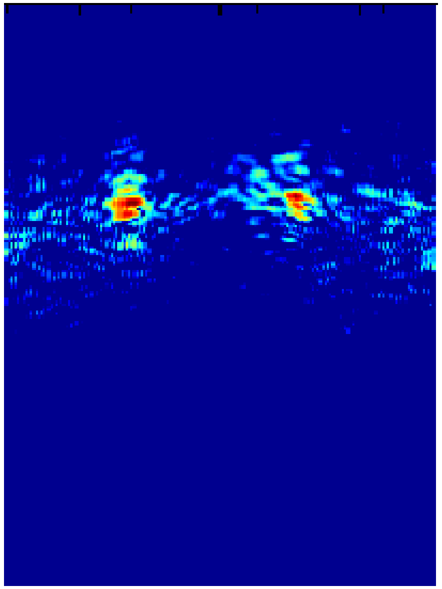
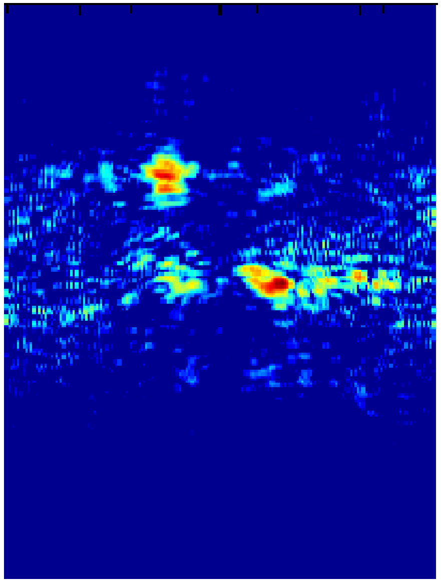
Real-Time Through-Wall Imaging
Using an Ultrawideband Multiple-Input Multiple-Output (MIMO) Phased-Array Radar System





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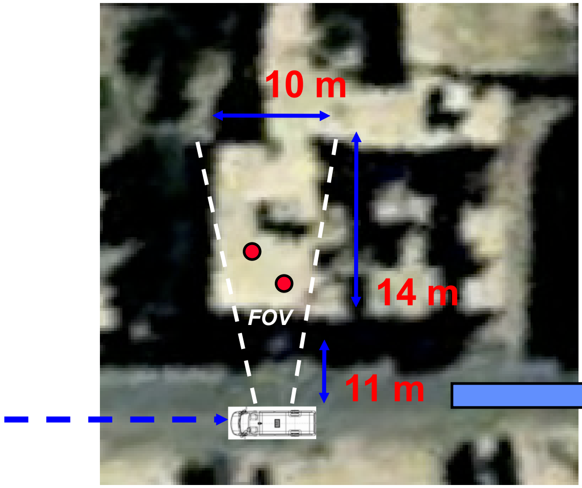
Opinions, interpretations, conclusions, and recommendations are those of the authors and are not necessarily endorsed by the United States Government.

Through-Wall Radar Imaging

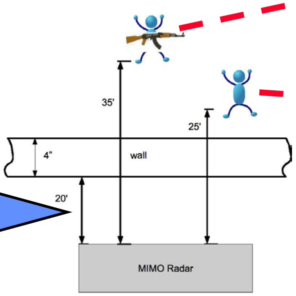
Locating moving objects through walls increases situational awareness

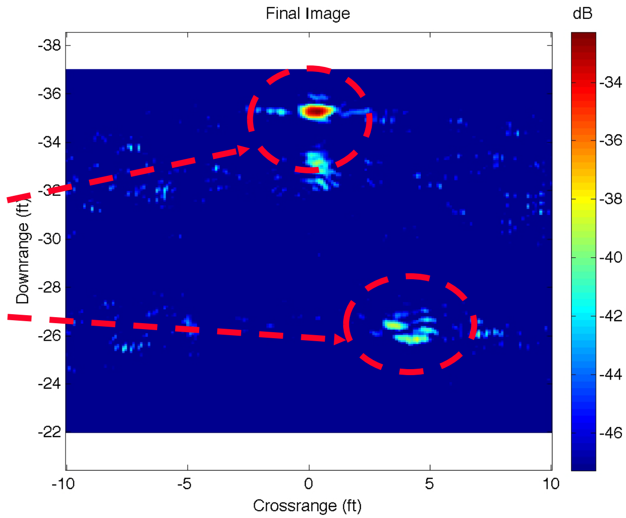
TDM MIMO Through-Wall Radar

- Stand alone sensor
- Continuous surveillance
- Video frame-rate imaging
- High resolution, S-band (2-4 GHz)
- Real aperture (no ambiguous returns due to sparse aperture)
- Reasonable size, fits on truck
- Range gate and coherent change detection mitigates clutter



(Humans inside house)





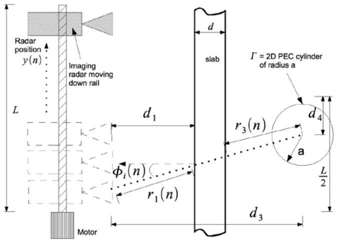
1. Radar vehicle deployed for search mission

2. Operator starts radar

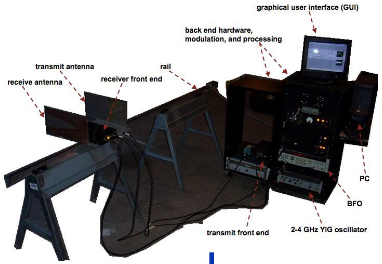
3. Human locations in house shown on screen continuously

Background

Modeling & Architecture [1,4]



Rail SAR [1,4]



Early Switched Array Prototype (0.5 Hz imager) [1,3,5]

TDM MIMO Real-Time Through-Wall Radar System

Time Line

Real-Time Inverse Synthetic Aperture Microscopy (ISAM) [2]

[1] G. L. Charvat, ``A Low-Power Radar Imaging System," Ph.D. dissertation, Department of Electrical and Computer Engineering, Michigan State University, East Lansing, MI, August 2007.

[2] T. S. Ralston, D. L. Marks, P. S. Carney, S. A. Boppart, ``Real-time interferometric synthetic aperture microscopy." *Optics Express,* vol. 16, no. 4, February 2008.

[3] G. L. Charvat, L. C. Kempel, E. J. Rothwell, C. Coleman. "A low-power, real-time, S-band radar imaging system" Boston, MA: Antennas Measurement Techniques Association conference, November 2008.

[4] G. L. Charvat, L. C. Kempel, E. J. Rothwell, C. Coleman, and E. L. Mokole, ``A through-dielectric radar imaging system," *IEEE Transactions on Antennas and Propagation,* vol. 58, Issue 9, pp. 2594-2603, August 2010.

[5] G. L. Charvat, L. C. Kempel, E. J. Rothwell, C. Coleman, and E. L. Mokole, ``An ultrawideband (UWB) switched-antenna-array radar imaging system," 2010 IEEE International Symposium on Phased Array Systems and Technology, 12-15 October 2010.

Challenges

Challenge	Approach
Increase image rate	Real-time SAR algorithm
	Data-acquisition pipeline
	1 ms UWB LFM waveform generation
Sensitivity	LNAs
	Transmit power
	Feedline efficiency
	Antenna efficiency
Image quality	High-isolation switches
	UWB antenna element
	Reduce mutual coupling
	Reduce back lobes

Technical Approach

Transmit elements (TX)

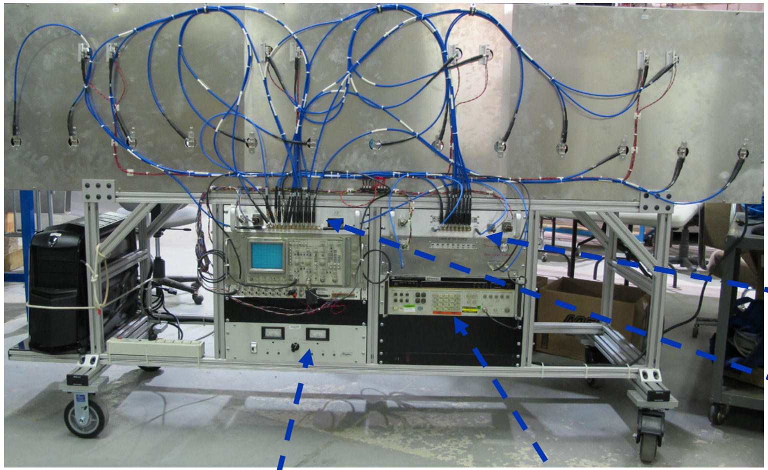
Receive elements (RX)

- Apply range-gated FMCW to TDM MIMO array
  – S-band, 2-4 GHz 1 ms LFM waveform
  – Separate transmitter and receiver
  – 8 receive and 13 transmit elements
  – TX ported to one element at a time
  – RX ported to one element at a time

Switches

TX

FMCW radar
with range-gate



Receiver
front-end

Transmitter
front-end

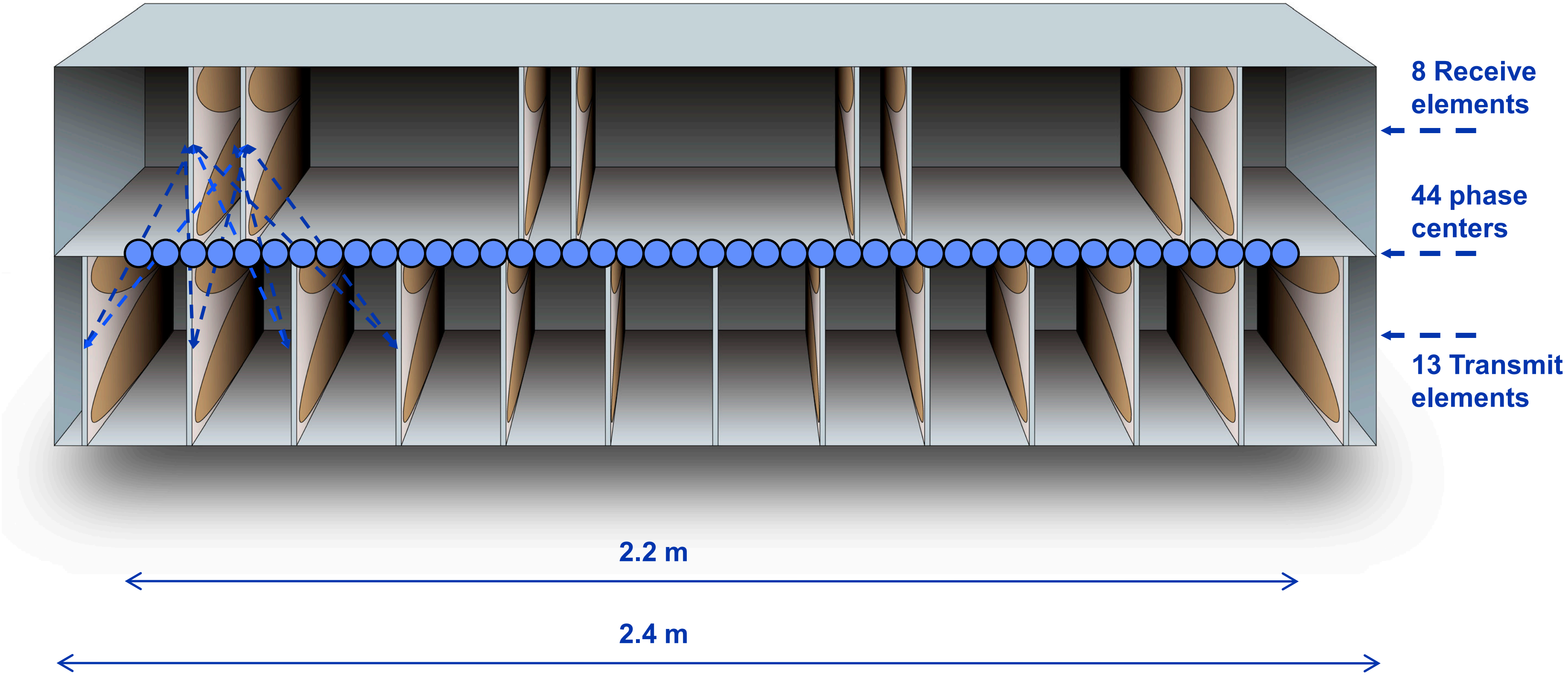
RX

Power supply

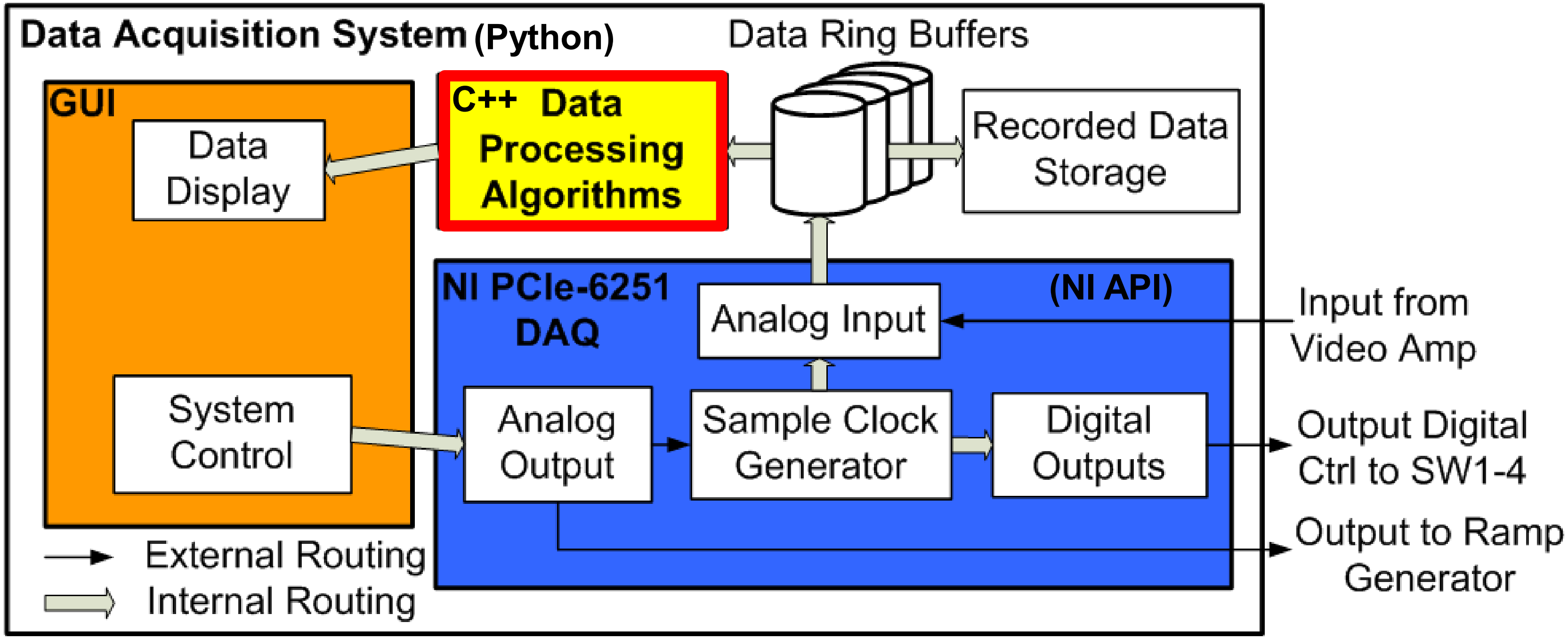
IF

TDM MIMO Bistatic Antenna Combinations

- **Apply range-gated FMCW to TDM MIMO array**
  - TX/RX to only one TX/RX element at any given time
  - 44 bi-static combinations of transmit + receive elements
  - Synthesizes 2.24 m long half-wave spaced linear phased array
  - Near-field solution



Data Acquisition System



- **Multithreaded Python controls**
  - **National Instruments data acquisition (DAQ) card**
  - **Data ring buffers and data storage**
  - **Software wrapper interface generator (SWIG) for C++**
  - **Graphical user interface (GUI)**

Real-Time Imaging Algorithm

- Range migration algorithm (RMA)

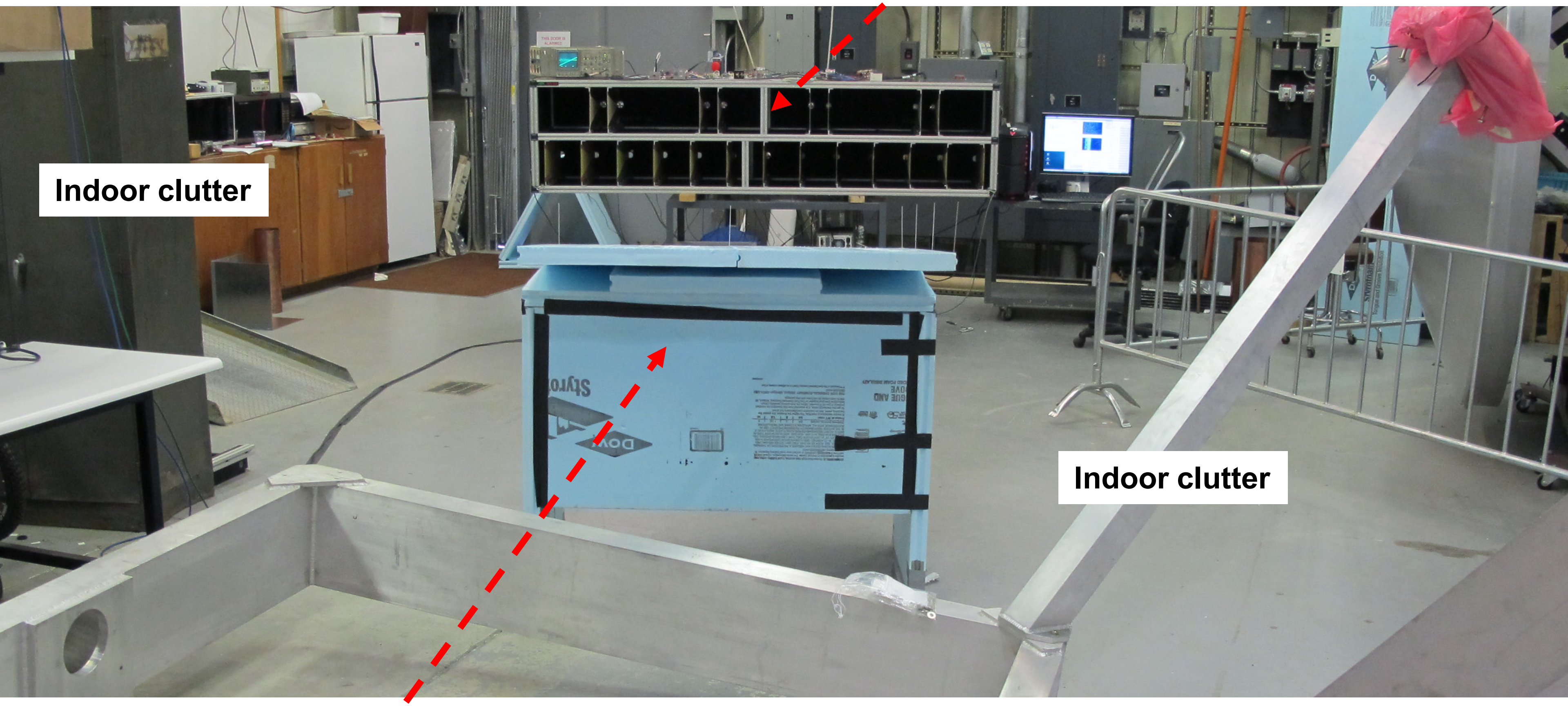
Background subtraction → Hilbert transform → Calibration matrix → Matched filter → Stolt transform

- Reducing latency in RMA
  - Provide direct memory access with minimal overhead copying
  - Call inline functions
  - Maintain high throughput by pre-allocating RAM
  - Utilize real-to-complex FFTs and hardware-accelerated routines

- Precompute values
  - Calibration matrix
  - Matched filter
  - Stolt transform resampling indices
  - Stolt transform interpolation tables

Free-Space Imagery Indoor Target Scene (high clutter environment)

Radar sensor



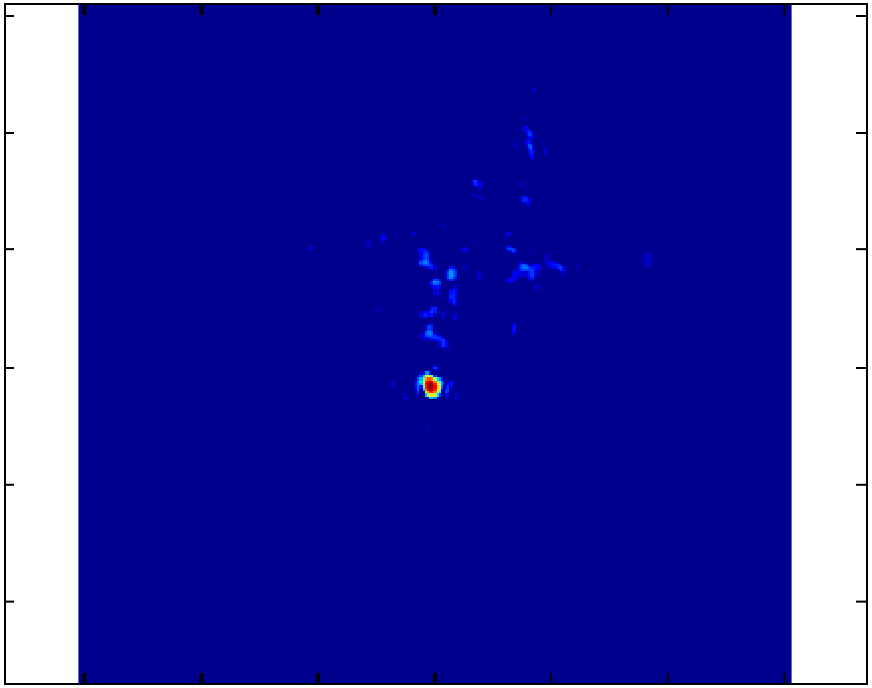
Indoor clutter

Indoor clutter

Targets placed on Styrofoam table

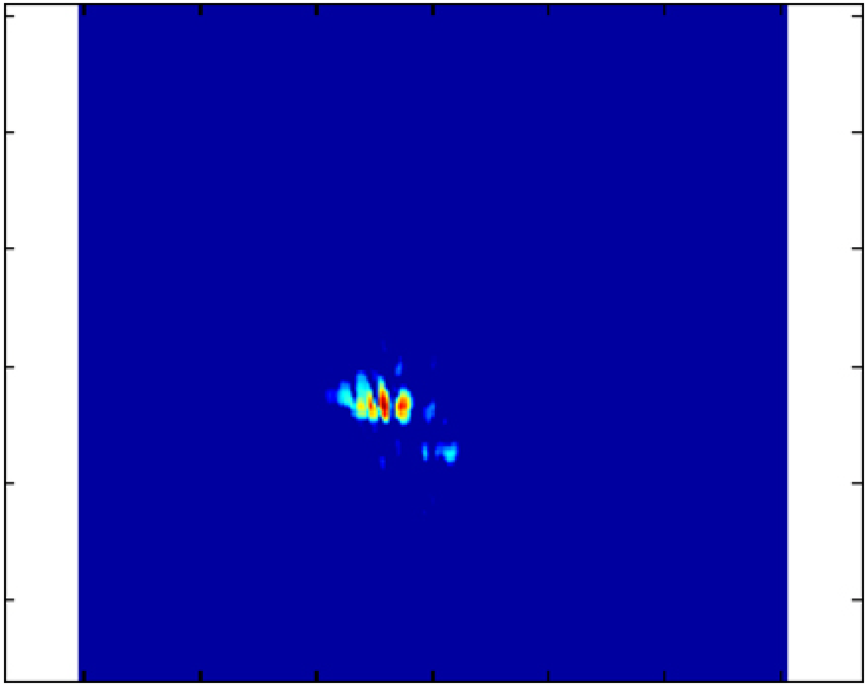
Measured Free-Space Data

Using coherent background subtraction



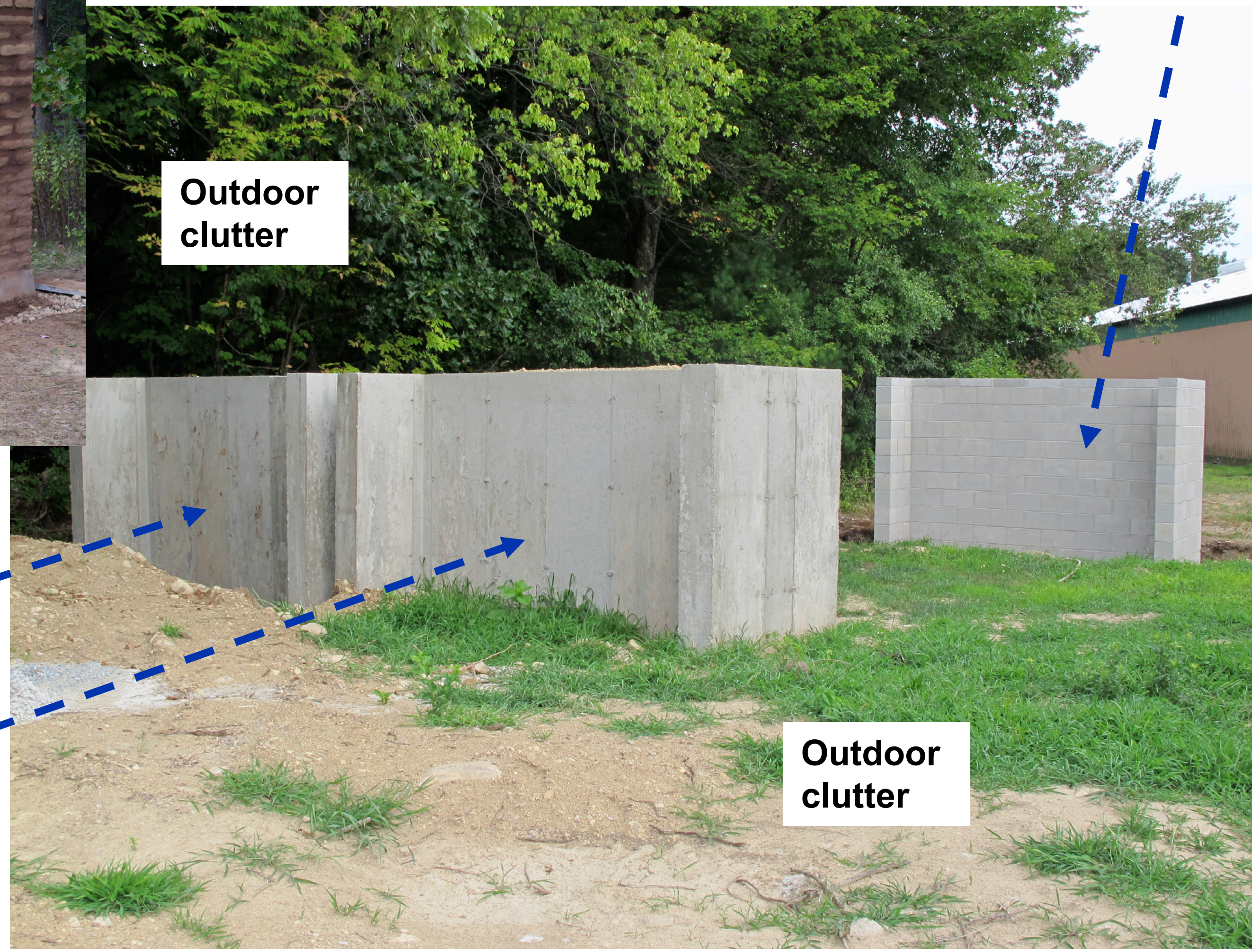
Human playing marbles with 1-inch diameter spheres

Using image-to-image coherent change detection



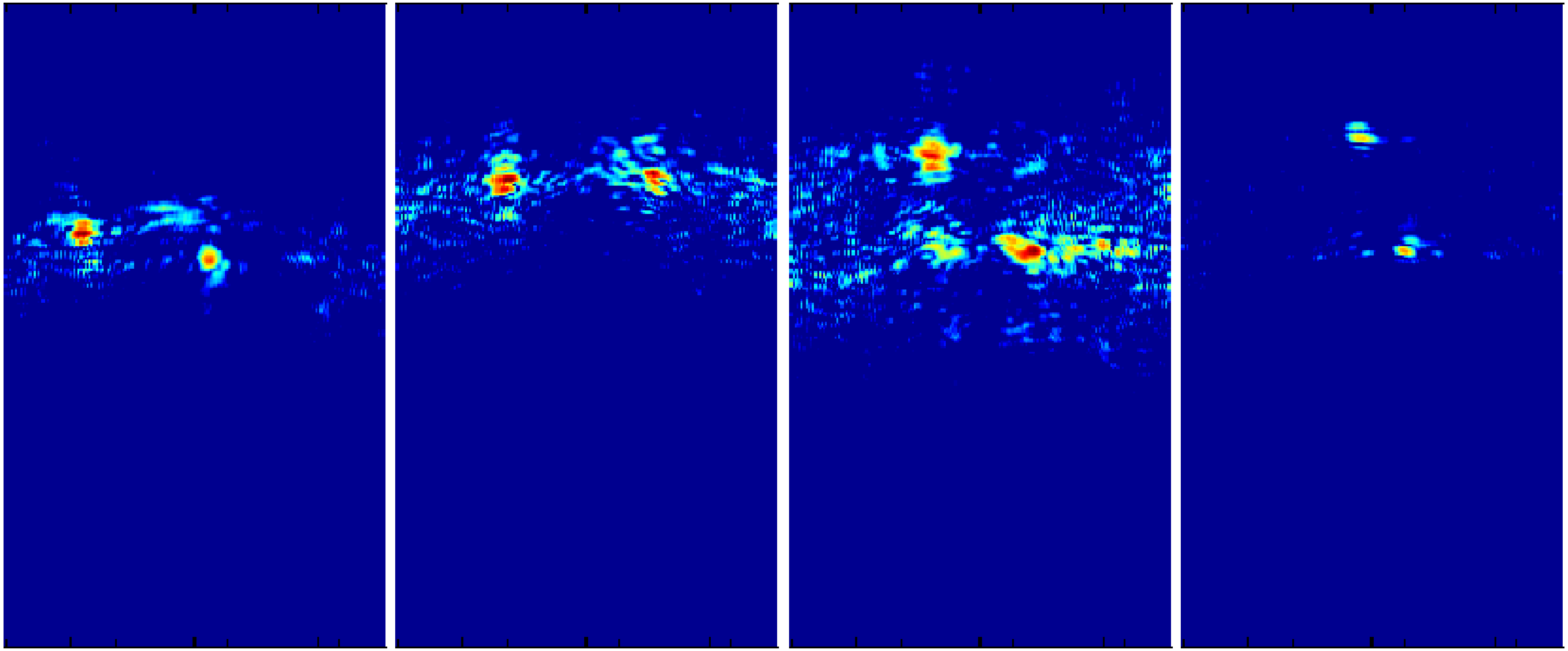
Human swinging 5-ft-long pipe (aka "Star Wars kid")

Through-Wall Target Scene



Humans Imaged Through Concrete Walls*

Two humans imaged in the four scenarios below



In free space | *Behind 4" solid concrete wall* | *Behind cinder block wall* | *Behind 8" solid concrete wall*

Using image-to-image coherent change detection

**Wall eliminated from image*

Summary

- **Results**
  - Free-space imaging of low RCS targets and human action
  - Through-wall imaging of moving humans
- **Benefits to this approach**
  - Stand-alone sensor, stand-off range, continuous surveillance
- **Objective: field rapid prototype**
- **Near-term plans**
  - Free-space testing, verify system model
  - Test on walls
- **Far-term goals**
  - Optimum configuration trade space
    - Frequency selection, resolution, wall loss budget
    - Increase number of receiver elements
    - Variations on array density
    - Imaging rates