StepRevive: 3-DOF Platforms Adaptive Ankle Rehabilitation Device

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Culver Academies

Introduction

Photo taken by student, 2024.

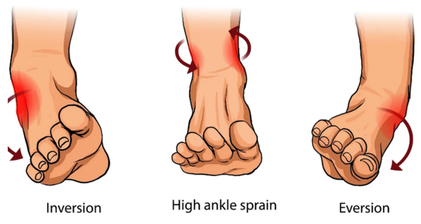


Image from https://www.coveorthopaedics.com.sg/conditions-we-treat/foot-ankle/ankle-sprain/

Ankle injuries are among the most common injuries worldwide and can cause significant inconvenience in people's daily lives. For groups such as athletes or the elderly, delayed or inefficient recovery from ankle sprains could increase the risk of sequelae or future injury.

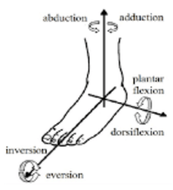


Image from https://www.researchgate.net/figure/Normal-ankle-movements_fig1_282655858

When patients receive treatment for ankle sprains, a common practice is to perform ankle exercises as their muscles or ligaments begin to recover. The human ankle can move in either direction along 3 rotational axes, all of which are important for daily activities, such as maintaining balance and normal walking.

CURRENT LIMITATIONS

Image from https://oldbridgefootdr.com/ blog/2024/4/15/relieve-foot-pain-with-extracorporeal-shockwave-therapy

Therapies at podiatric centers.
- **Need a professional therapist**
- **Inconvenience in traveling**
- **Unavailable domestically**

Image from https://dynasplint.com/product/ankle/

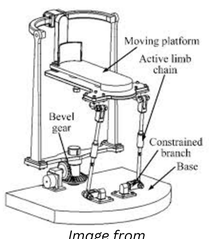


Image from https://www.researchgate.net/figure/Fig-3-An-ankle-rehabilitation-device-CN105125380_fig2_333356051

Current ankle rehabilitation devices.
- **Limited customization ability**
- **Unable to complete some of the rotation directions**
- **High prices lead to lack of affordability**

Engineering Goals

The research goal of this project is to create a device that...

- **Can be controlled by either phone or PC software through Bluetooth communication with a self-designed UI**

Screenshot of self-written software main page UI, 2026

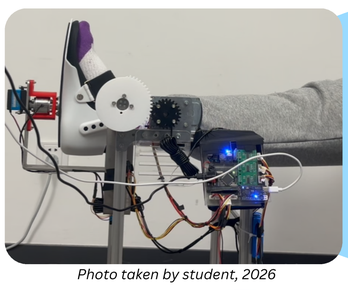
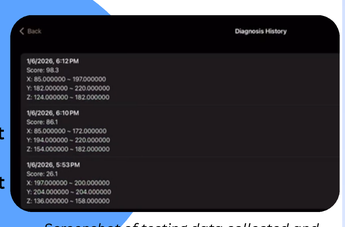


Photo taken by student, 2026

- **Records exercise procedures for the ankle and reperforms them, thus enabling convenient domestic access**

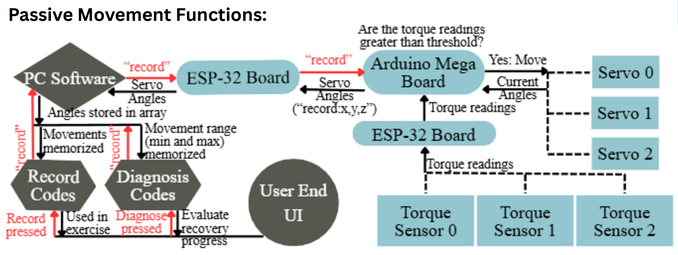
- **Collects real-time data of the patient's movement to be quantified and visualized (potential usage: uploaded online for accurate assessment of recovery progress; add to a large dataset for AI assessment through reinforcement learning)**



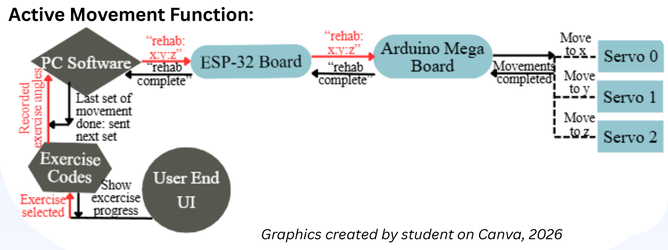
Screenshot of testing data collected and shown by self-written program, 2026

Functions Theoretical Design

Passive Movement Functions:



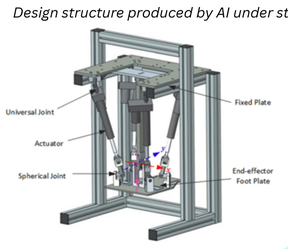
Active Movement Function:



Graphics created by student on Canva, 2026

Mechanical Design

Design structure produced by AI under student's instructions, 2025

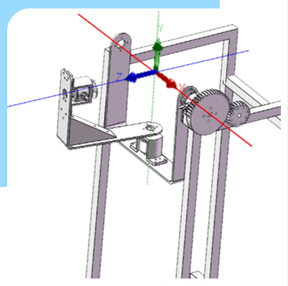


Initial Version of Design (Parallel)

4 actuators manipulating a platform
- **Complex calculations for controlling movement**
- **Unable to complete the movements of abduction and adduction**
- **No means of accurate user torque feedback on different directions**

3 platforms connected in series
- **Ensure that the servo motors' central rotational axes intersect at the center of the patient's ankle**
- **Able to complete all six movements of ankle**
- **A torque sensor on each platform, providing torque feedback on each axis.**

Final Version of Design (Series)

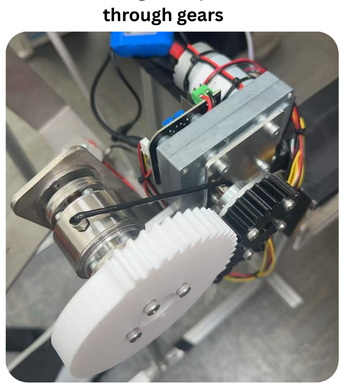


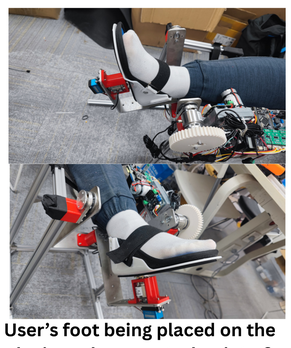
Screenshot taken from model created by student in SolidWorks, 2025

(6 photos below of device details taken by student, 2026)

DS3230 servo with torque 40kg connected to a torque sensor on each of the two smaller platforms

DH-03X servo with torque 300kg, controlling main platform through gears

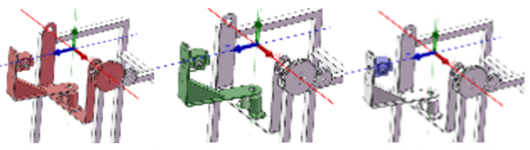




User's foot being placed on the device, where central point of ankle rotation is intersection of the platforms' rotational axes

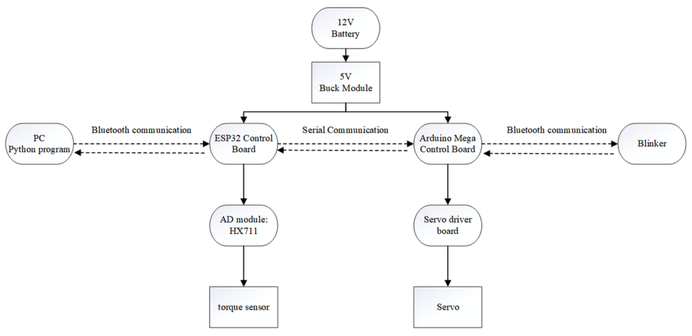
Framework of device constructed using plate metals, connected with screws and nuts

Main platform (red), which holds mass of user's foot, and two auxiliary platforms (green and blue)



Screenshots taken from model created by student in SolidWorks, 2025

Systemic Design and Electronic Components



Screenshot from diagram drawn by student, 2026

Software-hardware control structure

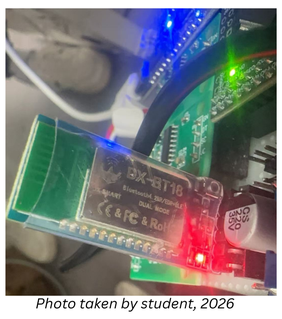


Photo taken by student, 2026

Bluetooth panel used for communication between device and Blinker app on phone

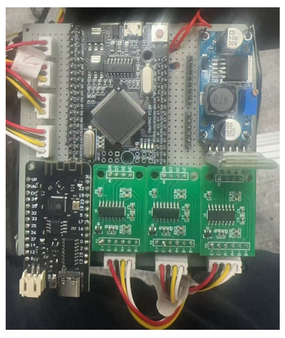
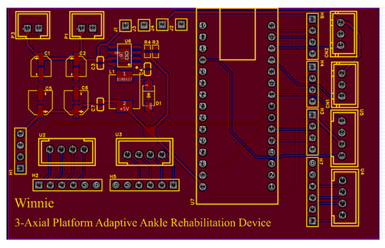
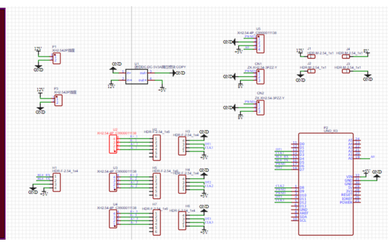


Photo taken by student, 2026

Electrical panel with needed boards and modules soldered

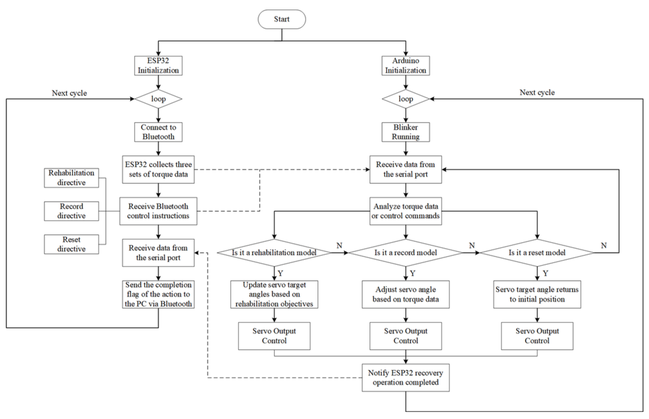




Screenshots taken by student from JlaLiChuang EDA, 2026

PCB layout structure and electrical components, designed and drawn in software

Software Control Design



Screenshot from diagram drawn by student, 2026

Logic of the program for the self-written softwares

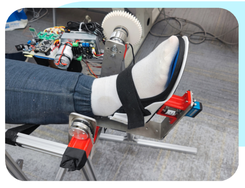
Screenshot from Blinker app on phone, 2026.

UI for control of all the functions from phone end

Screenshots from pages of PC end software written by Python, 2026.

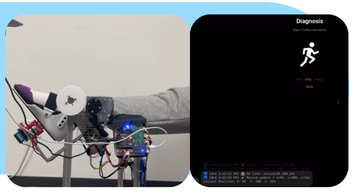
Home page Customized UI | **Diagnosis function page Tests patient ankle range** | **Rehabilitation function page Records/reperforms rehab exercise** | **User management page Independent data for each**

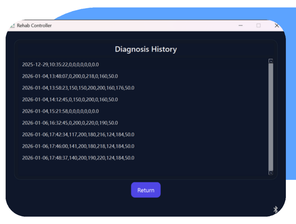
Experiments



1. **The tester (student) places foot on the device like a normal user, or patient, would.**

2. **The tester tries to move their ankle in all directions. Torque sensors will provide readings for the first experiement, and rotation range will be read for the second experiment.**





3. **The experiment data can be read directly from the connected Arduino serial portal (torque) and the coded software (rotation angles).**

Experiment 1: Torque Thresholds

Torque Thresholds	Forward Backward				Inward-Outward	Left-Right
Angle Range	Less than 140	140-160	160-190	More than 190	All angles	All angles
Positive	90	50	30	30	50	20
Negative	-20	-50	-90	-100	-50	-20

Screenshot taken from Word document recording experiment 1 results, 2026

When powered, the servos cannot move in response to external force, so the program needs to know what level of torque it receives for it to start gradually moving in the direction of the torque received, thus being able to follow the user's movements.

The program continuously prints the torque readings from the sensors, and the tester places their foot on the device and exerts force by trying to turn their ankle. The forward-backward direction is divided into distinct ranges due to the gravitational pull on the main platform when it is raised up to an angle.

Experiment 2: Human Ankle Rotation Angle

Human Ankle Range		Forward Backward	Inward-Outward	Left-Right
Trial 1	Minimum Angle	117	180	124
	Maximum Angle	200	216	184
Trial 2	Minimum Angle	141	180	124
	Maximum Angle	200	218	184
Trial 3	Minimum Angle	140	190	124
	Maximum Angle	200	220	184

Screenshot taken from Word document recording experiment 2 results, 2026

This experiment is possible only after the torque thresholds are tested. The normal human ankle's movement range is needed because while we have to ensure that the device can fulfill the needs of the user, these values are also needed to set mechanical stops on the device and guarantee safety.

Data is collected through the diagnosis function, which has been programmed to show all the history records of the ankle's movement range. A total of three trials were run, each in which the tester attempts to move their ankle to the largest angle possible in three directions.

Conclusions

In conclusion, the device has successfully accomplished the original engineering goals of this project. Experimental results show that the device's motion range fully covers normal ankle movement and that calibrated torque thresholds allow responsive and safe assistance.

The system adopts a serial multi-degree-of-freedom structure driven by three servo motors whose rotational axes intersect at the rotation center of the ankle, enabling all six fundamental ankle movements. Torque sensors provide real-time force feedback for motion assessment and safe usage, while an embedded controller and wireless communication support data acquisition and user interaction through PC end and mobile phone end applications. The system demonstrates the ability of combining quantitative evaluation and multimodal rehabilitation in a low-cost solution, helping to engage accessability from home.

Future Outlooks

In the future, the device could still...
- **Add a speaking function to help elders access better**
- **Create a website interface that can be connected through WiFi from different devices**
- **Be connected online to upload patient data to therapist or doctor for professional assessments**
- **Append other sensors to provide more accurate and complete collection of the patient injury conditions**
- **Train an artificial intelligence model using dataset from past patients (with consent)**

References

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