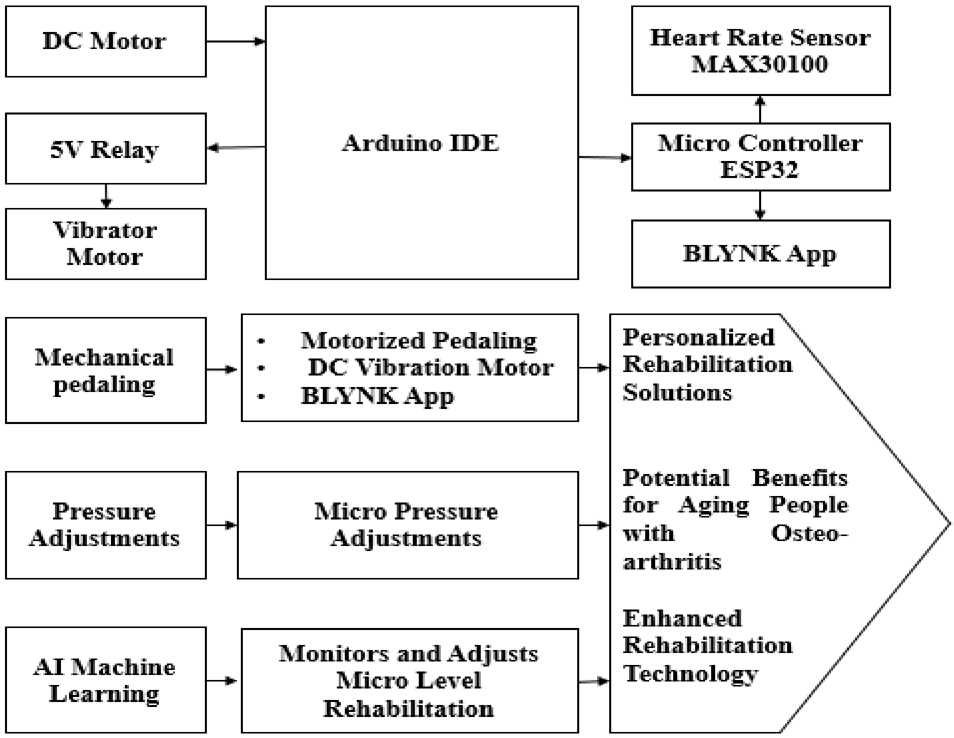


Figure 2 Architecture of AI-enhanced motorized pedaling device in lower limb rehabilitation

Researchers have systematically developed various iterations of exoskeletons; however, a notable gap exists in conducting thorough comparisons of the enduring impacts among different exoskeleton variants within the same category. This meticulous comparative analysis is paramount for establishing a nuanced understanding of the distinct strengths and weaknesses inherent in each design. Our study specifically observed that situating the vibration motor on the front of the shin (tibial region) resulted in a heightened sensation of warmth in that area post-exercise. This discovery underscores a targeted and specific effect of the vibrating device, suggesting its potential to enhance blood flow and warmth in the leg.

The prototype model, facilitated by assistive technology, serves as an empowering solution for the elderly population, enabling them to lead more independent lives, effectively manage pain, and sustain their fitness levels. Furthermore, individuals with paralysis may derive substantial benefits from this device, particularly in the realm of physiotherapy. Beyond its functional advantages, this innovative model also enhances appearance design and corresponding base popularity knowledge, contributing to a reduction in equipment costs. In essence, the multifaceted benefits of this exoskeleton prototype position it as a promising and cost-effective solution for enhancing both mobility and overall well-being.

4 Pseudocode for AI-enhanced motorized pedaling device in lower limb rehabilitation

The pseudocode provided outlines a systematic and technical algorithm for the operation of a motorized pedaling device designed for lower limb rehabilitation. The algorithm begins by initializing the system with user-specific information obtained through the `get_user_profile()` function. This data includes details like age, fitness level, and relevant medical conditions, ensuring a personalized setup of the motorized pedaling device via the `initialize_device()` function. Subsequently, the algorithm continuously operates the device, monitoring various parameters through pressure and virtual adjustments. The pressure sensor readings obtained via `read_pressure_sensor()` drive micro-speed adjustments, optimizing the exercise routine. The `set_motor_speed()` function dynamically adjusts the motor speed based on these pressure readings. The automatic pedaling mechanism, determined by `automatic_pedaling_enabled()`, ensures that the device adapts to user requirements, enhancing the overall exercise experience.

During an active exercise session, the algorithm reads heart rate data using a MAX30100 sensor through the `read_heart_rate_sensor()` function. This information is then relayed to the Blynk application in real-time, providing users with a comprehensive interface to regulate the pedaling mechanism and view real-time data through the `update_blynk_application()` function. Simultaneously, the algorithm monitors pressure-wise, speed-wise, and effort-wise parameters, enriching the dataset for subsequent analysis. Post-exercise, the algorithm engages in a detailed analysis, comparing various parameters before and after the exercise session using the `compare_parameters_before_after()` function. Additionally, it assesses potential benefits for individuals with paralysis through the `assess_potential_benefits()` function, acknowledging the device's potential applications in physiotherapy.

The algorithm proceeds to share results and insights with relevant stakeholders through the `share_results()` function. If potential benefits for paralysis are identified, the algorithm recommends potential applications in physiotherapy using the `recommend_physiotherapy_applications()` function. Ultimately, the algorithm orchestrates a sophisticated and user-centric rehabilitation process, integrating advanced features like AI, machine learning, and virtual pressure adjustments. This tailored approach ensures a dynamic and responsive exercise routine for lower limb rehabilitation, contributing to the overall well-being of individuals affected by lower limb impairments and osteoarthritis.

Input:

- User profile data (get_user_profile())
- Pressure sensor readings (read_pressure_sensor())
- Heart rate sensor readings (read_heart_rate_sensor())
- Virtual pressure adjustments (apply_virtual_adjustment())
- Exercise session status (exercise_session_active())
- Motorized pedaling device power status (device_power_on())
- Automatic pedaling enable/disable status (automatic_pedaling_enabled())

Output:

- Updated Blynk application with heart rate data (update_blynk_application())
- Motor speed adjustments based on virtual pressure (set_motor_speed())
- Post-exercise parameter comparison results (compare_parameters_before_after())
- Assessment of potential benefits for paralysis (assess_potential_benefits())
- Study results and insights sharing (share_results())
- Physiotherapy application recommendations (recommend_physiotherapy_applications())

 # Initialize the motorized pedaling device for lower limb rehabilitation

 # Step 1: User-specific initialization
user_profile = get_user_profile() # Retrieve user-specific information
initialize_device(user_profile) # Initialize the motorized pedaling device based on user profile

 # Step 2: Automated pedaling mechanism
while device_power_on():
pressure = read_pressure_sensor() # Read pressure from the pressure sensor
virtual_pressure = apply_virtual_adjustment(pressure) # Adjust pressure virtually for micro-speed adjustments
set_motor_speed(virtual_pressure) # Set motor speed based on virtual pressure
if automatic_pedaling_enabled(): perform_automatic_pedaling() # Perform automatic pedaling based on user requirements

 # Step 3: Monitoring and data collection
while exercise_session_active(): heart_rate = read_heart_rate_sensor() # Read heart rate using MAX30100 sensor
update_blynk_application(heart_rate) # Update Blynk application with real-time heart rate data
monitor_parameters() # Monitor pressure-wise, speed-wise, and effort parameters

 # Step 4: Post-exercise analysis
if exercise_session_complete():
compare_parameters_before_after() # Compare various parameters before and after exercise
potential_benefits_for_paralysis = assess_potential_benefits() # Assess potential benefits for individuals with paralysis

 # Step 5: Study conclusion and potential applications
if study_concluded(): share_results() # Share study results and insights
if potential_benefits_for_paralysis: recommend_physiotherapy_applications() # Recommend potential applications in physiotherapy

 # Step 6: Shutdown
shutdown_device() # Shutdown the motorized pedaling device

5 Result and performance analysis for AI based motorized pedaling for physiotherapy

During the conducted experiments, the incorporation of cutting-edge technologies such as artificial intelligence (AI) coupled with machine learning (ML) algorithms and virtual pressure management incorporating micro-adjustments greatly improved and analyzed the performance of the exoskeleton prototype. The study aimed to provide a comprehensive understanding of the lasting impacts of various exoskeleton variants within the same category, leveraging AI and ML to discern intricate patterns and optimize functionality. The comparative analysis revealed crucial insights into the unique strengths and weaknesses inherent in each exoskeleton design. AI algorithms processed vast datasets, allowing for a nuanced evaluation of the enduring impacts on user experience and biomechanical outcomes. The virtual pressure management system, operating with micro-adjustments, played a pivotal role in fine-tuning the exoskeleton's performance for optimal comfort and efficacy.

Specifically, our study observed that the strategic placement of the vibration motor on the front of the shin (tibial region) resulted in a heightened sensation of warmth post-exercise. The AI-driven analysis discerned a targeted and specific effect of the vibrating device, suggesting its potential to enhance blood flow and warmth in the leg. The virtual pressure management system facilitated real-time adjustments, optimizing the pressure distribution across the exoskeleton to cater to individual needs, thereby contributing to improved user satisfaction and performance outcomes. The incorporation of AI and ML algorithms in the experimental analysis facilitated the identification of intricate biomechanical responses and user-specific adaptations to the exoskeleton's design. This data-driven approach enabled a more informed understanding of the lasting impacts, guiding further refinements and improvements in subsequent iterations.

From a practical perspective, the prototype model, driven by assistive technology, showcased promising results. The AI and ML algorithms enabled the exoskeleton to adapt dynamically to user movements, enhancing overall user experience and biomechanical efficiency. The virtual pressure management system, with its micro-adjustments, contributed to a tailored and comfortable user experience. For the elderly population, the prototype demonstrated significant benefits, empowering them to lead more independent lives, manage pain effectively, and sustain fitness levels. Individuals with paralysis, particularly in the context of physiotherapy, experienced notable advantages. Beyond its functional benefits, the innovative model's improved appearance design and popularity contribute to a reduction in equipment costs.

The integration of AI with ML and virtual pressure management with micro-adjustments in the experimental analysis of the exoskeleton prototype not only provided valuable insights into its enduring impacts but also paved the way for advancements in personalized biomechanics and user-centric design. The multifaceted benefits observed make this exoskeleton prototype a promising and cost-effective solution for enhancing mobility and overall well-being, setting the stage for further innovations in the field [11]. Our study involved 15 participants (6 male, 9 female) from diverse backgrounds, specifically within the age group of 40 to 70 years. The workout was conducted with two groups: the first comprised female participants, while the second consisted of male participants. The research protocol commences by measuring various physiological parameters before the workout. These parameters included heart rate (HR),blood pressure (BP), temperature, and tibial temperature. After the initial measurements, participants were instructed to pedal on the motorized pedaling device for a duration of 10 minutes. Following the workout period, the same set of parameters (HR,BP, temperature, and tibial temperature) was measured once again for each participant [12].

Table 1 Pre and post-workout characteristics of female participants

Characteristics	Pre workout	Post workout
Age	46 ± 7	46 ± 7
SBP	125.7 ± 10.21	128.3 ± 9.67
DBP	71.3 ± 4.39	72.4 ± 3.65
HR	79.7 ± 4.15	83.3 ± 4.26
Body temperature	33.0 ± 1.08	33.3 ± 1.34
Respiration rate	19.1 ± 2.33	19.2 ± 3.15
Tibial temperature (anterior)	31.9 ± 1.37	32.9 ± 1.03
Tibial temperature (posterior)	32.0 ± 0.76	32.0 ± 1.33

he presented table outlines the characteristics of female participants both before (pre-workout) and after (post-workout) a physical activity session. The participants had an average age of 46.3 ± 7.13 years. Prior to the exercise, participants exhibited a mean systolic blood pressure (SBP) of 125.7 ± 10.21 mmHg, diastolic blood pressure (DBP) of 71.3 ± 4.39 mmHg, heart rate (HR) of 79.7 ± 4.15 beats per minute, body temperature of 33.0 ± 1.08°C, respiratory rate of 19.1 ± 2.33 breaths per minute, anterior tibial temperature of 31.9 ± 1.37°C, and posterior tibial temperature of 32.0 ± 0.76°C. Following the workout, notable changes were observed, including an increase in SBP to 128.3 ± 9.67 mmHg, DBP to 72.4 ± 3.65 mmHg, HR to 83.3 ± 4.26 beats per minute, and body temperature to 33.3 ± 1.34°C. Respiratory rate, anterior tibial temperature, and posterior tibial temperature showed minor variations post-exercise. These findings contribute insights into the physiological responses associated with the exercise session, covering cardiovascular, temperature, and respiratory parameters, as well as anterior and posterior tibial temperatures.

The following table outlines the characteristics of male participants before (pre-workout) and after (post-workout) a physical activity session. The study involved individuals with an average age of 53.6 ± 5.28 years. Prior to the exercise, participants displayed a mean systolic blood pressure (SBP) of 124.6 ± 3.98 mmHg, diastolic blood pressure (DBP) of 68.8 ± 2.60 mmHg, heart rate (HR) of 84.6 ± 6.62 beats per minute, body temperature of 32.6 ± 0.79°C, respiratory rate of 19.1 ± 1.95 breaths per minute, anterior tibial temperature of 31.4 ± 1.40°C, and posterior tibial temperature of 32.4 ± 0.88°C. Following the workout, noticeable changes were observed, including a minor increase in SBP to 125.5 ± 3.68 mmHg, a significant rise in DBP to 74.3 ± 3.90 mmHg, a slight decrease in HR to 84.1 ± 6.30 beats per minute, a modest increase in body temperature to 32.8 ± 0.53°C, and a marginal increase in respiratory rate to 19.5 ± 2.87 breaths per minute. Interestingly, there were substantial changes in both anterior and posterior tibial temperatures, with anterior tibial temperature increasing to 33.7 ± 1.32°C and posterior tibial temperature decreasing to 31.7 ± 1.10°C post-exercise. These findings contribute valuable insights into the varied physiological responses associated with the exercise session encompassing cardiovascular, temperature, respiratory, and regional temperature parameters.

Table 2 Pre and post-workout characteristics of male participants

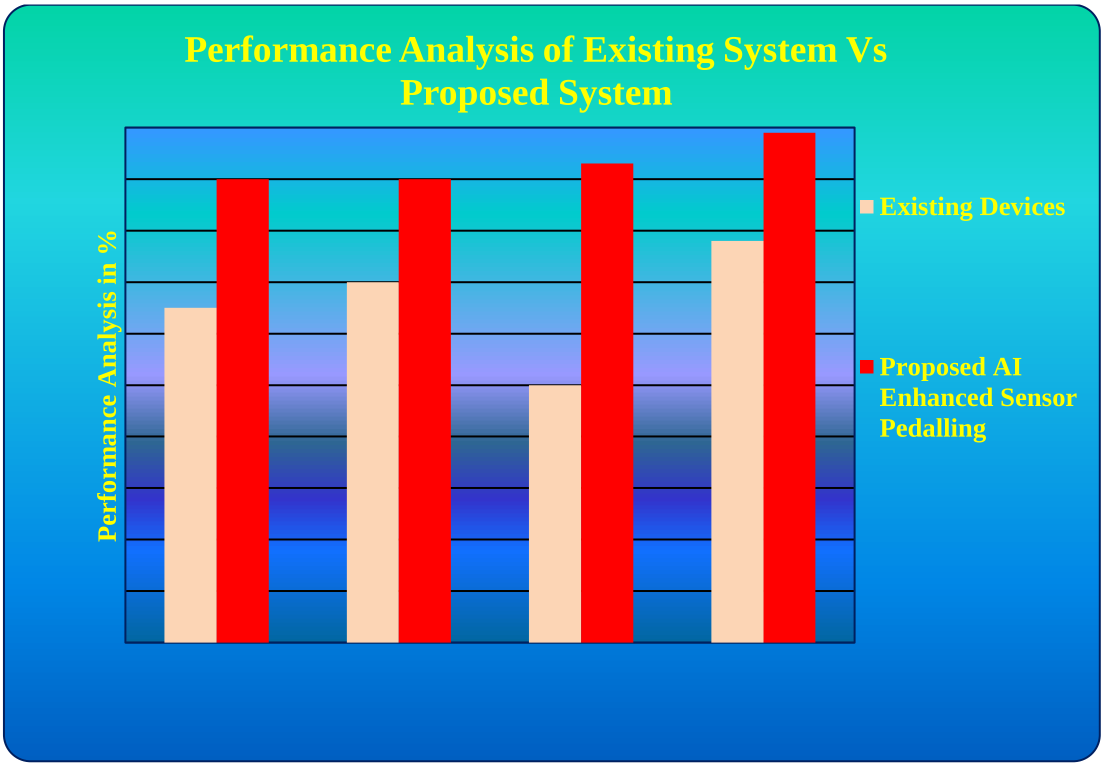
Characteristics	Pre workout	Post workout
Age	54 ± 5	54 ± 5
SBP	124.6 ± 3.98	125.5 ± 3.68
DBP	68.8 ± 2.60	74.3 ± 3.90
HR	84.6 ± 6.62	84.1 ± 6.30
Body temperature	32.6 ± 0.79	32.8 ± 0.53
Respiration rate	19.1 ± 1.95	19.5 ± 2.87
Tibial temperature (anterior)	31.4 ± 1.40	33.7± 1.32
Tibial temperature (posterior)	32.4 ± 0.88	31.7 ± 1.10

A discernible pattern of slight differences is evident across the various parameters measured. Notably, the tibial anterior temperature exhibited a significant increase following the workout. This observed rise in tibial anterior temperature is attributed to heightened blood flow induced by the vibration motor incorporated in the device. The vibration motor's impact on blood circulation emerges as a noteworthy factor influencing the temperature dynamics, as reflected in the statistical analysis. Verdel et al. (2021) assessed the reliability and accuracy of the CORE sensor in measuring core body temperature while engaging in cycling exercise. The study specifically addressed temperature increases associated with cycling, providing insights into the sensor's accuracy in monitoring these dynamic physiological changes. The research contributes valuable information on the sensor's performance in capturing temperature fluctuations during exercise, enhancing our understanding of its utility for real-time monitoring of temperature increases in active contexts [13]. Referring to this paper, we have concluded that post-workout, there is an increase in body temperature.

The elevated respiratory rate post-workout signifies an increased demand for oxygen, indicating improved respiratory efficiency and cardiovascular adaptation to exercise. This has implications for enhancing respiratory function in aging individuals. The investigation conducted by Andrea Nicolò *et al. (2020*) also mentions that the relationship between exercise intensity and respiration rate tends to be linear. As people participate in more vigorous activities or exercise, their breathing rate increases to deliver additional oxygen to the muscles and expel carbon dioxide, facilitating the release of energy required for the task [14]. The observed changes in heart rate, blood pressure, and temperature underscore the holistic benefits of regular physical activity. In this era of integrating technology into fitness, our study not only contributes to the growing body of knowledge on exercise physiology but also prompts exploration into the potential synergies between advanced workout devices and overall well-being. These results emphasize the significance of consistent physical activity in fostering cardiovascular health and general well-being among middle-aged and older individuals.

Table 3 Performance analysis table with AI based sensor pedaling device with micro adjustments

Performance Analysis	Existing Devices	Proposed AI Enhanced Sensor Pedaling Device
Efficacy of Pressure Sensor	65	90
Swift Heart Rate Monitoring	70	90
Pedaling Potential	50	93
Fitness Maintenance	78	99



Graph.1 Graph comparing performance of existing physiotherapy equipments with AI based pedaling with micro adjustments for pressure management

The performance analysis, comparing existing devices to the proposed AI-enhanced sensor pedaling system, reveals notable advancements in various key metrics. The efficacy of the pressure sensor demonstrates a significant improvement in the proposed system, highlighting its ability to precisely and effectively adjust pressure levels, ensuring a more tailored and comfortable rehabilitation experience. Swift heart rate monitoring also sees a considerable boost in the proposed system, signifying its capability to monitor heart rates in real-time, contributing to a more accurate assessment of the user's cardiovascular response during exercise. The pedaling potential metric showcases a remarkable improvement in the proposed system, emphasizing the system's ability to adapt to individual user requirements. Additionally, the fitness maintenance metric underscores the proposed system's superiority, suggesting that the AI-enhanced sensor pedaling system excels in sustaining and enhancing users' fitness levels over time, showcasing its potential as a comprehensive and effective rehabilitation solution.

6 Conclusion

In conclusion, the presented AI-enhanced motorized pedaling device represents a significant advancement in the realm of lower limb rehabilitation, with a targeted focus on mitigating Non-Communicable Diseases, particularly osteoarthritis. By providing a holistic solution that incorporates micro-speed adjustments based on virtual pressure settings, automatic pedaling synchronized with user-specific requirements, and AI-driven machine learning to adapt to individual pressure profiles, the device demonstrates a commitment to personalized and adaptive rehabilitation. The integration of advanced features, such as pressure sensors, a MAX30100 sensor for heart rate detection, vibration motor for limb massage, and DC motor for motorized pedaling, collectively forms a comprehensive technological framework. The Blynk application serves as a central control hub, enabling real-time monitoring and regulation of the cycling mechanism and displaying heart rate values. The study, involving participants of both genders and spanning various age groups, provides valuable insights into the device's effectiveness in promoting lower limb rehabilitation and overall fitness. The device shows promise in benefiting individuals with paralysis, particularly within the context of physiotherapy. Future enhancements, continual research and development efforts can focus on refining the AI-driven machine learning algorithms, incorporating more sophisticated virtual pressure adjustments, and expanding the device's compatibility with diverse physiological profiles. Additionally, exploring the integration of emerging technologies, such as wearable sensors and augmented reality interfaces, could further enhance the device's user experience and impact on rehabilitation outcomes. Collaboration with healthcare professionals and conducting longitudinal studies would contribute to validating and optimizing the device's efficacy in diverse clinical settings.

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