AN EMG CONTROLLED ADJUSTABLE LOWER LIMB EXOSKELETON FOR ASSISTANCE AND REHABILITATION

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Abstract- This paper focuses on the development of an adjustable lower limb exoskeleton (ALLE) to help people with lower limb limitations, especially the elderly, to gain mobility, independence, comfort, and assistance. In order to improve the lives of people with lower limb impairments the devised ALLE is composed of actuator gear mechanisms (AGMs), adjustable leg links, joints, and control and electric circuits. The ALLE can be operated in both manual (as a rehabilitation device) and EMG mode (for elderly user's assistance). For precise movements, a PID control, microcontroller, motor drivers, optical encoders, EMG electrodes, and EMG sensor module are incorporated. The performance of developed ALLE is tested for both manual and EMG modes during knee motion, hip motion, sit-stand motion, and walking motion. The testing shows that the performance of the devised ALLE is quite adequate and promising as an assistive device for users with constrained lower limb mobility.

Index Terms- EMG-controlled, Adjustable lower limb, Exoskeleton, Rehabilitation robotics, Assistive technology, Biomedical engineering.

I. INTRODUCTION

Lower limb mobility limitations have prompted the demand for assistive devices to increase mobility and independence, especially among the senior population. In order to help people with lower limb disabilities, adjustable lower limb exoskeletons have come to be recognized as a possible solution to these problems [1]. A customize lower limb exoskeleton that is specifically adapted to the demands and requirements of people who have trouble sitting, standing, or walking is gaining interest.

Work on lower limb exoskeleton is being conducted to improve the quality of life for people with lower limb disabilities, especially the elderly, moreover, such devices are also applicable for people with spinal cord injuries for permanent usage or as a rehabilitation tools. According to the global estimate provided by the National Spinal Cord Injury Statistical Center (NSCISC) [2], approximately 288,000 people are affected by spine injuries, which not only incur significant lifelong medical expenses but also limit movement and cause emotional misery. These people have a chance to restore movement and participate more effectively in daily activities thanks to the use of assistive exoskeletons [3].

The existing adjustable lower limb exoskeleton technology, however, has limitations that prevent its wide implementation and applications. There is a need to further integrate these exoskeletons into social interactions and everyday tasks, even if attempts have been made to improve flexibility, adaptation, and adjustability to the human users [4]. Development is concentrated on improving synchronization with human motion kinematics while still offering the required comfort and safe operation. It's critical to strike a balance between utility and aesthetics, because a bulky, rigorously built exoskeleton can prevent societal acceptability [5]. Internal and external testing [6] evaluated the adjustable lower limb exoskeleton's mechanical efficiency, user comfort, and influence on mobility and quality of life for lower limb disabled people.

II. LITERATURE REVIEW

Assistive technology has embraced adaptable lower limb exoskeletons. These exoskeletons help lower limb-impaired people to regain movement and quality of life.

Exoskeleton development has been reported in literature and moreover, these devices are also commercially available. A lightweight exoskeleton frame materials including Aluminum and Teflon to balance comfort and strength is reported in [8] [7]. Furthermore, adjustable design characteristics for diverse body types and shapes were analyzed.

An electromyography (EMG) controlled exoskeleton actuation mechanism to support lower limbs is produced in [8] [9]. In the exoskeleton, electric motors, gears, and transmission systems are integrated to accurately translate control signals. Microcontrollers generate control signals from sensors, like gyroscopes, accelerometers, and EMG muscle sensors.

A real-time feedback proportional integral derivative (PID) controller for accurate control is utilized in the exoskeleton [9] [10], so that the exoskeleton's control system is more responsive and adaptive to integrate with user movements. Muscle sensor signals are used to actuate the exoskeleton's movements. Exoskeleton frame materials must be lightweight and robust. Aluminum and carbon fiber composite frame materials for exoskeleton applications is tested in [10]. To maximize user experience and durability, studies advised balancing comfort and strength.

Lower limb exoskeletons must be adjustable to fit different body types. Adjustable joint angles and limb lengths allow a tailored fit and appropriate assistance [11]. The study found that with adjustable features, the exoskeletons further improve mobility and lower limb muscular strain.

Lower limb exoskeleton design and operation prioritize safety. Exoskeleton stability, joint alignment, and user training is examined in [12]. To utilize exoskeletons safely and effectively, thorough training and user education are essential.

Lower limb exoskeleton research has also examined user experience and acceptance. Moreover, adjustable lower limb exoskeleton user satisfaction is also examined [13]. The results showed that participants were comfortable and accepted the exoskeletons, which improved their mobility and daily activities.

Lower limb exoskeletons have also been tested for energy efficiency and gait improvement and examined lower limb exoskeleton biomechanics [14]. Walking speed, energy expenditure, and joint movement control improved. These results showed that lower limb exoskeletons can increase mobility and function.

Lower limb exoskeleton development and evaluation have advanced, however, there are still issues to overcome [15]. The exoskeleton technology's bulkiness and limited adjustability can impair user acceptability and incorporation into daily life. The report recommended more research to improve synchronization with organic human movement and balance utility and beauty.

Researchers tested adjustable lower limb exoskeletons ALLEs) extensively. Clinical investigations by [16] examined mechanical efficiency, user comfort, mobility, and quality of life. Walking abilities and daily effort improved significantly.

The exoskeleton uses sensors that are carefully positioned on both side of the user's body to provide tailored assistance. These sensors gather essential data, such as user movements, joint angles, and muscle impulses [17]. The microcontroller then processes the data that was collected for the actuators.

Overall, the ALLE and operating system integrate lightweight materials, an actuation-gear mechanism, sensors, and a microcontroller to produce a flexible and adaptable assistive device [18]. For people with lower limb impairments, this technology strives to improve mobility, independence, and all other aspects of quality of life.

Collectively, ALLEs can help those with mobility issues. However, lightweight materials, innovative actuation mechanisms, and sensitive control systems to promote mobility, comfort, and quality of life are real challenges. Moreover, the development of adjustable lower limb exoskeletons is also in demand due to the wide range of implementation in different-sized patients. Moreover, lower limb exoskeleton design and fabrication needs modification to address numerous aspects. The mechanical design requires considering lightweight exoskeleton frame materials like Teflon and Aluminum. Integrating motors, gears, and transmission systems into an actuation system that helps translate control signals into correct lower limb support. An adaptable control system that can handle EMG, sensor data is used to provide synchronized and responsive support [19]. Lab and clinical trials need to evaluate the changeable lower limb exoskeleton. The exoskeleton's mechanical efficiency, user comfort, and ability to improve lower limb disability mobility and quality of life require further investigations [20].

This work influences lower limb exoskeleton and assistive technology. It examines the development and construction of an adjustable lower limb exoskeleton that addresses the mobility concerns of those with lower limb limitations, notably the elderly. By fixing current technology's flaws and improving flexibility, adaption, and social acceptance, the ALLE could greatly improve mobility, independence, and well-being. The developed ALLE has the capability to be operated in manual mode as a rehabilitation device as well as in EMG mode for elderly user's assistance. The ALLE devised for the precise speed and torque is composed of a dual gear train mechanism, one is integrated with the DC electric motor, however, the other is part of the actuator gear mechanism at the knee and hip joints. Adjustable Femur link and Tibia link are incorporated to accommodate different height users. Additionally, in order to control the ALLE, a PID control, microcontroller, motor drivers, optical encoders, EMG electrodes, and EMG sensor module are implemented and tested with adequate results for both manual and EMG modes during knee, hip, sit-stand, and walking motions.

III. PROTOTYPE ARCHITECTURE AND WORKING PRINCIPLE

The solid model of an adjustable lower limb exoskeleton (ALLE) is shown in Fig. 1; however, for the joint movement the actuator-gear mechanism for the rotation is shown in Fig. 2.

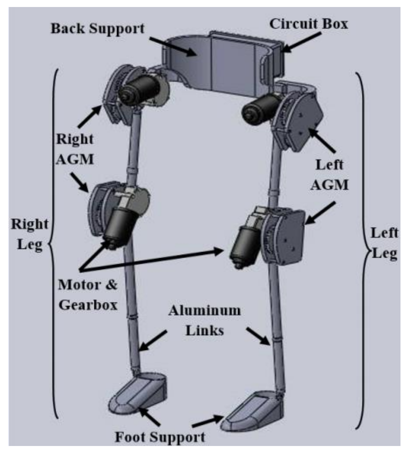

Figure. 1. 3D model of an adjustable lower limb exoskeleton

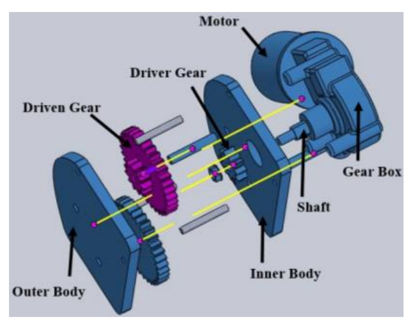

Figure. 2. Exploded view of the actuator-gear mechanism

To develop the ALLE to support and help those who have lower limb constraints. The exoskeleton is made up of several important components that cooperate to make it functional. The devised ALLE comprised of links, joints, actuators, control circuit, an EMG muscle sensor kit, electric motor drivers and position encoders. As depicted in Fig 1, the back support is attached with to exoskeleton legs, each composed of two actuator-gear mechanisms (AGMs), Femur link, Tibia link, foot link (for shoe or foot support). In order to accomplish the joint movements (rotation) at the hip and knee, the actuator-gear mechanism (AGM) is utilized. As shown in Fig 2, each AGM consisted of a DC motor with an integrated gearbox (speed reducer), a compound gear train to further tailor the speed and torque at the joints. Moreover, for the operation and control the ALLE has a control system comprised of a microcontroller, motor driver, and encoder. Additionally, for EMG mode operation, an EMG electrode and muscle sensor circuit (for EMG signal processing) is exploited. Moreover, in order to accommodate different sizes and height subjects in the ALLE, both links are kept adjustable, and adjustable lock belts are used.

A microcontroller-driven actuation-gear mechanism is the basis of the exoskeleton's operation. This mechanism allows for accurate joint control and movement due to its motors, gears, and actuation systems. The actuation-gear mechanism is driven by these control signals, allowing the exoskeleton to move in unison with the user's body. The control signals are meticulously tuned to deliver precise and accommodating support catered to the user's requirements.

During operation the microcontroller controls all the tasks, as shown in Fig 3, in the microcontroller a PID control is used to manage the AGM electrical motor (actuator) through the motor driver. Moreover, for a close loop operation, an encoder sends the actual motor rotation to the microcontroller, where it is compared with the desired input position.

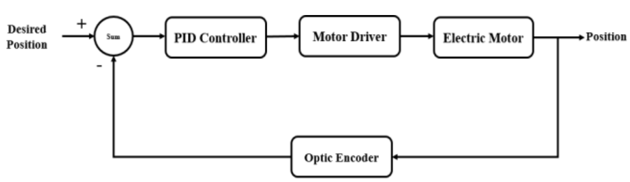

Figure.3. Feedback Control Loop of ALLE

The devised ALLE is supposed to be operated in two modes. Firstly, in manual mode, as a rehabilitation device and secondly, in EMG mode as a power assistive device. In the manual operation mode, command is given from a laptop and transmitted to the microcontroller. The microcontroller then processes the desired rotation information which is used to control the motor actuator through the motor driver and position encoder. The joint movements are adjusted accordingly, with encoder feedback ensuring accuracy. However, in the EMG operation mode, the overall setup remains the same, but in this, an EMG muscle sensor is employed to provide signals to the microcontroller. The EMG electrodes after collect the EMG signal, sends the pulse signal to the muscle sensor, which processed and refine the signal for a microcontroller. The subsequent steps remain identical, with the microcontroller processing the data to determine the desired rotation, enabling precise control over the exoskeleton's movements.

IV. DEVELOPMENT OF THE PROTOTYPE ALLE

The development process of the ALLE prototype involves the integration of various components and technologies to create a functional and user-friendly device. During the development the main tasks are; the fabrication of AGM, links and joints, and the development of control and electronic circuit. Aluminum, Teflon, and acrylic are among the lightweight, versatile materials used to build the exoskeleton's basic framework. This maintains a harmony between strength and comfort, enabling easy movement while offering sufficient support. [18]

A. *Fabrication of Actuator-Gear Mechanism*

The ALLE actuator-gear mechanism as shown in Fig 4, involves multiple components. It includes a 12V, DC electric motor with an integrated gearbox for desired rotation and speed. Teflon gears, including a driven and driver gear, for further speed and torque alteration, are used to transmit motor rotation to the exoskeleton's links. Optical encoders and modules provide reliable feedback. Acrylic makes the internal and exterior body sections strong but lightweight. The AGM and exoskeleton linkages transfer motion and support the user's lower limbs.

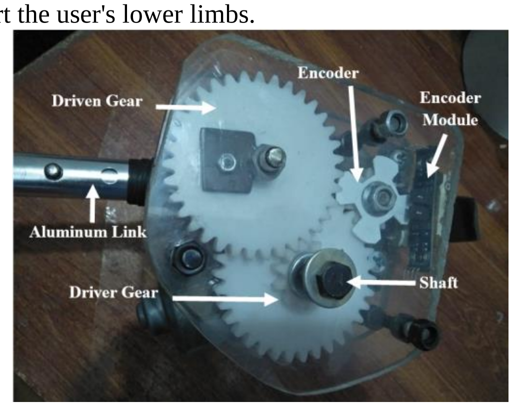

Figure. 4. The AGM of ALLE

B. *Fabrication of Links and Joints*

Aluminum rods are used in the fabrication of links for the ALLE as depicted in Fig 5. Users of varied heights can be accommodated by the changeable height of the links that connect the various exoskeleton components. Four of the AGM joints, which are placed at the knee and hip joints, are used as the exoskeleton's joints. Links that may be adjusted connect these joints, enabling flexibility and customization. The exoskeleton prototype is designed with these joints to support and help persons with lower limb constraints, encouraging movement and enhancing overall functionality.

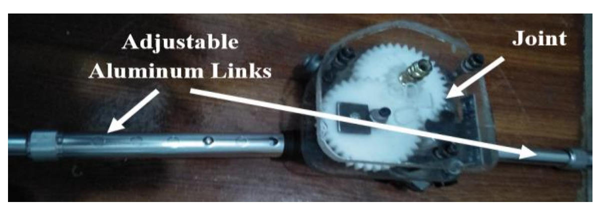

Figure. 5. Links & joint of adjustable LLE

C. Development of Control and Electronic Circuit

The control electrical circuit box of the ALLE prototype is composed Arduino Mega microprocessor, 43-amp motor driver, EMG electrodes, EMG muscle sensor, and Li-ion battery as shown in a flow chart (Fig 6) and circuit diagram (Fig 7). The exoskeleton is controlled by an Arduino Mega microcontroller which converts the EMG muscle sensor inputs into motor control signals. Motor driver connects the microcontroller to 12V DC motors. And then modulates motor power using microcontroller control signals to precisely control their movements. The developed control and electric circuit box are depicted in Fig 8. Together, these parts ensure that the exoskeleton is properly controlled and functional, allowing for precise signal interpretation and effective motor activity.

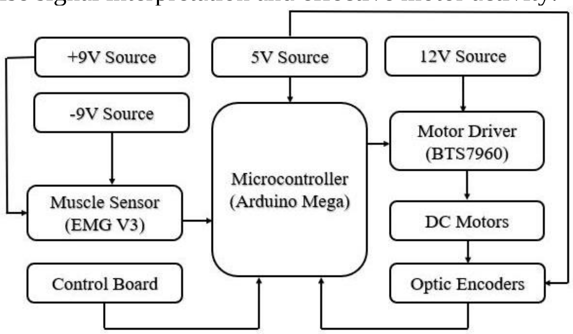

Figure. 6. Flow chart diagram of ALLE

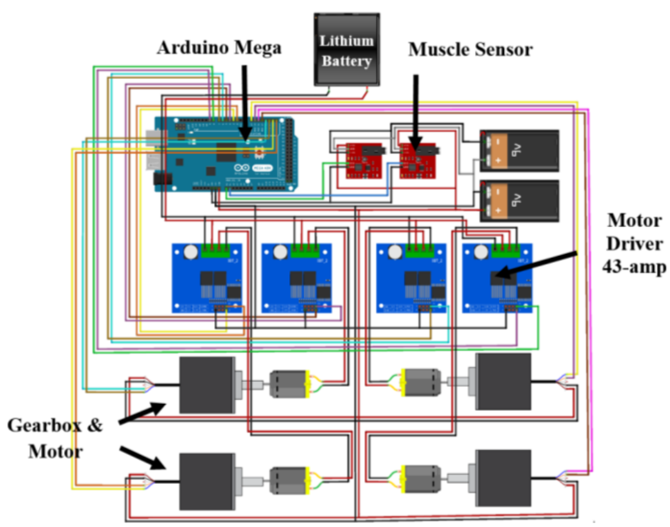

Figure. 7. The circuit diagram of ALLE

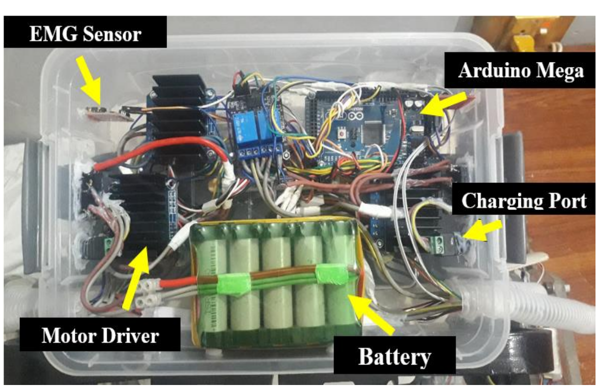

Figure. 8. Circuit Box Development

D. Assembly and Integration

The final exoskeleton prototype is created by assembling and integrating the individual components. In order to ensure appropriate alignment and functionality, this requires connecting the AGMs and links carefully. To attain the best performance and dependability, recent studies have stressed the significance of accurate assembly procedures and strong integration processes [21]. The image of the assembled ALLE prototype is shown in Fig 9.

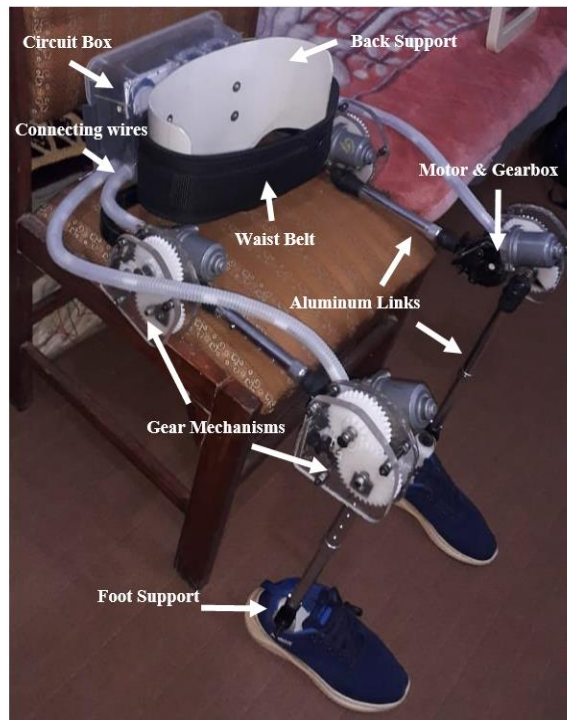

Figure. 9. Developed ALLE prototype

The specifications of the devised ALLE prototype are listed in Table 1.

TABLE I

DIMENSIONS AND PARAMETERS OF ALLE

Description	Value
DC Motor	12 V
Teflon Driver Gears	Teeth=11, Clearance=1mm , Pitch dia= 73mm, Pressure Angle= 20^0
Teflon Driven Gears	Teeth=35, Clearance=1mm , Pitch dia= 25mm, Pressure Angle= 20^0
Aluminum Link	(8″ × 0.9″)
EMG Muscle Sensor	V3 (1″ × 1″)
Lithium Battery	12V, 10 A
Microcontroller	Mega 2560
Motor driver	BTS 43-A
Encoder	Tacho LM393

V. TESTING OF DEVELOPED ALLE

The exoskeleton prototype is tested throughout the experimental phase to evaluate its functionality, comfort, and mobility. In order to assess the efficacy and possible advantages of the exoskeleton for users with lower limb impairments, the testing is performed in manual mode and EMG mode.

A. *Manual Operation Mode*

The ALLE prototype's manual mode operation enables the user to execute different lower limb actions as a rehabilitation device. The user can perform knee, hip, sitting, sit-to-stand, and walking motions by controlling its motion using a laptop and push buttons. This mode increases mobility and freedom by giving the user control over their movements while receiving support and help from the exoskeleton.

a) Knee Motion

The ALLE is used in this experiment (Fig 10) to evaluate knee mobility. Controlling position and torque allowed parallel and alternate knee motions. Parallel knee motion reached 70 degrees at 25 degrees per second. However, at 15 degrees per second, alternate knee motion reached 30 degrees. These results show that the prototype can support and help knee movements to reach specified angles and speeds and are helpful in rehabilitation purposes.

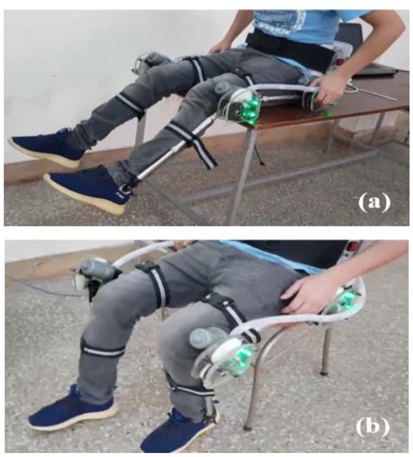

Figure. 10. Manual mode testing: (a) Knee Motion in Parallel, (b) Alternate Knee Motion

b) Hip Motion

In Fig 11, the ALLE was tested for hip mobility. The user could move the complete leg by giving position and torque commands. The prototype supported controlled hip motion, enabling hip-related movements that could reach an angle of 30 degrees at 15 degrees per second, showing its adaptability to user preferences.

Figure. **11**. Manual mode testing: Hip Motion

c) Sit Motion

The user used commands to sit in the ALLE is presented in Fig 12. The exoskeleton helped the user sit easily. The prototype supported seated movements by allowing the user to reach 90 degrees at 30 degrees per second. This investigation showed the potential to help lower limb-impaired people sit.

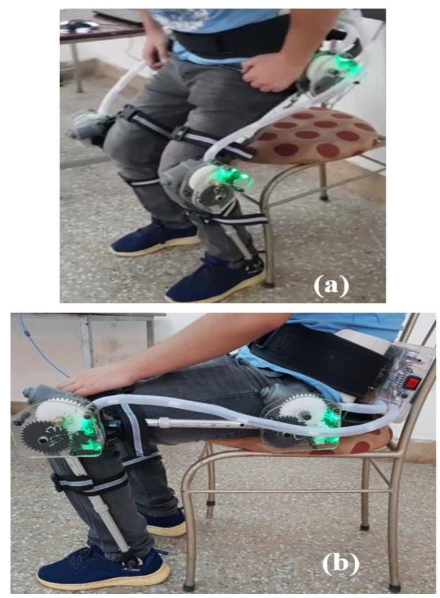

Figure. 12. Manual mode testing: (a) Undergoing sit position (b) Completed sitting position

d) Sit-to-Stand Motion

In the sit-to-stand motion experiment (Fig 13), the prototype helps the user transition from sitting to standing. The prototype allowed the user to sit-to-stand at 30 degrees per second with an angle range of 0 to 90 degrees. These results show that the prototype can help lower limb-impaired people sit-to-stand with greater mobility and stability.

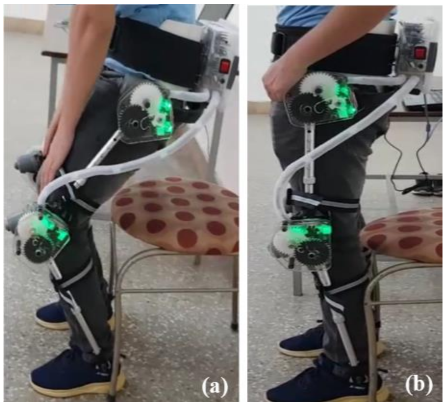

Figure. 13. Manual mode testing: (a) Undergoing standing position (b) Completely standing position

e) Walking Motion

The walking motion (Fig 14) tested the prototype's natural gait patterns. The ALLE allowed 20 degrees of joint movement at 10 degrees per second during walking. The exoskeleton assisted walking, suggesting it could improve lower limb mobility and can improve lower limb constraints by making walking more natural.

Figure. 14. Manual mode testing: Walking Motion

B. EMG Operation Mode

In ALLE, EMG mode operation uses EMG electrodes and V3 muscle sensors to record the electrical signals produced by the muscles. On particular muscle groups, EMG electrodes are applied, and these send EMG impulses to the EMG sensor module. The controller processes these signals and decides on the intended position and torque for the exoskeleton. The exoskeleton reacts to the user's muscle impulses and provides synchronized and coordinated support during a variety of actions, such as, knee and hip movements, sitting, sit-to-stand, and walking. With this mode, the user can engage with the exoskeleton in a more intuitive and natural way, improving mobility and making rehabilitation easier.

A. Discussions

The ALLE testing showed promising support for lower limb disability. The exoskeleton prototype can help lower limb-impaired people. It provides natural gait during the knee, hip, sit-to-stand & walking motion trial. This demonstrated the exoskeleton's ability to help lower limb-impaired people move faster.

The exoskeleton could accommodate patients of varying heights, which was a major benefit. This adjustability enhanced comfort and support during daily activities and recovery.

The exoskeleton's EMG muscle sensor showed it could comprehend and respond to muscle impulses. This improved user control and made the exoskeleton easier to use for lower limb limitations.

. Furthermore, this assistive device's functionality, use, and flexibility show its potential to improve lower limb impairment patients' quality of life. Moreover, in the devised ALLE the battery's limited life can also be enhanced with the motion-based [22-24], wearable-based [25-27], solar-based [28], RF-based [29-31], acoustic-based [32-35] or vibration based [36-56] energy harvesters.

VI. CONCLUSION

Adjustable lower limb exoskeleton (ALLE) device aims to build an assistive device that deals with lower limb disabilities. The work focused on lower limb disabilities and assistive technology, and it discussed issues, such as, exoskeleton evolution, human-robot interface, power and actuation systems, ergonomics, clinical evaluation, and user research. The project's two objectives were to construct an adaptable multiple-joint exoskeleton for lower limb support and rehabilitation and to develop an all-purpose exoskeleton for the rehabilitation of senior citizens. With manual and EMG operation modes boosting mobility and user control, the trials showed the exoskeleton's usefulness in knee and hip motions, sitting, and walking. Overall, this initiative advances the field, promotes the sustainability of assistive technology, and enhances the lives of people with lower limb restrictions.

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