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

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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

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]**

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Challenges

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<td>Real-time SAR algorithm</td>
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<td>Data-acquisition pipeline</td>
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<td>1 ms UWB LFM waveform generation</td>
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<td>Sensitivity</td>
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<td>Reduce mutual coupling</td>
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Technical Approach

- 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
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
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)

- 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)

Indoor clutter

Radar sensor

Targets placed on Styrofoam table

Indoor clutter
Measured Free-Space Data

- Using coherent background subtraction
- Using image-to-image coherent change detection

- Human playing marbles with 1-inch diameter spheres
- Human swinging 5-ft-long pipe (aka "Star Wars kid")
Through-Wall Target Scene

- Outdoor clutter
- 8" thick concrete wall
- 4" thick concrete wall
- Cinder-block wall
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