Engineering Advances, 2026, 6(1), 27-30
https://www.hillpublisher.com/journals/ea/
ISSN Online: 2768-7961

Design and Implementation of a Pneumatic Compliant Rehabilitation and Piano Instruction Intelligent Glove System

Yuanxin Ge

University of California, Santa Barbara, Santa Barbara, CA 93106, USA.

How to cite this paper: Yuanxin Ge. (2026) Design and Implementation of a Pneumatic Compliant Rehabilitation and Piano Instruction Intelligent Glove System. *Engineering Advances*, 6(1), 27-30.
DOI: 10.26855/ea.2026.03.006

Received: December 30, 2025
Accepted: January 27, 2026
Published: February 25, 2026

***Corresponding author:** Yuanxin Ge, University of California, Santa Barbara, Santa Barbara, CA 93106, USA.

Abstract

This paper presents the design and implementation of an intelligent glove system that utilizes pneumatic soft actuators to address two distinct application areas: hand rehabilitation and piano instruction. The project is motivated by the critical need for safe, effective, and home-based rehabilitation solutions for the growing elderly population suffering from hand function impairments due to conditions like stroke or arthritis. Simultaneously, it seeks to provide tangible physical guidance for piano beginners, who often struggle to develop correct fingering techniques through visual feedback alone. The system's core innovation is its dual-end "controller-controlled" architecture. On the "teaching end," flex sensors are employed to capture the finger movements of a demonstrator, such as a therapist or a teacher. This movement data is processed and transmitted in real-time via an ESP32-S3 microcontroller to an identical "execution end" glove worn by the user. Upon reception, pneumatic actuators within the glove drive the user's fingers to synchronously replicate the demonstrated movements, thereby offering compliant, physical guidance. This tactile-guided approach effectively surpasses the limitations of traditional methods reliant on visual-only cues or preset motion trajectories. The project has successfully culminated in a functional prototype that validates the technical feasibility and exploratory value of this system for both motor learning and rehabilitation applications.

Keywords

Pneumatic Soft Actuator; Intelligent Glove; Hand Rehabilitation; Piano Instruction; Haptic Guidance

1. Introduction

The trend towards a deeply aging society has increased the prevalence of hand function problems among older adults, often resulting from conditions like stroke aftereffects, Parkinson's disease, and rheumatoid arthritis. These issues severely impact activities of daily living (ADLs). Concurrently, in piano pedagogy, beginners frequently develop poor technique due to a lack of physical movement guidance. Existing solutions in both domains are inadequate; rehabilitation often relies on repetitive therapist-guided exercises, while piano teaching tools primarily offer visual cues. This project bridges this gap by developing a wearable, pneumatic soft glove system that provides direct, compliant physical guidance for both hand rehabilitation and piano instruction on a single hardware platform.

2. Comparison with Existing Products and Innovation

Current products have significant limitations. Many rehabilitation devices use a single-end driven structure with preset motion trajectories, lacking adaptability. Rehabilitation grip balls train only overall grip strength without addressing individual finger control. This project's key innovations are:

(1) A dual-end "controller-controlled" structure that replicates real-time human demonstrations [1].
(2) Independent control of each finger, enabling fine motor skill training.
(3) The integration of safety features like movement thresholds and time limits.

Figure 1. Start-up auto training.

3. System Design and Objectives

The overall system design objective is to create a safe, compliant, and wearable device suitable for home and teaching scenarios. The system architecture consists of three main modules, as illustrated in the system block diagram:

- **A. Teaching Module:** Uses flex sensors to capture finger movements from a demonstrator [2].
- **B. Control & Processing Unit:** An ESP32-S3 microcontroller handles data processing, mode switching, and network communication.
- **C. Pneumatic Soft Glove:** The user wears this glove, where pneumatic actuators, controlled by a pump and solenoid valves, provide compliant bending movements to each finger [3].

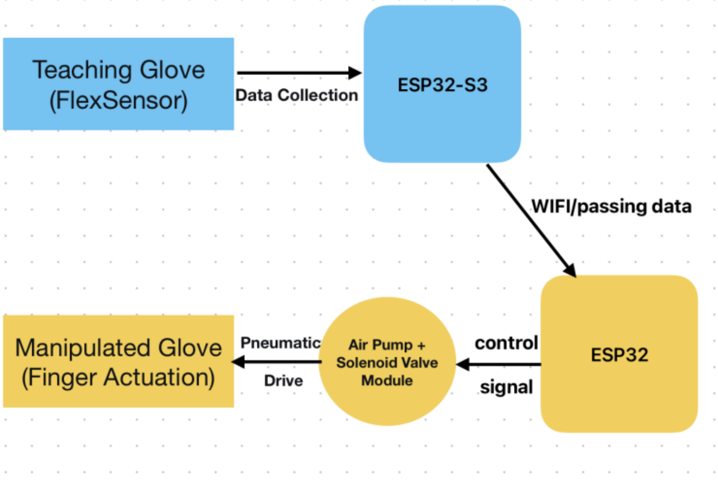

Figure 2. Operational Flowchart.

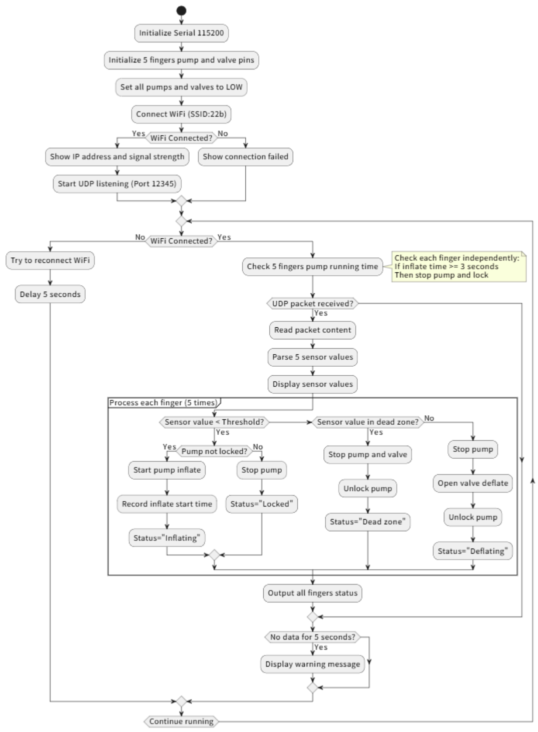

Figure 3. PCB Design.

4. Hardware Implementation

4.1 Main Control and Sensing

The ESP32-S3 was selected for its ample ADC channels, allowing simultaneous data acquisition from five flex sensors without WiFi interference. These sensors are mounted on the glove fingers to measure bending angles.

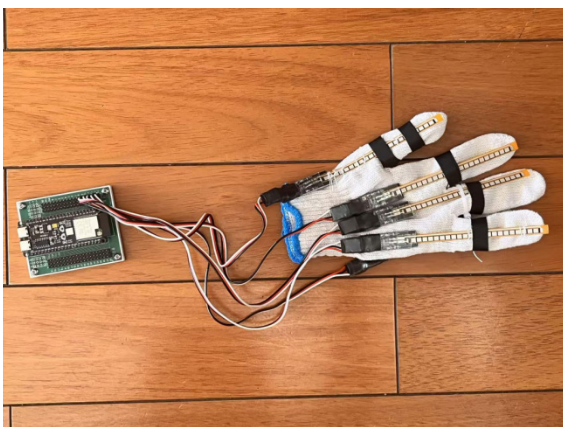

Figure 4. Glove Design.

4.2 Pneumatic Execution

An air pump provides the system's air source. Electromagnetic valves control the air path to each finger actuator independently. Tubes and connectors were selected to ensure sealing and stability [4].

4.3 Circuit and Structure

A dual-channel DC motor drive module controls the solenoid valves. Structural components for the mainboard, pump, and valves were designed, 3D-printed, and assembled to enhance system stability and maintainability.

5. Software and Control Strategy

The software prioritizes practical reliability over algorithmic complexity [5]. ESP32-S3 filters sensor data and performs threshold checks before transmitting it to the execution end. To ensure stability, the control logic incorporates a "dead zone" near actuation thresholds to reduce jitter from sensor noise and imposes a time limit (e.g., 3 seconds) on each inflation cycle to prevent pump overheating. Thresholds can be adjusted per finger to accommodate structural differences.

6. Results and Conclusion

A functional prototype has been successfully developed and tested. The system achieves:

- Real-time collection and transmission of finger bending data.
- Independent pneumatic actuation of all five fingers [6].
- Synchronized movement between the teaching and execution ends.

The prototype demonstrates the exploratory value and technical feasibility of this tactile-guided system for both rehabilitation and skill acquisition applications.

7. Future Work

Future development will focus on enhancing fine motor control:

(1) Multi-joint Actuation: Implementing separate actuators for different finger joints (e.g., knuckles, interphalangeal joints) [7].

(2) Graded Force Control: Refining control parameters for the pump and valves to enable precise control over bending angles and force levels, which is crucial for expressive piano playing.

(3) Application Expansion: Applying the refined system to complex hand skill training beyond basic rehabilitation [8].

References

[1] Pirbabaei E, et al. Exergames for hand rehabilitation in elders using Leap Motion Controller: A feasibility pilot study. Int J Hum Comput Stud. 2023;178:103099.

[2] Kabir R, et al. Hand rehabilitation devices: A comprehensive systematic review. Micromachines. 2022;13(7):1033.

[3] Hong XH, et al. Research on the design of hand rehabilitation training instrument based on self-efficacy of the elderly. In: Design Studies and Intelligence Engineering. IOS Press; 2023. p. 168-77.

[4] Kosar T, et al. A case study on the design and implementation of a platform for hand rehabilitation. Appl Sci. 2021;11(1):389.

[5] Lundberg E. The development of an interactive learning device for playing the piano [master's thesis]. 2015.

[6] Huang K, et al. PianoTouch: A wearable haptic piano instruction system for passive learning of piano skills. In: Proceedings of the 12th IEEE International Symposium on Wearable Computers. IEEE; 2008. p. 41-4.

[7] Yamada T, Matsunaga H, Ogata T. Paired recurrent autoencoders for bidirectional translation between robot actions and linguistic descriptions. IEEE Robot Autom Lett. 2018;3(4):3441-8.

[8] Et al. Synthesis of compositional animations from textual descriptions. In: Proceedings of the IEEE/CVF International Conference on Computer Vision. 2021.