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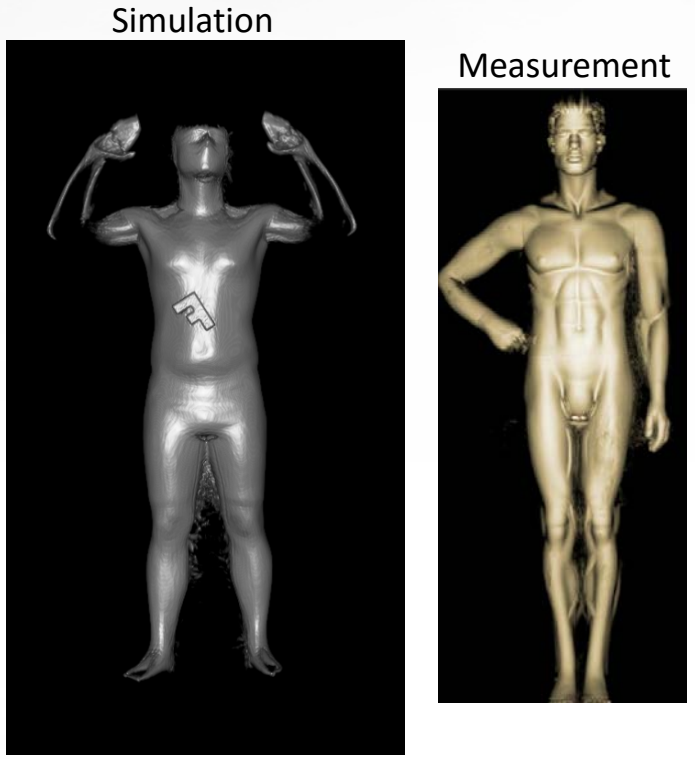
Simulation of Next-Generation Millimeter-Wave AIT Systems



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U.S. DEPARTMENT OF ENERGY

MMW AIT Simulation R&D – Benefit to DHS/TSA

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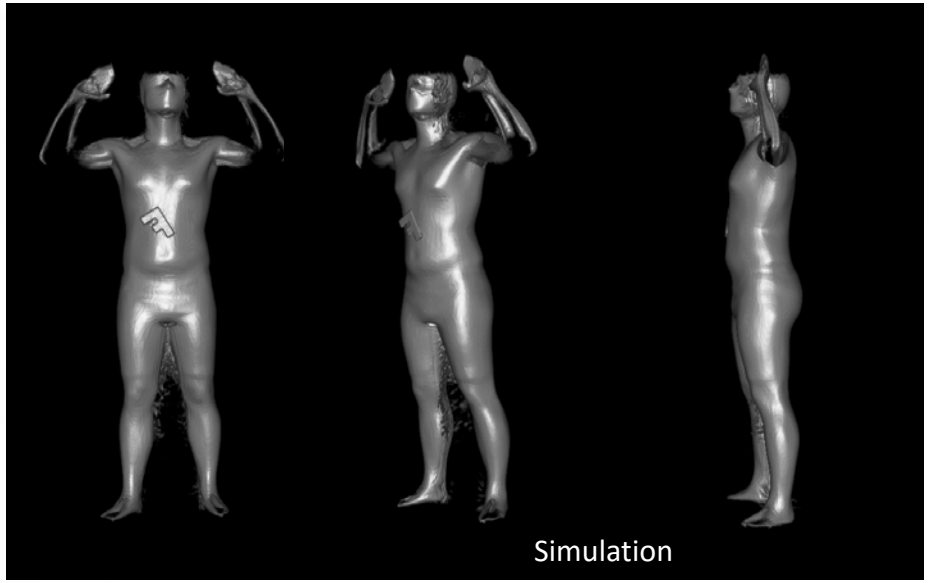
- Predict *end-to-end* performance of any MMW AIT system
  - Enable MMW AIT system design
    - Hardware (array, scanner, transceiver, etc.)
    - Image processing (focusing)
  - Scenario (person size, shape, gender, pose, clothing, threat placement, moisture, etc.)
  - Realistic physics-based modeling
  - Detection processing (ATR)
- R&D to extend and improve the simulation capability
  - Increase the computational efficiency
  - Add system non-idealities to the models
  - Add bulk dielectric effects to the models
  - Add clothing and moisture effects to the models
- Potential to use simulated images for testing
  - Allows virtual testing of systems not yet in existence
  - Allows virtual placement of explosives (with accurate dielectric properties)
  - Requires generation of a large number of images
    - TSL has captured over 2000 imaging using our HD-AIT system (Kaggle prize competition)
    - Numerous volunteers, clothing types, and target placements
  - Requires algorithm development and *training*
  - Requires the modeling to address the clothing and bulk dielectric effects
  - Requires development of CAD methods to easily generate wide variety of body types, clothing, and target placements

Summary and Introduction

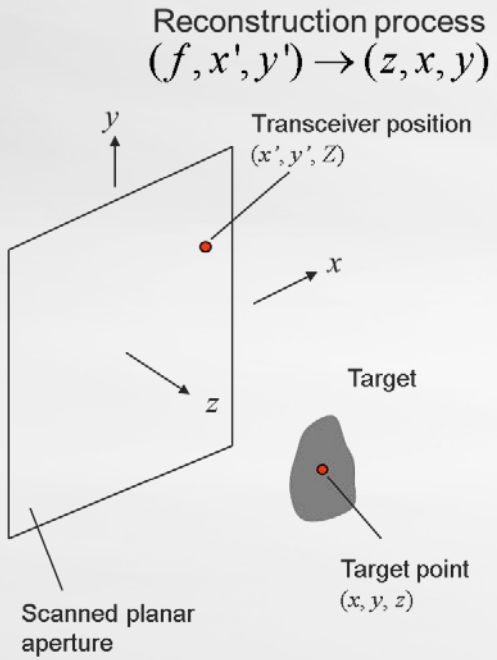
- Objective – design next-generation MMW AIT systems and demonstrate performance before costly fabrication
  - Laboratory scanning – old solution
  - Simulation (SBR) – new solution
  - Prototype design/fab/eval
- Impact to DHS/TSA – radically improved ability to explore novel system designs
- Goals for future imaging portals
  - Improved detection performance
  - High passenger throughput
  - Reduced cost and footprint
- High-Definition Advanced Imaging Technology (HD-AIT) prototype
  - Higher spatial resolution
  - Polarimetric signatures
  - 3-D data exploitation (ATD)
  - Novel antenna array designs

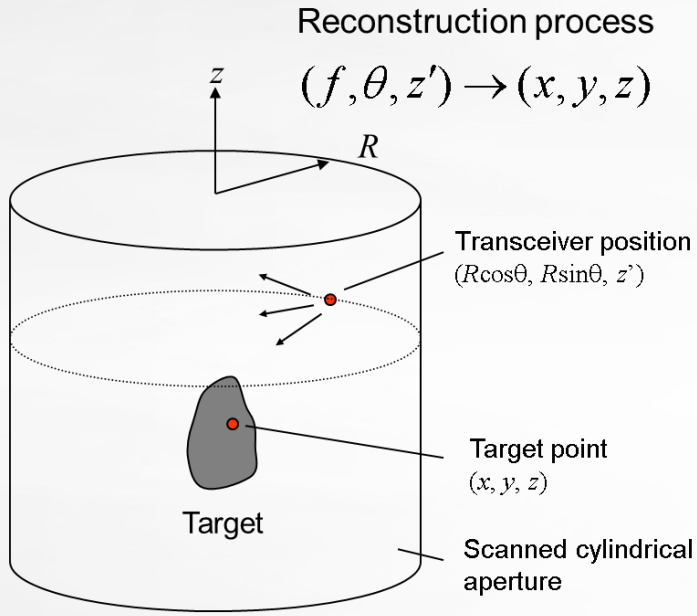


*https://www.kaggle.com/c/passenger-screening-algorithm-challenge

PNNL Holographic Imaging Techniques

- Simulation or measurement provides unfocused data
- Synthetic aperture imaging techniques mathematically focuses that data
- Wideband image reconstruction algorithm allows for fully-focused 3-D images using efficient FFT-based algorithms
- Planar, rotating target (individual segments), and combined (full 360)

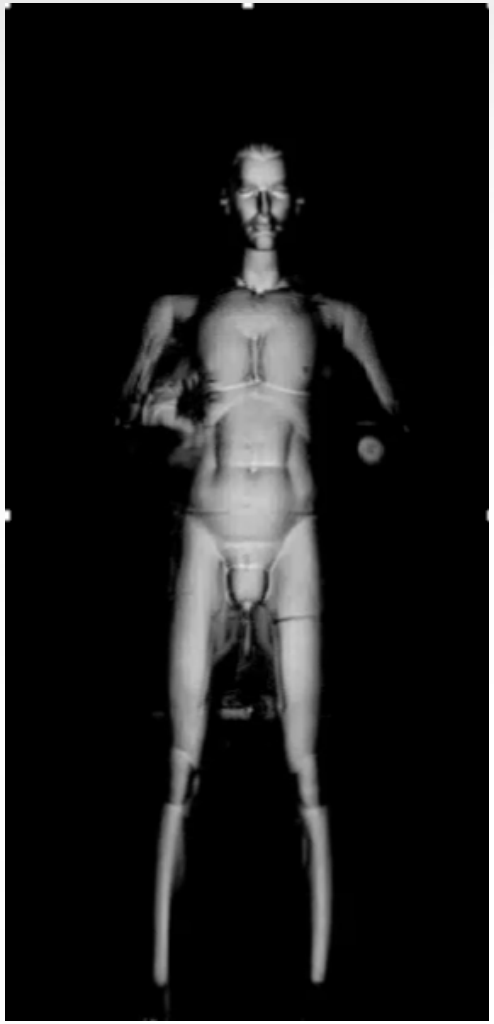




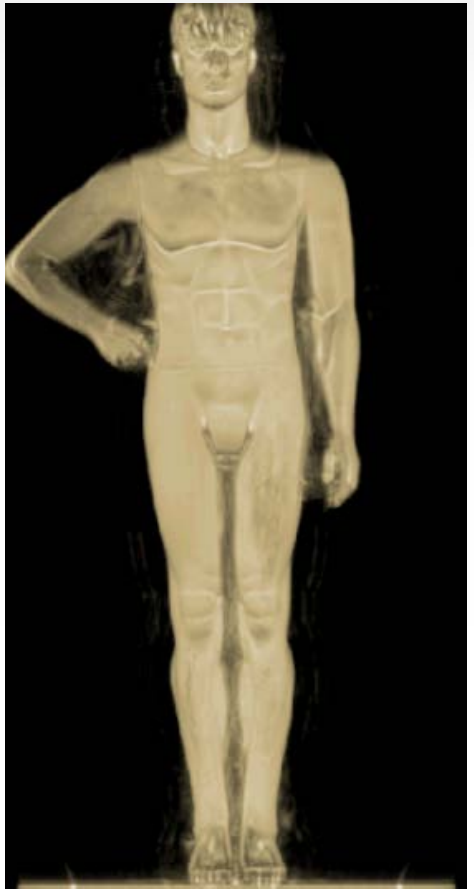
HD-AIT Prototype Next Generation Scanner

- High-Definition Advanced Imaging Technology (HD-AIT) prototype
  - Higher spatial resolution
  - Polarimetric signatures
  - Novel antenna array designs
  - 3-D data exploitation (ATD)
  - Acquire data from real people
- Exceptional image quality
  - Excellent range and lateral resolution (5 mm, 6 mm)
  - Full cylindrical (360 deg.) – uniform body coverage
  - Outstanding clothing penetration
  - Elimination of even-bounce artifacts
- HD-AIT data used in Kaggle algorithm challenge

10 – 40 GHz measurement

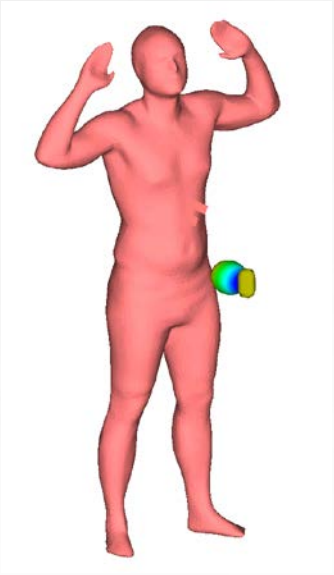


10 – 40 GHz measurement



Shooting and Bouncing Rays Method

- ANSYS HFSS SBR+
  - High Frequency Structure Simulator, Shooting and Bouncing Rays +
  - Formerly DelCross Savant
  - Useful for electrically large simulations (too large for full-wave methods)
- Hybridization of Geometric Optics (GO) and Physical Optics (PO)
  - GO rays launched from T antenna to object
  - Illuminated surfaces are determined and their equivalent PO surface currents are computed
  - Reflected rays are generated from bounce locations



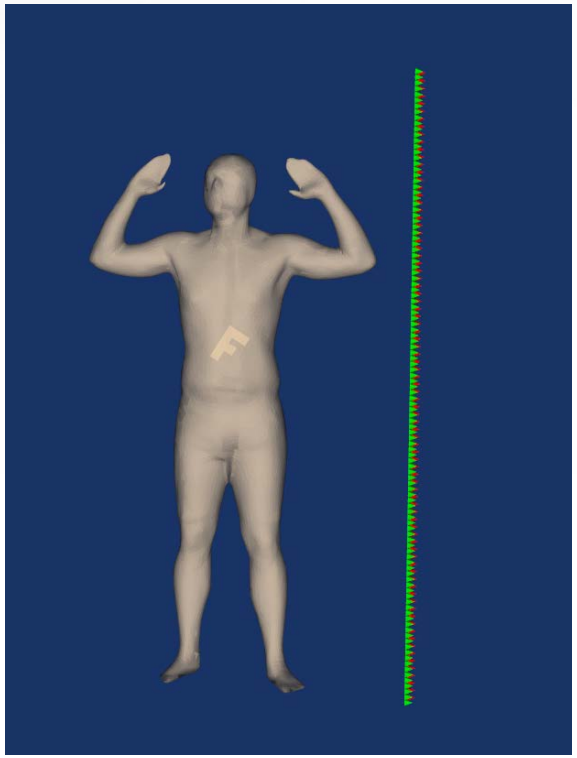
- Modeled
  - Person and attached objects
  - Array and scan configuration
  - Frequency range (resolution)
  - Multipath (multiple bounces)
  - Polarization (linear or circular)
  - Antenna beamwidth (parametric)
- Not modeled (yet)
  - Clothing effects
    - SBR method is reasonably amenable to adding clothing reflections/transmissions
    - Challenging to add the clothing from the CAD perspective, but can presumably leverage animation R&D
  - Bulk, penetrable, dielectric objects
  - Non-ideality of the transceiver and antenna array elements

ANSYS

Simulation – Details

- Person and objects simulated using a finely discretized polygonal mesh CAD model (e.g. *.obj or *.facet)
  - Body shape, size, gender, pose can all be varied using computer animation techniques
  - Simulated weapons or other objects can be placed as desired
- Antennas simulated using idealized parametric beam function (specified beamwidth – captures illumination characteristics)

- Simulations performed on modern PC
  - Dual 16-core Xeon processors
  - Ansys HFSS SBR+
  - 10 instances running in parallel
  - Detailed scripting required for scan configurations
- Cylindrical scan
  - 10-40 GHz in 512 steps
  - 0.63 m radius
  - 2.1 m linear array
  - 900 angles by 656 vert
  - PEC human body model
  - ~ 30 hr runtime
- Planar scan
  - 10-40 GHz in 512 steps
  - 0.5 m standoff
  - 1.4 m x 2.1 m aperture
  - 300 x 656 samples
  - PEC human body model
  - ~ 8 hr runtime



Imaging Trade Study – Bandwidth, Beamwidth, and Polarization

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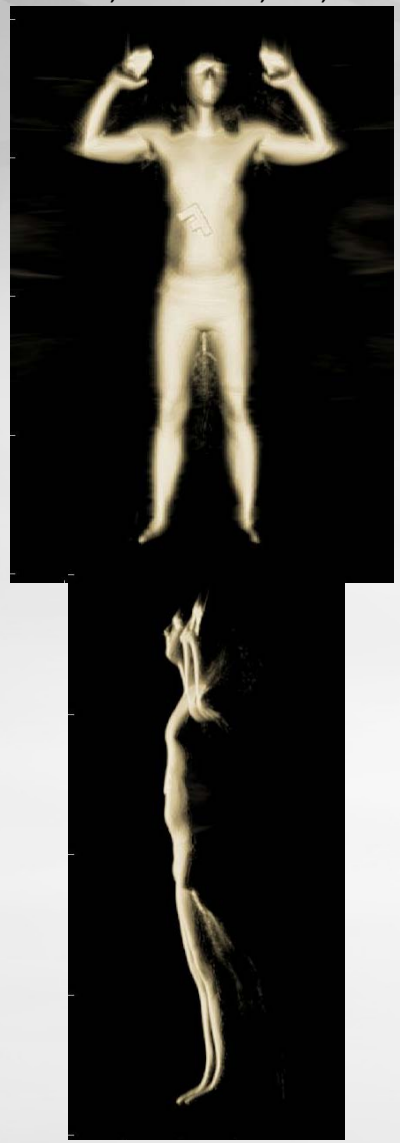
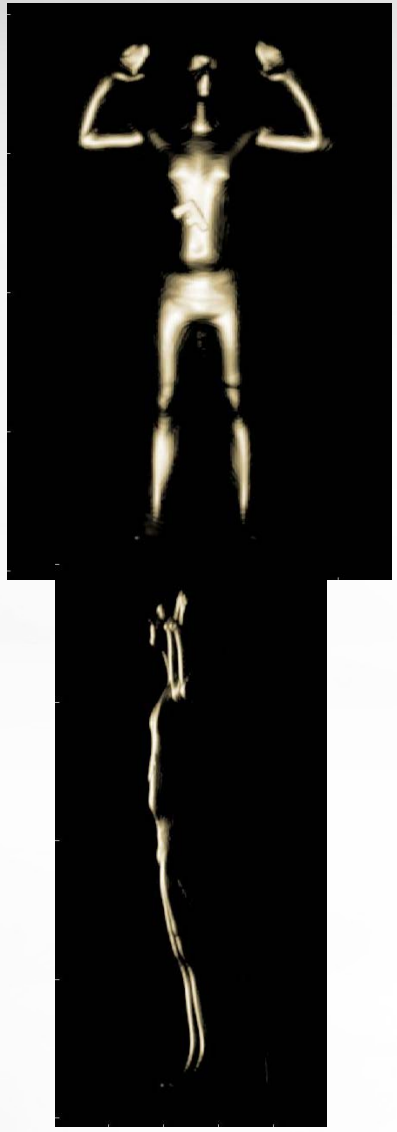
Planar, 10-40 GHz, 60°, RL



Planar, 22.5-27.5 GHz, 60°, RL

Planar, 10 – 40 GHz, 20°, RL



Planar, 10 – 40 GHz, 20°, VV

Cylindrical and Planar Scan Simulation and Measurement

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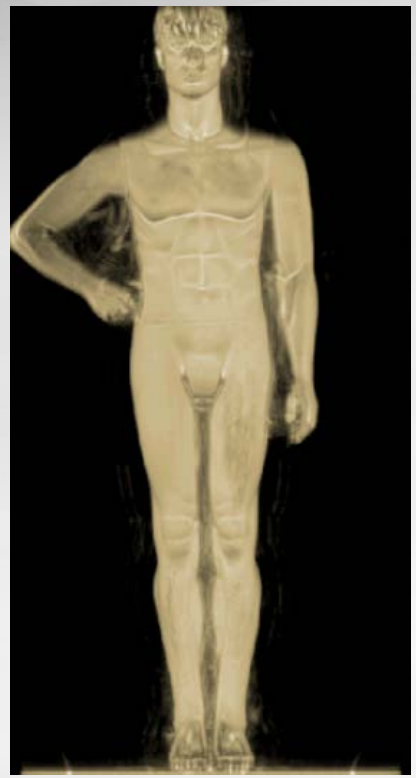
Cyl 90° HPBW, R-L CP



10 – 40 GHz
Measured

Cylindrical 60° HPBW, R-L CP

10 – 40 GHz
Simulated

Planar 60° HPBW, R-L CP

10 – 40 GHz
Simulated

Planar 20° HPBW, R-L CP

10 – 40 GHz
Simulated

Conclusions

- Millimeter-wave AIT systems can be accurately simulated to assess many aspects of imaging system design and performance
  - Quality of illumination and coverage of the body
  - Body type
  - Threat or benign object placement
  - Distortion or blockage due to shadowing
  - Multipath effects
  - Lateral resolution
  - Depth resolution
  - Polarization
- Shooting and bouncing rays (SBR) method generates data that is consistent with scanned measurements – nearly ideal for AIT system design simulation
- Clothing effects and volumetric penetrable dielectrics represent an exciting challenge to be addressed with new research