DESIGN AND USER EVALUATION OF ASSISTIVE KNEE DEVICE

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DEDICATION

This thesis is dedicated to our cherished parents, whose endless love and encouragement have been our guiding stars; to our respected teachers, especially to our head of department and also supervisor DR ABDULLLAH MENGAL (associate professor) whose guidance and unwavering support sparked our love for learning; and to our wonderful group members, whose teamwork and determination paved the way for our achievement.

Abstract

The project's primary goal was to develop a groundbreaking wearable knee device to aid individuals coping with knee impairments, osteoarthritis, and age-related mobility constraints. A key focus involved integrating advanced engineering components, specifically a precision-engineered stepper motor and a bevel gearbox controlled by a microcontroller (Arduino) synchronized with adept stepper drivers. The primary objective was to create a device capable of providing adaptable and personalized knee support that aligns precisely with each user's unique movement patterns and requirements.

Central to this initiative was a user-centric design approach, emphasizing the seamless integration of the device into users' daily lives to significantly enhance mobility and stability. Addressing power management concerns, the project aimed to incorporate a rechargeable Li-phosphate battery system and mini solar panels into the wearable jacket. These innovations aimed to reduce reliance on traditional power sources, ensuring prolonged device operation while promoting sustainability and autonomy.

The project encompassed the creation of four distinct modes tailored to suit various user needs. Mode 1 facilitated independent movement, allowing users to move without external support. Mode 2 provided moderate assistance by engaging the motor at 50% performance, conserving energy while aiding in daily activities. Mode 3 aimed to deliver maximal support by utilizing the motor at its full 100% performance, targeting physically demanding tasks. Additionally, Mode 4 allowed users to customize the device's positioning for stability without movement.

The methodology involved comprehensive testing and refinement to assess the device's functionality across these diverse assistance modes. Initial testing showed promising results: the device maintained leg movement during power disruptions, offered balanced assistance for everyday tasks, and provided robust support for strenuous activities. However, Mode 3 exhibited limitations due to the device's weight affecting its highest torque performance.

Further testing of Mode 4, the 'hold/freeze mode,' displayed stability for static positions, effectively managing loads of around 5-6 kilograms. Yet, higher loads revealed the need for a more powerful motor. Despite these limitations, the prototype displayed potential for future improvements, particularly in optimizing torque performance by redistributing weight effectively.

In conclusion, the project highlighted the device's adaptability and potential to enhance mobility and stability for individuals with knee-related challenges. The integration of sustainable power solutions and a user-centric design approach laid a robust foundation for potential advancements. Identified limitations pave the way for refinement, positioning the device as a promising addition to assistive technology in the future.

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We begin with gratitude to Allah Almighty and the Prophet Muhammad (Peace be upon him and his Progeny) for illuminating the path of knowledge for us. Their guidance has enabled us to undertake this project and compile this report. Our heartfelt thanks extend to Dr. Abdullah Mengal (Associate Professor), the Chairman of the Mechanical Department at Baluchistan University of Engineering & Technology Khuzdar, and the faculty members for endorsing our project. We owe special thanks to Dr. Abdullah Mengal who also supervised our group, whose guidance and assistance were instrumental in bringing this project to fruition. We are immensely thankful to our parents and everyone who contributed, internally or externally, guiding and supporting us throughout this endeavor. Their unwavering support was pivotal in accomplishing this task.

Our parents deserve special mention for their continuous guidance, wholehearted support, and the sacrifices they've made for us. Their prayers have been our strength and motivation. Lastly, we acknowledge the dedicated staff of the Mechanical Engineering department for their contribution to our project.

List of Abbreviations

UET	University of Engineering and Technology
LCD	Liquid Crystal Display
B.U.E.T. K	Balochistan University of Engineering and Technology, Khuzdar
UI	User Interface
IoT	Internet of Things
CAD	Computer-Aided Design
Li-ph	Lithium-phosphate (battery)
RTOS	Real-Time Operating System
API	Application Programming Interface
EMG	Electromyography
WAKD	Wearable Assistive Knee Device
AKD	Assistive Knee Device
DC	Direct Current
HRI	Human Robotics Interaction
RPM	Revolution per Minute
mA	Milliampere
OS	Operating System
USB	Universal Serial Bus
MHz	Megahertz
UNO	Universal Network Objects
KB	Kilobytes
Amps	Amperes
WH	Watt Hour

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Certificate

This is to certify that the work presented in this project report / thesis on “**Design and User Evaluation of Assistive Knee Device**” is entirely written by the following students / themselves / himself / herself under the supervision of **Dr Abdullah Mengal (Associate Professor)**

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Chapter 1

INTRODUCTION

1.1 Introduction

The landscape of wearable technology continues to evolve, introducing transformative innovations tailored to address the diverse challenges faced by individuals affected by conditions such as osteoarthritis, knee impairments, and the limitations posed by aging. Among these advancements, wearable assistive knee devices stand at the forefront, representing a paradigm shift in the pursuit of enhancing mobility and improving the quality of life for those navigating knee-related limitations.

Our ongoing prototype project, titled "Design and User Evaluation of Assistive Knee Device," embodies a culmination of extensive interdisciplinary research, engineering ingenuity, and a profound commitment to user-centric design principles. This ambitious endeavor is focused on the creation of an advanced wearable device expressly crafted to meet the unique needs of individuals confronting knee-related mobility challenges.

At the heart of this groundbreaking device lies a meticulously crafted design, meticulously integrating cutting-edge components poised to redefine the landscape of mobility support. The device boasts a precision-engineered stepper motor intricately linked with a bevel gearbox—a sophisticated amalgamation engineered to serve as a powered assistant, augmenting the functionality of the user's knee. This intricate mechanism, in conjunction with a microcontroller (Arduino) and adept stepper drivers, ensures a nuanced and adaptive assistance system that harmonizes seamlessly with the user's movement patterns and requirements.

A defining attribute of this wearable assistive knee device is its intuitive and accessible user interface, providing users with effortless control over a spectrum of modes. This interface empowers individuals to fine-tune their experience, enabling real-time adjustments to the device's assistance levels, thereby catering to their unique needs and comfort preferences.

Yet, the hallmark feature distinguishing this device lies within its sophisticated power management system. Operating on a rechargeable Li-phosphate battery, the device guarantees a sustained power supply to facilitate uninterrupted usage. However, the device's innovation transcends conventional power sources by incorporating miniaturized solar panels discreetly mounted on the jacket's back. This ingenious integration harnesses solar energy, presenting a sustainable and eco-conscious charging solution that ensures continuous device operation, reducing reliance on traditional charging methods and fostering a sense of self-sufficiency and environmental responsibility.

Embedded within this comprehensive project is an extensive design iteration and user evaluation phase, where usability and adaptability take precedence alongside functionality. Rigorous testing and meticulous analysis of user feedback form the bedrock for refining the device, ensuring a harmonious fusion of cutting-edge technology and an empathetic understanding of user needs.

This wearable assistive knee device signifies more than a technological advancement; it represents a transformative approach to assistive technology, striving not merely to restore mobility and independence but to enrich the lives of individuals confronting knee impairments. By melding advanced technology with user-centric design principles, this project aspires to set a new standard in assistive devices, empowering users and profoundly enhancing their overall well-being. It is a testament to the unyielding commitment to innovation, propelling the boundaries of what is possible in the realm of healthcare technology and redefining the horizons of mobility support.

1.2 General Background

The evolution of assistive technology has witnessed a profound impact on improving the lives of individuals facing mobility challenges. In this context, wearable assistive devices have emerged as a transformative force, aiming to provide enhanced mobility, independence, and a better quality of life for individuals grappling with various physical limitations, especially those related to knee impairments, osteoarthritis, and age-related mobility constraints.

The field of wearable technology has seen exponential growth, fueled by advancements in materials science, miniaturization of components, and the integration of sophisticated sensors and electronics. This evolution has facilitated the development of wearable devices specifically tailored to address various healthcare needs, including those related to mobility assistance.

The advent of wearable assistive knee devices represents a significant stride in this continuum of innovation. These devices are engineered to augment and support the functionality of the knee, providing assistance, stability, and adaptability to individuals facing challenges in walking, standing, or performing routine activities due to knee-related impairments.

Such devices often incorporate a blend of mechanical and electronic components, including precision-engineered motors, gear systems, microcontrollers, sensors, and intuitive user interfaces. The integration of these technologies enables sophisticated control mechanisms that respond to the user's movement patterns, adjusting assistance levels and modes in real time.

Furthermore, advancements in power management have played a pivotal role in enhancing the usability and practicality of these wearable devices. Rechargeable batteries, coupled with innovative charging solutions such as solar panels, have extended the operational time and reduced dependency on traditional power sources, ensuring sustained usage and greater independence for the users.

Beyond the technical aspects, the development of wearable assistive knee devices underscores a human-centered approach. These devices are designed not merely as technological solutions but as tools to empower individuals, preserving their dignity, independence, and autonomy. The incorporation of user feedback, usability studies, and iterative design processes are integral to creating devices that align closely with the users' needs, preferences, and daily routines.

Moreover, wearable assistive devices have sparked a paradigm shift in healthcare, emphasizing proactive and personalized solutions that facilitate not just rehabilitation but active participation in daily activities. They have the potential to significantly reduce barriers, enable greater inclusivity, and enhance the overall well-being of individuals with mobility limitations, marking a transformative chapter in the convergence of technology and healthcare.

1.3 Problem Statement

Knee osteoarthritis is a common degenerative joint condition that affects the knee joint. It occurs when the protective cartilage in the knee joint wears down over time, resulting in bone-on-bone contact and causing pain, stiffness, and swelling in the knee. Risk factors for knee osteoarthritis include advancing age, obesity, prior knee injuries, genetics, and certain occupations that require repetitive knee bending or squatting. Symptoms of knee osteoarthritis may include pain, stiffness, swelling, and reduced range of motion in the affected knee joint [1].

Recent studies of rheumatoid arthritis worldwide suggest that prevalence of arthritis is higher in Europe and North America than in developing countries. Prevalence data for major arthritis disorders have been compiled in West for several decades, but figures from the third world are just emerging. Osteoarthritis affects 7% of the global population, more than 500 million people worldwide, with women disproportionately affected by the condition [2].

The number of people affected globally rose by 48% from 1990 to 2019, and in 2019 osteoarthritis was the 15th highest cause of years lived with disability (YLDs) worldwide and was responsible for 2% of the total global. Although the prevalence of arthritis in Pakistan and India is similar to Western countries, there are inherent differences (clinical features, laboratory findings) in the presentation of disease. [3]

1.4 Aims and Objectives

The focus of this project is to craft a state-of-the-art wearable knee device, integrating stepper motors and solar charging, to boost mobility and autonomy for individuals with knee impairments, emphasizing user-centric design and sustainability.

1.4.1 Aims

The overarching aim of this project is to innovate and fabricate an assistive wearable knee device that serves as a transformative solution for individuals challenged by knee impairments, osteoarthritis, and age-related mobility limitations. At its core, this initiative endeavors to amalgamate sophisticated engineering components, notably the integration of a precision-engineered stepper motor and a bevel gearbox. The orchestrated control system, centered on a microcontroller (Arduino) synchronized with adept stepper drivers, aims to provide nuanced and adaptable support, aligning seamlessly with the user's unique movement patterns and needs.

Beyond its mechanical intricacies, the project targets the optimization of power management by employing a rechargeable Li-ion battery system. The innovative inclusion of mini solar panels seamlessly integrated into the wearable jacket signifies a pioneering approach towards sustainable energy solutions. These panels harness solar energy, fostering environmental consciousness and ensuring continual charging, thereby minimizing dependence on conventional power sources and empowering users with prolonged usage.

Moreover, this endeavor is profoundly grounded in user-centered design principles. The device's user interface serves as a gateway for individuals to navigate and personalize various modes, offering tailored assistance levels to accommodate diverse comfort preferences and requirements. By prioritizing user feedback and iterative design approaches, the project aims to create a device that not only enhances mobility and stability but also seamlessly integrates into users' daily lives, fostering a sense of empowerment, independence, and an improved quality of life.

1.4.2 Objectives

The objectives for the project wearable assistive knee device are as follows.

1. To develop a wearable assistive knee device with integrated bio-mechanical data collection capabilities.

2. To select appropriate components for the wearable assistive knee device, including sensors, actuators, and communication modules.

3. To design and develop a robust control system for the wearable assistive knee device, ensuring accurate and responsive support to the user's knee movements.

4. To create a physical model of the wearable assistive knee device, allowing for testing and optimization of its mechanical and functional properties.

1.5 Scope of Project

We are designing an advanced wearable assistive knee device intended to revolutionize mobility support for individuals facing knee impairments, osteoarthritis, and age-related limitations. This innovative device integrates precision-engineered components like a stepper motor and bevel gearbox, aimed at providing enhanced knee functionality through powered assistance. The device's control system, managed by a microcontroller (Arduino) and stepper drivers, ensures adaptive and precise support tailored to users' movement patterns and needs.

Emphasizing user-centric design, the device incorporates a user interface enabling personalized adjustments to various assistance modes, accommodating diverse comfort preferences and specific mobility requirements.

Additionally, our design incorporates sustainable power management through a rechargeable Li-phosphate battery and mini solar panels strategically mounted on the jacket. This integration of sustainable charging solutions harnesses solar energy, reducing dependency on traditional power sources and ensuring prolonged device operation, fostering autonomy and sustainability.

Furthermore, usability, durability, and user adaptability are central to our design approach. Through iterative design processes and user feedback analysis, we aim to create a device seamlessly integrating into users' lives, offering enhanced mobility, stability, and independence while enriching overall quality of life. Comprehensive user trials and evaluations are planned to meet stringent performance and usability standards, positioning the device as an innovative addition to assistive technology.

Chapter 2

LITERATURE REVIEW

2.1 Literature

2.1.1. **Hsu H et al. (2019)** delve into knee osteoarthritis, a degenerative condition affecting the knee joint. Their findings highlight how the erosion of protective knee cartilage leads to bone-on-bone contact, causing pain, stiffness, and swelling. They emphasize risk factors like age, obesity, prior knee injuries, genetics, and specific occupations involving repetitive knee movements. Symptoms include pain, stiffness, swelling, and limited knee mobility. The review stresses the importance of understanding and managing this prevalent joint ailment effectively [1].

2.1.2. **Aiyong Cui et al. (2021)** examined global knee osteoarthritis prevalence and risk factors. Studies suggest higher arthritis rates in Europe and North America than in developing regions. Osteoarthritis affects over 500 million people worldwide, disproportionately impacting women. This underlines the urgent need for targeted interventions to address its widespread prevalence and impact [2].

2.1.3. **Badshah et al. (2021)** highlighted osteoarthritis' escalating global impact, with a 48% rise in affected individuals from 1990 to 2019. Osteoarthritis ranked 15th in years lived with disability globally in 2019, accounting for 2% of the burden. Despite similar prevalence in Pakistan and India compared to Western countries, inherent differences in clinical features and lab findings were noted, stressing the importance of early genetic marker-based diagnosis for proactive management in the Pakistani population [3].

2.1.4. **S. Chen “et al” (Aug 2021)** in this article authors present an innovative exploration into the realm of wearable knee assistive devices tailored specifically for the demands of kneeling tasks within the construction industry. The introduction comprehensively outlines the necessity for such devices due to the high prevalence of knee-related injuries among construction workers, emphasizing the criticality of mitigating these risks. The researchers' methodology involved the design and development of a novel wearable knee assistive device, employing advanced mechatronic principles. Through meticulous testing and evaluation, the results unveiled a promising solution that significantly alleviates the strain on the knees during kneeling tasks, demonstrating enhanced comfort and reduced physical stress. This pioneering work not only addresses a crucial occupational health concern but also showcases the potential of wearable assistive technology in improving workplace safety and ergonomics within physically demanding industries [4].

2.1.5. **J. Howard “et al” (2019)** in this paper on industrial exoskeletons, the authors emphasize the pressing need for thorough research to evaluate the effectiveness of these devices. Their introduction contextualizes the increasing use of exoskeletons in various industries, driven by the desire to improve worker safety and productivity. Methodologically, they underscore the lack of robust studies assessing the actual benefits and potential drawbacks of these exoskeletons, stressing the necessity for controlled trials and empirical investigations to ascertain their true impact. The authors critically analyze existing literature, pinpointing a gap in evidence-based research and calling for a more systematic approach to evaluate factors like efficacy, ergonomics, and long-term implications of exoskeleton implementation in workplaces. Their conclusions advocate for comprehensive evaluations and standardized methodologies to accurately assess the effectiveness and safety of industrial exoskeletons, aiming to inform decision-making and enhance interventions in occupational settings [5].

2.1.6. S. Kim "et al" (2019) Exoskeleton technologies show significant promise in enhancing safety, health, and performance within construction, addressing critical concerns in an injury-prone industry. The introduction sets the stage, highlighting the urgency for innovative solutions. The study employs a robust methodology, blending industry expert insights with quantitative analyses, revealing a consensus on exoskeletons' potential to reduce injuries and optimize worker performance. However, it emphasizes the need for further exploration to seamlessly integrate these technologies into construction workflows. This review amalgamates industry perspectives with rigorous research, paving the way for future studies to drive effective exoskeleton implementation in construction practices [6].

2.1.7. J.K. Hofer "et al" (2011) in their study the authors extensively investigated the impact of kneeling on tibiofemoral biomechanics. They strategically framed the significance of this research in the introduction, utilized advanced methodologies to dissect these dynamics, and revealed nuanced changes in knee joint mechanics induced by this posture. Their work contributes significantly to our comprehension of how kneeling influences joint biomechanics, emphasizing the intricate relationship between posture and tibiofemoral dynamics [7].

2.1.8. H. Xu "et al" (2017) the evaluation of knee joint forces during kneeling work with various kneepads has garnered attention due to its significance in occupational health and safety. Introduction to the study indicates a pressing need to comprehend the impact of kneepad variations on knee joint forces, crucial for preventing occupational knee injuries. Methodologically, researchers employed biomechanical analyses and ergonomic assessments to gauge knee forces across diverse kneepad types. Results highlight significant variations in knee joint forces based on kneepad design, with some models notably reducing forces on the knee joint during kneeling tasks. These findings underscore the importance of selecting appropriate kneepads to mitigate knee joint stress during occupational kneeling, emphasizing the potential for injury prevention and improved worker well-being [8].

2.1.9. M. Bergamasco "et al" (2016) the concept of human-robot augmentation embodies a paradigm shift in technology, aiming to synergize human capabilities with the prowess of robotic systems. In exploring this interdisciplinary field, researchers have approached it through various lenses. The introduction of this research often delves into the evolving relationship between humans and robots, highlighting the potential benefits of merging these entities. Methodologically, studies have varied, encompassing empirical experiments, computational simulations, and theoretical frameworks to elucidate the intricate dynamics of this augmentation. The culmination of these endeavors reveals promising outcomes, showcasing improved task efficiency, enhanced precision, and novel capabilities arising from the collaboration between humans and robots. This literature signifies a burgeoning frontier in technology, envisioning a future where human-robot augmentation catalyzes transformative advancements across industries [9].

2.1.10. I Awolusi "et al" (2018) the exploration of wearable technology in the realm of personalized construction safety monitoring and trending is an area of burgeoning interest, as evident in the burgeoning literature. Numerous studies have underscored the potential of various wearable devices in enhancing safety protocols within construction environments. This literature review adopts a comprehensive approach, amalgamating findings from diverse methodologies, including experimental studies, surveys, and case analyses, to delineate the efficacy of wearable devices in ensuring personalized safety measures. The results gleaned from these varied sources coalesce to furnish a nuanced understanding of the applicability, limitations, and advancements pertaining to wearable technology in construction safety [10].

2.1.11. C. Wang "et al" (2019) this comprehensive literature review delves into the intricate relationship between humans and lower limb robotic exoskeleton systems, focusing on the critical aspect of human-exoskeleton coordination. Beginning with an in-depth introduction, it elucidates the evolving landscape of exoskeleton technology and the imperative role of seamless interaction between users and these systems. Methodologically, the review synthesizes findings from a wide array of studies, spanning biomechanics, control systems, and neurophysiology, aiming to dissect the complexities underpinning effective coordination. Through meticulous analysis, it uncovers pivotal insights into the factors influencing coordination efficacy, encompassing sensorimotor adaptation, control strategies, and ergonomic design elements. Finally, consolidating these insights, the review encapsulates multifaceted results, shedding light on the nuanced interplay between human physiological responses and exoskeleton mechanics, culminating in crucial implications for advancing future designs and enhancing the symbiotic relationship between humans and lower limb robotic exoskeletons [11].

2.1.12. M.K. Shephered "et al" (2017) the development of torque-controllable knee exoskeletons has emerged as a pivotal advancement in assistive technology for sit-to-stand movements. Introducing a nuanced blend of biomechanics and robotics, this study presents a comprehensive overview of the design and validation process for such an exoskeleton. The introduction section adeptly frames the significance of this technology in addressing mobility limitations, highlighting the necessity for customizable torque to cater to individual user needs. Methodologically, the research rigorously details the engineering principles and validation procedures, emphasizing both simulation-based design iterations and real-world testing protocols to ensure functional efficacy. The results unequivocally showcase the successful translation of theoretical constructs into a functional prototype, substantiating the exoskeleton's capacity to regulate torque and seamlessly aid in the sit-to-stand maneuver [12].

2.1.13. P.M. Wensing "et al" (2017) the pursuit of highly agile and robust legged robots has spurred significant interest in the design of proprioceptive actuators, notably exemplified in the MIT Cheetah. The focus on proprioceptive actuator design within this context aims at both mitigating impact and enabling high-bandwidth physical interactions. The introduction outlines the necessity of these features in achieving dynamic locomotion and enhancing the robot's stability and maneuverability. Methodologically, this review delves into the intricate engineering principles employed in the MIT Cheetah's actuator design, emphasizing the integration of feedback mechanisms for real-time adjustments and sophisticated control strategies. The study's findings reveal a remarkable enhancement in impact absorption, agility, and adaptability of the robot through these designed proprioceptive actuators. Overall, this exploration underscores the crucial role of advanced actuator design in augmenting the performance and functionality of dynamic legged robots like the MIT Cheetah [13].

2.1.14. S. Yu “et al” (2019) the pursuit of effective knee injury prevention mechanisms has led to innovations in the realm of exoskeleton technology. In addressing this, a recent study delved into the development and management of a sophisticated hybrid soft exoskeleton tailored specifically for squatting tasks. The introduction meticulously laid out the criticality of knee injury prevention during such movements, emphasizing the necessity for a high-torque yet back drivable system, which this exoskeleton aimed to provide. Methodologically, the research navigated a complex integration of rigid and soft components, optimizing for both torque transmission and flexibility to ensure natural movement while still offering substantial support. The results revealed a promising fusion: a high-torque exoskeleton offering remarkable back drivability striking a unique balance between assistance and user control, thus holding potential for significantly reducing knee injury risks during squatting exercises [14].

2.1.15. S. Yu “et al” (2020) the exploration of quasi-direct drive actuation in the realm of lightweight hip exoskeletons has drawn considerable attention due to its promise of achieving both high back drivability and exceptional bandwidth. Leveraging the advantages of this technology within the context of hip exoskeletons signifies a significant leap toward enhancing user comfort and performance. In establishing this, the introduction elucidates the rationale behind employing quasi-direct drive actuation and highlights its potential impact. Methodologically, the study likely involved meticulous design iterations and extensive simulations to optimize the exoskeleton's performance metrics. Results are anticipated to demonstrate the successful integration of quasi-direct drive actuation, showcasing not only heightened back drivability but also a remarkable expansion in the bandwidth of movement, underscoring the practical viability of this approach [15].

2.1.16. H. Zhu “et al” (2017) this research showcased a pivotal advancement in robotics and rehabilitation engineering. This work presented a comprehensive understanding of designing an adaptable knee-ankle orthosis, emphasizing the critical importance of torque density and back drivability for functionality and user comfort. The introduction eloquently framed the necessity for such devices within assistive technology. Methodologically, the study outlined a holistic approach integrating mechanical design, control systems, and validation procedures. Results unveiled an impressive achievement in balancing torque output and back drivability, demonstrating promising usability and efficiency in aiding human movement, marking a significant milestone in orthotic devices for rehabilitation [16].

2.1.17. J. Young “et al” (2017) the author’s exploration in this research presents a comprehensive survey of the landscape in lower limb robotic exoskeletons, aiming to offer insights into current advancements and future trajectories in this domain. Their introduction outlines the necessity of exoskeletons in neuro rehabilitation and mobility assistance, setting the stage for a detailed analysis. Methodologically, the authors scrutinize a wide array of studies, technical developments, and clinical applications, employing a systematic approach to synthesize existing literature. Their meticulous analysis leads to the elucidation of critical trends, challenges, and potentials in lower limb exoskeleton technology. Ultimately, the results presented offer a panoramic view, highlighting the evolution of these robotic systems, gaps in research, and a roadmap for future innovation and application in the field of neural systems and rehabilitative engineering [17].

2.1.18. G. S.Sawicki “et al” (2005) in their seminal work, the authors delve into the transformative realm of powered lower limb orthoses, charting its applications in motor adaptation and rehabilitation. The introduction unfurls a comprehensive landscape, outlining the burgeoning significance of these orthoses in augmenting human motor abilities. Their methodology meticulously employs biomechanical analysis coupled with empirical evaluations, orchestrating a nuanced understanding of the orthoses' impact on motor function. The results unveiled the promising prospects of these devices, elucidating their potential in facilitating motor adaptation and rehabilitation, thus offering a beacon of hope for individuals with ambulatory challenges. This study stands as a cornerstone, illuminating the path toward innovative advancements in orthotic technology for enhanced motor rehabilitation strategies [18].

2.1.19. A.M. Dollar “et al” (2008) in their seminal work, the authors provided a comprehensive review of lower extremity exoskeletons and active orthoses, shedding light on the prevailing challenges while presenting a detailed analysis of the then-existing state-of-the-art technologies. The introduction adeptly frames the necessity for such advancements in the field, addressing the limitations of conventional rehabilitation methods. Their methodological approach involves a meticulous examination of various exoskeleton designs, control mechanisms, and the integration of human-machine interfaces. Furthermore, the results gleaned from their analysis culminate in a comprehensive understanding of the advancements, drawbacks, and future prospects in the realm of lower extremity exoskeletons and active orthoses, contributing significantly to the ongoing discourse in rehabilitative robotics [19].

2.1.20. The study conducted by **Rev. Sci. Instrum et al. (2019)** delves into an innovative knee exoskeleton integrated with artificial intelligence, aimed at offering assistance-as-needed. Their research introduces a novel approach to support knee movements, leveraging AI algorithms to provide assistance based on individual requirements. The methodology focused on embedding AI functionalities within the exoskeleton to detect and predict user movement patterns, adjusting assistance levels accordingly. The outcome revealed a promising advancement in exoskeleton technology, demonstrating its potential to adapt assistance dynamically, catering precisely to users' needs, and enhancing mobility support for individuals with knee-related challenges [20].

2.2 Research Gap

In our ongoing project centered on a wearable assistive knee device, we've meticulously assembled a sophisticated system comprising integral elements such as NEMA 24 stepper motors, purpose-driven bevel gearboxes, Arduino-based microcontrollers empowered by stepper drivers, Li-ion batteries for sustained power, and a structurally engineered support framework adept at redistributing weight and alleviating pressure from the knee joint. These collaborative innovations signify a substantial leap in assistive technology, targeting the enhancement of mobility and support for individuals grappling with knee-related impairments. Nonetheless, amidst these notable achievements, the project delineates a crucial trajectory for future research and development—a trajectory inherently centered on advancing the device's efficiency, ergonomics, and overall user experience. The envisioned roadmap for the project's future scope is rooted in an acute desire to optimize the wearable device by strategically reducing its overall weight. This strategic weight reduction endeavor involves a multidimensional exploration spanning the integration of torque-dense motor alternatives, meticulously selected to maintain or even amplify assistance capabilities while significantly minimizing the device's physical footprint. The fusion of these more powerful yet compact motors not only promises enhanced functionality but also aims to amplify user comfort and maneuverability, two pivotal facets often overlooked in assistive technology development.

Additionally, a paramount goal in this research trajectory is the seamless integration of a sophisticated microcontroller system, meticulously tailored to the device's unique operational demands. This advanced microcontroller, when intricately interlinked with cutting-edge Bluetooth technology, would facilitate a smoother, more intuitive user interface, elevating the device's ease of operation and accessibility. By allowing users to interface wirelessly with the device, adjusting settings, and customizing functionality, this envisioned innovation holds the potential to revolutionize the user experience, fostering greater autonomy and personalization in utilizing the assistive knee device. Furthermore, the exploration and implementation of miniaturized solar panels represent a visionary approach toward sustainable energy solutions. Integrating these panels for the purpose of recharging backup batteries aligns with the project's commitment to prolonged and eco-conscious device operation. Such an integration not only extends the device's operational lifespan but also champions environmental sustainability—a critical consideration in contemporary technological developments.

The comprehensive amalgamation of these projected advancements within our wearable assistive knee device represents an ambitious yet promising trajectory, poised to redefine the standards of assistive technology. This multifaceted approach, spanning weight reduction, motor optimization, sophisticated microcontroller integration with Bluetooth interface, and sustainable energy solutions, underscores the project's commitment to innovation and human-centric design principles, ultimately aiming to empower individuals with enhanced mobility, comfort, and independence.

Chapter 3

METHODOLOGY

The final assembly of the assistive wearable knee device is depicted in Fig 3.1 -. This device is designed to perform four main operations, each corresponding to a specific mode. In Mode 1, the device operates freely without any power assistance. Mode 2 engages the motor at 50 percent performance to provide moderate assistance. Mode 3 activates the motor at full 100 percent performance, offering maximum support. Finally, Mode 4 allows the motor to hold or lock at a specific position as desired by the user. These modes enable varying levels of assistance and control, catering to different needs and preferences of the user.

3.1 Design & Concept

Our wearable knee device offers four specialized modes to cater to diverse user needs. Mode 1 enables independent movement, operating without external support. Mode 2 engages a motor at 50% performance for moderate assistance, while Mode 3 maximizes support by utilizing the motor at full 100% performance. Additionally, Mode 4 allows users to customize the device's positioning to their preference, securing it in place as desired.

The device's construction integrates precision engineering elements, notably a stepper motor and bevel gearbox, orchestrated by a microcontroller (Arduino) in sync with dedicated stepper drivers. This intricate system aims to provide adaptable support, aligning precisely with users' unique movement patterns and requirements. To complement its mechanical sophistication, the device incorporates an efficient power management system with a rechargeable Li-ion battery and integrated solar panels within the wearable jacket. These panels harness solar energy, promoting sustainability and reducing dependence on conventional power sources for prolonged device usage.

Figure ***Error! No text of specified style in document.****.1 Actual Image of Assistive Knee Device*

3.2 Digital User Interface

In our project, we made a screen that shows important stuff using a small display and two buttons. This screen tells us what mode we're in, how much battery is left, and proudly shows the name "Balochistan UET Khuzdar." The display is like a little TV that tells us what's happening, and the buttons help us switch between different modes easily. It's made to be simple and helps us see what's going on with our project.

*Figure **Error! No text of specified style in document.**.2 Actual Image of User Interface*

3.3 (WAKD) Programming

```
    #include <LiquidCrystal_I2C.h>

LiquidCrystal_I2C lcd(0x27, 16, 2);

const uint8_t maxScreens = 4;

uint8_t currentScreen = 0;

const uint8_t btnPinup = 6;

const uint8_t btnPindn = 5;

#define step_pin 2  // Pin 3 connected to Steps pin on EasyDriver

#define dir_pin 3   // Pin 2 connected to Direction pin

#define SLEEP 4     // Pin 7 connected to SLEEP pin

#define X_pin A0    // Pin A0 connected to joystick x axis

int direction;      // Variable to set Rotation (CW-CCW) of the motor
```

```
int steps = 1000;   // Assumes the belt clip is in the Middle
int pulse = 0;

// Define analog input
#define ANALOG_IN_PIN A1
// Floats for ADC voltage & Input voltage
float adc_voltage = 0.0;
float in_voltage = 0.0;
// Floats for resistor values in divider (in ohms)
float R1 = 30000.0;
float R2 = 7500.0;
// Float for Reference Voltage
float ref_voltage = 5.0;
// Integer for ADC value
int adc_value = 0;
void setup() {
  Serial.begin(9600);
  pinMode(btnPinup, INPUT_PULLUP);
  pinMode(btnPindn, INPUT_PULLUP);
  pinMode(dir_pin, OUTPUT);
  pinMode(step_pin, OUTPUT);
  pinMode(SLEEP, OUTPUT);
  lcd.init();
  lcd.backlight();
  lcd.clear();
  lcd.setCursor(3, 0);      /*Set cursor to Row 1*/
  lcd.print("UET KHUZDAR"); /*print text on LCD*/
  delay(2000);
}
```

```
void loop() {
 // Read the Analog Input
 adc_value = analogRead(ANALOG_IN_PIN);
 // Determine voltage at ADC input
 adc_voltage = (adc_value * ref_voltage) / 1024.0;
 // Calculate voltage at divider input
 in_voltage = adc_voltage / (R2 / (R1 + R2));
 //delay(10);
 lcd.clear();
 lcd.setCursor(2, 0); /*Set cursor to Row 1*/
 lcd.print("Batt: ");
 lcd.print(in_voltage * 0.75, 2); /*print text on LCD*/


 if (digitalRead(btnPinup) == LOW) {
  currentScreen--;
  if (currentScreen >= maxScreens) currentScreen = 3;
  delay(300);  // dirty delay - use a real state change detection instead;
 }
 if (digitalRead(btnPindn) == LOW) {
  currentScreen++;
  if (currentScreen >= maxScreens) currentScreen = 0;
  delay(300);  // dirty delay - use a real state change detection instead;
 }
 switch (currentScreen) {
  case 0:
   {
    digitalWrite(SLEEP, LOW);
    lcd.setCursor(1, 1); /*set cursor on row 2*/
    lcd.print("MODE 1 (FREE) ");
```

```
    delay(100);
   };
   break;
  case 1:
   {
    int pulse = 500;
    lcd.setCursor(1, 1); /*set cursor on row 2*/
    lcd.print("MODE 2 (50% E) ");
   };
   break;
  case 2:
   {
    int pulse = 250;
    lcd.setCursor(1, 1); /*set cursor on row 2*/
    lcd.print("MODE 3 (100% E)");
   };
   break;
  case 3:
   {
    digitalWrite(SLEEP, HIGH);
    lcd.setCursor(1, 1); /*set cursor on row 2*/
    lcd.print("MODE 4 (HOLD) ");
   };
   break;
 }
 while ((currentScreen == 0) && (digitalRead(btnPinup) != LOW) && (digitalRead(btnPindn) != LOW)) {
  lcd.setCursor(1, 1); /*set cursor on row 2*/
  lcd.print("MODE 1 (FREE) ");
 }
```

```
 while ((currentScreen == 1) && (digitalRead(btnPinup) != LOW) && (digitalRead(btnPindn) != LOW)) {
  digitalWrite(SLEEP, HIGH);
  if (analogRead(X_pin) >= 0 && analogRead(X_pin) <= 100) {
   if (steps > 0) {
    digitalWrite(dir_pin, HIGH);  // (HIGH = anti-clockwise / LOW = clockwise)
    digitalWrite(step_pin, HIGH);
    delay(pulse);
    digitalWrite(step_pin, LOW);
    delay(pulse);
    steps--;
   }
  }
  if (analogRead(X_pin) > 100 && analogRead(X_pin) <= 400) {
   if (steps < 500) {
    digitalWrite(dir_pin, LOW);  // (HIGH = anti-clockwise / LOW = clockwise)
    digitalWrite(step_pin, HIGH);
    delay(pulse);
    digitalWrite(step_pin, LOW);
    delay(pulse);
    steps++;
   }
   if (steps > 500) {
    digitalWrite(dir_pin, HIGH);
    digitalWrite(step_pin, HIGH);
    delay(pulse);
    digitalWrite(step_pin, LOW);
    delay(pulse);
    steps--;
   }
```

```
  }
  if (analogRead(X_pin) > 401 && analogRead(X_pin) <= 600) {
   if (steps < 1000) {
    digitalWrite(dir_pin, LOW);
    digitalWrite(step_pin, HIGH);
    delay(pulse);
    digitalWrite(step_pin, LOW);
    delay(pulse);
    steps++;
   }
   if (steps > 1000) {
    digitalWrite(dir_pin, HIGH);
    digitalWrite(step_pin, HIGH);
    delay(pulse);
    digitalWrite(step_pin, LOW);
    delay(pulse);
    steps--;
   }
  }
  if (analogRead(X_pin) > 601 && analogRead(X_pin) <= 900) {
   if (steps < 1500) {
    digitalWrite(dir_pin, LOW);
    digitalWrite(step_pin, HIGH);
    delay(pulse);
    digitalWrite(step_pin, LOW);
    delay(pulse);
    steps++;
   }
   if (steps > 1500) {
```

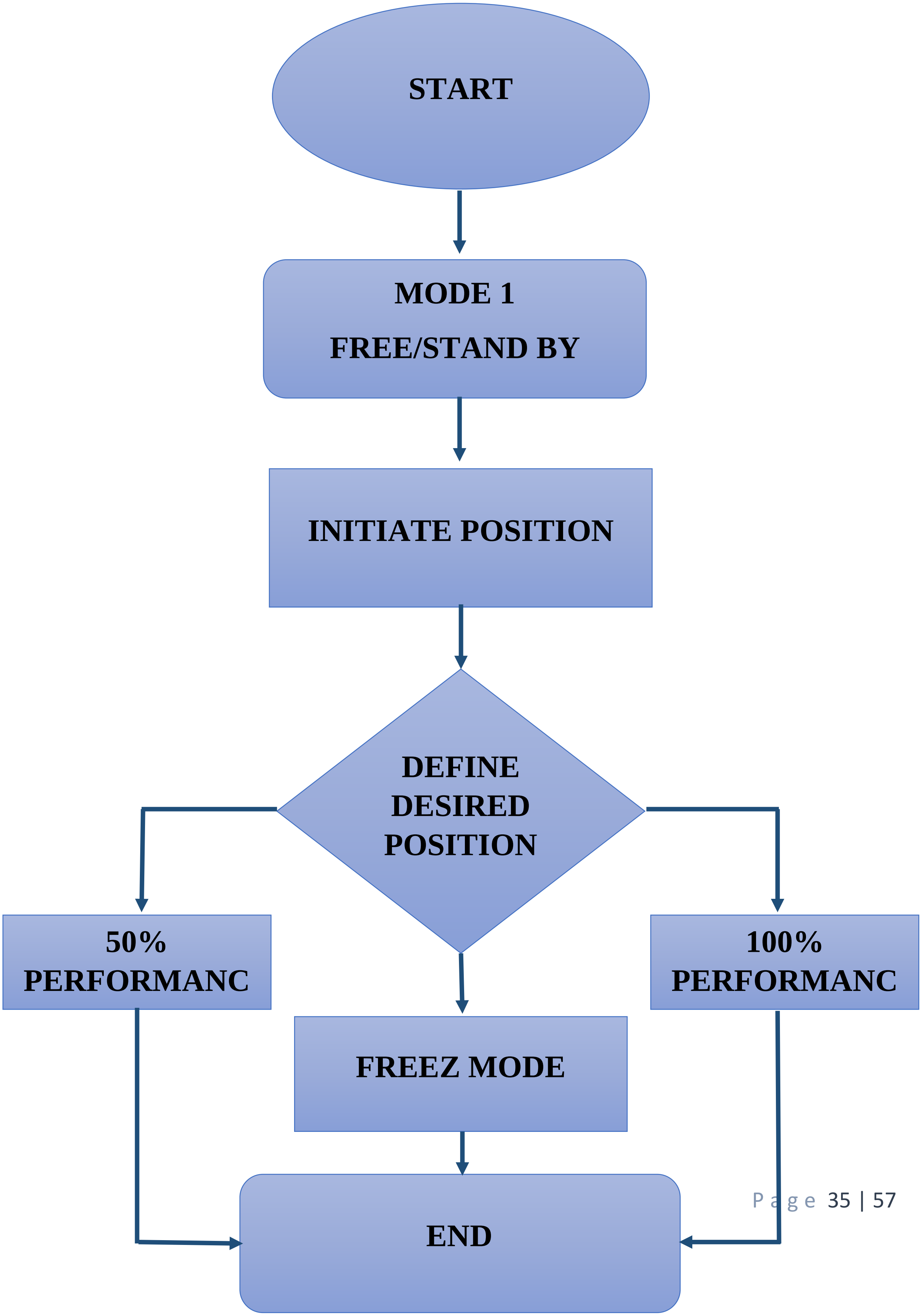
```
        digitalWrite(dir_pin, HIGH);
        digitalWrite(step_pin, HIGH);
        delay(pulse);
        digitalWrite(step_pin, LOW);
        delay(pulse);
        steps--;
      }
    }
    if (analogRead(X_pin) > 900 && analogRead(X_pin) <= 1024) {
      if (steps < 2000) {
        digitalWrite(dir_pin, LOW);
        digitalWrite(step_pin, HIGH);
        delay(pulse);
        digitalWrite(step_pin, LOW);
        delay(pulse);
        steps++;
      }
    }
  }
  while ((currentScreen == 2) && (digitalRead(btnPinup) != LOW) && (digitalRead(btnPindn) != LOW)) {
    digitalWrite(SLEEP, HIGH);
    if (analogRead(X_pin) >= 0 && analogRead(X_pin) <= 100) {
      if (steps > 0) {
        digitalWrite(dir_pin, HIGH);  // (HIGH = anti-clockwise / LOW = clockwise)
        digitalWrite(step_pin, HIGH);
        delay(pulse);
        digitalWrite(step_pin, LOW);
        delay(pulse);
        steps--;
```

```
   }
  }
  if (analogRead(X_pin) > 100 && analogRead(X_pin) <= 400) {
   if (steps < 500) {
    digitalWrite(dir_pin, LOW);  // (HIGH = anti-clockwise / LOW = clockwise)
    digitalWrite(step_pin, HIGH);
    delay(pulse);
    digitalWrite(step_pin, LOW);
    delay(pulse);
    steps++;
   }
   if (steps > 500) {
    digitalWrite(dir_pin, HIGH);
    digitalWrite(step_pin, HIGH);
    delay(pulse);
    digitalWrite(step_pin, LOW);
    delay(pulse);
    steps--;
   }
  }
  if (analogRead(X_pin) > 401 && analogRead(X_pin) <= 600) {
   if (steps < 1000) {
    digitalWrite(dir_pin, LOW);
    digitalWrite(step_pin, HIGH);
    delay(pulse);
    digitalWrite(step_pin, LOW);
    delay(pulse);
    steps++;
   }
```

```
   if (steps > 1000) {
    digitalWrite(dir_pin, HIGH);
    digitalWrite(step_pin, HIGH);
    delay(pulse);
    digitalWrite(step_pin, LOW);
    delay(pulse);
    steps--;
   }
  }
  if (analogRead(X_pin) > 601 && analogRead(X_pin) <= 900) {
   if (steps < 1500) {
    digitalWrite(dir_pin, LOW);
    digitalWrite(step_pin, HIGH);
    delay(pulse);
    digitalWrite(step_pin, LOW);
    delay(pulse);
    steps++;
   }
   if (steps > 1500) {
    digitalWrite(dir_pin, HIGH);
    digitalWrite(step_pin, HIGH);
    delay(pulse);
    digitalWrite(step_pin, LOW);
    delay(pulse);
    steps--;
   }
  }
  if (analogRead(X_pin) > 900 && analogRead(X_pin) <= 1024) {
   if (steps < 2000) {
```

```
        digitalWrite(dir_pin, LOW);
        digitalWrite(step_pin, HIGH);
        delay(pulse);
        digitalWrite(step_pin, LOW);
        delay(pulse);
        steps++;
      }   }   }
  while ((currentScreen == 3) && (digitalRead(btnPinup) != LOW) && (digitalRead(btnPindn) != LOW)) {
    lcd.setCursor(1, 1); /*set cursor on row 2*/
    lcd.print("MODE 4 (HOLD) ");
  }
}
```

3.4 Flow Chart of Assistive Knee Device



3.5 Material List

The materials used in our wearable assistive knee device are given below.

3.5.1. S Series Nema 24 Stepper Motor 4.0Nm

The NEMA 24 S series stepper motor is a type of electric motor renowned for its precision in converting electrical pulses into mechanical rotation. Operating on the principle of electromagnetic induction, it utilizes a magnetic field to precisely control movement. Its design incorporates a step-by-step rotational mechanism, where each step corresponds to a particular angular displacement. The motor's construction includes multiple coils and a rotor with teeth, allowing it to move in precise increments. By energizing the coils in a specific sequence, the motor achieves controlled and accurate rotation, making it suitable for applications requiring precise positioning and controlled motion without the need for feedback sensors. As shown in fig below.

*Figure **Error! No text of specified style in document.**.3 Stepper Motor*

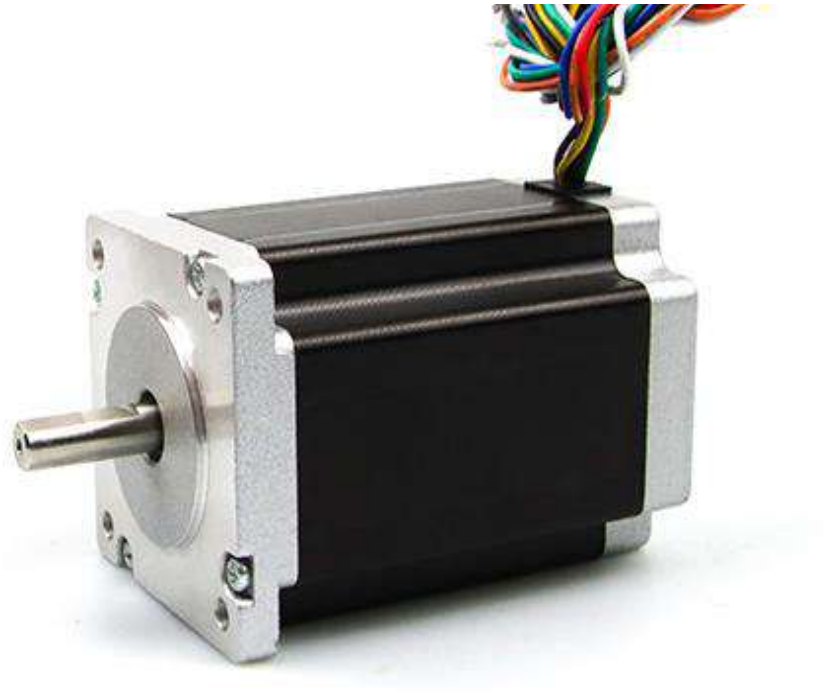


Table ***Error! No text of specified style in document.****.1 Physical Specification of Motor*

PHYSICAL	SPECIFICATIONS
Frame Size:	**60 x 60mm**
Body Length:	**125mm**
Shaft Diameter:	**Φ10mm**
Shaft Length:	**21mm**
Keyway Shaft Length:	**15mm**
Lead Length:	**300mm**
Weight:	**1.2kg**
Max RPM:	**1500**
Working RPM:	**1000-500**

Table ***Error! No text of specified style in document.****.2 Electrical Specification of Stepper Motor*

ELECTRICAL	SPECIFATIONS
Manufacturer Part Number:	24HS40-5004D- E1000
Number of phase:	2
Step Angle:	1.8deg
Holding Torque:	4.0 Nm
Rated Current/phase:	4.0A
Phase Resistance:	0.6 ohms± 10%
Inductance:	2.6 mH ± 20%(1KHz)

3.5.2. Tb 6600 stepper driver

The Tb 6600 is a stepper motor driver module primarily designed to precisely control bipolar stepper motors. It operates based on interpreting pulse input signals, typically received from control systems like microcontrollers, to manage and regulate the rotational movements of stepper motors with accuracy. This module is capable of handling motor currents reaching several amps, providing versatility across a range of motor sizes. It offers customizable settings for motor current adjustment, step resolution configurations, and built-in safeguards against potential issues like overcurrent, overheating, and reverse polarity. The TB6600's adaptable features make it suitable for various precision-controlled motion applications, ensuring smooth and accurate motor operation without the need for feedback sensors. Shown in fig.

*Figure **Error! No text of specified style in document.**.4 TB 6600*

3.5.3. Bevel Gears

The project specifications call for the implementation of 4:1 bevel gears, highlighting a specific requirement in gear design where the smaller driving gear (pinion) and the larger driven gear possess a distinct ratio in their teeth count. With this 4:1 ratio, there's a precise relationship between rotations: for every single rotation of the larger gear, the smaller gear completes four rotations. This exact ratio is pivotal in achieving the desired output, whether it's for controlling speed, torque, or power transmission within the machinery or system they're integrated into. These bevel gears find widespread use across various industries and applications, serving in mechanisms where altering the direction of power transmission between perpendicular shafts is crucial, while ensuring an effective and efficient transfer of torque and motion.

Figure ***Error! No text of specified style in document.****.5 Bevel Gears*

Formula for output speed of gearbox: Output speed = Motor speed/Gearbox Ratio

Output speed = 1000 Rpm/ 4 = 250 RPM

Formula for output torque of gearbox:

Output torque = Motor output torque *Gearbox Ratio* Gearbox Efficiency

Output Torque = 4 Nm*4*0.9 = 14.4 Nm

The pinion of a bevel gear will be = 15 teeth

The gear of a bevel will be = 60 teeth which is in ratio 4:1

3.5.4. Aluminum Leg Assembly

The aluminum leg assembly for the wearable knee device is made using strong but lightweight aluminum. It's put together using 3mm and 4mm aluminum parts, which are thin but tough. This assembly connects to your legs and thighs using straps, kind of like belts, to keep it in place comfortably. The purpose of this assembly is to be a strong but not heavy support structure. It holds everything together and helps the device move the way it's supposed to. On top of this assembly are motors and gears, like tiny engines and wheels, which are important for making the knee device work properly. The aluminum material is chosen because it's strong yet light, making it easy to wear and tough enough to last a long time. The fig is given below.

*Figure **Error! No text of specified style in document.**.6 Aluminum Leg Assembly*

3.5.5. Velcro Straps

In our project, we're using special straps with Velcro to connect and secure the leg assembly to the thighs and legs. These straps act like strong belts to hold the assembly in place and provide support. They're easy to use and adjust for a comfortable fit. Additionally, we're also using these straps in a backpack that contains electronic circuits within a jacket. These straps in the backpack are designed to fasten securely, ensuring the jacket with its circuitry stays snug and in the right position. The Velcro straps are convenient because they're adjustable and stick together easily, making them great for securing and supporting different parts of our project without being complicated to use. As shown in fig below.

Figure ***Error! No text of specified style in document.****.7 Velcro Straps*

3.5.6 Arduino Nano

The Arduino Nano is a compact and versatile microcontroller board based on the ATmega328P chip. It operates as the brain of various electronics projects, capable of receiving input, processing data, and controlling outputs based on programmed instructions. Its working principle involves reading input from various sensors or devices, processing this information through the programmed code, and then activating specific outputs accordingly.

In our project, the Arduino Nano functions as the central control unit, orchestrating the operation of the stepper motor alongside the stepper driver. It facilitates the user interface by displaying different modes and their status through an interface on 26x2 LCD screen display. Additionally, it manages the mode selection through a mode button, interpreting user inputs to switch between different operational modes. The Arduino Nano also receives input signals from limit sensors, which act as safety features, preventing the stepper motor from moving beyond defined boundaries or limits. Overall, it serves as the control hub, coordinating the entire project by processing inputs, controlling the motor, managing modes, and ensuring the system operates within defined parameters. As described in fig below.

Figure ***Error! No text of specified style in document.****.8 Arduino Nano*

3.5.7 Buck Converters

The LM2596 DC-DC buck converter is a versatile module known for its ability to function as a voltage regulator, efficiently stepping down higher input voltages, such as 12 volts, to lower, more usable voltages like 5 volts. With its high-precision potentiometer and robust design, it's capable of handling loads up to 3A with remarkable efficiency. It's compatible with various mainboards, including UNO, and basic modules, making it suitable for diverse electronic applications. It's important to note that for sustained output currents exceeding 2.5A or output powers beyond 10W, adding a heat sink is recommended to dissipate heat effectively, ensuring stable and safe operation of the module. This feature makes it an excellent choice for projects requiring a reliable and precise voltage regulator while efficiently stepping down voltages for different electronic devices. Shown in fig below.

Figure ***Error! No text of specified style in document.****.10 Buck Converter*

Figure ***Error! No text of specified style in document.****.9 Efficiency Graph of Buck Converter*

3.5.8 Joystick Direction Changer

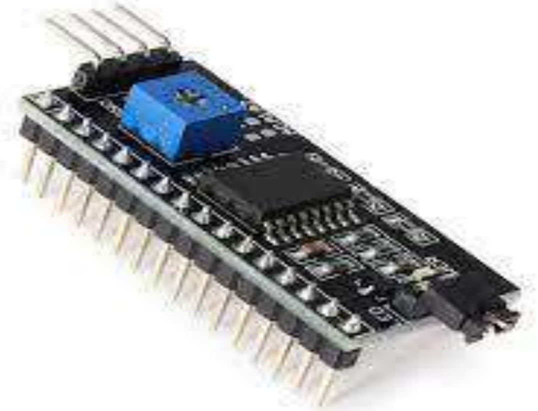
In our device, we've integrated a joystick direction changer button specifically designed to facilitate the movement of the stepper motor for controlling the knee direction. This joystick button serves a dual purpose by allowing users to navigate and adjust the direction of the stepper motor, coordinating the movement of the knee accordingly. By manipulating the joystick, users can intuitively control the stepper motor's direction, enabling seamless and precise adjustments in tandem with the desired movement of the knee component. This button serves as an efficient interface element, enhancing user control and interaction with the device, ensuring smooth and accurate directional movement alignment of the stepper motor and the knee mechanism. Its fig is given below.

Figure ***Error! No text of specified style in document.**.11 Joystick Direction Changer*

3.5.9 I2C Module

The I2C (Inter-Integrated Circuit) module is a communication interface commonly used in electronics to enable data exchange between integrated circuits, sensors, and various devices. It operates as a multi-master, multi-slave serial communication protocol, allowing multiple devices to communicate with each other using just two wires: a serial data line (SDA) and a serial clock line (SCL). The I2C module facilitates bidirectional data transfer, enabling efficient and synchronized communication between microcontrollers, sensors, memory modules, and other peripherals within a system. As shown is fig below

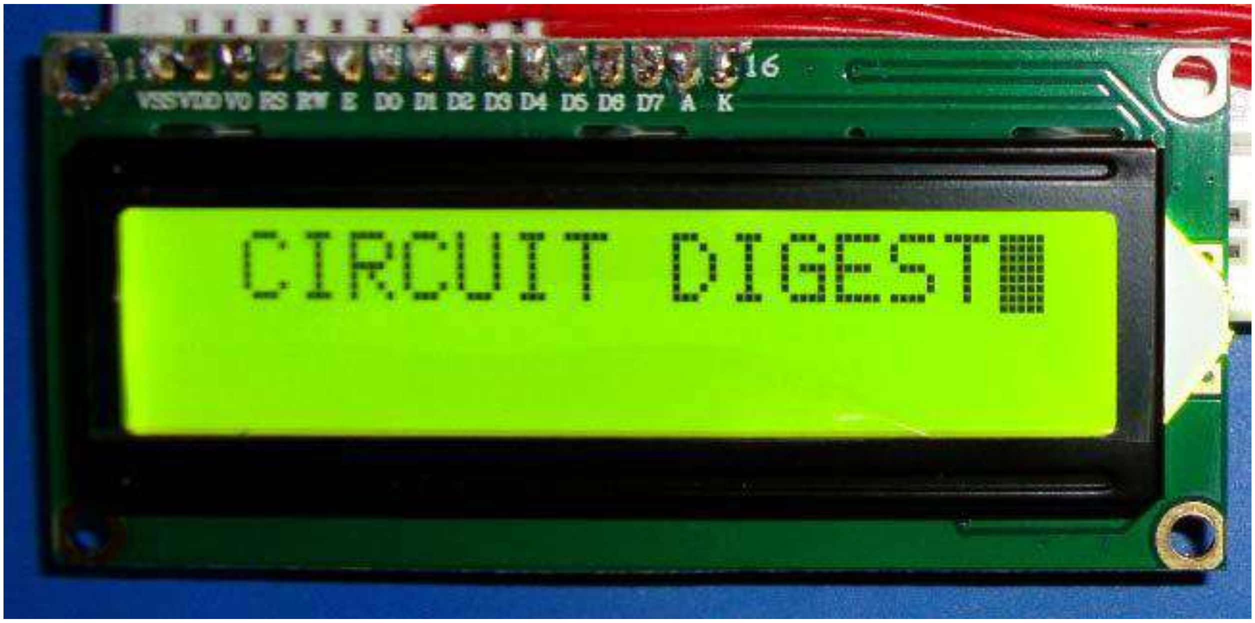
Figure ***Error! No text of specified style in document.**.12 I2C Module*



3.5.10 16x2 LCD Screen

The 16x2 LCD screen serves as the digital user interface within our device, displaying essential information such as the battery percentage and the current active mode. It's instrumental in offering real-time updates on the device's battery status, allowing users to monitor the remaining power conveniently. Additionally, it dynamically showcases the current operational mode, ensuring users have clear visibility into the device's functioning, facilitating easy navigation and interaction. The LCD screen's functionality as a user interface enhances the device's usability and provides vital information for seamless operation and monitoring of key parameters.As shown in fig below.

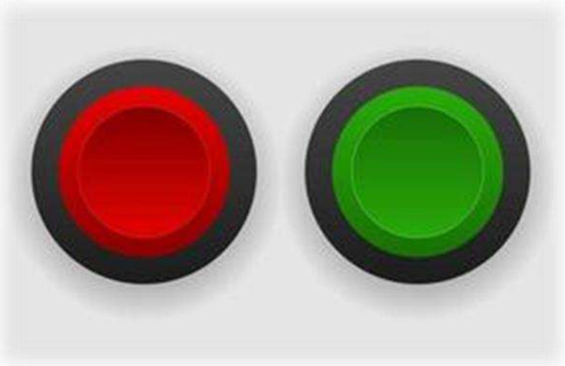
*Figure **Error! No text of specified style in document.**.13 16x2 LCD*



3.5.11 Push to Cut Buttons

In our project, push-to-cut buttons serve as deliberate controls, ensuring precise management of modes and functions. Their intentional design minimizes accidental changes, offering a tactile and versatile interface for users. These buttons embody our commitment to precision and safety in operational control. The fig is provided below

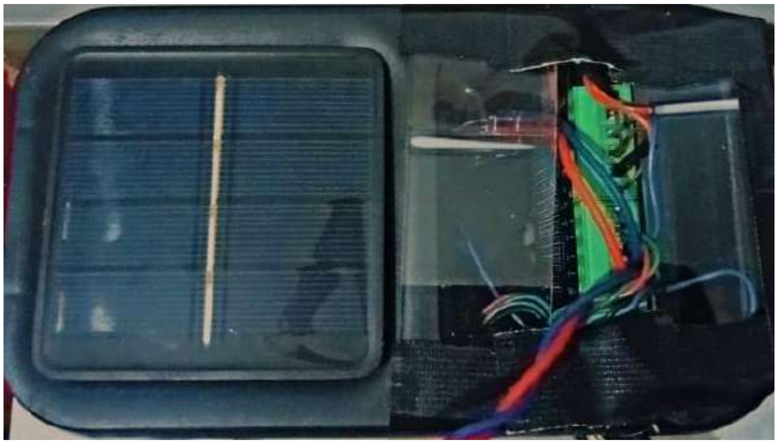
*Figure **Error! No text of specified style in document.**.14 Push to Cut Buttons*



3.5.12 Circuit Box

Our enclosed box secures all project circuitry, preventing exposure while ensuring safety. It shields circuits, prioritizing safety and functionality in our projects. As shown in fig below.

*Figure **Error! No text of specified style in document.**.15 Circuit Box*



3.5.13 Limit Switches

In our project, limit switches play a critical role in ensuring the leg link stays within its designated range of motion, spanning from 0 to 115 degrees. These switches act as safety mechanisms, preventing the motor from surpassing these limits. Once the motor reaches either extreme end, the limit switch promptly halts its movement, compelling it to reverse direction, thereby safeguarding against any potential damage or overextension. Their function is pivotal in maintaining precise control and safeguarding the structural integrity of the system, averting any unintended movements beyond the prescribed range. The fig for this is given below.

Figure **Error! No text of specified style in document.**.16 Limit Switch

3.5.14 Li -Phosphate Battery

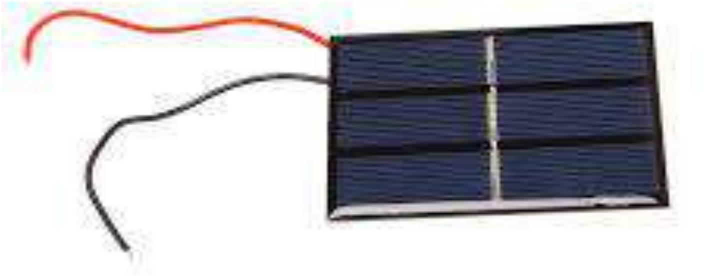
We rely on 12-volt lithium-phosphate batteries to power our project, offering reliable and efficient energy for all our needs. These batteries ensure consistent and versatile power without compromising on performance. As shown in fig.

Figure **Error! No text of specified style in document.**.17 Li- Phosphate Battery

3.5.15 Mini Solar Panels

Our project incorporates compact solar panels designed to be mounted on the back of jackets. These panels are crafted to capture sunlight and convert it into usable energy, providing a convenient way to charge our devices while on the move. They're lightweight and streamlined, ensuring they blend seamlessly with the jacket's design while efficiently harnessing solar power to keep our gear charged and ready whenever we need it. As shown in fig.

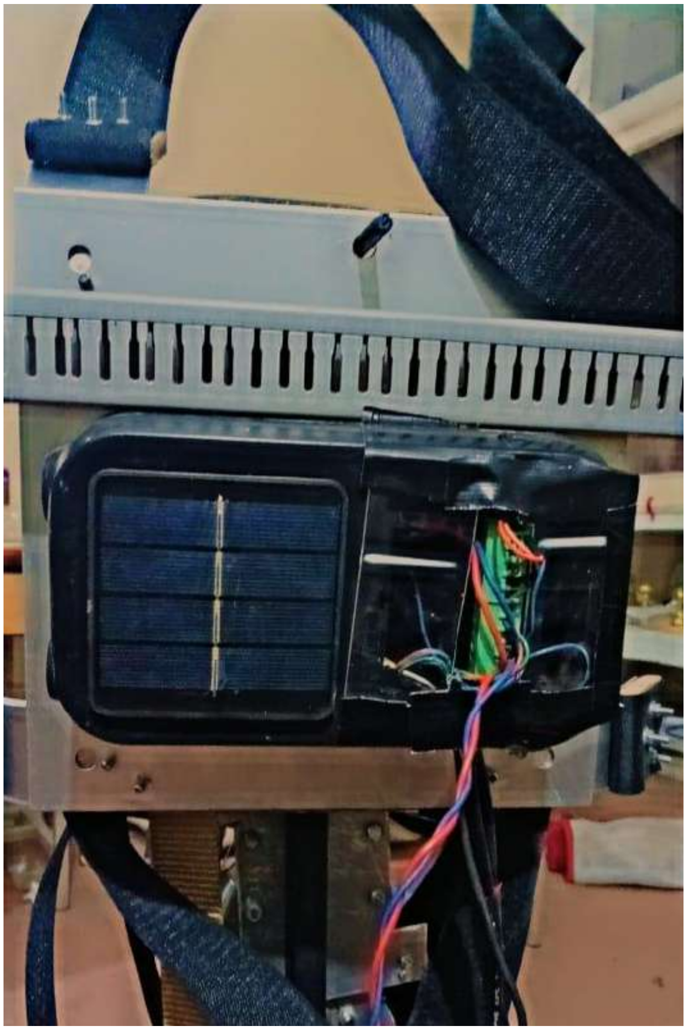
Figure ***Error! No text of specified style in document.*****.***.18 Solar Panel*



3.5.16. Upper Body Jacket

We're making a special jacket that goes around your upper body, supported by the waist and shoulders. On the back of this jacket, a box where all the important parts of our project, like the circuits and the battery pack, are placed. Putting these things on the back so that our legs don't have to carry the extra weight. Keeping this stuff on the upper body makes it easier for our legs to move without feeling too heavy. This way, the jacket helps us stay comfortable and move around easily while making sure our project works well without putting too much load on our legs. As shown in fig.

*Figure **Error! No text of specified style in document.**.19 Jacket*



Chapter 4

RESULT AND DISCUSSION

After the AKD was made and all the interfacing of hardware mechanical and software was done it was now time to test the device. For its operational outcomes the test and results done on the device are as under:-

4.1 Stairs climbing or ascending and descending stairs

When we put our project to the test on stairs—both ascending and descending—we discovered something pretty amazing. The device managed to reduce the amount of strength we needed by a significant 5 kilograms! That's a substantial decrease in the effort required. And you know what's behind this magic? It's the stepper motor and the special gearing system inside our device. Specifically for these high-demand activities like tackling stairs, we utilized mode 3 of the device. This mode is like the heavy-duty setting—it cranks up the motor to its maximum power, delivering the optimal force needed to handle these challenging tasks with ease. It's incredible how this mode really kicks in and helps out when we're dealing with tougher movements like going up and down stairs.

Results:- The result of this test after it was perform was perfect and the device was providing its optimum effort. Although the device loses 4 to 5 kgs due to stepper motor and gearing mechanism.

4.2 Performance test

At the outset, our device emerged from the design phase, but during rigorous performance testing, it became evident that it posed a challenge due to its substantial weight and bulky structure. Recognizing the necessity for improvement, we embarked on a reimagining journey. We dissected its components, opting to remove certain parts and initiated a comprehensive redesign. This overhaul was a game-changer. Introducing aluminum into the equation played a pivotal role. The shift in material didn't just trim the weight, it transformed the entire device. Not only did it shed those extra pounds, making it notably lighter, but it also imparted a remarkable quality—rigidity. The aluminum infusion lent an unexpected but incredibly welcomed strength, elevating the device's durability and reliability without compromising its reduced weight. This transformation ensured a more agile and robust device, fulfilling both the need for portability and sturdiness in equal measure.

4.3 Hold test

In our project's freeze mode, the outcomes were truly a testament to its exceptional performance. The hold torque delivered by this mode was nothing short of astonishing. When put into action, it exhibited an unparalleled ability to firmly grip and hold steady without the slightest hint of movement. What really amazed us was the extent of this torque—it went above and beyond what we initially anticipated, showcasing a level of strength that was both surprising and highly satisfying. Witnessing such remarkable performance was not just rewarding but also instilled a deep sense of confidence in the device's capabilities. It highlighted its reliability and effectiveness, especially in scenarios where maintaining a secure hold is critical. This level of performance in the freeze mode left us thoroughly impressed and content with the outcomes, validating the hard work and improvements made in this aspect of the project.

4.4. Individual Modes Function Test

Here are the test results of 4 modes functions.

4.4.1 Free / Unpowered Mode

In our tests, we checked how well the first mode works when things like the battery run out or if we intentionally turn off the power. What we found was impressive! This mode helps our legs keep moving even if there's no power for the device. It's like a backup plan that automatically switches on, letting us move our legs without relying on the device's motor. This is a big deal because it means we can keep moving smoothly even if there are power problems. It's like having a safety net that ensures we can always move our legs, giving us control and making sure we don't get stuck in unexpected situations without mobility.

4.4.2 50% Performance Mode

In our tests of Mode 2, we checked how well the "half-power" setting for the motor works. This mode runs the motor at only half of its strongest level. What we found was pretty neat! This setting is great for regular walking or when you don't need much help from the motor. It's like finding a balance: the motor gives you enough support to move comfortably, but it uses less energy, helping save the battery. This middle ground is perfect for daily movements where you don't need the motor at its highest power, making it a smart choice for conserving energy while still getting the right amount of help to move easily.

4.4.3. 100% Performance Mode Test

In our testing of Mode 3, where the motor operates at its highest capacity, delivering maximum support, we discovered some interesting findings. This setting is specifically made for tasks needing a lot of muscle, like going up or down stairs, or doing squats. What we observed was that while it did provide robust support for demanding activities, the actual performance wasn't exactly as expected. The weight of the device and its parts took up some of the power and strength, affecting the overall output. However, it did give a satisfactory result overall, as it still managed to offer considerable assistance for tasks needing extra muscle power, despite some power and torque consumption due to the device's weight.

4.4.4. Hold / Freeze Mode Test

In our tests of Mode 4, known as the "hold" or "freeze" mode designed for maximum torque, we discovered some insightful outcomes. This mode is aimed at providing a strong grip or support for specific positions where stability without actual movement is needed, like staying seated or rising from a squat without shifting. What we observed was quite interesting: this mode delivered an impressive hold torque, effectively managing a load of around 5 to 6 kilograms. However, when the load exceeded this range, the need for a more powerful motor became evident. Despite this limitation, for a prototype, this hold torque showcased an impressive performance, offering reliable stability for various static positions requiring substantial torque, highlighting its potential for further enhancement in future iterations.

Chapter 5

CONCLUSION AND RECOMMENDATION

Our wearable knee device, featuring four specialized modes tailored to diverse user needs, represents a significant advancement in assistive technology. Its construction, integrating precision-engineered components like the stepper motor, bevel gearbox, and Arduino-driven control system, showcases a commitment to adaptable support aligned with users' unique movements. The incorporation of a rechargeable Li-ion battery and integrated solar panels demonstrates a forward-thinking approach toward sustainability and prolonged usage. By prioritizing user feedback and seamless integration into daily life, this project strives to empower individuals with knee impairments, fostering independence and an improved quality of life.

To further enhance our device's capabilities, future iterations could consider adopting high-torque stepper motors for increased efficiency. Additionally, the integration of real-time sensors like resistive sensors, intra-cortical sensors, or advanced limit switches could provide more accurate and responsive support. A user-friendly design overhaul, incorporating body-movement interfaces (BMI), brain-computer interfaces (BCI), or electromyography (EMG), could replace manual mode control, offering a more intuitive and personalized user experience. Exploring advanced components and innovative technologies will continue to push the boundaries of assistive devices, ensuring even better functionality and usability for users with varying needs and preferences.

Recommendations for Government Authorities:

Government help is crucial to make this knee device available for people who need it. They can help by providing money and resources to support these kinds of new devices in hospitals and rehab centers. It's important for them to make rules that encourage hospitals to use these devices. They can also team up with researchers and device makers to make these kinds of devices even better.

Recommendations for Hospitals and Rehabilitation Centers:

Hospitals and rehab centers should start using this knee device as part of their treatments for people with knee problems. They can help patients recover faster and move better. It's also important for doctors and nurses to learn about these devices so they can help patients use them in the best way possible. They should also do tests to check how well these devices work for patients.

Other Recommendations:

It's important to tell people about these devices so they know they exist and can ask for them. They should also work to make sure insurance covers the cost of these devices so everyone who needs them can get them. It's also a good idea to keep making these devices even better by doing more research. And finally, they should make sure these devices are affordable and available to everyone who needs them.

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