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Multifrequency Doppler Signatures of Human Activities

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Introduction - 1

- Ability to identify human movements is an important tool in applications such as surveillance, military combat, search and rescue operations, and hospital patient monitoring
- Preferred sensors for barrier (e.g. wall or foliage) penetration applications are radars rather than lasers or IR
- Doppler radars are used to recognize signs of life behind barreiers by recognizing micro-Doppler signatures of human activity, such as arm swinging, breathing, and torso bending, and sudden movements
- Such movements induce different types of Doppler spectra depending on the manner in which limbs and other body parts move, and can thus be used to remotely infer human activity

Introduction - 2

- At higher frequencies, smaller movements such as finger motion, riding on larger movements such as arm swinging, can be isolated and recognized
- Generally, movements with displacements larger than the wavelength are much better detected
- Simple electromagnetic models based on biomechanical principles are useful for acquiring general estimates at what the Doppler response could look like
- We will discuss the modeling and characterization of micro-Doppler signatures from human activities at microwave and millimeter-wave radar wavelengths

Doppler Phenomenon

- Object moving with a radial velocity of v towards a radar operating at a frequency of f_0 induces a Doppler shift of $f_d = 2vf_0/c$ where c is the speed of light
- We can estimate Doppler caused by various motions if we can estimate the speed v and assuming a particular frequency f_0

Analysis Approach

- Simple biomechanical models of breathing and limb movement are used to derive Doppler signals
- Models are refined using experimental data from S-band and W-band radars
- Unique feature vectors from different movements are used for remotely classifying human activity

Human Vital Sign Montoring

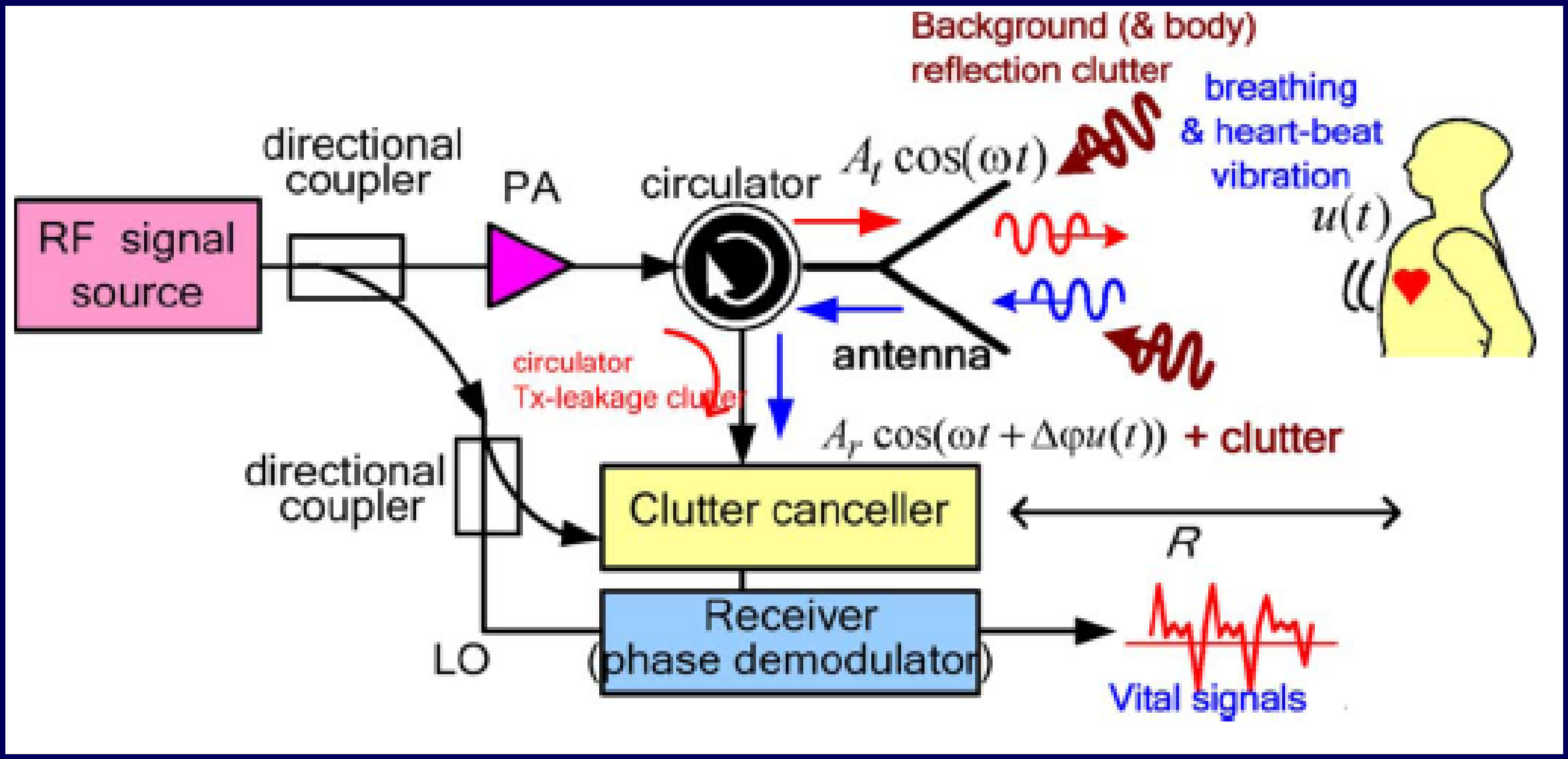
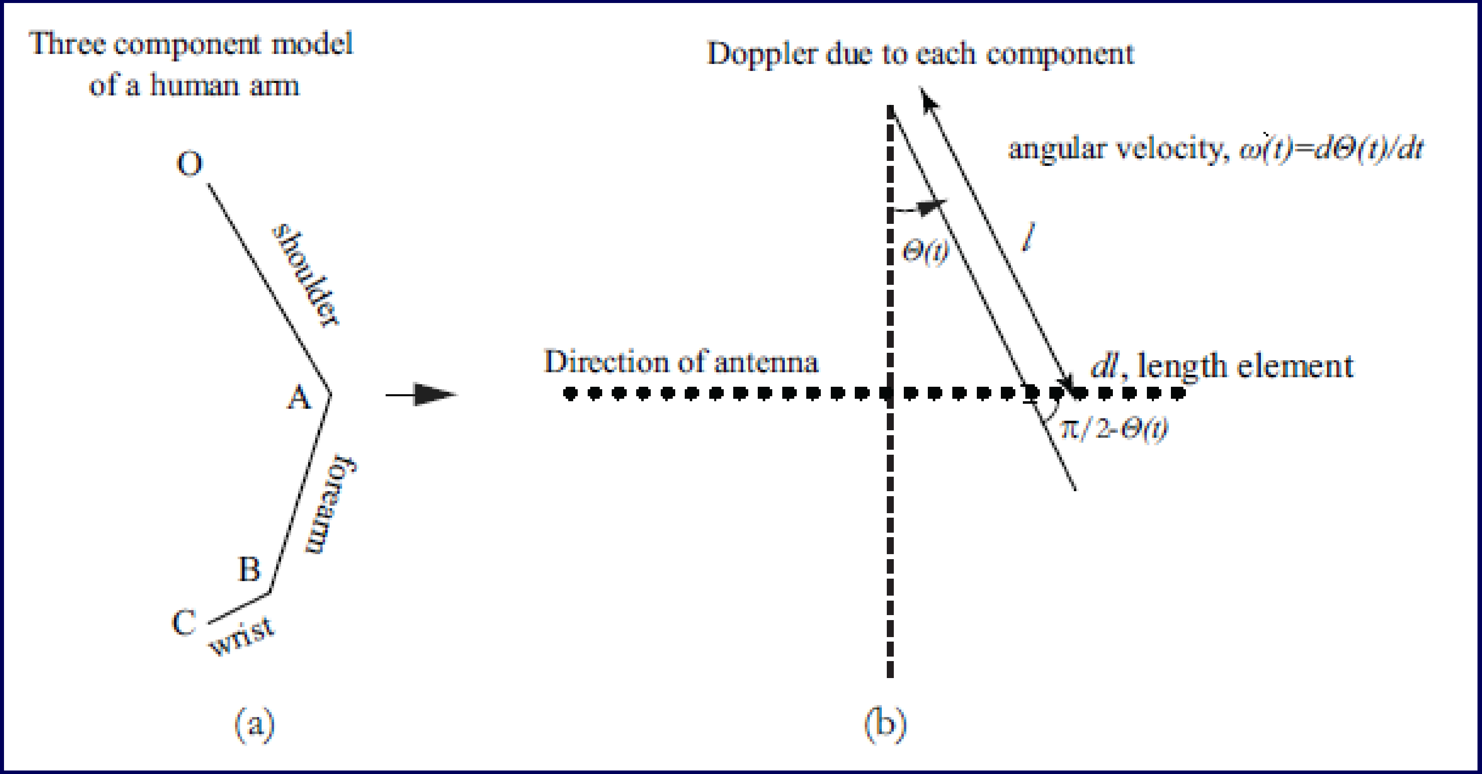


Illustration of a noncontact life detection system for human vital signal monitoring

Doppler Characterization of Arm Swinging

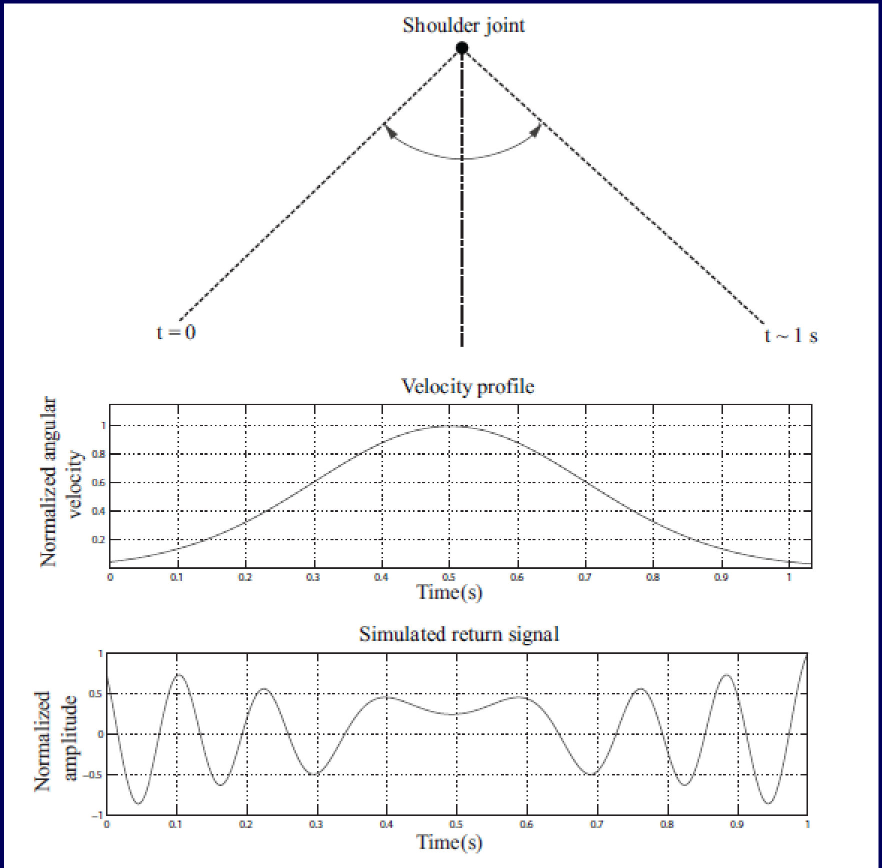


(a) Schematic diagram representing the components of a human arm
(b) Doppler due to one such component that is rotating around a joint

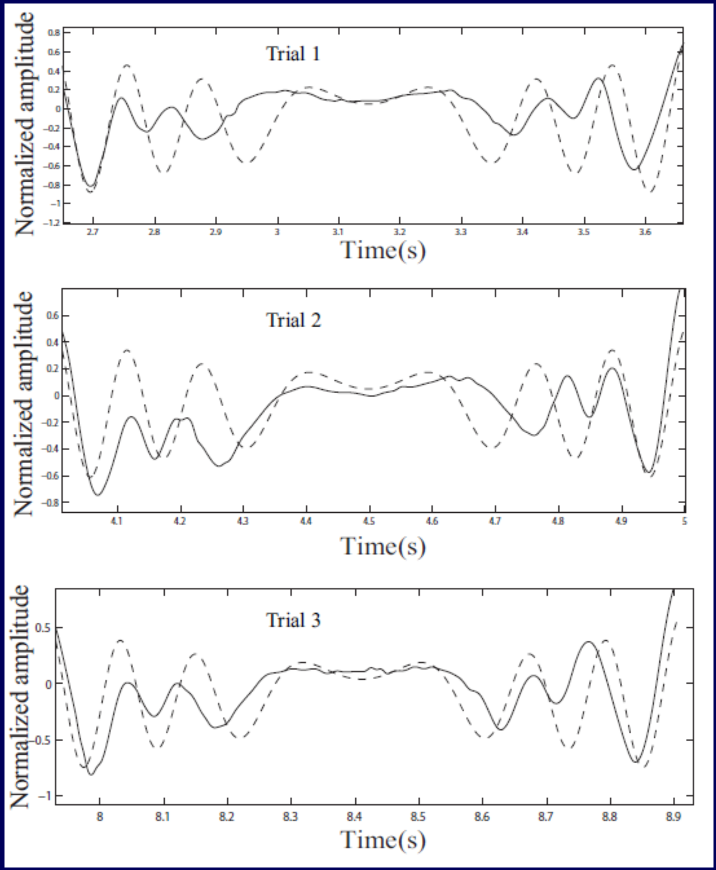
Doppler Caused by Breathing and Arm Swinging

- Chest expands about 3 cm in about 0.8 s (75 heartbeats per minute; thus v = 3.75 cm/s
  - ➢ For $f_0 = 2$ GHz, $f_d = 0.5$ Hz
  - ➢ For $f_0 = 90$ GHz, $f_d = 22.5$ Hz
- Assume average arm swinging speed is 0.4 m/s
  - ➢ For $f_0 = 2$ GHz, $f_d = 5.3$ Hz
  - ➢ For $f_0 = 90$ GHz, $f_d = 240$ Hz

Shoulder Joint Modeling

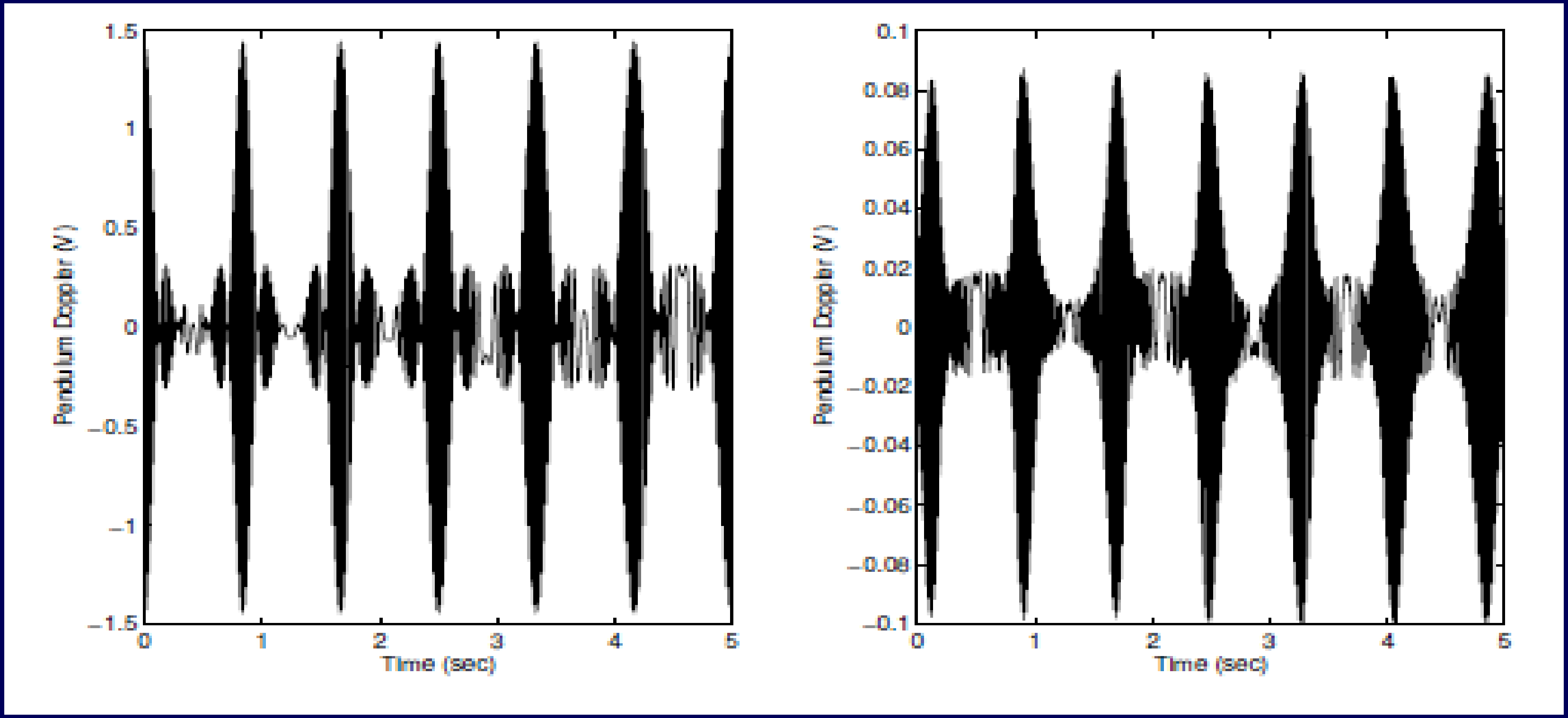


Model



Experimental results

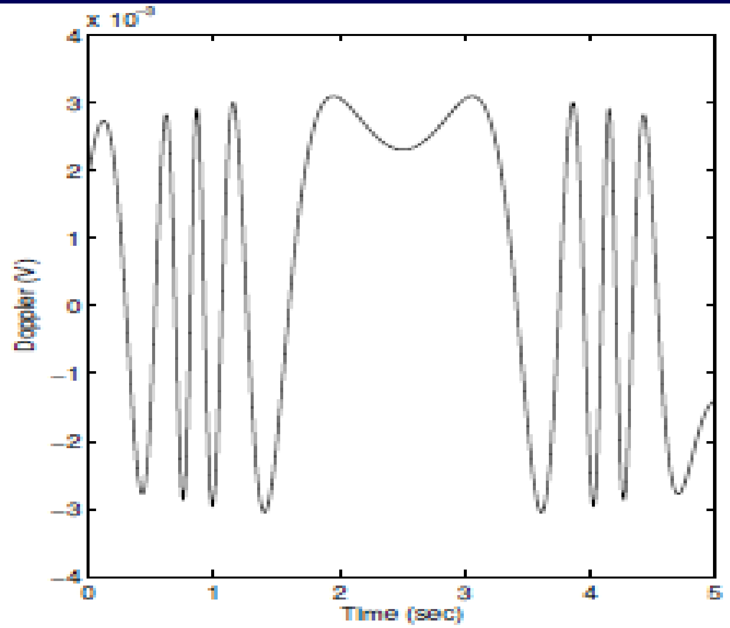
Swinging Pendulum



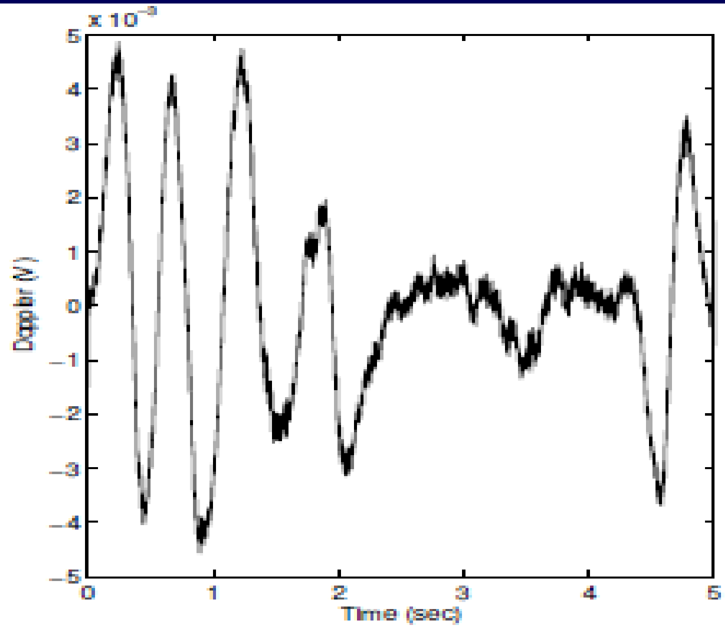
Simulation | Experiment

Data collected by W-band radar at 10 feet range

Breathing Human



Simulation

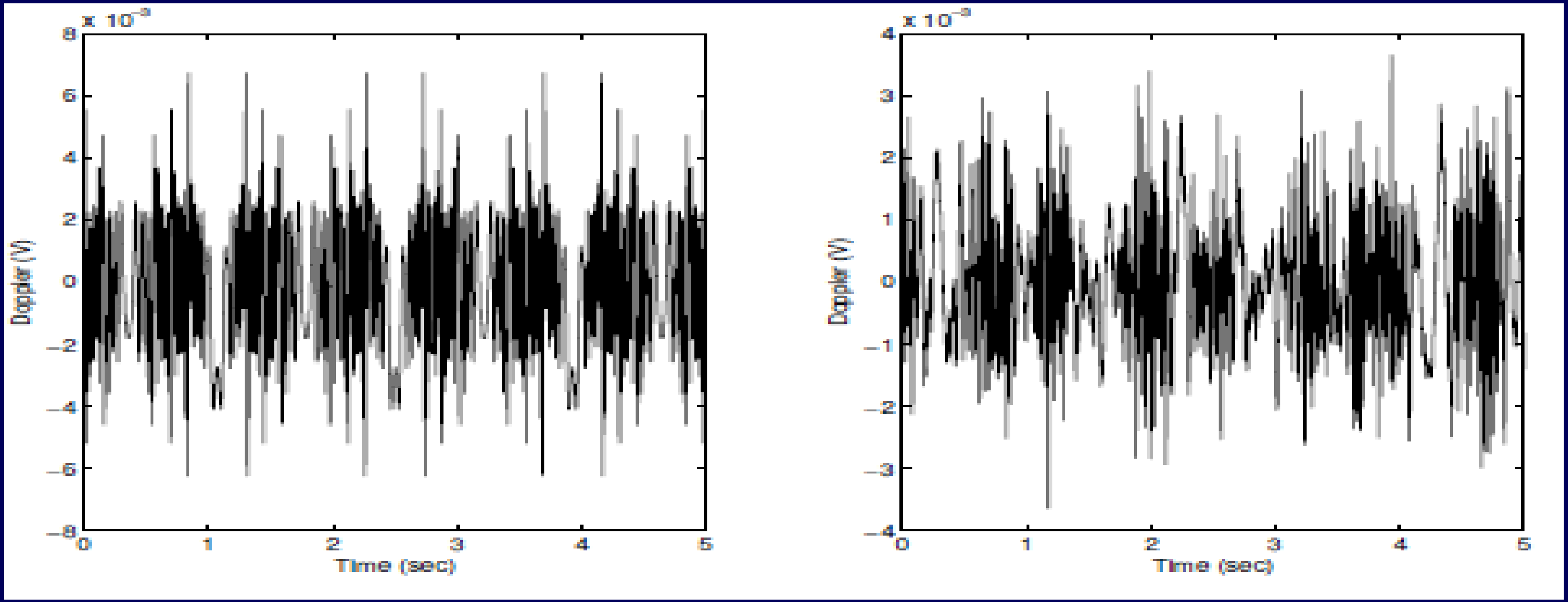


Experiment

Data collected by W-band radar at 50 feet range

Human was seated to minimize other involuntary movements

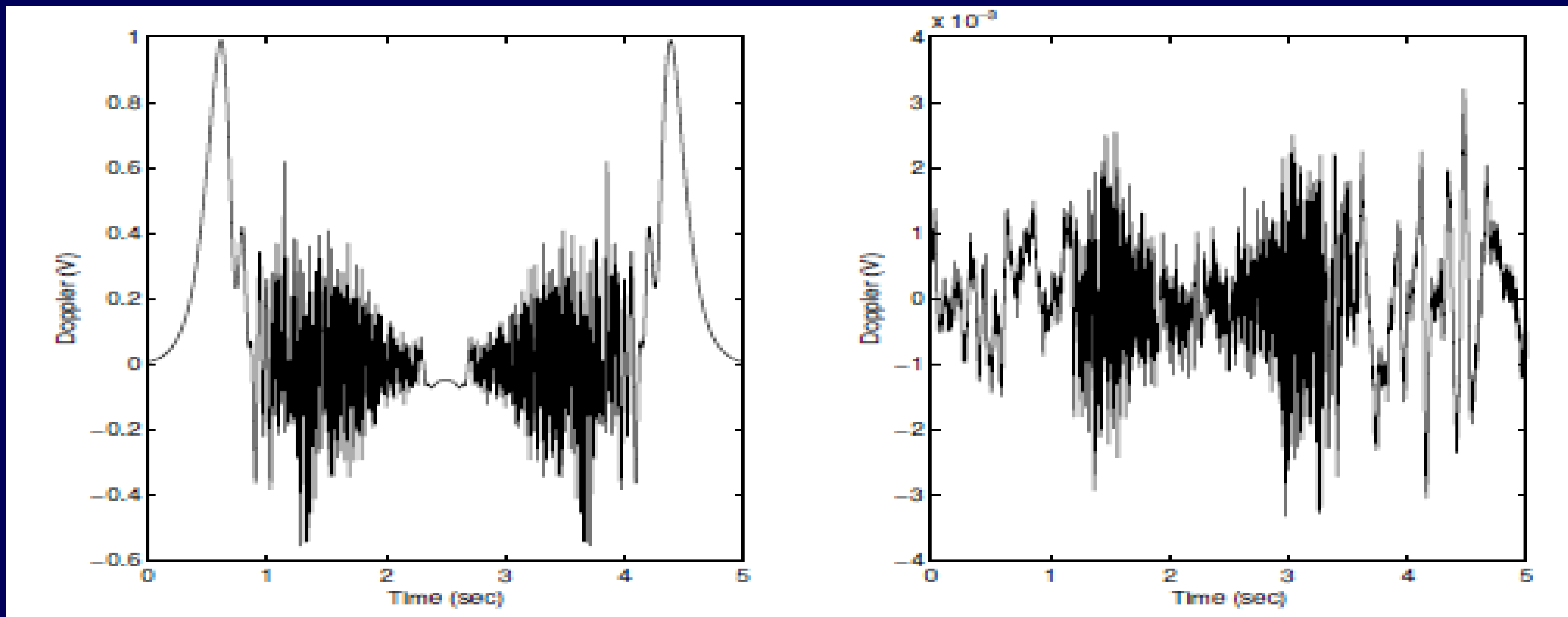
Swinging Arms



Simulation Experiment

Data collected by W-band radar at 100 feet range

Picking Up Object from Ground

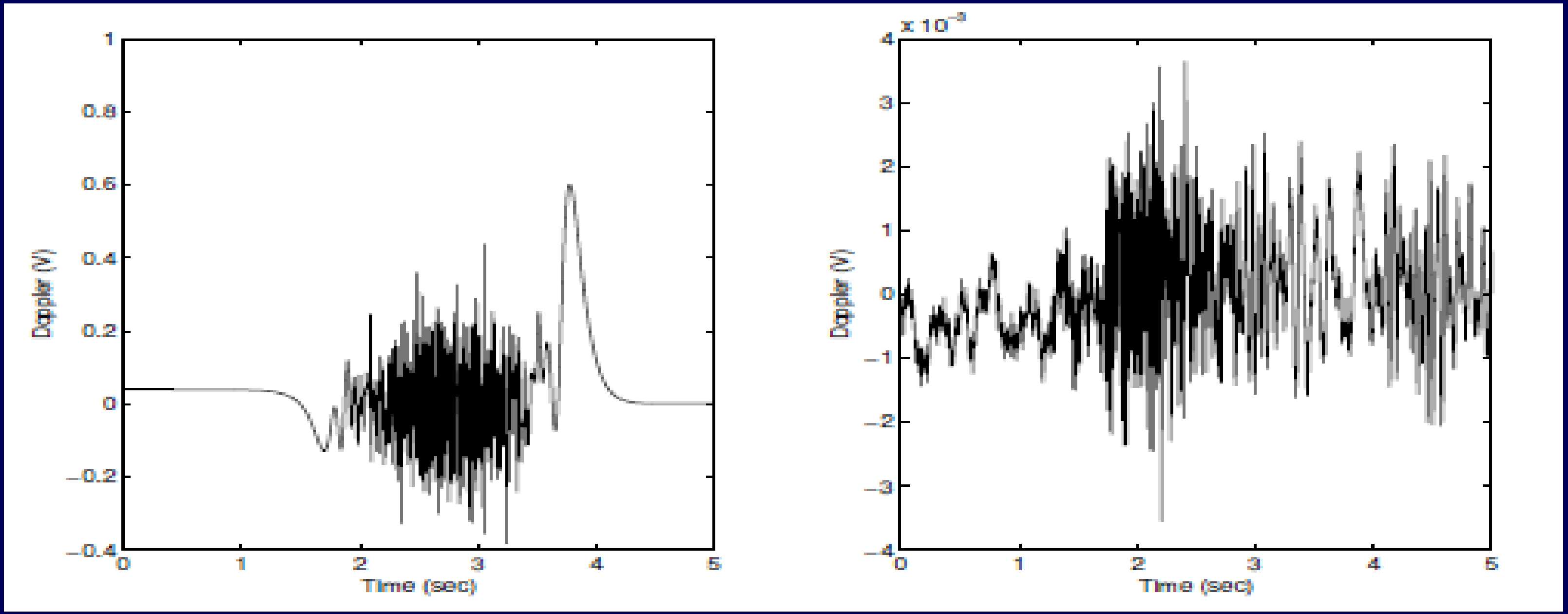


Simulation

Experiment

Data collected by W-band radar at 100 feet range

Crouching to Standing



Simulation

Experiment

Data collected by W-band radar at 100 feet range

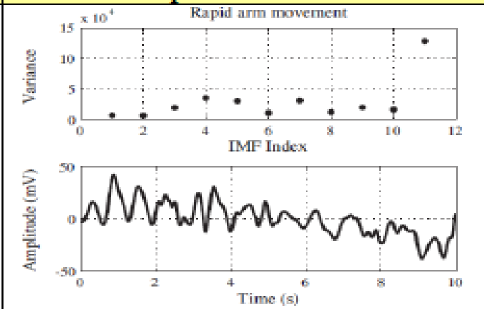
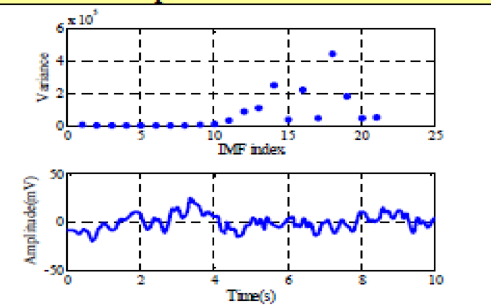
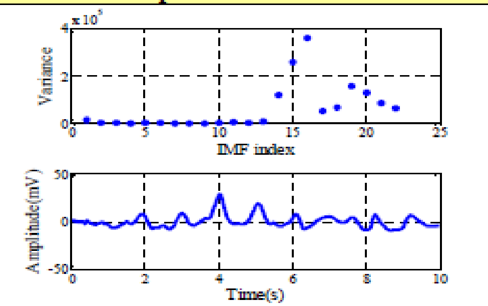
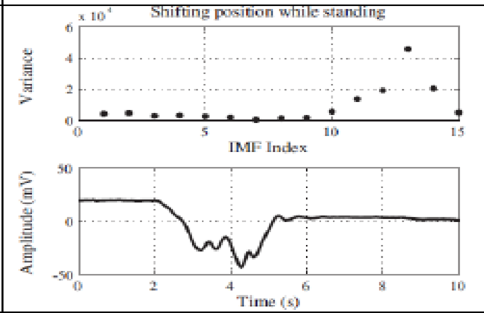
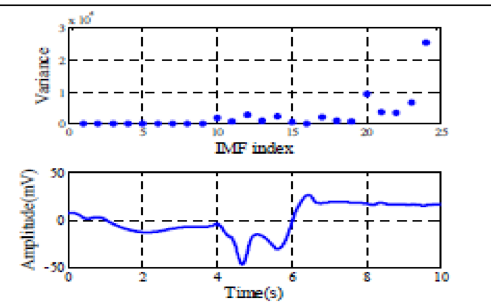
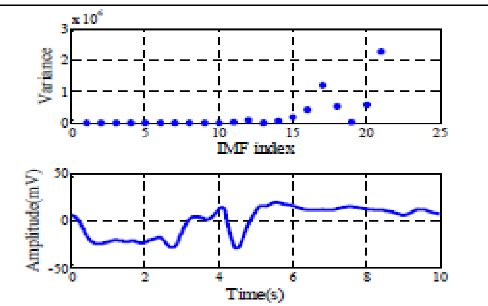
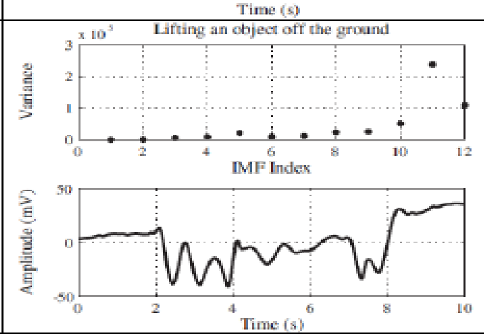
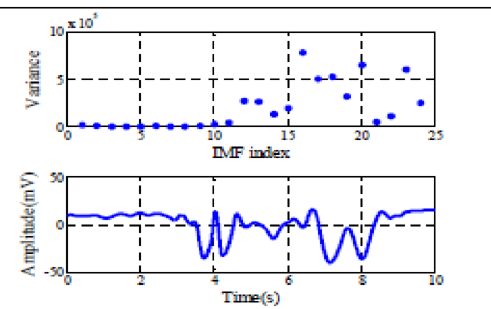
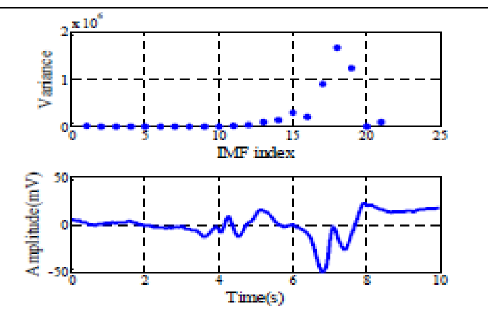
Through Barrier Experiment

Experiment Setup

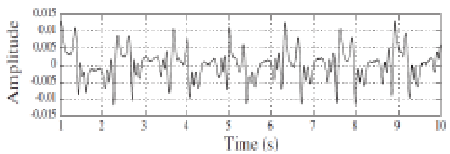
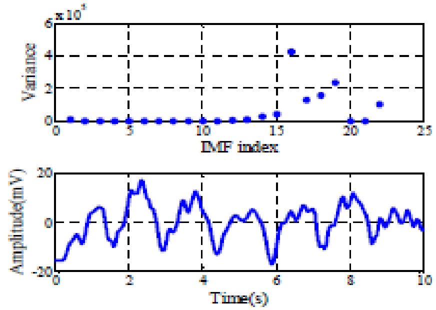
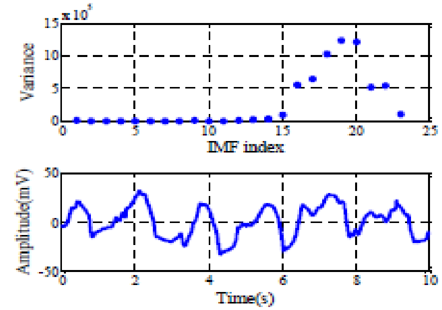
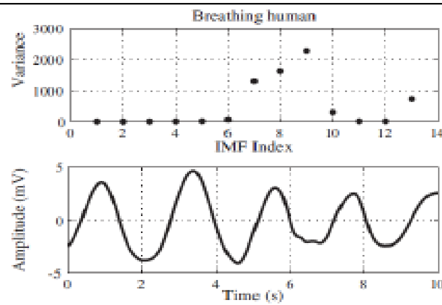
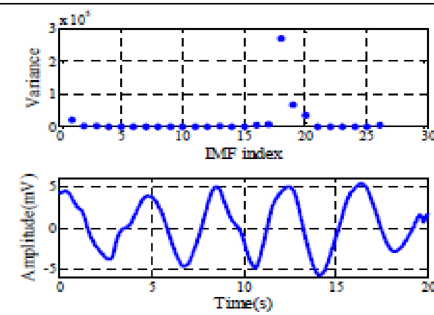
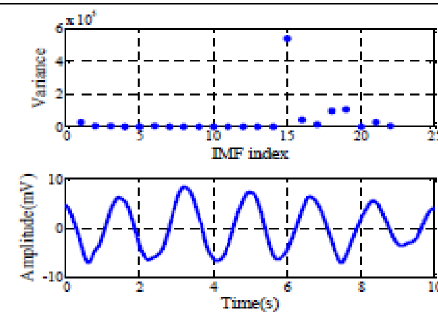
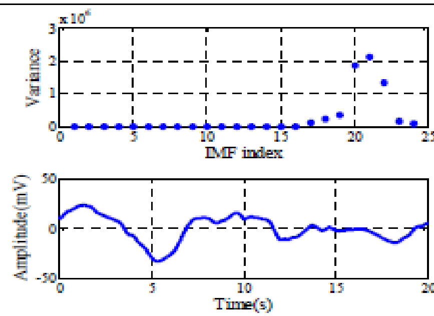
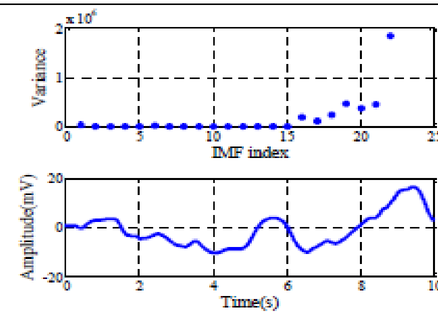
Breathing with Heavy Load

Data collected by UHF radar at 30 feet range

Summary of UHF Radar Data - 1

Micro-Doppler detection of human activities at a distance			
Activity	Close to the radar (PIER paper) Tx power = 0 dBm	5 m stand off from the shed Tx power = +20 dBm	9 m stand off from the shed Tx power = +20 dBm
Moving arms repeatedly in an up-and-down movement in a rapid manner			
Human shifting position			
Human lifting a large object off the ground over a duration of about 7 second			

Summary of UHF Radar Data - 2

Activity	Close to the radar (PIER paper) Tx power = 0 dBm	5 m stand off from the shed Tx power = +20 dBm	9 m stand off from the shed Tx power = +20 dBm
Arm waving			
Breathing			
Breathing (heavy loaded)			

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Activity Classification

- 5 movements are considered:
  - Background (no person present)
  - Breathing
  - Swinging arms
  - Picking up an object
  - Standing up from a crouching position
- For classification to be feasible, each type of movement must produce a unique feature vector

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EMD and SVM Analysis Method

- Empirical Mode Decomposition (EMD) followed by Hilbert Transform Analysis is used to extract Intrinsic Mode Functions (IMFs) from micro-Doppler data of various human activities
- Relevant IMF features are used in human activity classification algorithm via a Support Vector Machine (SVM) using a one-against-all (1-a-a) approach

Human Activity Classification: S-Band Radar

	Subject #1		Subject #2		Subject #3		Subject #4	
	Cross-Validation Set	Test Set	Cross-Validation Set	Test Set	Cross-Validation Set	Test Set	Cross-Validation Set	Test Set
Min Accuracy (%)	80.00	72.00	83.33	64.00	86.67	66.00	76.67	66.00
Max Accuracy (%)	96.67	92.00	93.33	76.00	96.67	82.00	93.33	80.00
Avg. Accuracy (%)	87.33	85.00	90.00	71.80	92.33	74.40	89.00	73.80
Standard Deviation	6.2460	5.4365	3.1427	4.1580	3.1623	4.9710	4.7271	7.7563

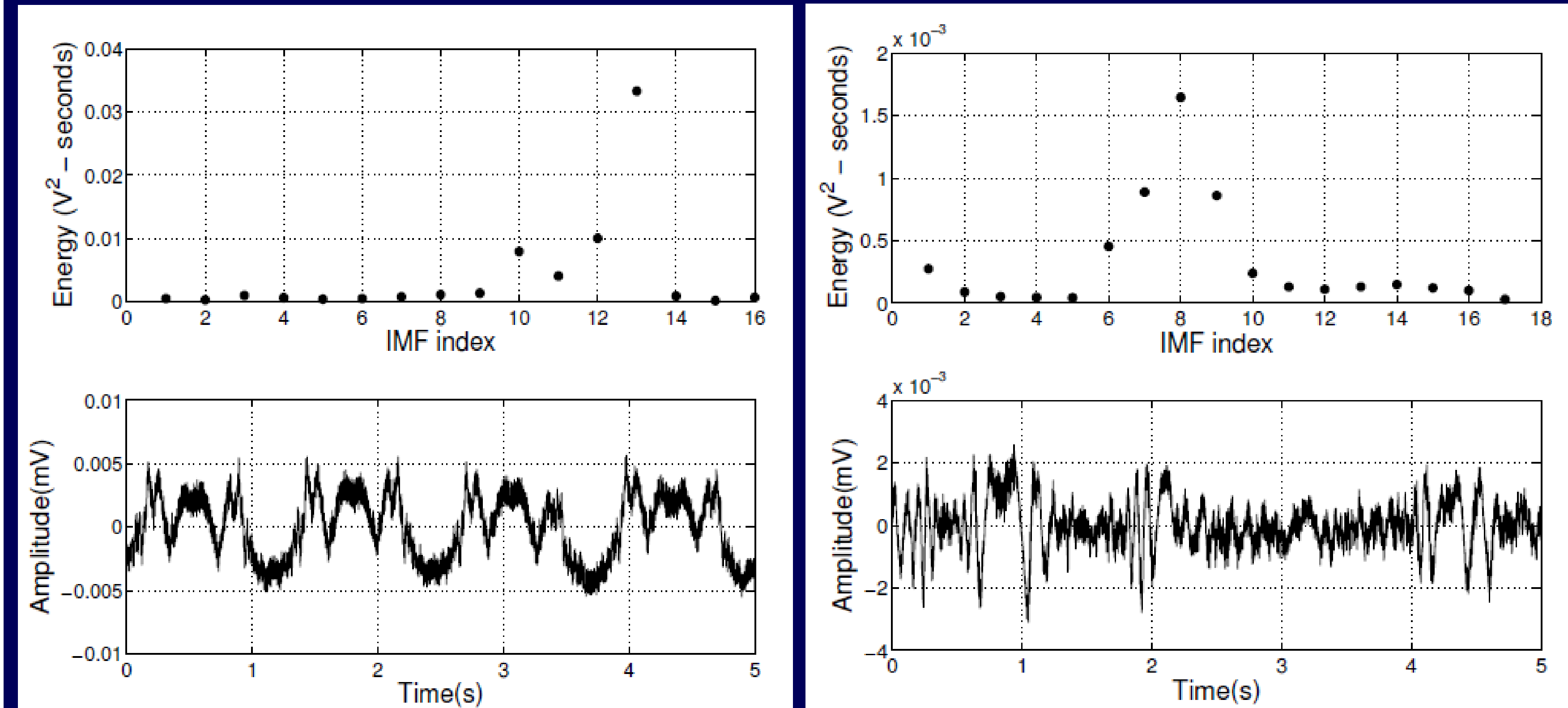
- Through-wall radar
  - Test subjects located about 10 feet from radar
  - Subjects were behind a 4 inch thick cinderblock wall
- 10 Trials were averaged for each test subject
- Average classification accuracy:
  - Cross-Validation Set = 89.67%
  - Test Set = 76.25%

Human Activity Classification – W-band Radar

	Subject #1		Subject #2		Subject #3		Subject #4	
	Cross-Validation Set	Test Set	Cross-Validation Set	Test Set	Cross-Validation Set	Test Set	Cross-Validation Set	Test Set
Min Accuracy (%)	86.67	62.00	83.33	78.00	86.67	72.00	83.33	82.00
Max Accuracy (%)	100.00	76.00	96.67	92.00	96.67	86.00	96.67	94.00
Avg. Accuracy (%)	94.33	68.00	88.33	85.60	91.00	77.00	88.33	88.20
Standard Deviation	4.4583	4.2164	4.2310	5.1467	3.8650	5.4365	4.5134	3.9384

- Subjects located 100 feet from radar.
- Avg. Accuracy:
  - Cross-Validation Set = 90.5%
  - Test Set = 79.7%
- Dependant on the person performing the movements
- Lower accuracy for #1 suggests motions performed differently than others

Comparison of S-Band and W-Band Radars



Swinging arms

S-Band

W-Band

Finer details can be seen in W-Band data

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Future Work

- Improve classification accuracy
  - Select additional features from EMD
- Test accuracy of W-band radar for penetration of light foliage
- Test accuracy of W-band radar for longer distances than 100 feet
- Test accuracy of S-band radar for other wall materials and thicknesses

Conclusions

- Reliable simulation of human motions using simple models has been accomplished
- EMD is a reliable option of obtaining feature vectors for classification
- Classification of human movements is feasible with our proposed procedure
  - Both through-wall and longer distance applications
- Classification accuracy is typically ~80%
  - Frequently as high as 90%
- Can obtain Doppler signatures from human targets at ranges up to 275 feet with the W-band radar

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Questions?

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