mm-Wave Radar: Through-Wall Imaging

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Overview

- Motivation
- Problem Statement
- Experiment
- Results
- Conclusion
- Future Work

Hardware Exploration

$$d_{max} = \frac{c}{2S} F_s$$

$$d_{res} = \frac{c}{2B}$$

$$S = \frac{B}{T_C}$$

$$v_{max} = \frac{1}{4T_c} \cdot \frac{c}{f_{RF}}$$

$$v_{res} = \frac{1}{2N_c T_c} \cdot \frac{c}{f_{RF}}$$

- Altering Slope
- Altering Sampling Frequency
- Altering Number Of Chirps

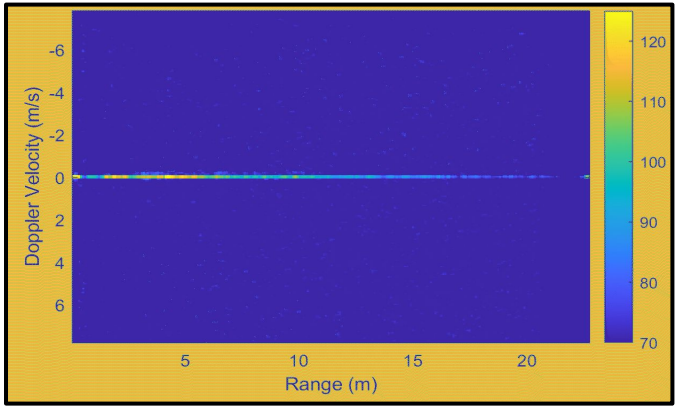
Limitations

- Environment and Target
  - Too many other objects in the environment causes much cluttering
  - Imperfect target reflectivity causes waves to scatter
  - Does not work for stationary targets
- Sensor
  - Limited bandwidth of the sensor limits the range resolution
  - Limited Nc of the sensor limits the velocity resolution
  - Lowering sampling rate results in trade-off between better resolution vs. undesired aliasing
- Data Collection
  - Imperfect environmental conditions

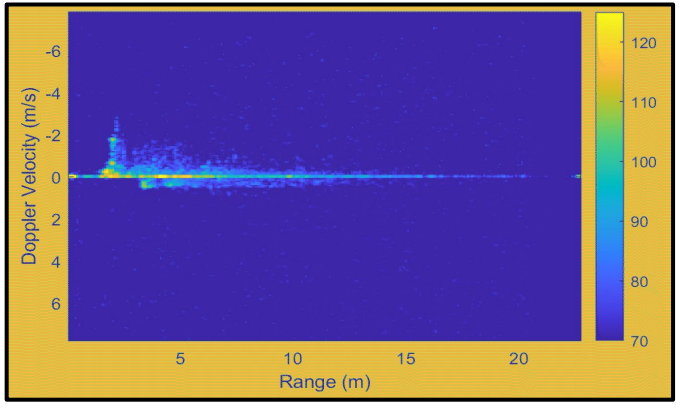
Algorithms

- Data Pre-processing
  - Different Filtering Masks
  - Convolution
- Clustering
  - K-Means clustering + Elbow method
  - FindPeaks + Euclidean distances
  - Find connected components

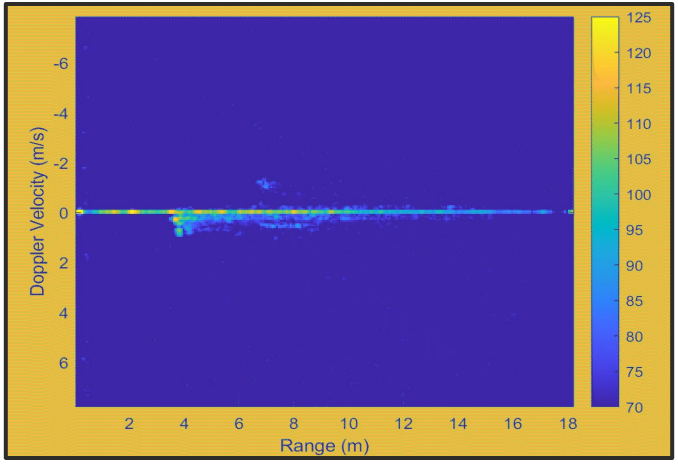
Pre-Range Shrink



One Person

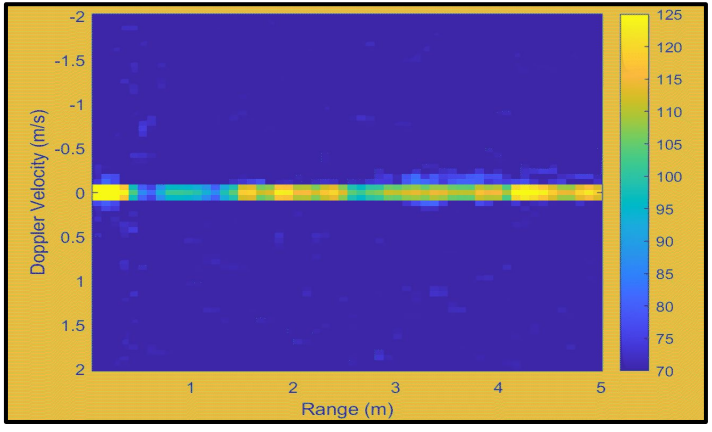


Two People

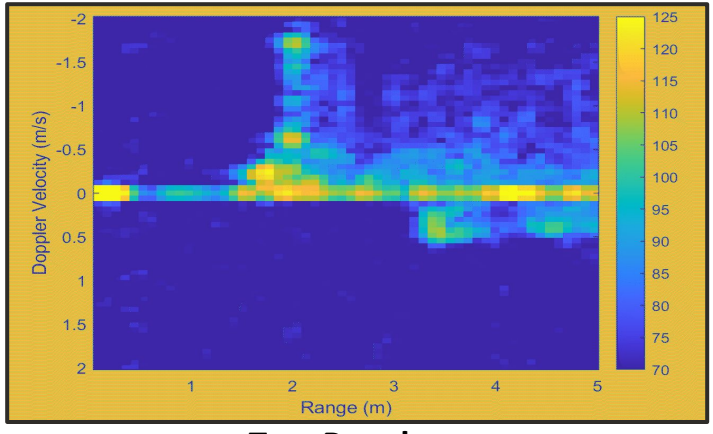


Three People

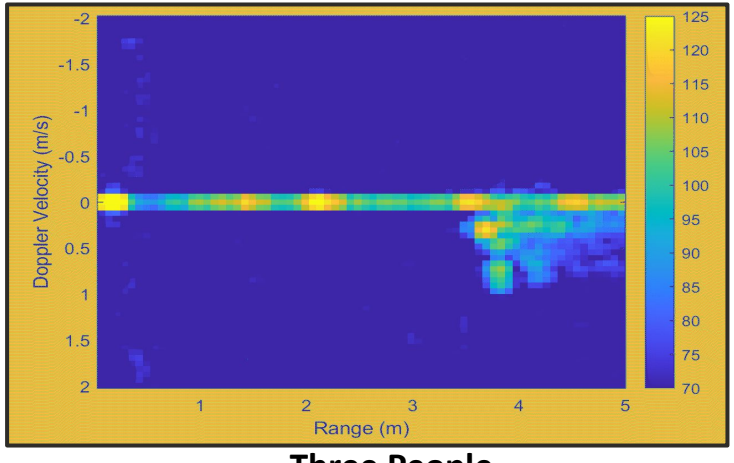
Post Range Shrink



One Person

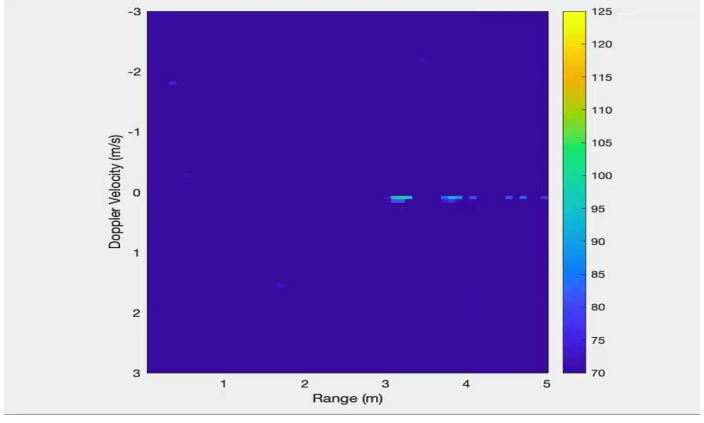


Two People

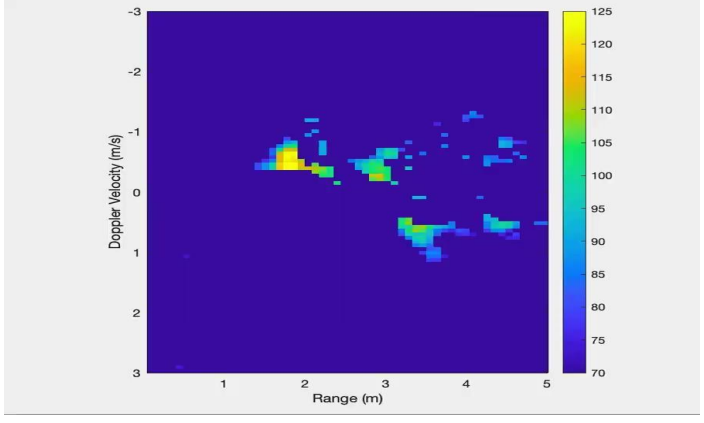


Three People

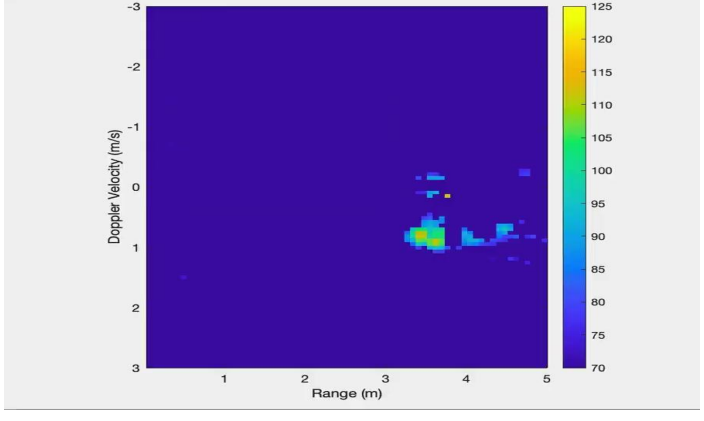
Post Filtering [Filter = (Min + Max)/2]



One Person

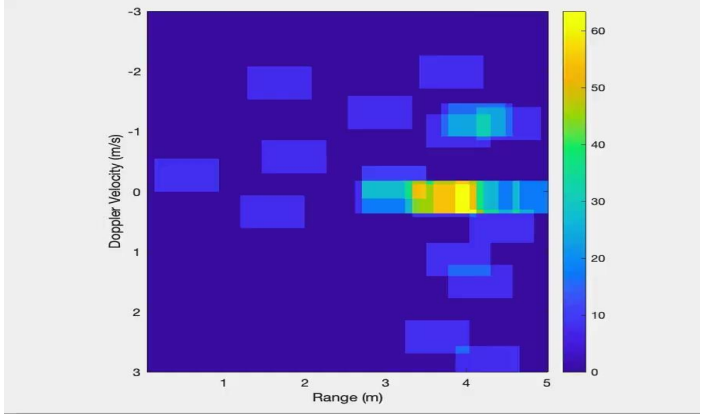


Two People

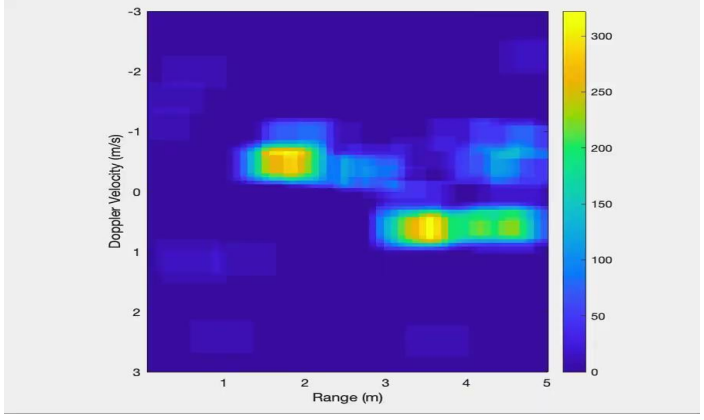


Three People

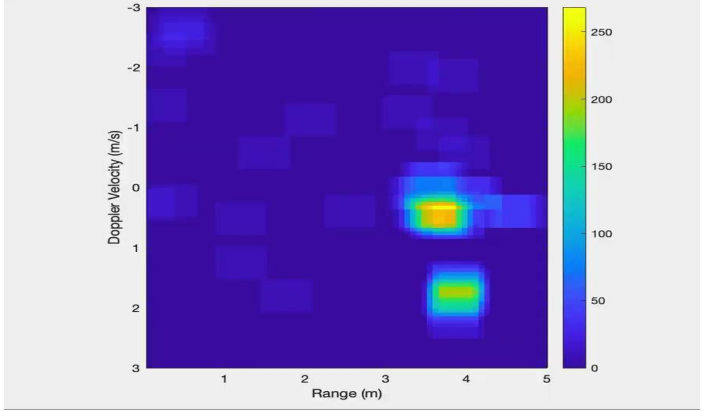
Post Convolution (3x3 ones)



One Person



Two People



Three People

K-Means Clustering + Elbow Methods

Explore: Varying Cut Offs For K means Clustering

- Experimental: Different cutoff value for K-means clustering
- Preprocessing: $\text{conv } 3\text{x}3 + \text{conv } 3\text{x}3 + \text{filter } (\text{med}+\text{max})/2$

Cut Off Value	Single Target Detection Accuracy	Two Targets Detection Accuracy	Three targets Detection Accuracy
0.8	0.5	0.2	0
0.88	0	0.8	0.89
0.9	0	0.6	0.88
0.95	0	0	1

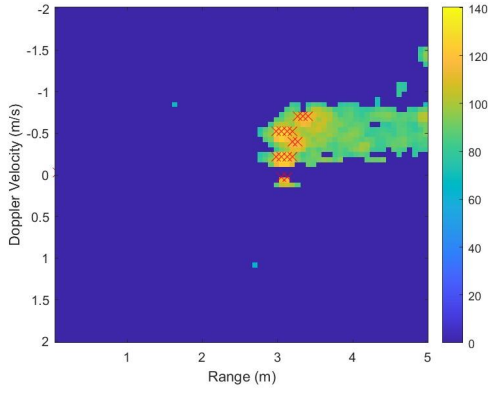
Explore: Preprocessing method

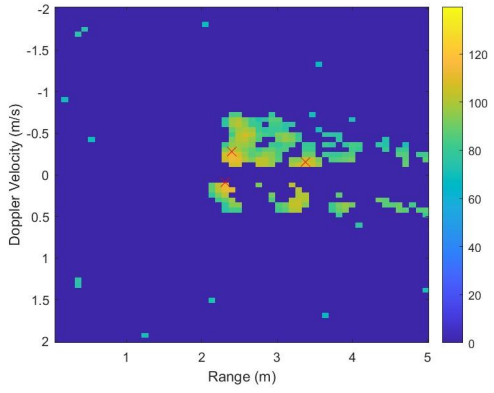
- Experimental: Different preprocessing methods
- K-means cutoff: 0.88

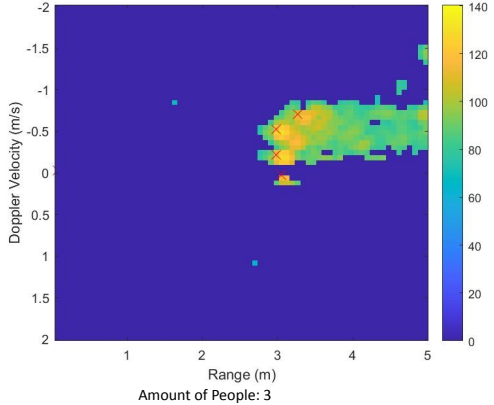
Preprocessing		Single Target Detection Accuracy	Two Targets Detection Accuracy	Three targets Detection Accuracy
Conv 3x3	Filter	0	0.8	0.89
Conv 2x2	Filter	0	0.4	0.22
Filter	Conv 3x3	0	0.8	0.1
Filter	Conv 2x2	VERY BAD		

FindPeaks + Euclidean Distances

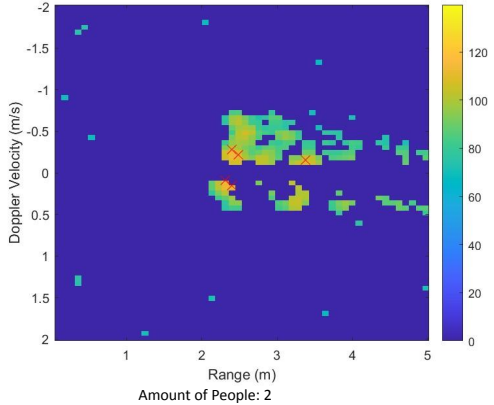
FindPeaks and Euclidean Distances







Amount of People: 3
Max Peak Cutoff: 0.85
Euclidean Distance Cutoff: 0.15



Amount of People: 2
Max Peak Cutoff: 0.95
Euclidean Distance Cutoff: 0.30

Step 1: Find Peaks

We find all the peaks in the graph that are within a certain threshold of the max peak (Max Peak Cutoff)

Step 2: Find Euclidean Distances

We calculate the distance between each of the peaks and if a group of peaks are within a certain threshold of each other (Euclidean Distance Cutoff), we remove all but one

Results - Different Max Peak and Euclidean Cutoffs

No of People	Filename	Results (Average Over All Frames)	Results (Rounded)	Error	Peak Cutoff	Euclidean Distance Cutoff
1	0529_5	1.7	2	0.7	0.95	0.3
		2.29	2	1.29	0.95	0.15
		4.04	4	3.04	0.85	0.3
		6.79	7	5.79	0.85	0.15
2	0529_9	2.33	2	0.33	0.95	0.3
		2.88	3	0.88	0.95	0.15
		5.08	5	3.08	0.85	0.3
		9.14	9	7.14	0.85	0.15
3	0603_9	2.14	2	0.86	0.95	0.3
		2.27	2	0.73	0.95	0.15
		2.58	3	0.42	0.85	0.3
		3.54	4	0.54	0.85	0.15

Results - Different Max Peak and Euclidean Cutoffs

Euclidean distance threshold	Find Peaks Threshold	Single Target Detection Accuracy	Two Targets Detection Accuracy	Three targets Detection Accuracy
0.3	0.95	0	1	0
0.4	0.92	1	1	0.22
0.3	0.9	0	0.5	0

Find Connected Components

Explore: Varying Filters

- Filter 1: (med + max) / 2
- Filter 2: (med*5 + max*7) / 2
- Filter 3: (avg + med) / 2

Preprocessing		Single Target Detection Accuracy	Two Targets Detection Accuracy	Three targets Detection Accuracy
Filter 1	Conv 2x2	0.5	0.6	0.56
Filter 2	Conv 2x2	1	1	0.44
Filter 1 + Conv 2x2	Filter 3 range + Conv 2x2	0.5	0.8	0.22

Conclusion

- The Find Connected Components Algorithm works best for 1-2 people.
- The FindPeak and Euclidean Algorithm works best for 1-2 people, but not for 3 people.
- The K-means Algorithm works best for 3 people.

Future Work

- Apply better noise filtering techniques so that background noise doesn't affect the data as much
- Apply additional machine learning techniques to cluster the data
  - Support Vector Machine (SVM)
  - Convolutional Neural Networks (CNN)
- Experiment with walls of different materials

Thank You