

Background

Prosthetic socket comfort plays a major role in successful prosthesis use, directly affecting mobility, stability, and long-term usability. However, residual limb volume and shape can fluctuate throughout the day due to activity, fluid movement, and environmental conditions. These variations make it difficult for traditional rigid sockets to maintain a consistent fit. As a result, many users rely on sock layering or frequent socket replacements to accommodate these changes, which can be inconvenient and costly. Adjustable socket technologies, such as systems developed by Click Medical, allow users to manually modify socket tightness and improve fit compared to rigid designs. While helpful, these systems still rely on user input and typically apply uniform compression, limiting their ability to address localized pressure differences. Emerging sensing technologies and intelligent control systems create opportunities for adaptive prosthetic interfaces capable of dynamically responding to changes in limb conditions.



Fig. 1. Comparison of pressure distribution and adjustable prosthetic socket systems.

To address the limitations of traditional and adjustable sockets, this project introduces Neo-Limb: Adaptive Socket Intelligence, a prosthetic socket designed to actively respond to changes in residual limb volume and pressure. The system uses a pneumatic bladder controlled by a microcontroller (Arduino) and integrated with a computer-based AI interface to adjust pressure in real time. A two-zone pneumatic control setup enables targeted adjustments, allowing the socket to maintain consistent fit and comfort across different regions of the limb. Computational modeling supports optimized pressure distribution, while future integration of sensors and machine learning will enhance responsiveness. This approach aims to improve user comfort, stability, and overall prosthetic performance without requiring manual intervention.

Experimental Setup

The Neo-Limb prototype was developed using a combination of computer-aided design, rapid prototyping, and embedded control hardware. A conceptual air bladder system was first modeled in SolidWorks to explore geometry, volume distribution, and placement within a prosthetic socket. The design focused on creating a flexible chamber capable of expanding and contracting to adjust pressure between the residual limb and socket interface.

Based on the digital model, a prototype air bladder was fabricated using flexible materials and sealed to create an airtight chamber. The bladder was integrated with a miniature DC air pump, tubing, and a one-way check valve to regulate airflow and maintain pressure stability. This setup allowed controlled inflation and deflation of the chamber to simulate adaptive socket compression.

Fig. 2. Digital fabrication of a model Air Bladder. SolidWorks model of the air bladder, highlighting its key sections: the main chamber, inlet/outlet ports, and structural walls. Each component is labeled to illustrate the design features enabling controlled inflation and deflation within the prosthetic socket.

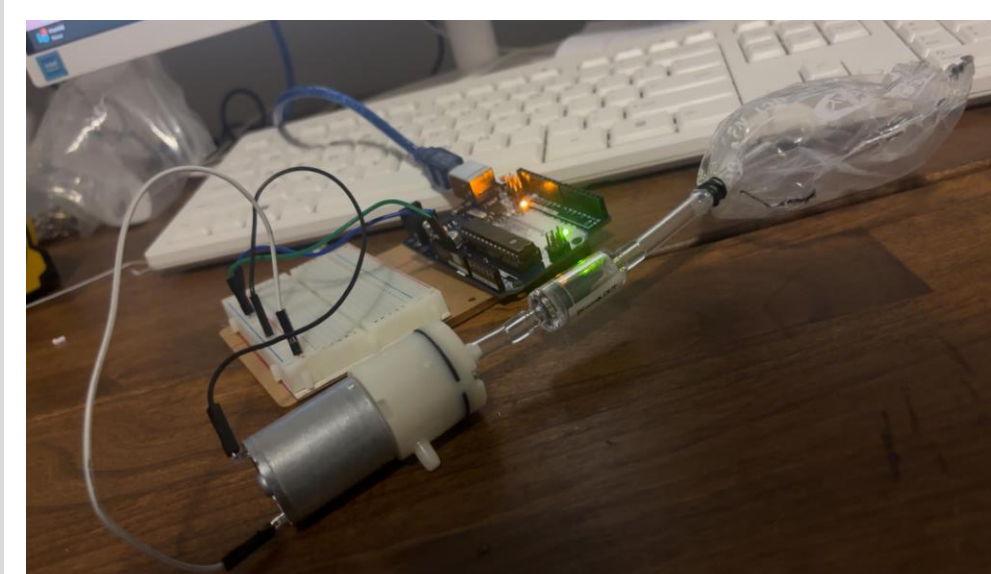


Fig. 3. Model setup of an Air Bladder Socket System. Experimental setup of the makeshift air bladder system, showing the assembled bladder, connected air pump, and tubing. This configuration demonstrates the practical implementation of inflation and deflation control for testing within the prosthetic socket.

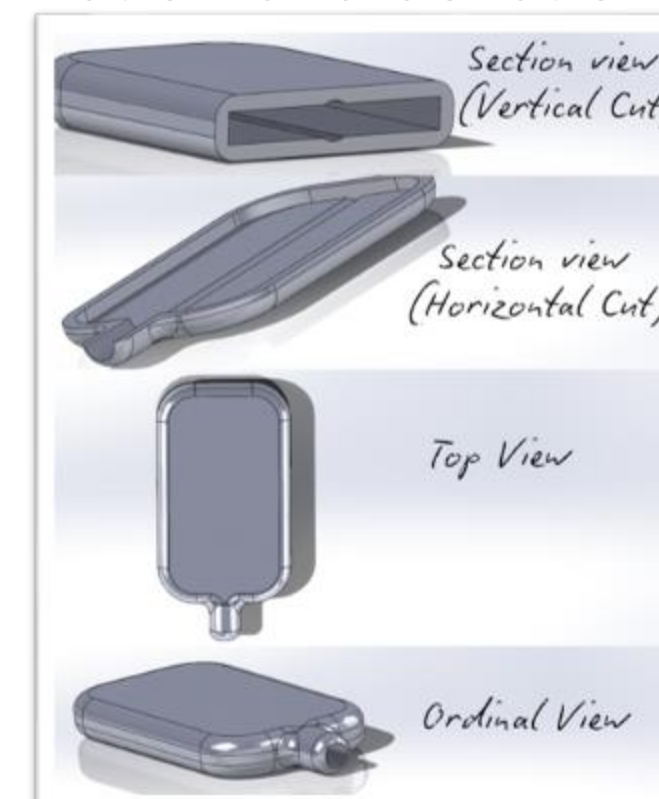


Fig. 4. Experimental validation workflow of the Neo-Limb system. A four-stage framework was used to evaluate actuation, pressure monitoring, localized control, and AI-based personalization. User-controlled inputs, real-time pressure feedback, and data-driven recommendations were integrated and assessed using response time, pressure accuracy, stability, zone selectivity, and logging consistency.

Experimental Results

- **Pneumatic control system functionality:** Successfully inflated and deflated the air bladder, producing measurable changes in internal pressure.
- **Microcontroller activation:** DC air pump delivered air into the sealed bladder, generating outward force for controlled compression.
- **Repeated cycles:** System reliably inflated and maintained pressure briefly, aided by a one-way check valve.
- **Deflation:** Occurred upon deactivation, allowing the bladder to return to its original shape.
- **Feasibility confirmed:** Demonstrates potential for dynamically adjusting prosthetic socket interface pressure.
- **Future improvements:** Suggests higher-efficiency micro pump and better sealing materials for enhanced performance.
- **Core concept validated:** Prototype proves the viability of an adaptive pneumatic interface for prosthetic sockets.

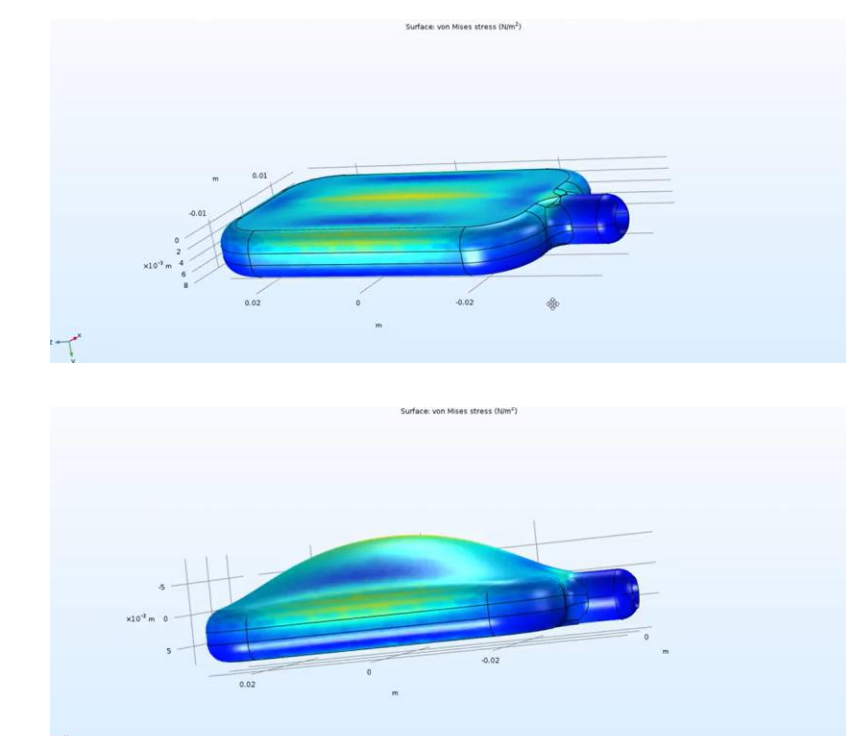


Fig. 5. Pneumatic Bladder Expansion and Functionality. Comparison of the prototype air bladder in its deflated (left) and inflated (right) states during experimental testing. Air delivered by the pump system causes the sealed chamber to expand outward, illustrating the bladder's ability to generate adjustable compression forces that could be used to dynamically modify prosthetic socket fit.

Fig. 6. Dynamic Inflation of Prototype Pneumatic Bladder. Pneumatic Bladder Expansion Demonstration Comparison of the prototype air bladder in its deflated (left) and inflated (right) states during experimental testing. Air delivered by the pump system causes the sealed chamber to expand outward, illustrating the bladder's ability to generate adjustable compression forces that could be used to dynamically modify prosthetic socket fit.



Summary

- Lower-limb prosthetic sockets are the critical interface between an amputee and their prosthesis, but daily residual limb volume changes often cause sockets to become too tight or too loose, leading to discomfort and reduced mobility.
- Neo-Limb: Adaptive Socket Intelligence is an adaptive prosthetic socket concept designed to dynamically regulate pressure at the limb–socket interface using pneumatic adjustment. The prototype was evaluated using a two-zone pneumatic control system integrating Arduino-based actuation with a computer-based AI interface.
- Future development will incorporate sensors and machine learning to enable real-time adaptive comfort and stability.

References

Vitali, Andrea, et al. "Design and Additive Manufacturing of Lower Limb Prosthetic Socket." Proceedings of the ASME 2017 IMECE.