Contact Localization via Active Oscillatory Actuation

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Introduction

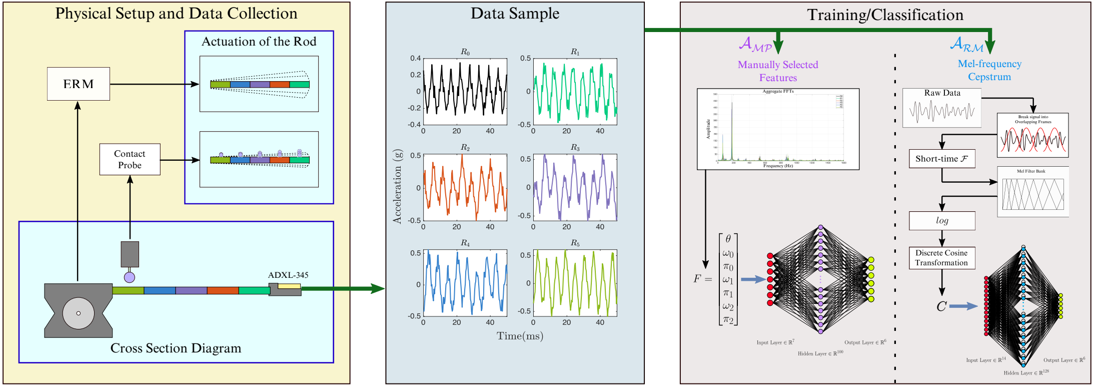
Introduction

Motivation for this study:

- Contact localization in robotics.
  - Grasping, manipulation
  - Telelocomotion
  - Medical robotics
- Current technologies are expensive.
  - Piezoelectric
  - Serial links
- Seek non-intrusive and readily implemented alternative.
  - Accelerometers are inexpensive and non-intrusive.

Procedure

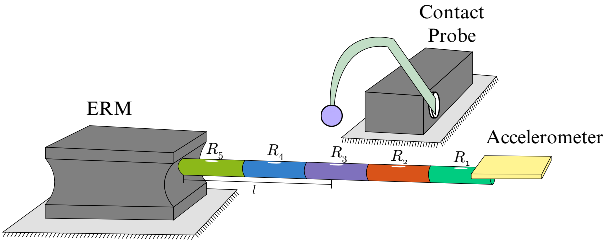
Procedure



Physical Setup and Data Collection
Actuation of the Rod
ERM
Contact Probe
ADXL-345
Cross Section Diagram
Data Sample
Acceleration (g)
Time(ms)
Training/Classification
Manually Selected Features
Mel-frequency Cepstrum
Aggregate FFTs
Amplitude
Frequency (Hz)
Raw Data
Break signal into Overlapping Frames
Short-time $\mathcal{F}$
Mel Filter Bank
log
Discrete Cosine Transformation
$F =$
C
Input Layer $\in \mathbb{R}^7$
Hidden Layer $\in \mathbb{R}^{100}$
Output Layer $\in \mathbb{R}^6$
Input Layer $\in \mathbb{R}^{14}$
Hidden Layer $\in \mathbb{R}^{128}$
Output Layer $\in \mathbb{R}^6$

Procedure
Hardware Setup

The hardware setup consists of a rigid link, contact probe, ERM, and an accelerometer. The ERM actively actuates the rigid link, while contacts are made at appropriate locations between R_1 - R_5, R_0 is untouched. Inertial data is collected via the IMU.



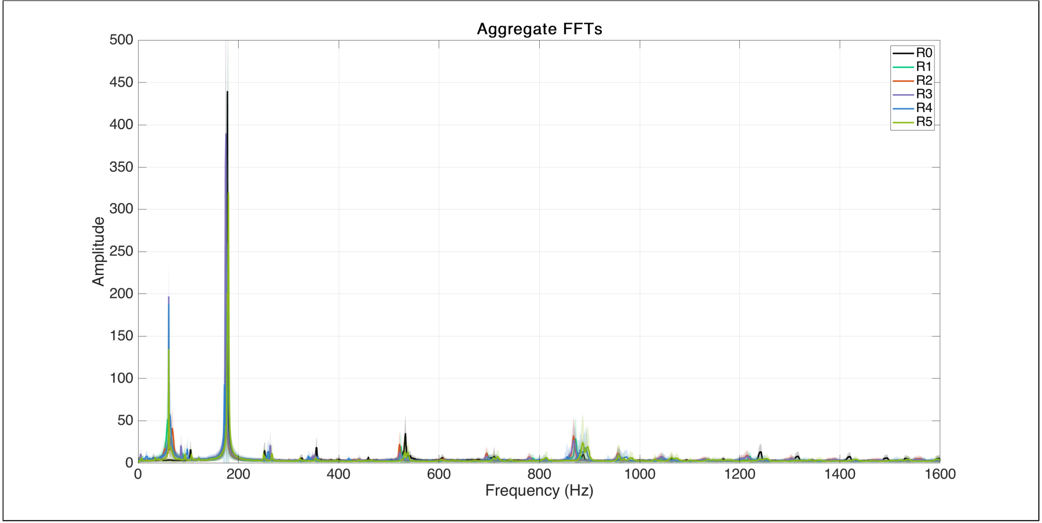
Contact Point	R_1	R_2	R_3	R_4	R_5
D[mm]	10.0	30.6	51.2	71.8	92.4

Procedure
Data Collection

- The contact probe and the ERM actuator were automated using a Raspberry Pi.
- The ERM was actuated for one second with no load and constant current.
- Accelerometer measured, at 3200 Hz, the 3-axis acceleration.
- The setup is reset and allowed to rest for 180 seconds.
- 150 samples were collected for each section to form an aggregate database of 900 one-second time series.

Classification

Manual Features



Manual Features

$$F = \begin{bmatrix} \theta & \omega_0 & \pi_0 & \omega_1 & \pi_1 & \omega_2 & \pi_2 \end{bmatrix}^T \quad (1)$$

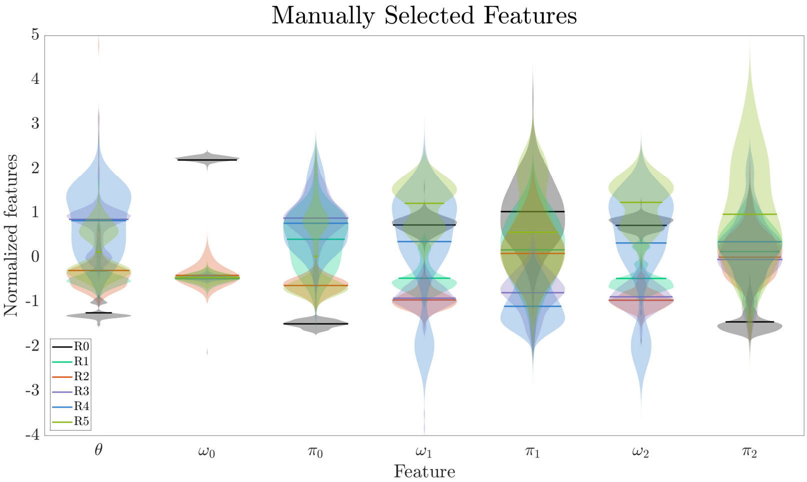
Feature space constructed from seven measures

- θ : atan2 of ratio of RMS vertical and horizontal acceleration
- ω_i : peak frequency within band i
- π_i : peak prominence within band i

Bands were empirically defined from the Aggregate FFT.

Band 0: [0, 120] Hz
Band 1: [500-550] Hz
Band 2: [825-925] Hz

Manual Feature Space



MFCC Features

$$X(k) = \mathcal{F}\{x(n)\} \tag{2}$$

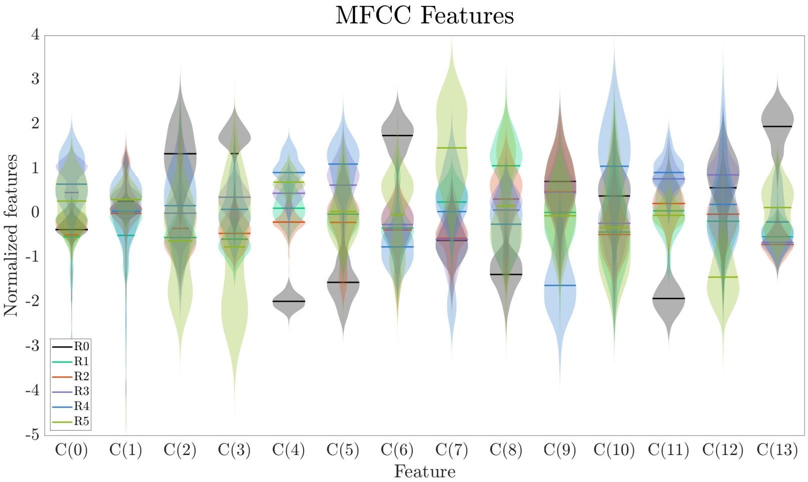
$$f_{mel} = 2595 \log_{10}\left(1 + \frac{f}{700}\right) \tag{3}$$

$$s(m) = \sum_{k=0}^{N-1} \left[|X(k)|^2 H_m(k)\right]; \quad 0 < m < M - 1 \tag{4}$$

$$C(n) = \sum_{m=0}^{M-1} \log_{10}(s(m)) \cos\left(\frac{\pi n(m - 0.5)}{M}\right) \tag{5}$$

The first 14 coefficients constitute the $\mathcal{A}_{RM}$ feature space, i.e. $0 \leq n \leq 13$ in (5).

MFCC Feature Space



Classification Algorithms

Two contact localization algorithms were proposed in this work:

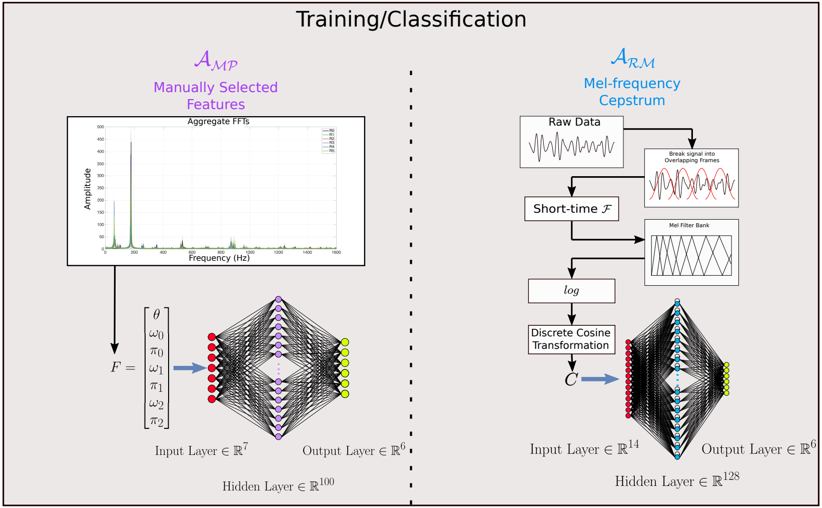
1. $\mathcal{A}_{\mathbf{MP}}$: Multiclass Perceptron with manually selected features, F

   Input: Seven manually selected features in F
   Structure: A single layer of 100 perceptrons
   Optimization: Scaled conjugate gradient backpropogation to optimize cross entropy

2. $\mathcal{A}_{\mathbf{RM}}$: Recurrent Neural Network - with Mel-frequency cepstrum features C.

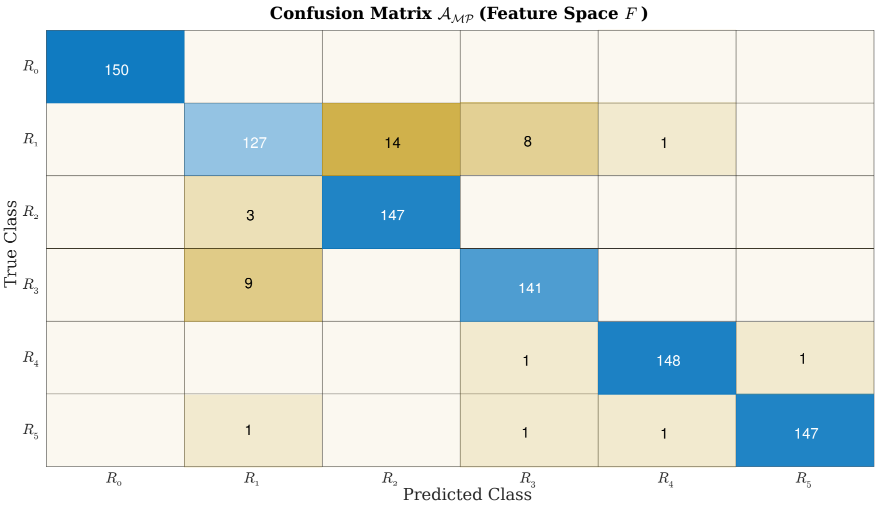
   Input: Sequences of 98 C feature vectors per sample
   Structure: Bidirectional LSTM recurrent neural network with 128 hidden units
   Activation: Sigmoid gate activation and hyperbolic tangent state activation

Classification Algorithms



Results

Classification with $\mathcal{A}_{\mathcal{MP}}$



Classification with $\mathcal{A}_{\mathcal{MP}}$

Table 1: Multi-class Perceptron Classifier ($\mathcal{A}_{MP}$) Performance

Class	Precision	Recall	Accuracy	F1-score
R_0	1.0	1.0	1.0	1.0
R_1	0.9071	0.8467	0.9600	0.8759
R_2	0.9130	0.9800	0.9811	0.9453
R_3	0.9338	0.9400	0.9789	0.9369
R_4	0.9867	0.9867	0.9956	0.9867
R_5	0.9932	0.9800	0.9956	0.9866

Overall accuracy : 95.56%

Classification with $\mathcal{A}_{\mathcal{RM}}$

Confusion Matrix $\mathcal{A}_{\mathcal{RM}}$ (Feature Space C)

True Class \ Predicted Class	R_0	R_1	R_2	R_3	R_4	R_5
R_0	150					
R_1		139	4	6		1
R_2		1	144	5		
R_3		1		147	2	
R_4		1		3	146	
R_5				2		148

Classification with $\mathcal{A}_{\mathcal{RM}}$

Table 2: Bi-LTSM Classifier ($\mathcal{A}_{RM}$) Performance

Class	Precision	Recall	Accuracy	F1-score
R_0	1.0	1.0	1.0	1.0
R_1	0.9789	0.9267	0.9844	0.9521
R_2	0.9730	0.9600	0.9889	0.9664
R_3	0.9018	0.9800	0.9789	0.9393
R_4	0.9865	0.9733	0.9933	0.9799
R_5	0.9933	0.9867	0.9967	0.9900

Overall accuracy : 97.11%

Conclusion

Summary

Designed, constructed and evaluated a repeatable active contact localization mechanism

- Actuate oscillations on physical link
- Contact link in separate regions (R_0 - R_5)
- Measure frequency response
- Classify response to contact region using two different models
- We observe:
  - Ease of contact sensing
  - In general, further section from the actuator are harder to identify

Future Work

- Actuation Modality
- MFCC features can be tuned to task
- Expansion of data set in multiple dimensions
- Implementation of asymmetric rigid link
- Acoustic Contact Sensing

Thank you!

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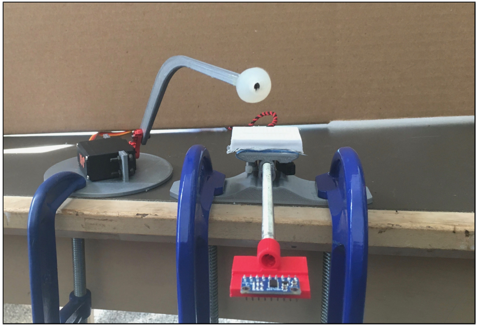
Appendix

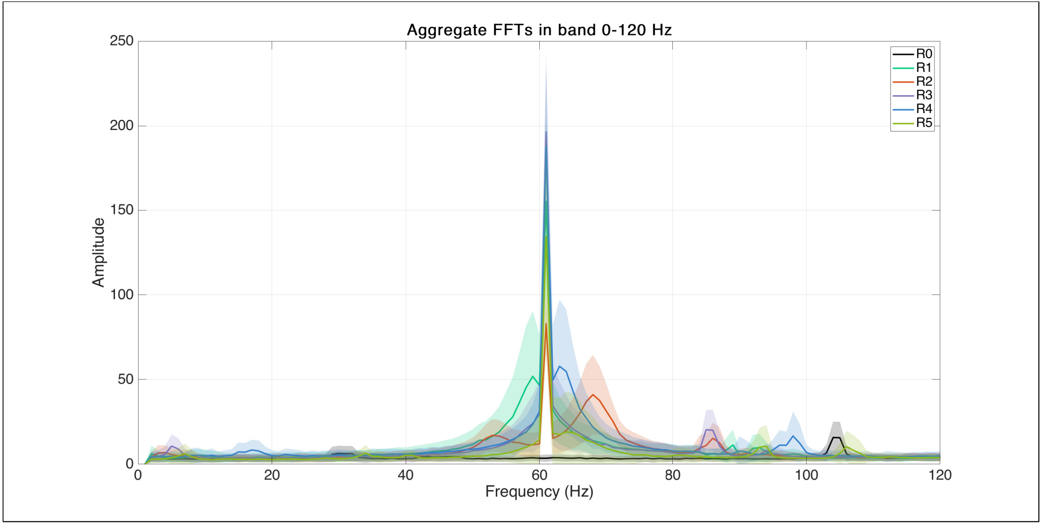
Hardware Setup Implementation

The physical setup is realized using:

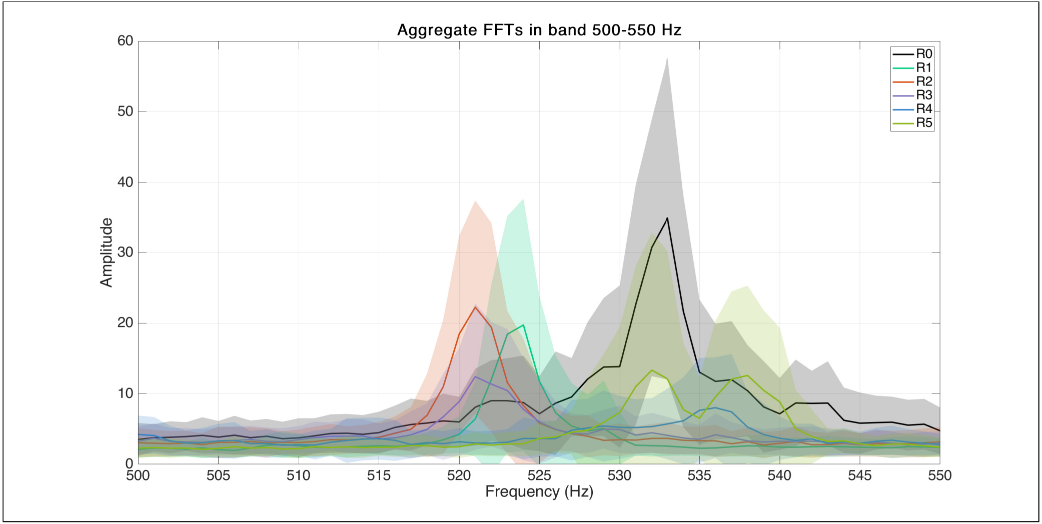
- ¼ inch Zinc Coated Steel Rod
- Secured with PLA mounts
  - ADXL 3-axis accelerometer
  - Eccentric Rotating Mass
  - MG995 metal gear servo



Band0

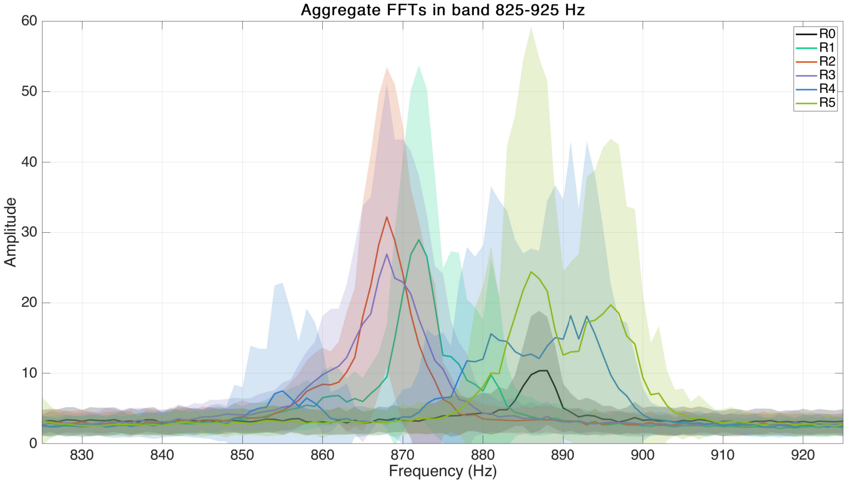

Aggregate FFTs in band 0-120 Hz
Amplitude
Frequency (Hz)
R0
R1
R2
R3
R4
R5
0
50
100
150
200
250
0
20
40
60
80
100
120

Band1



Aggregate FFTs in band 500-550 Hz
Amplitude
Frequency (Hz)
0
10
20
30
40
50
60
500
505
510
515
520
525
530
535
540
545
550
R0
R1
R2
R3
R4
R5

Band2



Aggregate FFTs in band 825-925 Hz
Amplitude
Frequency (Hz)
R0
R1
R2
R3
R4
R5
0
10
20
30
40
50
60
830
840
850
860
870
880
890
900
910
920

MFCC feature for a sample