Development of a Lower-Limb Exoskeleton for Gait Assistance

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MOTIVATION

Many people struggle with limited leg mobility. Injuries, surgeries, or neurological conditions can impact walking. Exoskeletons can help but are expensive and hard to access.



OBJECTIVE

Design an exoskeleton to assist people with mobility issues and support rehabilitation, with a focus on the knee joint.

DESIGN REQUIREMENTS

Customers for this project are clinical patient, physical therapist, and prosthetist. They need to assist with walking and reduce strain during rehabilitation sessions.

CUSTOMER NEEDS

Usability: Low maintenance, Affordable, robust, easy to put on and take off
Performance: maintain natural gait, varying assistance levels, navigate variety of terrain
Comfort: Adjustable fit, Breathable and skin-safe materials, even weight distribution

DESIGN CONSTRAINTS

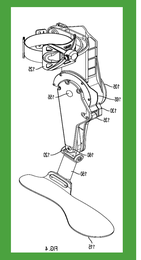
Budget: $3000 maximum
Weight: less then 15lbs to minimize fatigue
Safety: Ergonomic and electrical standards
Runtime: Battery lasts more than 2 hours

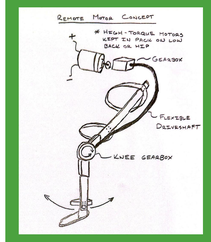
DESIGN PROCESS

Ideas were generated using the Five-Step Method to explore multiple designs and mix mechanical, electrical, and comfort.

CONCEPT GENERATION

External Search: Patent databases and academic sources were used to identify key features such as joint configurations, actuator types, and ergonomics. Insights from commercial products and research inspired novel combinations for our designs.





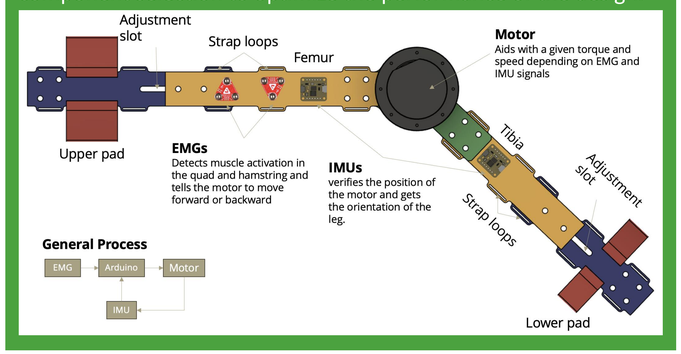
Internal Search: Brainstorming sessions focused on actuation methods, sensors, comfort methods, and modular frames. Concepts were sketched and refined based on team feedback, user needs, and feasibility. These were put into a combination table to generate more ideas.

CONCEPT SELECTION

Criteria	Importance Factor	Concept 1 Exo Side Motor	Concept 2 Exo by Wire	Concept 3 Exo Cage Front Motor	Concept 4 Exo by Spring
Durability	1 - 3	2	1	3	1
Cost	1 - 4	2	3	1	4
Ease of Use	1 - 4	3	2	2	2
Aesthetics	1 - 5	5	2	2	1
Complexity	1 - 5	3	4	2	5
Size	1 - 4	3	2	1	3
Power Delivery	1 - 3	3	2	3	1
Totals		***21***	***16***	***14***	***17***

SELECTED DESIGN

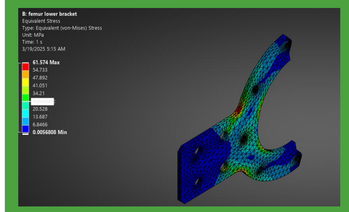
Side motor was chosen for consistent performance across all design criteria. More comparisons were made for individual component selection to optimize the performance of the design.



DESIGN VERIFICATION

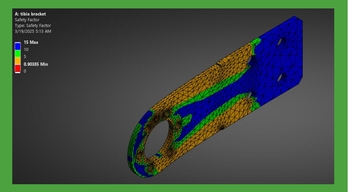
Design verification ensured each iteration aligned with the project goals. Prototypes confirmed functionality, and testing highlighted areas for improvement. Team members collaborated across roles to integrate mechanical and electrical systems effectively.

ANALYSIS & SIMULATIONS



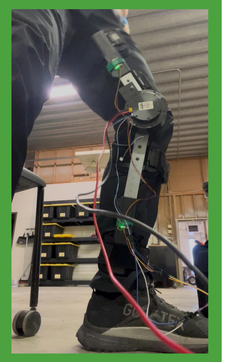
Femur Motor Bracket – Stress: Under double the producible torque moment, the maximum stress of 61.57 MPa remains well below aluminum's yield strength. Stress point is concentrated at corners and solved with a larger radius.

Tibia Motor Bracket – Safety: Critical regions approach a minimum factor of 0.9, while the rest of the bracket remains high. Increasing material around the holes would improve the minimum above 1.



PROTOTYPING & TESTING

Component Validation: Testing began on an existing medical brace to verify the functionality of the selected components. This also informed comfort, natural motion range, and potential placement of components.



1st Design: The first custom brace design was 3D printed to assess geometry, motor positioning, and alignment. Testing revealed issues with fit, rotational misalignment with the knee, and mechanical interference.



Refinement: Focused on distributing the load and reducing bulk. A hip pack was added to hold heavy batteries in a more ergonomic spot. Straps were adjusted for improved retention and reduced interference when adjusting length.

2nd Design: Updated design was reprinted. This version successfully accommodated all components, while maintaining comfort and security. Small adjustments were made before machining the final link designs out of aluminum.

RESULTS

The final prototype successfully assisted the knee joint using sensor input. IMUs tracked leg position accurately, and EMG signals triggered motor responses. The system operated smoothly and remained secure during movement. The machined aluminum provided much more support and improved comfort over the previous 3D printed prototypes. Blow showcases a simplified response of the system for a single step.





CONCLUSIONS

A functioning prototype was successfully developed that responds to user's muscle movements to assist with walking. It achieved its goal of a low-cost assistive exoskeleton and met design requirements while remaining within constraints.

Future improvements:

- Customizable comfort components
- Easier adjustability and wearability
- Better EMG signal and processing
- Additional joints or limbs
- Machine learning for adaptive control