DEVELOPMENT OF A COST-EFFECTIVE LOWER LIMB EXOSKELETON FOR MOBILITY SUPPORT

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Introduction:

Lower-limb mobility impairments severely restrict independent walking and participation in everyday activities. Robotic exoskeletons show strong potential for gait assistance and rehabilitation, but many current systems are hindered by high cost, heavy frames, and poor usability. This project addresses those limitations through the development of a lightweight, low-cost lower-limb exoskeleton designed to enhance mobility while maintaining simplicity, comfort, and functional reliability for the user.

The system uses Electromyography (EMG) as a non-invasive biological control interface, capturing muscle activity via skin-mounted sensors and translating it into motion commands through an Arduino microcontroller that drives MG995 servo actuators at the joints. The mechanical structure is built from PLA using FDM 3D printing, emphasizing natural joint alignment, balanced load distribution, and ergonomic support. This design is especially suited for individuals who retain partial muscle function but need mechanical assistance to perform routine tasks, offering an accessible pathway toward improved mobility and rehabilitation.

Objectives:

1. To Design and create a lightweight and strong prototype of an artificial leg for partial support of the limb.
2. To Integrate surface EMG sensors to detect muscle contraction and relaxation signals in real time.
3. To Design an Arduino-based control system that can process the EMG inputs for driving servo motors to perform joint actuation.

Methodology:

EMG signals from forearm muscles are captured via skin-mounted sensors, amplified, filtered (10-500 Hz bandpass), and processed by an Arduino microcontroller using 10-bit ADC sampling and threshold logic (above 100 ADC units triggers contraction command). Processed signals generate PWM outputs to drive waist-mounted MG995 servo motors for coordinated hip and knee flexion-extension, with real-time serial monitoring ensuring responsive control (~500 ms latency) and safety hysteresis to prevent oscillation. Iterative prototyping involved CAD modeling in Fusion 360, 3D printing, assembly, signal calibration, and bench testing for joint alignment and load-bearing.

- Techniques:

Parametric CAD design in Autodesk Fusion 360 created adjustable components like thigh links, knee pivots, and ankle joints for ergonomic fit and stress optimization via fillets and cutouts. FDM 3D printing fabricated all plastic parts at 80% infill; manual assembly used stainless steel hardware for low-friction pivots; signal processing included rectification, smoothing, and binary state detection. Threshold-based control mapped muscle intent to servo angles (0-180°), with neutral positioning for safety during no-signal states.

- Materials:

PLA (Polylactic Acid) filament forms lightweight, rigid structural links and housings, chosen for printability, dimensional accuracy, smooth finish, and moderate load support. Stainless steel screws, bolts, nuts, and rods ensure durable, precise joints with minimal friction. Foam sheets and Velcro straps provide adjustable, comfortable user interfaces at thigh and waist; EMG sensors and wiring complete the electronics.

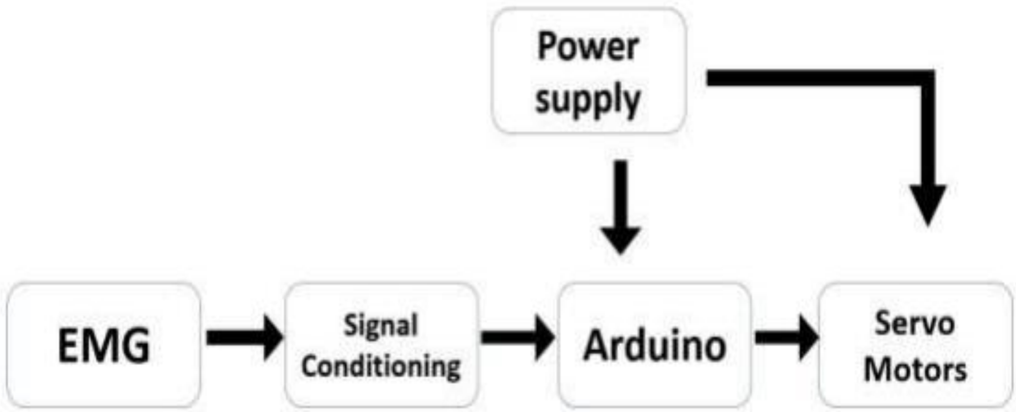

Figure 1: Block Diagram of Lower Limb Artificial Leg

Result and Conclusion:

In conclusion, the prototype successfully demonstrated real-time EMG-driven control of a lower-limb exoskeleton using low-cost hardware. EMG signals from forearm surface electrodes (output range 0.5 – 4.2 V) were reliably distinguished into rest (<50 ADC) and active contraction (>200 ADC) states. The threshold-based Arduino control dispatched PWM signals to the two MG995 servos, achieving knee extension (0–90°) and flexion with a response time of under 500 ms. The 3D-printed PLA linkage assembly exhibited no deformation under repeated operation. Safety features including servo neutral position hold and hysteresis were validated. The system proved the viability of an affordable EMG–servo approach for assistive mobility, with potential for future enhancements including multi-joint actuation, IMU integration, and adaptive control algorithms.

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Future Scope:

1. **Improved exoskeleton actuation and sensing**
   Integrate additional joints (ankle and hip) with proportional EMG control and multi-channel muscle sensing to achieve a more natural, full gait-cycle replication and smoother walking assistance.
2. **Real-time motion monitoring and remote rehabilitation**
   Add IMU sensors and wireless communication for real-time gait monitoring, gait-phase detection, and remote-controlled rehabilitation sessions with live data feedback.
3. **Clinical validation and adaptive intelligent control**
   Conduct extensive clinical user trials, optimize mechanical comfort and ergonomic fit, and adopt machine-learning-based pattern recognition to enable adaptive, personalized assistive control that learns and adapts to each user's gait and fatigue.