"DESIGN AND DEVELOPMENT OF BIOMIMETIC EXOSKELETON ARM FOR REHABILITATION"

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College : Visvesvaraya Technological University, Belagavi
Branch : Department of Mechanical Engineering
Guide(s) : Dr. Venkatesh. M. Kulkarni
Mr. Nikhil M Changoli
Student(s): Ms. Rakshitha A
Ms. Rakshitha S H
Ms. Usha S

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Introduction:

An exoskeleton is an external structure designed to support and protect the body it surrounds.
This concept is deeply rooted in nature, where creatures like insects and crustaceans use exoskeletons for survival.

In modern technology, exoskeletons have been adapted for human use—enhancing strength, endurance, and mobility.
They are wearable devices, often powered, that assist or augment body movement.

Exoskeletons are now applied across a range of fields, including:

- Healthcare, for rehabilitation and mobility support
- Military, for boosting soldier performance and load-carrying capacity
- Industry, to reduce worker fatigue and injury risk
- Sports, for performance enhancement and injury prevention

In biomedical engineering, exoskeletons play a key role in helping patients with spinal cord injuries or stroke regain movement.

Some designs are passive, relying on structural support alone, while others are active, incorporating motors, sensors, and control systems.

Inspired by nature, these systems reflect a fusion of biology and robotics, showing great potential in improving human capability.
Their development is shaping a future where machines extend not only what we can do—but who we can be.

Objectives:

This study aims to design and develop a biomimetic exoskeleton arm powered by an electrically driven linear actuator to enhance human capabilities in rehabilitation, industrial assistance, and physical augmentation. The focus is on replicating human arm biomechanics through detailed analysis of joint alignment, range of motion, and movement patterns. By studying human anatomy, the exoskeleton is designed to function intuitively with appropriate degrees of freedom at the shoulder, elbow, and wrist.

The project emphasizes selecting actuators that balance force, speed, and precision with energy efficiency. Lightweight materials like carbon fiber composites and aluminum alloys are chosen for strength and comfort. A responsive control system is developed using advanced algorithms and sensors—including EMG, force, and position sensors—for real-time user interaction. Feedback mechanisms ensure smooth motion and task adaptability. Additionally, energy consumption is analyzed to improve power efficiency using energy recovery and smart control logic. The study prioritizes safety, reliability, and long-term usability of the device.

Methodology

The development of a biomimetic exoskeleton arm follows a structured, multidisciplinary approach.
It begins with problem definition, identifying user groups, design requirements (motion, force, speed), and constraints (weight, power, cost).
Regulatory standards for safety and quality are also considered.

Next, biomechanical analysis studies joint angles, force, torque, and muscle simulation to understand human arm dynamics.
Based on this, a conceptual design is created using CAD models, with material selection focused on strength and weight efficiency.
Linear actuator placement is optimized for power transfer and minimal bulk.

A control system is developed with sensors (EMG, force, position) and control algorithms like PID or MPC.
A user interface, such as a mobile app, allows easy customization and operation.

A working prototype is built using techniques like 3D printing and CNC machining, integrating actuators, sensors, and power systems.
Testing includes range of motion, load capacity, latency, and energy efficiency, followed by user feedback collection.

Based on results, iterative refinements are made to design, control logic, and ergonomics.
Safety and reliability tests (failure mode, durability, overload protection) ensure robust performance.

Finally, all processes are documented, with technical specifications, manuals, and research publications.
Deployment and future work explore AI integration, wireless control, and modular design for broader applications.

This methodology ensures a user-friendly, efficient, and reliable exoskeleton arm.

Result and Conclusion:

In conclusion, the project successfully developed a cost-effective and efficient biomimetic exoskeleton for rehabilitation, improving motor recovery for individuals with limited access to traditional rehabilitation services. The exoskeleton effectively replicates human arm biomechanics, aids in muscle strengthening, and supports up to 18 kg for lifting tasks. Its reliable performance, real-time control, and comfort make it suitable for prolonged use. This solution offers potential for both urban and rural healthcare settings. Future enhancements could focus on expanding movement capabilities, improving energy efficiency, and integrating remote monitoring features.

Future Scope:

1. Expansion of Range of Motion: Future developments could focus on supporting more complex movements, such as pronation, supination, and fine motor tasks, to enhance the versatility of the exoskeleton.
2. Integration of Advanced Sensors: Incorporating additional biosensors for real-time monitoring of muscle activity and progress, enabling more precise rehabilitation exercises and adaptive control.
3. Customization for Individual Needs: Developing modular designs that allow for adjustments based on the user's anatomy, injury type, and stage of rehabilitation, ensuring a more personalized approach.
4. Energy Efficiency Improvements: Enhancing battery life and power consumption to support longer usage durations, reducing the frequency of recharging and improving the exoskeleton's operational efficiency.
5. Tele-rehabilitation and Remote Monitoring: Adding IoT capabilities for remote monitoring by healthcare professionals, enabling continuous therapy and feedback for patients in remote or underserved areas.