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Lower Limb Auxiliary Exoskeleton Based on Gait Dataset

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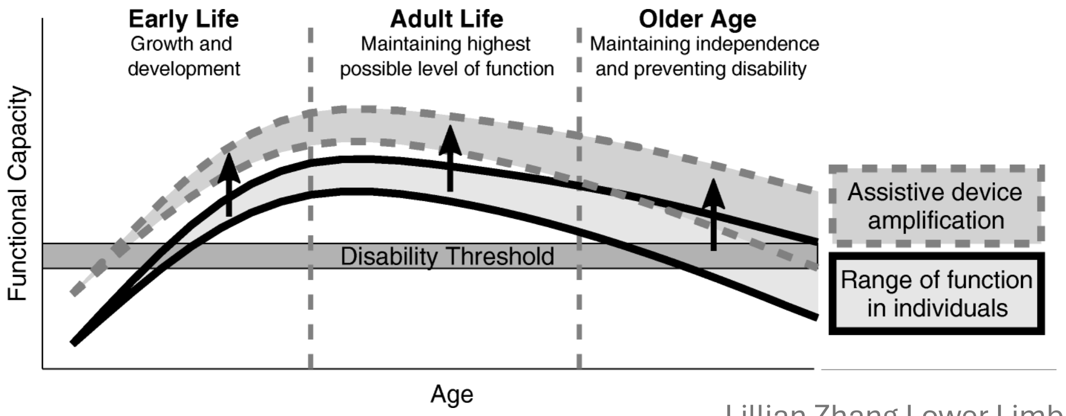
Introduction

Reduced mobility is a common consequence of aging, often stemming from frailty, muscle weakness, and joint issues.

- These limitations significantly impact daily life, leading to physical activity, potential isolation, and an increased risk of injury.

- Most traditional mobility aids, including canes and mobility scooters, require upper-body strength to operate and do not address the complex nuances of gait and muscle engagement.



Traditional mobility aides are not suitable for the elderly in several ways:

- Requires upper-body strength to operate
    - E.g. canes and mobility scooters require the user to use their arms to hold them in place and provide walking assistance
- Do not address the nuances of gait and muscle engagement

Exoskeleton technology can counter these issues by providing more structural support to the lower body and is more customizable.

- These wearable robotic devices, which can be programmed and tailor-made, have a better ability to amplify human mobility, granting aging individuals the potential to regain stability and identify incorrect gait.

Introduction

Traditional mobility aids can cause hunching and require strong arm strength for the user to support themselves

Rigidity of exoskeleton enforces a better posture

Engineering Goal: Design a mobility aid to address the flaws of traditional mobility aids and provide lower body support with gait management

Methods

Part 1: Mechanical Design Overview

The main frame of the walking assistance exoskeleton comprises three main elements: the main skeletal framework, Servos (steering motors), 3D-printed and laser-cut custom elements, and a torso attachment.

1: Main Skeletal Framework
- Composed of individual metal bars that serve as limb segments
- Incorporates rotational components designed to imitate the movement of the human lower body

2: Four DH-03X Large Torque Alloy Servos: the joints
- High-performance motors are powered by a 12V lithium-ion battery
- Placed at the hip and knee joint locations to mimic the movements of said joints

3: 3D Printed and Laser Cut Components
- Two pairs of C-shaped, 3D-printed elements that are securely affixed to each metal bar
  - Based on user's leg measurements
  - Provides a snug fit and anchors the exoskeleton in place
  - Reinforced with nylon straps
- System of three laser-cut acrylic components designed to govern the movements of the calf section
  - Connected a Servo positioned above the knee on the calf metal bar

4: Torso Attachment
- Encircles the user's waist to provide support for the spinal cord
- Designed to help with the user's posture

Methods

Part 2: Electronics Design Overview

Electric Components

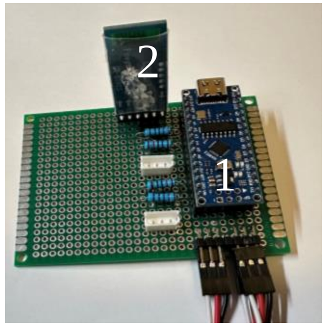
1: Arduino Nano Board: the central control module

- A powerful microcontroller with digital and analog pins compatible with an extensive array of sensors and other modules.

2: Bluetooth module: for easy control

- Controlled by the library Blinker.h
- Allows the user to initiate and pause the exoskeleton’s movements through the app Blinker

Pressure sensors: for gait analysis



Code Design

“map ()” Function

- Converts analog-to-digital converter (ADC) values, ranging from 0 to 1023, into pulse-width modulation (PWM) values spanning from 0 to 255
- PWM values are then mapped to represent the full range of motion from 0 to 180 degrees, thereby facilitating the movement of the Servos in tandem with the user's natural movements

```
void loop() {
  Blinker.run ();
  x = digitalRead (2);
    a = analogRead (A1);
  Serial.println (a);
  b= map (a, 0, 1023, 0, 255);
  c = map (b, 0, 255, 0, 180);
```

Bluetooth Module

- Uses the library “Blinker.h” and app “Blinker”
- Incorporates Boolean variable to dictate the start (false) and stop (true) of the exoskeleton’s movements

```
#define BLINKER_BLE
#include <Blinker.h>
BlinkerButton Button1 ("Xyz");
BlinkerButton Button2 ("Abc");
bool setstop = false;

void stop () {
  setstop = true;
}
void start(){
  setstop = false;
}
```

Methods

Part 3: Data Collection

Data collection device with potentiometers record gait in ADC values → map() function converts ADC values to 0-180 degrees → Servos rotate according to the calculated degrees

A simple data collection device of laser-cut thin wood planks and four potentiometers placed at the joints is used to record the user's gait

After the trackers relay the information to the Arduino Nano board, the numbers are printed in Arduino's Serial Monitor

A tool called ArduSpreadsheet is able to export the data into an Excel file, as shown on the right

05:14.5	-7	20
05:14.5	-7	20
05:14.5	-7	21
05:14.5	-7	20
05:14.5	-7	20
05:14.5	-7	20
05:14.5	-6	20
05:14.6	-6	20
05:14.6	-6	20
05:14.6	-5	20
05:14.6	-5	20
05:14.6	-5	19
05:14.6	-5	19
05:14.6	-5	19
05:14.6	-4	19
05:14.6	-4	19
05:14.6	-4	19
05:14.6	-4	19

Results

Reaching the goal of a more efficient mobility aid

- Because the exoskeleton focuses on giving the lower body external support, it does not require upper body strength
- Torso attachment provides structural support for the spinal cord and prevents hunching
- Rigid force of the Servos, when programmed to imitate a correct gait, and leg attachments helps the user to maintain the correct gait
- Simple controls with the Bluetooth “Blinker” app allow easy initiation and pause of the exoskeleton

Testing for muscle engagement

- I intentionally tensed up different muscle areas to walk in different gaits
- The approximate average ADC values recorded by the pressure sensors are shown in the chart on the right (I conducted three trials for each gait)

	Left Quad	Left Calf	Right Quad	Right Calf
Normal Gait	128	53	192	51
Calf Pushes Off Ground Hard	210	69	218	78
Quad Pushes Against Exoskeleton	317	48	356	53

Discussions

Muscle Engagement Data

- Gait when calf pushes off the ground hard: This gait is the most similar to walking patterns caused by equinus. However, equinus is largely associated with neurological factors such as cerebral palsy, so there should still be significant differences between a true equinus gait and mine (Physiopedia).
- Gait when the thighs push against the exoskeleton hard: This gait is the most similar to the posterior lurching gait, where the hip is extended and there is a lack of glute engagement (Ataullah et al., 2023). I felt my glutes relax substantially when I tensed my quads to push against the exoskeleton's leg attachments, but this relaxation is not backed by empirical statistics at the current stage of my testing.

Areas of Challenge/Improvement

- The pressure sensors should be replaced with sensors such as muscle sensors (EMG) that are more accurate when testing for muscle engagement and activity
  - More sensors can be added to other major muscle regions such as the glutes
- The exoskeleton is relatively heavy due to the metal bars and four large Servos
- The 3D-printed leg attachments are not adjustable

Improvements Over Current Solutions

- Does not require upper body strength
  - Unlike traditional mobility aids, this exoskeleton provides structural support to the lower limbs through its metal bars and leg attachments
- Helps maintain gait
  - While traditional mobility aids largely focus on stabilizing the user's weight, this exoskeleton's torso attachment and rigid Servo rotations enforce a correct gait

Conclusions

Did your project turn out as you expected?

- While this project did mostly turn out as I expected by providing good lower body support, the data on the user’s gait may be improved
- More work is being done on data collection and gait analysis
- Several challenges were met when constructing the exoskeleton (e.g. buying the correct connectors for wires and batteries), but the bulk of them surrounded the code design of data collection to program the Servos and gait analysis

Applications

- As stated previously, the target audience of mobility aids is seniors and people with incorrect gait
- Seniors
  - The spinal cord and lower limbs support is incredibly concrete
  - Bluetooth control makes the system easy to use
  - Weight of the entire exoskeleton may be an issue to seniors with weak waists
- People with incorrect gait
  - While walking with the exoskeleton on does force the user to follow a correct gait, it is unclear as to how effective or scientific this is due to lack of experiment (progress is underway)

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