CYSF 2025-2026 Logbook

"Augmenting Balance and Spatial Awareness in Parkinson's Disease: Quantitative Postural Stability Analysis of a Wearable Assistive Tail"

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We investigated multiple topics of interest related to movement and mobility, such as fall-prevention strategies, wearable balance-assist devices, and rehabilitation approaches for motor disorders. Ultimately, we chose to focus on balance problems in people with Parkinson's disease, older adults, and individuals with conditions such as autism, since balance impairments are common and highly impactful across these populations.

Parkinson disease (PD) is a common neurodegenerative disease of older adulthood. Population-based data on 36 million Medicare beneficiaries over the age of 65 suggests that 1.6% of Americans are treated yearly for PD, approaching the rate of stroke or migraine. The cardinal clinical symptoms of Parkinson disease - limb tremor, shuffling gait, slowness, stiffness, and postural instability - can be accompanied by autonomic nervous system dysfunction, depression, dementia and psychosis. In addition to physical disability, PD is associated with an increased likelihood of death.[1–3] The shifting demographics of the U.S. population due to the aging of the Baby Boomers has placed more adults at risk of PD than ever before, underscoring the need for increased understanding of PD diagnosis, clinical

ariation in PD Diagnosis

nown, environmental factors are suspected.[4–7] PD

Medication for Parkinson's disease

Once the doctor diagnoses Parkinson's disease, the next decision is whether a patient should receive medication, which depends on the following:

- The degree of functional impairment
- The degree of cognitive impairment
- Ability to tolerate antiparkinsonian medication
- The advice of the attending doctor

No two patients react the same way to a given drug, therefore, it takes time and patience to find an appropriate medication and dosage to alleviate symptoms.

Sammons Preston Padded Gait Belt

Infection Control Gait Belts

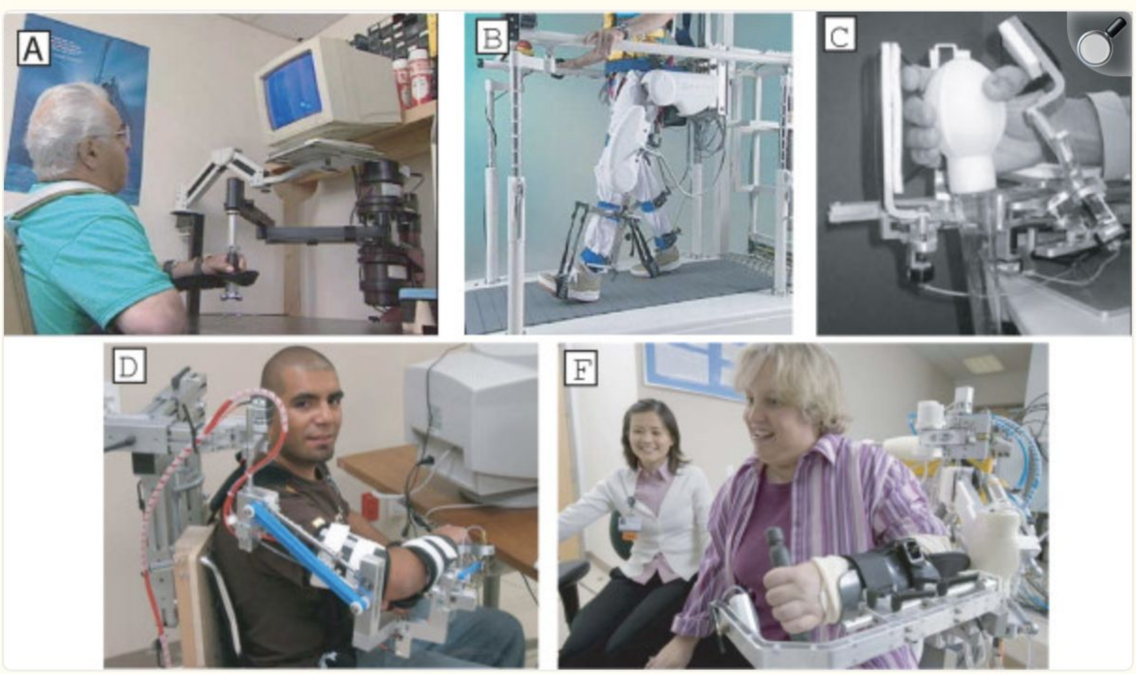
Department Gait Belts

Further research led us to compare traditional gait belts with a novel wearable "robotic tail" used for balance support. We found that robotic tails can provide more dynamic and responsive stabilization than standard gait belts, making them more effective for improving balance and potentially reducing falls in our target populations. Specifically, we wanted to mimic the natural tail in animals like cats or kangaroos, animals that rely on their tail to balance.

Abstract

There is increasing interest in using robotic devices to assist in movement training following neurologic injuries such as stroke and spinal cord injury. This paper reviews control strategies for robotic therapy devices. Several categories of strategies have been proposed, including, assistive, challenge-based, haptic simulation, and coaching. The greatest amount of work has been done on developing assistive strategies, and thus the majority of this review summarizes techniques for implementing assistive strategies, including impedance-, counterbalance-, and EMG- based controllers, as well as adaptive controllers that modify control parameters based on ongoing participant performance. Clinical evidence regarding the relative effectiveness of different types of robotic therapy controllers is limited, but there is initial evidence that some control strategies are more effective than others. It is also now apparent there may be mechanisms by which some robotic control approaches might actually decrease the recovery possible with comparable, non-robotic forms of training. In future research, there is a need for head-to-head comparison of control algorithms in randomized, controlled clinical trials, and for improved models of human motor recovery to provide a more rational framework for designing robotic therapy control strategies.

Figure 1.



We have started researching two types of attachments for the gait belt:

1) Attached at the chest, providing support to upper body
2) Attached at the lower back, providing support for legs

We noticed benefits with both even upon our own balancing skills. Thus, we will devise a way to connect the two in order to optimize stability. This may also make haptic sensing and feedback easier, as there will be two points of input rather than one to determine user action.

We conducted a preliminary experiment by holding onto large weights to determine the approximate effectiveness of various weight ranges on our own bodies. Around 3 lbs of weight felt substantial to significantly alter our bodily momentum once we swung it around in all directions, so we strived for a 400g to 1200g design.

Title: **Segment Prototype 1**

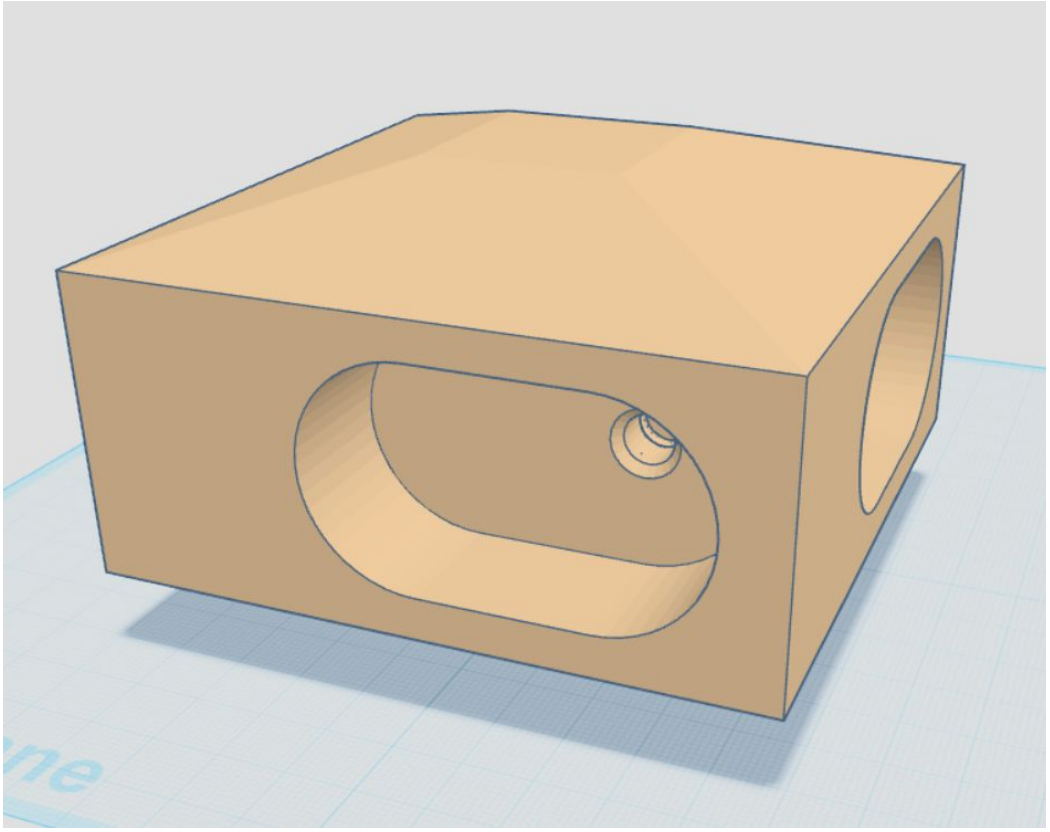
Test

Our first prototype for the weighted segments involved a 30 degree rotation angle between each segment that eliminated the gaps within.

This prototype was built taking into consideration several key factors:

1. Structural rigidity
2. Cross sectional strength
3. Ability to easily insert and remove weights
4. Possible to be made in TinkerCAD

However, printing time was roughly 5 hours for one segment at standard 3D printing speeds with our Bambu Lab A1 Mini printer, and it also used a significant amount of infill filament. The placement of the holes, where we could attach weights to, was also not efficient as many places required an external snap-fit lid. Although it was possible to print the remainder of the segments for the tail according to this assembly, the discrete bending angles possible in the trapezoidal prism design heavily limited the range of motion for the tail as well. For these three reasons, we decided to pursue a second prototype.



Segment Prototype 2 & 3

Our second prototype for the weighted segments needed to address a critical flaw in our first prototype:

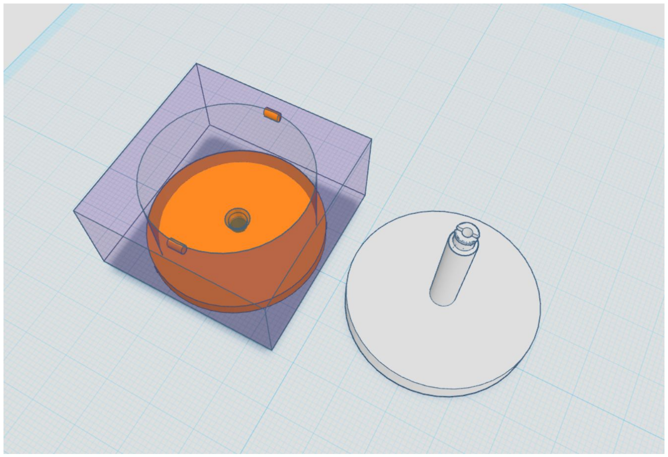
1. We needed to significantly reduce the print time from the 5-hour window, as this used a lot of filament and was therefore inefficient.

We therefore arrived at the design on the left, but the attachment lid was still noticeably flimsy and we did not believe it could withstand the force of constantly moving 100g weights. We therefore had a second major flaw to address:

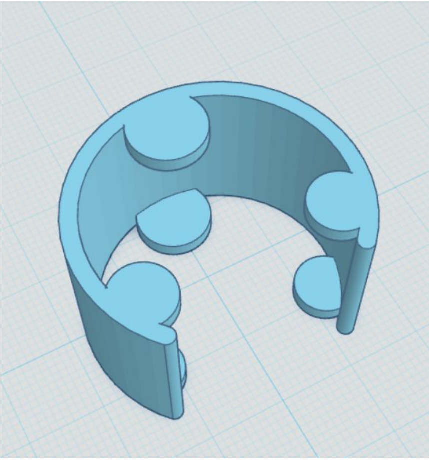
2. We needed to optimize the attachment points of the weights, ideally with a static design, so that they could be secure and won't require additional lids at the same time

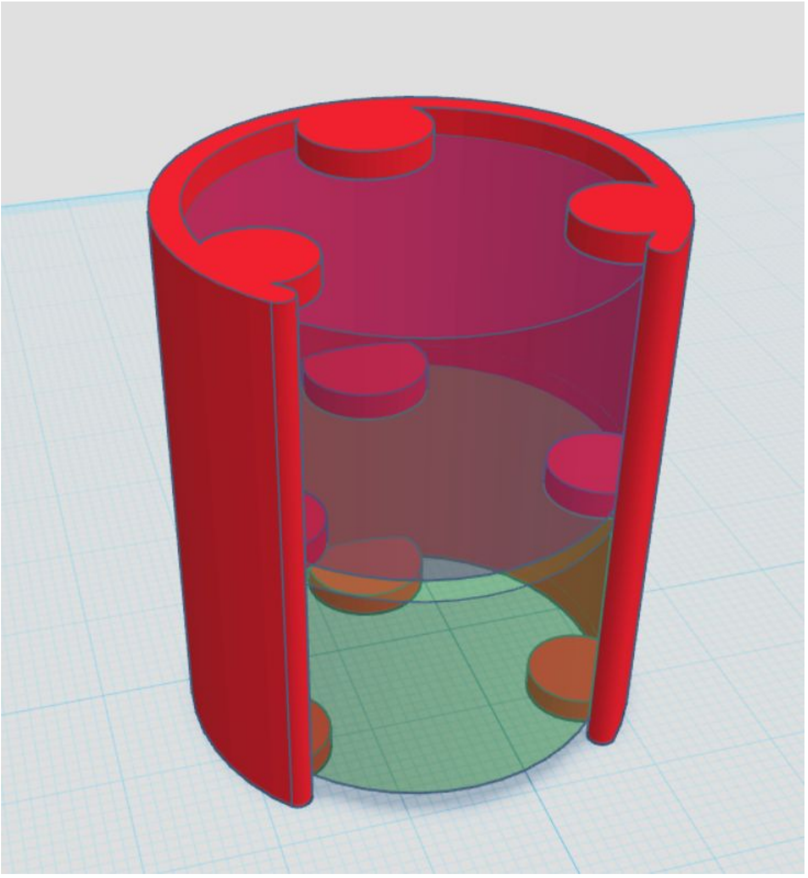
This allowed us to arrive at our third and final snap-fit design for the weights, which securely held onto each of the weights while retaining their ability to be easily attached and removed.

Prototype 2

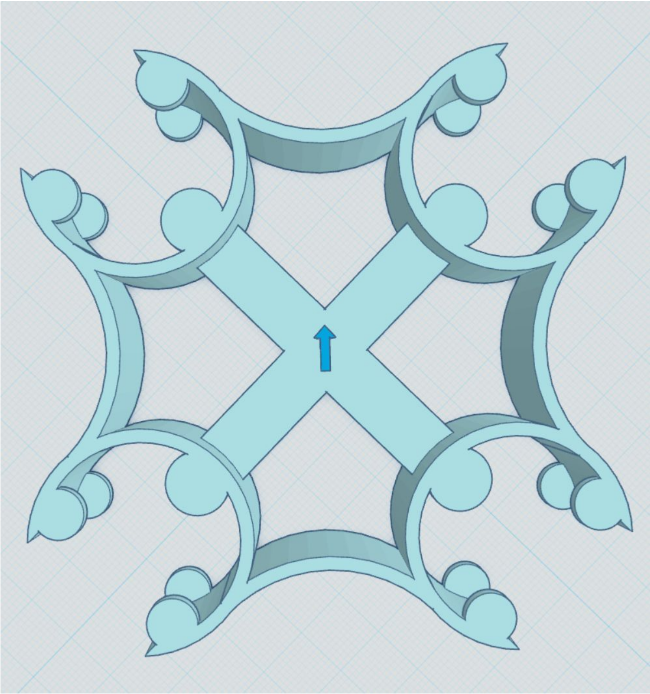


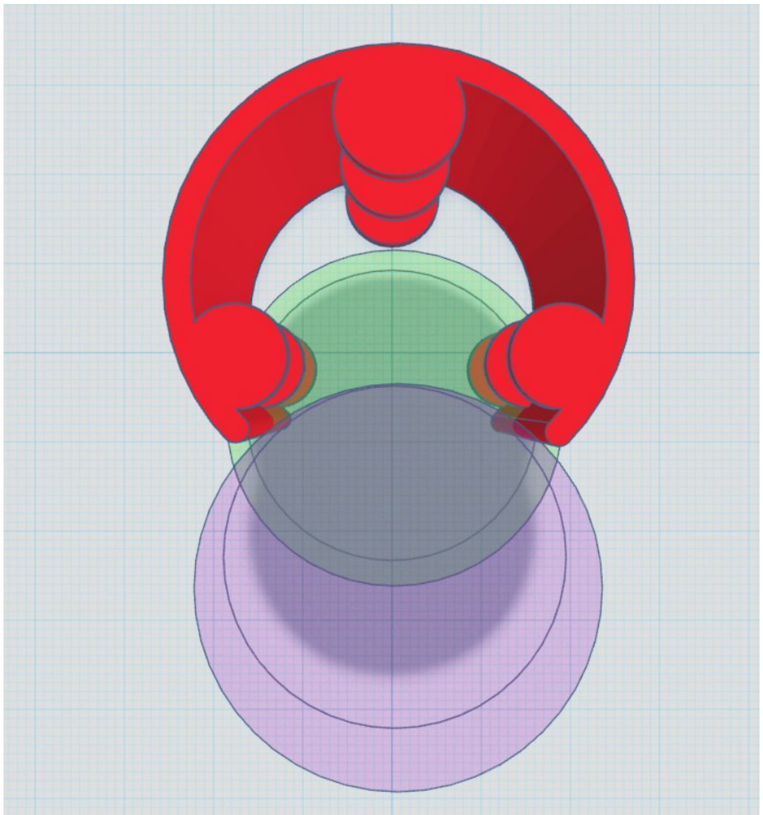
Prototype 3 (FINAL)





Various weights attached to the tail to optimize processes.





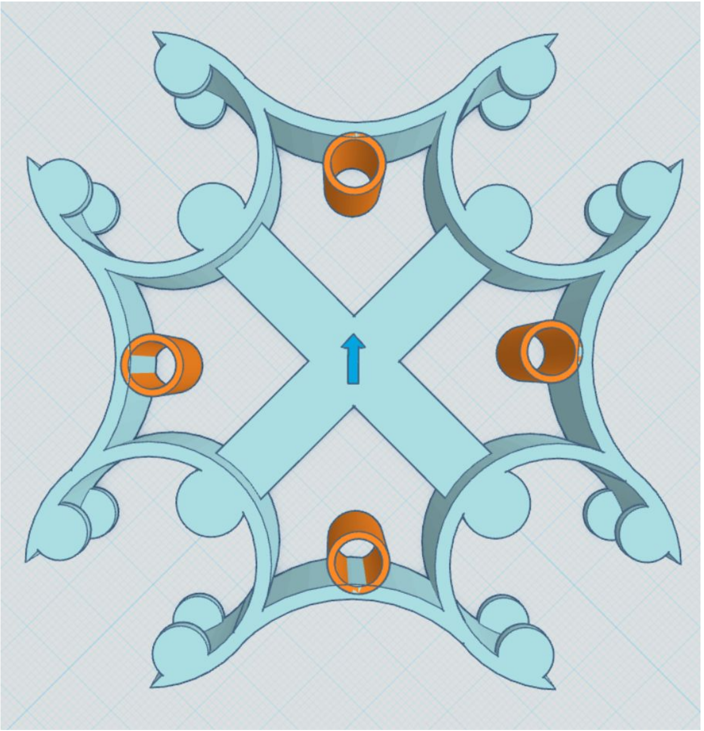
Devised a method to easily add and remove weights, which will be beneficial for different patients and diverse needs.

(Purple weight = closest distance without stretching, Green weight = maximum flex position)

Title: Preparing Segment Design

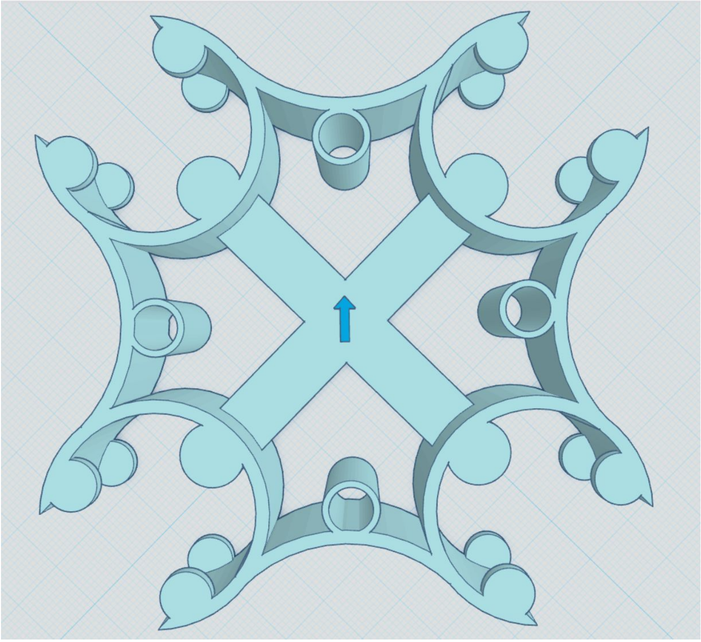
Plan

Building off of our third and final prototype for the segments, we needed to minimize torque required for the servos to pull the tendons, and to also remove unwanted torsion effects. Since both of these effects are caused by the tendons being too close to each other, the apparent force of the weights is decreased when the tendons are further apart. Consequently, we decided to keep the weight attachment points near the outside for easy modification but to construct holes for the 3D-printable design.



Unmerged

Merged



Title: **External Sensors**

Plan

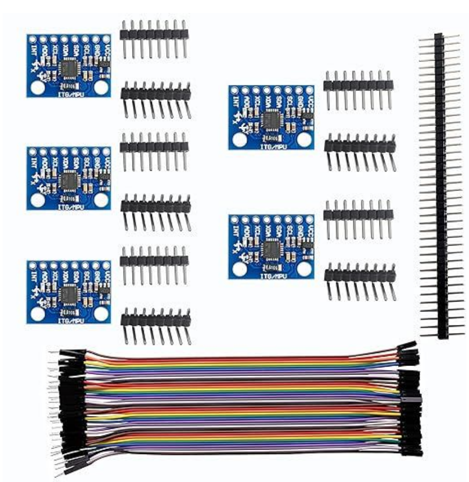
To detect sudden pertubations or possible environmental obstructions that could pose a hazard to the wearer, we planned to integrate a variety of sensors and feedback devices to alert the wearer and provide sensory metrics for the tail. We've compiled a full list for part ordering. These items include:

Vibration/Haptic Feedback

- A DC 5V 9000RPM Vibration Module from Amazon
- DRV2605L Haptic Motor Controller

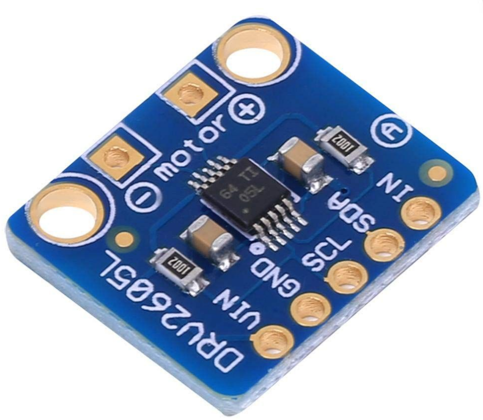
Sensors

- Thin-Film Force Sensitive Resistors
- HC-SR04 Ultrasonic Sensors
- MPU-6050 Gyroscopic Accelerometers



MPU-6050

DRV2605L



HC-SR04

Title: # Tendons

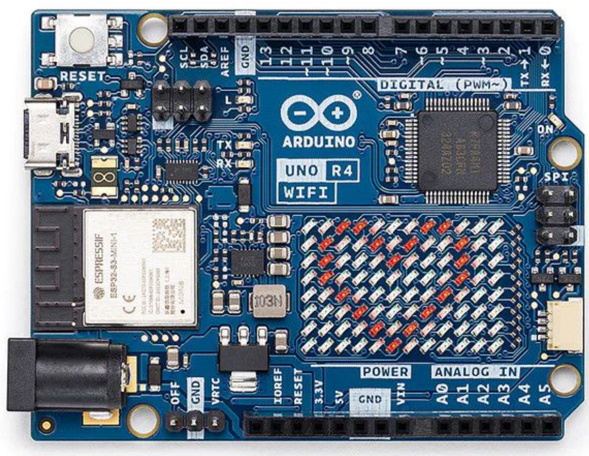
Plan

When we brainstormed strategies to implement tendons into our actuated design, we came across various types of plastics or natural fibres that could imitate a fibrous structure. Since tendons are naturally elastic and considerably tough in strength, many softer fibres would not be applicable for our tail device.

To select our tendon material, we investigated the quantity of flexural stiffness, a metric common in structural engineering. EI flexural stiffness is defined as the product of Young's Modulus (E) with the material's area moment of inertia (I), with EI proportional to the radius of the tendon raised to the fourth power (r^4). Since materials like rope or string-like fibres would be small in radius and are low in stiffness (E), they were eliminated from our brainstorming.

For our prototype models, we decided to experiment with plastic tubes of a moderate range of width and stiffness. Taking into consideration affordability, we decided to pursue flexible polyvinyl chloride (PVC) tubes with a maximum width of around 6 mm for testing. Later, if we need to, this approach allows the stiffness (E) constant to be manipulated, such as by attaching a 3D printed segments that would act as a housing for the tubes. This would restrict the range of movement and thereby increase the apparent stiffness of the system.

Arduino Uno R4 WiFi



MG996R

When we brainstormed ideas to build the electronics for the system, we deliberated many alternatives, such as motors, servos, and even pneumatic or hydraulic actuators. In the end, we decided to experiment with an Arduino with bluetooth connectivity and high-torque servos as our actuators, because of the low-cost scalability of the components. We researched several online sites on the functionality of various builds and arrived at the Arduino Uno R4 WiFi, mainly due to its competitive pricing with a customizable LCD screen on top of its connectivity features (https://docs.arduino.cc/hardware/uno-r4-wifi/).

To support the arduino, we decided to move forward with the MG996R high-torque servo after viewing its spec sheet (https://components101.com/motors/mg996r-servo-motor-datasheet), which can deliver up to a maximum torque of 11 kg/cm, enabling us to pursue a range of designs.

Title: **Testing Metrics** Test

Narrowed down to several key testing metrics (originally had 7-8 of consideration) based on uniqueness to our innovation and available patient data.

- Sway Range:
  - Ultrasonic sensor records distance at 20 Hz
  - Compare each reading to baseline → get sway (fwd + / back -)
  - Sway range = max – min sway over trial
  - Shows how much total movement there was
- Ground Contact & Step Imbalance:
  - Insoles track pressure with FSR sensors
  - Ground contact time = how long each foot's on the ground
  - Step imbalance index compares left/right contact times
  - 0% = perfect symmetry; >15% = meaningful imbalance (seen in Parkinson's)
- Perturbation Recovery Time:
  - Perturbation = sway > 3 cm from baseline
  - Recovery time = from start of deviation → back within ±3 cm zone
  - When detected → tail + haptic feedback trigger
  - Tells how fast balance is regained
- Perturbation Detection Speed:
  - Accelerometer logs at 100 Hz when perturbation starts
  - Measure time from onset → peak acceleration
  - Shorter = sharper reaction (no tail)
  - Longer = smoother, tail helps cushion response

Using the manual provided for the ultrasonic HC-SR04 module, we constructed a function that used the echo/trig pins to read a distance value from each ultrasonic sensor, in centimetres:

```

// -------------------------
// Ultrasonic
// -------------------------
float readCm() {
  digitalWrite(TRIG_PIN, LOW);  delayMicroseconds(2);
  digitalWrite(TRIG_PIN, HIGH); delayMicroseconds(10);
  digitalWrite(TRIG_PIN, LOW);

  uint32_t dur = pulseIn(ECHO_PIN, HIGH, 30000UL);
  if (!dur) return NAN;

  float cm = (dur * 0.0343f) / 2.0f;
  if (cm < 2.0f || cm > 400.0f) return NAN;
  return cm;
}

```

To implement the ultrasonic sensors, we coded a calibration process to read the distance according to an apparent baseline value, and to provide updates based on a calculated time value as the user experiences a sway movement. A stable state variable was created in the process and is dependent on minimum and maximum threshold constants, ensuring that the movement of the tail will be activated when the observed sway values surpass these set limits.

```
// ------------------------
// Calibration
// ------------------------
void calibrate() {
  Serial.println("Calibrating (~3s)...");
  float sum = 0;
  int n = 0;

  for (int i = 0; i < 30; i++) {
    float d = readCm();
    if (!isnan(d)) {
      sum += d;
      n++;
      distF = (n == 1) ? d : (0.7f * distF + 0.3f * d);
    }
    delay(100);
  }

  baseline = (n ? sum / n : 30.0f);
  distF = baseline;

  Serial.print("Baseline: ");
  Serial.print(baseline, 1);
  Serial.println(" cm");
}

// ------------------------
// Updates
// ------------------------
void updateSway() {
  float d = readCm();
  if (isnan(d)) return;

  distF = 0.7f * distF + 0.3f * d;

  uint32_t now = millis();
  float sway = distF - baseline;

  if (now - winT > SWAY_WIN_MS) {
    winT = now;
    maxS = -1e9f; minS = 1e9f;
  }
  if (sway > maxS) maxS = sway;
  if (sway < minS) minS = sway;
  swayRange = maxS - minS;

  float a = fabsf(sway);

  if (!inPert && a > ENTER_CM) {
    inPert = true;
    pertT = now;
    stableCt = 0;
    contactLogged = false;
    contactLat = 0;
    tailStart(sway);
  }

  if (inPert) {
    if (a < EXIT_CM) {
      if (++stableCt >= RECOVERY_STABLE_SAMPLES) {
        lastRec = now - pertT;
        inPert = false;
      }
    } else {
      stableCt = 0;
    }
  }
}
```

Title: Custom Structs

Coding

We created a custom “Foot” structure to help us assess how each feet is moved in live-time. Various helper functions were made accordingly to assess the position of each foot (off or on the ground) with consideration of the current gait position. These metrics allow us to analyze how each foot is lifted off the ground, and allow us to calculate stability metrics in our data analysis. All data is logged to the Serial Monitor in real time.

```
struct Foot {
  bool down = false;
  uint32_t t0 = 0;          // strike time
  uint32_t gct = 0;         // last ground contact time
  uint32_t lastUpdate = 0; // last time gct updated
};

```

```
void updateFoot(Foot &F, int val) {
  uint32_t now = millis();

  if (!F.down && val > FSR_TH) {
    F.down = true;
    F.t0 = now;
  } else if (F.down && val < FSR_TH) {
    F.down = false;
    F.gct = now - F.t0;
    F.lastUpdate = now;
  }
}

void updateGait() {
  updateFoot(L, analogRead(FSR_L_PIN));
  updateFoot(R, analogRead(FSR_R_PIN));

  uint32_t now = millis();
  if (L.gct && R.gct && (now - L.lastUpdate < 2000) && (now - R.lastUpdate < 2000)) {
    float avg = (L.gct + R.gct) / 2.0f;
    imbalance = fabsf((float)L.gct - (float)R.gct) / avg * 100.0f;
  }
}

void updateContact() {
  if (!inPert || contactLogged) return;
  if (analogRead(CONTACT_PIN) > CONTACT_TH) {
    contactLogged = true;
    contactLat = millis() - pertT;
  }
}

void updateTail() {
  if (tailOn && millis() - tailT >= TAIL_HOLD_MS) {
    center();
    tailOn = false;
  }
}
```

INFORMED CONSENT FORM 2C

CALGARY YOUTH SCIENCE FAIR

You are invited to take part in a research study. Before you decide to be a part of this study, you need to understand the risks and benefits. This consent form provides information about the research. If you agree to participate in this research, you will be asked to sign this consent form before taking part. This process is known as *Informed Consent*.

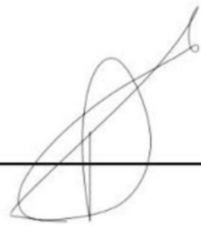
Student Researcher (1): Luotong Shi School: Western Canada High School School Phone: 403-228-5363	Student Researcher (2): Allen Guo-Lu School: Western Canada High School School Phone: 403-228-5363
Project Title: Augmenting Balance and Spatial Awareness in Parkinson's Disease: Quantitative Postural Stability Analysis of a Wearable Assistive Tail	
Science Fair Coordinator (Adult Supervisor): Name: Sharon Lu Phone: 403 262 8468	
Project Description: This project was chosen to explore a wearable assistive tail system modelled after common biological structures that enhances its wearer's postural stability, which is quantitatively assessed through selected balance and responsiveness metrics. The dual integration of proximity sensing with the balancing module in a modular, non-invasive belt, pre-emptively alerting seniors to nearby hazards. As we seek to assess the performance of the technology in individuals with Parkinson's disease, participants will be selected of their own volition and will receive a thorough briefing on the necessary actions.	
Your benefits from participating: Participants have an opportunity to participate in product research, and contribute to a holistically affordable and innovative module that mitigates fall risk and assists common movement patterns for individuals with limited motor function	
Your risks from participating: Participants in the investigation will be required to walk around and stand still as normal, following various modes and tests with active sensors. They will not be subjected to tests that cause emotional distress, as the skill test simulates everyday movement, and participants are not compared to a group average, minimizing any potential negative impact.	
Your time commitment: 15min appointments, x2 if adjustments are needed.	
The confidentiality of your data: The results of this research will be given with all information about individual participants removed. No personal information will be stored on a computer. All information on paper that could be used to identify individuals will be shredded at the end of the research project.	
Withdrawal: Your participation is voluntary, and you have the right to withdraw at any time for any reason. If you wish to do so, please talk to the Science Fair Coordinator/Adult Supervisor.	
Review: This project has been reviewed by the Ethics Committee of the Calgary Youth Science Fair Society and has received permission to proceed.	
Feedback: The results of this research will be provided to you in the public presentation of the Science Fair Project.	

By signing below, you are agreeing to participate in this study.

Name Dora Ng____________________________ (please print)

____

Signature ____



Date 02/06/2026____________

If this participant is under the age of 18, permission of a parent or guardian is also required:

I give permission for the person named above to participate in this study.

Name __________________________________ (please print) Phone ___________________

Signature ________________________________ Date ___________________________

By signing below, you are agreeing to participate in this study.

Name Kieu Quan_________________________ (please print)

______

Signature ____

Date 02/03/2026____________

If this participant is under the age of 18, permission of a parent or guardian is also required:

I give permission for the person named above to participate in this study.

Name _________________________________ (please print) Phone __________________

Signature _______________________________ Date __________________________

By signing below, you are agreeing to participate in this study.

Name Eleanor Xu________________________ (please print)

Signature ________________________

Signature ______________________________

Date 02/04/2026

If this participant is under the age of 18, permission of a parent or guardian is also required:

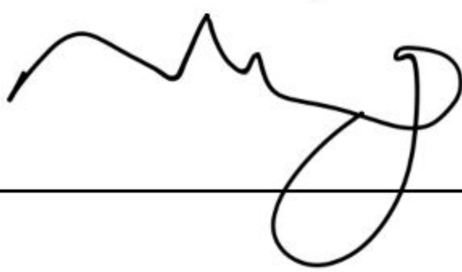
I give permission for the person named above to participate in this study.

Name ________________________________ (please print) Phone __________________

Signature ______________________________ Date _________________________

By signing below, you are agreeing to participate in this study.

Name Amy Kwan-Webber_________________ (please print)



Signature ______________________________

Date 02/07/2026____________

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Signature ______________________________ Date _________________________