Multi-modal Standoff Through-the-Wall Imaging Radar and Personnel Location System using Biometric and Gait Responses

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OUTLINE

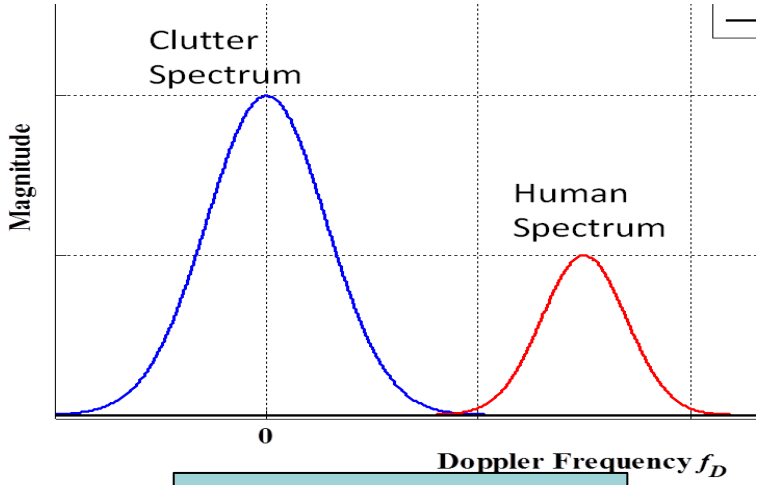
- Introduction
  - Background and motivation
- Theory of operation
  - Through-the-wall radar imaging
  - System design
  - Micro-Doppler responses for Biometric and gait exploitation
- Results
  - Experimental measurement campaign
  - Imaging examples
- Conclusions and next steps

BACKGROUND AND MOTIVATIONS

- **Applications**
  - **Military, law enforcement and security**
  - **Situational awareness**
  - **Disaster recovery and search-and-rescue**
- **Human detection poses serious technical challenges**
  - **Clutter objects such as walls have much higher RCS**
- **Exploit human specific signal features**
  - **Micro-Doppler, biometric, gait, etc.**

Situational awareness for security forces

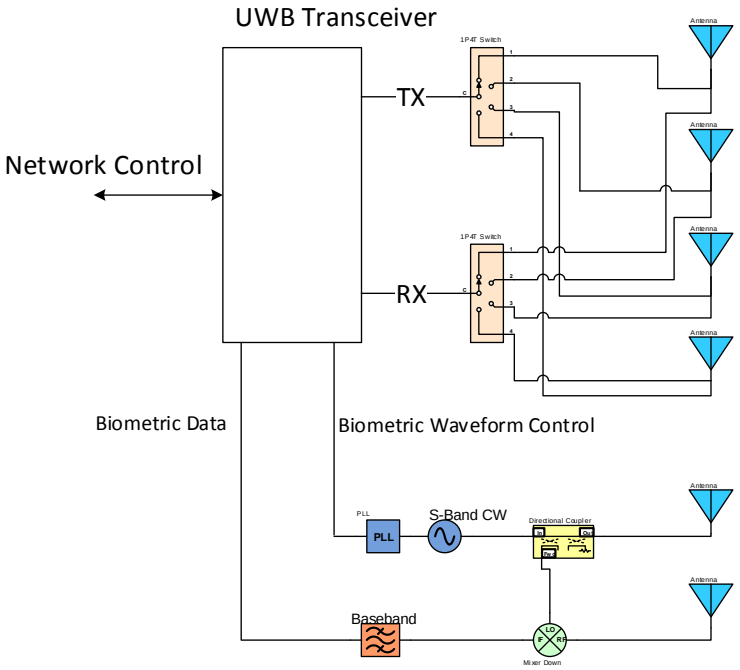
Disaster recovery



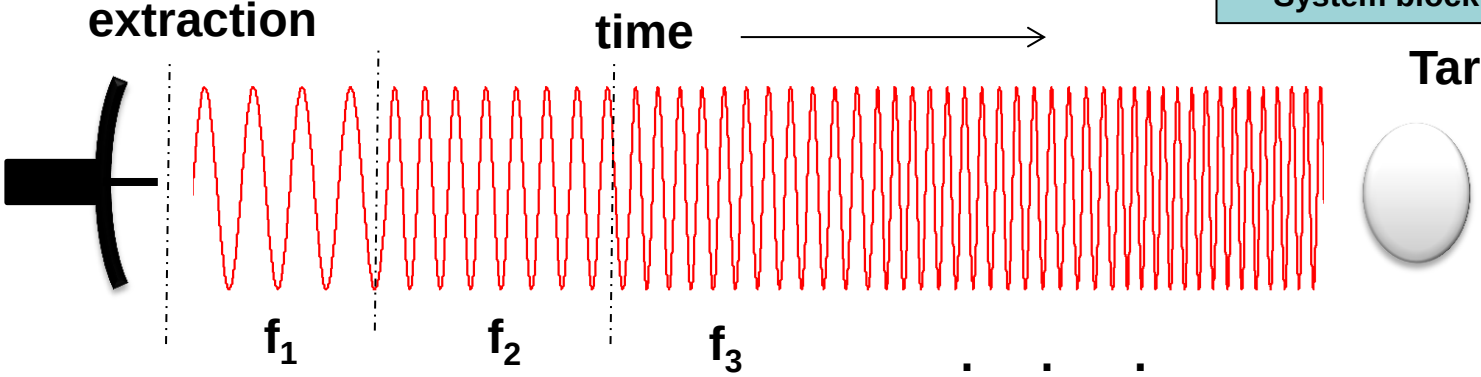
Clutter limited operations

SEE-THROUGH-THE-WALL SYSTEM SPECIFIC DETAILS

- See-through-the-wall (STTW) Radar Imaging System
  - 4 switched TX/RX ports
  - Expandable CW channels for Micro-Doppler
  - Low SWaP
  - Licensed operation in US
- Stepped- Frequency Modulated Continuous Wave (S-FMCW) Waveform
  - Spectral control allows for both range estimation and Micro-Doppler extraction



System block diagram



SFCW waveform example

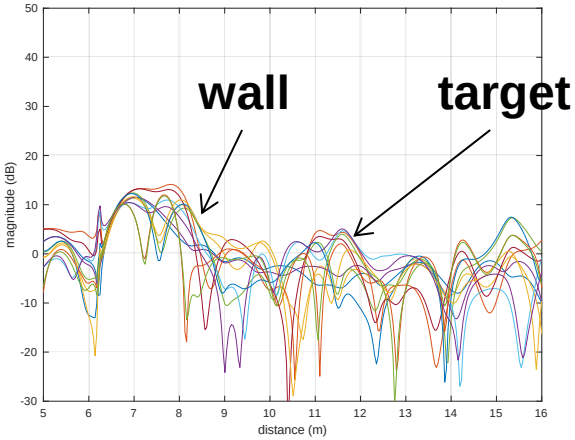
PROCESSING AND EXPLOITATION ALGORITHM BLOCK DIAGRAM

- **Exploit Micro-Doppler/biometric response**
- **Extraction via FIR filtering**

$$E_B(z) = \frac{b_o + b_1 z^{-1} + b_2 z^{-2} + \cdots}{1}$$

$$E[k,m] = E[k,m] * E_B(z)$$

- **As target moves, significant blur & multi-path can arise**



Unfiltered range profile

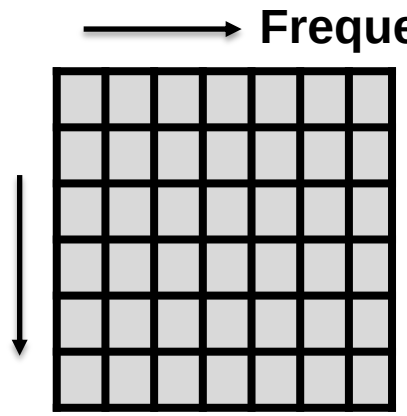
Data Acquisition

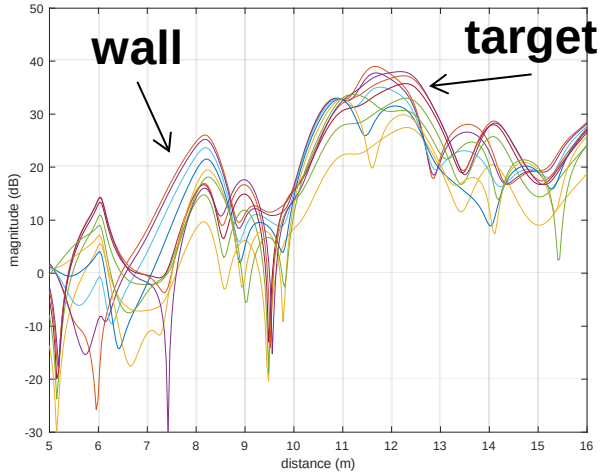
Micro-Doppler Extraction

Image Formation

Motion Estimation

Target Focusing





Raw extracted response

FOCUSING AND MOTION CORRECTION

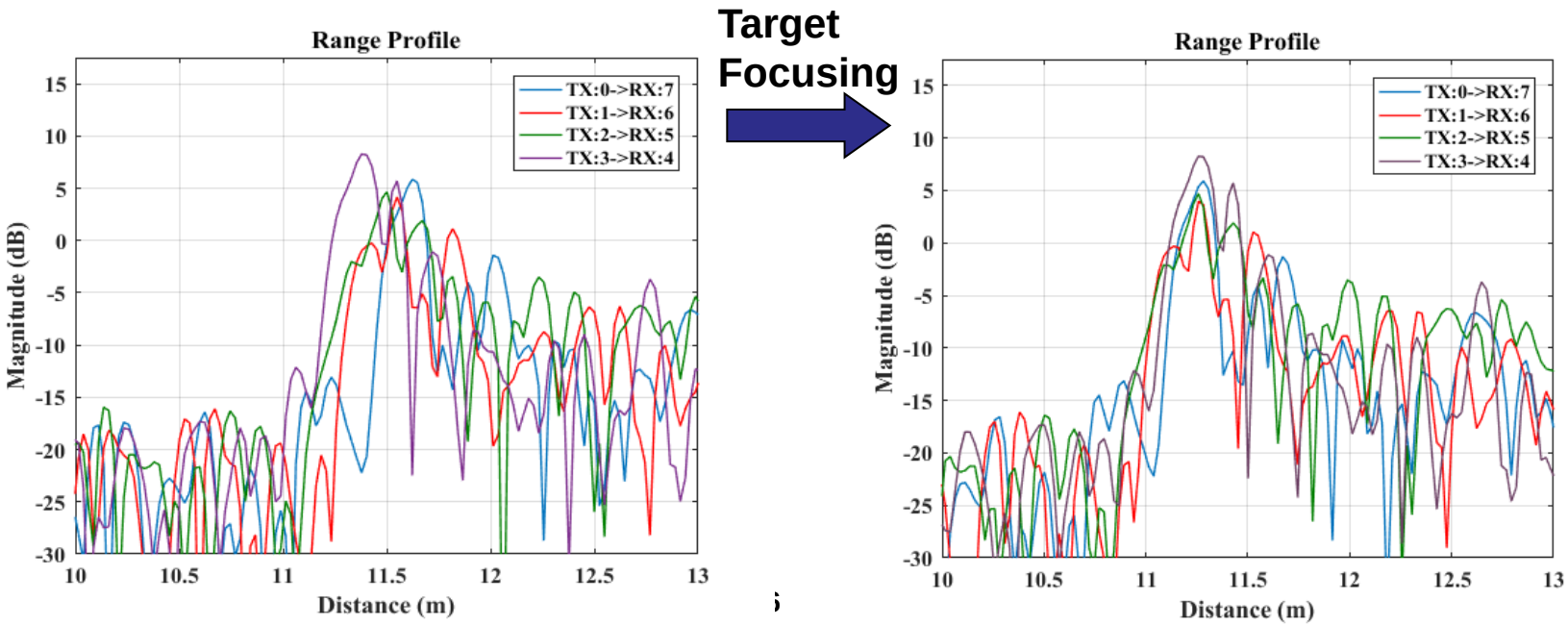
- **Compensate for blurring effects, an estimate of targets motion is required**

$$\hat{S}(x,y;m+1) = \hat{S}(x-d_x, y-d_y; m)$$

- **Correlation measure smooth coherent transform (SCOT) to determine displacement**

$$[\hat{d}_x,\ \hat{d}_y] = \arg\max_{x,y}\ Q(x,y)$$

- **Track trajectory of target over the entire collection sequence**
- **Use the estimated position to focus target range-profiles to correct position**

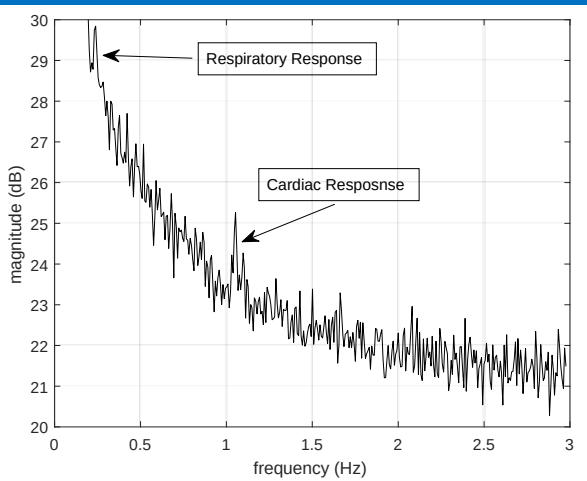


EXPERIMENTAL MEASUREMENT CAMPAIGN

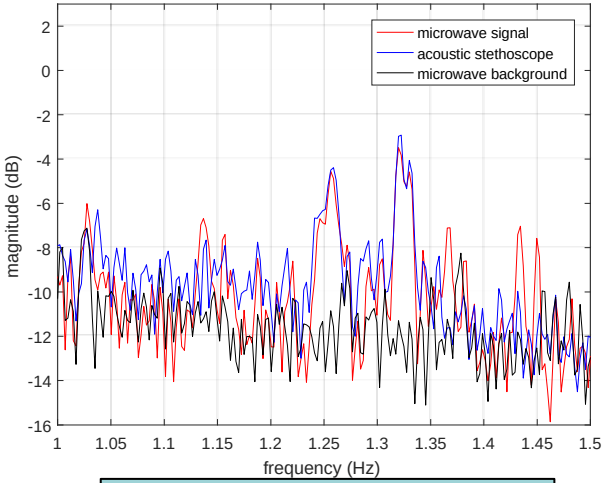
- **Extensive data set collected using portable STTW system at a realistic test and training facility**
  - **Determine detectability of moving personnel**
  - **Leverage extracted Micro-Doppler to improve reconstructed imagery**
  - **Assess system performance in realistic urban environments**
- **Multiple target configurations**
  - **Results focus on stationary and moving targets**
- **Data taken at US Indiana National Guard MUTC facility**
  - **Urban environment**

STTW MICRODOPPLER RESPONSES

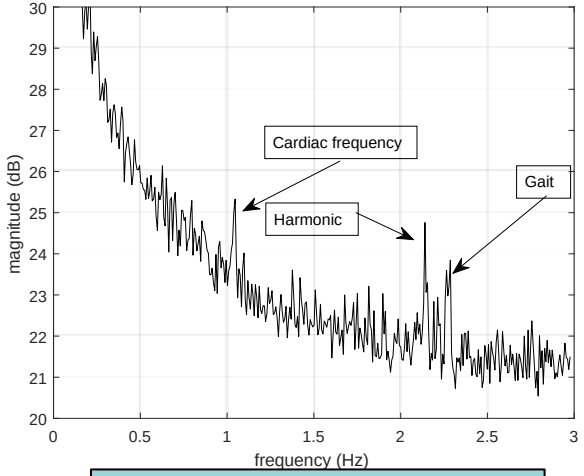
- Micro-Doppler responses from from receive SFCW data
  - Sampled in the collection, m direction
- Power spectrum estimated using short-time Fourier transform
  - Power spectrum estimated using Welch's Method
- Discrete spectral components correspond to respiratory, cardiac and main gait response



Stationary response



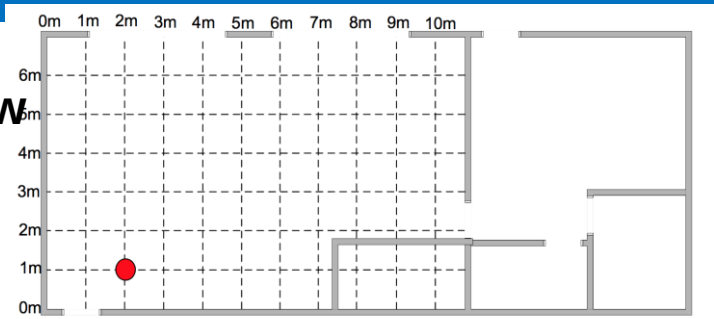
Laboratory measurement of cardiac response



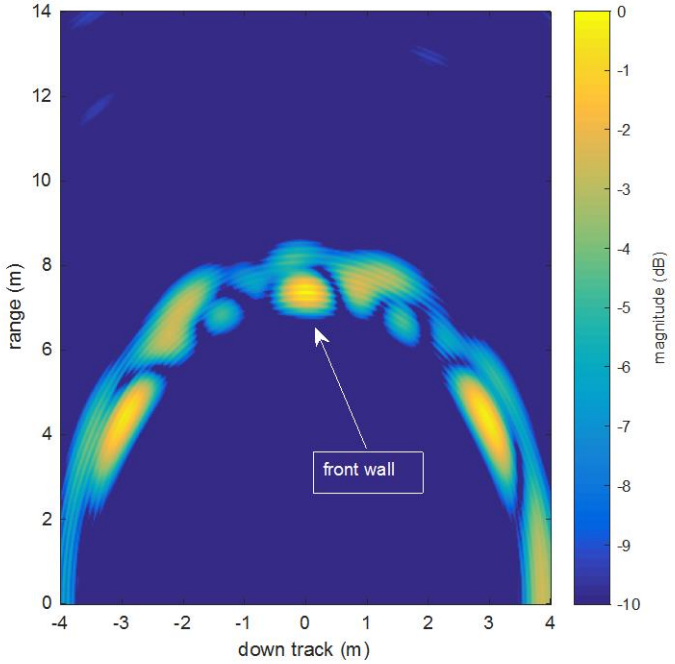
Walking response

FOUR ELEMENT ARRAY RESULTS
STATIONARY TARGET

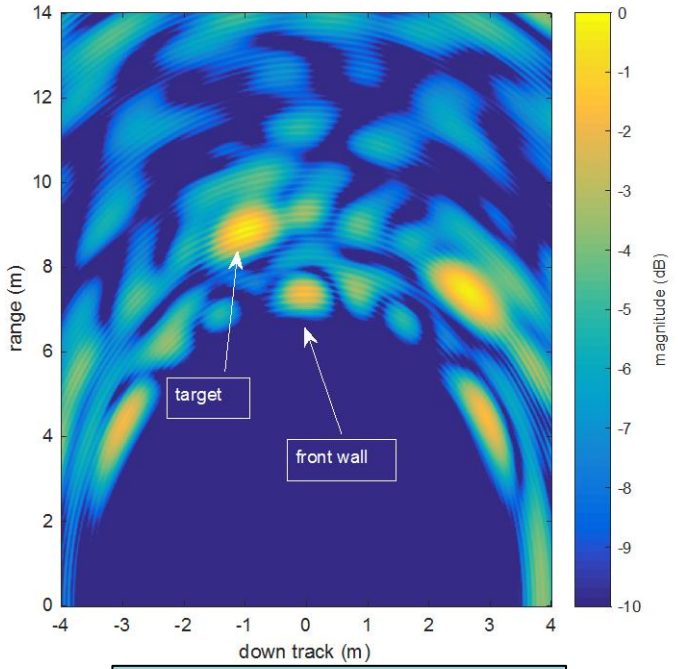
- 20cm thick concrete reinforced wall
- Using extracted Micro-Doppler response raw scattering data can be filtered to enhance frequencies of interest
  - Standing target
- Target not directly visible in raw imagery



Target ground truth



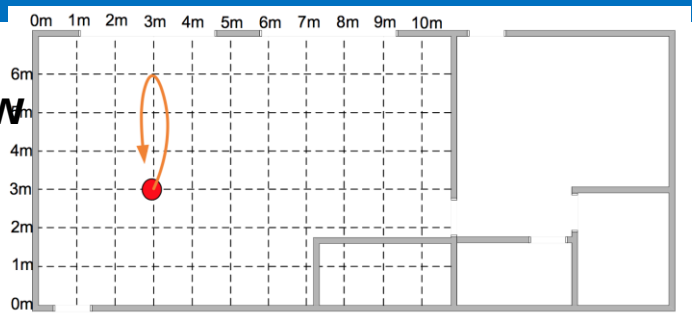
Unenhanced imagery



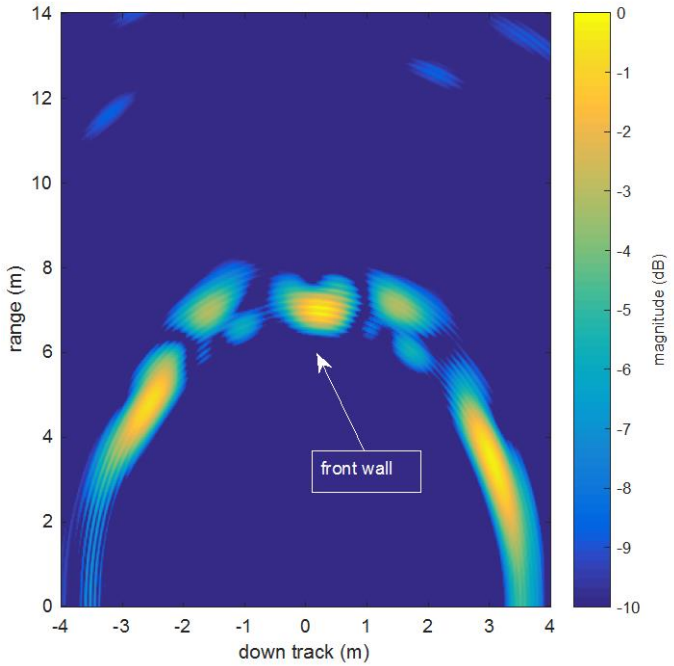
Filtered response

FOUR ELEMENT ARRAY RESULTS
MOVING TARGET (RANGE)

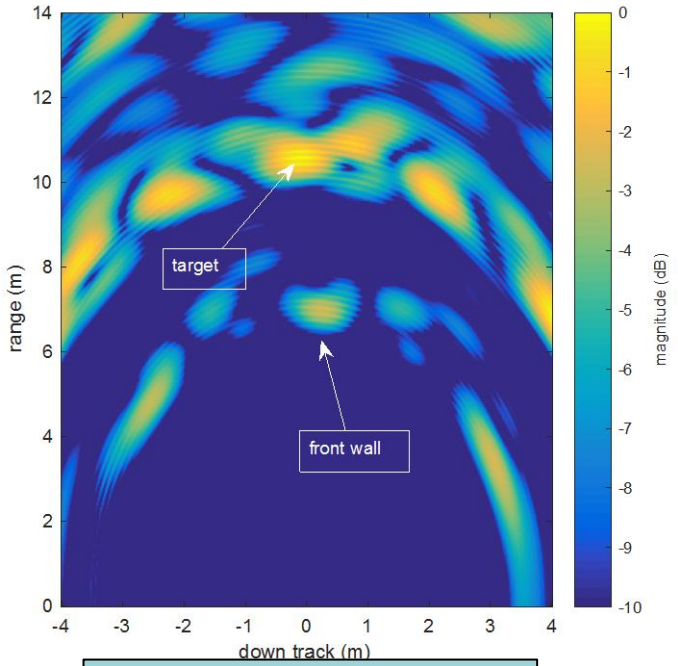
- 20cm thick concrete reinforced wall
- Using extracted Micro-Doppler response raw scattering data can be filtered to enhance frequencies of interest
  - Target moving in range
- Limited aperture sets system performance



Target ground truth



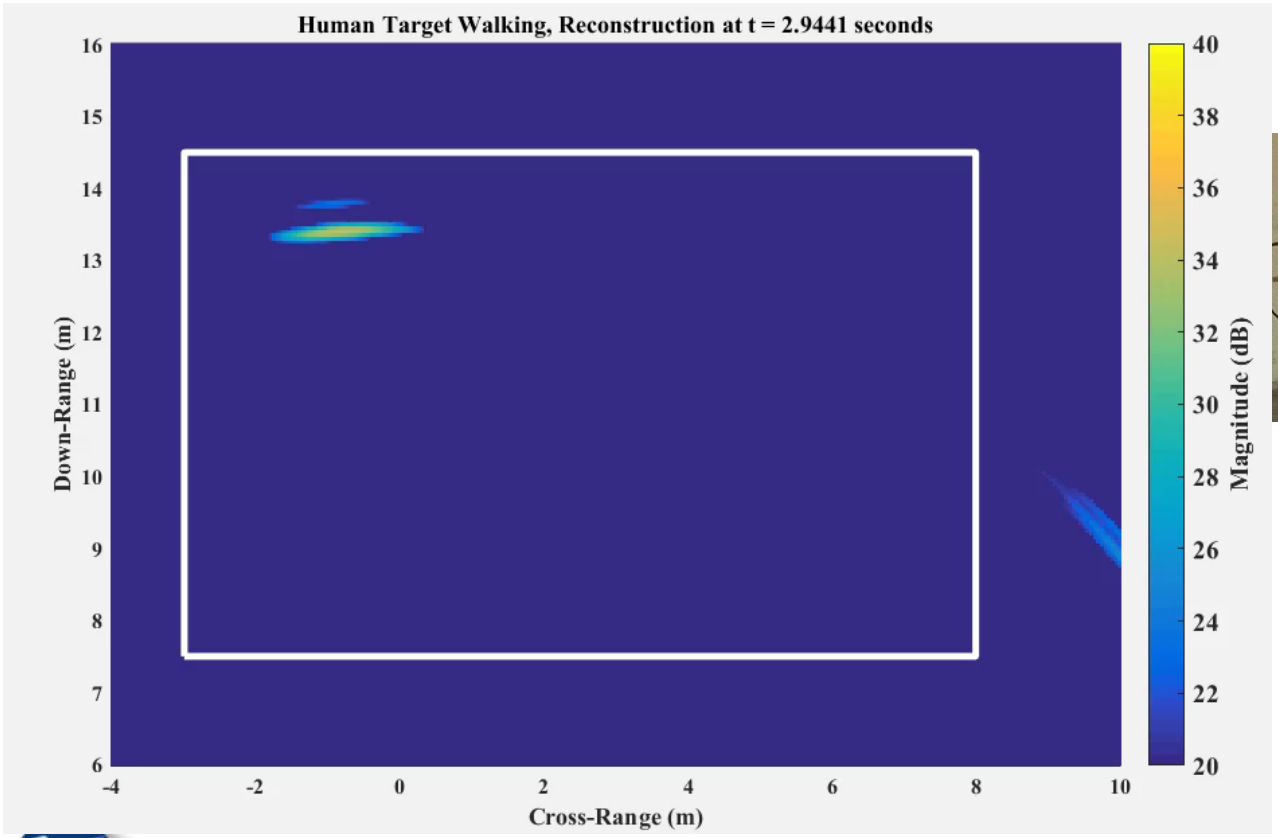
Unenhanced imagery

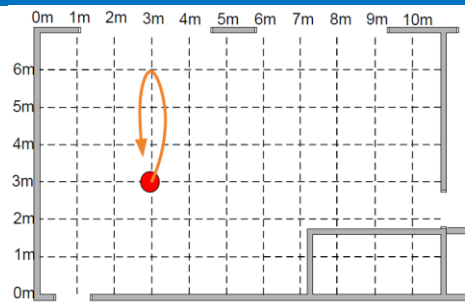


Filtered response

EIGHT ELEMENT ARRAY RESULTS
MOVING TARGET (RANGE)

- 20cm thick concrete reinforced wall
- Aperture doubled
  - Significant improvement in target localization
  - Same Micro-Doppler/gait enhancement



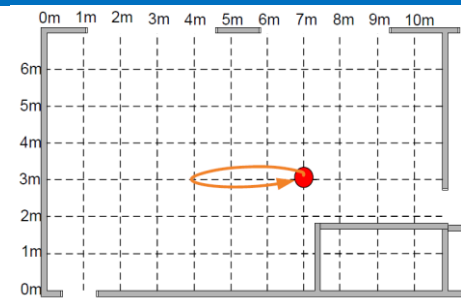


Target ground truth

Eight element system

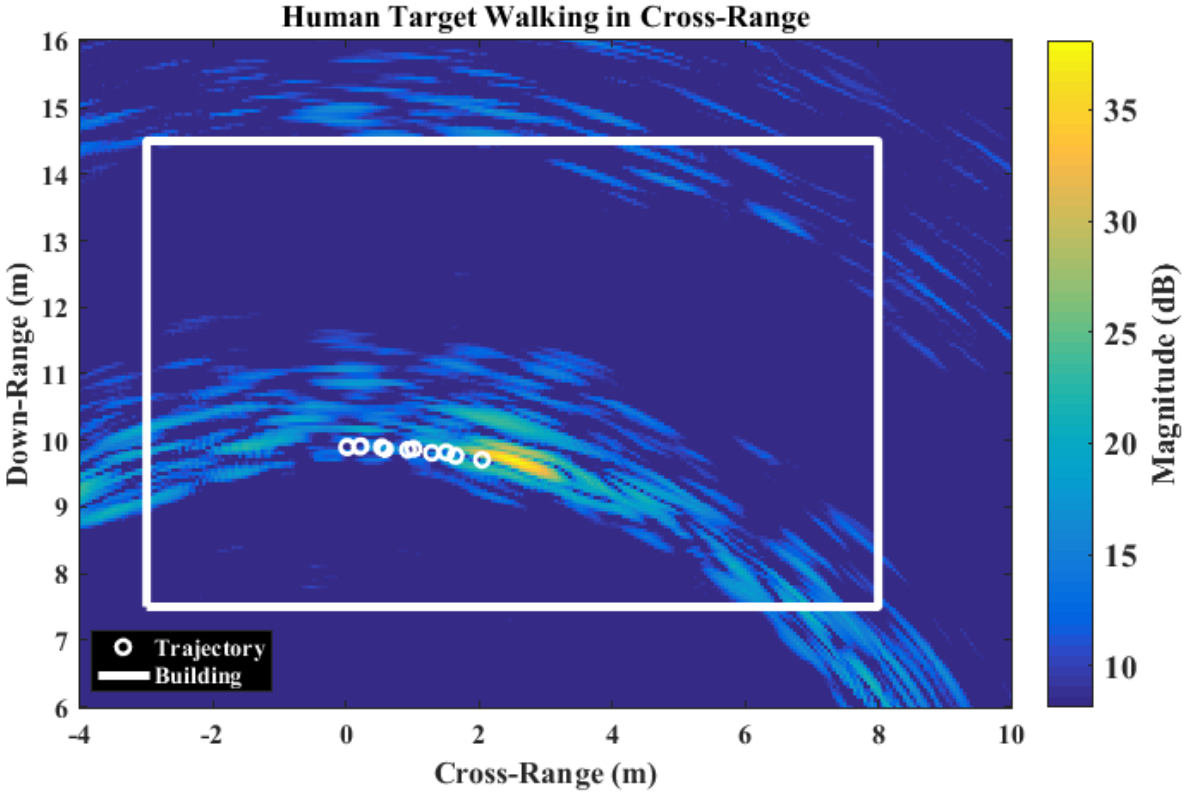
EIGHT ELEMENT ARRAY RESULTS
MOVING TARGET (CROSS RANGE)

- 20cm thick concrete reinforced wall
- Increased aperture allows localization in cross range
  - Grating lobes sill present
  - Focusing mitigates their effect



Target ground truth

Eight element system



CONCLUSIONS AND NEXT STEPS

- This talk has has shown an algorithmic framework for processing and set of results from a man portable STTW imaging system
  - Data collected in realistic environment
  - Micro-Doppler enhancement aids in detection

- Focusing and target motion exploitation allows for significant clutter mitigation
  - Naïve technique presented
  - More sophisticated Micro-Doppler exploitation techniques can be used in practice

- Aperture still significant driving factor in system performance
  - Tradeoff between system SWaP and desired performance
  - Man portable adds constraints

- Currently investigating non-coherent combination of multiple separate apertures
  - Allows significant increase in array size without added LO distribution complexity

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