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 rowing sport is essential to preventing such injuries and improving performance overall [2]. The UW women's rowing team 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]. In creating the design, achieving an affordable solution and maintaining an appropriate level of accuracy that doesn't disrupt users' rowing technique was considered. The final design, the Load Cell Force Sensor, consists of a circuit-based sensor system that is predicted to be seamless and an accurate assessor of force magnitude [4]. Through use of an Arduino microprocessor connected to a laptop for display, results were presented to users while they rowed.

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 [6].
- Current methods do not involve a way to quantitatively assess asymmetry in rowers.
- 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, reduce the risk of lower back injury, and make quantitative judgements on return from injury.

Background

- Rowing requires a high magnitude of force from the entire body, especially from the legs.
- The torque in the upper body causes over rotation of the spine, leading to stress in the lumbar spine due to uneven loading
- There are four phases of rowing:
  - Catch, Drive, Finish, Recovery
- Rowers typically only hold an oar on one side in a "sweep rowing" position.

Figure 1. Phases of the rowing stroke [7].

Design Criteria

- Must be compatible with Concept2 RowErg
- Must not impede natural rowing motion, must follow shape of ergometer
- Must be within dimensions of ergometer (61 cm width)
- Force magnitude must be measured within margin of error of 5%
- Service life of 10-12 years
- Must withstand temperatures from 8.3 degrees Celsius to 22.2 degrees Celsius
- Must be reproducible

Final Design

Fabrication:

- Circuit:
  - A 200kg-capacity HX711 load cell was connected to its compatible amplifier.
    - The load cell contains four strain gauges in a Wheatstone Bridge configuration.
  - Small changes in resistance inside the load cell were sent to the Arduino by an HX711 amplifier
  - An EEPROM Write and Read code was uploaded on the Arduino and readings were shown in lbs in the serial monitor.
  - A serial plotter was also used to provide a graph of real-time force exertion.
- Load Cell Housing:
  - Two plates were fabricated using HDPE found in the TEAM Lab.
  - Figure 3 was first trimmed longitudinally with a bandsaw, then drilled into with a 51/64" drill bit to embed the load cell.
  - A 7mm cut was made on the bandsaw to accommodate the wire.

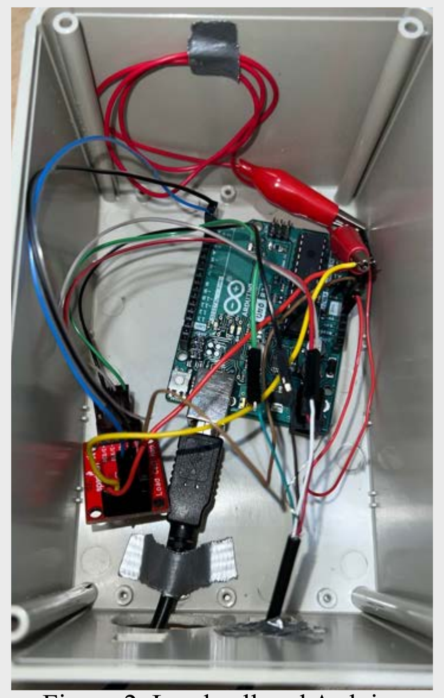


Figure 2. Load cell and Arduino circuit.

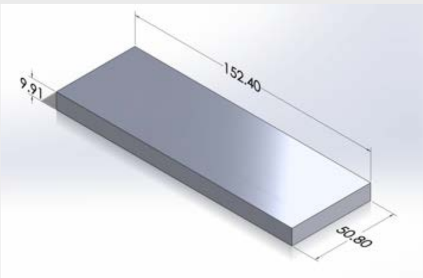


Figure 3. SolidWorks model of heel support plate. Dimensions in mm.

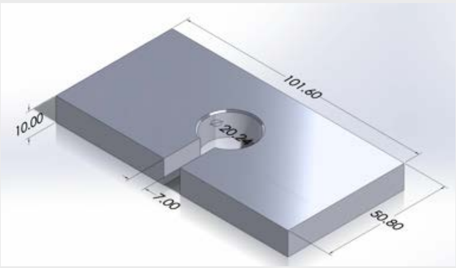


Figure 4. SolidWorks model of load cell housing. Dimensions in mm.

Assembly:

- Device Construction
  - A plastic housing block was created to enclose the load cell and mounted underneath a thin metal plate using duct tape.
  - A separate plastic rectangular block was covered with a thin metal plate using double sided tape.
- Foot Plate Adherence
  - The load cell construction was adhered to the ergometer footplate using a 2 inch Velcro strip and placed approximately level with the footplate strap.
  - At the heel position on the footplate, the additional plastic and metal rectangle was affixed via a 5 inch strip of Velcro on both sides of the foot plate so as to not interfere with the sliding flex foot.
  - One more thin metal sheet was placed above the load cell, again using 2 inch Velcro strips for secure attachment.

Figure 6. Load cell in plastic housing and metal top plate.

Figure 5. Final product on foot plate.

Figure 7. Side view of load cell assembly.

Testing

- Load Cell Calibration:
  - A set of calibration weights were obtained.
  - A 500g weight was placed on top of the load cell in its housing.
  - The calibration factor in the Arduino code was adjusted until the reading was accurate.
  - This was repeated for the 1kg weight, as well as with different team members standing on the prototype.
- Testing on the Ergometer:
  - In-person testing was conducted with a former UW rower.
  - The load cell housing was secured with duct tape onto the toe rest of the Flexfoot.
  - The subject completed several 30-60 second intervals of rowing at steady state, with a real-time force output display and data stored on the Arduino.
  - During testing, alterations were made to the device's placement and attachment:
    - The box was shifted further down the footplate to better align with the metatarsophalangeal joint of the subject.
    - Velcro was used to attach the device instead, with promising stability.

Figure 13. Subject's foot placement on the device.

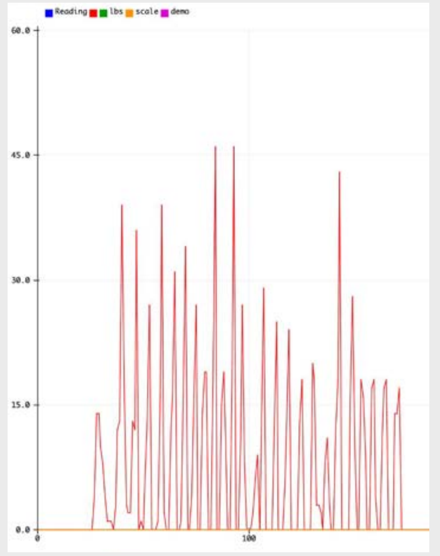
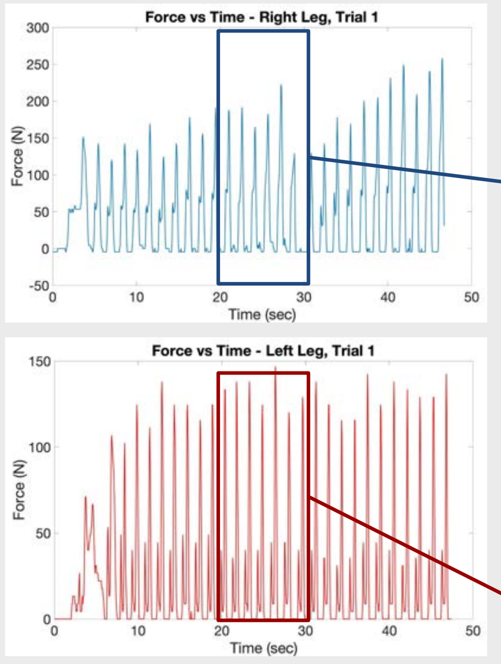
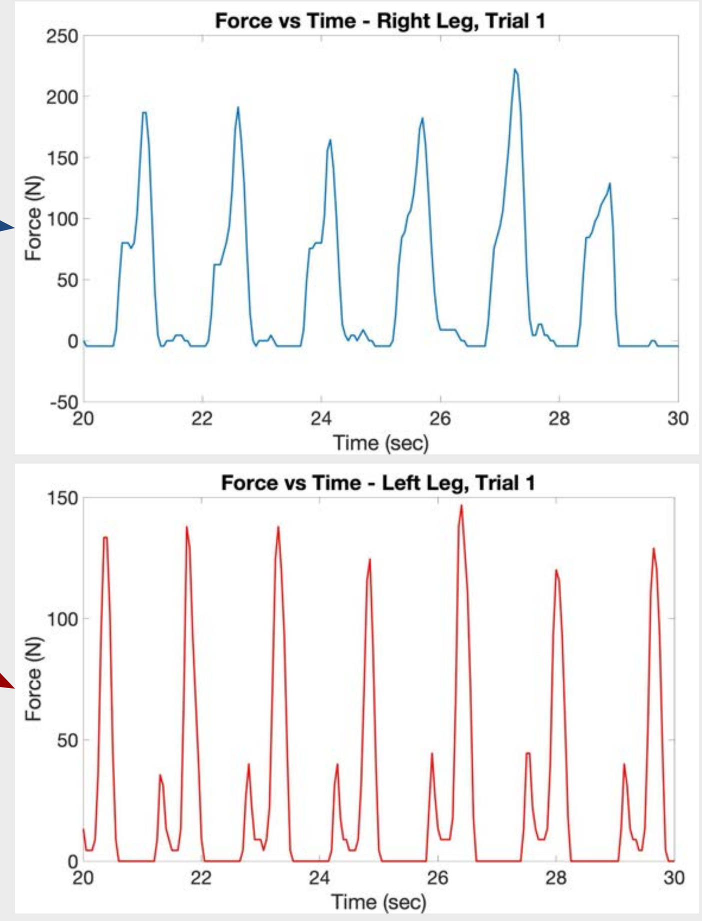


Figure 14. Screenshot of real-time display from Arduino Serial Plotter.

Results and Discussion





Figures 8, 9: Force vs Time graphs for the right leg (top left) and left leg (bottom left).
Figures 10, 11: Force vs time graphs for a 10s steady state interval for the right leg (top right) and left leg (bottom right).

Sources of Error

- The code implemented a 50ms delay so data was not in real-time.
- Arduino's EEPROM can only store integer values, so readings were rounded for storage.
- The load cell was calibrated to read a minimum weight of 500g, so any fluctuations in weight smaller than that may not have been detected accurately.
- The load cell most accurately sensed point loads, but a distributed load was applied through the subject's foot, making the load cell sensitive to slight fluctuations in balance and pressure.
- Different placements of the device on the footplate also affected accuracy.

Data Analysis and Interpretation

- Data was read from the EEPROM of the Arduino and imported into MATLAB for plotting and analysis.
- Each peak force was isolated from the data, corresponding to the force exerted during the finish phase of the stroke.
  - A secondary peak can also be seen in each stroke, corresponding to the drive phase.
- A two-sample t-test was performed on peak forces from each foot for a single trial to evaluate significance in asymmetry.
- Since $p < 0.05$, we can conclude there is significant asymmetry.

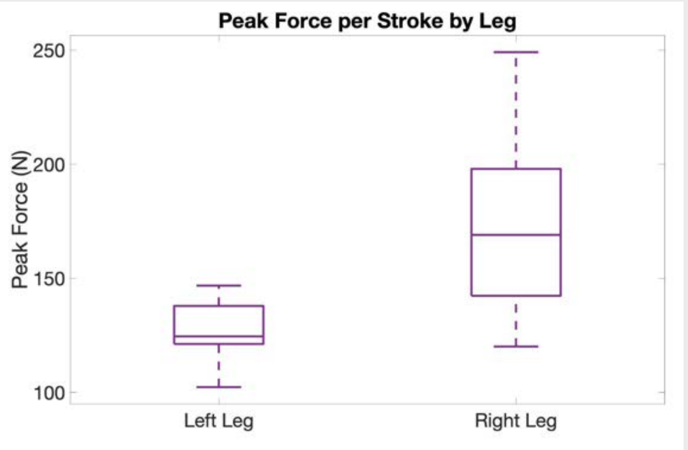


Figure 12: Box and whisker plot of peak forces on each stroke by foot for a single trial.

Table 1. Average and Standard Deviation of Peak Force per Stroke by Foot

	Left Leg	Right Leg
Average Force (N)	127.19	173.32
Standard Deviation (N)	11.26	36.90

Future Work

- Integrate multiple load cells into one plate
- Present all output on one display
- Improve accuracy by altering shape of load cell
- Relocate design to 18.9 m long shell, or an eight-seater rowing boat used for races [7] to better resemble outdoor racing conditions
- Waterproof circuit components

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