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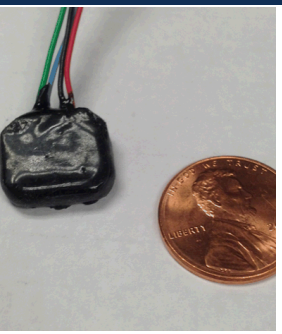

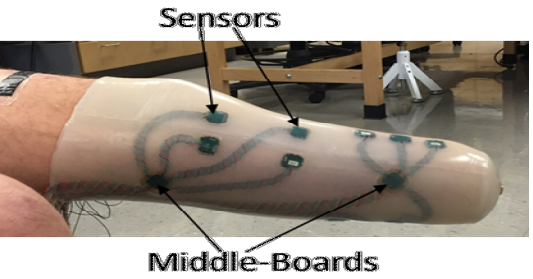

Optical Shear and Pressure Measurement in Prosthetic Sockets and other Human Interfaces

Design of Medical Devices Conference

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Jason Wheeler, Ph.D.

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Introduction

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- Measuring loads applied to the skin has several important clinical applications:
  - Assessment of fit and comfort of human interfaces such as prosthetic sockets, insoles, seats, beds, orthotics and rehabilitation devices
- Researchers and clinicians should understand features and limitations of sensors used in these systems
- There is generally a trade-off between sensor performance and other factors, such as size, cost and portability and several performance factors should be considered
- This talk will discuss some of these trade-offs and introduce a novel type of sensor for pressure and shear monotiring

Socket Sensor Evaluation

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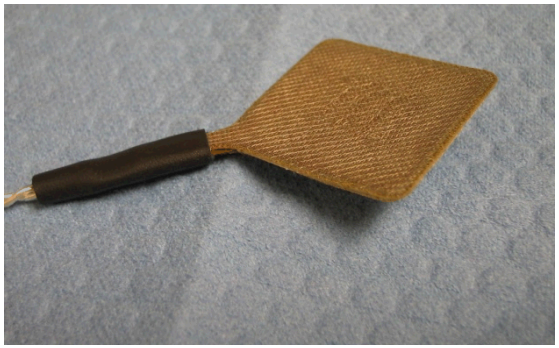
- There is no gold standard or ground truth pressure sensor for prosthetic sockets
- We tested several sensors to set bounds on performance in key categories
  - Drift
  - Hysteresis
  - Sensitivity/Linearity
  - Repeatability
  - Temperature Sensitivity
  - **Shear Sensing Capability**

Commercial Sensors Tested

Sensor	Sensing Mechanisms
Tekscan Flexiforce	Piezoresistive
Interlink FSR	Piezoresistive
Pressure Profile Systems (PPS)	Capacitive

Tekscan

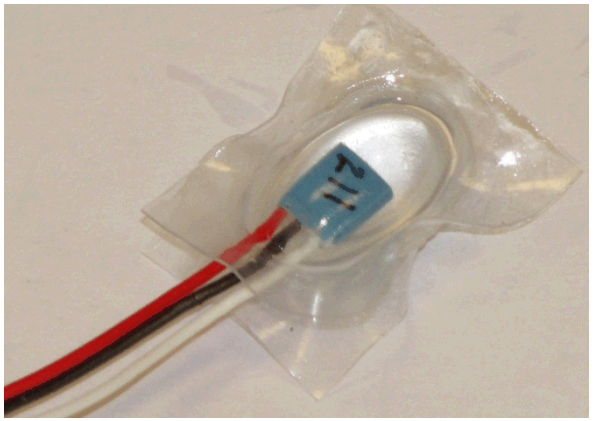


PPS

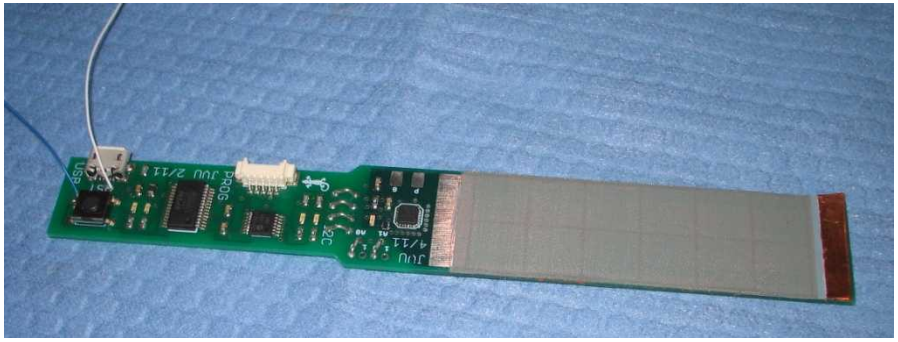
Interlink

R&D Sensors Tested

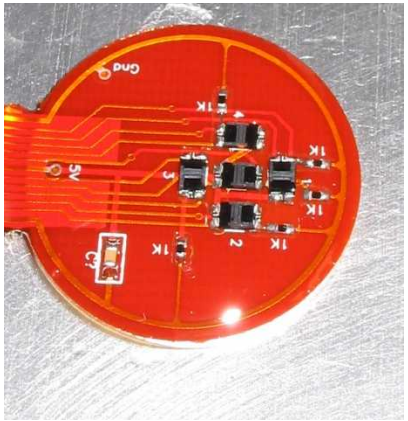
Developer	Sensing Mechanisms
Sandia National Labs	MEMS Diaphragm
Sandia National Labs	Optical (3-axis)
Stanford	Capacitive



SNL Bubble



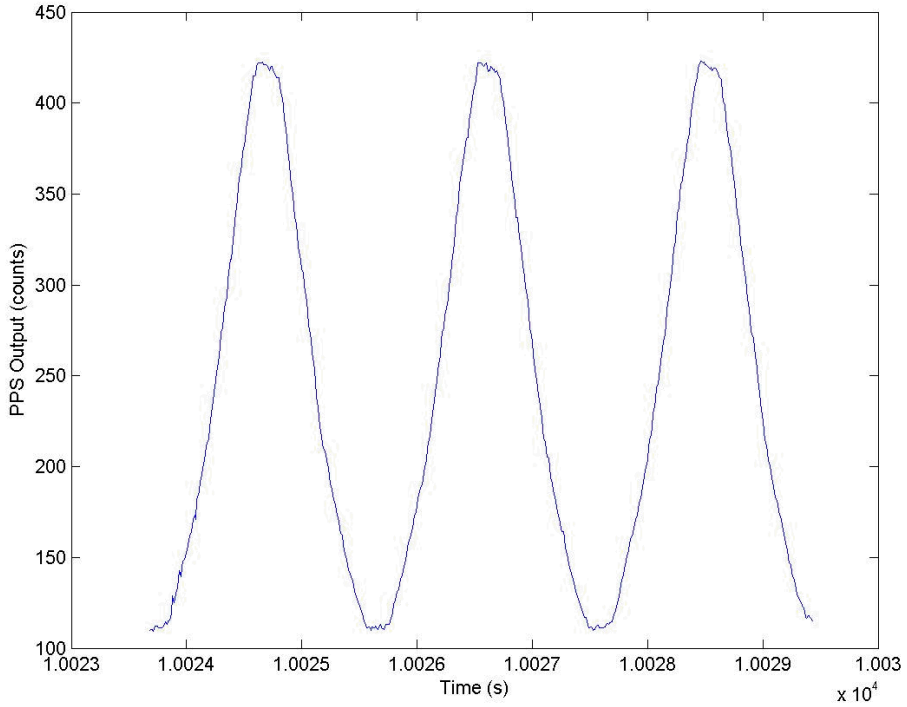
Stanford Capacitive



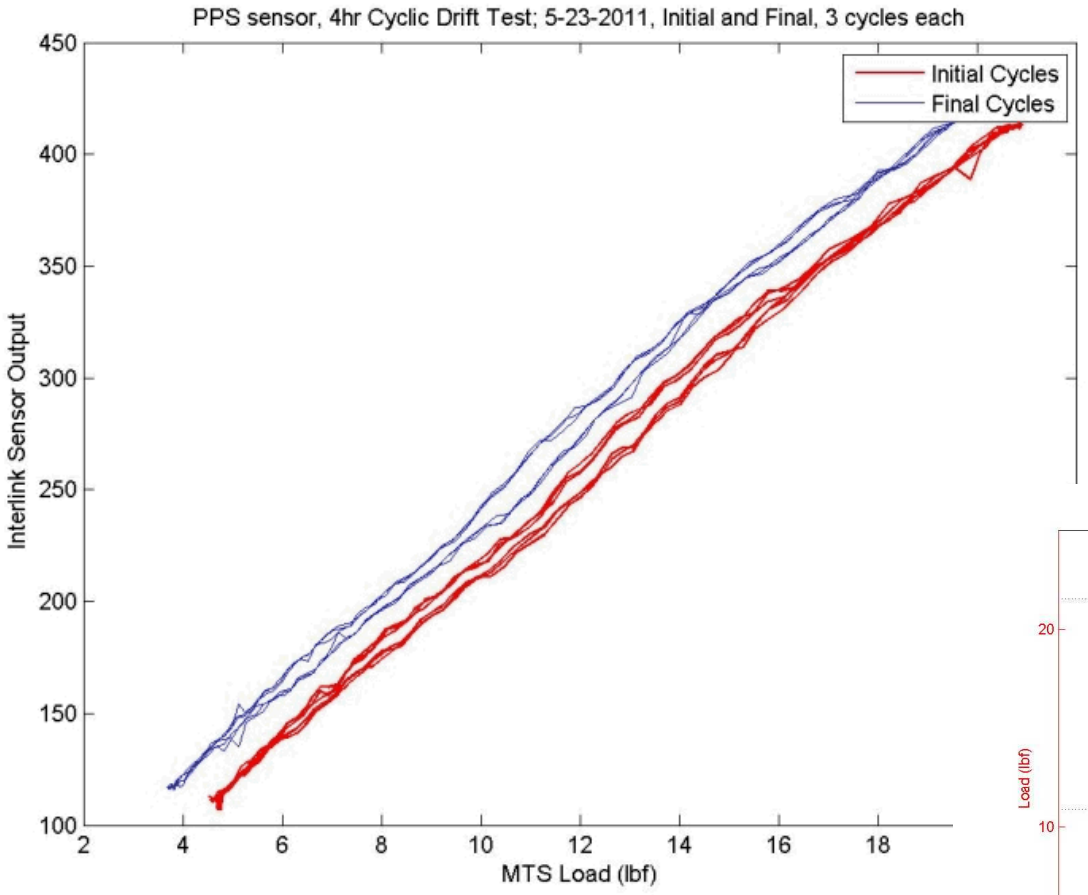
SNL Optical

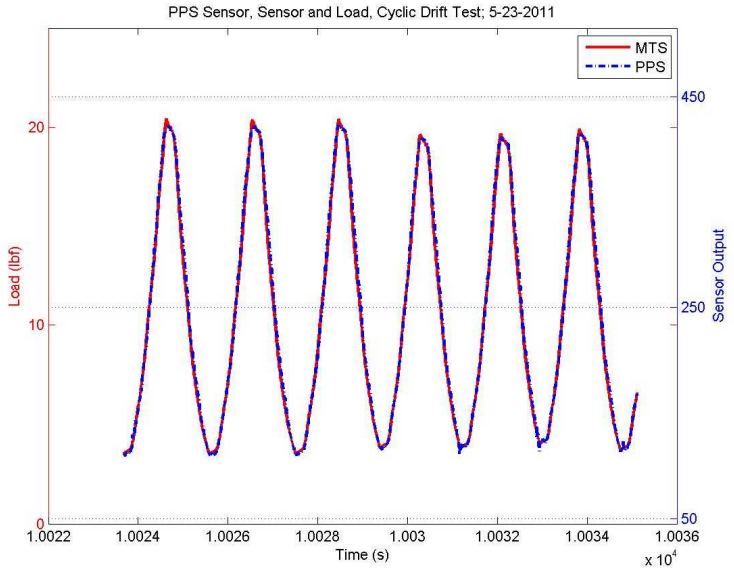
Test description

- Cyclic drift – a load cycling between 2.0-26.5 psi at approximately .5 Hz is applied to the sensor for 4 hours

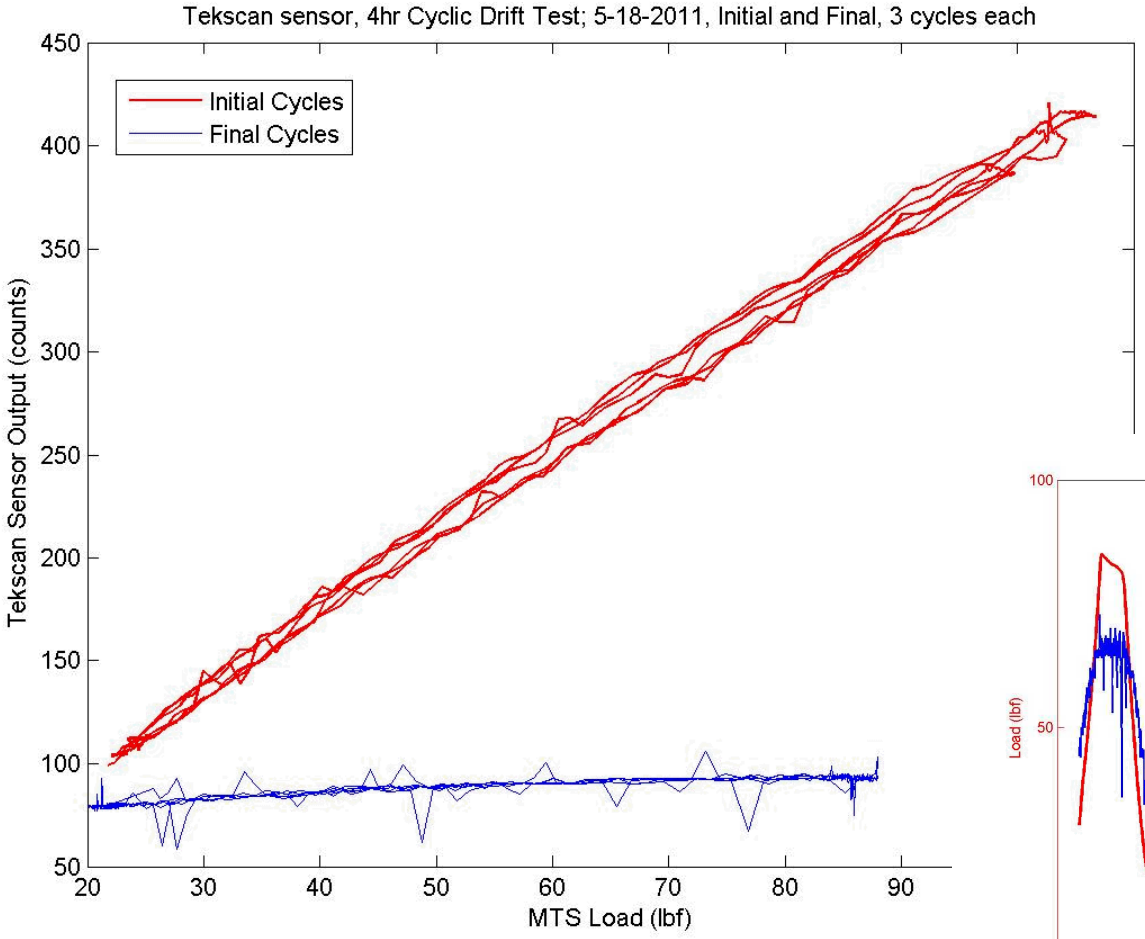


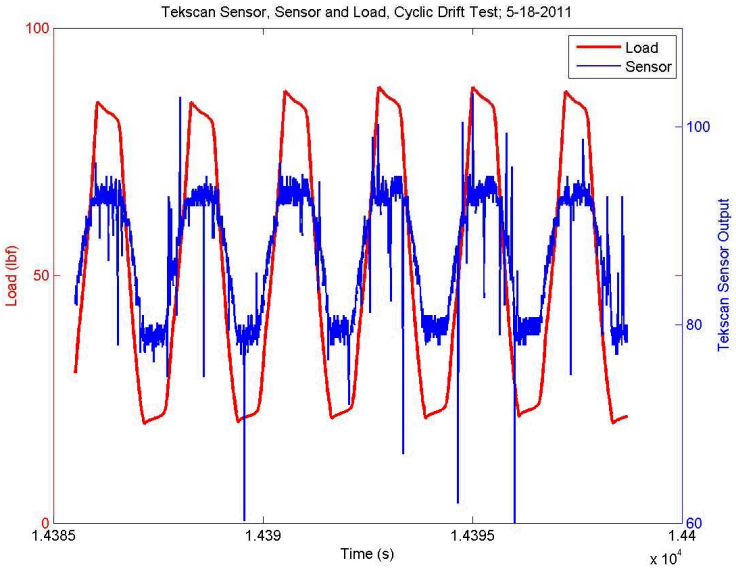
Results: PPS Cyclic Drift



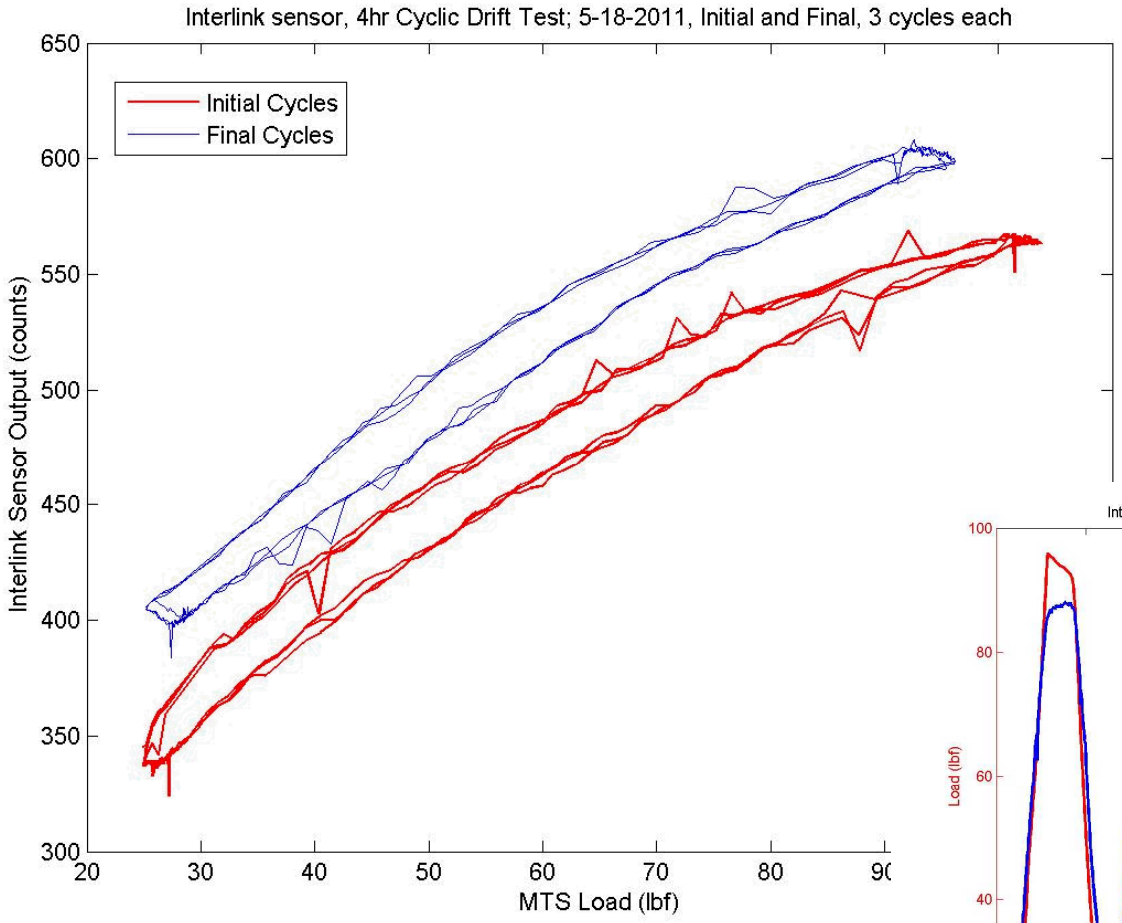


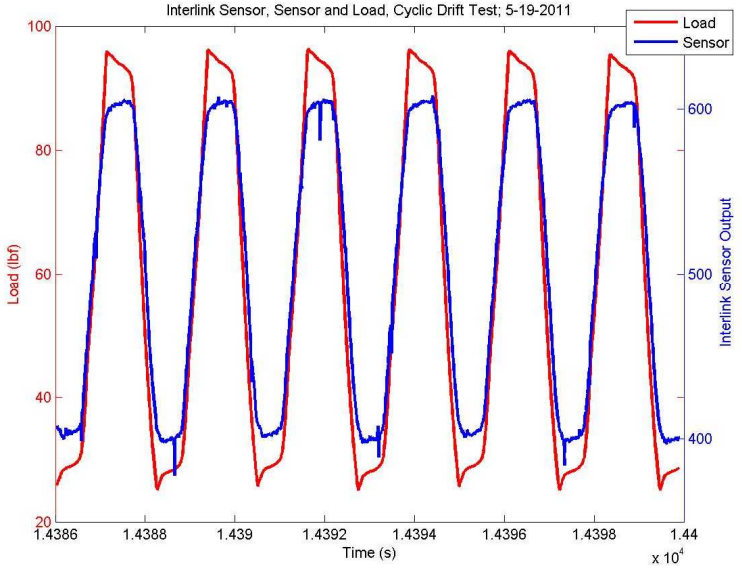
Results: Tekscan Cyclic Drift



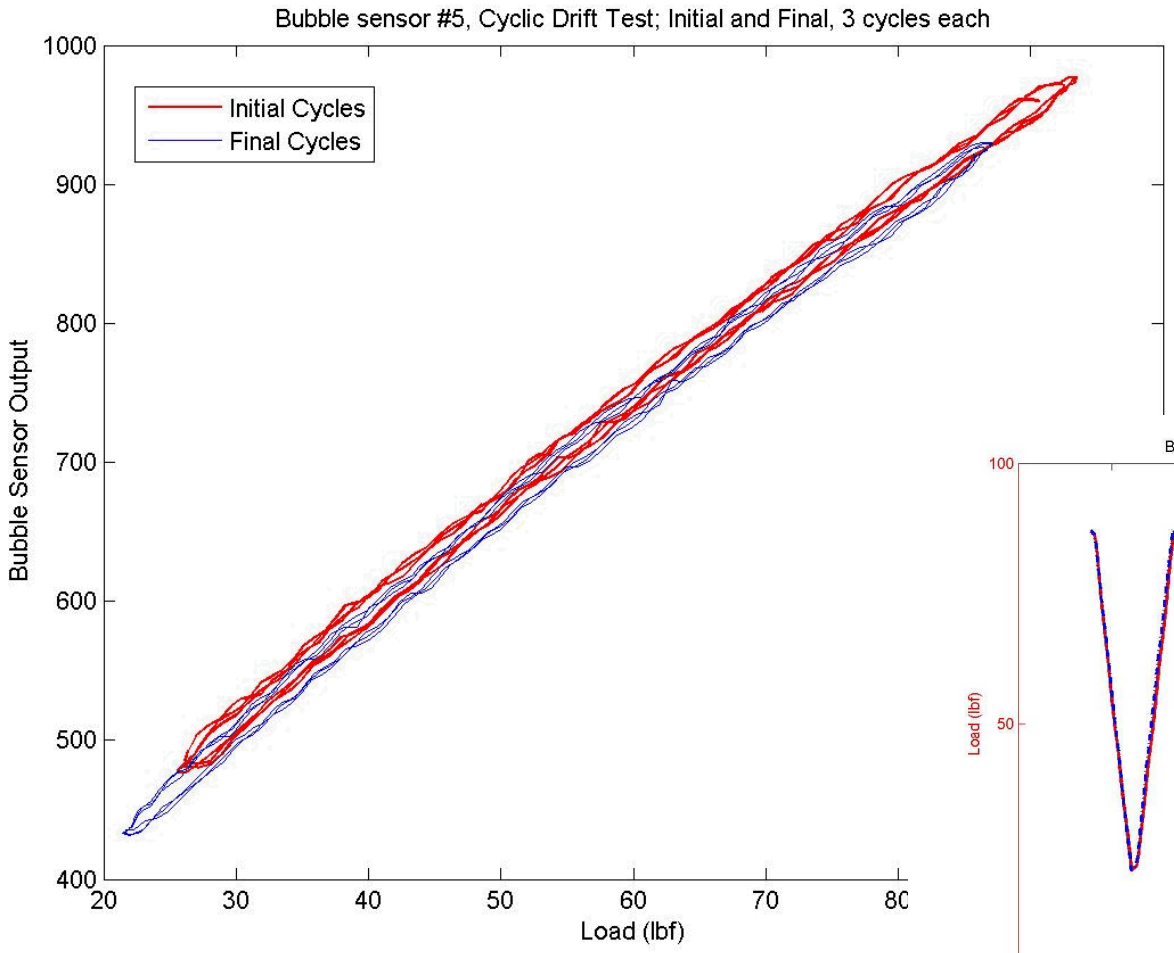


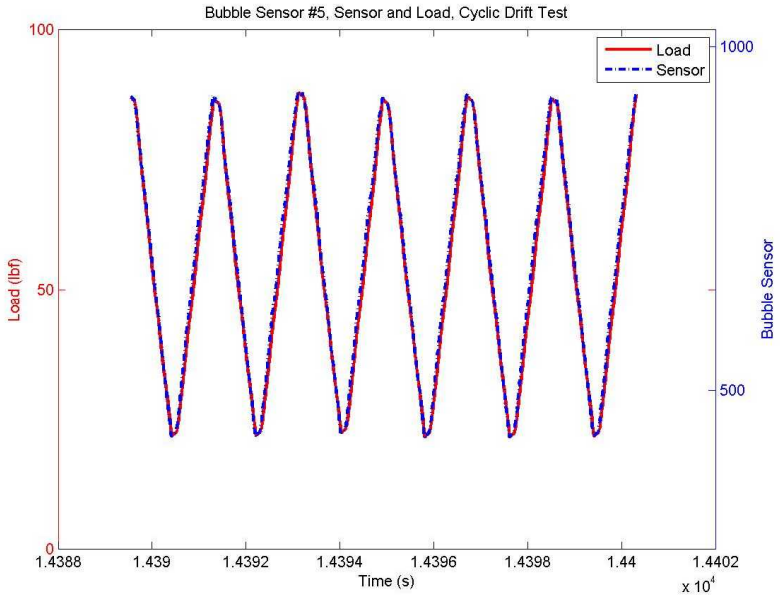
Results: Interlink Cyclic Drift





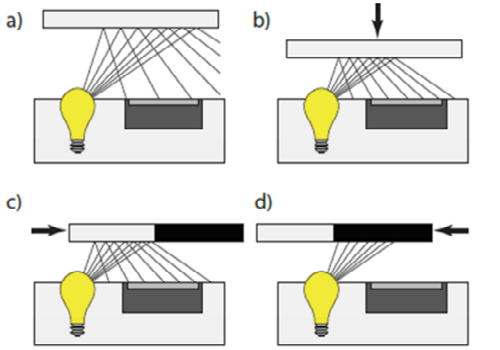
Results: Bubble Cyclic Drift

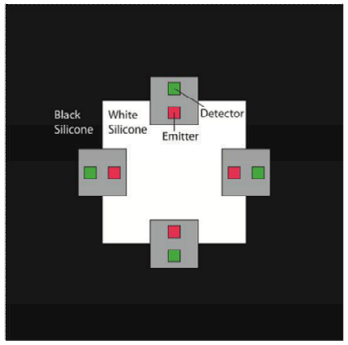


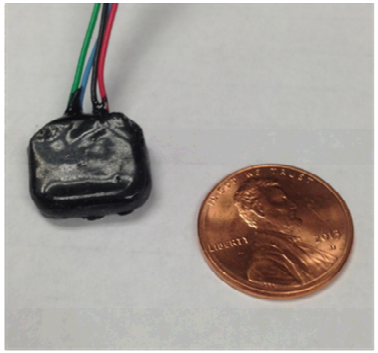


Multi-axis Optical Sensor

- Sensor designed for measuring multi-axis shear in prosthetic sockets.
- Infrared emitter/detector pairs used to measure the displacement of a silicone marker (white square).
- Use of optical sensing enables miniaturization and fabrication into soft, elastomeric materials.
- High signal to noise, low hysteresis, and minimal drift.

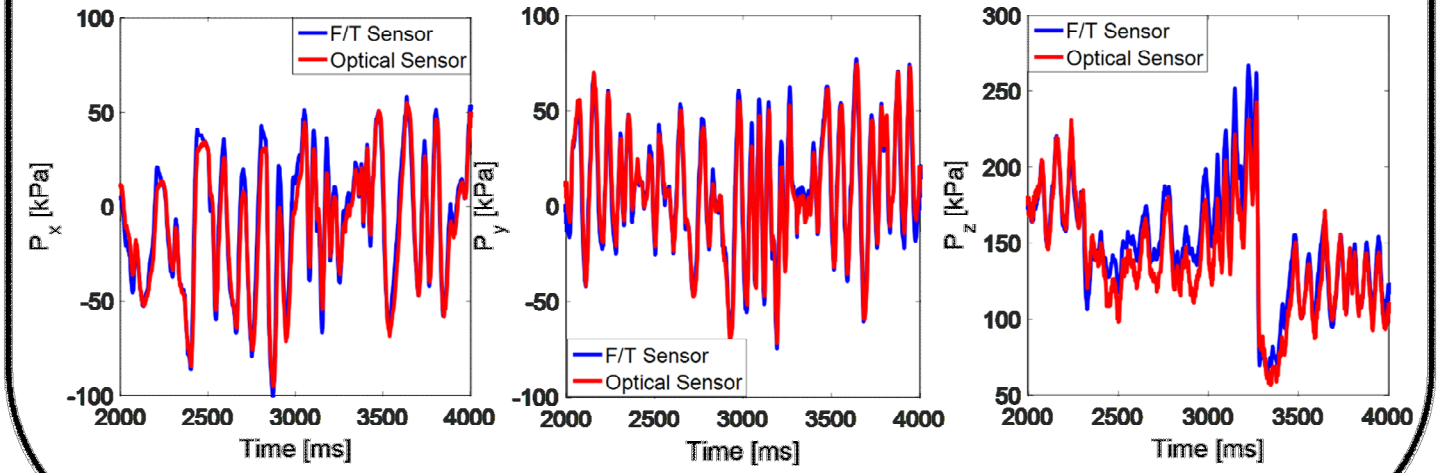






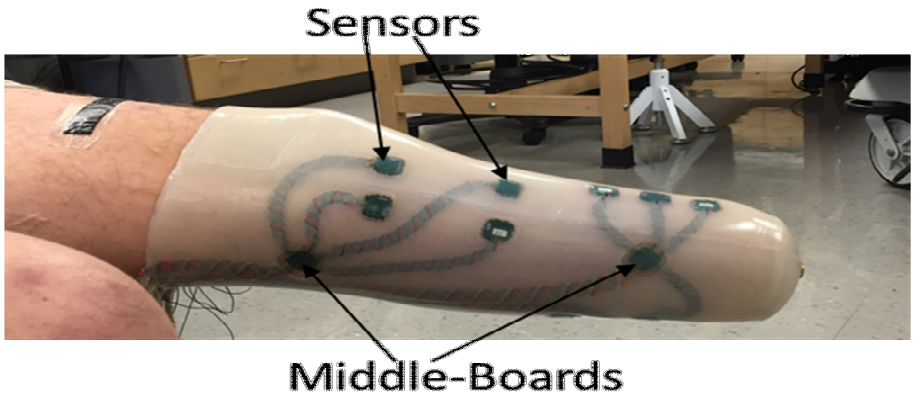
Multivariable Parametric Fit

- Parametric fit used to train sensor 4 emitter/detector pairs to force estimates.
- Sensors calibrated using multi-axis ATI Force/Torque sensor. Fits for shear (x,y) are very good.
- Fits for normal (z) have more error due to higher signals, and reduced sensor sensitivity in that axis.



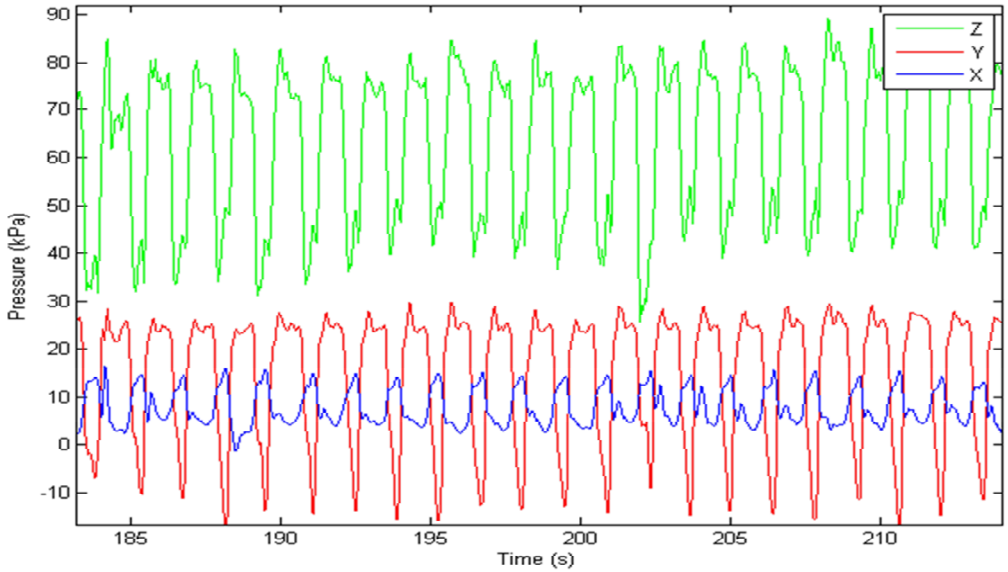
Instrumented Liner

- Sensors and data acquisition middle boards were embedded into a custom silicone liner.
- Sensor/liner design enables large ranges of motion and inversion of liner for donning/doffing.
- Sensors were placed to maximize biomechanical relevance (areas of high curvature or near bony prominences).
- 16 total sensors used



Walking Data

- Walking data taken from amputee at the University of Washington.
- Preliminary data illustrates good signal to noise, adequate sampling, and interesting shear behavior.
- Trials consisted of sitting, standing, and walking.
- Initial testing illustrates good comfort and overall feel.



Insole Development

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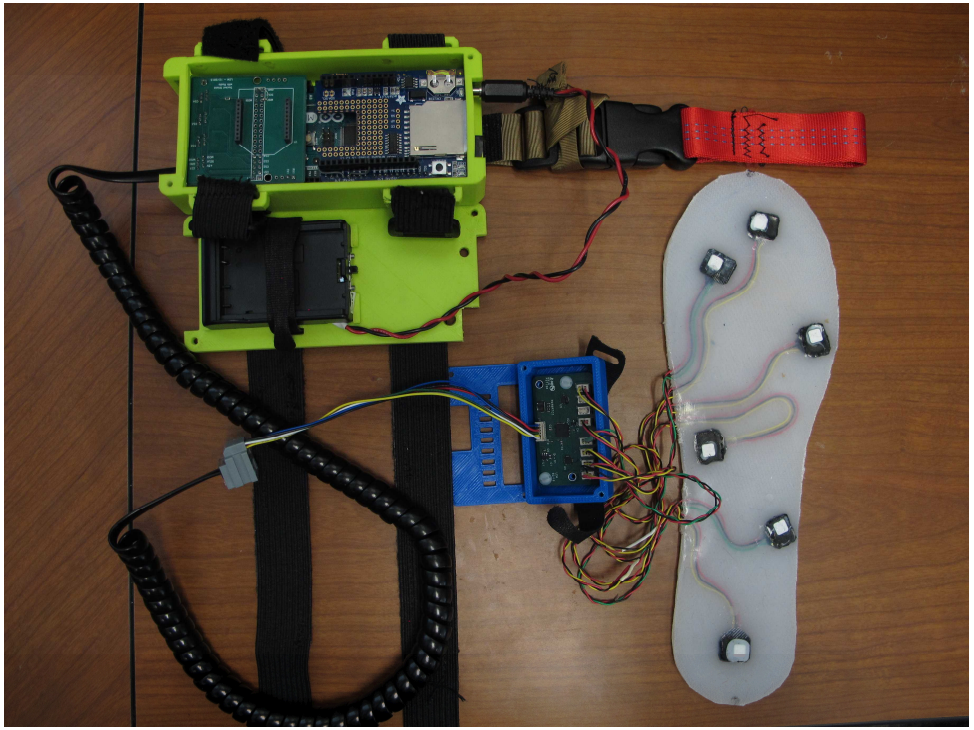
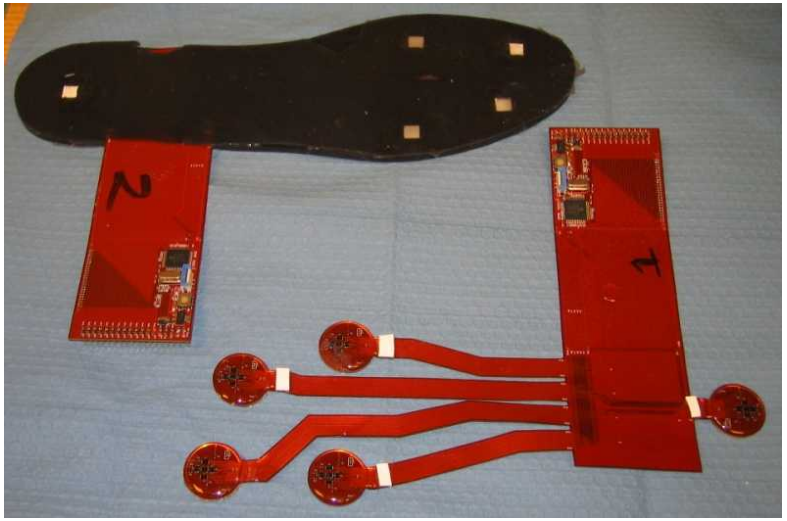
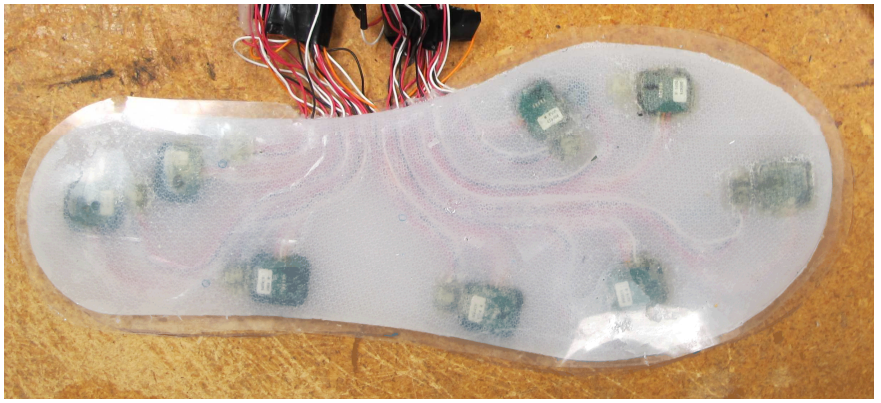
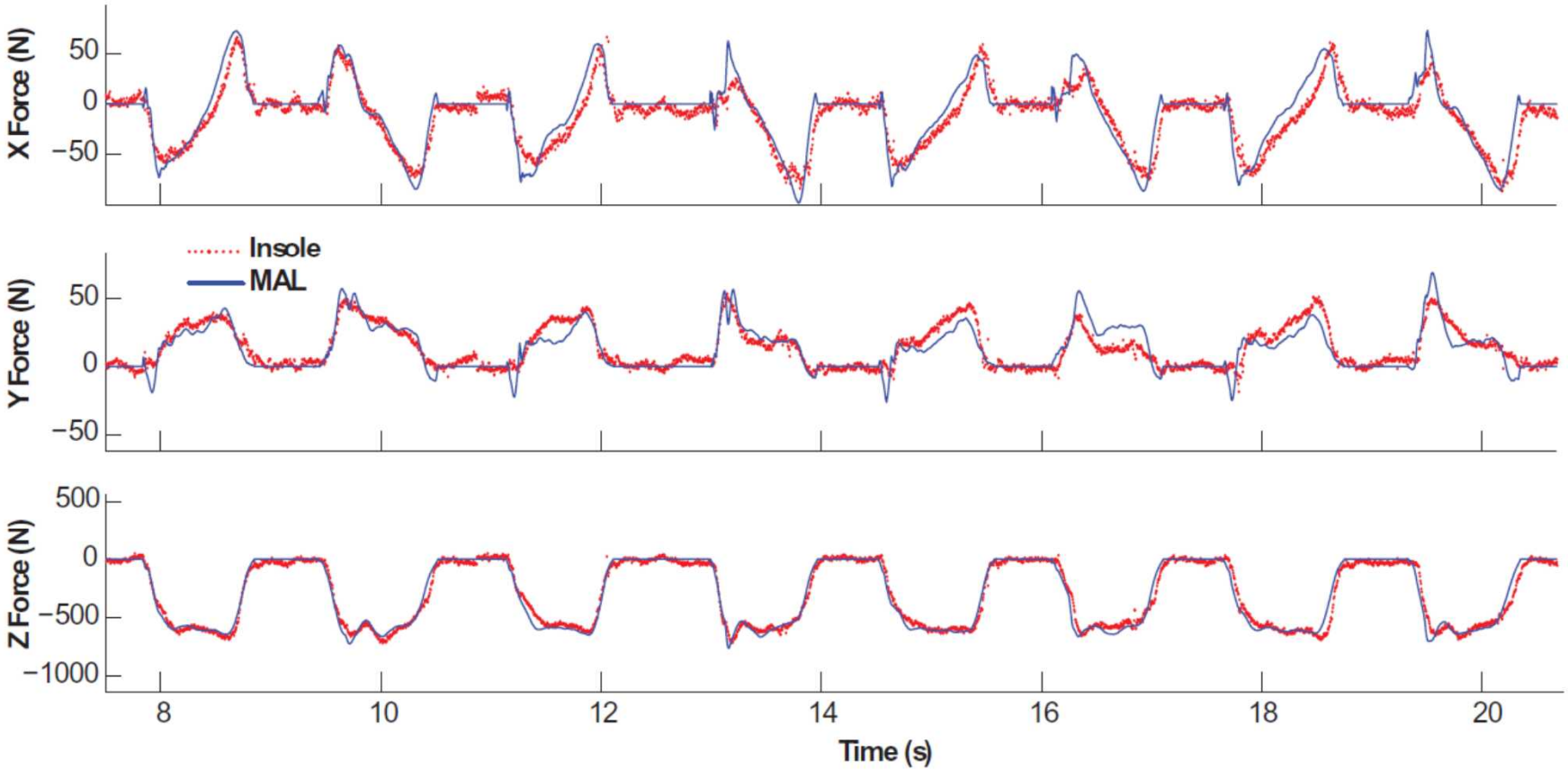






GRF Reconstruction



Features and Limitations of Optical Sensor

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Features

- Size and load range tailored to measuring **3-axis** human interface loads
- Less drift, hysteresis than most commercial sensors (<5% error typical)
- Easily integrated into elastomeric structures
- Smaller and cheaper than commercial shear sensors (strain gauge based)
- Composed of inexpensive components
- Can be calibrated for specific load ranges and combinations

Limitations

- Larger and thicker than thin-film pressure (only) sensors
- Not currently commercially available
- Hand-calibration currently required
- Can be calibrated for specific load ranges and combinations
- Some inaccuracy due to coupling between axes
- Less accuracy in normal direction
- Moderately complex data acquisition requirements and slower sample rates

Future Directions

- Improved calibration and fabrication methods
- Prosthetic Socket
  - Ongoing amputee testing
  - Closed-loop feedback for variable-shape sockets
- Insoles
  - Integration of pressure sensors to increase CoP accuracy
  - Optimization of sensor locations
  - Local pressure sensing and/or CoP reconstruction
- Other applications
  - Wheelchair seats
  - Hospital beds
  - Robotic hands and legs