MilliCam: Hand-held Millimeter-Wave Imaging

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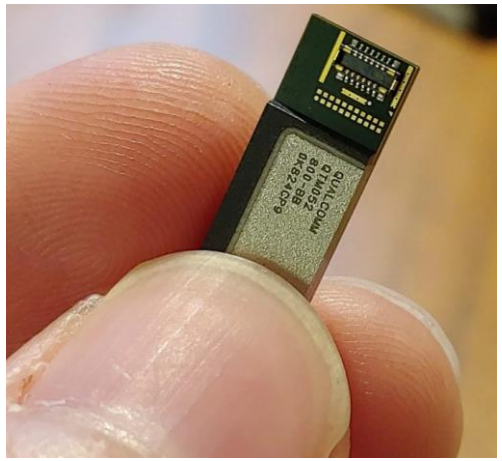
5G Mass Deployment

Key enabling technology:
Millimeter-wave



1.9 Billions

1.3 Billions

~7x

190 Million subscribers

10x increase in 5G subscriptions within the next 4 years

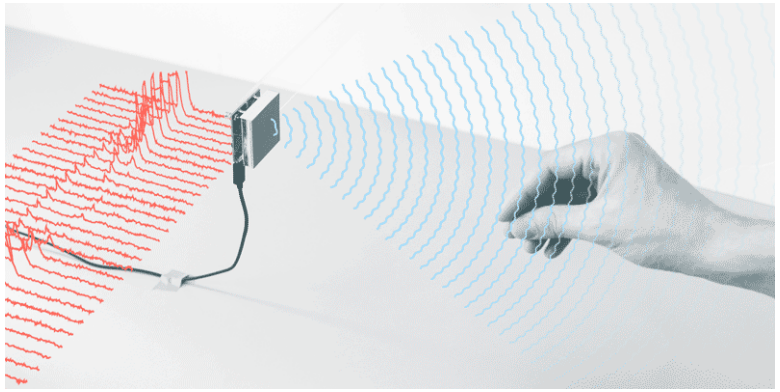
Source: Statista, 2020 - 2024

5G

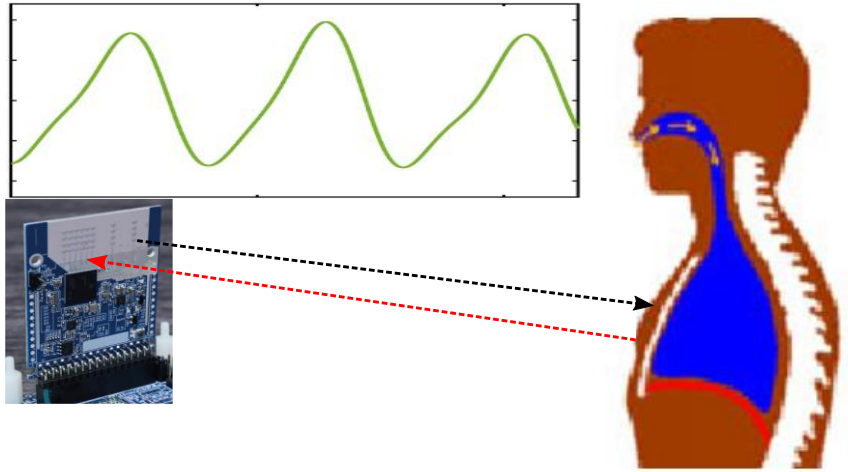
2020 2023 2024

Opportunity for New Internet of Things Applications

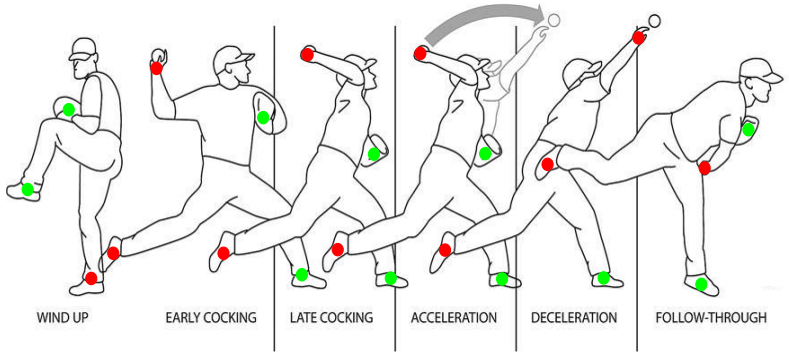
Detecting finger movement

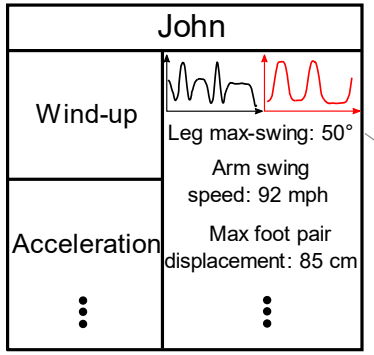


Monitoring vital signs

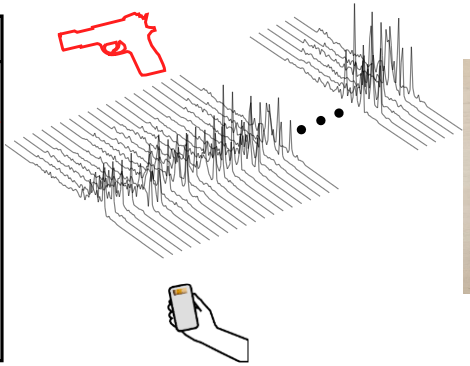


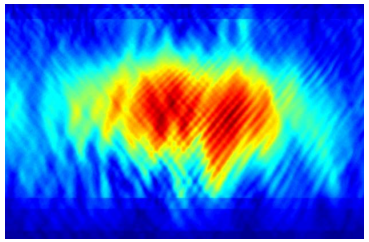
Enabling sports analytics



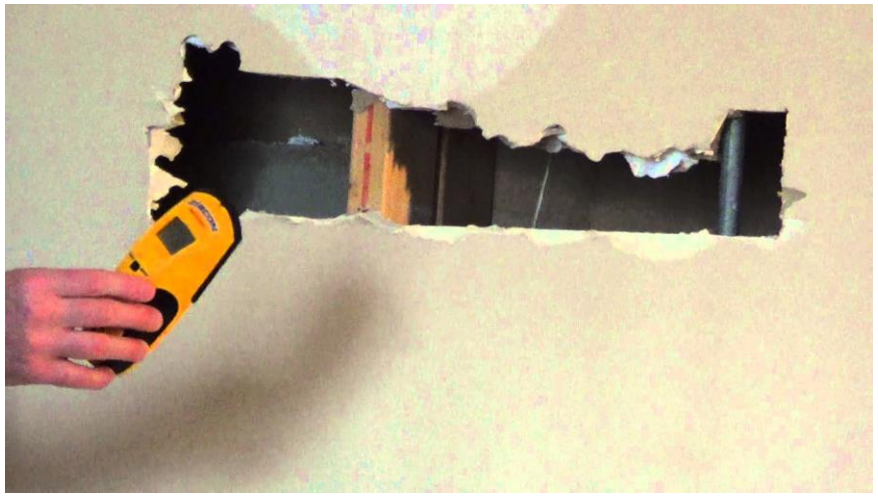


Imaging concealed objects

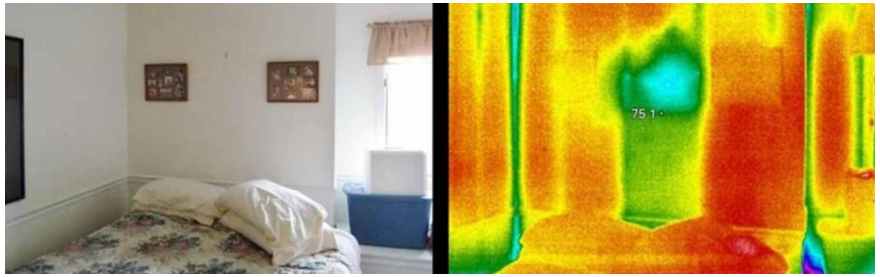




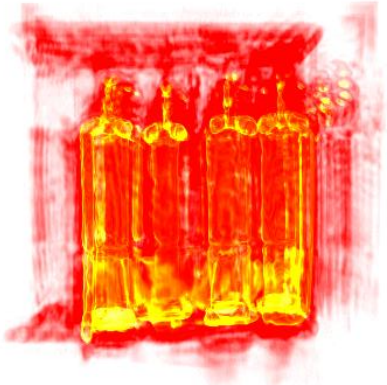
Imaging Concealed Objects: Applications



Hidden structure detection



Moisture detection

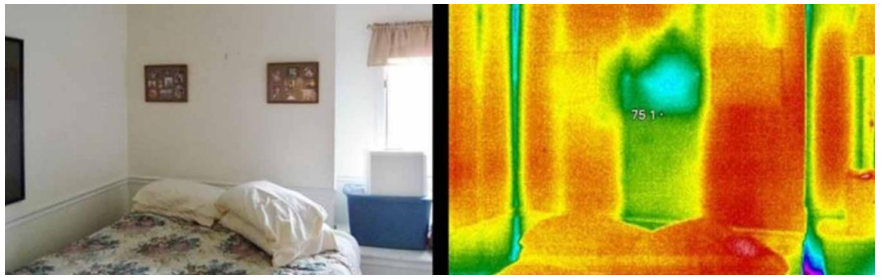


Inventory counting, Missing/damaged items detection

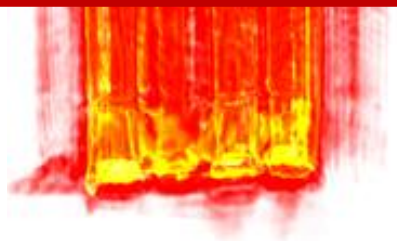
Contra-band detection

Imaging Concealed Objects: Applications

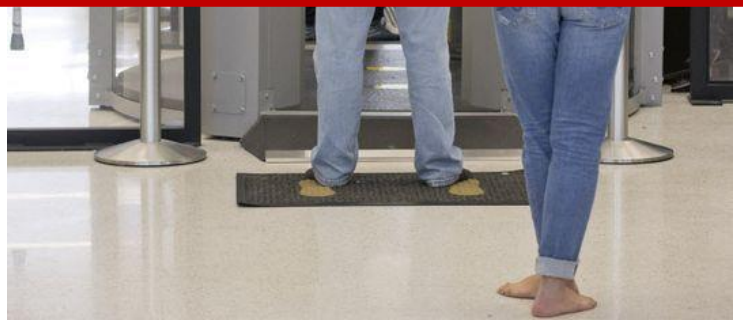
Can we bring these functionalities to commodity 5G smartphones?



Moisture detection

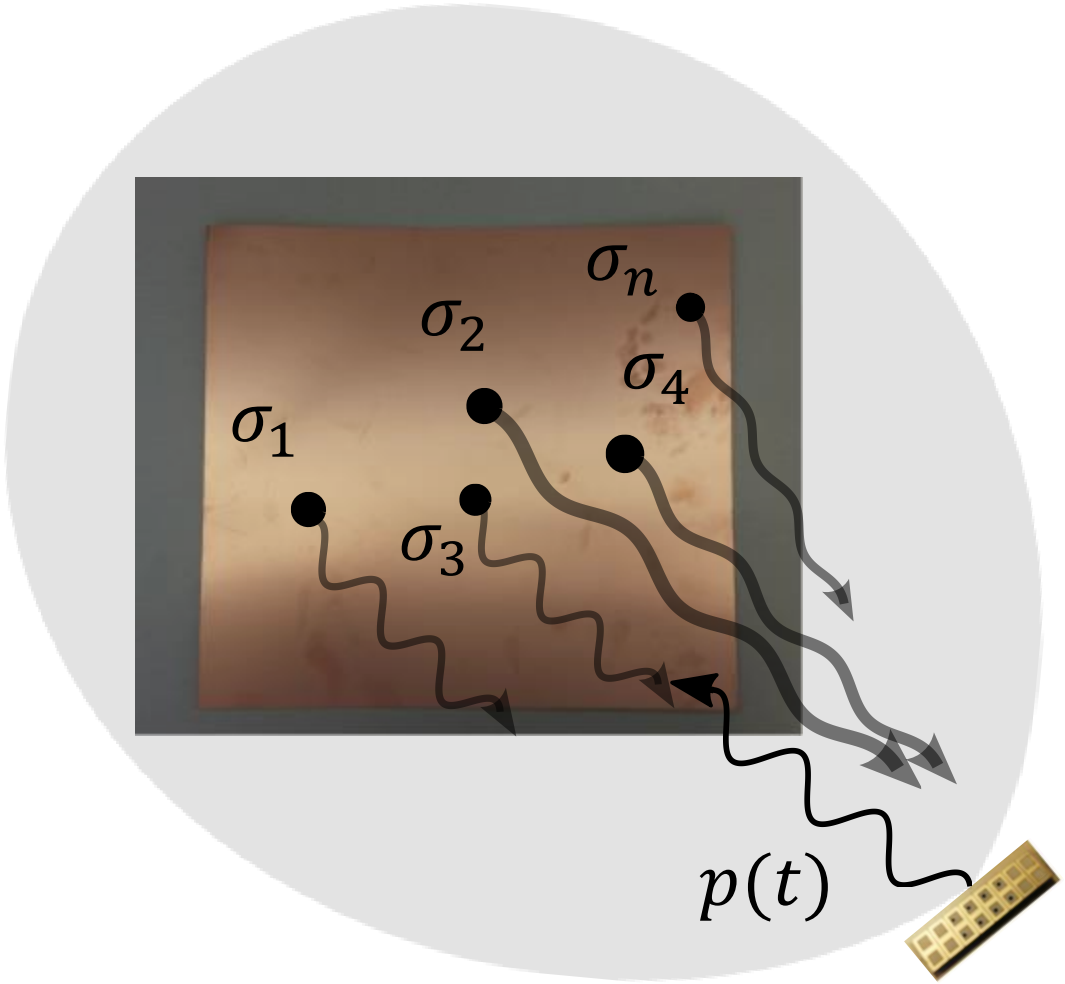


Inventory counting, Missing/damaged items detection



Contra-band detection

Constructing Millimeter-Wave Image



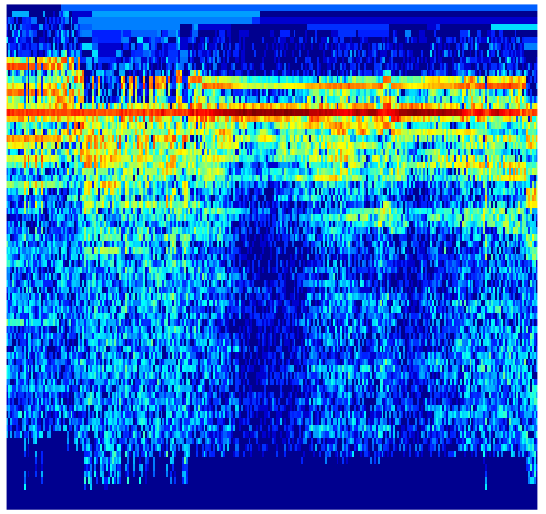
σ_1

σ_n

mmWave antenna

Reflected signals

Constructing Millimeter-Wave Image



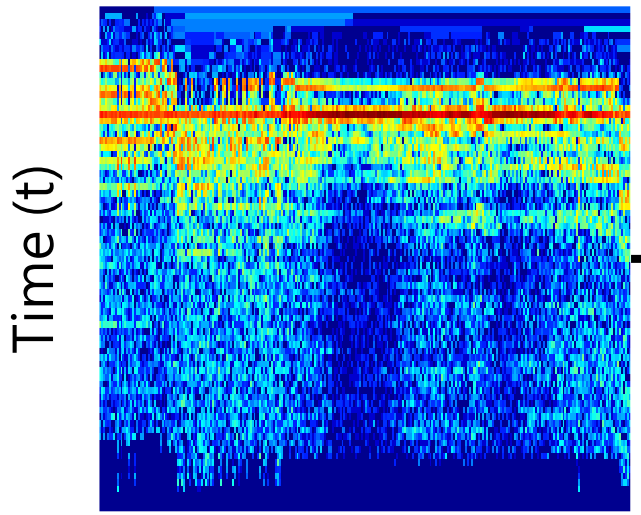
Time (t)

Space (u)

From Measured Signal to Image

FFT: Fast Fourier Transform

IFFT: Inverse Fast Fourier Transform



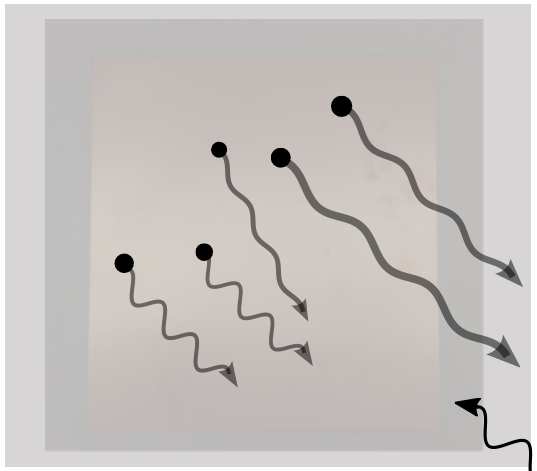
FFT (t)

FFT (u)

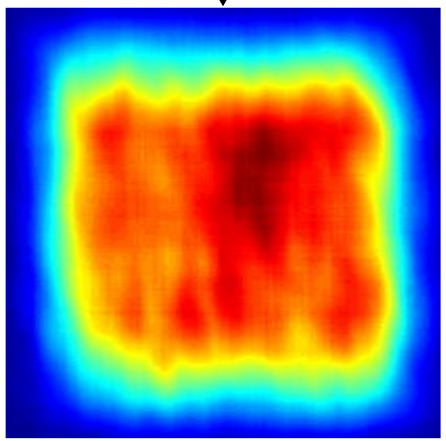
p(t)*

X

IFFT (t,u)

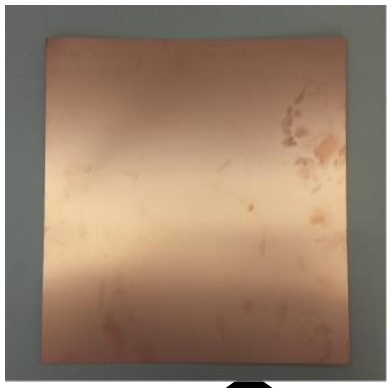


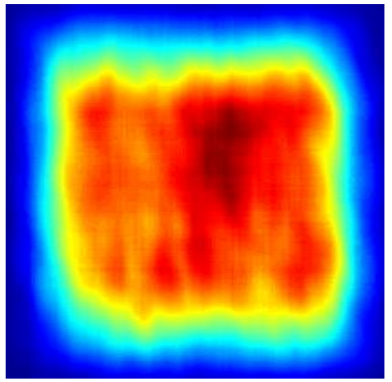
Camera image



mmWave image

Challenges

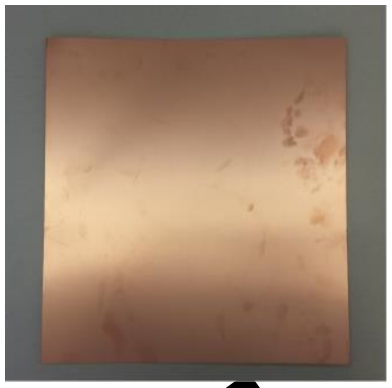


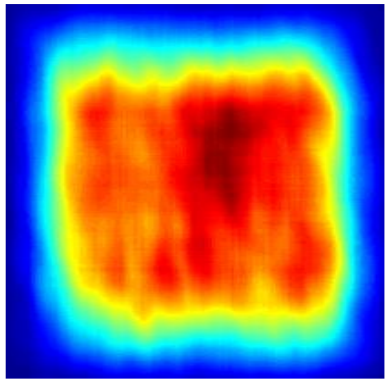


Hand-held motion error

Unknown object location

Challenges

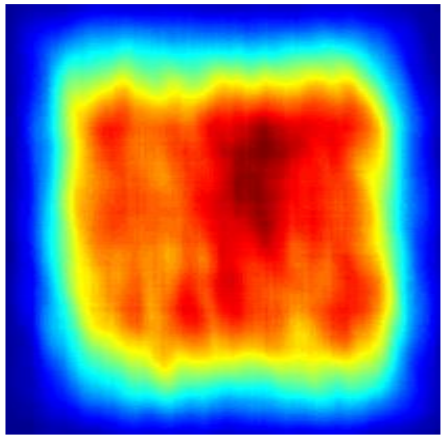




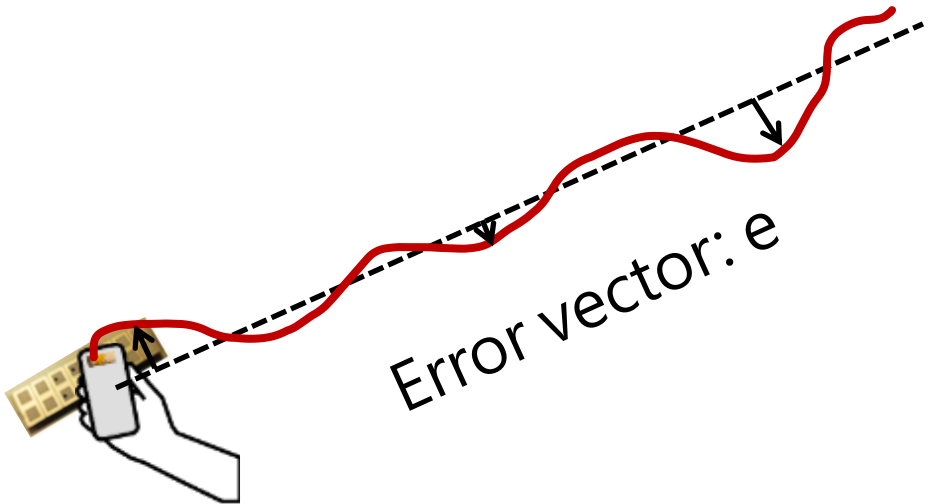
Hand-held motion error

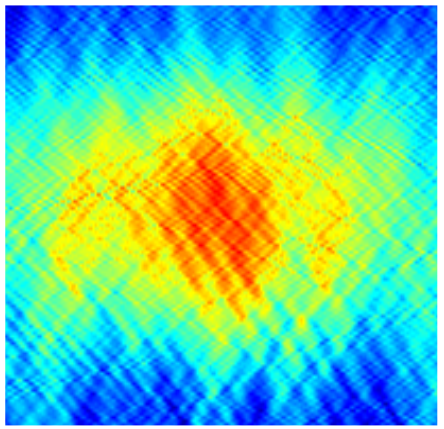
Unknown object location

Hand-held Motion Error



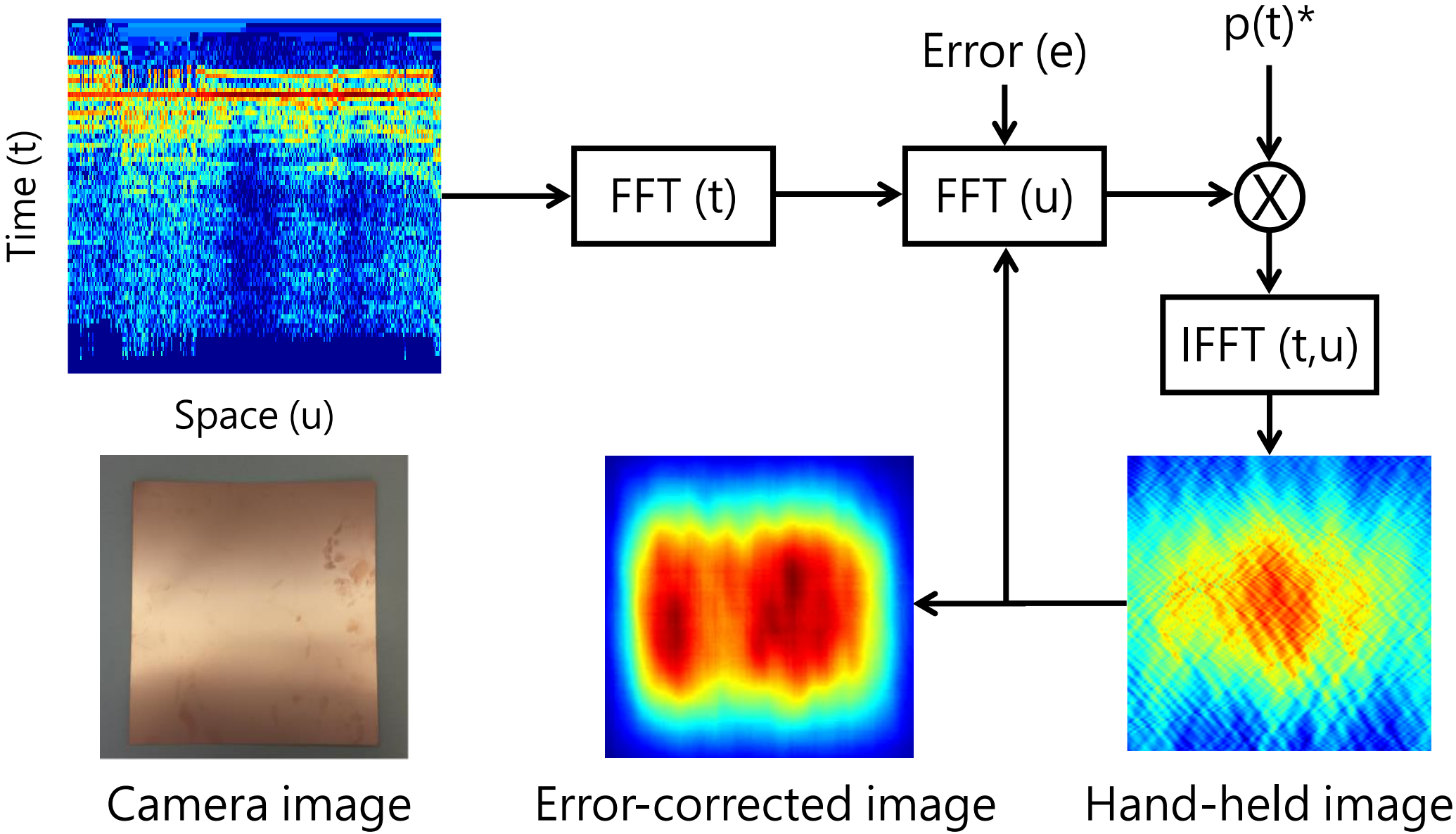
Controlled movement-based mmWave image



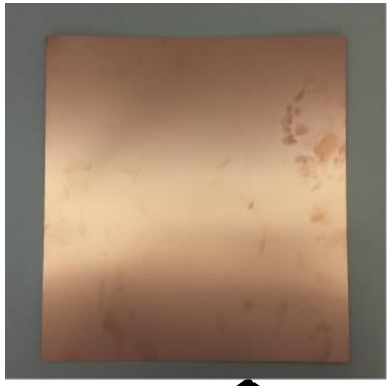


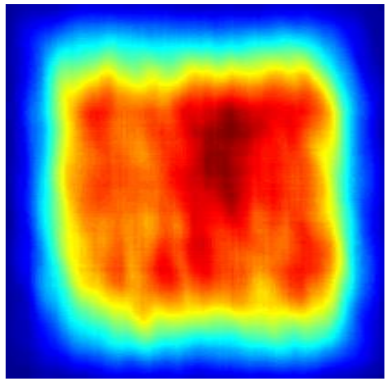
Hand-held mmWave image

Error Correction for Hand-held Imaging



Challenges

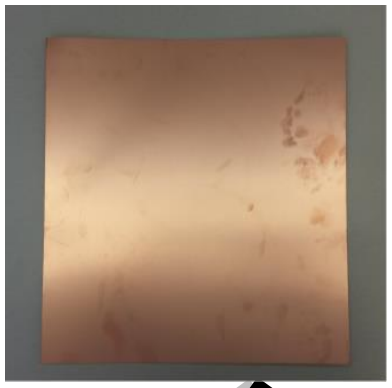


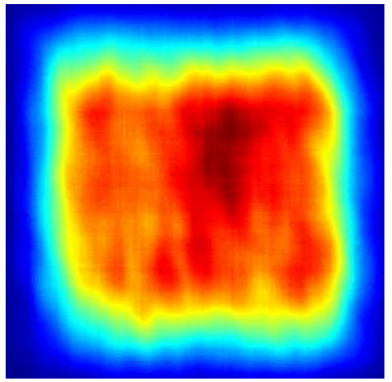


Hand-held motion error

Unknown object location

Challenges

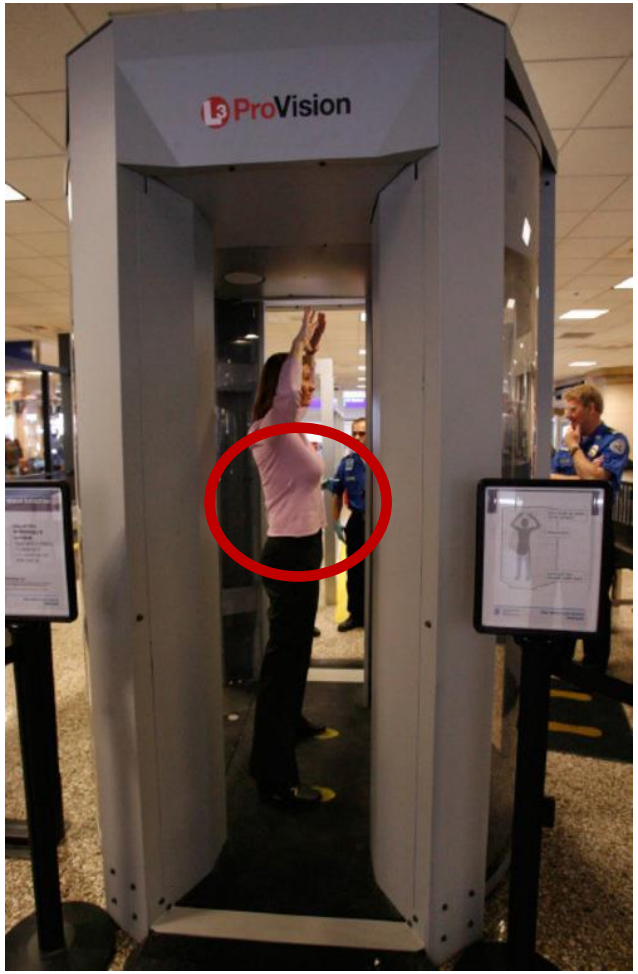




Hand-held motion error

Unknown object location

Unknown Object Location

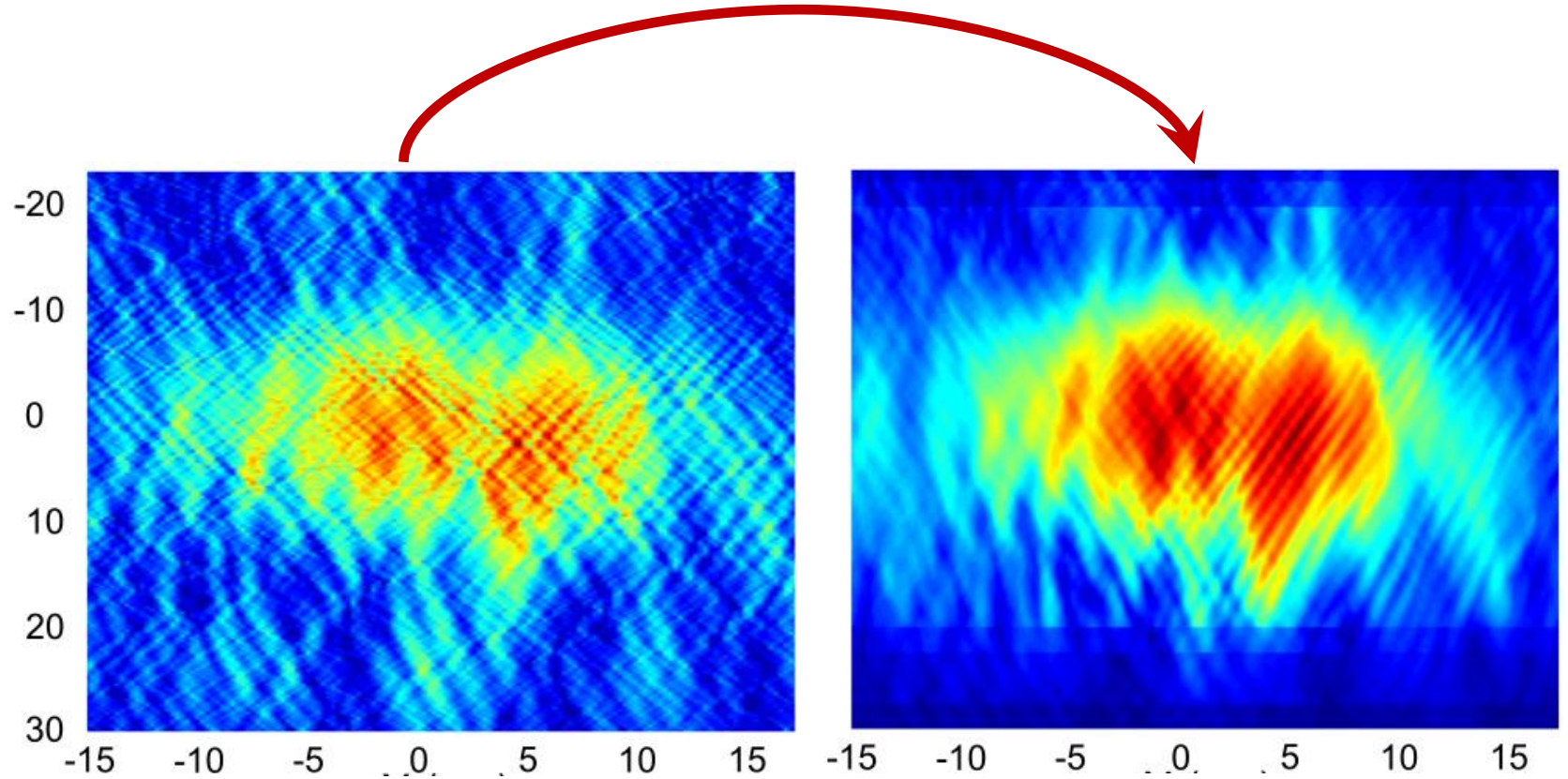


Known object location

Unknown object location

De-focused Image with Unknown Location

Camera image



mmWave image with *unknown* object location

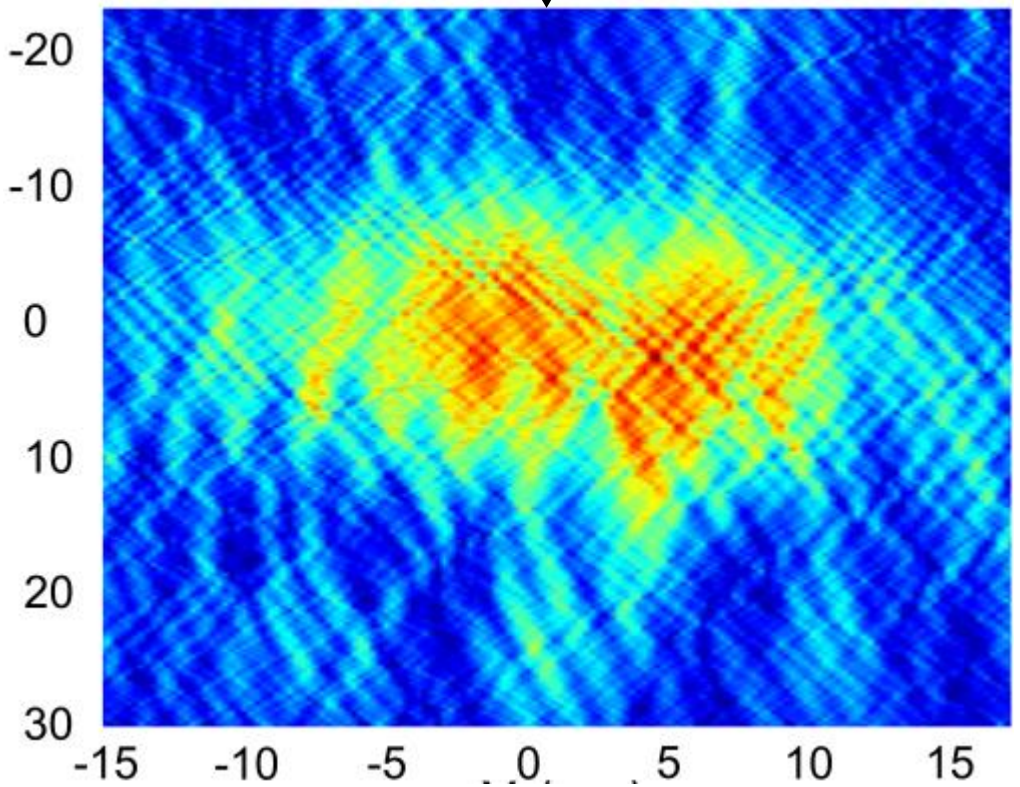
Image with *known* object location

Autofocusing with Unknown Object Location

mmWave imaging with hand-held error correction centered at (X_C, Y_C)

(X_C, Y_C)

Image center



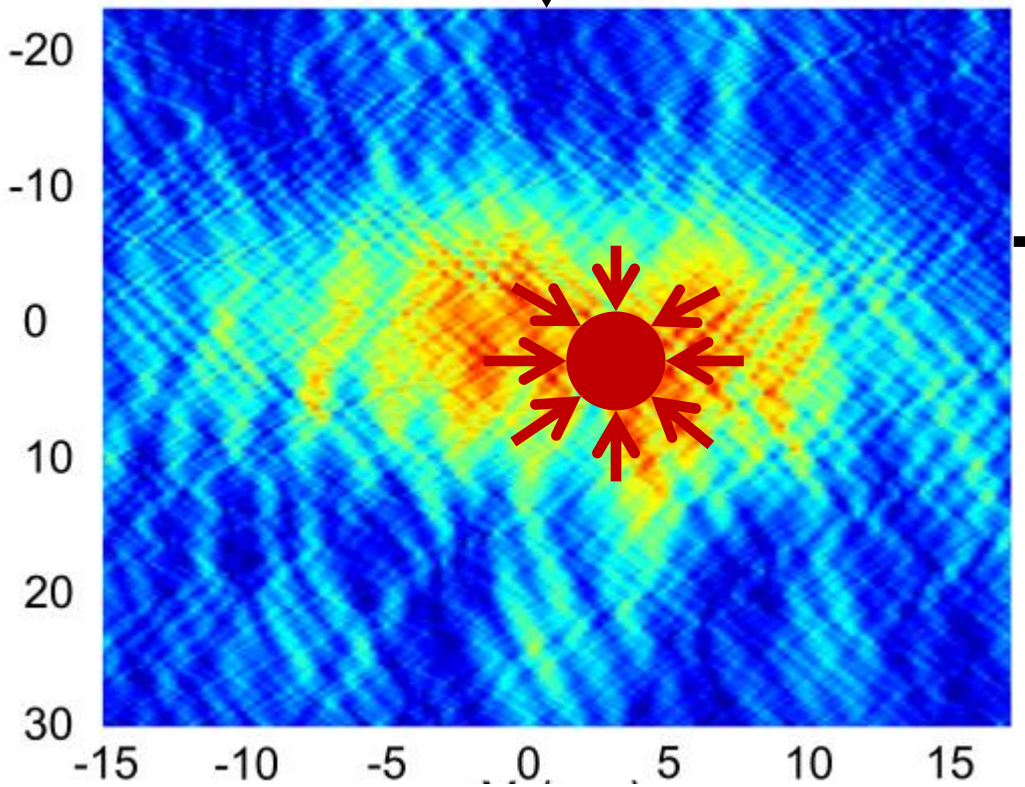
Autofocusing with Unknown Object Location

mmWave imaging with hand-held error correction centered at (X_C, Y_C)

New (X_C, Y_C)

(X_C, Y_C)

Image center

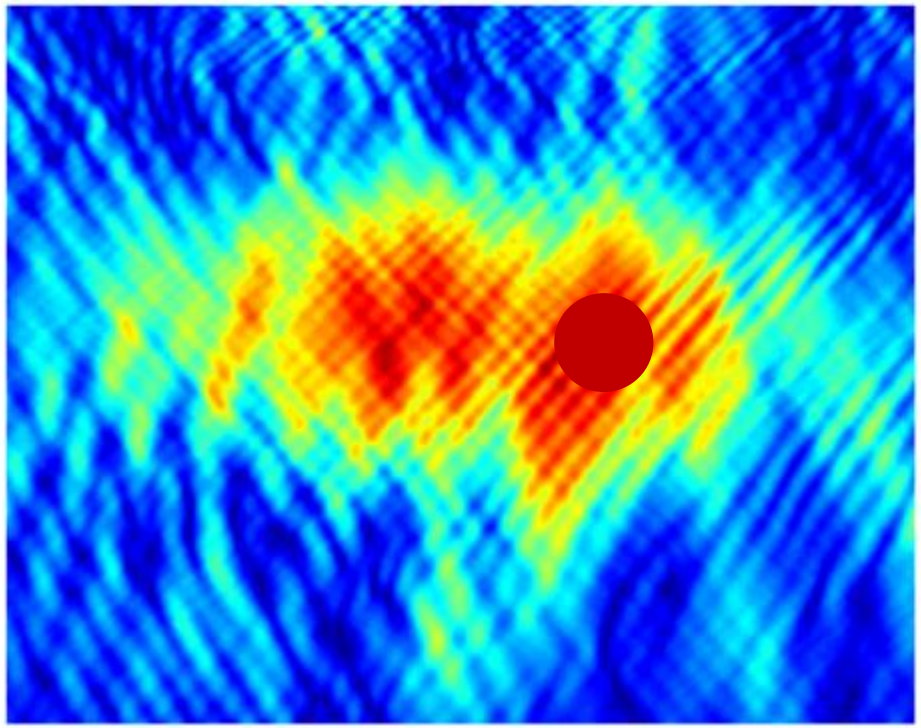


Autofocusing with Unknown Object Location

mmWave imaging with hand-held error correction centered at (X_C, Y_C)

New (X_C, Y_C)

Image center

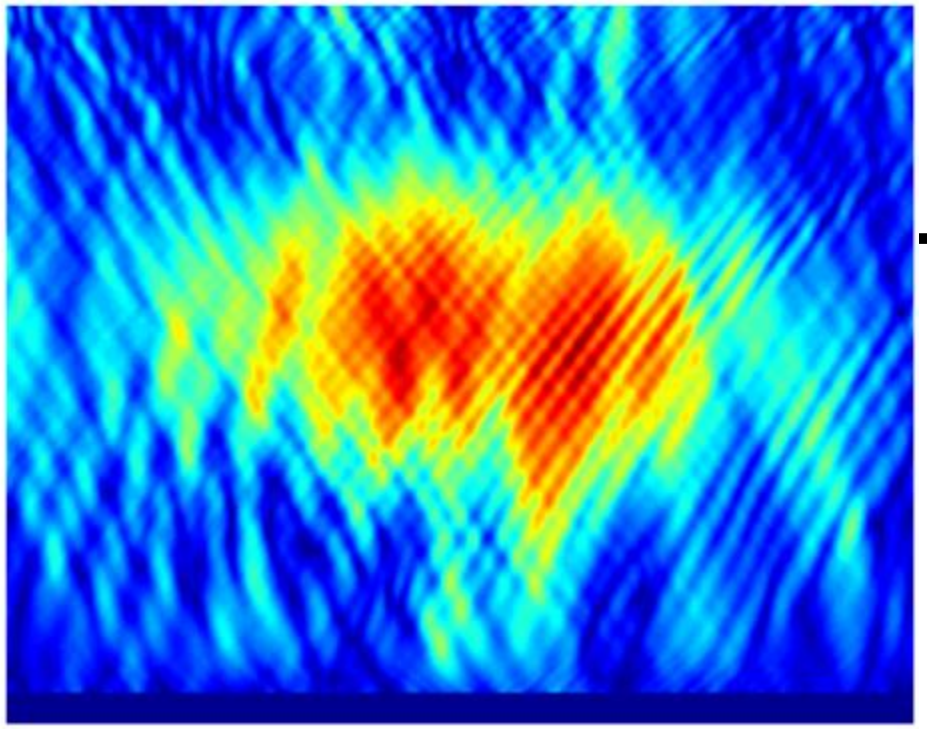


Autofocusing with Unknown Object Location

Image center

New
(X_C, Y_C)

mmWave imaging with hand-held error correction centered at (X_C, Y_C)



PSNR improvement
> 3 dB?

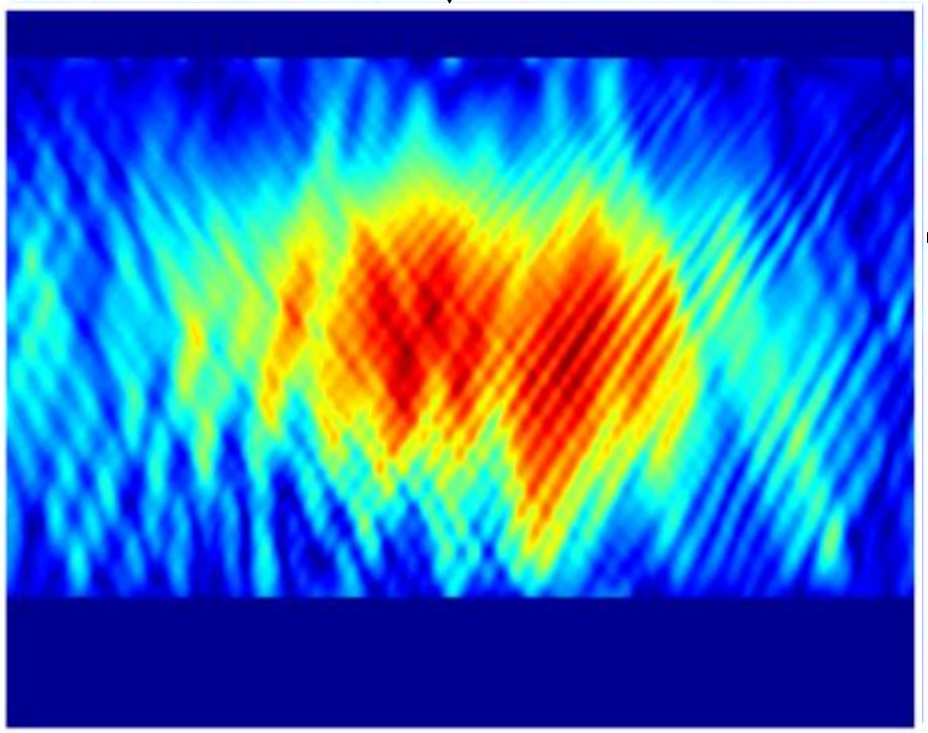
PSNR: Peak Signal-to-Noise Ratio

Autofocusing with Unknown Object Location

mmWave imaging with hand-held error correction centered at (X_C, Y_C)

New (X_C, Y_C)

Image center



PSNR improvement > 3 dB?

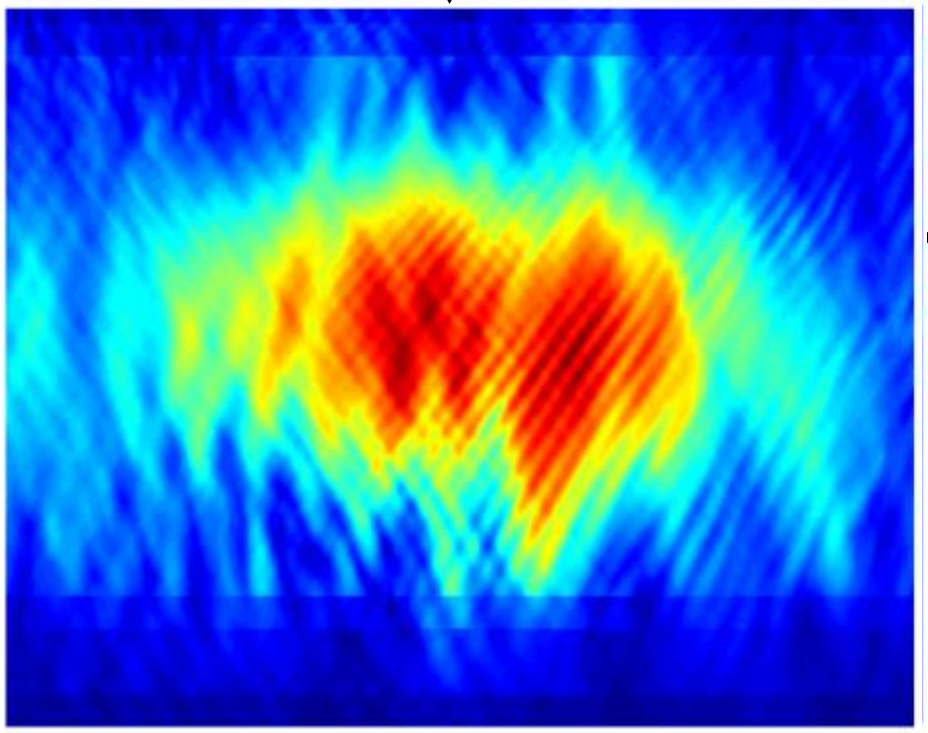
PSNR: Peak Signal-to-Noise Ratio

Autofocusing with Unknown Object Location

New
(X_C, Y_C)

Image center

mmWave imaging with hand-held error correction centered at (X_C, Y_C)

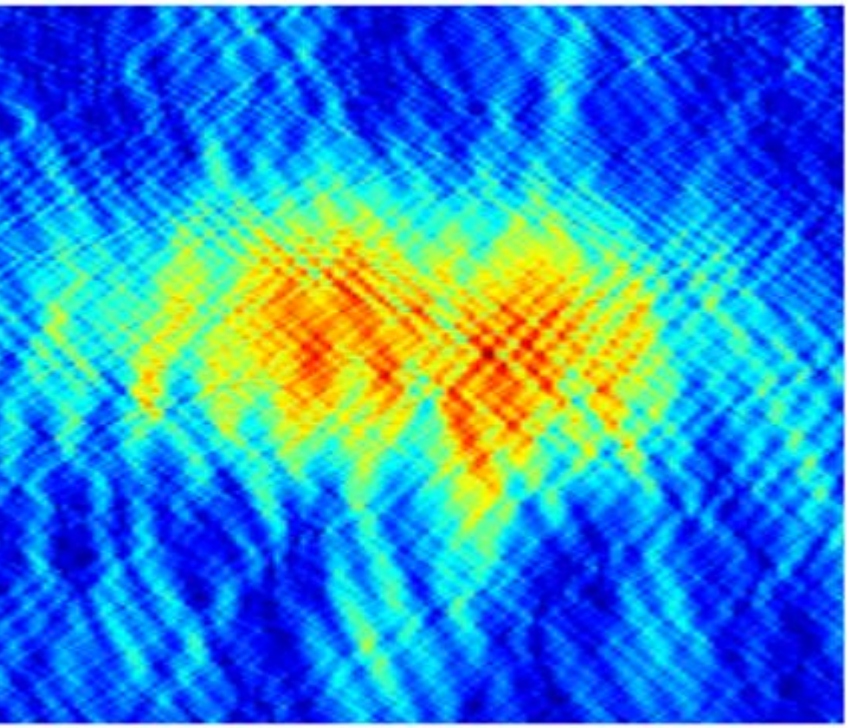


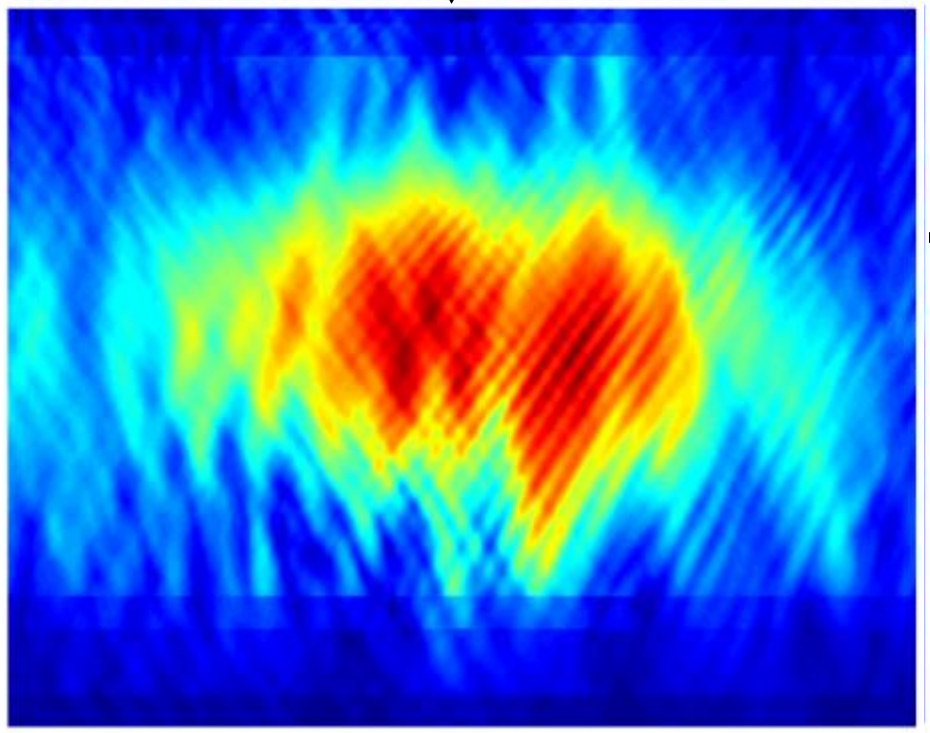
PSNR improvement > 3 dB?

PSNR: Peak Signal-to-Noise Ratio

Autofocusing with Unknown Object Location

mmWave imaging with hand-held error correction centered at (X_C, Y_C)





PSNR improvement > 3 dB?

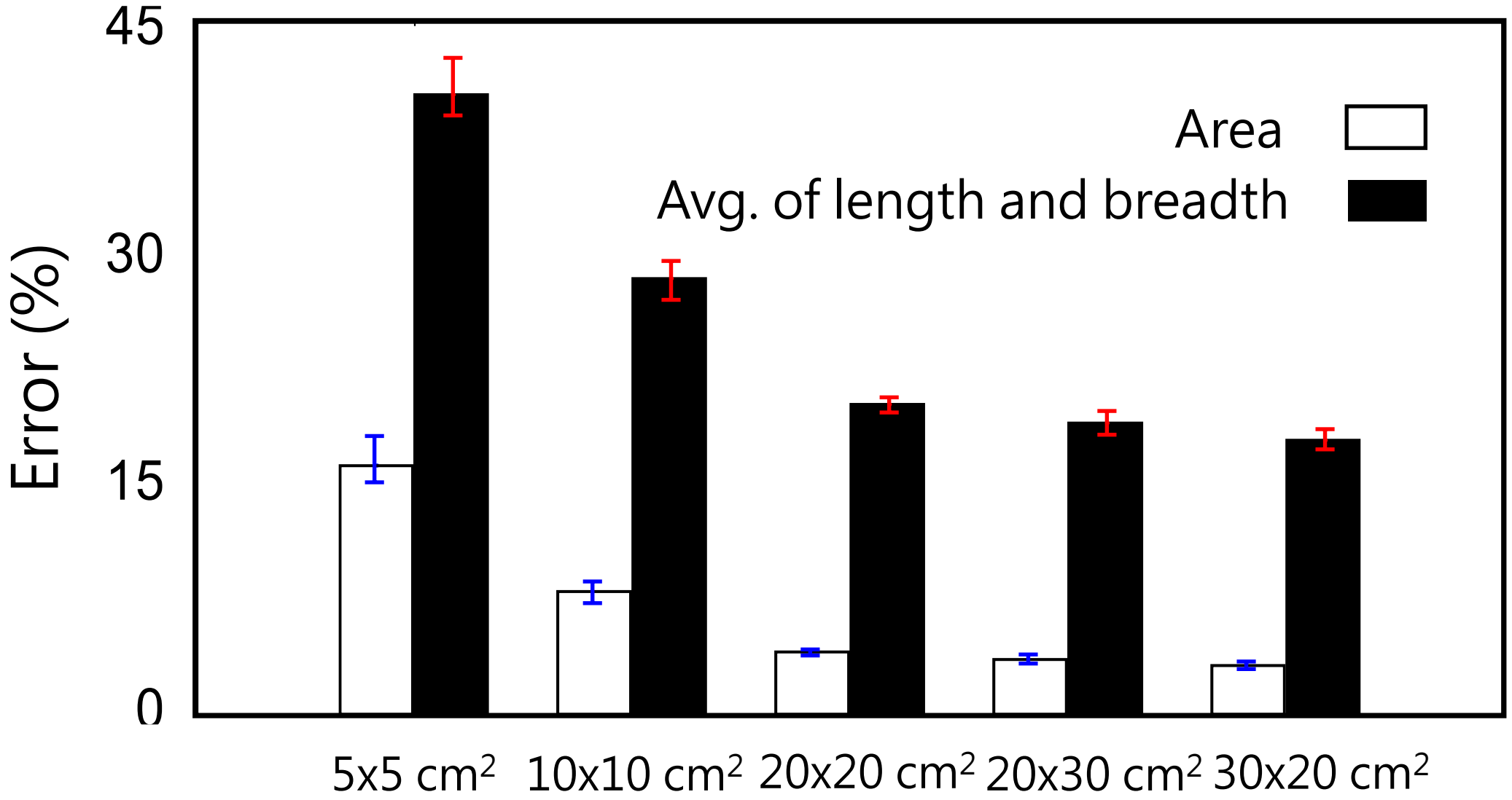
PSNR: Peak Signal-to-Noise Ratio

Hand-held Experimental Platform

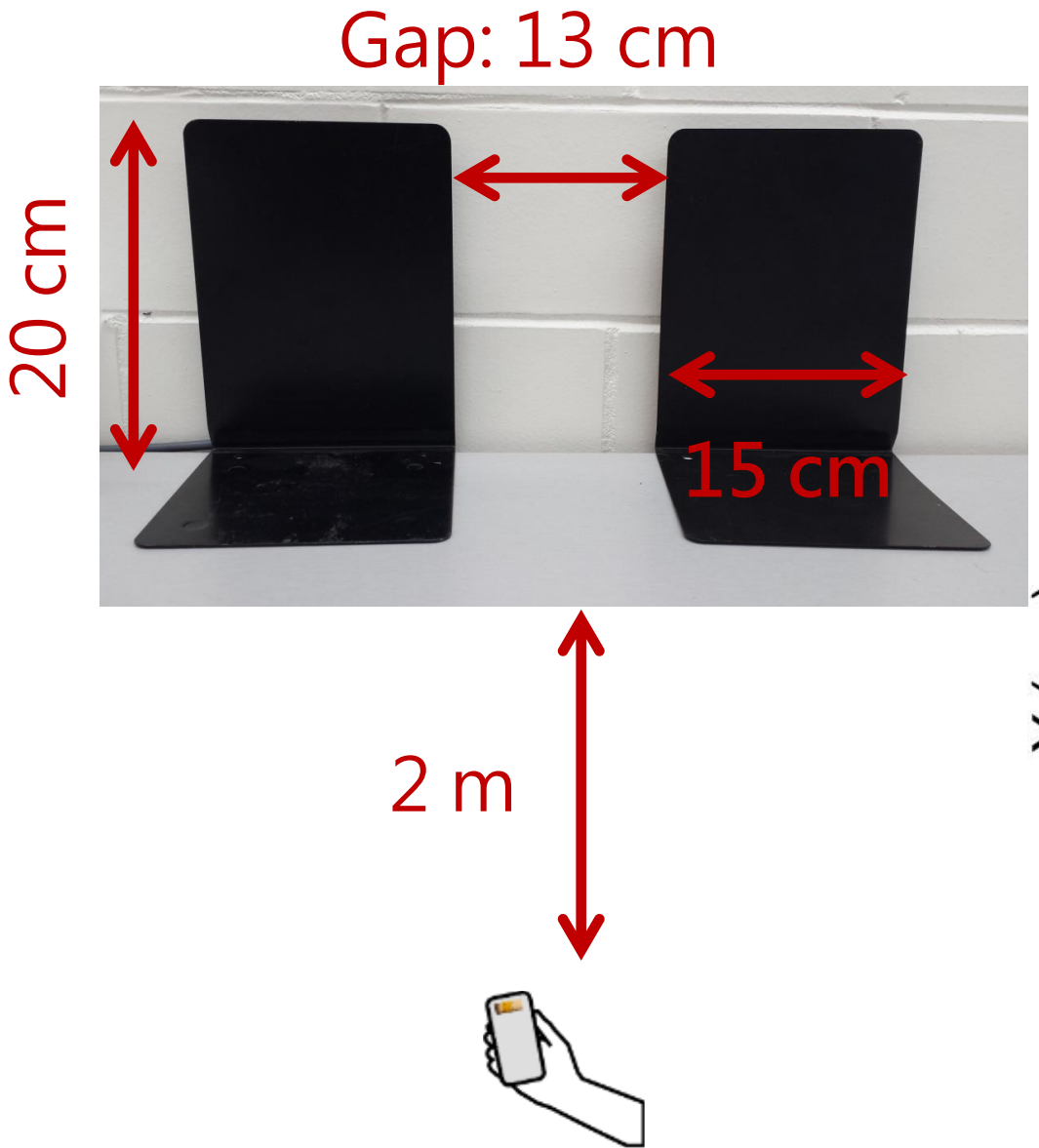
- Intel Galileo IoT platform + Qualcomm IEEE 802.11ad
- 64 beams at 60 GHz
- 2 GHz channel bandwidth == 0.5 ns timing resolution
- A repurposed off-the-shelf communication device

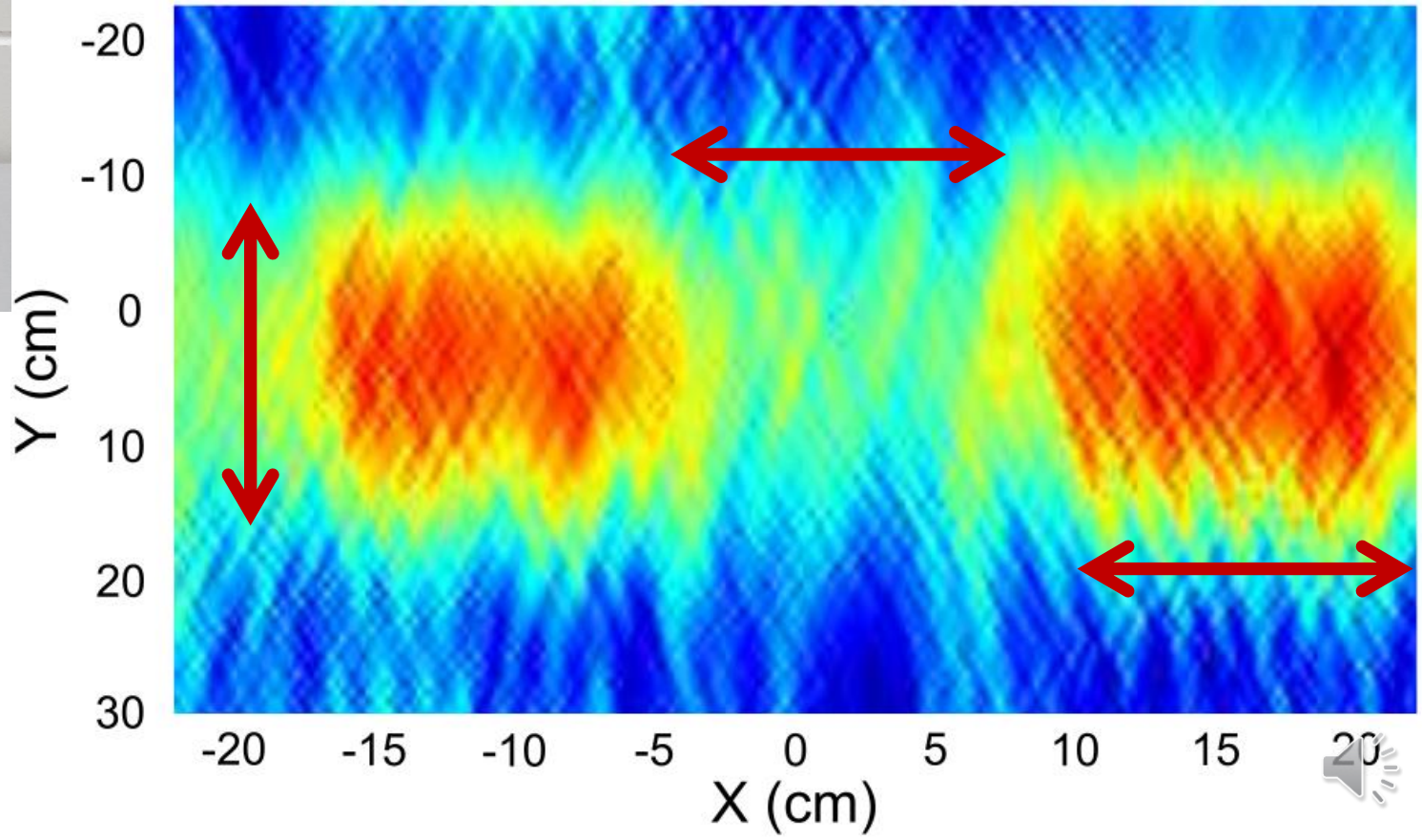
Shape Discrimination

Shape Dimensions Estimation



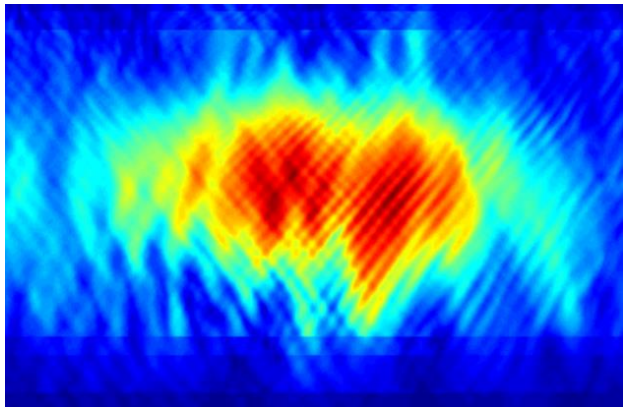
Imaging Multiple Objects





Imaging More Complex Object

Camera image



mmWave image

MilliCam summary

Potentials and challenges of hand-held mmWave imaging

* Wide-bandwidth and small wavelength at millimeter-wave enable high precision see-through imaging.
* But, hand-held motion error and unknown object location can affect the image quality severely.

System summary

* MilliCam employs sensor-based error correction and iterative autofocusing to overcome the challenges.
* MilliCam is a first-of-a-kind system to enable high-quality see-through imaging on 5G devices.