2022UBICOMP

MiShape: Accurate Human Silhouettes and Body Joints from Commodity Millimeter-Wave Devices

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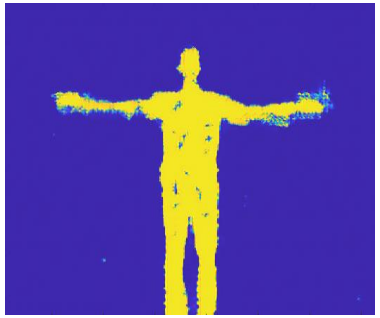

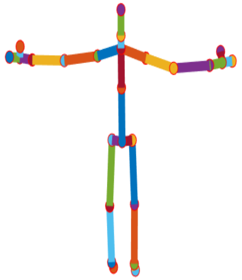

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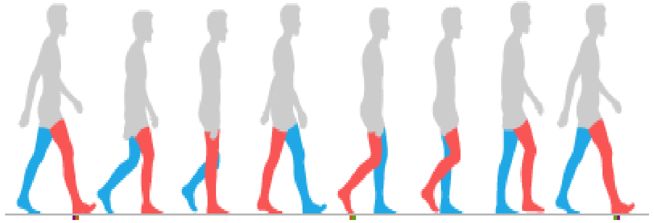
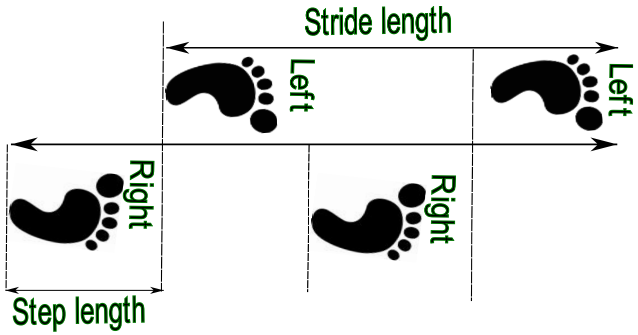
Monitoring At-home Human Activities

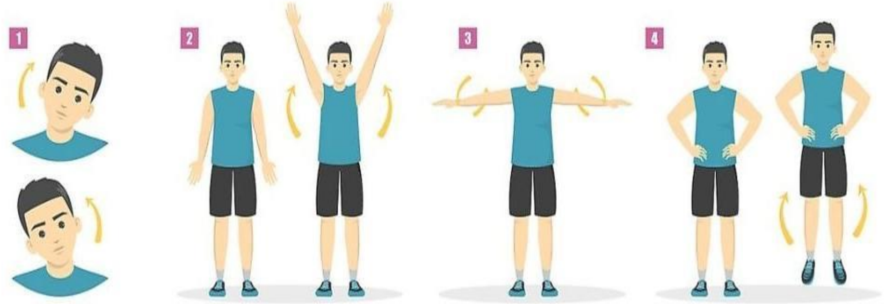
Elderly Patient Monitoring

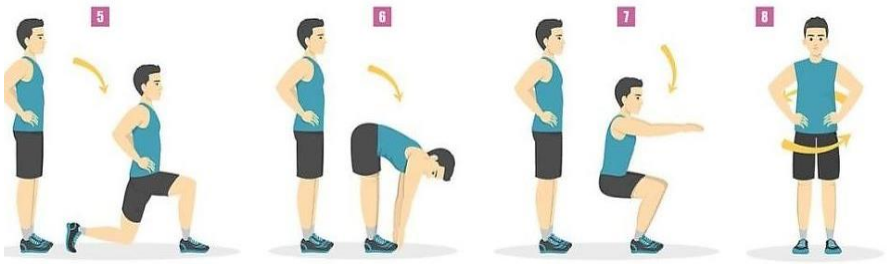
Gait Monitoring





Exercise Monitoring





At-home monitoring unlocks numerous healthcare applications

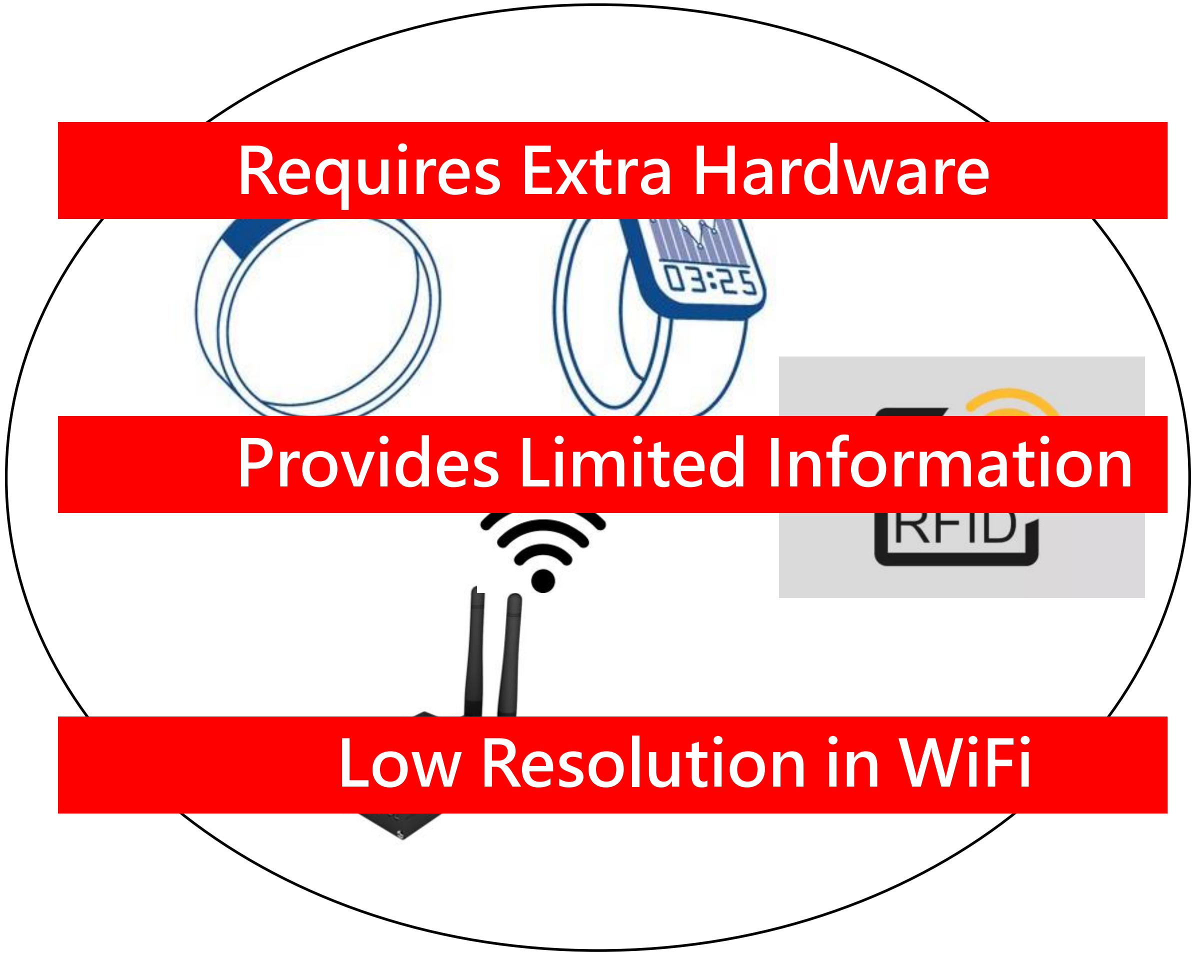
Existing Techniques

Limited by Low Light and Low Visibility

Additional Hardware Requirements

Expensive and Privacy-invasive

Requires Extra Hardware

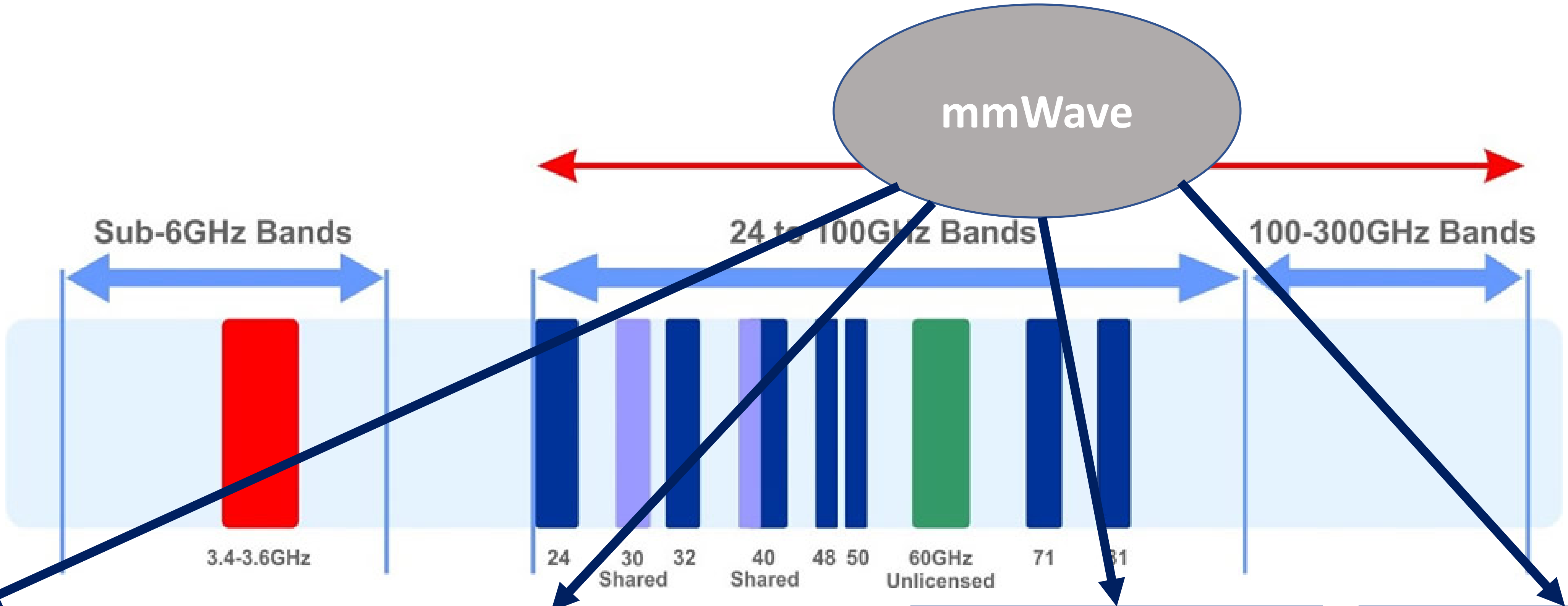


Provides Limited Information

Low Resolution in WiFi

Millimeter-Wave in 5G as an Opportunity

5G and MmWave



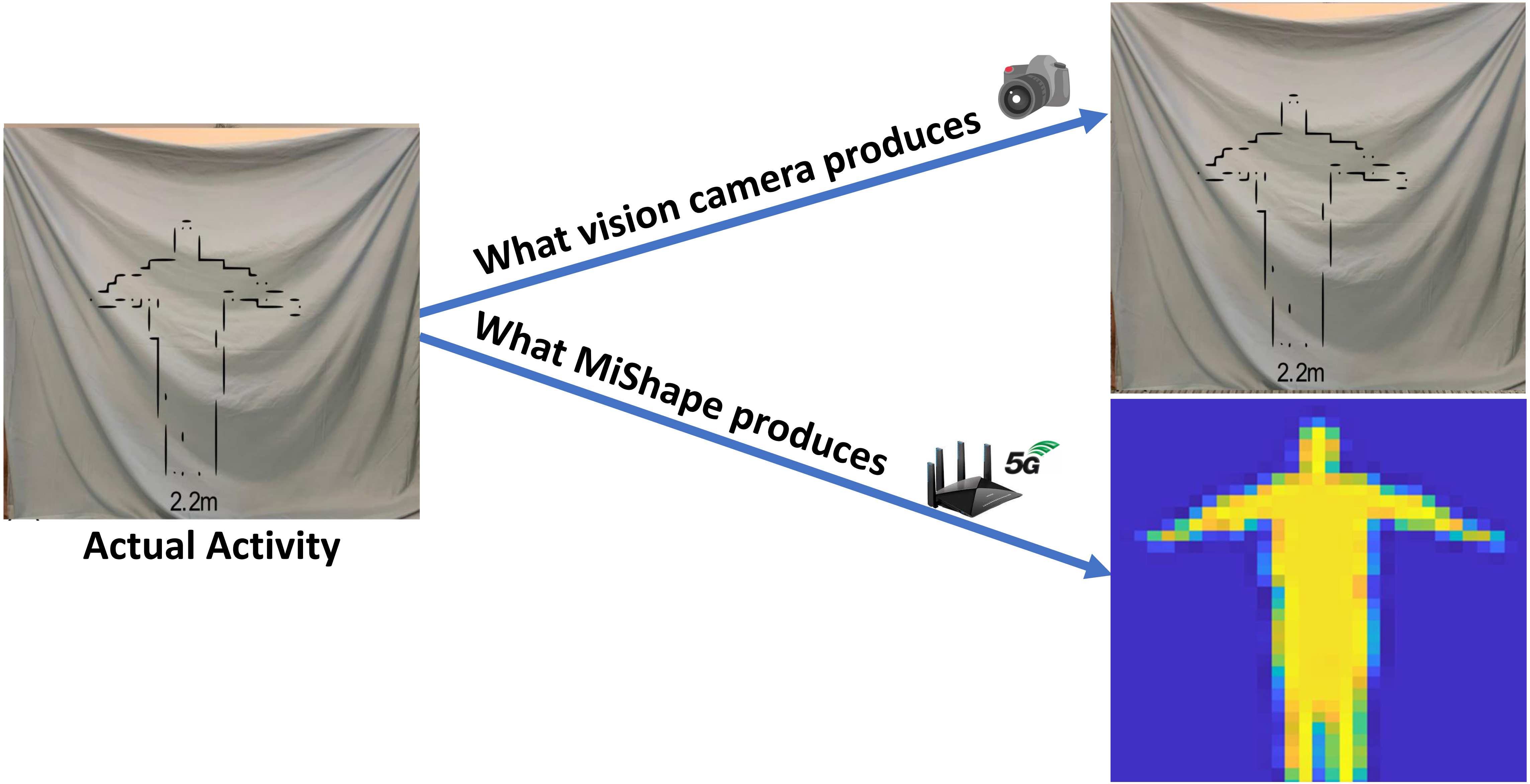
Smaller Wavelength(mm)

Illuminates Target Scene with High-Frequency

Works Through-occlusion

Robust to Low Light and Low Visibility

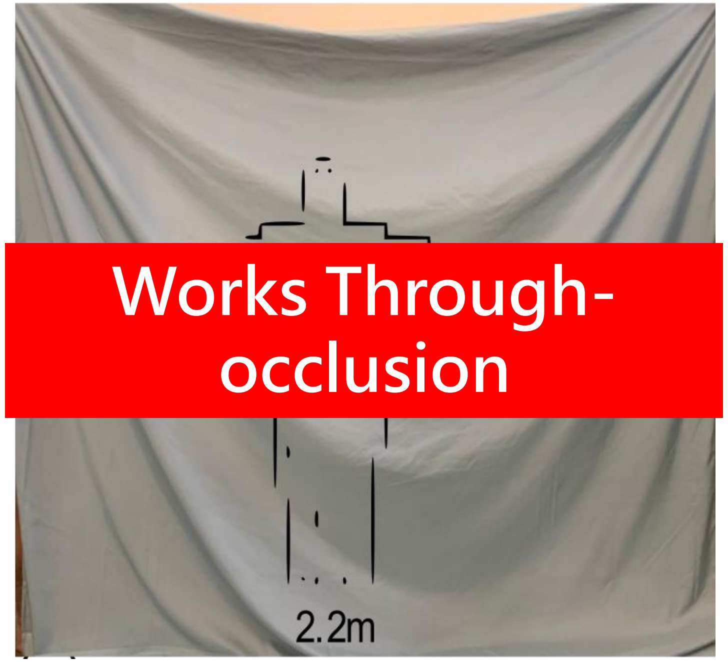
MiShape


2.2m
Actual Activity
What vision camera produces
What MiShape produces
5G
2.2m

MiShape

Preserves Privacy

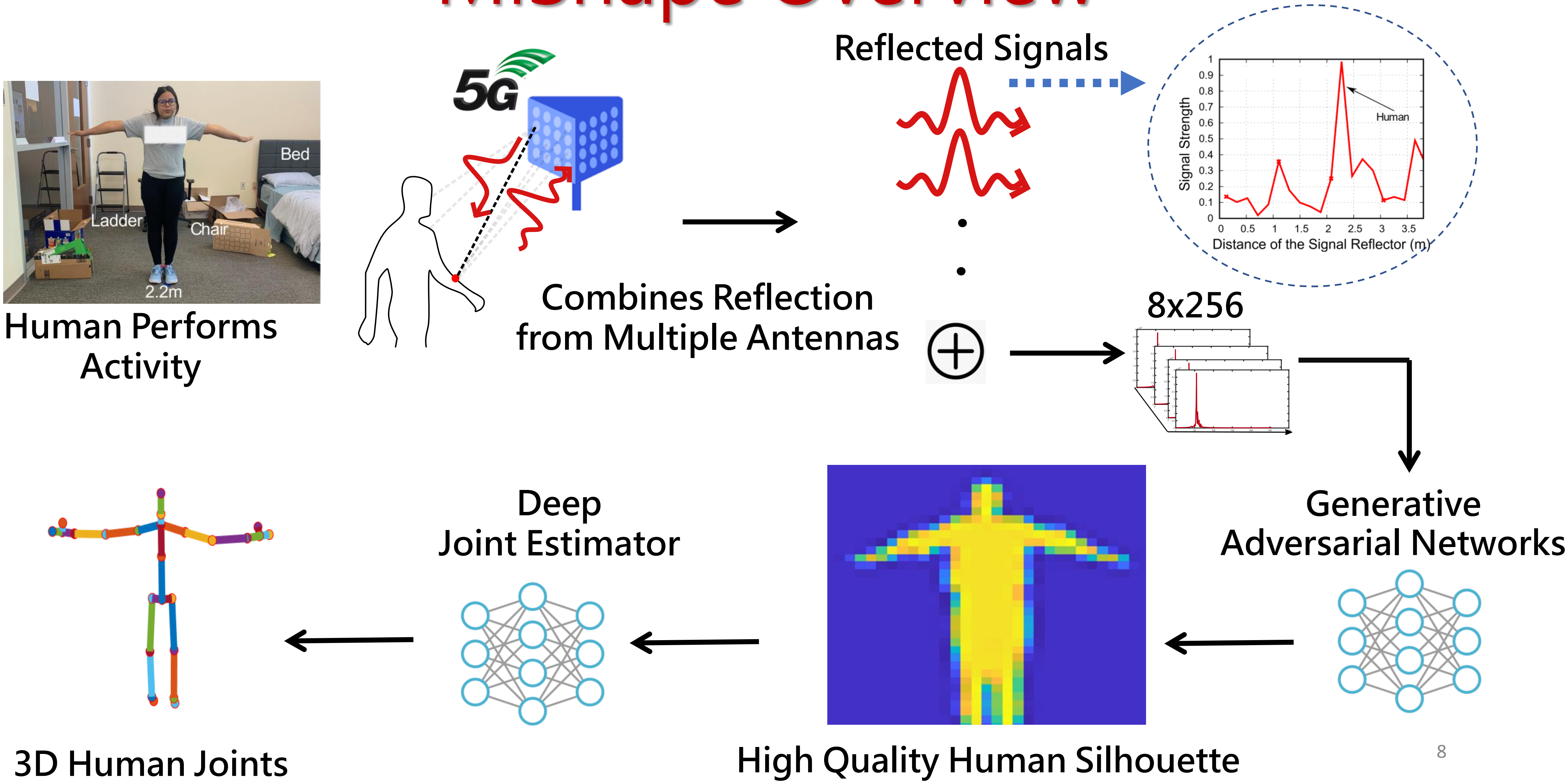
Works Under Low Light and Low Visibility



Works Through-occlusion

MiShape captures accurate shape information comparable to vision camera

MiShape Overview



Challenges

- Specularity and Weak Reflectivity
- Low Imaging Resolution
- Image Aliasing

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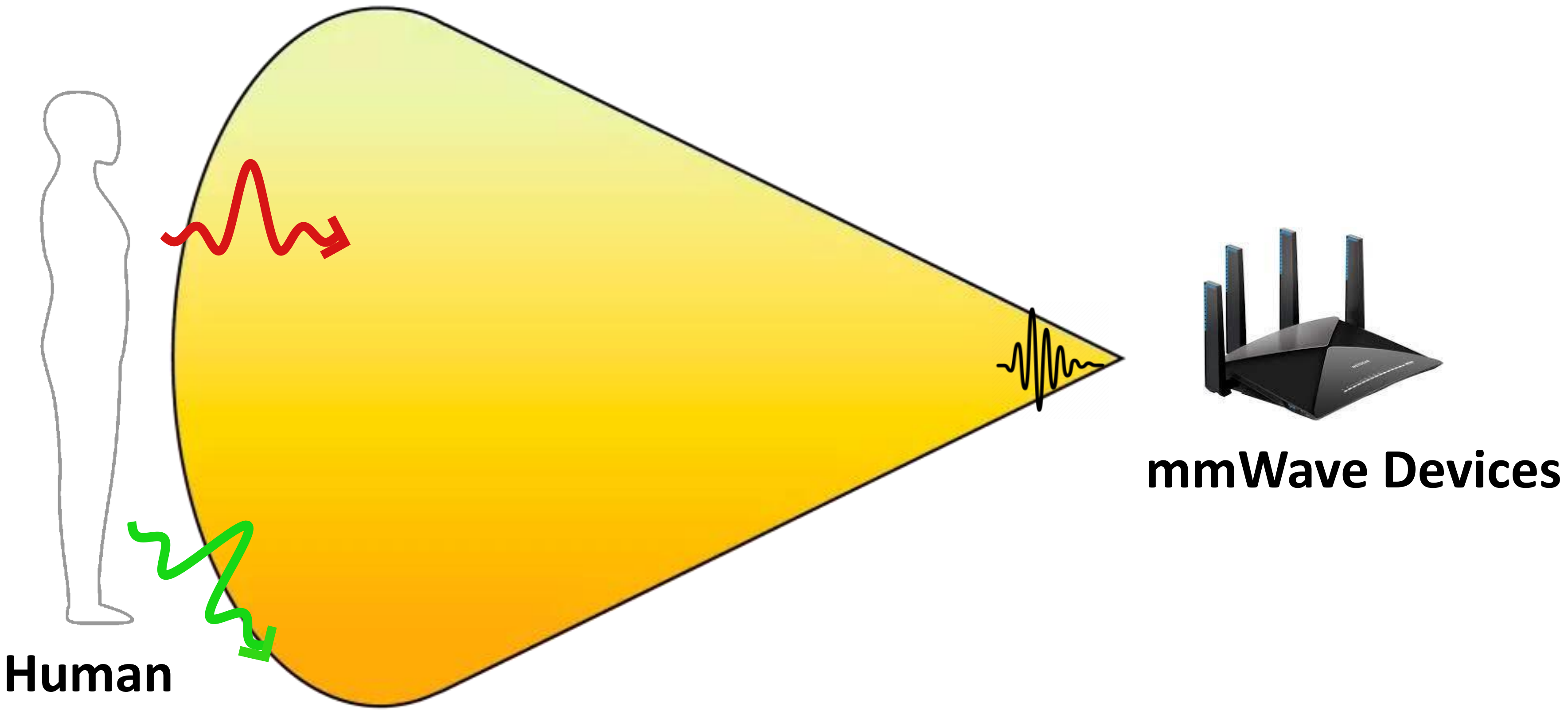
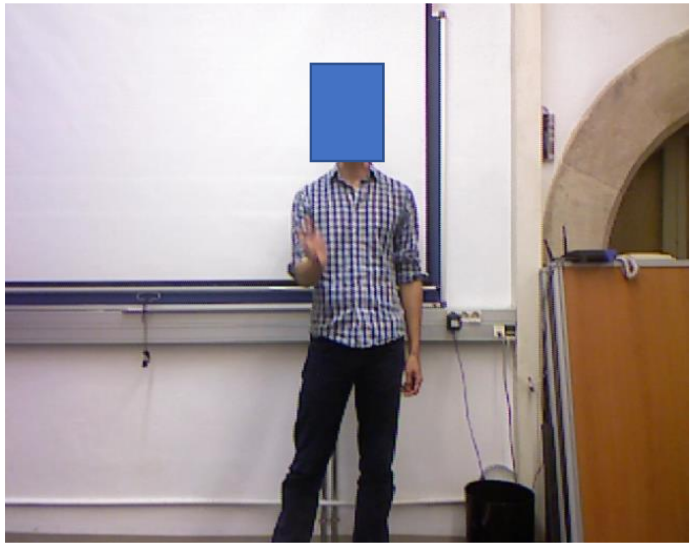
Reflections From Human Body



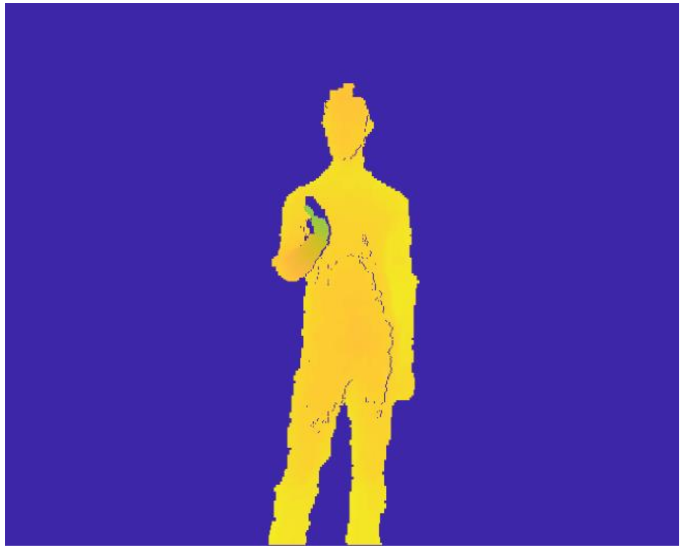
Most of the signals transmitted do not reach back to the mmWave receiver

Reflections From Human Body

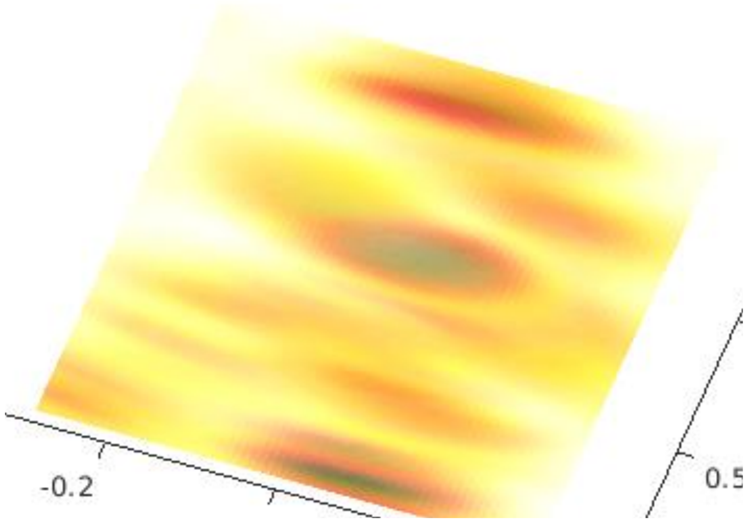
RGB Image



Depth Image



mmWave Image



Imperceptible human shape with many missing parts

Challenges

Specularity and Weak Reflectivity

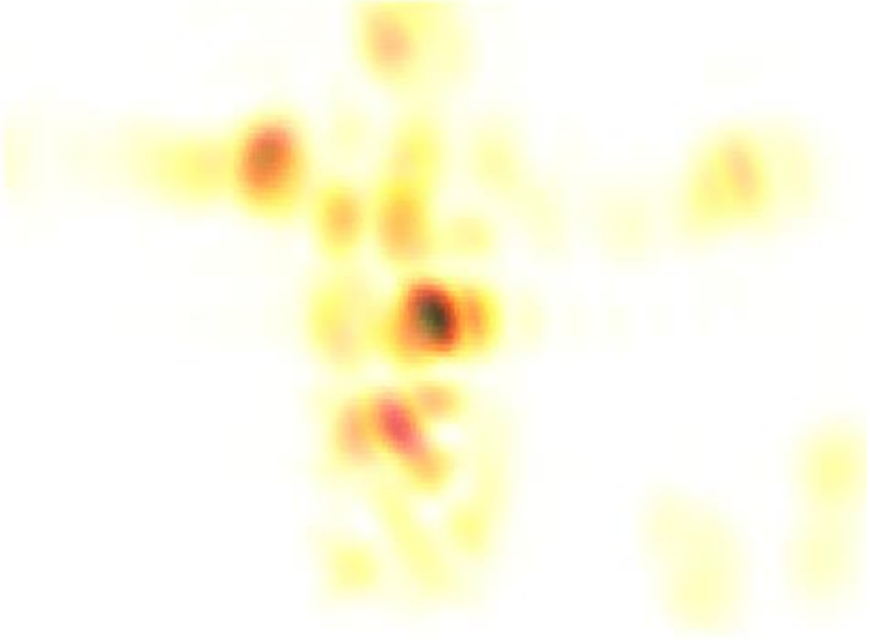
Low Imaging Resolution

Image Aliasing

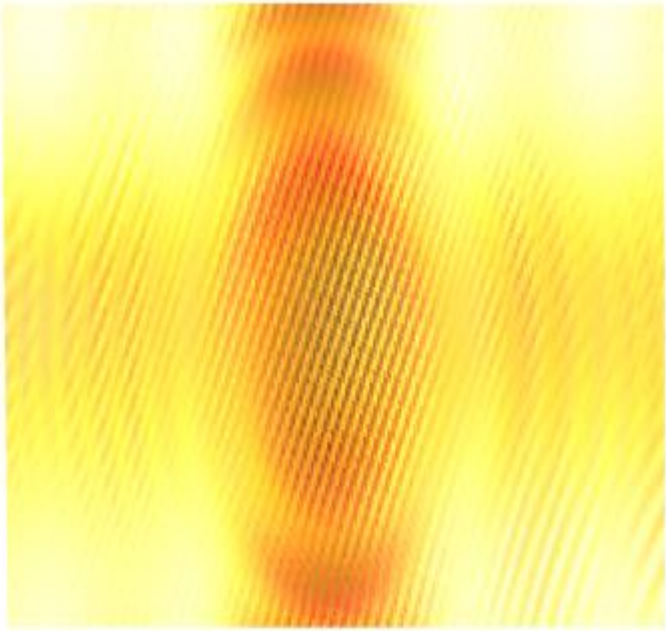
Small Antenna Array Size

Depth Image

32x32 Antenna Array



2x8 Antenna Array



The resolution of mmWave images depends on the antenna array size

Challenges

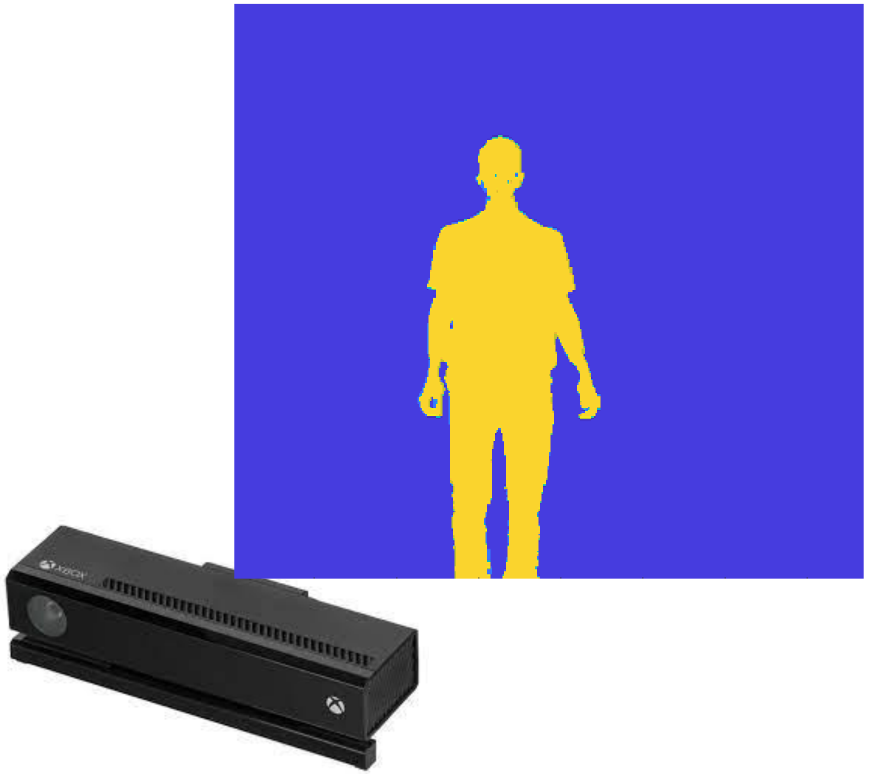
Specularity and Weak Reflectivity

Low Imaging Resolution

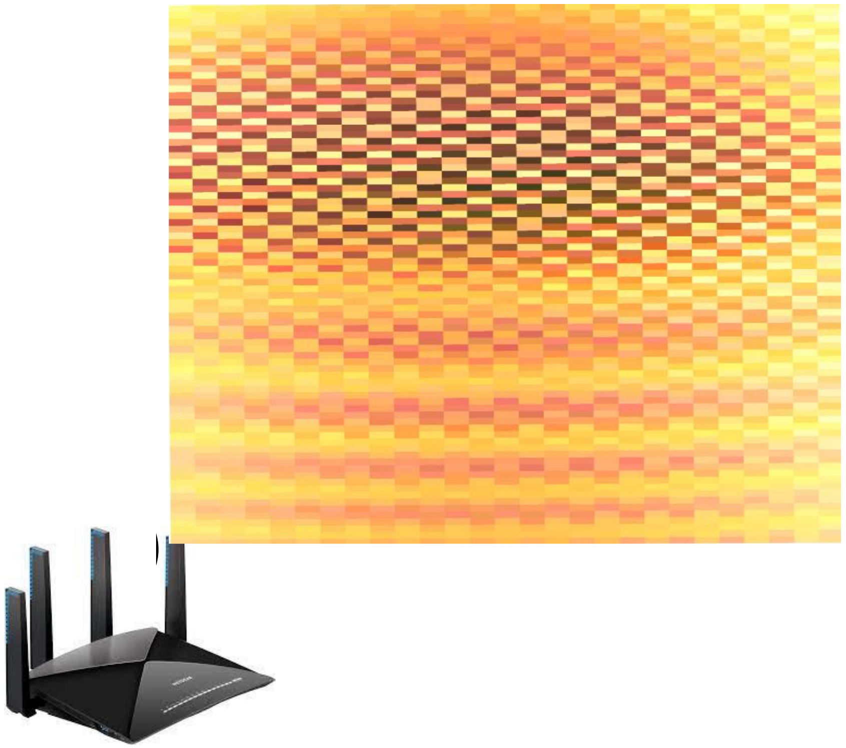
Image Aliasing

Non-Uniform Antenna Placements

Depth Image



MmWave Image

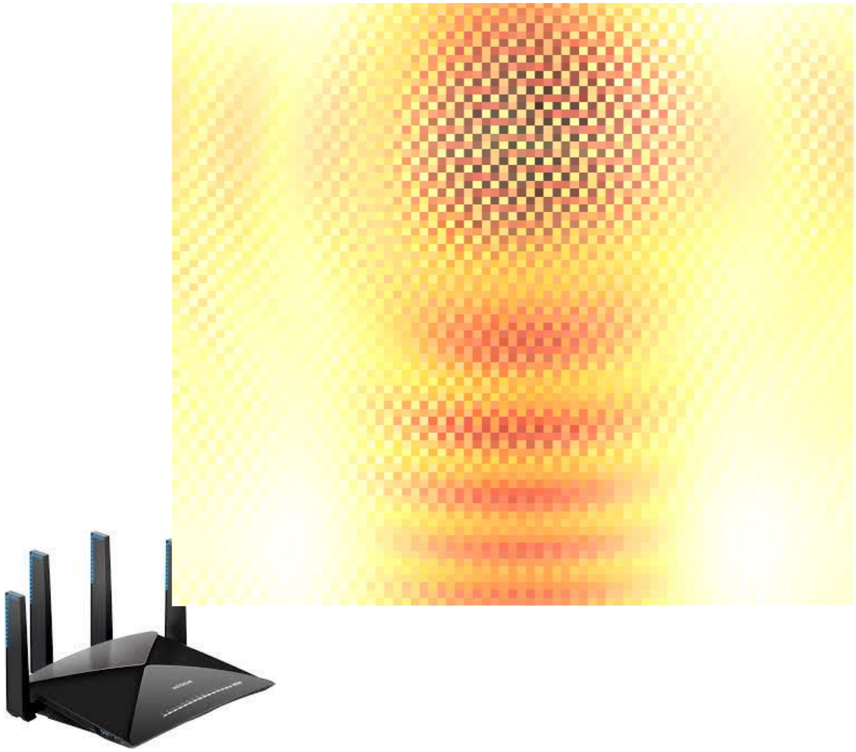


Aliasing due to non-uniform antenna placements in COTS mmWave devices

Non-Uniform Antenna Placements

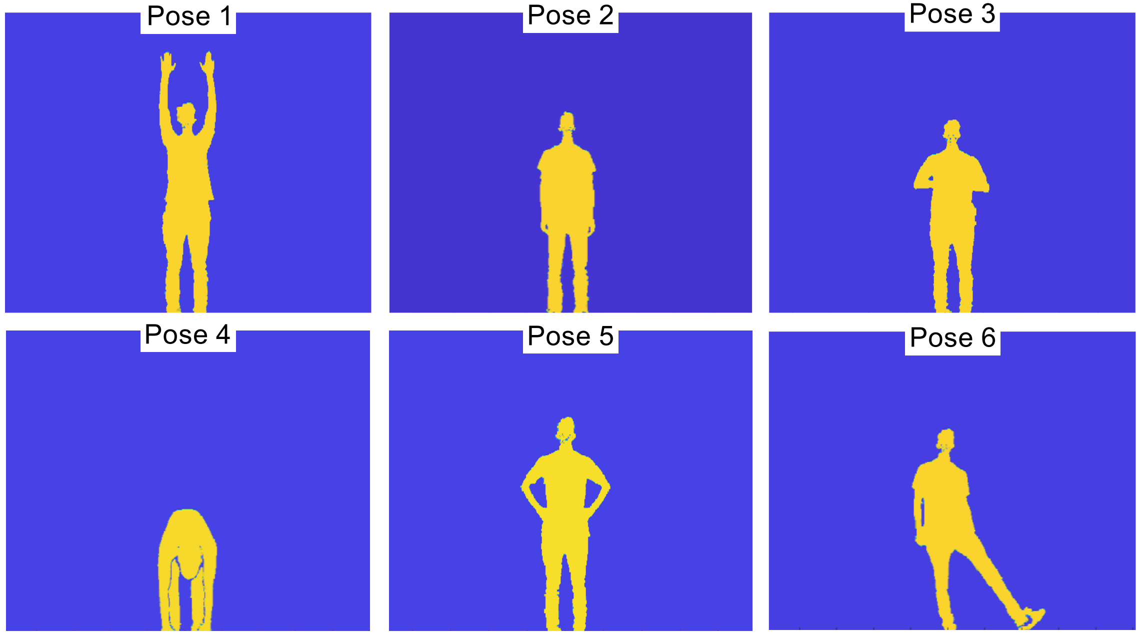
Depth Image

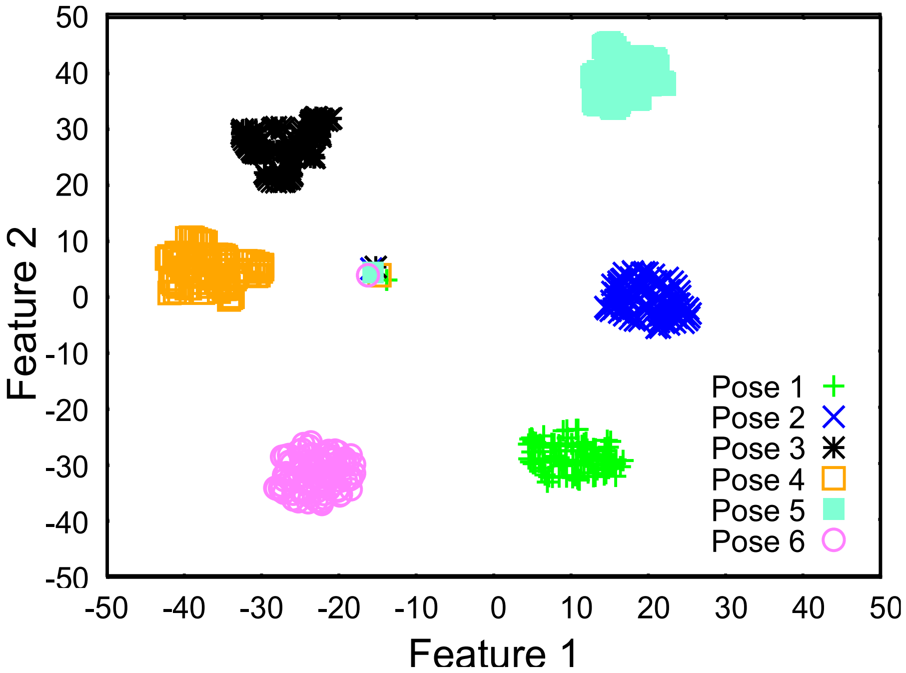
MmWave Image



Leverage Signatures in Reflected Signals

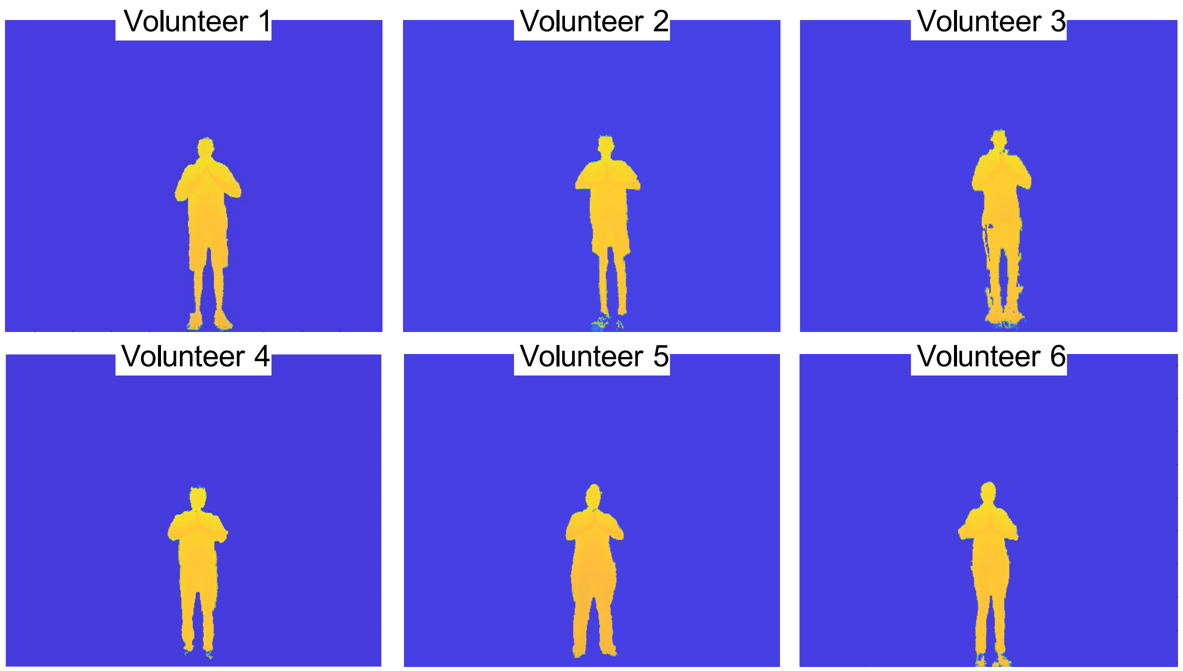
Reflected Signal Analysis

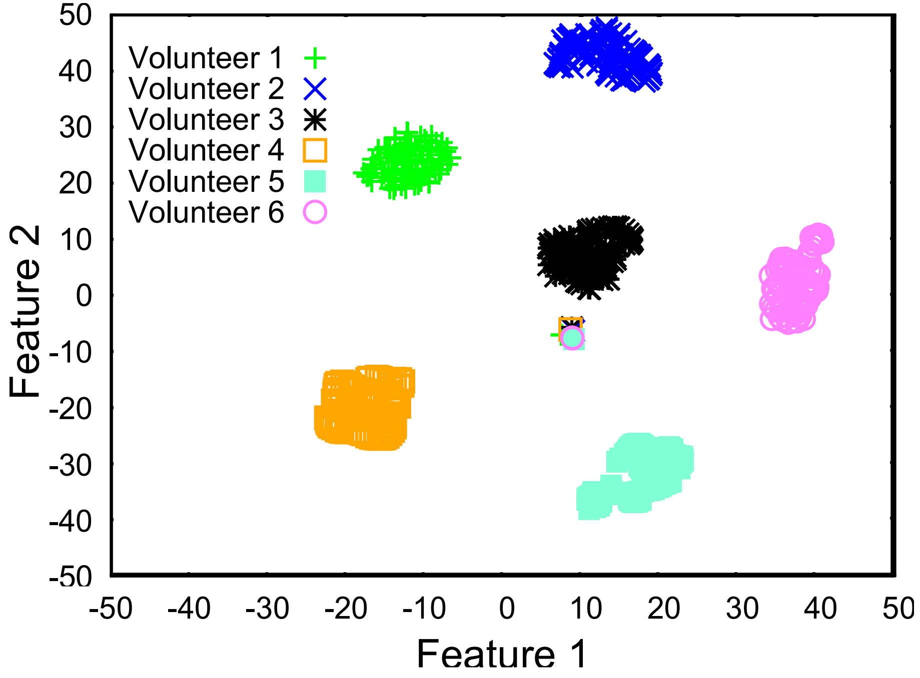




There exists correlation between reflected signals and different postures

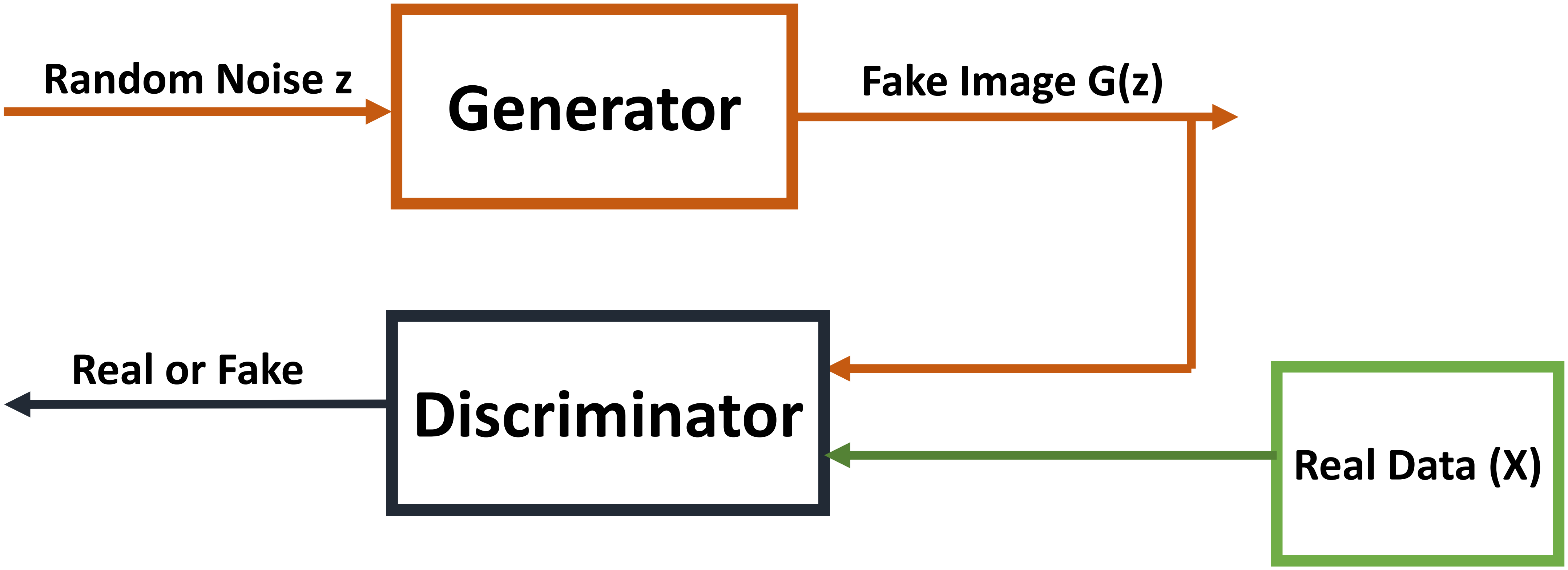
Reflected Signal Analysis



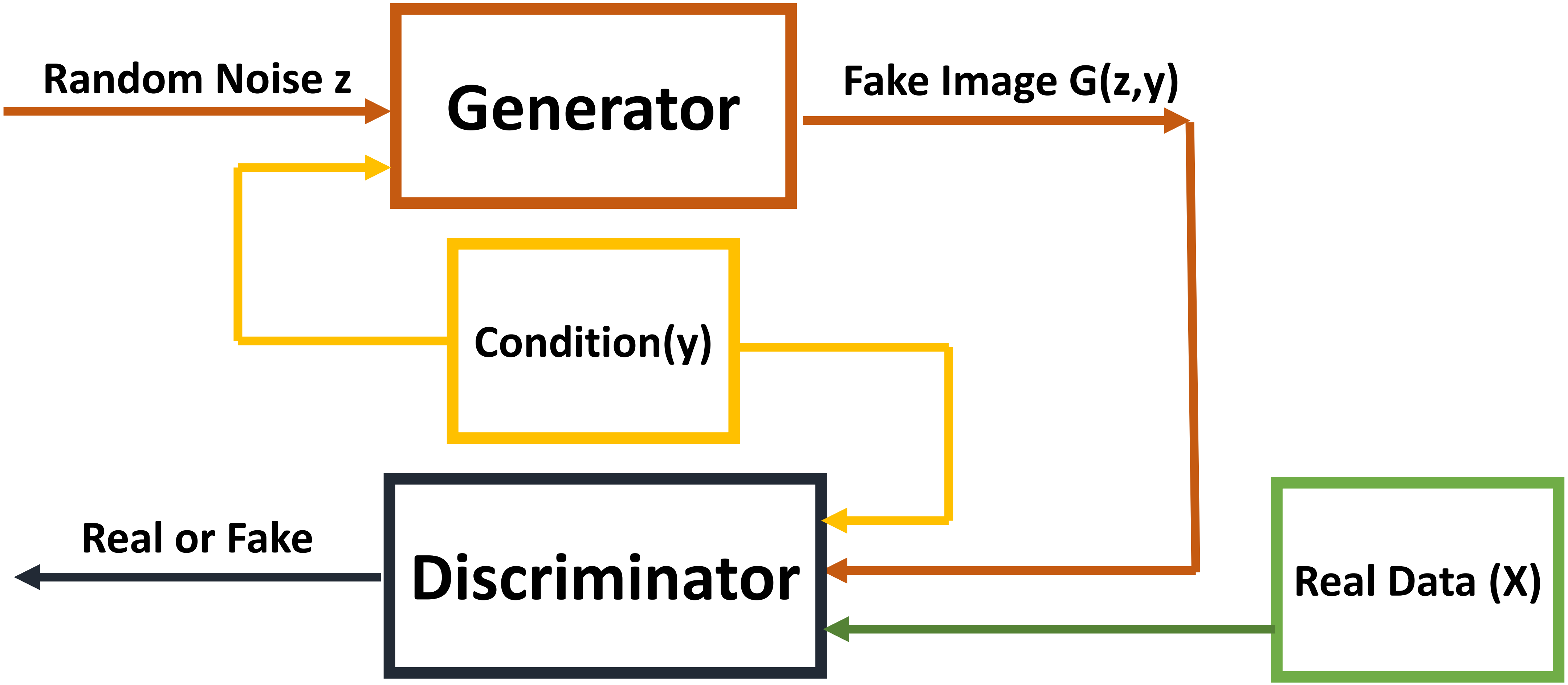


There exists correlation between reflected signals and different volunteers

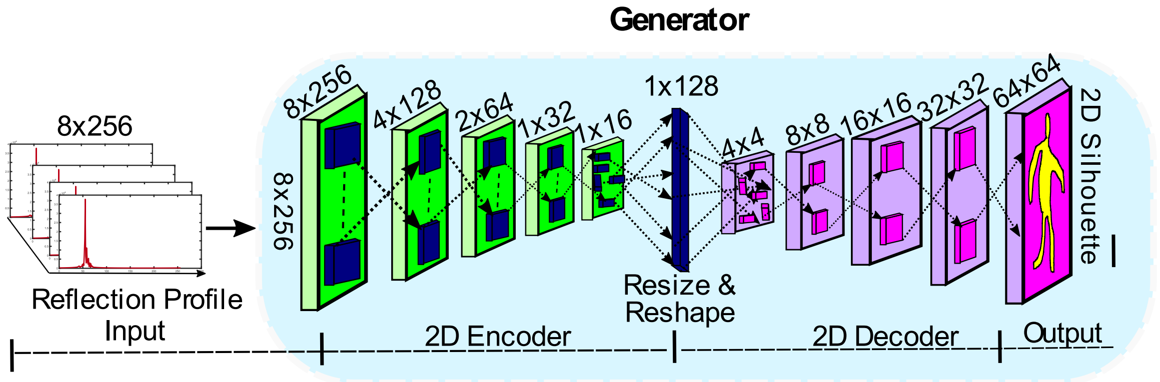
Generative Adversarial Networks

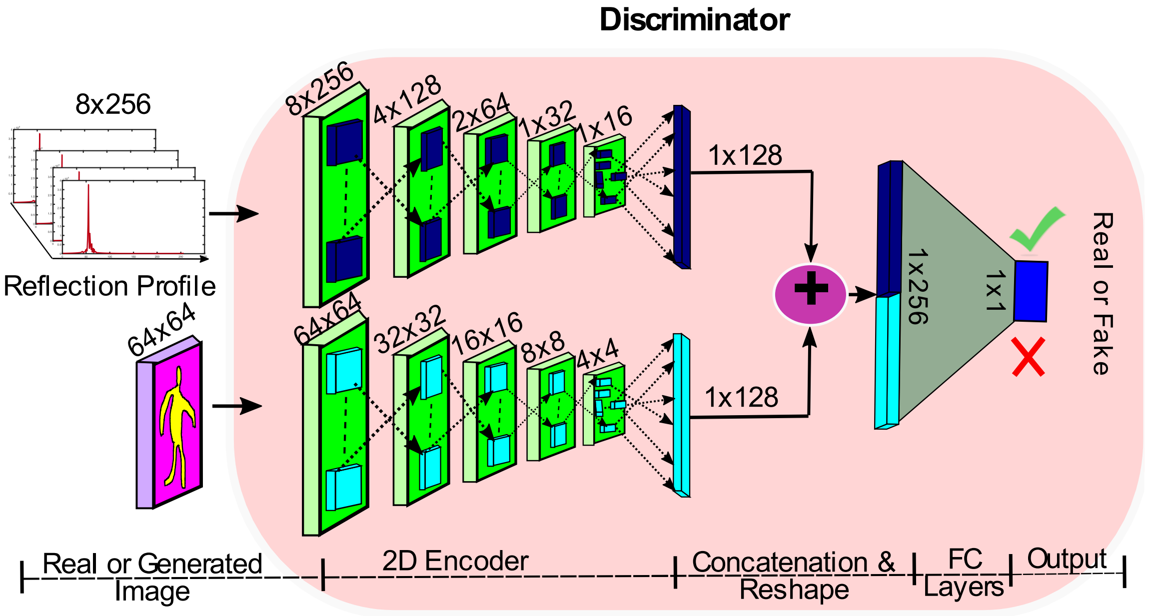


Conditional Generative Adversarial Networks

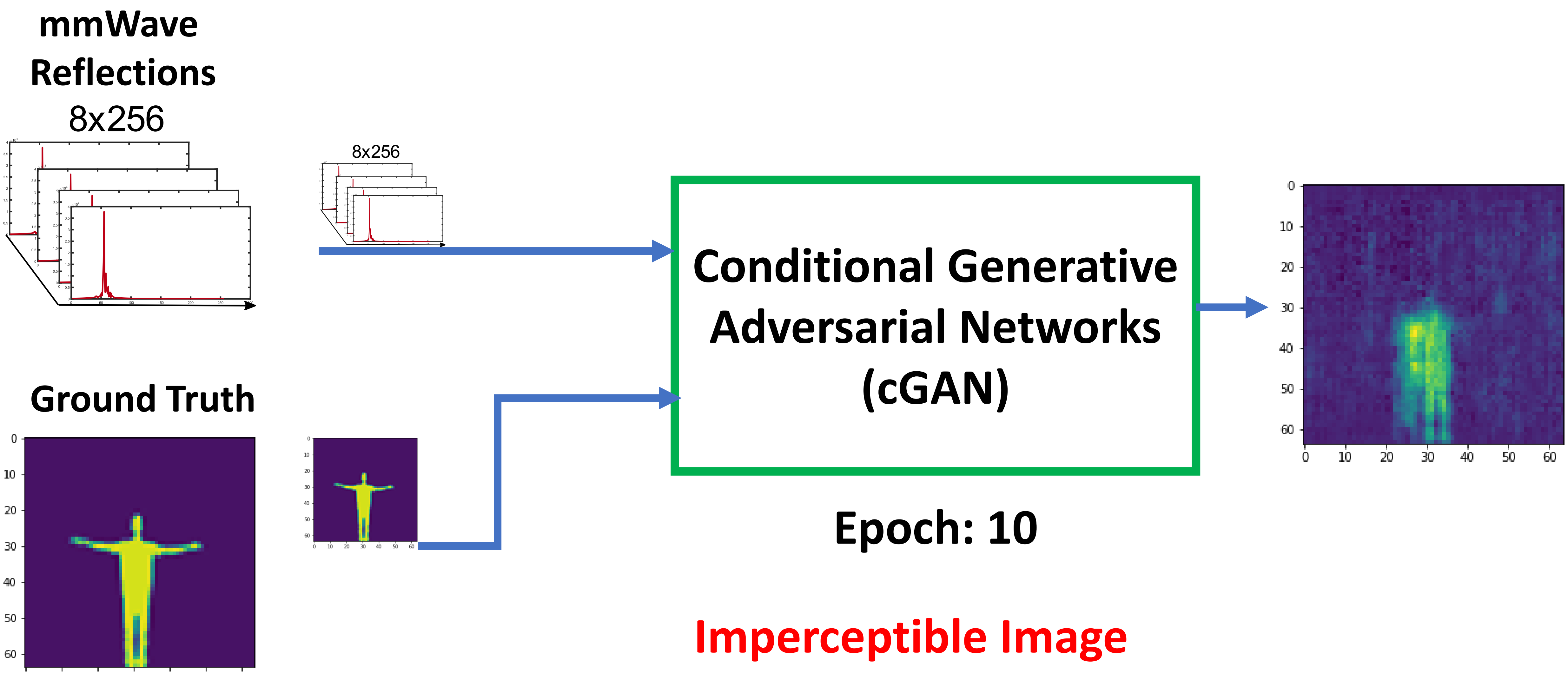


Conditional Generative Adversarial Networks

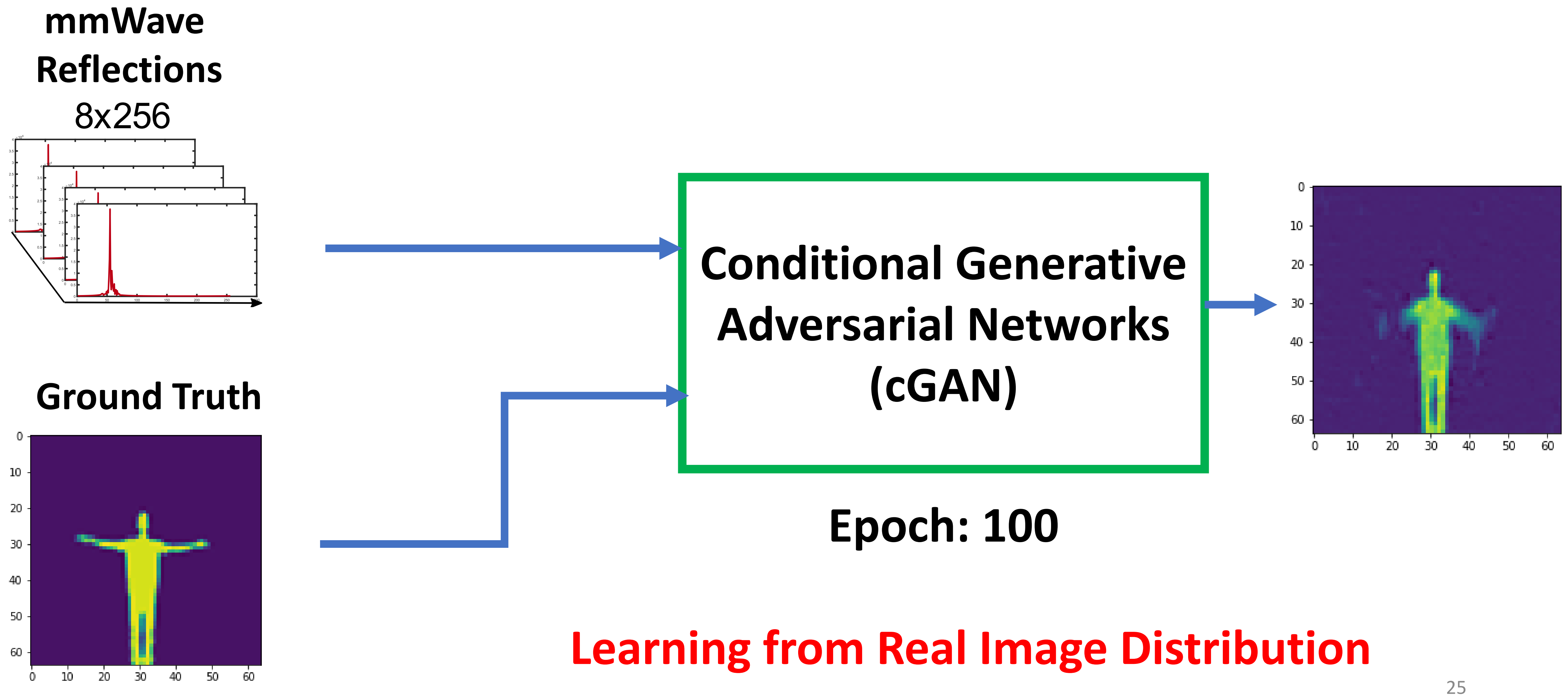




Conditional Generative Adversarial Networks



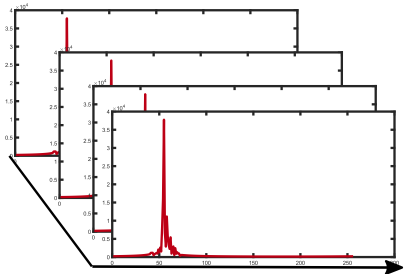
Conditional Generative Adversarial Networks



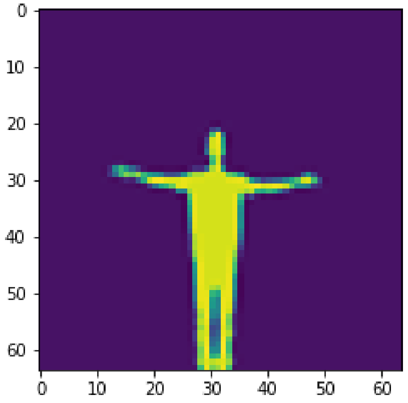
Learning from Real Image Distribution

Conditional Generative Adversarial Networks

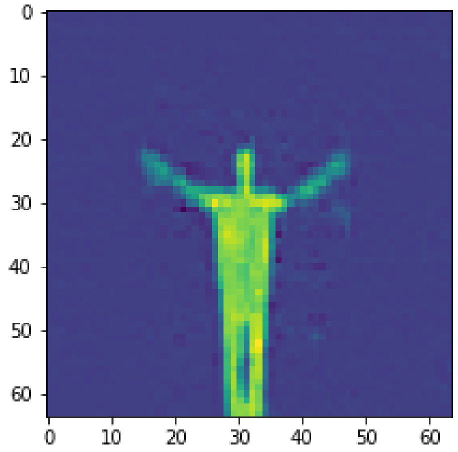
mmWave Reflections
8x256



Ground Truth



Conditional Generative Adversarial Networks (cGAN)



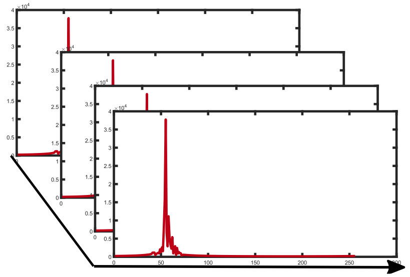
Epoch: 1000

Perceptible Human Silhouette

Conditional Generative Adversarial Networks

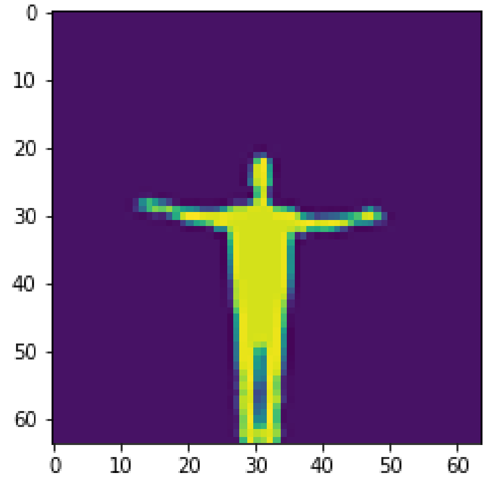
mmWave Reflections

8x256



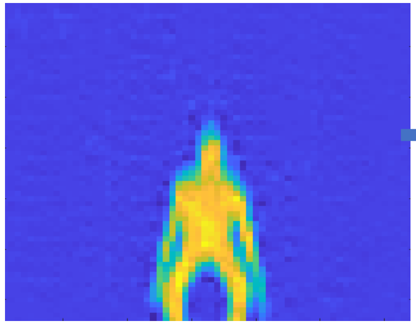
Generator

Post Training



Perceptible Human Silhouette

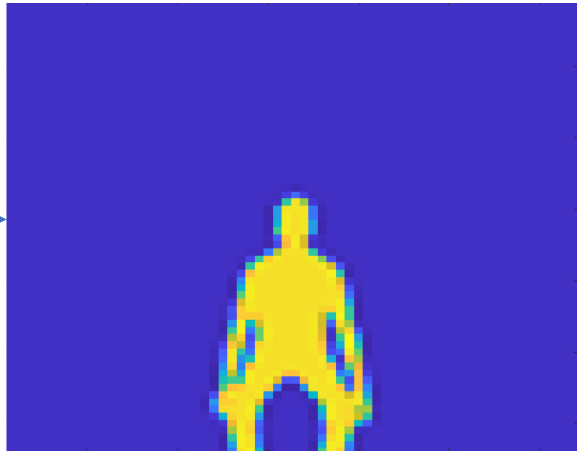
Generating High-Resolution Silhouette



64x64

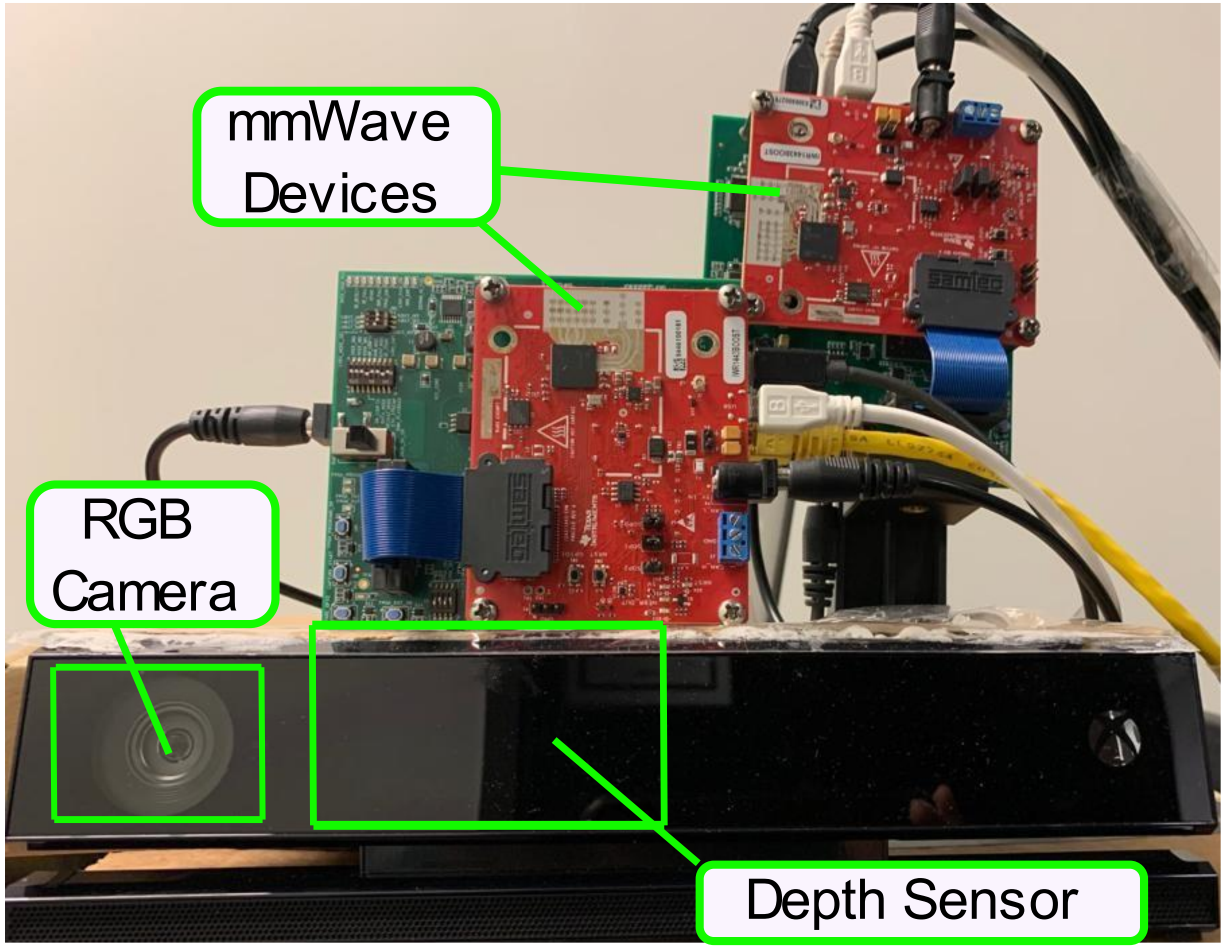
Super-Resolution GAN (SRGAN)

512x512



Improves resolution and recovers any missing information

Implementation



mmWave Hardware

- 77–81 GHz mmWave transceivers
- BW 1.62 GHz
- TI IWR1443BOOST
- Each with one transmit and four receive antennas

Ground Truth

- Microsoft Kinect Xbox One

Two transceivers with one rotated 90◦ counter-clockwise w.r.t. another

Data Collection

- Subject is asked to stand at approximately 2 m distance from the setup
- Dataset includes input-output pairs of mmWave reflections, human silhouette images, and 3D joint locations

- **Baseline Data Collection**
  - We collect datasets from a single subject with 17 diverse poses
  - Each experiment takes 12 seconds to complete

- **Additional Data Collection**
  - We collect data from additional 9 volunteers for 5 diverse poses
  - Each experiment takes 60 seconds to complete

In total, 100 K input-output pairs from 10 volunteers with diverse ages, gender, height, and somatotype

Evaluation

- Specularity and Weak Reflectivity
- Low Imaging Resolution
- Image Aliasing

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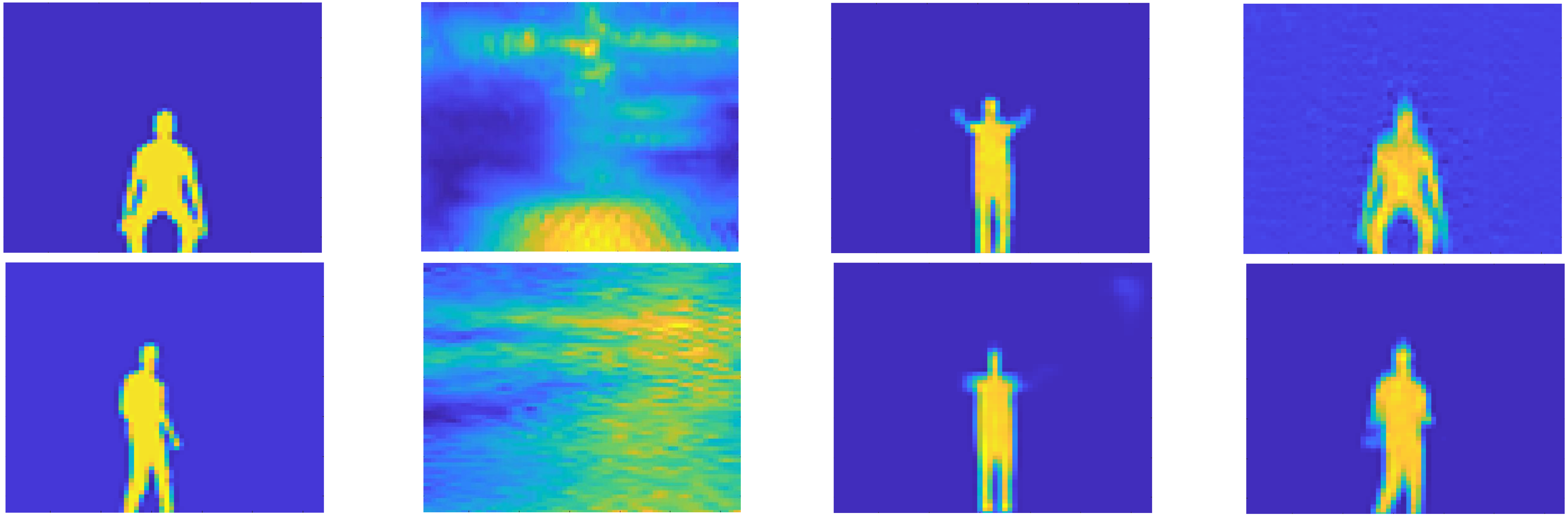
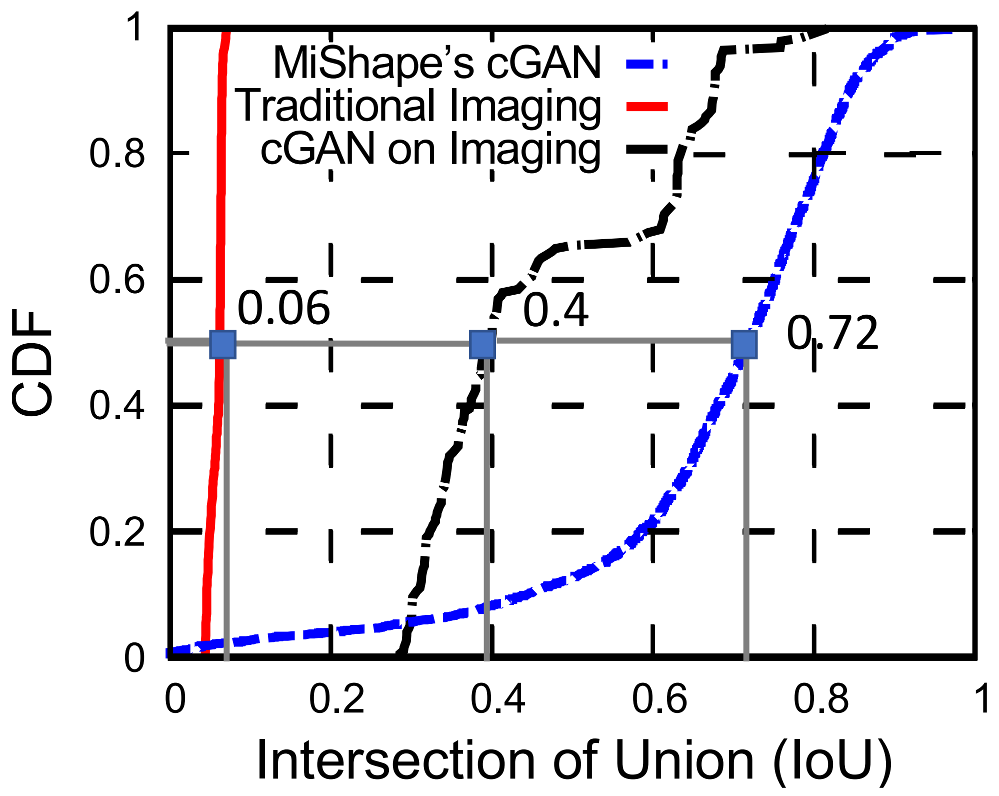
Full Silhouette Recovery with MiShape

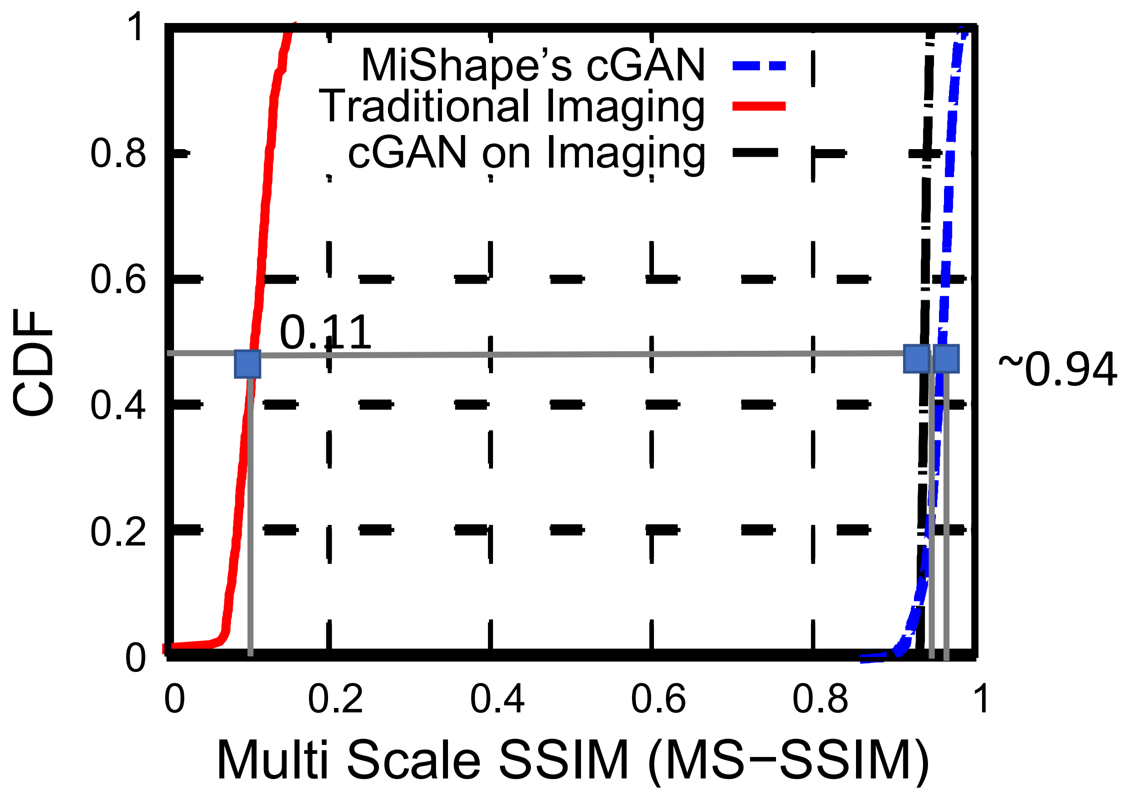


Ground Truth | Traditional Imaging | cGAN on Imaging | MiShape

MiShape generates human perceptible complete silhouette

Full Silhouette Recovery with MiShape





MiShape's cGAN model produces images close to ground truth

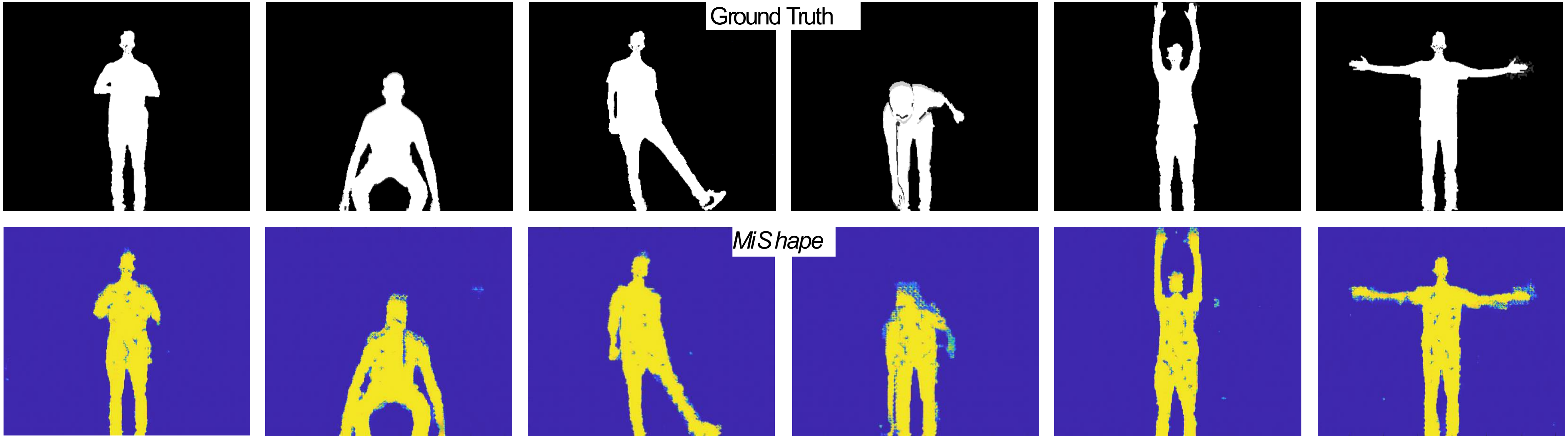
Evaluation

Specularity and Weak Reflectivity

Low Imaging Resolution

Image Aliasing

High-resolution Imaging



High-resolution silhouette generated by Generator similar to ground truth

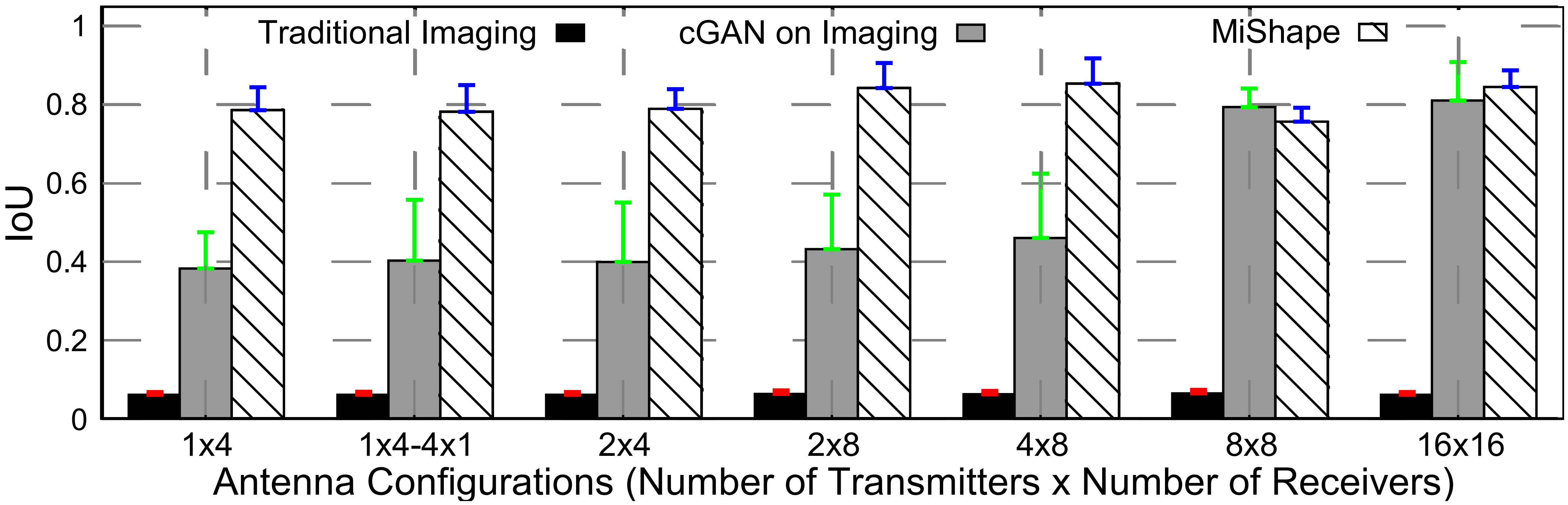
Evaluation

Specularity and Weak Reflectivity

Low Imaging Resolution

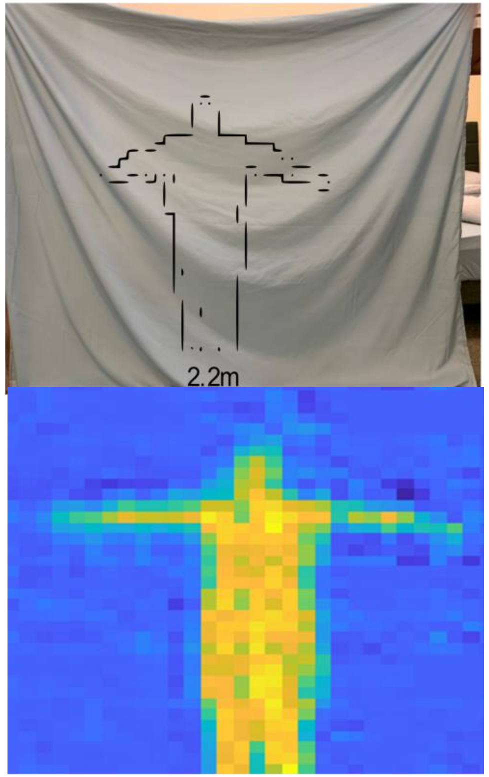
Image Aliasing

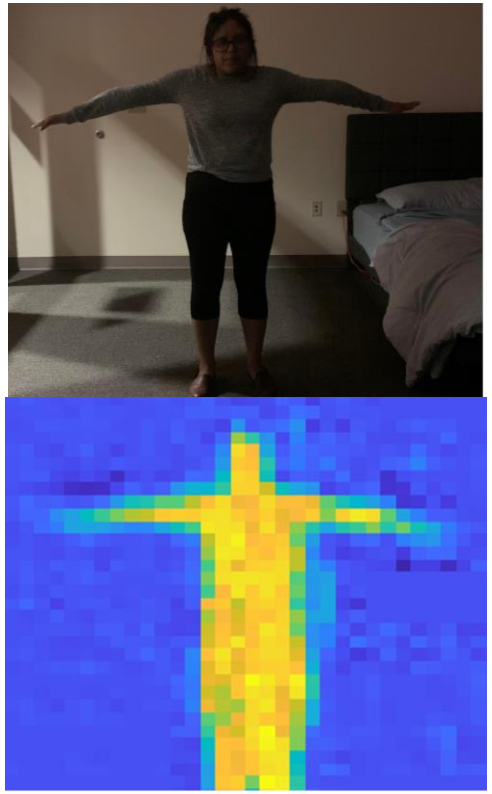
Diverse Antenna Configurations

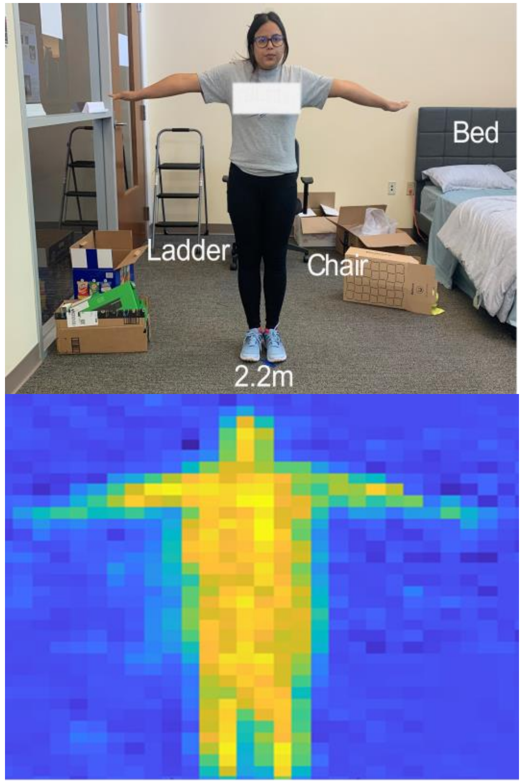


MiShape is consistently better across diverse antenna configurations

Evaluation under Different Conditions





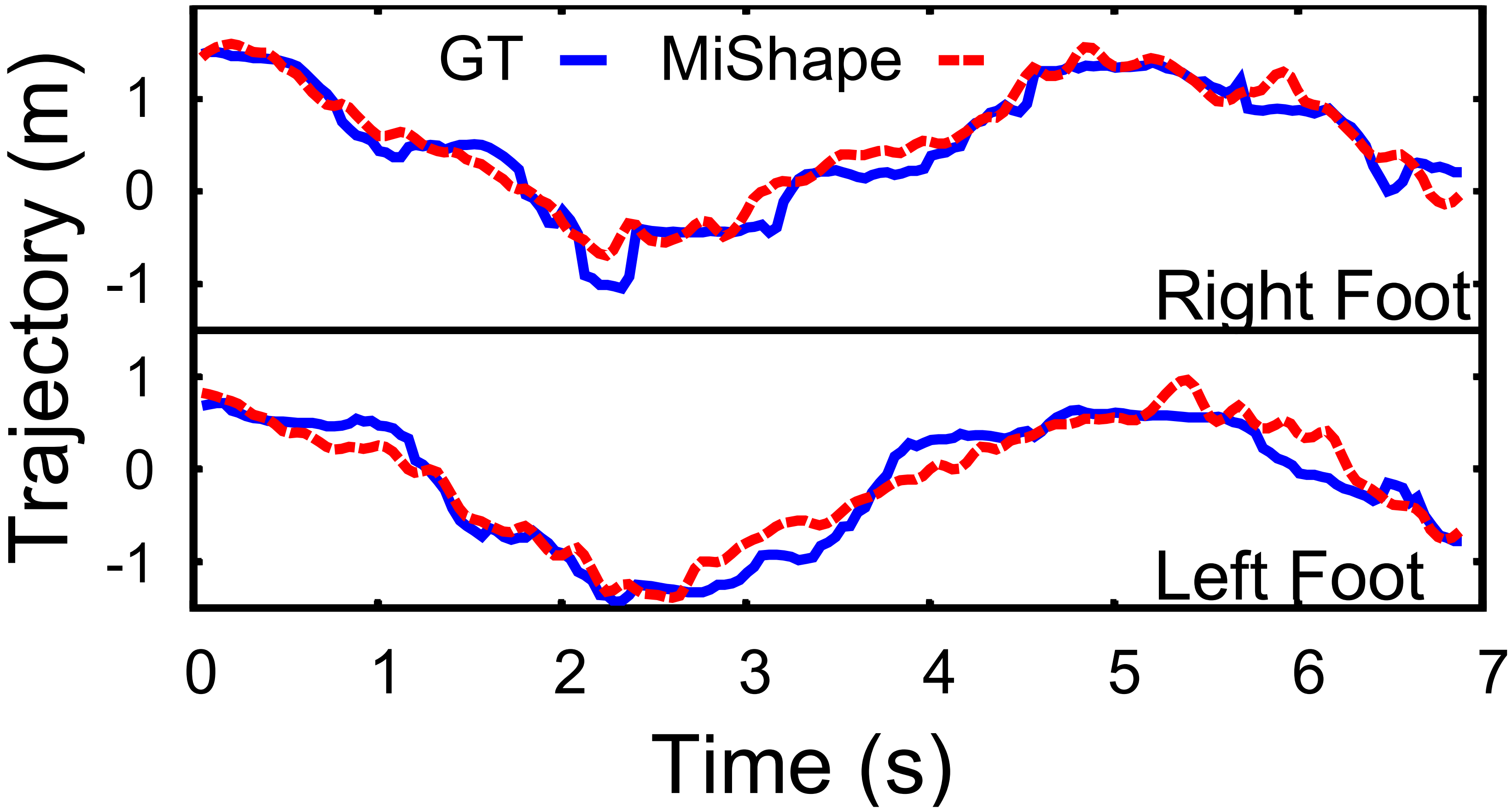


Works Under Occlusion

Works Under Low Light and Low Visibility

Works in Presence of Multiple Objects

Gait Monitoring



MiShape follows ground truth walking trajectories well

Conclusion

- MiShape generates high-quality human silhouettes and predicts 3D locations of body joints on par with existing vision-based systems
- MiShape brings **high-resolution**, through-occlusion imaging into **ubiquitous commodity 5G devices**
- MiShape enables application in gait monitoring with higher accuracy

Thank you!

Please check out our paper for more results:

Any Questions: Please email to aakriti@email.sc.edu