Authentic Science Research Program

Byram Hills HS, Armonk NY

USING FORCE SENSORS TO EFFECTIVELY CONTROL A BELOW-ELBOW INTELLIGENT PROSTHETIC DEVICE

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Review of Literature

Introduction

- US troops in Iraq required limb amputations at twice the rate of past wars (The Boston Globe, 2004)
- 795 amputations for soldiers in Iraq and Afghanistan since December 2001 (The Seattle Times, 2007)

Figure 1: Wounded Soldier (thememoryhole.org, 2004)

Review of Literature

Myoelectric Prosthetic Control

- Myoelectric Control
  - Current applied state-of-the-art
  - Residual muscle contractions control hand
  - Myoelectric signals (MES) measured from muscles (Muzumdar, 2004)

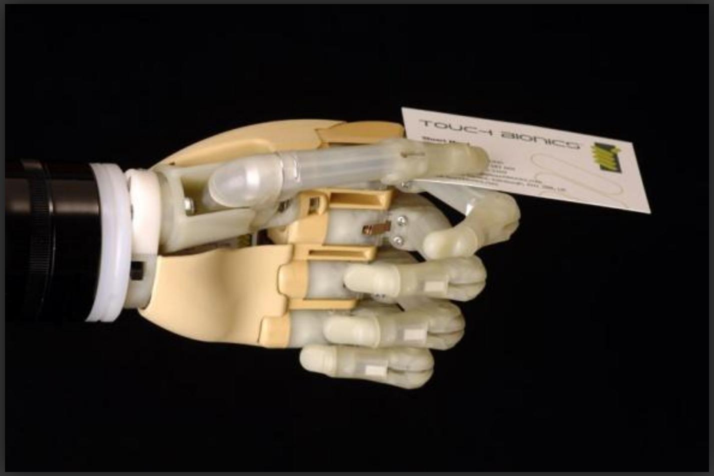


Figure 2: i-Limb Hand
(Touch Bionics, Inc., 2007)

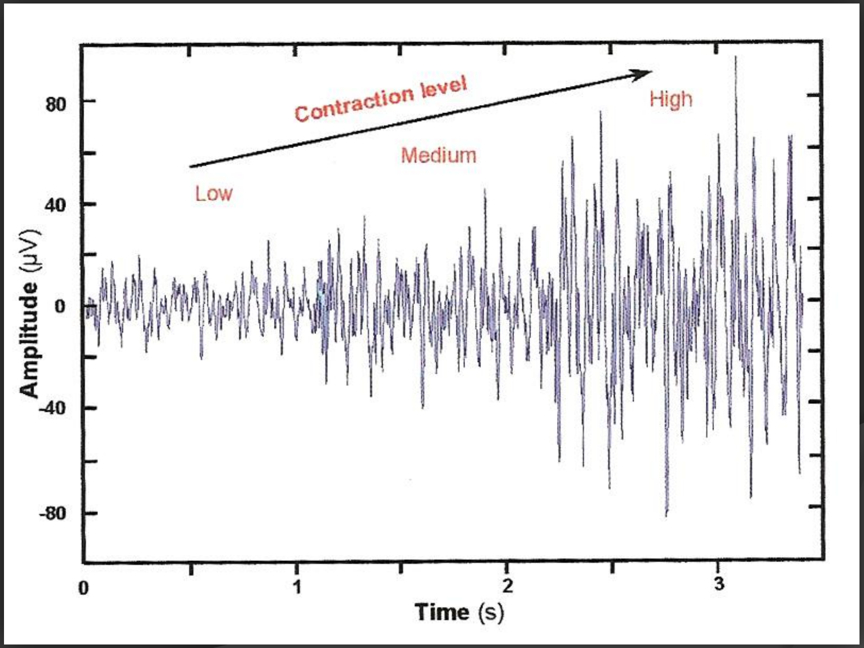


Figure 3: Variation of Myoelectric Signal with Contraction Level
(D.F. Lovely, 2004)

Review of Literature

Limitations of Pattern-Recognition Myoelectric Control

- **Only 95% Accurate**
  - Advanced models predict accurately 95% of the time (L. J. Hargrove et al., 2007)
- **Surgical Implantation Required for Pattern Recognition**
  - Electrodes may become infected or fall out of place (Muzumdar, 2004)
- **Signal Processing Required**
  - No processing technique is perfect (L. P. J. Kenney et al., 1999)
  - Difficult to customize hand (A.S. Poulton et al., 2002)
- **High Cost**
  - Each electrode can cost $2000 (P. Kyberd, 2007)

Review of Literature

Force Sensors – A More Accurate Control Method

- Force sensors
  - Applied Pressure → Change in output voltage
  - Can measure muscle contraction
  - Never before used in multi-sensor, pattern recognition setup with the purpose of controlling a prosthesis (L.J. Kenney et al., 1999)

SO WHY USE FORCE SENSORS?

Review of Literature

Force Sensors – A More Accurate Control Method

LESS EXPENSIVE

Review of Literature

Force Sensors – A More Accurate Control Method

NO SURGERY NEEDED

Review of Literature

Force Sensors – A More Accurate Control Method

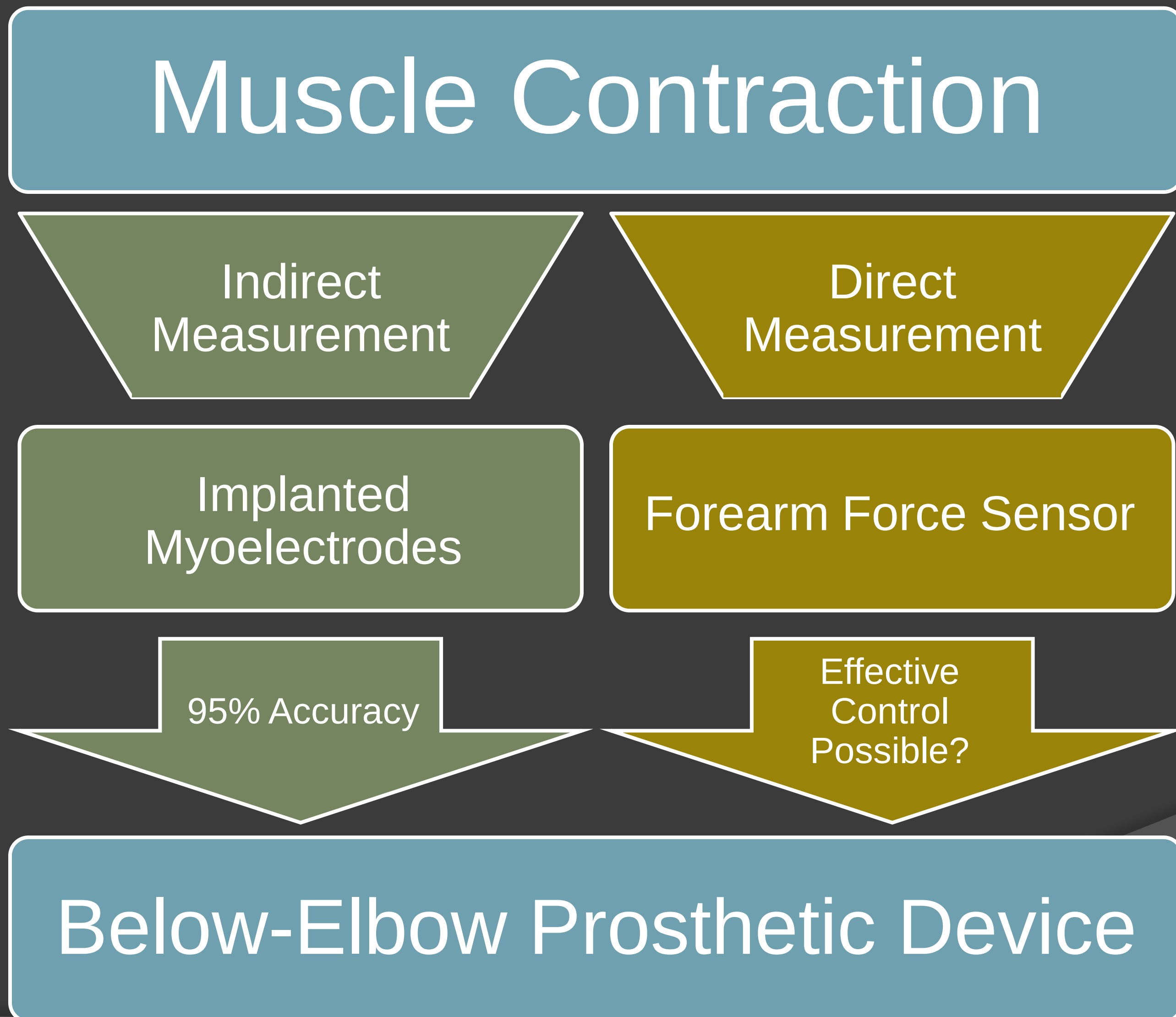
POTENTIAL TO *ELIMINATE* OR *REDUCE* NEED FOR SIGNAL PROCESSING

Review of Literature

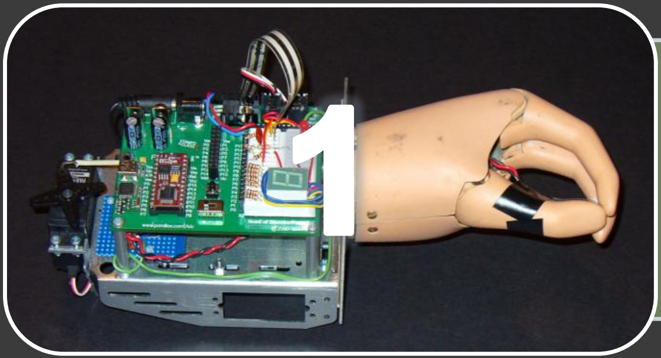
Force Sensors – A More Accurate Control Method

Are Force Sensors as accurate as myoelectrodes?

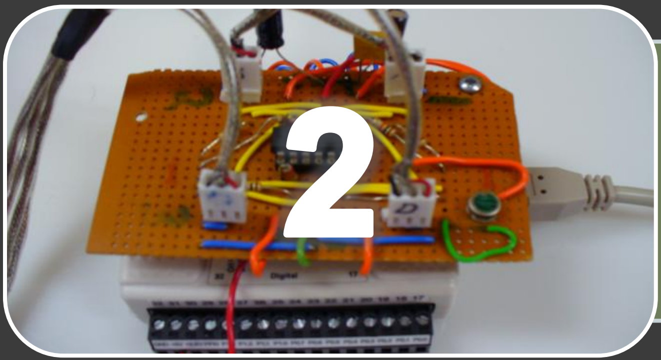
Hypothesis


Muscle Contraction
Indirect Measurement
Direct Measurement
Implanted Myoelectrodes
Forearm Force Sensor
95% Accuracy
Effective Control Possible?
Below-Elbow Prosthetic Device

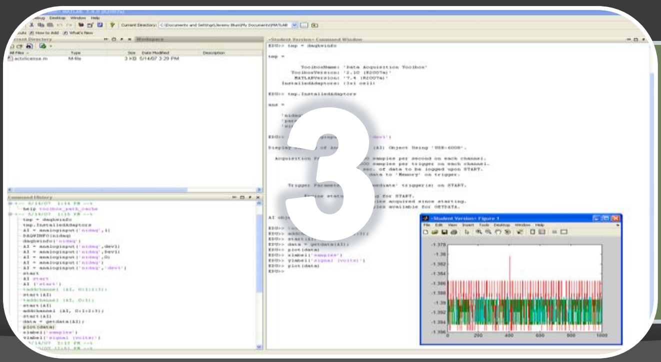
Objectives



- Build proof-of-concept hand

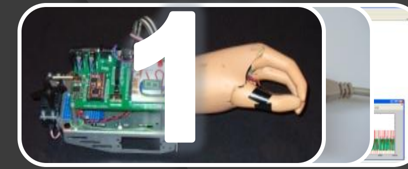


- Develop computer interface and acquire raw data



- Write and implement input analysis program

Methods and Materials



Objective 1 - Prosthetic Prototype

- **Inputs**
  - Force Sensor
  - Vibration Sensor & Amplifier
- **Processor/Board**
- **Chassis and Power Supply**
- **Programming**
- **Outputs**
  - Force Readout
  - Vibration LED
- **Hand and Servo**

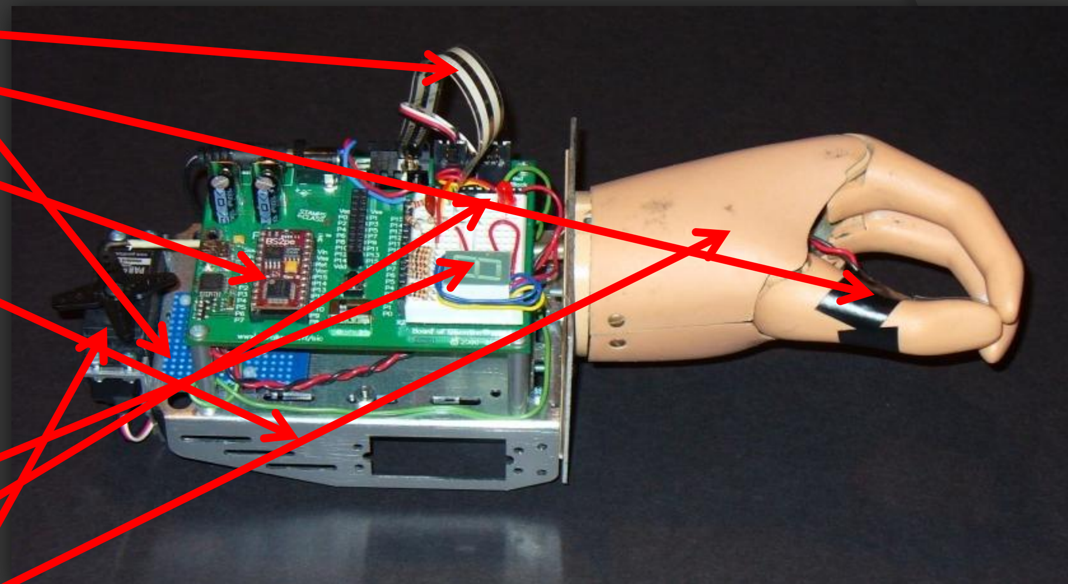


Figure 4: Prosthetic Prototype (Blum, 2007)

Figure 5: FlexiForce Sensor (tekscan.com, 2006)

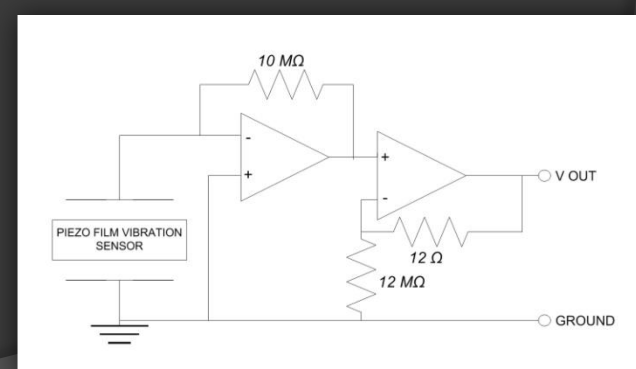
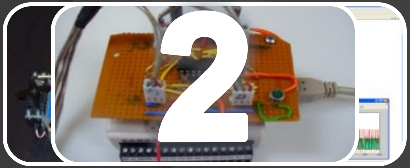


Figure 6: Vibration Sensor Circuit (Kyberd/Blum, 2007)

Methods and Materials



Objective 2 - Computer Interfaced Force Sensor circuit

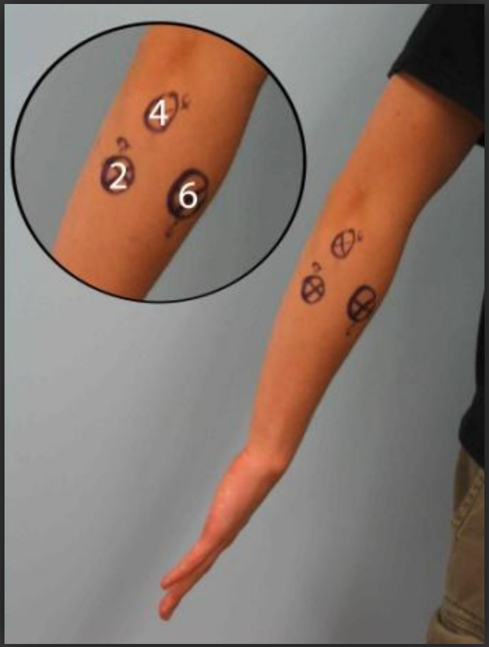


Figure 7: Lateral Arm Aspect (Blum, 2007)

#2-Extensor Carpi Ulnaris
#4-Supinator
#6-Extensor Carpi Radialis Brevis

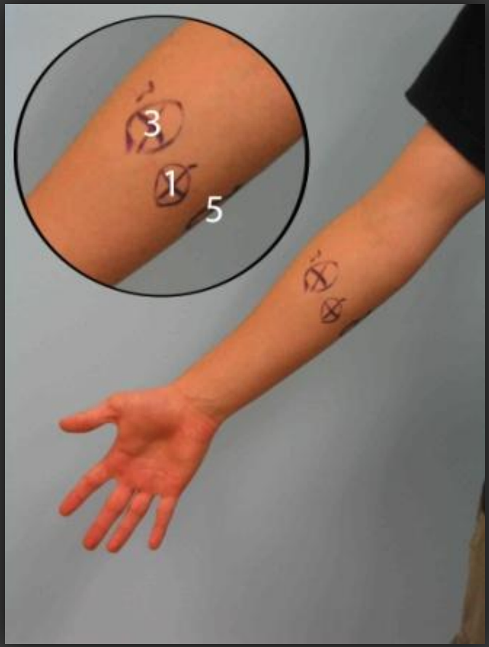


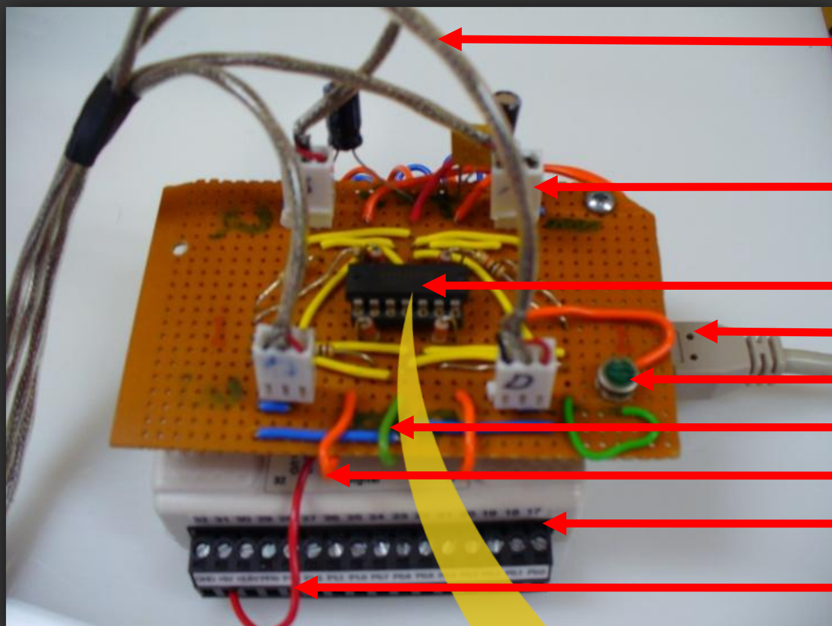
Figure 8: Medial Arm Aspect (Blum, 2007)

#1-Pronator Teres
#3-Flexor Digitorum Superficialis
#5-Flexor Carpi Ulnaris

Table 1: Six Forearm Muscles Tested (Green Muscles had sensors) (Blum, 2007)	
Flexor Digitorum Superficialis - finger flexion	Extensor Carpi Ulnaris - finger extension
Flexor Carpi Ulnaris - wrist flexion	Extensor Carpi Radialis Brevis - wrist extension
Pronator Teres - wrist pronation	Supinator - wrist supination

Methods and Materials

Objective 2 – Computer Interfaced Force Sensor circuit



Sheathed FSR extension wires

FSR connection to amplification board

TLC2274 Quad Op Amp

USB cable for computer connection

Variable Resistor to adjust amplification

Wire to ground

Output from amplified signal to DAQ

National Instruments 6008 USB DAQ

+5V power, DAQ → amplification board

Figure 9: DAQ and amplification circuit board with four force sensors connected (Blum, 2007)

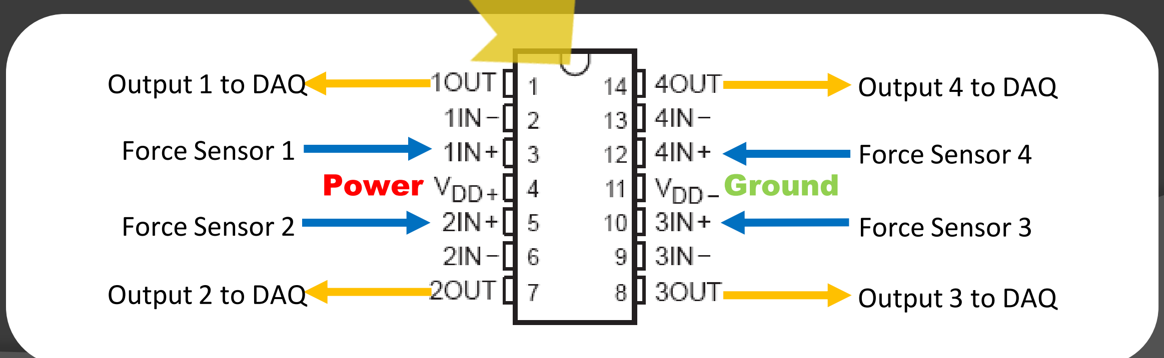
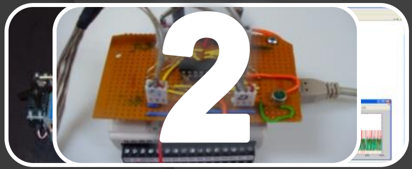


Figure 10: TLC2274 Operational Amplifier (adapted from Texas Instruments, 2007)

Methods and Materials



Objective 2 - Computer Interfaced Force Sensor circuit

Figure 11: Internally mounted force sensors (Blum, 2007)

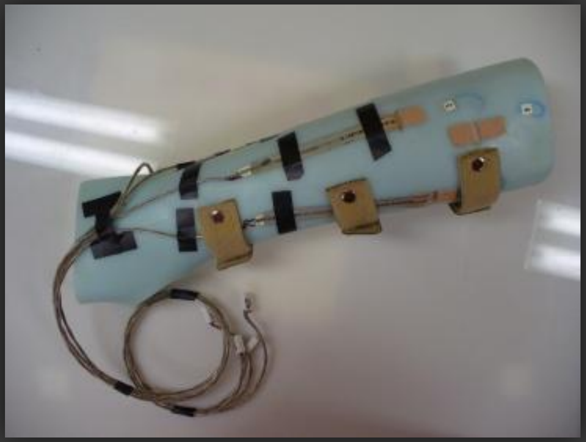


Figure 12: Cast fully equipped with sensors mounted (Blum, 2007)

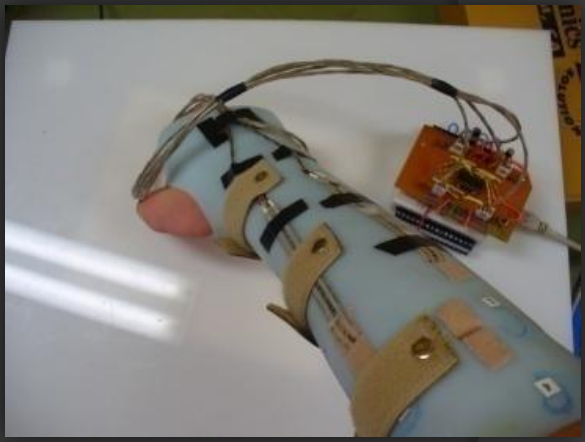
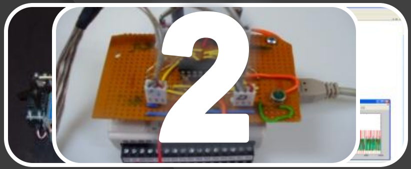


Figure 13: Cast worn by Blum, Connected to DAQ (Blum, 2007)

Methods and Materials

Objective 2 - Computer Interfaced Force Sensor circuit

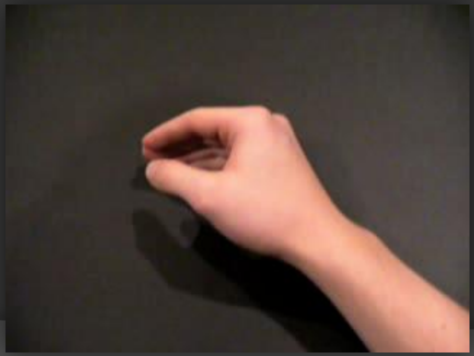


Action Data

- All six muscles – force and myo

Resting Calibration Data

- All six muscles for each action data muscle

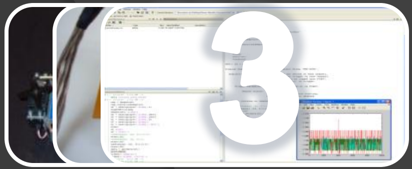


Active Calibration Data

- All six muscles for each action data muscle

Methods and Materials

Objective 3 – Computer input analysis program



SVEN Function – linear discriminant analysis (Torunn Midtgaard, 2006)

$$F(x) = Wx + w_0$$

$F(x) > 0$ ACTIVATION

$F(x) \leq 0$ NO ACTIVATION

When calibration muscles matches activation muscle, F(x) *should* be > 0

- 1,000 Samples per second (1KHz)

10 seconds $X_1(t)$

Function F solicited

+

- 1,000 Samples per second (1KHz)

10 seconds $X_2(t)$

Function F not solicited

→

$m_1 = F(x_1)$

$m_2 = F(x_2)$

$C = cov(x_1)$

means and covariance calculated

→

$W = inv(C)*(m_1+m_2)$

$w_0 = (-.5)*((m_1+m_2)')*W$

W and w_0 calculated

→

→

$F(x) = Wx + w_0$

First SVEN value calculated

+

- 1,000 Samples per second (1KHz)

10 seconds $X_3(t)$

Action Data solicited

→

$F(x) = Wx + w_0$

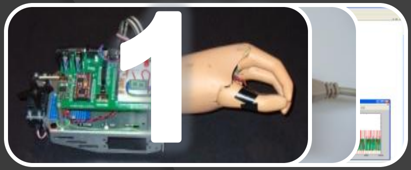
Final SVEN value calculated

→

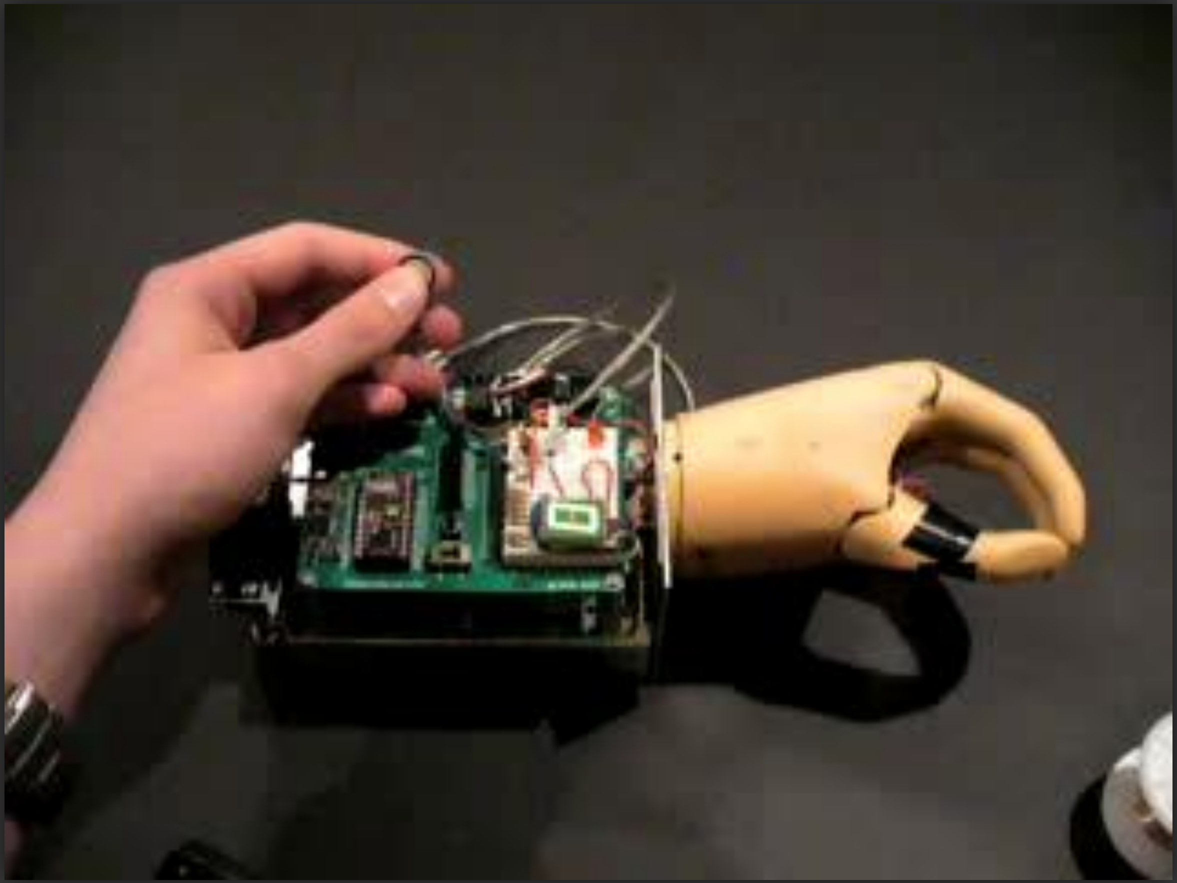
-SVEN Graph
-Smoothed SVEN Graph
-Digital SVEN Graph

SVEN Graphs Exported

Results and Discussion



Objective 1 – Prosthetic Prototype



Video 1: Prosthetic Prototype Demonstration (Blum, 2007)

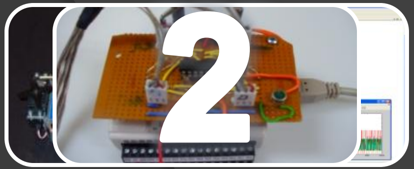
- ✓ Hand opens and closes upon force input
- ✓ Force Approximation
- ✓ Hand can grip objects
- ✓ Slip circuit successfully arrests slip

*Low cost (force sensors are 100 times less expensive than myoelectrodes)

*no surgery required

Results and Discussion

Objective 2 – Matlab Data Acquisition



Muscles Relaxed

(a) Inactive Calibration Data for **Myoelectrodes** (b) Inactive Calibration Data for **Force Sensors**

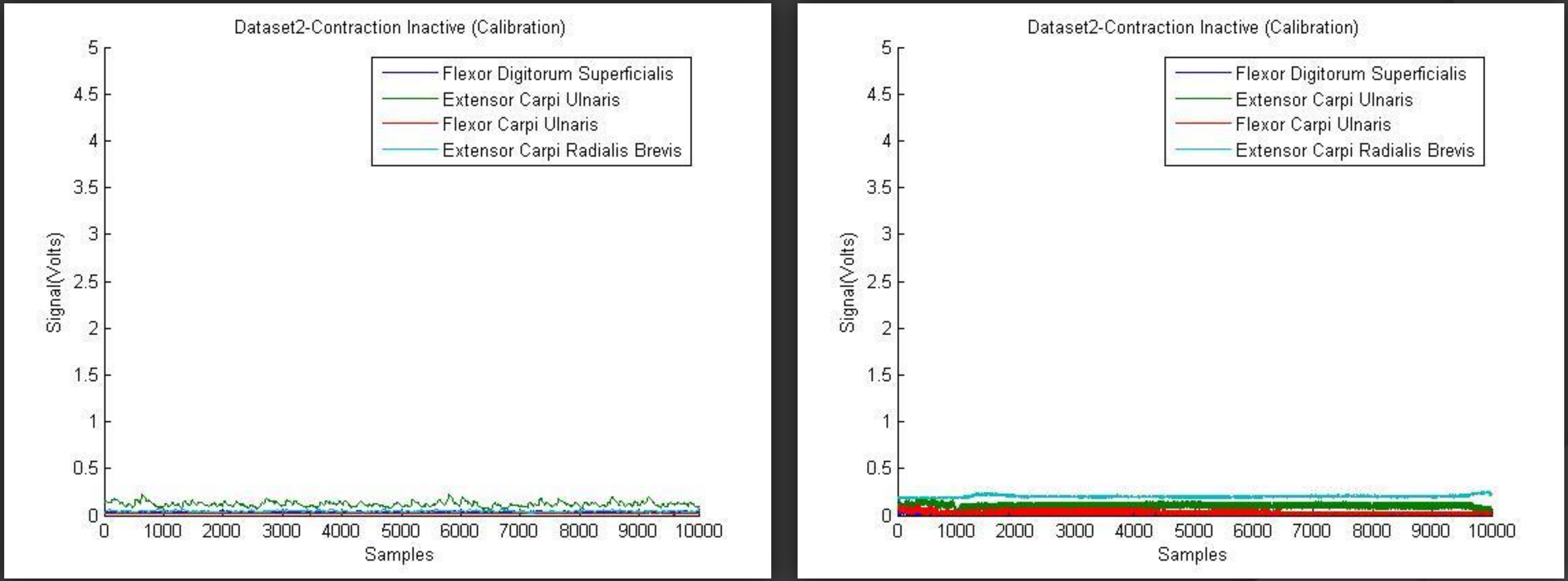
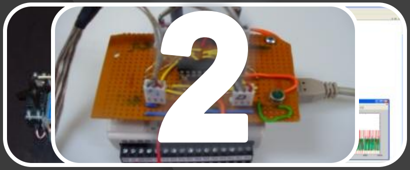


Figure 14 (a & b): Inactive Myoelectrode and Force Sensor Calibration Data (Blum, 2007)

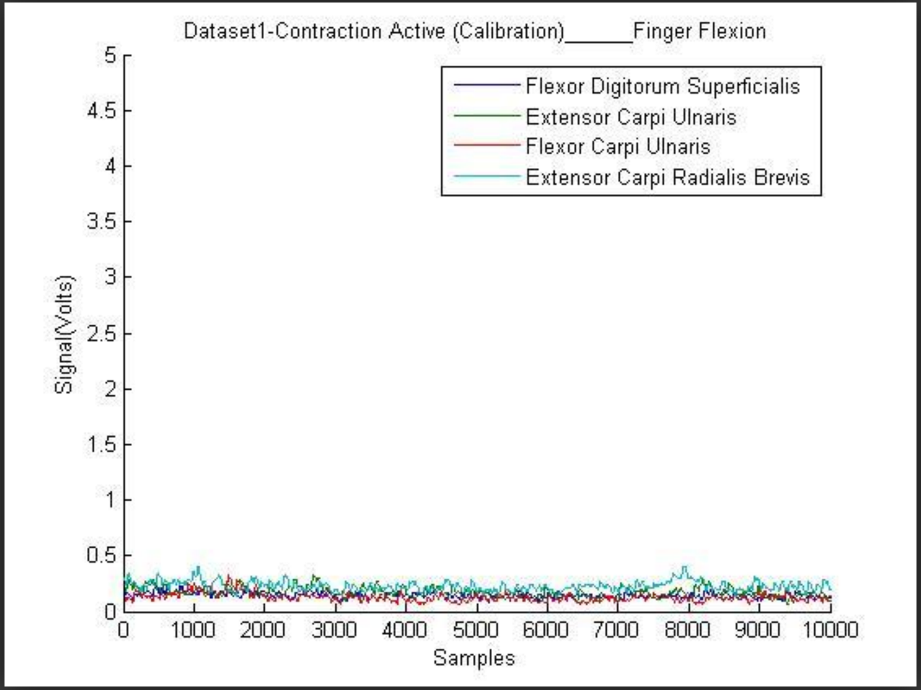
Results and Discussion

Objective 2 – Matlab Data Acquisition



Finger Flexion *(Flexor Digitorum Superficialis)*

(a) Active Calibration Data for **Myoelectrodes**



(b) Active Calibration Data for **Force Sensors**

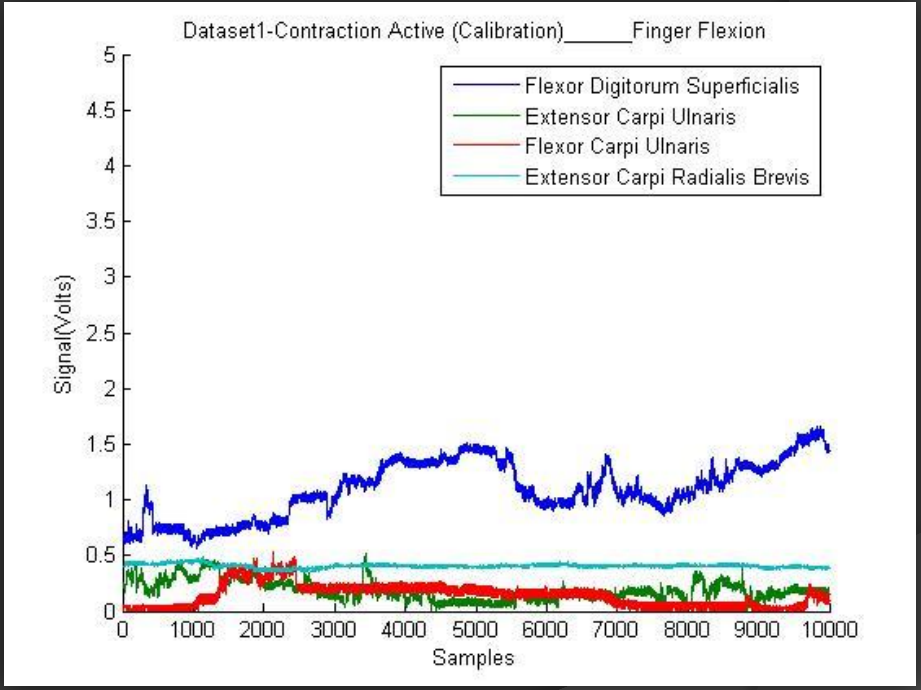
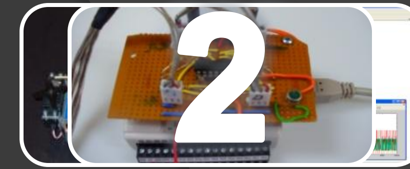


Figure 15 (a & b): Comparison of Finger Flexion Raw Calibration Data (Blum, 2007)

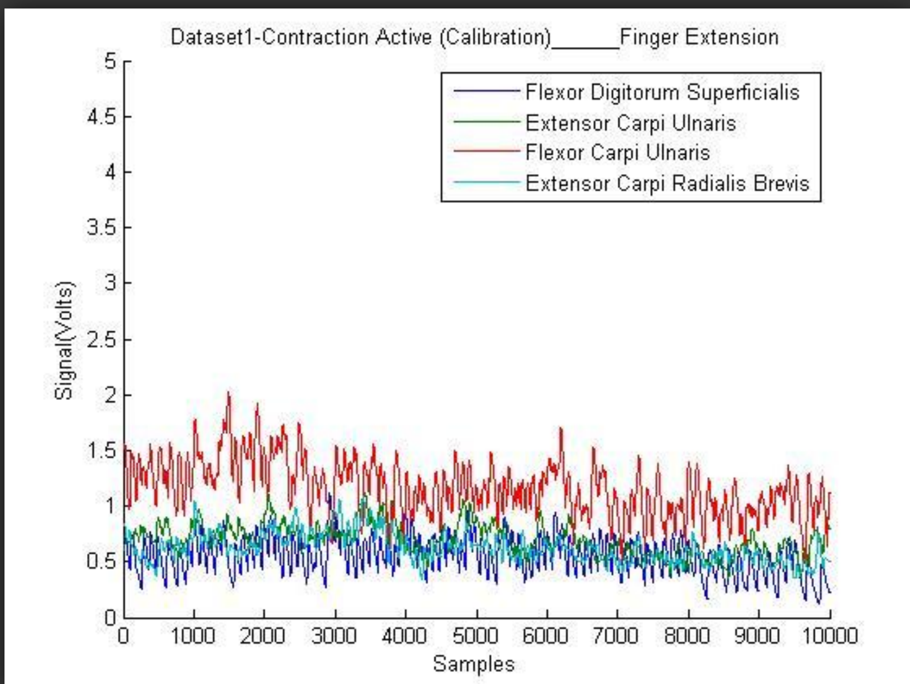
Results and Discussion



Objective 2 – Matlab Data Acquisition

Finger Extension *(Extensor Carpi Ulnaris)*

(a) Active Calibration Data for **Myoelectrodes**



(b) Active Calibration Data for **Force Sensors**

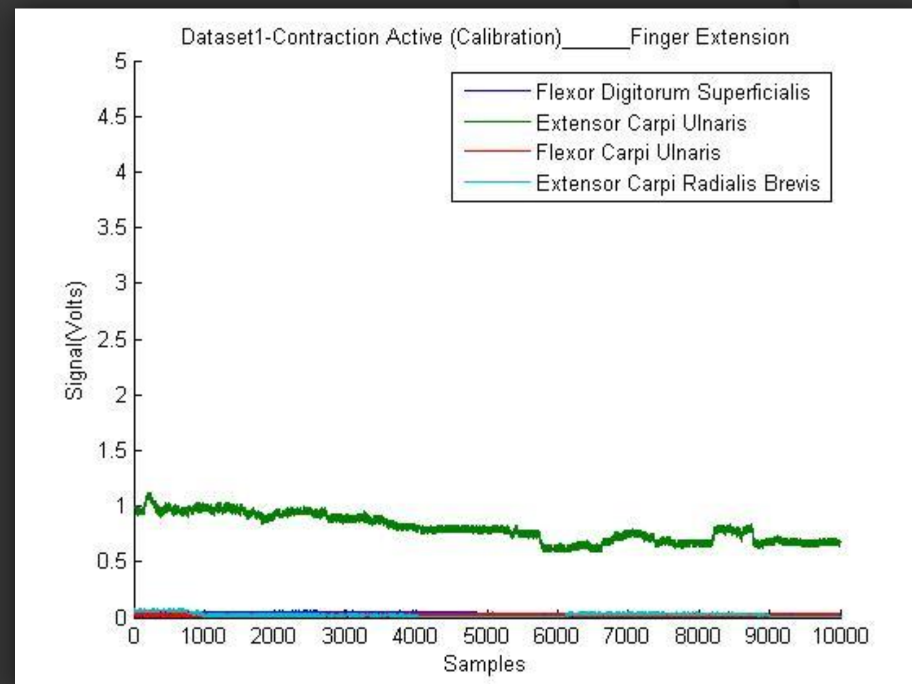
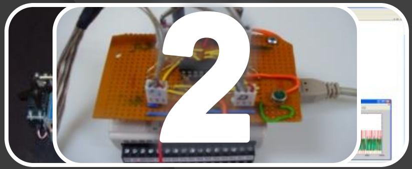


Figure 16 (a & b): Comparison of Finger Extension Raw Calibration Data (Blum, 2007)

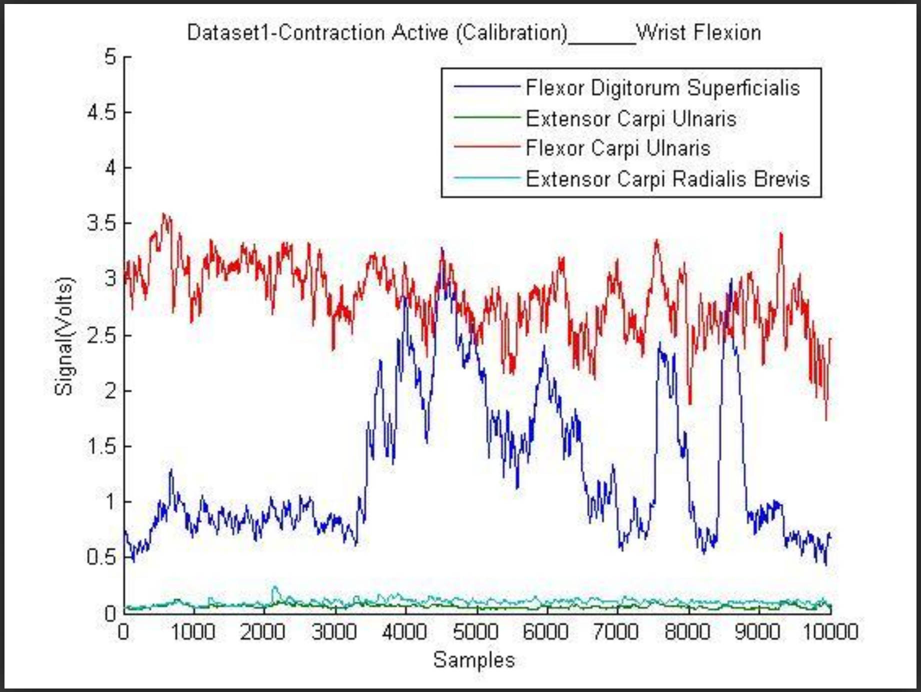
Results and Discussion

Objective 2 – Matlab Data Acquisition



Wrist Flexion (*Flexor Carpi Ulnaris)*

(a) Active Calibration Data for **Myoelectrodes**



(b) Active Calibration Data for **Force Sensors**

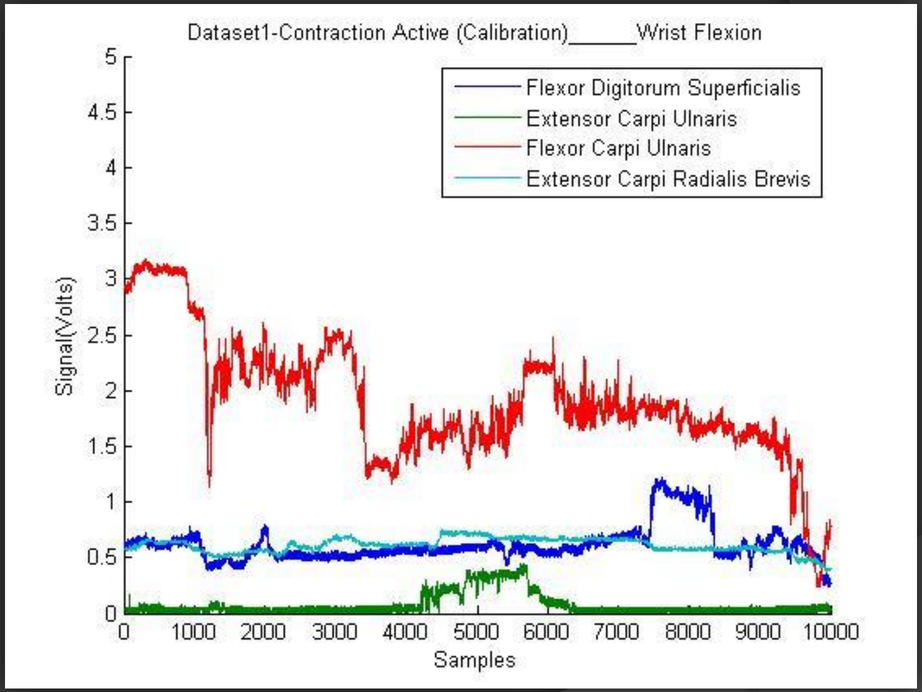
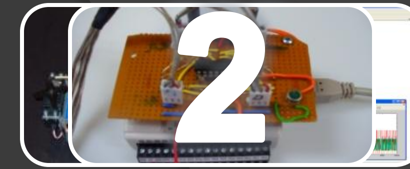


Figure 17 (a & b): Comparison of Wrist Flexion Raw Calibration Data (Blum, 2007)

Results and Discussion

Objective 2 – Matlab Data Acquisition



Wrist Extension *(Extensor Carpi Radialis Brevis)*

(a) Active Calibration Data for **Myoelectrodes**

(b) Active Calibration Data for **Force Sensors**

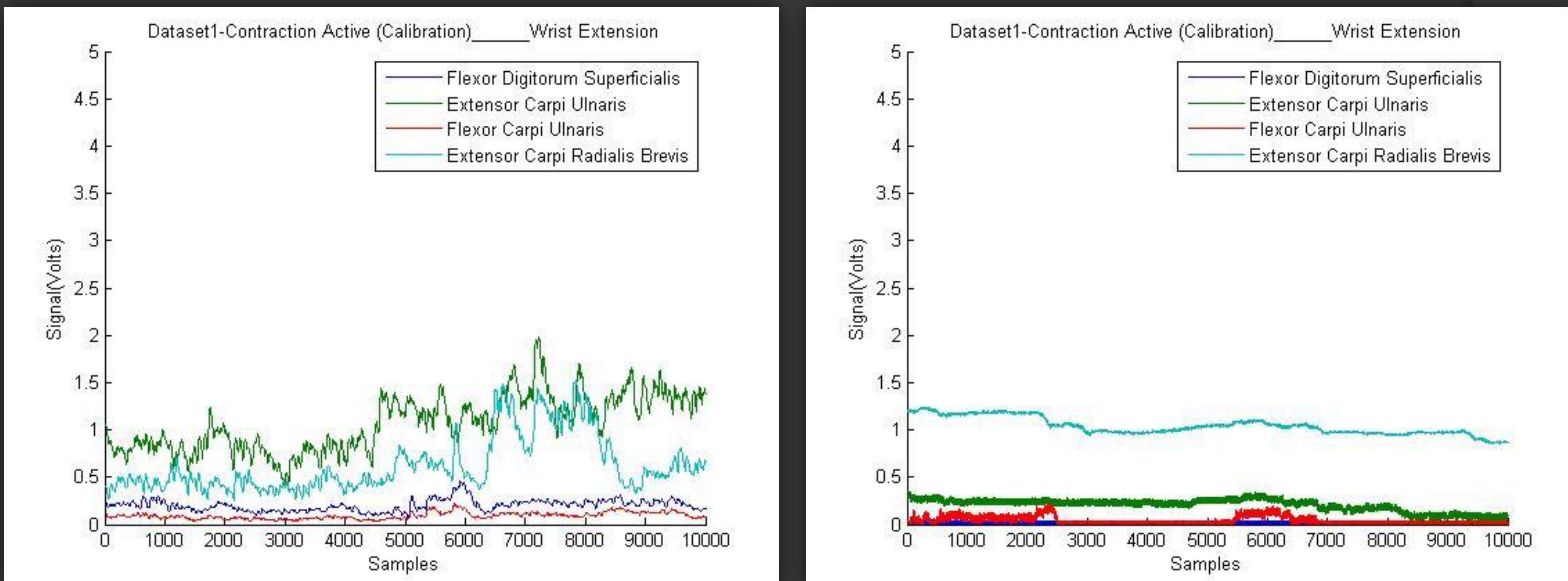
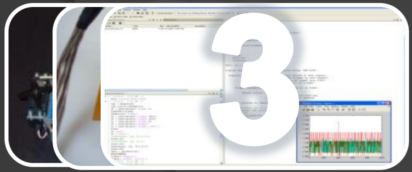


Figure 18 (a & b): Comparison of Wrist Extension Raw Calibration Data (Blum, 2007)

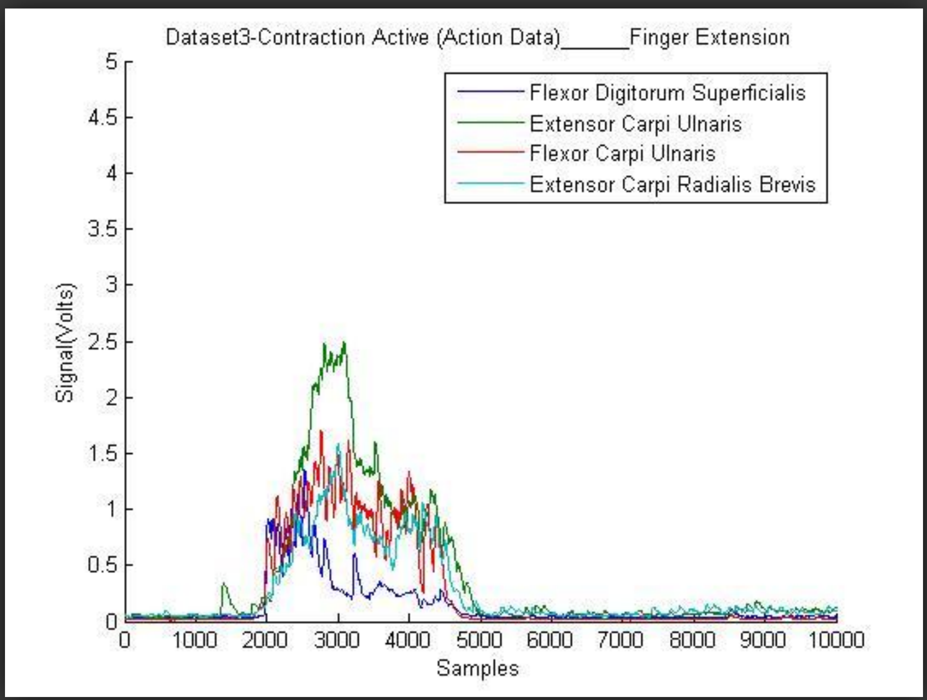
Results and Discussion

Objective 3 – Matlab Analysis of Accuracy with SVEN



Finger Extension *(Extensor Carpi Ulnaris)*

(a) Action Data for **Myoelectrodes**



(b) Action Data for **Force Sensors**

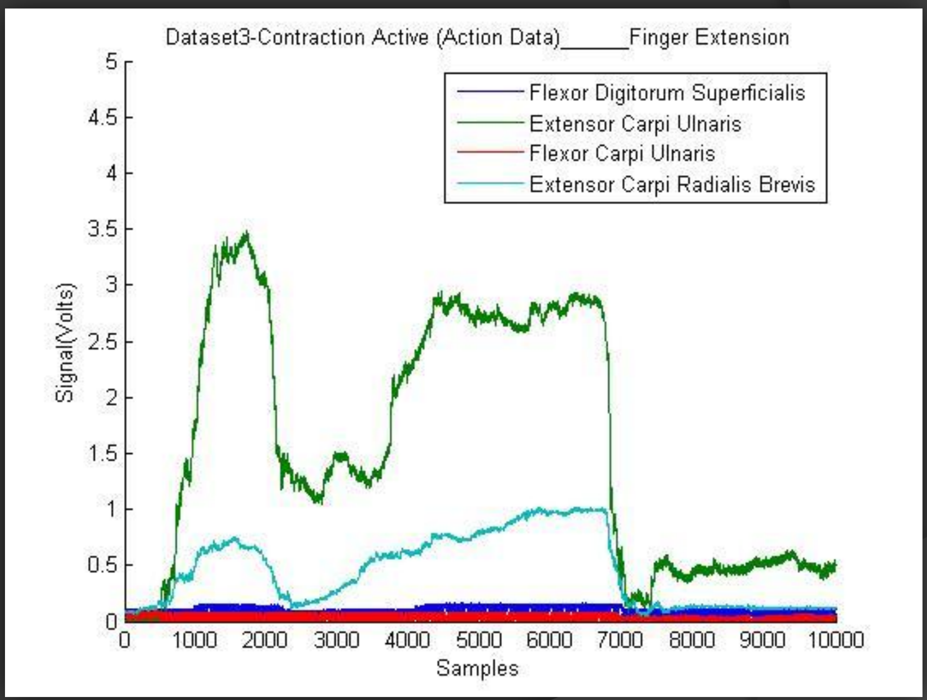
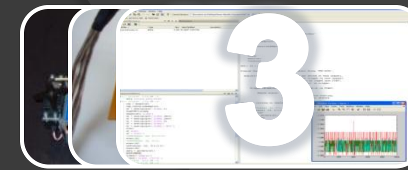


Figure 19 (a & b): Myoelectric and Force Sensor **Finger Extension** Action Data for SVEN Function (Blum, 2007)

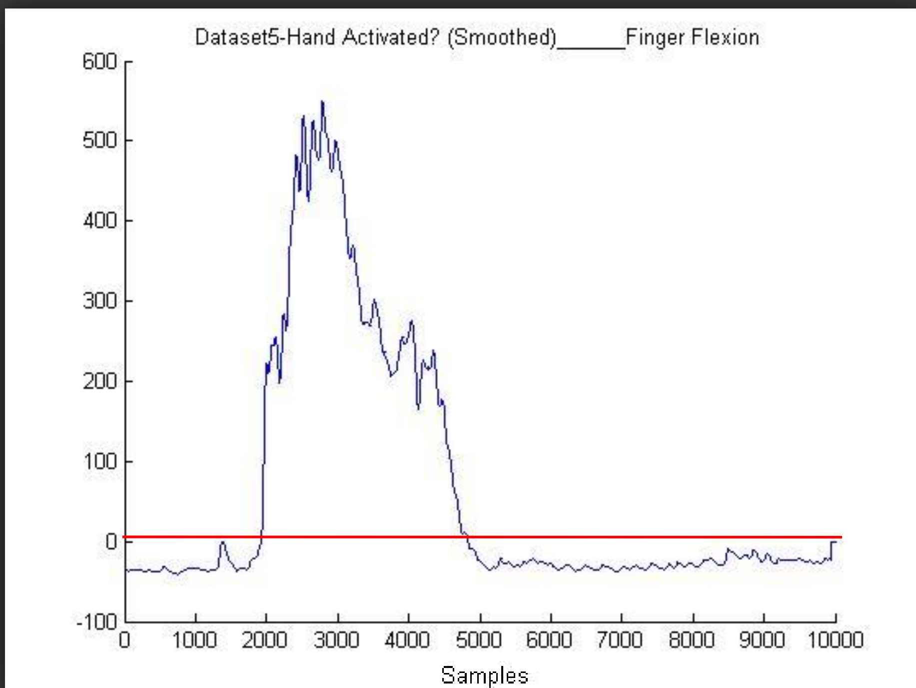
Results and Discussion

Objective 3 – MATLAB Comparison of Accuracies



<u>Finger Flexion</u> ≠ Finger Extension *(Should not exceed zero)*

(a) SVEN Function for **Myoelectrodes**



(b) SVEN Function for **Force Sensors**

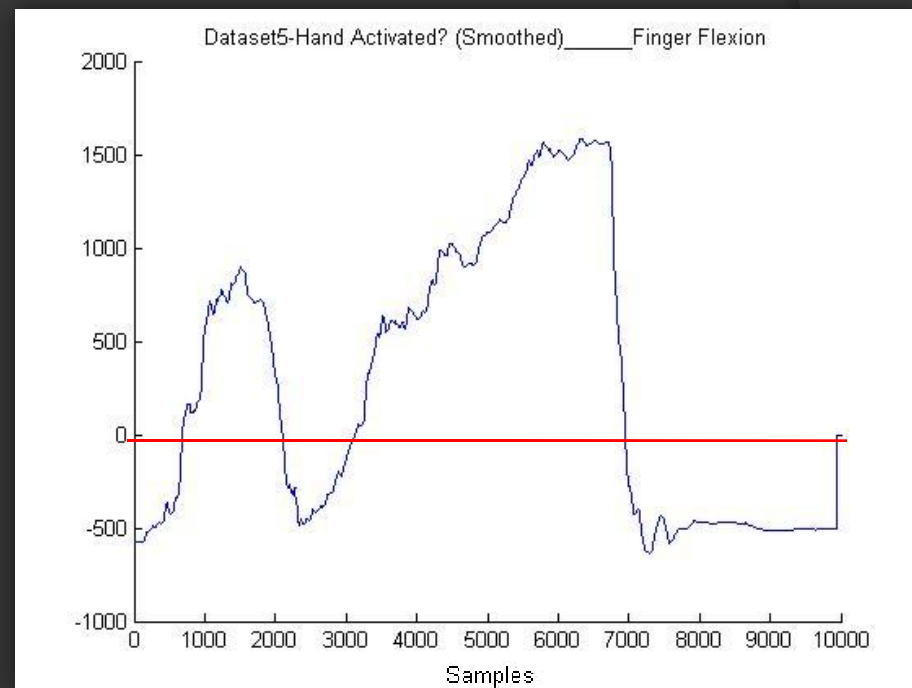
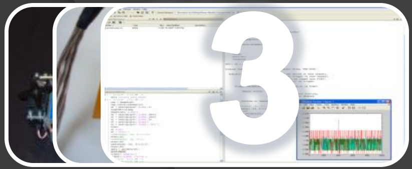


Figure 20 (a & b): Myoelectric and Force Sensor **<u>Finger Extension</u>** Smoothed SVEN Function (Blum, 2007)

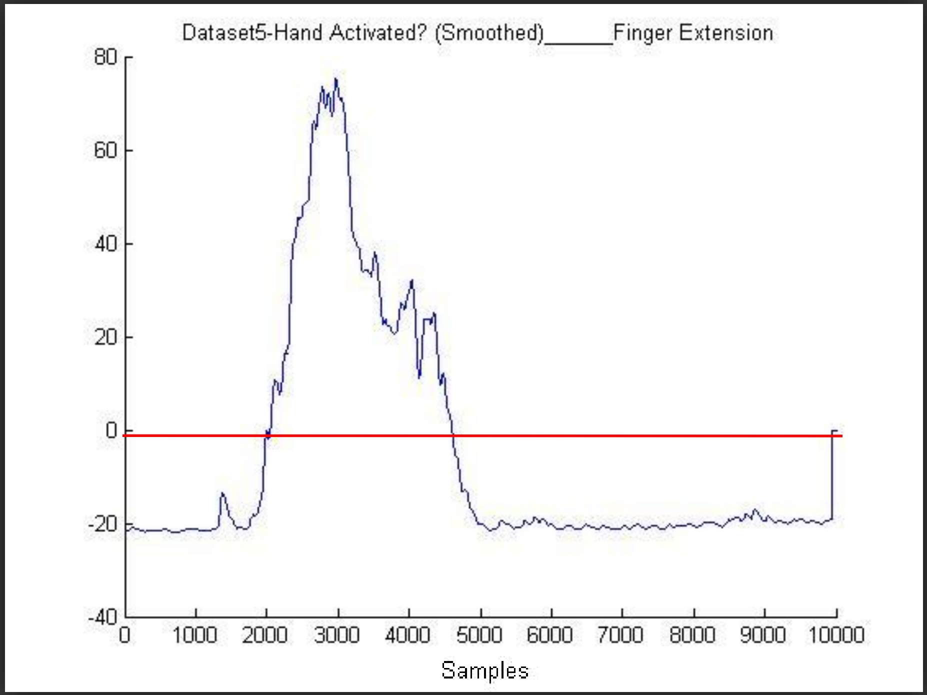
Results and Discussion

Objective 3 – MATLAB Comparison of Accuracies



<u>Finger Extension</u> = Finger Extension *(Should exceed zero)*

(a) SVEN Function for **Myoelectrodes**



(b) SVEN Function for **Force Sensors**

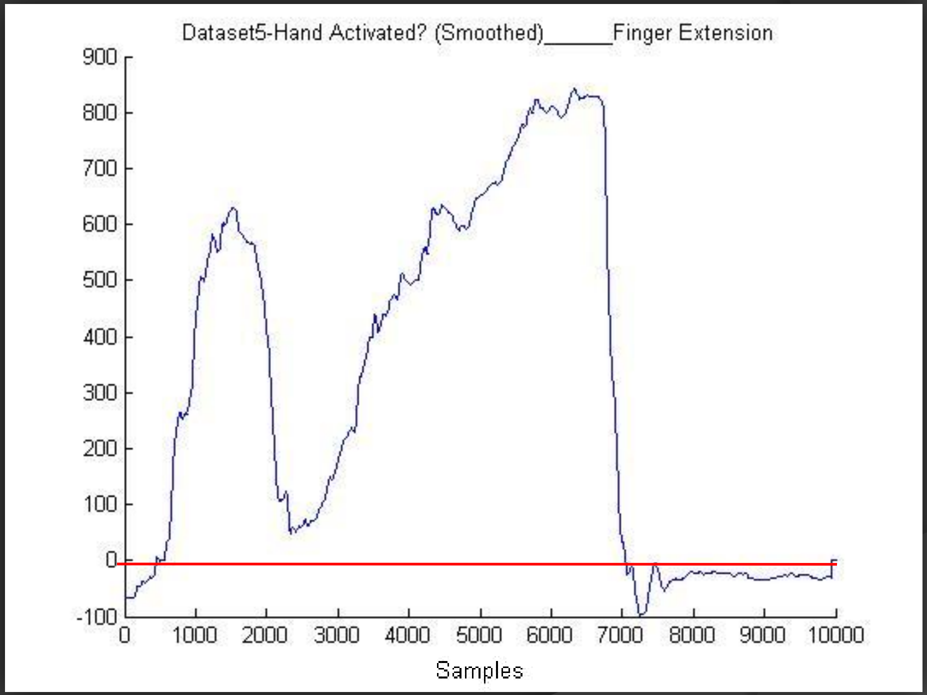
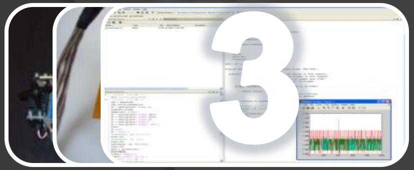


Figure 21 (a & b): Myoelectric and Force Sensor **<u>Finger Extension</u>** Smoothed SVEN Function (Blum, 2007)

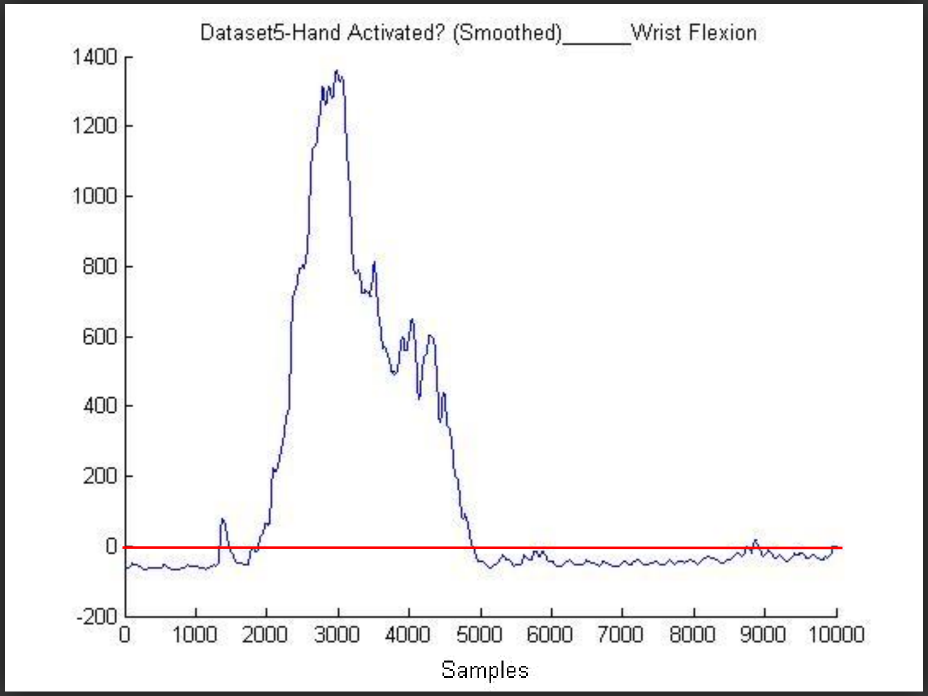
Results and Discussion

Objective 3 – MATLAB Comparison of Accuracies



<u>Wrist Flexion</u> ≠ Finger Extension *(Should not exceed zero)*

(a) SVEN Function for **Myoelectrodes**



(b) SVEN Function for **Force Sensors**

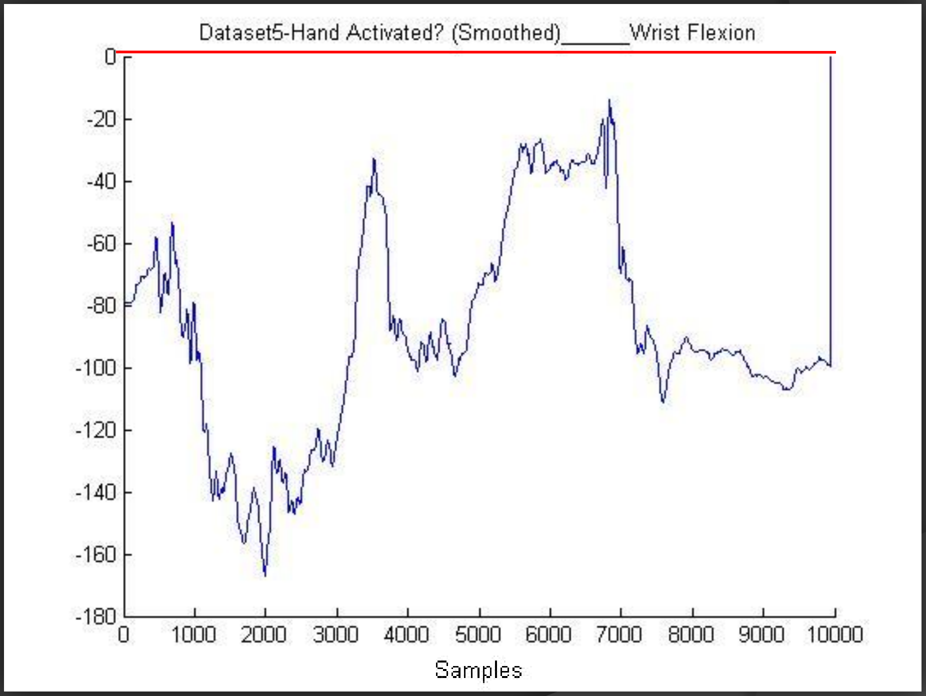
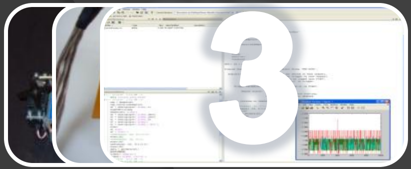


Figure 22 (a & b): Myoelectric and Force Sensor **<u>Finger Extension</u>** Smoothed SVEN Function (Blum, 2007)

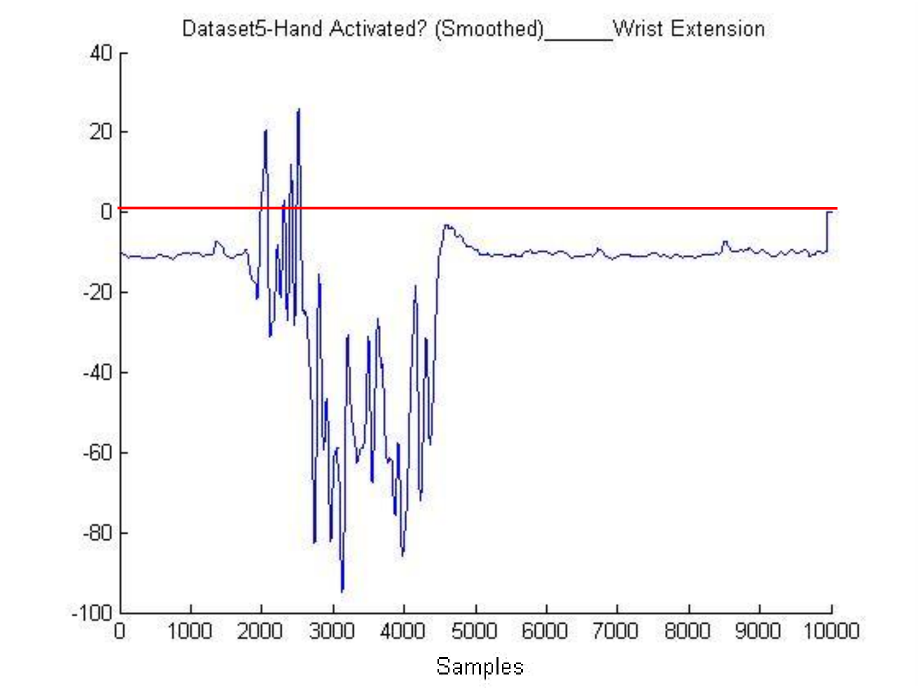
Results and Discussion

Objective 3 – MATLAB Comparison of Accuracies



Wrist Extension ≠ Finger Extension *(Should not exceed zero)*

(a) SVEN Function for **Myoelectrodes**



(b) SVEN Function for **Force Sensors**

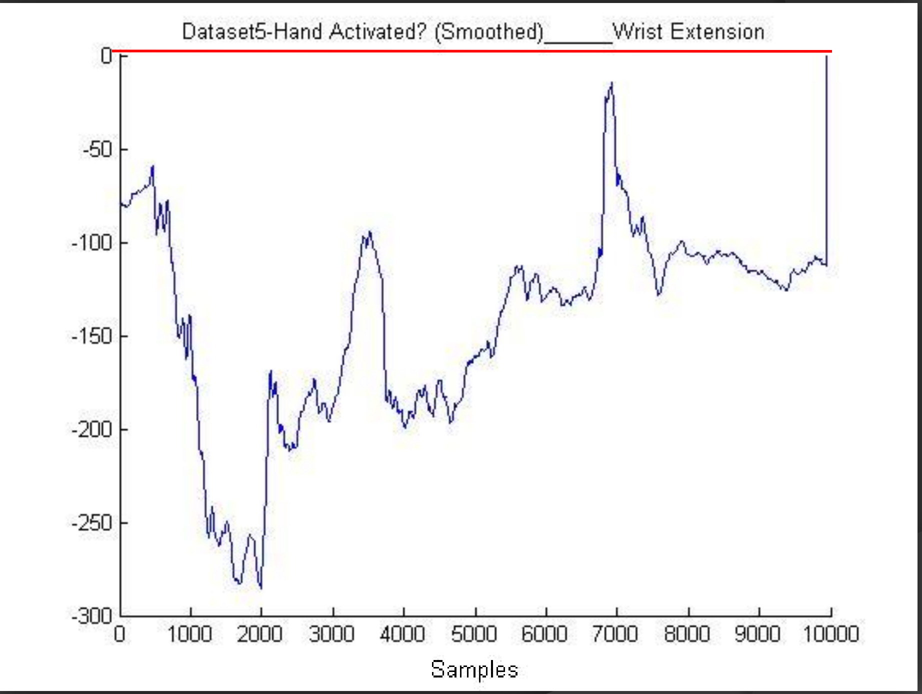


Figure 23 (a & b): Myoelectric and Force Sensor **Finger Extension** Smoothed SVEN Function (Blum, 2007)

Conclusions

- Low cost → open to new socioeconomic group
- No implantation → no risk of infection or sensor movement
- Prosthesis can be easily removed
- Little interference + low cross-talk = high accuracy rates
- Pattern Recognition (SVEN function) mostly works, but is not perfect for use with force sensors
- Sufficient voltage separation → eliminate post processing (voltage boundary can be measured using a comparator circuit with a fixed reference voltage)

With additional research, force sensor technology can be used in future prosthetic devices

Acknowledgements

- Grant Provider
  - Mu Alpha Theta Math Honor Society
- Mentor
  - Dr. Peter Kyberd, University of New Brunswick (UNB), Canada
- Clinical Team
  - Dr. Bernie Hudgins, UNB, Canada
  - Greg Bush, UNB, Canada
  - Walter Young, UNB, Canada
  - Gabriel Arseneau, UNB, Canada
- Research Teachers
  - Dr. Robert Pavlica
  - Mr. David Keith
  - Mr. Steven Borneman
  - Mr. Ken Kaplan
  - Ms. Stephanie Greenwald
  - Ms. Zenaida Bongaarts
- Parents
  - Ms. Stacy Wilder
  - Mr. Allen Blum

Figure 24: Jeremy Blum and Dr. Peter Kyberd at UNB