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Biomedical Engineering
UNIVERSITY OF WISCONSIN–MADISON

Force Sensor for Rowing Biomechanics

BME 301

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Overview

- Problem Statement
- Background Research
- Competing Designs
- Product Design Specifications
- Preliminary Designs
- Design Matrices
- Conclusion and Future Work
- Acknowledgements
- References

Figure 1. UW-Madison rowing team. [1]

The Clients

Figure 2.

Tricia De Souza
UW Athletic Trainer
[2]

Figure 3.

Jill Thein-Nissenbaum
UW Athletics Physical Therapist
[3]

Figure 4.

Sarah Navin
PT Student
Former UW Crew
[4]

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Problem Statement

- Rowing athletes, particularly women, are susceptible to lower back or hip injuries
    - Asymmetric weight distributions on each leg while rowing

- Current methods
    - Studies outside of the environment
    - Real-time data is hard to obtain on the water

- Sensor system to collect biomechanical data from rowers' lower extremities
    - Capture load distribution during time of use in the rowboat

- User-friendly interface
    - Assess lower extremity asymmetry
    - Improve both performance and safeguarding against injuries

Background

What is sculling vs sweeping?

UW primarily races with 8 SWEEP rowers.

Figure 5. Rowing Phases. [5]

- When rowing, most force is exerted by the leg [6]
- Having one oar can cause asymmetry in force exertion through the lower extremities based on which side the oar is placed
- The UW Madison Porter Boathouse has ergometers with only sweep rowing configuration

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Competing Designs

- BioRow 2D Stretcher [7]
  - Load cells utilize strain gauges
  - Senses horizontal and vertical force components
  - Two load cells per foot
  - Too expensive, no interactive display
- Bertec Force Plate [8]
  - Load cells on each corner
  - Collects forces in all three directions
  - Designed for gait, balance, and performance analysis
  - Too large and expensive

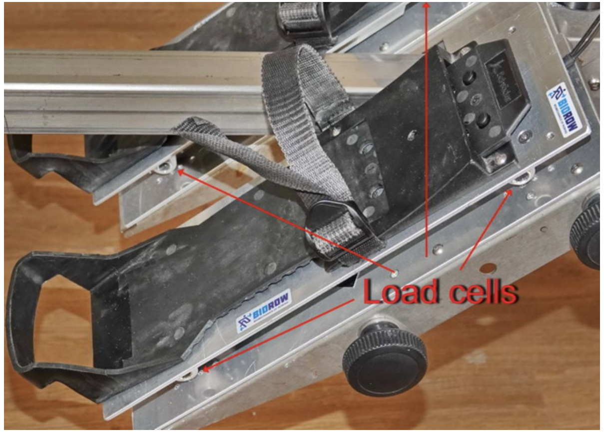

Figure 6. BioRow 2D Stretcher. [7]

Figure 7. Bertec Force Plate. [8]

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Product Design Specifications

Force Sensor/Footplate

- Compatible with RowErg
- Margin of error < 5% [9]
- Adjustable to foot size
- No technique impedance

Display/User Interface

- 24 Hz frame rate [10]
- Mounted at 1.1 m height
- Clear indication of asymmetry

Figure 8. Foot stretcher on Concept2 RowErg.

Figure 9. RowErgs in the boathouse tank.

Figure 10. Concept2 RowErg. [11]

Footplate Design 1: Stationary Uniplate

- Sits between existing footplate and Flexfoot
  - Flexfoot maintains functionality
- One plate secured with screws
  - Load cells screwed underneath
- Strengths:
  - Secure load cell mounting
  - Limited modification of existing setup
- Weaknesses:
  - Load cells don't adjust to foot size
  - Signal interference from Flexfoot or shared plate

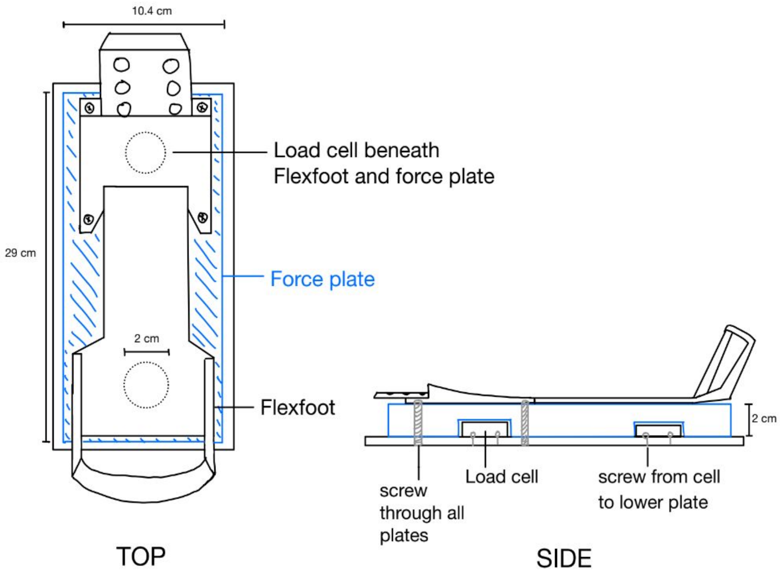

Figure 11. Sketch of Stationary Uniplate Design.

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Footplate Design 2: Multiplate Slider

- 2 plates, toe plate secured with screws
- Heel plate on slider rail
  - Flexfoot adjustable on top
- Strengths:
  - Load cell can be easily adjusted to foot size
- Weaknesses:
  - Possible load cell signal interference with slider plate

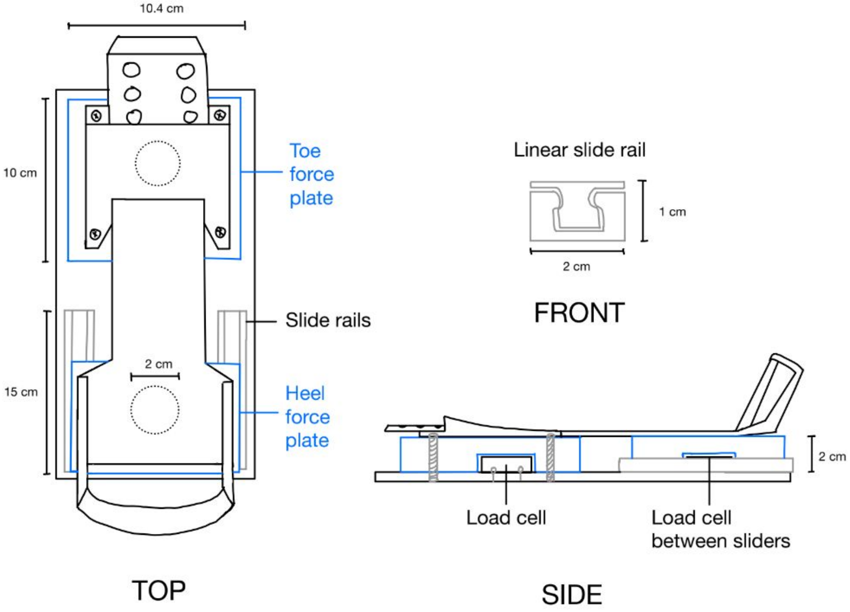

Figure 12. Sketch of Multiplate Slider Design.

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Footplate Design 3: Multiplate Placer

- Two plates secured with screws
- Load cell can be picked up and moved to 1 of 3 different locations depending on foot size
- Strengths:
  - Adjustable to different foot sizes
- Weaknesses:
  - Load cell wires could be insecure in plate
  - Not as ergonomically user-friendly

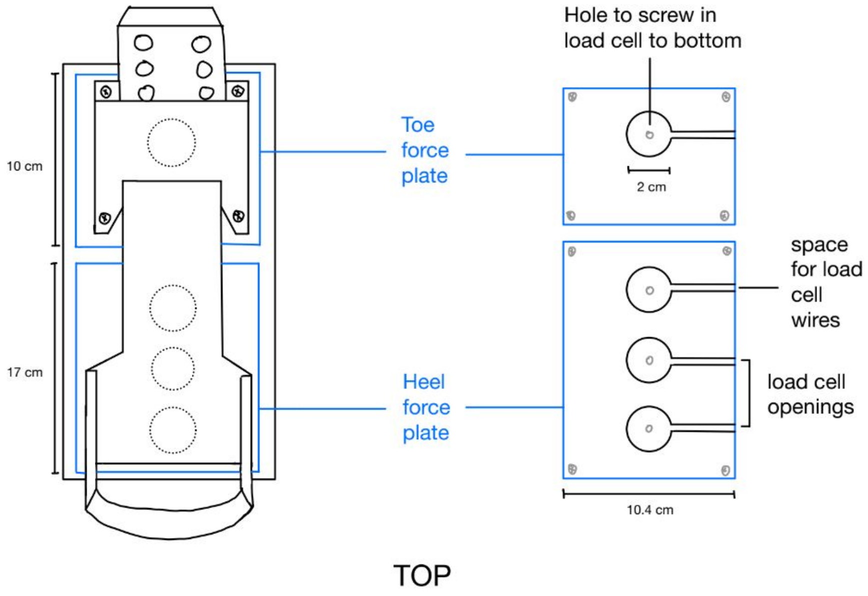
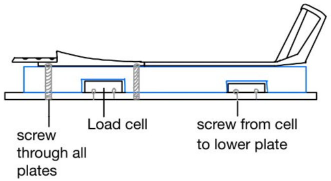
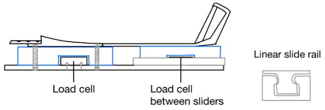
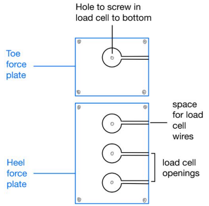


Figure 13. Sketch of Multiplate Placer Design.

Footplate Design Matrix







		Stationary Uniplate		Multi-Plate Slider		Multi-Plate Placer	
Criteria	**Weight**	Score (5 max)	Weighted Score	Score (5 max)	Weighted Score	Score (5 max)	Weighted Score
Reliability	25	5	25	4	20	2	10
Adjustability	25	2	10	5	25	3	15
Cost	20	4	16	3	12	4	16
Ease of Fabrication	20	5	20	3	12	4	16
Technique Interference	10	4	8	2	4	3	6
Sum	**100**	**Sum**	79	**Sum**	73	**Sum**	63

Display Design 1: LED Array

- No screen/monitor
- 5 LEDs connected to Arduino
- Light up when you cross an asymmetry threshold
- Strengths:
  - Inexpensive
  - Simple fabrication
  - Easy to interpret
- Weaknesses:
  - Only full foot force
  - Cannot convey complex information
  - Difficult data storage

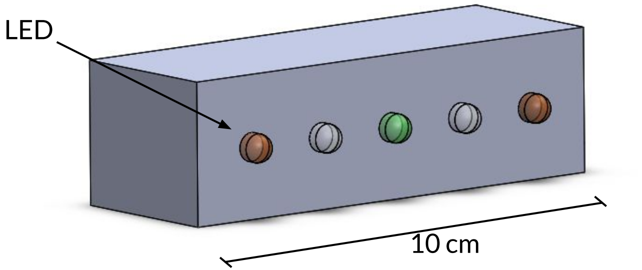


Figure 14. Solidworks representation of LED array design for the force sensor display.

Display Design 2: Arduino 5” Display

- 5” LCD display attached to Arduino Uno
- TkInter graphical user interface (GUI)
- Strengths:
  - Conveys complex information
- Weaknesses:
  - Limited GUI libraries
  - Uses 4 Arduino pins
  - Difficult data storage

Figure 15. 5” Arduino TFT display. [12]

Display Design 3: Raspberry Pi 7” Display

- 7” LCD display attached to Raspberry Pi
- Graphical user interface (GUI) - real-time feedback
- Data storage: USB drive or SD card
- Strengths:
  - Conveys complex information
  - Larger screen (HDMI)
  - Easy data storage
  - Many GUI libraries
- Weaknesses:
  - Expensive
  - Must convert load cells to Raspberry Pi

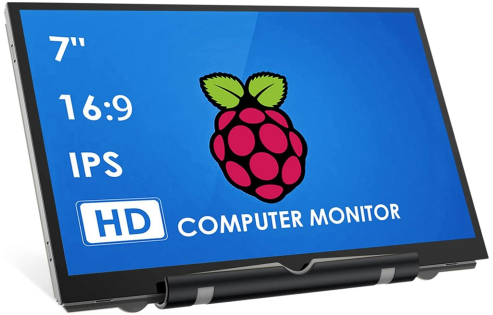
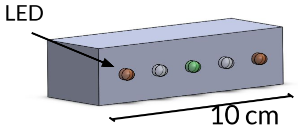
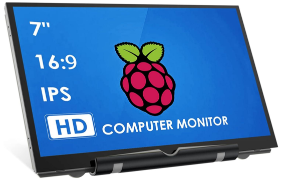


Figure 16. 7” Raspberry Pi HDMI display. [13]

Figure 17. Raspberry Pi 4 Model B. [14]

Display Design Matrix

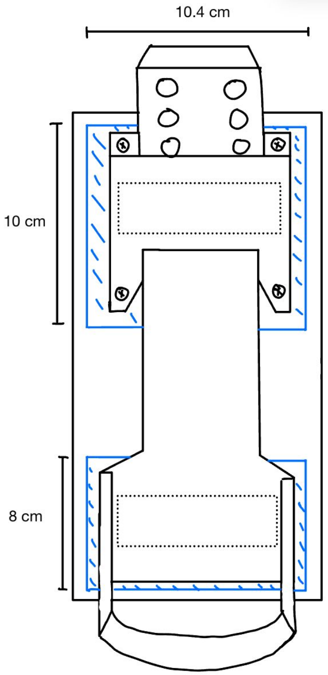




		LED Array		Arduino 5”		Raspberry Pi 7”	
Criteria	**Weight**	Score (5 max)	Weighted Score	Score (5 max)	Weighted Score	Score (5 max)	Weighted Score
User experience	35	3/5	21	4/5	28	5/5	35
Frame rate	25	5/5	25	3/5	15	5/5	25
Value of data	20	2/5	8	4/5	16	5/5	20
Ease of Fabrication	10	4/5	8	3/5	6	5/5	10
Cost	10	5/5	10	4/5	8	2/5	4
Sum	**100**	**Sum**	72	**Sum**	73	**Sum**	94

Final Design: Footplate + Display

- 2 stationary screwed in plates between Flexfloot and lower footplate
- Bar load cells
- Raspberry Pi Microcontroller
- Raspberry Pi 7'' Display



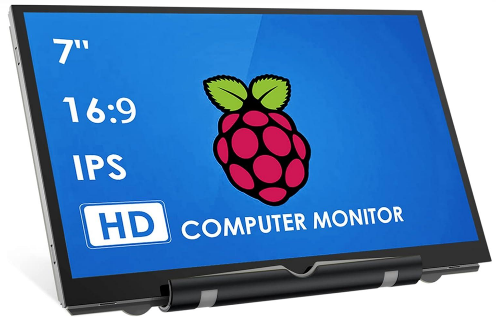


Figure 16. 7" Raspberry Pi HDMI display. [13]

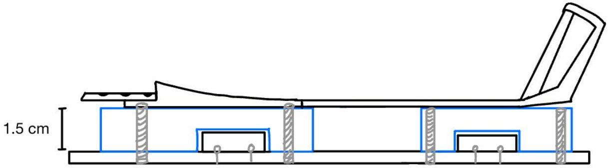


Figure 18. Sketch of final footplate design.

Future Work

- This semester:
  - Fabricate footplate
  - Display and data storage
    - GUI for toe vs heel timing and loading asymmetry
    - Visualization of stored raw data

- Future semesters:
  - Alternate load cells or force sensors
  - Integration of design into boat
    - Water proofing, wireless connection
  - Clinical testing and reliability
    - statistical analysis and validation

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- Ms. Sarah Navin
- Dr. John Puccinelli
- Dr. Dave Bell
- UW Rowing Team Staff and Athletes

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Questions?