Asymmetrical Force Sensor for Rowing Biomechanics

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Abstract and Problem Statement

Elite rowers that engage in a high volume of training can suffer from injuries pertaining to the lumbar spine [1]. Perfecting technique and maintaining proper form in the full body movement of rowing is essential to preventing such injuries and improving performance overall [2]. The UW Women's Rowing staff has tasked the team with creating a force sensing system to measure real-time biomechanical data in order to determine the presence of any lower extremity asymmetries. Existing products often involve expensive and highly advanced equipment [3], so achieving an affordable solution and maintaining an appropriate level of accuracy that doesn't disrupt users' rowing technique was paramount. The final design consists of a top footplate that translates vertically to transmit force to load cells that are housed underneath it. The device was tested by applying shear and normal loads at different locations on the plate and analyzing precision and accuracy.

Motivation

- Many members of the University of Wisconsin Women's Rowing team have been dealing with lower back pain and other injuries, potentially due to asymmetric force output while rowing.
- Many rowers experience back injuries due to various reasons: consistently exerting force when the back is flexed, repetition of the rowing movement, and failure to properly adapt to the size of the ergometer or boat [4].
- Current methods do not involve a way to quantitatively assess asymmetry in rowers or correlate it with other risk factors.
- With this device, the athletic training staff hopes to be able to interpret differences in symmetry of a rower's force output, fix athletes' form, identify and reduce the risk of lower back injury, and make quantitative judgements on return from injury.

Background

- The rowing motion can be modeled as a deadlift with the athlete pushing their feet off the footplate and pushing their oar against the water.
- There are four phases of rowing:
  - Catch, Drive, Finish, Recovery
- Most in-season rower training occurs on an ergometer due to weather conditions.
  - Therefore, most technique deficiencies are developed on the ergometer, leading to injury.

Figure 1. Phases of the rowing stroke [5].

Design Criteria

- Must be compatible with Concept2 RowErg specifications.
  - Footplate dimensions: 13.3 cm x 30.7 cm
- Must not impede natural rowing motion.
- Must have an easily interpretable real-time biofeedback display.
  - Frame rate > 24 Hz, delay < 0.5 s, font size > 10 mm [6, 7, 8]
- Life in service of at least 6800 hours.
- Force measured within a margin of error of 5%.

Final Design

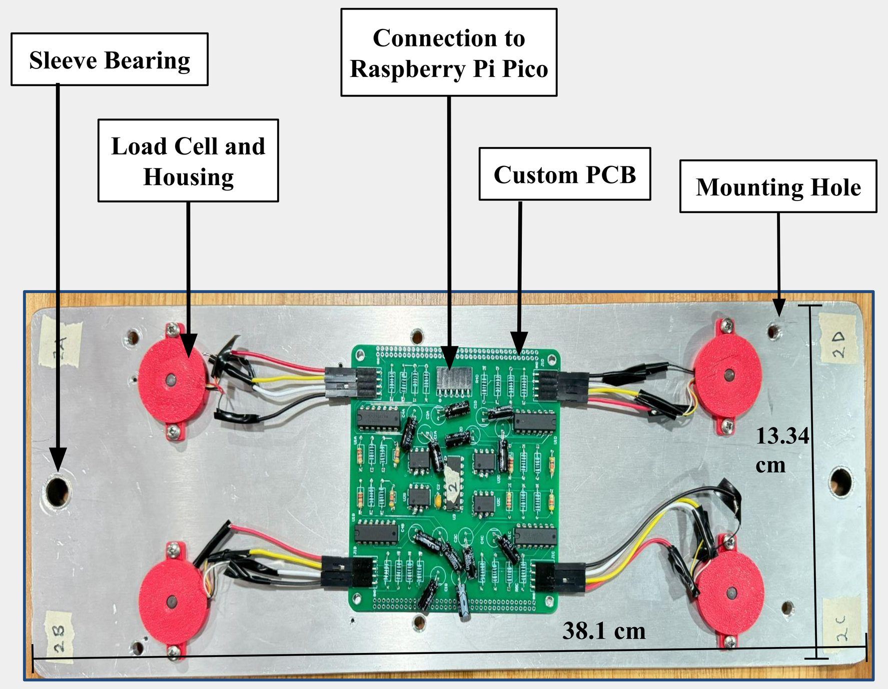

Figure 2. Top view of bottom foot plates with components labeled.

Footplate:

- 0.25" aluminum plates fabricated using CNC mill
  - Holes drilled for shoulder screw and bearing, load pins, load cell housings, ergometer mounting, and Flexfoot attachment.
- Top and bottom plates attached using shoulder screw fitted inside longitudinal bearing for frictionless translation.
- Load cells housed in 3D-printed fixtures that attach to bottom plate.
- Compression springs underneath bottom plate apply pre-load so load cells can measure relative tension.

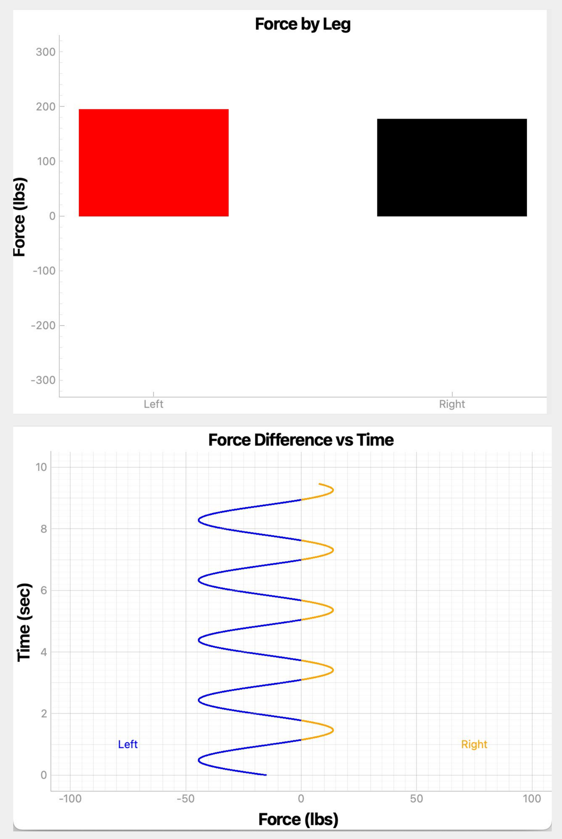

Figure 5. Two GUI examples for rower display.

Figure 3. Side view of left foot plate assembly attached to the Ergometer.

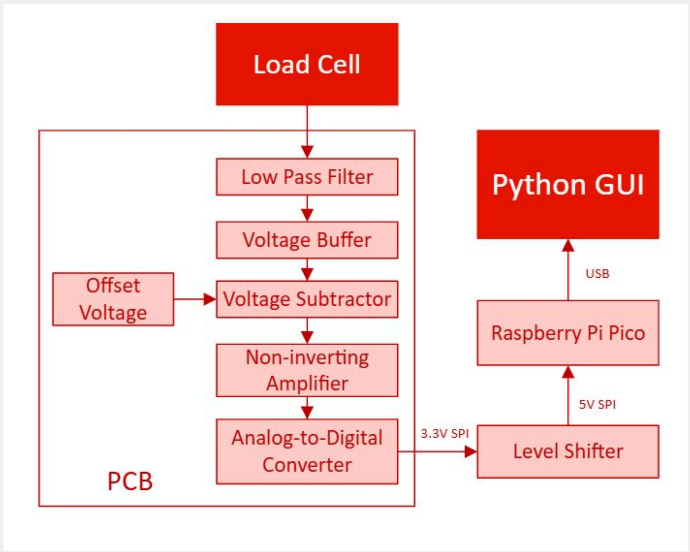

Figure 4. Hardware Block Diagram.

Electronics:

- PCB on each footplate to amplify, buffer, offset, and convert the signal from each load cell from analog to digital.
- Output from each PCB is fed into Raspberry Pi Pico, which communicates serially with packaged Python script to integrate with GUI.
- Rowers/coaches can choose to display force difference between legs or absolute force on GUI in real time.

Testing

Load Cell Calibration:

- 5 point load cell calibration on MTS.
- Line of best fit for each load cell (Force vs ADC value) used to obtain calibration factors.

Full Assembly Accuracy Testing:

- The full design was elevated on wooden blocks and a loading mechanism was placed onto the top plate.
- Metal weights were added onto the mechanism up to 130 lbs.
- The location of the applied load to the plate was changed for each testing cycle to examine accuracy when pressure is applied to the front, middle, and back of the plate.
- Shear loading was applied using a pulley system to assess if shear force would alter the normal force reading.

Figure 6. MTS calibration.

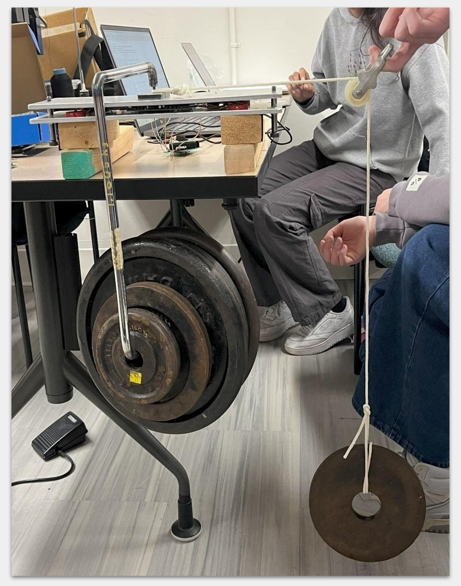

Figure 7. Shear load testing setup.

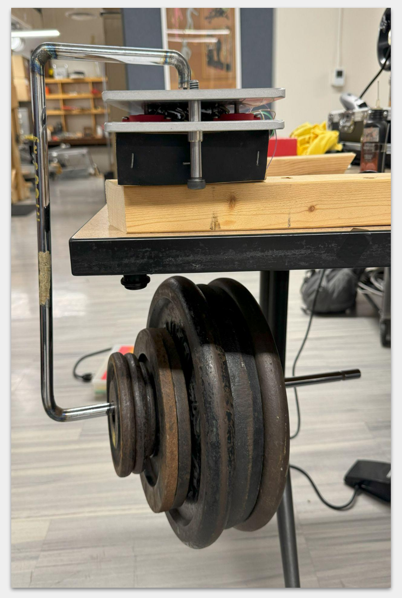

Figure 8. Full assembly test setup.

Results and Discussion

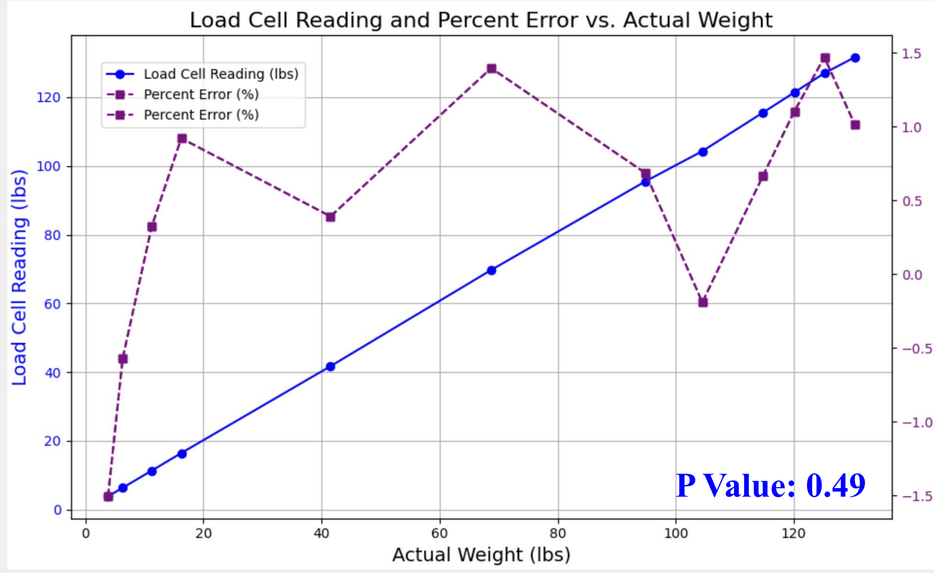

Figure 9. Load cell reading and percent error vs actual weight loaded at center of force plate.

Data Analysis and Interpretation

- Load cell readings (center position) showed no significant difference from actual weight (p-value = 0.49).
- Significant difference between load cell readings with and without 5.11 lbs of shear force was detected (p-value = 0.0063)
- The load position showed no significant change in load cell readings based on an ANOVA analysis (p-value = 0.518)
- Meets PDS criterion of 5% margin of error

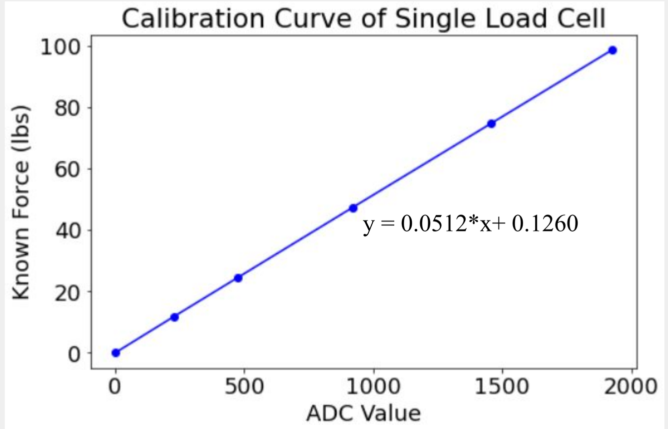

Figure 10. Force vs ADC Value for a single load cell, recorded during calibration.

Sources of Error

- Load cell non-linearity and hysteresis
- Off-axis loading errors
- Calibration error
- Electrical noise, capacitor charging delays
- Friction between shoulder screw and sleeve bearing

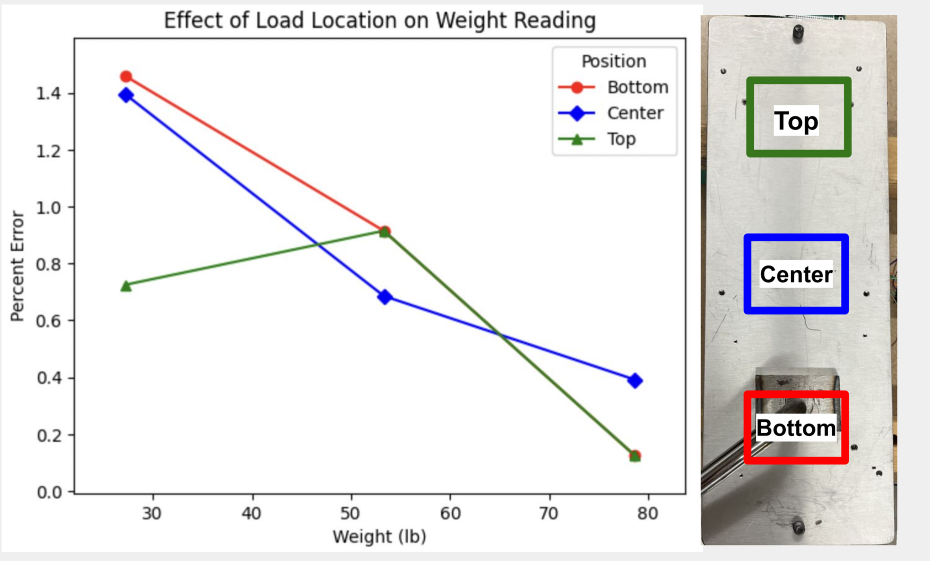

Figure 11. Load cell percent error at different loads applied in 3 different locations to the top plate.

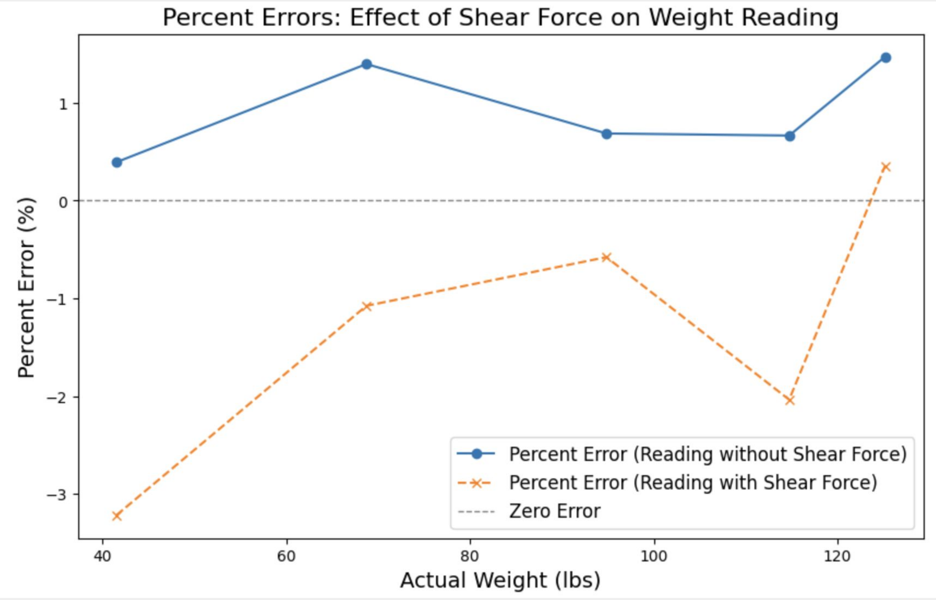

Figure 12. Percent errors of load cell reading and actual weight with and without applied shear force.

Future Work

- Test plates with a variety of shear forces
- Test plates with athletes of various weight groups (lightweight, openweight)
- Complete device validation testing with a large sample size of rowers.
- Investigate factors affecting force asymmetry (height, weight, leg length, stroke rate, etc).
- Investigate which graphical cues allow for best real-time adaptation in rowers.

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